CHARACTERIZATION, TREATMENT AND USE OF SEWAGE SLUDGE

Commission of the European Communities

CHARACTERIZATION, TREATMENT AND USE OF SEWAGE SLUDGE

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F O R E W O R D

The Concerted Action "Treatment and Use of Sewage Sludge" is a research programme implemented jointly by the European Communities and Austria, Finland, Norway, Sweden and Switzerland. It aims at coordinating in the most flexible way all relevant research receiving public funding in this area in the countries involved.

Obviously, research in Europe cannot be isolated from scientific progress abroad; informal but fruitful working relationships were established with scientists from non-European countries, in particular from Canada.

The Concerted Action, continuing a more limited research programme executed in the early 70s, was running from 1977 to 1980. During this period some 400 national research projects have been identified; an attempt is made now to evaluate the results of this effort in order to make them available to the scientific community and to administrative bodies concerned with the disposal of sewage sludge and its utilisation on cultivated land.

In early 1979, a first Symposium was organized in Cadarache, France, which permitted to outline the state of knowledge at the onset of the programme. The second Symposium in Vienna will serve as an important collection of scientific knowledge to enter the evaluation process mentioned above. The organizers stressed therefore to include a fair number of reviews which should summarize the major achievements of the Concerted Action.

It seems indicated to reiterate briefly the general objectives of the programme :

- to evaluate technological processes and equipment,

- to elaborate and evaluate analytical procedures, aiming at establishing standardized or harmonized "European" methods,

- to assess the impact on the environment of sludge treatment and disposal,

- to evaluate the constraints to the use of sludge and its conversion products (compost) in agriculture due to the content of pollutants and pathogens,

- to contribute knowledge necessary for optimum utilisation of sludge, considered to be a valuable resource.

The reader of these proceedings may profit also from some information of the practical implementation of the programme. The research area was subdivided in 5 areas and working parties were established in order to promote the coordination in these areas. These working parties are the following :

- Sludge processing
- Chemical pollution of sludge
- Biological pollution of sludge
- Utilization of sludge
- Environmental effects of sludge

The organisation of the Symposium followed this subdivision of the whole area.

We hope that this volume will be a useful contribution to the important problems of treatment and utilisation of sewage sludge. Moreover, it may demonstrate that coordination of research on European level is a rewarding task.

The organizers wish to express their sincere thanks to the Austrian Government for hosting this Symposium. We appreciate in particular the support received from Dr. E. Pescheck and Dr. K. Stangel, Bundesministerium für Gesundheit und Umweltschutz, Dr. R. Weiss, Österreichischer Wasserwirtschaftsverband und Prof. Dr. H. Supersperg, Universität für Bodenkultur - Institut für Wasserwirtschaft, and from the regional government of Burgenland.

We wish to express our gratitude also to Andritz Maschinenfabrik AG, Graz, and Voest-Alpine AG, Linz, who kindly supported the organisation of the Symposium.

Brussels, January 1981

H. OTT P. L'HERMITE

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LA POLITIQUE DE L'ENVIRONNEMENT DES COMMUNAUTES EUROPEENNES ET LA VALORISATION DES DECHETS EN AGRICULTURE

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Abstract : The agricultural use of waste and sludge is considered as a priority by the Commission of the European Community. The treatment of waters leads obviously to a large production of sludge of about 6 million tons expressed in dry matter per year or 230 million cubic meters of raw sludge per year for the Community. A sensible increase is to be expected in the future. About 29 % of the sludge is used in agriculture. Regulations on the agricultural use of sludge are scarce in the Community; so, the Commission of the European Communities is already setting up a directive in this field aiming at the promotion of the agricultural use of sludge in emphasizing on their agricultural value taking into consideration the necessary steps for avoiding the negative environmental effects.

Les deux programmes d'action des Communautés Européennes en matière d'environnement du 22 novembre 1973 et du 13 juin 1977 soulignent la nécessité d'une politique communautaire en matière de déchets industriels et de résidus de consommation.

Toute action en matière de déchets comporte un double objectif : d'une part, la protection de la santé de l'homme et de l'environnement contre les effets nocifs des opérations liées à l'élimination de ces déchets; d'autre part, la protection des ressources naturelles en luttant contre le gaspillage et en prenant en particulier des mesures destinées à faciliter le recyclage et la réutilisation des déchets.

Dans le cadre du Comité de Gestion en matière de déchets institué par la Commission en 1976 (1), qui formule des avis sur l'élaboration et la mise en oeuvre d'un programme communautaire dans ce domaine, un groupe de travail a été créé pour étudier les possibilités d'utiliser les déchets en agriculture.
Par type de déchet utilisable en agriculture, on entend le terme général "matière organique fermentiscible" et plus spécialement le compost, les effluents d'élevage et les boues de stations d'épuration".

L'utilisation de ces déchets en agriculture permet, d'une part, de résoudre de manière substantielle le problème de l'élimination des déchets, et, d'autre part, elle peut être d'un intérêt non négligeable pour l'agriculture.
Si de grandes possibilités existent dans ce domaine, l'utilisation des déchets en agriculture comporte néanmoins certains aspects négatifs (pathogènes, métaux lourds ...). Il importe donc de préserver, tant à moyen qu'à long terme, notre environnement ainsi que les conditions de production les meilleures pour l'agriculture.
C'est pourquoi l'action du groupe de travail développe ses efforts dans les directions suivantes :

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(1) J.O. n° L 115 du 01.05.76

1. Faire le point des expériences tendant à promouvoir l'utilisation agricole des déchets dans la C.E. et les pays tiers.

2. Examiner les possibilités actuelles et potentielles d'une telle utilisation en tenant compte des aspects techniques, économiques, juridiques et écologiques du problème.

3. Recommander des mesures communautaires adéquates, notamment dans les domaines suivants :

   - normes visant la qualité des produits organiques
   - organisation de la commercialisation
   - recherche et développement

Parmi les différentes utilisations de déchets en agriculture, celle relative aux boues d'épuration a été considérée comme prioritaire par la Commission.

L'épuration des eaux résiduaires aboutit, en effet, à une énorme production de boues d'épuration. En ce qui concerne la Communauté, celle-ci est estimée à quelque 6 millions de tonnes de matières sèches par an ou encore à plus de 230 millions de m3 de boues fraîches par an.

Chaque habitant produit donc de l'ordre de 800 kgs de boues/an auxquelles il faut ajouter les boues industrielles biodégradables (brasseries et industries alimentaires).

Les perspectives futures laissent supposer un accroissement sensible de la production de boues d'épuration au niveau de la Communauté. Ainsi, en 1980, pourrait-elle atteindre 15 à 20 x 10^6 tonnes de matières sèches/an (ERL, 1979).

Le tableau en annexe donne un aperçu des productions et des moyens d'élimination des boues dans les différents pays de la Communauté. L'élimination des boues se répartit de la façon suivante : (moyennes)

- 45 % partent en décharge contrôlée
- 19 % sont déversées en mer
- 7 % sont incinérées
- 29 % sont utilisées en agriculture.

Il est évident que les 3 premières pratiques ne constituent pas des solutions satisfaisantes pour l'élimination des boues; en effet, les décharges en mer ou sur terre posent des problèmes de nuisances olfactives, d'eutrophisation, de pollution bactériologique et chimique de l'eau. Même si l'on procède à leur incinération, une pollution de l'eau et de l'air peut encore se produire et le processus est onéreux.

Les 29 % utilisés en agriculture ne constituent donc qu'un faible pourcentage alors que les boues présentent un intérêt certain pour le sol étant donné que les boues sont sources de matière organique, d'azote et de phosphore.

Pour ce qui est des législations relatives aux boues, celles-ci sont assez rares : ou bien elles font partie de lois-cadre, ou elles sont à l'état d'ébauche ou même inexistantes.

La Commission prépare une proposition de la directive dans ce domaine visant à favoriser l'utilisation de ces boues en agriculture en soulignant leur valeur agronomique mais en établissant les précautions à prendre pour une bonne utilisation.

Il est bien connu, en effet, que l'élimination des boues des stations d'épuration pose aux gestionnaires de ces stations et aux collectivités locales des problèmes complexes. Il importe, bien sûr, de procéder à l'élimination de ces boues en essayant de tirer parti de leur valeur : l'utilisation agricole des boues devrait donc constituer une voie privilégiée car elle bénéficie des remarquables propriétés épuratives du sol tout en lui offrant les propriétés non moins intéressantes qui caractérisent certaines boues.

Il est bien certain, cependant, que l'épandage des boues d'épuration ne se fera dans de bonnes conditions que si les agriculteurs sont convaincus de son intérêt.

Il convient donc de préciser les conditions de mise en place d'une telle voie en essayant de satisfaire à la fois à quatre contraintes essentielles :

1. la protection de l'homme, des animaux d'élevage et de l'environnement contre les effets préjudiciables causés par l'épandage incontrôlé des boues résiduaires;

2. la protection des milieux naturels récepteurs (sols et plantes) en limitant l'apport d'éléments-trace pour éviter toute intoxication et à long terme leur accumulation dans le sol;

3. la protection des eaux souterraines et superficielles en limitant l'apport d'azote par les boues;

4. la recherche de la filière de traitement et d'élimination la moins onéreuse et la plus pratique compte tenu des contraintes précédentes et des possibilités locales offertes sur le lieu de production des boues.

La directive devra porter sur les boues issues des stations d'épuration d'eaux usées domestiques ou d'eaux industrielles lorsqu'elles sont raccordées à ces stations.

Les boues provenant de stations d'épuration de petite taille (le nombre d'équivalent - habitants reste à préciser) ainsi que les boues dont la teneur en métaux lourds ne dépasse pas une certaine limite seraient exclues du champ d'application de la directive.

Les autres boues devront subir un traitement approprié suivant le type d'utilisation envisagé. Aucun traitement ne serait obligatoire pour les boues utilisées en sylviculture, horticulture, restauration de sols voire même pour certaines cultures industrielles. Pour les autres types de culture, les boues devront au moins être stabilisées, que ce soit par digestion anaérobie ou aérobie ou par traitement chimique.

Les procédés de désinfection et leurs effets n'étant pas encore suffisamment connus à l'heure actuelle, la directive se bornera à recommander de respecter un délai minimum entre l'épandage des boues et la mise en culture ou en pâture.

En ce qui concerne les doses permissibles de boues à épandre, celles-ci seront fonction :

- de la concentration en éléments-trace dans les boues et dans les sols;
- de la teneur en éléments fertilisants des boues;
- du type de culture.

Les boues ayant une concentration en éléments-trace (en mg/kg matière sèche) supérieure à certaines normes seront exclues; elles seront alors à considérer comme déchets toxiques et dangereux.

Pour les boues ayant une concentration en éléments-trace inférieure à ces normes, les Etats membres fixeront les quantités d'éléments-trace pouvant être apportées par hectare et par an en tenant compte des conditions locales (du type de sol, de la teneur "antécédente" des éléments-trace dans les sols); ils veilleront toutefois à respecter une concentration limite de ces éléments dans le sol.
Les éléments essentiellement visés sont le cadmium, le zinc, le cuivre et le nickel. En ce qui concerne les autres éléments, les Etats membres pourront en fixer les normes en fonction du type de sols et de cultures. Les quantités d'azote et éventuellement de phosphore apportées par les boues ne devront pas dépasser les quantités utilisées par la culture recevant l'épandage.

Avant de pouvoir être utilisées, les boues devraient être analysées au moins plusieurs fois par an. Les analyses porteraient sur les paramètres suivants : matières sèches, matières organiques, cendres, azote, cadmium, zinc, cobalt, nickel. S'il intervenait un changement brutal dans la qualité des eaux épurées, la fréquence de ces analyses serait augmentée. Les échantillons de boues analysés seront constitués sur la base d'échantillons moyens à partir de prélèvements effectués à des périodes différentes.

Il est à noter que ce type d'information ne devra pas être dissocié des conseils d'utilisation; l'analyse chimique sans interprétation n'est pas suffisante.

D'autre part, les sols destinés à recevoir les boues devront au préalable faire l'objet des mêmes analyses. En effet, les teneurs en azote, en phosphore et surtout en cadmium, zinc, cobalt, nickel varient énormément selon le type de sols, les types de cultures et surtout les types et quantités d'engrais chimiques ou d'effluents d'élevage utilisés. Il est donc essentiel de connaître "l'antécédent" d'un sol, avant de pouvoir déterminer la quantité de boues applicables et donc les quantités d'éléments-trace tolérables qu'elles apportent.

On veillera également à ce que le pH de ces sols soit au moins supérieur à 6 - 6,5 , étant donné que les éléments-trace sont moins disponibles à pH élevé qu'en conditions acides.

La directive devra également comprendre certaines contraintes d'épandage. On n'épandra pas sur les sols fortement drainés afin de ne pas polluer les eaux de surface et les eaux souterraines; on ne contaminera pas directement les cultures afin d'éviter l'ingestion par les animaux d'élevage et les êtres humains. C'est pourquoi un délai d'au moins 3 semaines devra être respecté entre l'épandage des boues et la mise en cultures ou en pâtures. Ce délai sera même d'un an lorsque ce sont des fruits et des légumes consommés crus qui seront cultivés.

Telles sont les grandes lignes et orientations qui guideront la Commission dans son travail. Certes, cette proposition ne prétend pas couvrir tous les problèmes que comporte l'utilisation agricole des boues d'épuration. Elle vise simplement à établir, à travers un certain nombre de règles, un équilibre entre l'intérêt des producteurs de boues qui cherchent à les éliminer et des utilisateurs qui trouveraient là un engrais à faible coût.

Un Comité d'adaptation au Progrès technique devra être prévu dans le cadre de la directive pour permettre de tenir compte d'une manière simple et efficace de l'évolution des progrès scientifiques et des expériences qui découleront de l'application de la directive.

BOUES D'EPURATION : PRODUCTION ET UTILISATION AU NIVEAU DE LA C.E.E. **ANNEXE**

PAYS	Production totale (i)	Projection future	Utilisation en agriculture	Incinération	Décharge contrôlée	Rejet en mer
IRELAND	18.000 T/a (1977)	40.000 T/a (1977)	4 %	-	39 %	47 %
GERMANY	2.014.324 T/a (1974)	4.000.000 T/a (1985/1990)	34 %	8 %	51,6 %	?
FRANCE	1,6 à 2 x 10^6 T/a	augmentation de 5 à 8 %/an	27 %	20 %	53 %	-
BELGIQUE	76.000 T/a (1978)	augmentation de 28.000 T/a	10 %	10 %	80 %	-
U.K.	1.250.000 T/a (1975)	faible augmentation	44 %	3 %	33 %	23 %
DENMARK	130.000 T/a (1972)	320.000 T/a (1982)	45 %	9,5 %	55 %	interdit
ITALY						
NEDERLAND	202.500 T/a (1974)	400.000 T/a (1985)	31 %	2,6 %	4,9 %	
LUXEMBOURG	11.000 T/a (1977)	6.500 T/a (1982)				

(i) : Production totale brute (non stabilisée) exprimée en matière sèche par an

(ii) : 33 % épandues sur terres pon agricoles

SESSION I - SLUDGE PROCESSING

Introductory remarks

I.1 - Sludge production and characterization

Characterization of sewage sludges

Sludge production in the Netherlands

Standardized sludge parameters and methods for their determination

Differential thermal analysis for the characterization of the stability of sludge

I.2 - Sludge dewatering

Dewatering of municipal sludges

Dewatering of activated sludge

Die Bedeutung von Kennwerten zur Charakterisierung der maschinellen Fest-Flüssig-Trennung von Klärschlamm

Influence of precipitation on the behaviour of sludge in the case of dewatering

An application of natural sludge dewatering at small sewage treatment plants in Finland

Klärschlammbehandlung in Oesterreich

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Behandlung von Klärschlamm mit Branntkalk - Voraussetzungen und Absatzmöglichkeiten

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I. 4 - Economic aspects of sludge processing

Etude de comparaison technico-économique des filières de traitement et élimination des boues résiduaires urbaines

Experiences in large scale treatment and utilisation of sewage sludge

Sludge generation, handling and disposal at phosphorus control facilities in Ontario

Computer control of sludge fermentation: process monitoring and data treatment

ACTIVITIES OF WORKING PARTY 1 "SLUDGE PROCESSING"

INTRODUCTORY REMARKS

by
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Coordinator of the Working Party

The interest of this Working Party was rather different to the four other Working Parties which comprised the COST 68 bis programme and was certainly less controversed.
Thus, Working Party 1 was concerned with the chemical and engineering problems associated with sewage sludge rather than an evaluation of the effects of its use. At the first Symposium on the Characteristics, Treatment and Use of Sewage Sludge held at Cadarache in February 1979, the objectives of Working Party 1 were defined as "to render sewage sludge suitable for disposal at minimum cost and with maximum benefit".

- Working Party 1 was formed in July 1978 with U.K. as the pilot country and Norway and Switzerland as co-pilot countries. More than 80 technical papers had been produced by the Members.

- The scope of Working Party was particularly wide and covered all aspects of sewage sludge from primary treatment to the final disposal site. The key tasks of the Working Party were :

  1° Identify/classify national research projects on sewage sludge : more than 100 projects had been identified to date and it was interesting to note regional variations in interest. For example, most of the projects on composting of sewage sludge were carried out in the Federal Republic of Germany.
  Additional projects covering characterization of sewage sludge, treatment of return liquors, economics and energy considerations had also been identified.
  2° Exchange of information
  3° Prepare "State of Art" reviews on aspects of treatment of sewage sludge
  4° Identify need for further research.

- The interests of Working Party 1 also extended to the harmonization of methods for the characterization of sewage sludge and to the evaluation and recommendations of new methods.

- Seventeen papers will be presented at the Symposium on this session and for convenience they have been grouped into the following four subject areas :

  1) Sewage sludge characterization
  2) Sewage sludge dewatering
  3) Sewage sludge stabilization
  4) Economics of sewage sludge processing.

CHARACTERIZATION OF SEWAGE SLUDGES

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Summary

Sludge characterization involves description of sludge behaviour in treatment processes and disposal. Appropiate characterization methods facilitate understanding and prediction of sludge properties. The characterization parameters belong to one of three cathegories: Indication of quantity, treatability or quality. Discussion of quantity and treatability reveals a large number of proposed parameters. Unfortunately there is a lack of universally accepted parameters to describe centrifugation. In stabilization one has no common method suitable for sludges from anaerobic, aerobic and chemical stabilization. This makes the degree of offensiveness hard to compare between sludges of different origin.

Sludge behaviour in thickening and most dewatering processes can be evaluated by several accepted methods. Characterization of physical properties is still in its infancy, but methods have recently been proposed.

Common sludge characteristics are reflections of fundamental properties that can often be identified even if their influence is hard to quantify. The diversity and complexity of the sludge microcosmos make generally valid relationships very hard to find.

INTRODUCTION

The object of sludge characterization must be to get quantitative measures for sludge behaviour in treatment processes and when disposed of.

Thus the incentive for characterization could be one of the following:

1. Because sludges exist in large quantities we want to know the amounts and the expences involved in their treatment and disposal.
2. Because sludges are environmental nuicances/hazards, energy sources, fertilizers or even food sources; we want to know their potential.
3. Because the processes change the sludge properties, we want to know their "treatability".
4. Because sludges have a history, we want to know how the generation process affects the quantities and the properties of raw sludge.

Parallel to the characterization of the sludges runs characterization of the sludge treatment-processes and the environment in which we dispose of the sludge.

In the following discussion we will group parameters related to sludges into three cathegories:

1. Sludge Quantity. Both total and per capita sludge production data from all common sewage and sludge treatment methods are of interest.
2. Treatability parameters. These are characteristics of how a sludge behaves in a specific process. Typically; dewaterability and digestability.
3. Sludge quality parameters. These are indicators of how the sludge could influence the environment when disposed of. Sludge quality changes through most sludge treatment processes (stabilization, thermal etc.) and include concentrations of chemical compounds, pathogenes etc.

Sludge quality in relation to final disposal is the object of Working Parties 2-5 in this COST-action. The sludge parameters defining chemical and biological composition, toxicity, fertilizer value etc. will therefore not be further discussed below.

1. SLUDGE PRODUCTION

Sludge production can be given in mass or volume, in total or in per capita values. The production will depend heavily on the given sewage treatment process and on the subsequent sludge treatment. The human body excretes approx. 110 g of organic matter pr. day. This includes some 14 g of N and 2 g of P. In sewage, other sources of pollutants are: "Grey" waters from households, industrial effluents and urban storm drainage. Within a particular sewage works the sludge production will be related to the total volume of influent and to its quality. The amount of water and pollutants reaching the works will most certainly differ from that generated in the district served. This is due to infiltration and exfiltration in the servers.

Table I (1) gives sludge production per capita pr. day in a number of treatment processes. The figures are approximate. In chemical treatment the precipitating chemical is dosed proportional to the volume of influent. The amount of chemical precipitates will increase with amount of coagulant added, and therefore with volume of influent. To achieve per capita figures one must assume a figure for the per capita water consumption, a very uncertain venture indeed. The sludge production in biological processes will depend on the organic load on the plant, and could be very much influenced by industries with high organic effluents. The volume of sludge from the first separation process is reduced through thickening and dewatering.

Table I	Sludge mass and volume prior to thickening							
	Mechanical		Biological		Chemical		Total	
	g/DS/p·d	l/p·d	g/DS/p·d	l/p·d	g/DS/p·d	l/p·d	g/DS/p·d	l/p·d
Mechanical	60	1.2-3.0	-	-	-	-	60	1.2-3.0
Activated	-	-	80	4.0-8.0	-	-	80	4.0-8.0
Mech.+Activ.	60	1.2-3.0	35	1.8-3.5	-	-	95	3.0-6.5
Primary and secondary								
w/aluminium	60	1.2-3.0	-	-	70	3.5-7.0	130	4.7-10.0
w/ferric	60	1.2-3.0	-	-	75	3.5-7.0	135	4.7-10.0
w/lime	60	1.2-3.0	-	-	200	5.0-10.0	260	6.2-13.0
Simultancous Precipitation								
w/aluminium			80	-	20	-	100	4.0-10.0
w/ferric			80	-	25	-	105	4.0-10.0
Post precipitation								
w/aluminium	60	1.2-3.0	35	1.8-3.5	30	1.5-3.0	125	4.5-9.5
w/ferric	60	1.2-3.0	35	1.8-3.5	35	1.5-3.0	130	4.5-9.5
w/lime	60	1.2-3.0	35	1.8-3.5	160	4.0-8.0	155	7.0-14.5

2. SLUDGE TREATMENT

Fig. 1 (2) shows processes and pathways available to alter properties and volumes of the untreated sludge. The treatment processes can be grouped according to their objective:

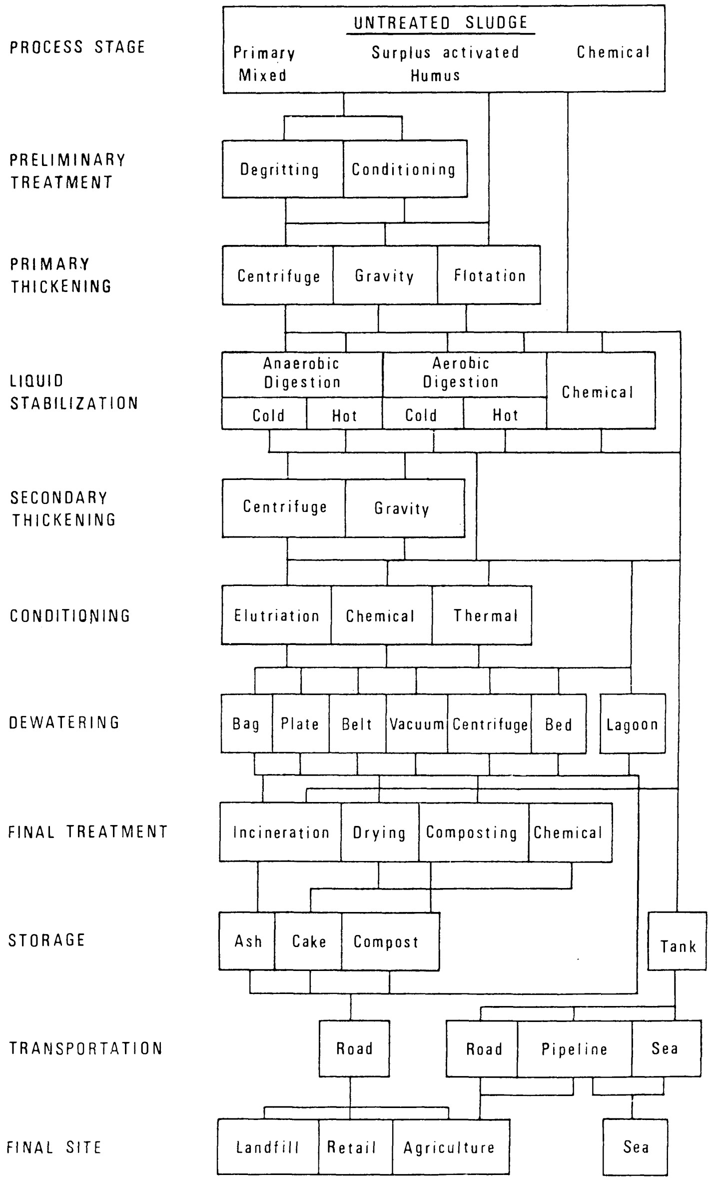

Fig. 1 Sludge treatment processes and pathways.

2.1 Thickening

2.2 Dewatering

2.3 Stabilization

2.4 Final treatment and disposal

Parameters relevant to these groups of processes will be discussed below.

2.1 Thickening

Through thickening of the sludge one can achieve a 1 to 4 times reduction in volum. How well the sludge thickens can be estimated through a number of tests:

Table II Thickening test.

Parameter	Measurement
Sludge volume	Volume of settled sludge after 30 min. in graduated sylinder. (ml sludge/l sample)
Sludge Volume Index (SVI)	Sludge Volume/Suspended Solids concentration (ml/g)
Stirred SVI (SSVI)	SVI in a slowly stirred graduated sylinder (ml/g)
Low speed centrifugation	Sludge blanket settling velocity in a field of 10-100 G
Ultimate Solids	Dry Solids concentration after settling or centrifugation
Flotation tests	Specific air requirement in lab thickener Dry solids achieved Flux of thickener

Of these the SVI (and lately in Britain the SSVI) have found widspread use. In activated sludge, an SVI of less than 100 ml/g is considered "well settling" while sludges with greater values are often troublesome (3). The SVI can however be misleading if the SS value is high, as one can get a low SVI even with poor or no settling.

Careful use of a low speed centrifuge (5) can directly model sludge performance in thickeners. A new device called "WRCfrozen image centrifuge" (5) is a promising tool for predicting thickener; - performance - flux and ultimate solids for a specific sludge. The method can also be employed to evaluate particle mobility and sludge compressibility.

The thickening tests can be used to design and determine operational parameters of thickeners. The tests all reflect more fundamental properties of the liquid and the solid matter in the sludge. Among these properties are:

- The suspended solids concentration (SS)
- The specific gravity of the solids
- Chemical and electrical interaction between individual sludge particles (surface charge)
- Particle area
- Particle size distribution
- Compressibility of individual particles
- Presence of filamentous organisms
- Viscosity of sludge and sludge liquour
- Ionic strength
- Distribution of water around and in the flocs
- Shear strength of sludge flocs
- Aggregate volume index (α) = $\frac{\text{water volume}}{\text{sludge solids volume}}$
- Nature and amount of exocellular polymers
- Etc.

The fundamental properties that affect thickening are also important in dewatering. The parameters measured to evaluate dewatering are different however. The listed fundamental properties are of great research interest even if microlevel interactions in sludges to day are hard to quantify and relate to both process performance and sludge behaviour.

2.2 Dewatering

Prior to dewatering sewage sludges are nearly always conditioned. This operation can only be appreciated in the way it succeeds to improve the dewatering properties of the sludge. The parameters related to conditioning are thus measurements of the dewatering properties and the amount of chemicals and energy required.

The parameters of dewatering model forces acting in full scale dewatering processes. They are often liable to scale effects and will sometimes better predict relative changes in dewaterability with conditioning than give exact figures for fullscale process performance. The parameters are often as much functions of test variables as of sludge properties. The data are nevertheless useful when obtained under standardized conditions. The parameters listed in table III are directly related to specific dewatering methods. Parameters related to dewatering by filtration (vacuumfilter, filterpresses and belt filters) are commonly used to caracterize sludges. Surprisingly there is a lack of universally accepted methods to predict sludge behaviour in centrifuges. This is all the more unfortunate as centrifuges are common in many countries.

The dewatering parameters CST (10) and specific resistance to filtration have found widespread use and acceptance, and are by far the most commonly quoted indicators of dewaterability. Both are measured under standardized conditions. With the CST a standardized test procedure is available indicating sludge shearstrength and conditioning dose demand. CST and specific resistance data are available from reported research works over a number of years. The CST method has been further developed (13) and the "multi radii CST" may facilitate very rapid determination of important dewatering characteristics.

Filter Leaf Testing relate directly to vacuumfilters, quite uncommon in Europe apart from France.

Filter belt presses enjoy increasing popularity and recently a two stage test procedure was proposed (9) to investigate conditioning and dewatering with these machines. Experience with the method is still scarce, but it may help to achieve a more rational approach to polyelectrolytic conditioning.

Filtration processes inevitable cause a resistance buildup in the filter cloth due to increasing sludge solids deposited in the pores. The degree and rate of resistance increase in the medium (referred to as blinding) is dependent upon sludge quality after conditioning. Measurement of specific resistance in successive filtration cycles will give an indication of the degree of blinding. Little experience is available with this as a test method.

Table III. Dewatering tests.

Parameter/related process	Measurement
Specific resistance to filtration (r)	Rate of solids buildup in a filtercake
Capillary suction Time	Rate of liquid with rawal from a sludge by capillary suction (seconds)
Multi Radii CST (filtration)	Modified CST-method.
Compressibility (filter presses)	Rate of increase in "r" with increasing pressure in filtration.
Shearstrength	Rate of change in CST or "r" with turbulent stress on sludge particles.
Filter leaf yield (vacuum filters)	Sludge solids captured pr. unit area in a vacuum filter. Cake solids concentration achieved.
Filter belt press yield (filter belt presses)	1. Rate of gravity water drainage from sludge on filter belt 2. Rate and extent of water removal from sludge subjected to compression subsequent to drainage
Blinding index. (filtration)	Degree of in resistance buildup in filter cloths though a sequence of filtration cycles.
Extent of dewatering	Dry Solis measurement of sludge cake.

2.3 Stabilization

The object of all stabilization processes are genereally to make the sludge "less offensive". The degree of "offensiveness" exhibited by the the sludge is primarily linked to the character and the intensity of its odour. The first COST-68 action proposed the following definition of an aerobically stabilized sludge: "A sludge where the odour intensity Index (OII) does not exceed 11 at any time prior to 14 days of storage at 20 ^{o}C unless the odour can be classified as a typical "soil" odour." (8). Odour is a highly individual perception and its measurement requires a panel of test persons and a rather laborious test procedure. Odour measurements have therefore found little practical application in sludge treatment.

Rather, several researches have tries to link "stability" to other more convenient characteristics of the sludges. The parameters measured to determine stability vary among the different stabilization processes.

Table IV Stability Tests.

Stabilization method	Property	Test
All (Biological and chemical)	Odour	Odour: - intensity - number Number of liquid or gas dilutions necessary to make odour indetectable. Odour identification: Gas chromatography followed by simultaneous concentration recording and human detection.
	H_2S emission	Time to colour lead acetate paper (Rüffer-test)
Biological	Volatile solids	Reduction of organic material through process
	Potential degradability	Total organic carbon content
	Nutrients in sludge liquour	Sludge liquour COD and BOD variation through reactor
	Viability	ATP concentration Enzyme "
" Anaerobic	Gas Production	Carbondioxide and Methane production rate
	Gas composition Volatile fatty acids Bicarbonate alkalinity	CO_2/CH_4 ratio
" Anaerobic	Activity Nitrification pH Denitrification	Oxygen uptake rate Nitrate concentration Change of pH during process Flotation detection during storage
Chemical (lime)	pH	Stability of high pH during storage

In an-aerobic and aerobic stabilization, the biodegradable fraction of the volatile solids may vary with time, and from one sludge to another. Stability measurements based on volatile solids reduction, must therefore be made on the assumption that a specified fraction is biodegradable.

This limits the accuracy and comparability of volatile solids measurements as a stability indicator. Apart from pH and oxygen uptake rate, other parameters of stability are limited by either requirement of laborious test procedures, limited reproducability or weak correlation with the odour emission. Oxygen uptake rate has been proposed as an indicator of sludge stability obtained in aerobic processes (7), while an elevated pH (>11) during storage indicates low biological activity after lime stabilization (7).

Anaerobically stabilized sludge is characterized by process related parameters like gas-production, composition, fatty acid content and alkalinity. These give useful informasion of digester performance, but less precisely indicate the appearance of the sludge.

Recently a "biological evolution index" was suggested (14) as a general indicator of sludge stability. The index is defined:

$$I = \left[\text{ATP conc}\right]\left[\log \text{ interstitial } BOD_5 + \left(\frac{VS}{DS}\right)^2 \cdot (\text{Enzymatic activity level})\right]$$

The index however, requires complex analytical procedures and equipment. It's application will therefore be restricted to research purposes.

2.4 Final treatment and disposal

Relating to the final sludge disposal a large number of parameters are of interest. In particular contents of pathogenes, heavy metals and nutrients; the potential hazards and benefits will be the topic of numerous papers at this Vienna conference.

From the point of view of sludge treatment, sludge behaviour in drying, incineration, composting, transportation and disposal (spreading etc.) is of interest. Heat drying of sludges take place to convert wet sludge into a possible fertilizer, soil conditioner, or as a pretreatment ment to combustion. Of interest is the energy required to evaporate the desired amount of water from the sludge.

Table V a. Characterization of physical properties. Identification of physical state.

State	Definition or test requirements
Liquid	Sludge will drain from a specified vessel through a calibrated orifice in a specified time.
Plastic	1. Not liquid 2. Sludge can be extruded in a continuous sylinder from a specified pressure cell.
Solid "with" shrinking	1. Not plastic or liquid 2. Experiences reduction in volume upon drying
Solid "without" shrinking	No reduction in volume upon drying

Table V b. Tests characterizing sludges within each physical state.

State	Property	Test
Liquid	Viscosity	Flow rate through a specified tube viscosimeter
Plastic	Degree of plasticity	Pressure needed to extrude sludge through a specified orifice.
	Mechanical stability	Casagrandes shock apparatus (Adapted from geotechnical ana lysis)
	Shearstrength	Penetrometry test
	Adhesion	Force needed to ectract specified cones from adhesion to plastic sludge
Solid state	Shearstrength	As above
	Degree of shrinking	Volume reduction upon drying

Combustion of dry sludge solids will liberate energy. Any sludge will therefore have a specific heat value, typically from 8.000-20.000 Btu/kg dry solids.

Economics of incineration are dependent of the specific heat value, the water content and ash content of the sludge.

Sludge handling after final treatment depend on the sludges physical state and rheological properties.

The physical state of sludges is determined by the nature and amount of solids present. Methods developed in soil science and rheology can be adapted to fill the need for a system to characterize the physical state of sludges. In this COST-action has been suggested (11), table V a and b, that the physical state of a sludge can be classified in one of four groups: Liquid, plastic, solid "with" and "without" shrinking. A number of test have been defined to identify to what group a given sludge belongs. Within each group tests have been defined to measure important properties.

Other useful information of the physical properties of sludges include: Specific weight, bulk weight, dry solids concentration and water retaining properties.

Testing physical properties of sludges is almost a virgin area of research. One has yet to see to what extent one in sludge treatment and disposal can apply results obtained through research on physical characterization.

Characterization is an area of research where more fundamental knowledge is desired, but made hard to aquire by the extreme complexity and diversity of sewage sludges.

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SLUDGE PRODUCTION IN THE NETHERLANDS

by

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Summary

Any solution of the problem of sludge disposal starts with the collection of reliable data on quantities and qualities of the produced sludges. Since 1959 the Standing Committee on Sludge Disposal of the Netherlands Association of Wastewater Treatment and Water Quality Management (NVA) undertakes inquiries of purification methods, methods of sludge stabilisation, sludge production, ways of sludge disposal, disposal costs and composition of the sludge.
The paper describes the way in which the questions are asked in the inquiry among the circa 30 Water Authorities and industries with private purification plants and the presentation of the results. Some results of the 1978 inquiry are given.

A sewage treatment plant delivers in principle two products, namely the effluent and the sewage sludge.
Nowadays it is not really a problem to produce a good quality of effluent;
However from the beginning of the practice of sewage treatment the treatment and disposal of sewage sludge is the problem child of those who are concerned with sewage treatment.
Quantities and qualities of the sludge are dependent on the composition of the sewage and the process of sewage treatment.
The number of sewage treatment plants in the Netherlands increased from 200, with a capacity of 2.250.000 i.e. in 1959, to 568 with a capacity fo 18.000.000 i.e. at this moment.
This increase is attended with an increase in sludge production and a more than proportional increase of the problems of the treatment and disposal of the sludge.
However one will think about it, the sludge should be disposed off in the environment in one way or the other.
The actual method depends on factors like, among others, quality, quantity, local circumstances, and seasons.

A right approach to the problem of treatment and disposal of sludge starts with the collection of reliable data on quantities and qualities of the produced sludges.
With this in view the Standing Committee on Sludge Disposal of the Netherlands Association of Waste Water Treatment and Water Management (N.V.A.) undertakes inquiries among the circa 30 Water Authorities and industries with private sewage plants since 1959.
In the beginning these inquiries were undertaken at intervals of some years, at present it is use to have an inquiry each year.

As a matter of course every year the way in wich the questions are asked has impoved as well as the processing of the data.
In the following the inquiry of 1978 is described.

In the spring of 1979 we did sent two forms, A and B, to each Water Authority and industry with private sewage plant to be filled up before the 1^{th} of September.
Before half September we got back ± 80% of the forms.
We called upon those who did not reply and at the end of October the total response was 94%.
The remaining 6 percent that did not send back their forms were small industries.
Only data of the sewage plants with over 1000 i.e. are processed.
In form A details of the plants are asked, as location, capacity (both design and actual capacity), purification method, method of sludge stabilisation, sludge conditioning and dewatering, the transporter of the sludge and the destination.
With the exception of the capacity all these data are filled up in code according to a code list enclosed with the forms.
Moreover figures are asked about sludge quantities before and after dewatering, the dry matter and ash content, costs of sludge transportation and disposalcosts of proceeds.

Form B contains questions about the quality of the sludge, such as: organic matter, pH, nitrogen, phosphate, calcium, potassium, chloride, zinc, lead, copper, manganese, chromium, cadmium, nickel, mercury, cobalt, molybdenum and iron content. The methods of destruction and analysis of the samples are also asked.

The data are processed by a computer; therefore it is possible to combine the results in every possible way. Only the useful combinations are worked out because it has no sense to get more theoretical interrelationships.

In 1978 we got the information of 479 sewage plants. (At that moment there were in the Netherlands 568 plants with more than 1.000 i.e.).
Some of these plants have more than one stream of sludge, often different in the dry matter content, sometimes diffe-

FORM A

PRODUKTIE EN BESTEMMING VAN ZUIVERINGSSLIB IN NEDERLAND BLAD A <u>Soorten, hoeveelheden, bestemming, kosten.</u>

		Waterkwaliteitsbeheerder:											Kontaktpersoon:						Tel.			
Nr.	1 plaats rioolwaterzuiveringsinstallatie.	2 methode zuivering	3 methode slibstabilisatie	4 methode conditionering	5 conditioneringsmiddelen		6 methode ontwatering.	7 vervoerder.	8 bestemming slib.	9 ontwerpcapaciteit RWZI.	10 werkelijke belasting RWZI.		11 vóór ontwatering			12 na ontwatering			13 kosten vervoer.	14 overdrachtskosten/opbrengst slib.		
					type	dosering					huishoudelijk	industrieel	hoeveelheid slib	droge stofgehalte	asgehalte	hoeveelheid slib	droge stofgehalte	asgehalte				
		code	code	code	code	kg/ton d.s.	code	code	code	(i.e.)	(i.e.)	(i.e.)	(m^3/j)	(%)	(%)	(m^3/j)	(%)	(%)	(ƒ/j)	(ƒ/j)	(ƒ/j)	

FORM B

PRODUKTIE EN BESTEMMING VAN ZUIVERINGSSLIB IN NEDERLAND BLAD B samenstelling.

Enquête
NVA Slibkommissie.

Gegevens over het jaar:			Waterkwaliteitsbeheerder:									Kontaktpersoon: tel:											
Nr.	plaats rioolwater-zuiverings-installatie		Bemestingswaarde % op droge stof									Gehalte zware metalen mg/kg											
			orga-nische stof	N totaal	Fos-for (P_2O_5)	Calcium (CaO)	K	Mg		Cl	pH (KCl)	Zn	Pb	Cu	Mn	Cr	Cd	Ni	Hg	Co	Fe	Mo	
		laagste waarde																					
		hoogste waarde																					
		gemiddelde waarde																					
		aantal analyses																					
		laagste waarde																					
		hoogste waarde																					
		gemiddelde waarde																					
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		aantal analyses																					
		laagste waarde																					
		hoogste waarde																					
		gemiddelde waarde																					
		aantal analyses																					

N.B. Gaarne voor iedere slibsoort met andere kwaliteit een aparte regel gebruiken.

Geanalyseerd door:welke instantie:
Gebruikte methode(n):

rent by the purification method and so they can have two or more destinations of the sludge.
With the 479 sewage plants went 537 streams of sludges.

With all these detailed data coming from so many sewage plants we are pretty sure of the reliability of the results. So we have for instance no doubts about the quantity of sludge produced per inhabitant equivalent (à 54 g BOD^{20}_{5}).
In 1976 these production was 13.9, in 1977 13.5 and in 1978 12.6 kg dm/i.e.
In literature (Imhoff, Taschenbuch der Stadtentwässerung 1969) a quantity of 25 - 28 kg dm/i.e. is admitted; in the Netherlands the situation clearly is different.

The results of the inquiry are published in the Journal H_2O. (H_2O (13) 1980, nr. 13). All the figures are summed up in eight tables. (See Appendix).

An other interesting matter we were able to work out, is the so called base-concentration of heavy metals in sludge: the heavy metals content that satisfy 10% of the sludges.
The underlying thought was that this figure would be about the concentration of the metals if all the industrial discharge of these elements were eliminated.
We found that 10 percent of the sludges can satisfy the following concentrations:

Zn	820	ppm
Cu	222	ppm
Pb	156	ppm
Ni	17	ppm
Cr	25	ppm
Cd	3	ppm
Hg	0	ppm

It is worth to strive after a good qualtity of sludge without affecting the qualtity of the effluent, which has proven to be possible!

This way of processing enables us to follow trends in sludge production, destination and composition over the years.

Tabel 1

		ie	ie	kg/ds ie jaar
1. mechanische zuivering	66	2.212.700	3.040.460	13,1
(idem zonder Den Haag)	65	812.700	880.460	
2. aktief slib	88	7.462.300	5.492.060	13,6
3. oxidatiesloot	216	4.887.110	2.954.420	14,1
4. oxidatiebed	89	2.927.500	2.661.030	9,1
5. compactinstallatie	7	16.120	9.535	11,3
6. combinatie aktief slib en oxidatiebed	0	0	0	0,0
7. combinatie oxidatiebed en derde trap zuivering	11	1.683.500	1.210.290	11,0
Totaal	479	19.195.700	15.367.800	12,6
Totaal zonder Den Haag	478	17.795.700	13.207.800	
Purification method	number	design	actual capacity (inh.e.q.)	d.m.prod.in kg/inh.e.q./ year

The purification plants surveyed

Tabel 2

Type inrichtingen in percenten

type zuivering	1976	1977	1978
1. mechanische zuivering	15	14	14
2. aktief slibinstallatie (incl. ox.tank)	16	17	18
3. oxidatiesloot (incl. carroussel)	45	44	45
4. oxidatiebed	22	22	19
5. compactinstallatie	1	1	1
6. combinatie aktief slib en oxidatiebed	1	2	0
7. combinatie oxidatiebed en derde trap	0,2	0,2	2,3

Tabel 3

Overzicht methoden slibstabilisatie

(getallen tussen haakjes geven de waarden voor 1977 aan)

methode slibstabilisatie	aantal rwzi	belasting installatie ie	verhouding slibstabilisatie tov belasting	idem zonder Den Haag
1. niet behandeld	53 (53)	5.343.250 (4.881.694)	35 (33.0)	24,2 (22.7)
(idem zonder Den Haag)	52 (52)	3.183.250 (2.921.694)		24,2 (22.7)
2. aeroob gestabiliseerd	246(237)	3.183.710 (3.079.255)	21 (20.8)	24,2 (24.0)
3. anaeroob gestabiliseerd	177(196)	6.549.600 (6.565.598)	43 (44.3)	49,7 (51.1)
4. combinatie aeroob en anaeroob gestabiliseerd	2 (1)	248.900 (255.970)	2 (1.7)	1,9 (2.0)
Totaal	478(488)	15.325.500(14.812.227)	100 (100)	
Totaal zonder Den Haag	477(487)	13.165.500(12.852.227)		100 (100)
	Number of plants	capacity in inh.e.q.	% related to total capacity	idem without The Hague

Methods of sludge stabilisation (1977) and 1978

Tabel 4

Slibafvoer in relatie tot d.s. gehalten
(excl. Den Haag)

Klasse d.s. gehalte %	Afgevoerde hoeveelheid slib m^3	Verhouding tov totaal %
0 - 5	1.607.080	65,1
5 - 10	491.064	19,9
10 - 20	121.242	4,9
20 - 30	102.357	4,1
30 - 40	96.557	3,9
40 - 50	41.414	1,7
50 - 60	710	,0
60 - 90	50	,0
90 -100	9.611	,4
Totaal	2.470.085	100
Range in % d.m.	m^3 disposed	% of total

Sludge disposal related to the d.m. content (without The Hague)

Tabel 5

Hoeveelheid afgevoerd slib.

Slibafvoer	als volume m^3	als droge stof totaal in ton d.s.	gemiddeld d.s. gehalte %
1977 zonder Den Haag	2.456.829	182.448	7,4
met Den Haag	4.954.329	202.448	4,1
1978 zonder Den Haag	2.470.085	177.450	7,2
met Den Haag	5.070.085	200.850	4,0
	in volume m^3	dry matter tons	concentration %

Quantities of sludge disposed.

Tabel 6

Destination
Bestemming van het slib

Afgevoerd slib als volume	aantal meldingen	hoeveelheid m^3	Bestemming in percenten 1	2	3	4	5	6	7	8	9	13	14	15	16	17	23	24	25	34	46
met Den Haag	537	4.763.934	25,95	,30	,09	3,49	7,66	1,67	3,01	54,58	,60	,18	,80	,27	,29	,76	0,00	0,00	,04	,04	,27
zonder Den Haag	536	2.163.934	57,12	,67	,19	7.69	16,87	3,68	6,62	0,06	1,32	,39	1,76	,60	,63	1,67	0,00	0,00	,09	,09	,60

Afgevoerd slib als d.s.	aantal meldingen	hoeveelheid ton	Bestemming in percenten 1	2	3	4	5	6	7	8	9	13	14	15	16	17	23	24	25	34	46
met Den Haag	537	183.925	34,14	,47	,29	2,90	12,04	4,80	24,74	12,72	2,80	,68	,43	,37	,34	1,36	0,00	0,00	,13	,13	1,63
zonder Den Haag	536	160.525	39,12	,54	,33	3,33	13,80	5,50	23,35	0,00	3,20	,78	,50	,43	,39	1,56	0,00	0,00	,15	,15	1,87

Kodering bestemming:

1. landbouw
2. tuinbouw, inkl.bollenteelt
3. sportvelden, plantsoenen etc.
4. nuttige bestemming anderszins
5. overdracht aan tussenhandel
6. storten op eigen terrein
7. storten elders
8. afvoer naar oppervlaktewater
9. verbranden
13. kombinatie van bestemming 1 en 3
14. kombinatie van bestemming 1 en 4

etc.

Tabel 7

Bestemming ten nutte in percenten van totale slibproduktie.

	1977	1978
Afgevoerd slib als volume in volume		
incl. Den Haag	33.5	38.8
excl. Den Haag	67.8	85.5
Afgevoerd slib als droge stof in drymatter		
incl. Den Haag	52.7	51.6
excl. Den Haag	58.5	59.1

Tabel 8

Kwaliteitsgegevens zuiveringsslib
(getallen tussen haakjes geven de waarden voor 1977 aan)

	gewogen gemiddelde samenstelling (totaal)	respons	gewogen gemiddelde samenstelling van slib dat naar de landbouw gaat	respons
org.stof	61,3 (54.5)%	70,0 (53.4)	60,6 (60.9)%	87,6 (71.1)
N	5,5 (4.8)%	71,5 (38.5)	5,4 (3.4)%	92,2 (53.4)
P205	5,7 (4.8)%	72,1 (38.4)	5,8 (5.2)%	92,2 (53.4)
CaO	5,7 (6.5)%	57,4 (35.2)	5,6 (4.9)%	86,3 (49.0)
K	,4 (0.3)%	57,6 (32.6)	,3 (0.4)%	86,7 (49.0)
Mg	,3 (0.4)%	45,3 (32.6)	,3 (0,4)%	63,9 (42.5)
Cl	,7 (1.1)%	8,8 (2.6)	,8 (1.2)%	17,2 (8.1)
Zn	1231 (3828)mg/kg	99,6 (55.4)	1570 (2008)mg/kg	99,2 (71.9)
Pb	385 (500)mg/kg	76,4 (52.4)	337 (395)mg/kg	91,4 (66.7)
Cu	591 (580)mg/kg	76,7 (56.8)	570 (558)mg/kg	92,5 (72.0)
Mn	531 (332)mg/kg	4,0 (4.3)	481 (418)mg/kg	5,4 (3.9)
Cr	203 (540)mg/kg	76,0 (52.9)	208 (259)mg/kg	91,3 (69.2)
Cd	10 (18)mg/kg	76,2 (52.7)	11 (13)mg/kg	91,4 (64.0)
Ni	60 (138)mg/kg	76,0 (55.4)	60 (69)mg/kg	91,1 (68.8)
Hg	5 (6)mg/kg	51,0 (32.3)	6 (9)mg/kg	75,4 (53.3)
Co	18 (9)mg/kg	8,2 (3.6)	19 (8)mg/kg	15,8 (10.3)
	Overall values	response	values in sludge for agricultural use	response

Quality of sludge in (1977) and 1978

STANDARDIZED SLUDGE PARAMETERS AND METHODS FOR THEIR DETERMINATION

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Summary

A short description of the development of standardization is given with regard to impulses which had come from the research group "Standardization" in ECE's first concerted action COST 68 which ended 1975.

At present, the German Institute for Standardization (DIN = Deutsches Institut für Normung) coordinates and leads all standardization activities in the Federal Republic in the field of water, sewage, and sludge through its committee called "Normenausschuß Wasserwesen (NAW)" which coordinates the activities of seven special committees and a great number of subcommittees. The author is chairman of the committee "Sludge and Sediments" which was set up in 1969 as a working group of the German Chemical Society. In a first phase, this group has worked out a number of German Standard Methods which were published in "Deutsche Einheitsverfahren zur Wasser-, Abwasser- und Schlammuntersuchung".

The second phase comprises work on the revision of these methods, transformation into German Standards of DIN (DIN-Normen) and preparation of other methods not yet standardized. With a view to harmonizing all these methods and new ones required for sludge treatment and disposal, the above named committee has set up a table listing the necessary and desired sludge characterization and investigation methods. It is hoped that the discussions and work within COST 68bis will influence progress in this field to give aid to scientists and technicians working in sludge treatment and disposal to improve processes and to come to solutions acceptable both from the economical and environmental points of view.

As a consequence of increased efforts in the field of water pollution control, the treatment, utilization, and disposal of sewage sludges have gained in economic and technical importance in recent years. During the coming years, continuation of this development is expected to meet with a lot of success but also to raise numerous problems. There will be solutions for these problems if onward development of methods is accompanied by the development and improvement of proper conditions for sludge treatment and disposal.

In this context, sludge examination and analysis are playing important roles. The significance of this field is examplified by the agricultural utilization of sludges where the analysis of heavy metals in sludges, soils, and plants is of prime importance. There have been numerous comprehensive programmes of study on the international level, among them Project COST 68 bis under the auspices of the Commission of the European Communities (CEC).

Besides heavy metals, there are numerous other factors influencing the characterization and evaluation of sewage sludges. Within the first CEC Project COST 68 (1), the study group "Standardization" established a list of parameters and methods to be used in sludge characterization that has been a guideline for onward activities. Unfortunately, these international activities of the past met with little response by circles outside the research programme proper.

Thus, the international standardization work by ISO does not yet include work on sludge investigation and analysis although a basis for such activities has been provided by preparatory work in a number of countries, e.g. in the U.K. and in the Federal Republic of Germany(2, 3).

The following is to give a brief account of German activities in this field and to submit proposals to be included in a list which is thought to serve as a basis for future international cooperation.

Intensive work on the German Standard Methods (DEV) (3) included the formation of a specific working party within the Water Chemistry Division of Gesellschaft Deutscher Chemiker (GDCh) as early as 1969. This working party has been dealing with the elaboration of corresponding methods of characterization under the name of "Methods of examination of sludges and solid wastes". The author has participated in this work which, until 1975,has resulted in the following methods: S 1 - Sampling, S 2 - Water Content and Dry Residue, S 3 - Loss on Ignition and Residue, S 4 - Leachability (water), S 5 - pH Value, and S 10 - Sludge Volume (activated sludge).

Later on, there has been close cooperation between the above mentioned division of GDCh and Deutsches Institut für Normung (DIN) with a view to a future revision of DEV methods to form DIN standards. The working party has been re-named Special Committee "Sludge and Sediments". Thus, it has become a sub-committee within the Standards Committee "Water Management" of DIN. When the long-standing chairman of this working party/ subcommittee, Professor Dr. F. von Ammon, Munich, retired in 1979, the author was asked to become his successor. Work has since been continued in accordance with the programme which had been set up under Professor von Ammon's chairmanship.

The transformation of the DEV methods into DIN standards (No. DIN 38 414/part 1 - part 10) is under way. The methods are revised and completed taking into account experience with their application after their publication in 1975. The first to appear in the near future will be DIN 38 414/part 5 "Determination of pH value in sludge and sediments" and DIN 38 414/part 10 "Determination of settled sludge volume and sludge volume index". A new item that has been included in the list of methods will be the one on "Determination of the anaerobic digestion of sludges". Methods for the analysis of surfactants will also be discussed.

Despite such progress, the number of standardized methods of analysis has remained a rather limited one and is not at all corresponding to the requirements of practice. Although the manuals, handbooks, and other publications in this field provide a number of other rules and guidance in matters of sludge investigation, these are frequently of a quite general nature and only rarely meet the requirements of binding standards.

Fast progress in this field is a necessity to provide material that would permit e.g. a comparison of the performance of sludge treatment installations. Such material should have been developed on the basis of generally recognized and exactly described chemical, physical, and technical methods of characterization. For this purpose, cooperation with a committee of "General Problems of Sludges and Solid Wastes" of Abwassertechnische Vereinigung (ATV) which is also under the author's chairmanship has started.

As a first result of such cooperation a table has been prepared listing methods of characterization that have either been used in the field of sludge investigation or proposed for such purpose on the basis of scientific studies (4). This list has been related to an enumeration of the common methods of sludge treatment and disposal and includes a rating that provides information on the necessity of the application of the former. This list does not include the microbiological methods needed for an evaluation of the agricultural use of sludges. Standardization of these methods is a task of hygienists. As has been shown by work under the COST 68bis Project (Working Party 3), this task is still meeting with difficulties and will take a certain time.

The author and his colleagues within the working parties would welcome proposals by the experts of other countries that could help to improve and complete the list provided.

Method of characterization \ Method of sludge treatment and disposal	Transportation	Sedimentation	Activat. sludge process	Stabilization: aerobic	Stabilization: anaerobic (digestion)	Stabilization: chemical	Stabilization: thermal	Thickening by gravity	Thickening by flotation	Thickening by mechanical methods	Dewatering natural (drying beds)	Dewatering artificial (mechanical methods)	Tipping, barging	Composting	Incineration	Agricultural use
Temperature				+	+						+	+				
Density	+									(+)						
Dynamic viscosity	+															
Rheolog. properties	+										+	+	+			
Settling behaviour	(+)	+		+	+	+	+	+								
Sludge volume/ sludge index		+	+					+								
Moisture content/total solids residue		+	+	+	+	+	+	+	+	+	+	+	+	+	+	(+)
Volatile substance/ fixed residue			(+)	+	+	+	+				+	+	+	+	+	+
Organic carbon			(+)	(+)	(+)	(+)	(+)						(+)	+	+	(+)
COD of liquid phase				+	+	+	+				+	+				
Digestibility	+				(+)								+			
Digestion behaviour					+											
Digester gas composit.					+											
pH value	+		+	+	+	+					+		+	+		+
Acid consumption					+								+			+
Volatile acids					+											
Fats and oils				+	+								+			(+)
Surfactants					+				(+)				+			(+)
Heavy metals					+								+	+		+
Other pollutants (cyanides, halogenated hydrocarbons etc.)			+	+	+								+	(+)		+
Nutrients (N,P)			+	+										+		+
Enzymatic activity			(+)	(+)												
Conditionability					+	+		+		+		+				
Particle size distrib.				+	+		+	(+)		+		+				
Dewaterability				+	+	+	+					+				
Capill. suct. time (CST)								+	+	+		+				
Spec. resist. to filtrat.								+	+	+		+				
Compressibility												+				
Centrifugability												+				
Calorific value				(+)	(+)		(+)								+	
Heat. by autoxidat. etc.														+		
Leachability by water													+			+

Table 1: Characterization of sewage sludges for evaluation of methods of treatment and disposal

+ : necessary (+) : desirable

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DIFFERENTIAL THERMAL ANALYSIS FOR THE CHARACTERIZATION OF THE STABILITY OF SLUDGE

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Abstract

In stabilization processes such as aerobic stabilization, composting and digestion, the organic matter in the sludge is transformed to products with a lower total free energy content. Differential thermal analysis (DTA), is a method in which the weight and enthalpy changes in a sample are continuously registered during the heating of the sample. DTA should thus be of potential interest for the characterization of the stability of sludges.

In this study DTA has been used to characterize the stability of sludges from

- a pilot scale experiment with the composting of mixed biological-chemical sludges.
- a full scale composting unit for the composting of a bark - biological mixture.
- a laboratory scale aerobic stabilization unit and some samples from full scale aerobic stabilization units.

The DTA-analysis of compost samples made it possible to study the transformation of the organic matter in the sludge. The transformation could be characterized as a shift of the combustion energy release to higher temperatures.

The origin of the sludges seems to influence the shape of the thermogrammes, but some of the characteristics of the compost sample thermogrammes could also be found in the thermogrammes of the aerobic stabilized sludge samples.

Introduction

Parameters for the characterization of stability

Sludge stabilization processes have been in use for many decades, but there are still not any generally accepted methods for the characterization of sludge stability. The implication of this situation is that the design and operation of the sludge stabilization processes lack elementary fundamentals. A large number of sludge stability parameters has been developed. These parameters can be classified into three categories;

- parameters related to the objective of the stabilization process e.g. odour and hydrogen-sulphide production
- parameters related to the properties of the sludge e.g. loss on ignition and liquid content
- parameters related to the biological activity of the sludge e.g. respiratory activity and the TTC-test.

From the fundamental point of view a parameter for the characterization of stability should be related to the principal process and that is the mineralization of the biodegradable organics of the sludge. From this point of view the widely used loss on the ignition - mineralization index can be justified. Experience has ruled out the mineralization index as a parameter for sludge stability.

Differential Thermal Analysis (DTA) is a method that is largely untried in sludge characterization. DTA is of interest as it is related to the fundamental process in the sludge stabilization and it could be regarded as a sophisticated loss on ignition method.

The objective of this study was to make a preliminary appraisal of the usefulness of DTA for the characterization of the stability of sludges.

The DTA method

When DTA is applied, a small sample (about 20 mg) is heated in a furnace. Simultaneously an inert reference sample e.g. Al_2O_3 is heated. The sample crucible is coupled to a sensitive balance and the weight loss of the sample is monitored continuously. Any endo- or exothermic reaction in the sample during the heating will give rise to a temperature difference between the sample and the reference. The temperature difference, ΔT, is recorded continuously. Integration of the ΔT-curve over a temperature interval gives a relative measure of the enthalpy changes.

Material and methods

DTA-analysis

A Mettler TA-HE-20 instrument was used. The sample consisted of 10-25 mg dry matter. An inert reference sample of Al_2O_3 ignited to 900^oC was used. The furnace was continuously supplied with air at a rate of 5 l/h. The ΔT curves were normalized to a linear temperature increase and to a 100 mg sample size. The base line was established at 100^oC. The ΔH-values in arbitrary units have been calculated in the whole of the 100-850^oC range and at graduations of 50^oC.

Dehydrogenase activity

Dehydrogenase activity was determined according to German Standards in the "Deutsche Einheitsverfahren".

Composted sludge

The composted sludge was produced from primary-chemical (Al) sludge composted in a batch reactor with forced aeration at the Norwegian College of Agriculture, Dep. of Microbiology.

Composted sludge-bark mixture

Composted sludge-bark mixture was obtained from a full-scale composting plant in Gothenburg. The sludge originated from a high-rate activated sludge plant without presettling. The composting plant was run according to the Windrow principle.

Activated sludge

Activated sludge was obtained from six continuously operating laboratory units. The activated sludge units were fed with unsettled and settled domestic waste-water.

Aerobic stabilized sludge

Aerobic stabilized sludge was produced in a Sapromat-B (Voith) unit operating at 25°C. Surplus activated sludge from a high-rate activated sludge plant without presettling (sludge age 1 day) was added to the six vessels of the Sapromat unit. Respiration was monitored continuously. Due to the limited oxygen transfer capacibility of the Sapromat unit, initial sludge concentration in the vessels was limited to 2,0 g/l.

Results

Composted sludge

Samples have been analyzed after 0, 4, 11, 30 and 40 days of composting. The results are shown in figure 1.

The heat of combustion of the sludge was reduced by about 30% during 40 days of composting.

The enthaply changes are subdivided in temperature intervals (figure 2 raw sludge, figure 3 composted sludge) and it is obvious that there is a shift in the "ΔH-distribution" towards higher temperatures. Table 1 gives additional data.

Table 1. Percentage distribution of the heat of combustion versus temperature for a raw and a composted sludge.

Days of composting	Percentage distribution of the heat of combustion 350-400°C	500-550°C	600-650°C
0	18,9	10,8	1,7
40	17,1	9,4	7,9

Composted sludge-bark mixture

Sludge-bark mixture was analyzed after 0, 3, 6 and 7 weeks of Windrow composting. The results are shown in figure 4.

The "ΔH-distribution" exhibits also here a shift towards higher temperatures, as can be seen for 0, 3 and 7 weeks of composting in figures 5, 6 and 7 and table 2.

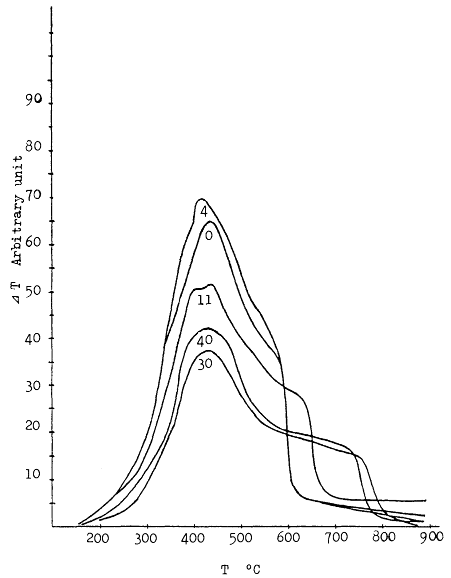


Fig. 1 - DTA analysis of samples after 0, 4, 11, 30 and 40 days of composting

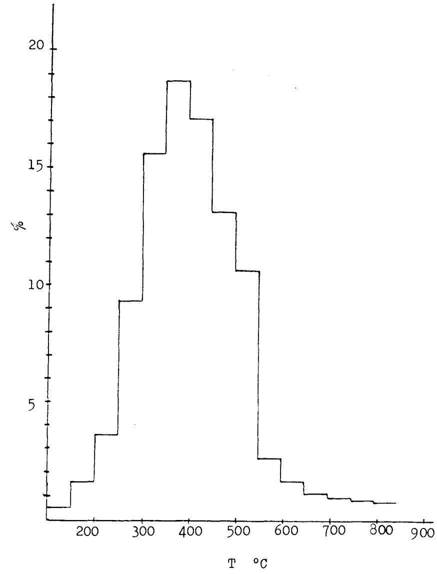


Fig. 2 - Enthalpy changes subdivided in temperature intervals: raw sludge after 40 days

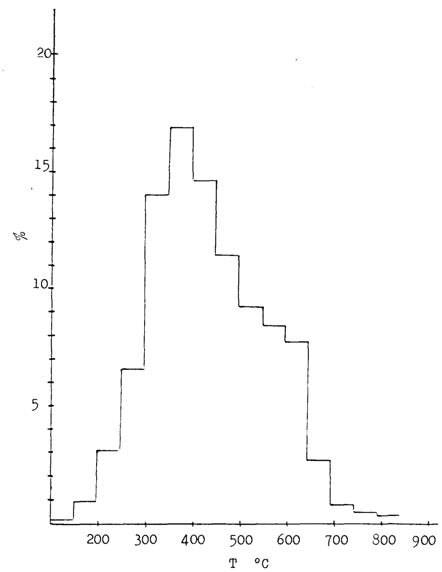


Fig. 3 - Enthalpy changes subdivided in temperature intervals: composted sludge after 40 days

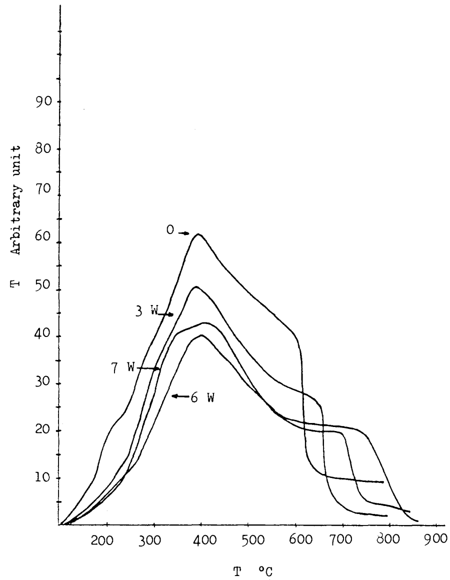


Fig. 4 - DTA analysis of sludge-bark mixture after 0, 3, 6 and 7 weeks of Windrow composting

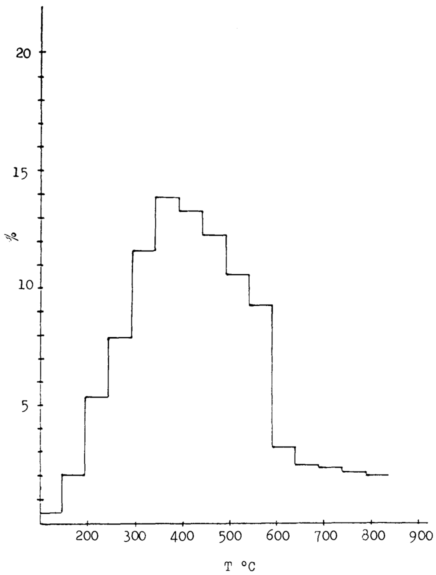


Fig. 5 - Enthalpy changes subdivided in temperature intervals after 0 week of Windrow composting

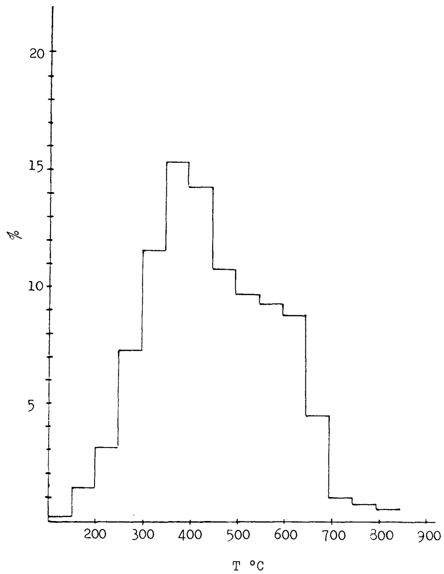


Fig. 6 - Enthalpy changes subdivided in temperature intervals after 3 weeks of Windrow composting

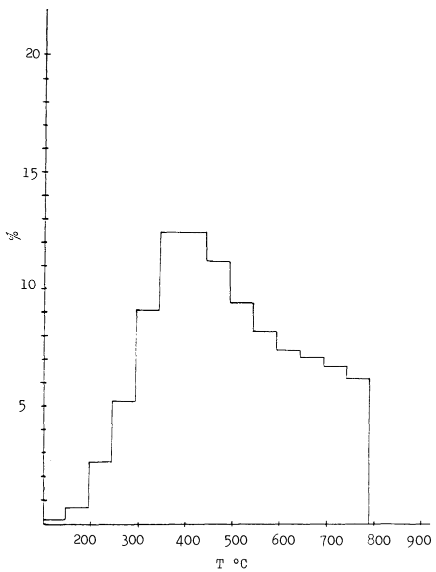


Fig. 7 - Enthalpy changes subdivided in temperature intervals after 7 weeks of Windrow composting

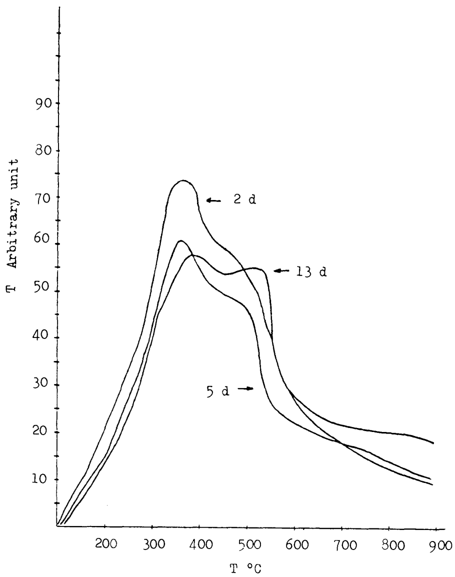


Fig. 8 - DTA analysis of samples of inactivated sludge developped on unsettled domestic water with a sludge age of 2, 5 and 13 days

Table 2. Percentage distribution of the heat of combustion versus temperature for a raw and a combusted sludge-bark mixture.

Weeks of composting	Percentage distribution of heat of combustion 350-400°C	500-550°C	600-650°C
0	14,0	10,7	3,3
3	15,5	9,8	8,9
7	12,5	9,5	7,5

In the 700-800°C temperature range the fraction increases from 1,9% in the 3 week sample to 13,0% in the 7 week sample.

Activated sludge

Activated sludge developed on unsettled domestic waste-water with a sludge age of 2, 5 and 13 days was analyzed (figure 8), as well as activated sludge developed on settled domestic waste-water with a sludge age of 5, 13 and 30 days (figure 9).

There is a shift in the "ΔH-distribution" towards higher temperatures as in the compost samples. It should also be observed that the general appearance of the thermogrammes of the two sludge types (figures 8 and 9) are quite different.

Aerobic stabilized sludge

Samples were withdrawn for analysis after 1, 4, 7, 14, 18 and 21 days. The thermogrammes will be found in figure 10. Respiration activities and results of the TTC-test will be found in figure 11. The heat of combustion was reduced by almost 40% during 21 days of stabilization.

The "ΔH-distribution" for 0 and 21 days can be seen in figures 12 and 13 and in table 3. The shift previously noted can again be observed.

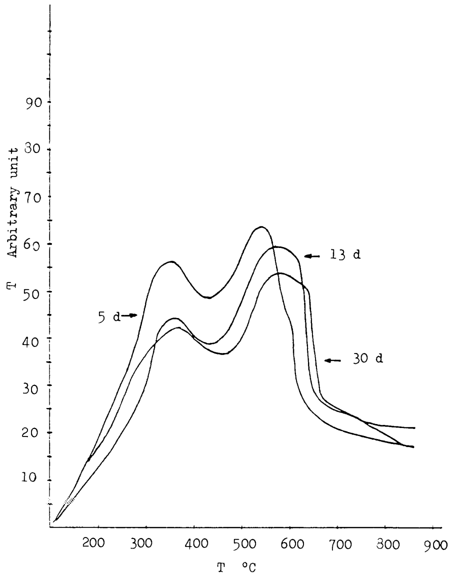


Fig. 9 - DTA analysis of samples of activated sludge developped on settled domestic waste water with a sludge age of 5, 13 and 30 days

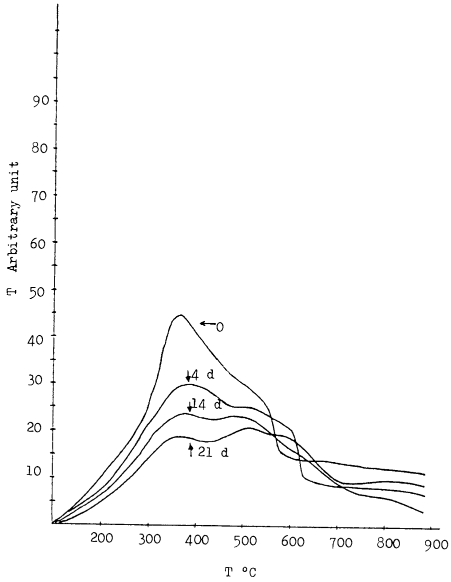


Fig. 10 - DTA analysis of samples of aerobic stabilized sludge after 1, 4, 14 and 21 days

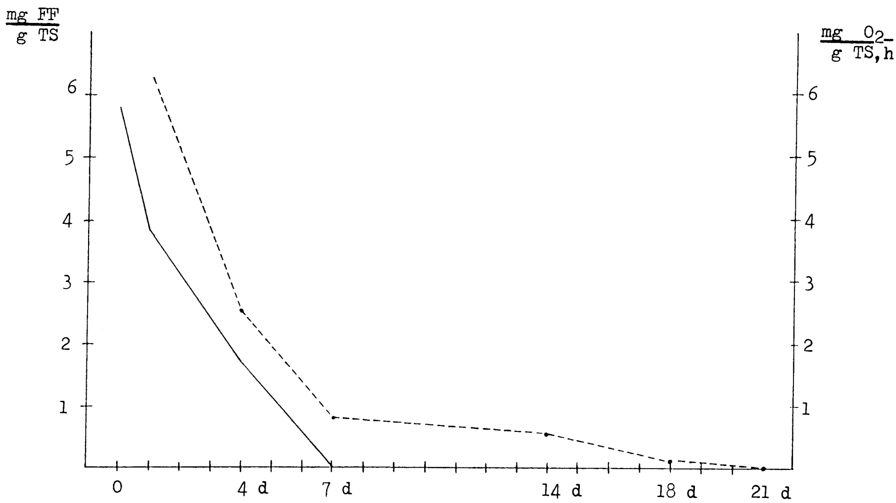
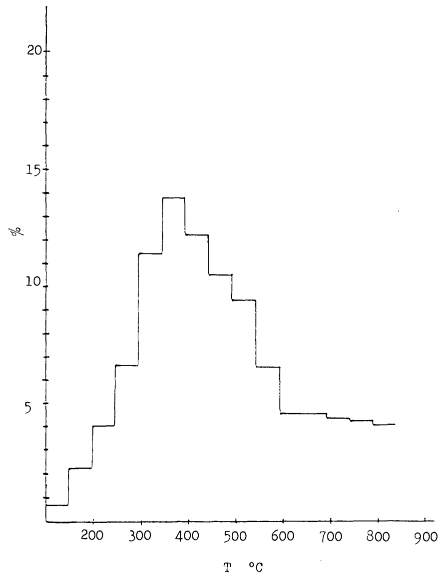
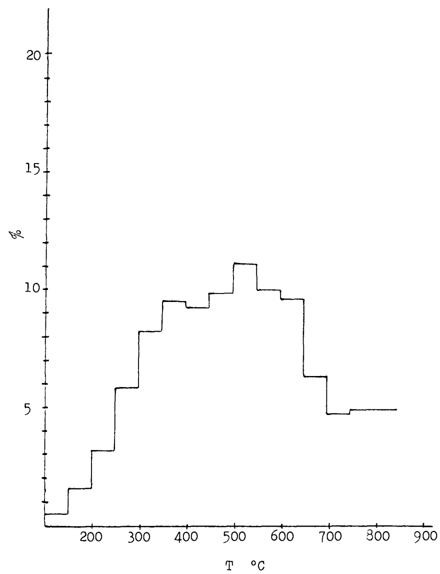


Fig. 11 - Respiration activities and results of the TTC-test on samples of aerobic stabilized sludge after 1, 4, 7, 14, 18 and 21 days



<u>Fig. 12 -</u> Enthalpy changes subdivided in temperature intervals : aerobic stabilized sludge after 0 day



<u>Fig. 13 -</u> Enthalpy changes subdivided in temperature intervals: aerobic stabilized sludge after 21 days

Table 3. Percentage distribution of the heat of combustion versus temperature for raw and aerobic stabilized sludges.

Stabilization time Days	Percentage distribution of the heat of combustion 350-400°C	500-550°C	600-650°C
0	13,9	9,5	4,6
4	12,3	10,4	7,0
14	11,4	10,9	7,4
21	9,6	11,2	9,7

Discussion

In this study activated sludge samples with sludge ages of 2-30 days, sludge stabilized aerobically for 1-21 days and sludge composted for 0-7 weeks have been analyzed. There are no fundamental differences between activated sludge treatment and aerobic stabilization. Composting may also be regarded as an aerobic stabilization process. Thus it could be expected that thermogrammes of these sludge types should exhibit some general similarities.

With increasing sludge age or stabilization time the heat of combustion has been observed to decrease. A general tendency that a greater part of the combustion occurs at higher temperatures for more stabilized sludges has also been observed. With the thermogrammes it seems to be possible not only to study the degredation of the organics to end products but also the transformation of the organics.

It is interesting to observe that while parameters as respiration- and dehydrigenaseactivity change only very little after 7 days of stabilization at 25°C, (figure 11) the thermogrammes indicate that large transformations of the organic material occur after this time.

In the study some deviations from general tendency have been observed. There are no good explanations but shifts in bacterial populations and in the type of substrate utilized have been discussed by other investigators (McKinney (1960), Middlebrooks and Garland (1968), Obayashi and Gaudy (1973), Yang and Gaudy (1974), Molland (1980) et. al.).

When the thermogrammes of activated sludge derived from unsettled and settled waste-water are compared, the differences are obvious. These differences were not detected in the normal analysis of the sludge. DTA may thus have some possibilities as a general characterization tool.

It should be stressed that DTA is a research tool. The operation of the equipment requires skilled personnel and the small sample size requires very careful homogenization.

It is too early to draw any final conclusions on the usefulness of DTA in the characterization of sludge stability or as a general sludge characterization parameter, but it seems to have several interesting possibilities.

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DEWATERING OF MUNICIPAL SLUDGES

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Summary

Dewatering processes considerably affect costs of sludge treatment and disposal.

On the basis of a survey carried out in European Countries, the status and trends regarding conditioning and dewatering of municipal sludges are discussed.

Conditioning methods and laboratory tests for determining optimal conditioner dosages and predicting sludge behaviour in dewatering are outlined briefly.

The paper also presents a general description of dewatering systems and attention is given to the influence of operating variables on dewatering performance.

A literature data analysis allows us to outline typical conditioner demand and performance of each dewatering operation, as functions of feed sludge type. The discussion is completed with data on labour and energy requirements.

Furthermore, a few results of experimental activity carried out within the EEC Concerted Action to study the mechanisms of conditioning and some dewatering operations are presented.

1. INTRODUCTION

Sludge treatment and disposal is one of the major problems at wastewater treatment facilities, from both a technical and economical point of view.

For sludge processing there are many alternatives. The ultimate disposal can, however, be made less costly by reducing the volume, i.e. the moisture content. Through dewatering, a volume reduction greater than that achieved by thickening is obtained and sludges result in a semi-solid material. This operation can be accomplished by drying beds and lagoons or by different mechanical equipment.

Dewatering usually requires sludge conditioning, in order to increase the efficiency of the operation.

2. EUROPEAN SURVEY ON SLUDGE DEWATERING PRACTICE

A survey on sludge conditioning and dewatering practice in Countries participating in EEC Concerted Action was carried out. The results are summarized in Table I.

Drying beds utilization is very different, since percentage values in the whole range from 0 (Norway) to 100 (Ireland) are present.

Lagooning is limited to the United Kingdom.

As far as mechanical dewatering is concerned, centrifuges and filter-presses seem to be the most widely used. Where centrifuge percentage exceeds the average (Finland, Norway and Sweden), the filter-press percentage is below the average. Other Countries (Belgium and the United Kingdom) show apposite figures.

Belt-presses find quite uniform use (20%), while no interest is shown in vacuum-filters, except for France.

TABLE I-Conditioning and dewatering practice in European Countries

COUNTRY	Total mass of sludge (10^3 t dry solids/year)	Percentage dewatered	Percentage of sludge dewatered by:							Percentage of sludge conditioned by:					
			Drying beds	Lagoon	Belt-press	Centrifuge	Filter-press	Vacuum-filter	Other	Iron salts	Alum. salts	Polyelectr.	Heat treat.	Freez./Thaw.	Other
B	10	100	25	--	25	--	50	--	--	75	--	25	--	--	--
DK	89	95	15	--	15	40	30	--	(*)	X	X	X	--	--	--
FI	117	89	3	1	42	52	--	2	--	2	--	94	--	4	--
F	800	90	47	--	3	10	22	17	1(°)	29	<1	10	17	--	--
D	1300	77	20	5	35	10	25	1	4	30	10	50	10	--	--
IR	14	31	100	--	--	--	--	--	--	--	--	X	--	--	--
I	1200	95	15	--	20	35	25	5	--	25	15	60	--	--	--
NL	200	13	60 (drying beds to centrifuge)				37 (filter-press and vacuum-filter)		3(+)	X	--	X	X	--	--
NO	65	77	--	--	20	75	5	--	--	5	--	95	--	--	--
SW	200	90	7	<1	28	62	--	2	1	--	--	90	--	10(')	--
CH	122	32	4	--	7	35	54	--	--	18	--	41	37	--	--
UK	1240	56	20	25	10	3	35	5	2('')	20	24	15	1	--	40(^)

Notes:
(*) container
(°) thermal drying
(+) incineration and drying
(') natural
('') rotoplug
(^) none

General trends show an increasing interest towards belt-presses and filter-presses. The latter are still giving the driest cake. The percentage of sludge dewatered by centrifuges can be expected to keep constant.

Regarding conditioning, polyelectrolytes and iron salts, with or without lime, have found widespread use; but there is an increasing preference given to polyelectrolytes.

3. SLUDGE CONDITIONING

Prior to dewatering, sludges must nearly always be conditioned. Conditioning is a physical-chemical process whose primary purposes are to enhance water removal and improve solid recovery. In some cases, a more hygienic sludge can be obtained.

There are three basic processes: chemical conditioning, thermal conditioning and elutriation.

Chemical conditioners alter the surface characteristics of sludge (destabilization) and provide bridging of particle into a floc structure (flocculation). They can be inorganic or organic (polyelectrolytes). The inorganic chemicals normally used are iron and aluminium salts and lime.

Investigations [1] on the effectiveness of iron salts for raw mixed sludge conditioning showed that the best effects are provided by ferric chloride with lime.

Sludge behaviour in dewatering and the optimal conditioner dosage can be evaluated by laboratory tests.

For filtration processes, Specific Resistance to Filtration and Capillary Suction Time (CST) are the most widely used and accepted parameters. For vacuum filtration, the filter-leaf test can be useful, since it allows the simulation of the phases of the full-scale operation.

A method for predicting the performance of a belt-press has recently been proposed [2], while there is a lack of accepted parameters for centrifugation. Floc strength measurements can be used, however, as an indicator of sludge centrifugability. Two methods have been developed [3, 4, 5]; the one based on centrifugation by laboratory equipment [6] has found limited practical application.

In full-scale operation, sludge often has worse dewaterability characteristics than those determined by laboratory test, mainly owing to different methods of conditioner/sludge mixing and to higher mechanical stresses in full-scale equipment. Experimental results /_7, 8_/ confirmed the importance of stirring and mixing conditions.

Thermal conditioning involves heating (180 to 240 °C) under pressure (15 to 30 kg/cm^2) for a period of 15 to 40 minutes. Flocs are lysed and water contained inside is released. This process allows us to obtain a sludge with very good dewatering characteristics (cake solids up to 50% are obtainable by filter-pressing) and, at the same time, to sterilize it. The disadvantages are high costs, production of an odorous gas and a concentrated supernatant which must be recycled to the plant. Thermal conditioning is adopted in France, Germany and Switzerland for large plants.

Eluatriation is the washing of the sludge and generally follows anaerobic digestion. Washing reduces the alkalinity and removes the fine solids, thus lowering the chemical demand of sludge. When eluatriate is recycled back to the treatment plant, the fine solids could degrade the effluent. Eluatriation also tends to remove nitrogen from the sludge.

4. DEWATERING

The purpose of dewatering processes is to reduce sludge volume, in order to decrease the costs of the subsequent sludge processing and/or disposal. To meet this goal, natural (drying beds and lagoons) or mechanical (filtration, by vacuum-filters, filter-presses and belt-presses, and centrifugation) processes can be used.

4.1. Drying beds and lagoons

When land is available, dewatering by nature can be attractive.

On the beds, sludge is 15 to 30 cm in depth and the time required for dewatering to a liftable state ranges from a few days to several months, depending on sludge type and climatic conditions. For these reasons, the required minimum area was found to be between 0.05 and 0.10 m^2/person in Italy, 0.10 and 0.21 in France, 0.33 and 0.53 in the United Kingdom, 0.40 and 1.40 in Scandinavian Countries.

Drainage characteristics can be improved by the addition of chemical conditioners and also by elutriation. In order to prevent re-wetting of sludge by rain and reduce bed area, drying beds are sometimes covered. Odour problems and potential health hazards often require that sludges are digested first.

The use of drying beds is now much less common that it was some years ago. At some older plants, the beds have been replaced by mechanical dewatering equipment and, often, the sludge from small sewage works is transported to a central works for mechanical dewatering.

Lagoons are simular to drying beds; however, the sludge is placed at depths 3 to 4 times greater than it would be in a bed. English experiences indicate that, in some cases, if the sludge is allowed to remain undisturbed for some years, vegetation grows on the surface and even large trees may developed. The lagoon can then represent a hazard because intruders to the works may fall through the crust into the wet sludge. For these various reasons lagoons are only used for long-term storage. They may be used also for cold digestion.

4.2. Vacuum-filters

From the European survey, it appears that the use of vacuum filters is declining. The main disadvantages in vacuum-filtration lie in high power requirements and the presence of very noisy auxiliary equipment.

The performance of a vacuum-filter is characterized by the filter yield, in terms of kg solids/$m^2 \cdot h$. The most important sludge characteristics, which affect filtration performance, are the Specific Resistance, which must be of the order of 10^{12} m/kg at 0.5 kg/cm^2, and the feed solid concentration, which must generally be higher than 3%, although, in some cases, good results have been obtained at a lower concentration. Typical yields and cake solid concentration are shown in Fig. 1.

Operating variables of the machine are: vacuum, drum submergence and drum rotational speed. A further important process variable is the filter media; filter aids can be necessary to minimize clogging.

Ferric chloride and lime are widely used for sludge conditioning. However, use of polyelectrolytes has been reported /_9_/ with cost savings. Typical conditioner dosages are reported in Table II.

TABLE II-Typical conditioner dosages for vacuum-filters/9/

Sludge type	$FeCl_3$ (kg/t)	CaO (kg/t)	Polyelec. (kg/t)
Raw Primary	20- 40	80-100	0.3-0.5
Raw Activated	60-100	0-160	4.0-7.5
Raw Primary+Activated	25- 60	90-160	2.0-5.0
Raw Primary+Trickling filter	20- 40	90-120	1.3-2.5
Anaer. Digested Primary	30- 50	100-130	0.8-2.0
Anaer. Dig. Prim.+Activ.	30- 60	150-210	2.5-6.0

Power consumption is 3 to 6 kWh/m^3 sludge treated.

4.3. Filter-presses

Pressure filtration is an advantageous process if high cake solid content (> 30% up to 50%) is required. Disadvantages include factors such as batch operation, low filter yield

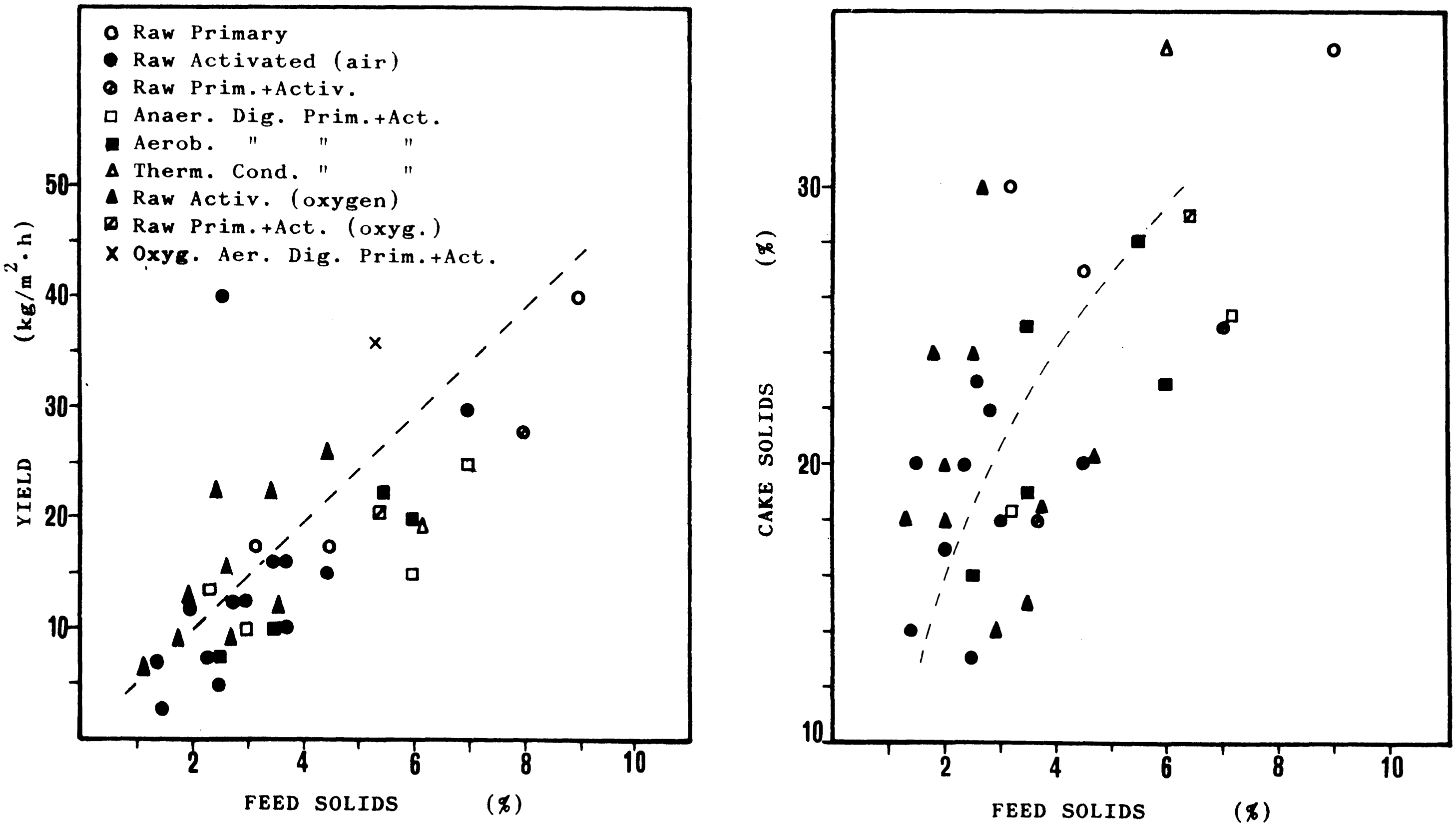

Fig. 1 - Dewatering performance of vacuum-filters

and high labour cost, especially compared to belt-press and centrifuge. Recently, new systems have been developed to overcome these problems. The introduction of mechanical plate movement has allowed us to reduce labour costs, while the overall press cycle has been shortened by means of the membrane presses.

Operating variables which influence the process are operating pressure and pressing time. Correlations between these variables and sludge characteristics have been studied in pilot scale-filter-press tests carried out with several types of sludge [10, 11].

In order to compare the performance of fixed-plate and membrane filter-presses, parallel dewatering tests were carried out with a lime conditioned ferrichloride precipitated sludge [12]. Yields as a function of lime conditioning dose are shown in Fig. 2. The results indicate that membrane presses can dewater satisfactorily on lower conditioning doses and give

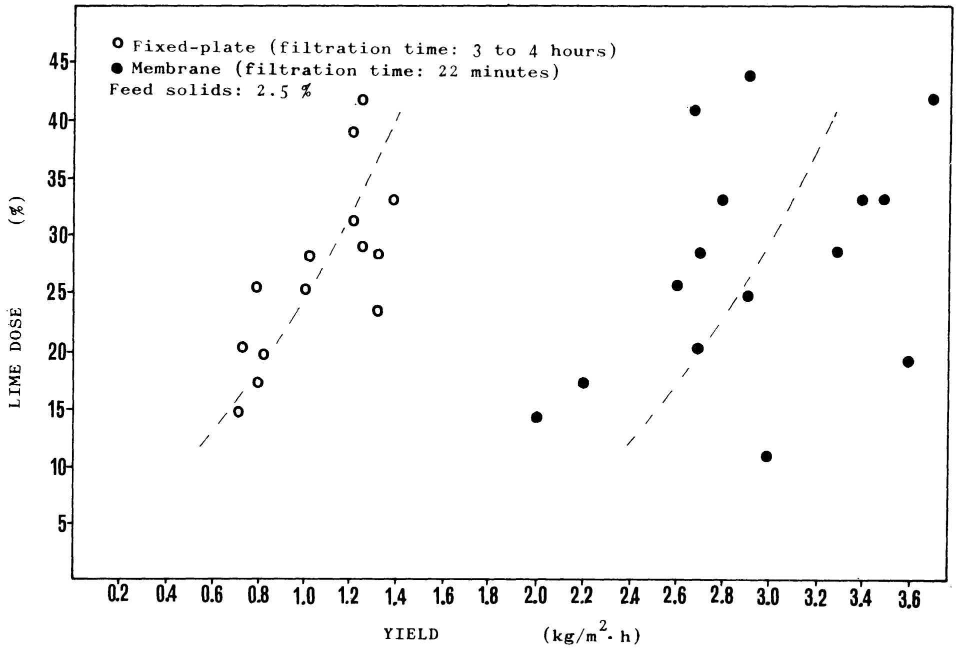

Fig. 2 – Yield of fixed-plate and membrane filter-presses [12]

higher capacities and drier cakes. They have, however, higher capital costs per unit filter area.

Ferrichloride, with or without lime, and Aluminium Chlorohydrate are generally used for sludge conditioning. Several English studies have indicated that polyelectrolytes can be effectively used, if done with care.

The effect of ferrichloride and lime conditioning on chemical precipitated sludges has been studied [12]. At low lime dose (5%), increasing the Fe dose caused an improvement in the yield. Increasing the lime dose to 17% showed the yield would decrease with an increasing Fe dose.

Dewatering performance data and conditioner dosages are reported in Table III.

TABLE III - Performance data of filter-presses

	Sludge type	Feed solids (%)	Cake solids (%)	Pressing period (min)	Conditioner dosages		
					$FeCl_3$ (kg/t)	CaO (kg/t)	Alum-Chl. ($kgAl_2O_3$/t)
Fixed volume	Raw Primary [9]	5.0-10.0	45	-	40-60	100-140	-
	Digested Primary [15]	3.8- 4.0	23-37	60-180	40-60	200	-
	Raw Primary+Activated [9]	1.0- 6.0	45	150	50-60	100-120	-
	" " " [14]	4.6- 7.6	27-41	290-390	-	-	15-39
	Anaer. Digested Primary+Activated [9]	3.5- 5.0	42	-	27	170	-
	Aerob. Digested Activated [10]	4.4- 5.6	37-42	240-360	-	-	12-13
Variable volume				Yield (kg/m^2h)			
	Raw Primary+Activated [9]	4.0	40	4.4	50	150	-
	Anaer. Digested Primary+Activated [9]	2.5- 6.4	36-50	3.0-9.8	40-90	110-290	-

Power requirement is estimated to be 1.5 to 3.0 kWh/m^3 sludge treated.

4.4. Belt-presses

Belt-presses have recently been introduced for sewage sludge dewatering. First type machines have been widely modified, thus obtaining more compact equipment, although belts have been lengthened.

Dewatering occurs in three phases: during the drainage phase (sometimes under vacuum) feed sludge concentration is increased 2 to 3 times, up to 10%. The sludge is then subjected to increasing pressure between two belts and, finally, to a shearing action due to different relative movements of the two belts. Generally good performance is obtained with an initial concentration of not less than 4%.

The operating variables which affect machine performance are sludge flow rate, belt speed, pressure and rinsing water flow rate.

Input sludge flow rate varies between 1.5 and 7.0 $m^3/h \cdot m$ belt width. A linear relationship has been found between cake solids and belt speed. Low speed (0.01 m/s) is not economical, but gives a drier sludge cake, while belt speed above 0.10 m/s gives a sludge which is not sufficiently dry.

Variation in pressure can be obtained by adjusting the rollers. The influence of pressure and sludge solid flow rate on cake solids is reported in Fig. 3.

Treatment plant effluent is generally used for belt cleaning at a flow rate of 50 to 100% feed sludge and at a pressure of 4 to 6 kg/cm^2.

For sludge conditioning cationic polyelectrolytes are used. Typical dewatering performance data and levels of conditioner addition are reported in Table IV.

Power consumption is very low and ranges between 0.5 and 1.0 kWh/m^3 treated sludge.

4.5. Centrifuges

The most widely used machine for dewatering by centrifugation consists of a cylindrical-conical solid bowl shell with an internal Archimedean screw (the scroll) which revolves slightly more slowly than the bowl.

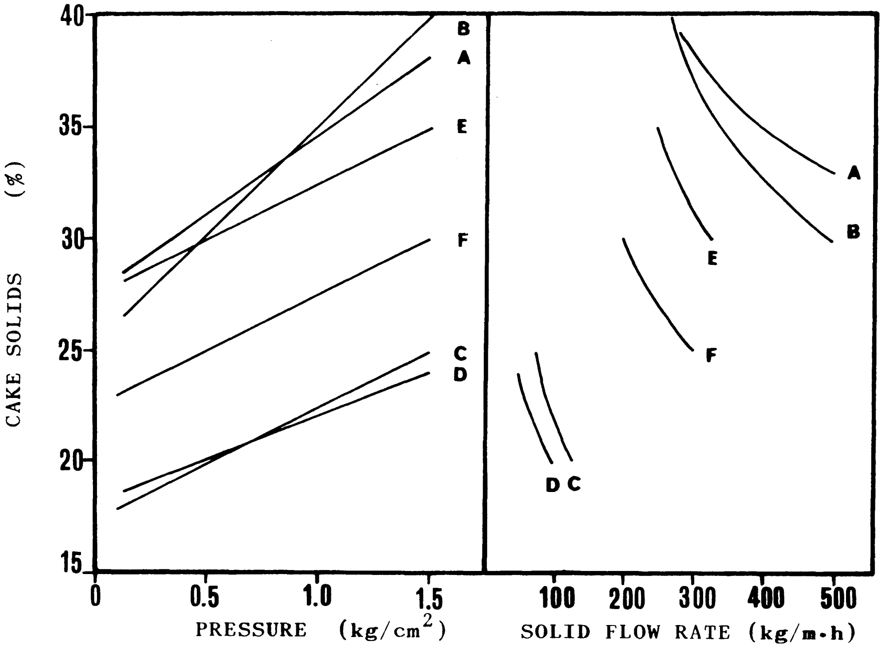

Fig. 3 - Influence of pressure and sludge flow rate on cake solids for belt-presses (by courtesy of Sernagiotto S.p.A.)

A - Raw Primary, 6-7%
B - Anaer. Dig. Prim., 4-5%
C - Raw Activated, 4%
D - Anaer. Dig. Act., 4%
E - Raw Prim.+Act., 5-6%
F - An. Dig. Prim.+Act., 4-5%

TABLE IV - Performance data of belt-presses [9,13]

Sludge type	Feed sol. (%)	Cake sol. (%)	Condit. dos.(kg/t)
Raw Primary	3-10	25-44	0.6-4.5
Raw Activated	0.5- 4	12-32	1.0-6.0
Raw Primary+Activated	3- 6	20-35	0.6-5.0
Aerob. Digested	1- 8	12-30	0.8-5.0
Anaer. Digested	3- 9	18-34	1.5-4.5
Thermal conditioned	4- 8	38-50	-

The machine variables, which dewatered sludge concentration and solid recovery depend on, are length/diameter ratio, beach angle, bowl rotational speed, liquid ring volume and bowl/conveyor differential speed. There is not a generally accepted point of view regarding the effects of bowl speed. It seems [9] that in most cases, low speed machines (< 1400 rpm) give significant advantages (less energy, maintenance and noise level). In addition, low rotational speed gives less mechanical stress on the flocs, thus reducing polymer consumption.

Although a theoretical approach to the process is very difficult because of the many factors involved, statistical analyses of experimental data were carried out [10, 11] in order to correlate dewatered sludge concentration and solid recovery to the operative variables and sludge characteristics. Results are reported in fig. 4.

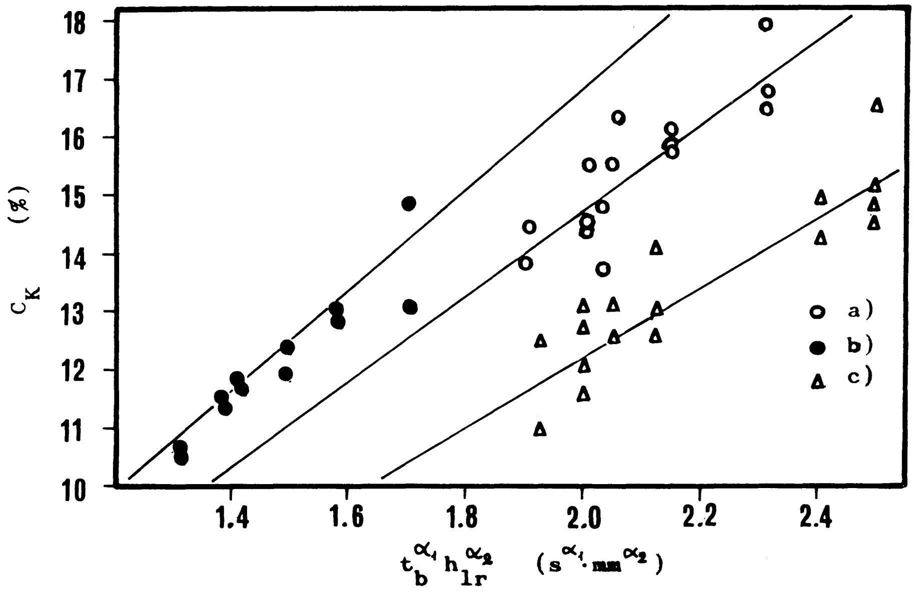

Fig. 4 - Statistical correlations for dewatered sludge concentration by centrifuge [10]

C_K=dewatered sludge conc.(%); t_b=beach resid. time (s)
h_{lr}=liquid ring height (mm)

a=Aerob. Dig. Activ.;4.8%;α_0=73.75; α_1=0.215; α_2=0.273
b=as a) deph. by $Al_2(SO_4)_3$; 3.2%; 81.79; 0.203; 0.093
c= " " " " $FeSO_4 \cdot 7H_2O$; 4.5%; 61.25; 0.244; 0.263

Cationic polyelectrolytes are used for aerobic sludge conditioning. The structural strength of the solids is increased, and larger flocs of the fine particles are produced, thus increasing the settling rate. Typical performance data and conditioner dosages are reported in Table V.

TABLE V-Typical performance data for solid bowl centrifuge [9]

Sludge type	Feed solids (%)	Cake solids (%)	Condit. dosages (kg/t)	Recovery (%)
Raw Primary	5- 8	25-36	0.5-2.5	90-95
		28-36	0	70-90
Raw Activated	0.5- 3	8-12	5.0-7.5	85-90
Raw Primary+Activated	4- 5	18-25	1.5-3.5	90-95
Anaer. Dig. Prim.+Act.	2- 4	15-18	3.5-5.0	90-95
	4- 7	17-21	2.0-4.0	90-95
Therm. Cond. Pr.+Act.	9-14	35-40	0	75-85
	13-15	29-35	0.5-2.0	90-95

Power requirement is of 2 to 3 kWh/m^3 treated sludge.

5. CONCLUSIONS

Sludge treatment and disposal must be considered as a whole. Therefore, the selection of the dewatering system will be influenced by the disposal method planned for the sludge cake as well as the type of sewage treatment process used.

If the aim is to maximize cake solid concentration, filter-presses are preferred. Lower solid concentrations in the cake are obtained by vacuum-filter, belt-presses and centrifuges.

Although vacuum-filters achieve higher yields than filter-presses and can be operated continuously, they have several disadvantages, such as a higher energy consumption (about double), higher initial costs, and a more complex and noisy machine.

The main disadvantage of filter-presses lies in the high labour cost (about five times higher than belt-press and centrifuge). This can be overcome by automatization of filter-loading and cake discharge. The filtration run can be remarkably reduced, with a consequent increase of the yield, by membrane filter-presses, which are still very expensive.

If it is not necessary to achieve high cake solid concentration, the centrifuges and belt-presses are preferred. Belt-presses consume less energy than centrifuges (two or three times less) but the machine costs more. Total cost analysis has not, however, pointed out any remarkable advantage in the use of one or the other machine. The above mentioned figures are summarized in Table VI.

TABLE VI - Dewatering equipment comparison

	Vacuum filter	Filter press	Belt press	Centrifuge
Capital costs	XXX	XX	XX	X
Operat. costs (energy, chemicals, mainten., labour)	XXX	XXX	X	XX
Cake solid concentration	XX	XXX	XX	X
Solid recovery	XXX	XXX	XX	X

It is necessary to carry on research regarding dewatering, so that the process can be optimized. There is also a need for better ways of predicting dewaterability of sludges without using pilot-scale or full-scale tests; this is especially true for centrifugation, so that all the variable factors involved can be evaluated and the performance of each dewatering machine optimized.

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DEWATERING OF ACTIVATED SLUDGE

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Summary

Activated sludge is often conditioned with the aid of polyelectrolyte to a highly flocculent state to facilitate dewatering by filtration. Activated sludges in this condition have excellent drainage characteristics when subject to low solids stress, as in gravity drainage at low filter loadings. When subject to large hydraulic gradients, however, as in pressure filtration, the solids are compressed by flow-generated drag forces and resistance to filtration increases. At constant applied pressure, the average specific resistance to filtration varies with time and filtrate volume discharged. The widely used simple model of cake-filtration, which implies a linear correlation of reciprocal filtration rate and filtrate volume is not valid in such circumstances. Thus, the specific resistance to filtration, as measured by the Buchner funnel method is of limited value as a measure of filterability. Using a scaled-up version of the Buchner funnel system, employing positive pressure in place of vacuum, the influences of applied pressure and solids loading on the filterability of polyelectrolyte - conditioned activated sludge were experimentally investigated. The results illustrate the dominant effect of compressibility in pressure-filtration and the need for a better understanding of compressible filtration mechanics.

1. INTRODUCTION

The problem of phase separation in particle/liquid mixtures is encountered in many process technologies including the water pollution control field. The processes used to effect phase separation can be classified broadly into two groups. The first group includes all processes which depend on the existence of a density difference between the particles and the surrounding liquid. The processes of sedimentation, flotation and centrifugation belong to this category. The second group consists of filtration processes, of which there are two kinds, depth-filtration and cake-filtration. In depth-filtration, the particulate fraction is retained within the interstices of the filter medium as in the sand filtration process commonly used in potable water production. In cake-filtration, the filtered solids are retained on the surface of the filter medium, thus forming a cake of increasing thickness, through which the expressed filtrate must flow. Processes of this latter type are widely used in sludge dewatering and manufacturing industry. There is thus a considerable accumulated experience on the practical aspects of the process and, perhaps, a lesser knowledge of its fundamental mechanics. The materials on which the process is used range from easily filtered inorganic slurries to the more difficult compressible materials. Activated sludge belongs to the latter category. This paper examines its cake-filtration characteristics when conditioned to a highly flocculated state by addition of polyelectrolyte.

2. MECHANICS OF FILTRATION

In the course of sludge dewatering by filtration, the filter medium forms a barrier to the passage of solids, which build up to form a cake of increasing thickness on the medium surface. In the general practical application of the process, the hydraulic resistance of the medium is negligible compared to that of the sludge cake which develops on its surface. The cake may be regarded as a water-saturated porous medium through which liquid flows according to the Darcy (1) equation:

$$v_x = - \frac{K_d}{\mu} \frac{\partial p}{\partial x} \qquad (1)$$

where v_x is the volumetric flow rate per unit area in the x-direction, K_d is the Darcy coefficient of permeability and $\frac{\partial p}{\partial x}$ is the pressure gradient in the direction of flow. Flow is taken to be laminar, hence the inverse relationship of flow rate to dynamic viscosity μ. It is often more convenient in filtration analysis to correlate filtration rate and pressure gradient by means of hydraulic resistance in place of hydraulic permeability. The resulting formulation of the Darcy equation is as follows:

$$v_x = - \frac{1}{r\rho_s(1-\varepsilon)\mu} \frac{\partial p}{\partial x} \qquad (2)$$

where r is the specific resistance to filtration, ρ_s is the density of the particle fraction and ε is the cake porosity i.e. the ratio of void volume to total volume. The resistance to flow through a porous medium is obviously related to the size and extent of its flow passages. The Carman/Kozeny (2/3) equation is often used to correlate porosity and particle surface area to hydraulic resistance. It is based on a capillary tube model of pore structure and may be written in the following form:

$$r = \frac{KS^2(1-\varepsilon)}{\rho_s \varepsilon^3} \qquad (3)$$

where S is the specific surface of the solid fraction i.e. the surface area per unit volume of solid and K is the Kozeny constant. If the particles in a filter cake are hydraulically equivalent to spherical particles of diameter d_e, for which $S = \frac{6}{d_e}$, the correlation of specific resistance, porosity and particle diameter, according to equation (3), is as follows:

$$r = \frac{36K(1-\varepsilon)}{\rho_s d_e^2 \varepsilon^3} \qquad (4)$$

while this idealised model might not be a very accurate representation of cake resistance to filtration, it nevertheless highlights its sensitivity to porosity and particle size.

The rate of filtrate discharge in cake-filtration is conventionally modelled (4) by an equation of the form:

$$\frac{dV}{dt} = \frac{pA}{\frac{rcV}{A} + Rm} \qquad (5)$$

where $\frac{dV}{dt}$ is the rate of filtrate discharge, p is the applied pressure, A is the filter surface area, c is the sludge solids concentration, r is the average specific resistance of the cake and Rm is the hydraulic resistance of the medium. Equation (5) can be re-arranged in the form;

$$\frac{dt}{dV} = \frac{rcV}{pA^2} + \frac{Rm}{pA} \qquad (6)$$

If p, r and Rm are constant, equation (6) may be integrated as follows:

$$\frac{t}{V} = \frac{rcV}{2pA^2} + \frac{Rm}{pA} \qquad (7)$$

The foregoing filtration rate expressions imply a linear correlation of both the reciprocal filtration rate $(\frac{dt}{dV})$ and its mean value $(\frac{t}{V})$ with filtrate volume V. While incompressible materials exhibit this linear characteristic, highly compressible materials, such as conditioned activated sludge, do not. Compressibility is measured by the extent to which pore volume is reduced by an increase in the solids compressive stress, the latter undergoing a plastic - type deformation, resulting in a more closely packed structure. As the liquid flows through the cake pores, it exerts a cumulative frictional drag force on the cake solids, resulting in a solids stress gradient, increasing in the direction of the medium. This stress gradient creates a porosity gradient, in which the porosity decreases from a maximum value at the sludge/cake interface to a minimum value at the medium. In constant pressure filtration of compressible materials, therefore, specific resistance to filtration varies over the cake depth and the average specific resistance r is not necessarily time-invariant.

More detailed mathematical models of compressible cake-filtration have been presented in the literature (5, 6, 7, 8). While the constraint in space in this paper does not permit a detailed discussion of such models, they can be said, in general, to treat filtration as an unsteady flow process in which there is a flux of both liquid and solid phases towards the filter medium. These fluxes are modelled by Darcy and continuity equations, subject to the appropriate initial and boundary conditions. The generally unknown factor however, is pressure/permeability relationship within the filter cake. Its measurement is discussed in the following section.

3. LABORATORY MEASURES OF FILTERABILITY

The properties of a liquid sludge and its cake derivative, which may influence dewatering by filtration, include particle size, shape and density, viscosity of the liquid phase, suspended solids concentration, solids compressibility porosity and hydraulic permeability. Particle size, shape and density are very much stress-dependent in a flocculent material such as activated sludge and hence are greatly altered in the transition from liquid sludge to sludge cake. Hydraulic permeability, which is a function of solids stress in compressible cakes, can be measured in compression-permeability cells, which are used in filtration studies in chemical engineering (5) and soil mechanics (9). In these devices, the test sample is compressed between permeable faces by a mechanically applied load, while the rate of water flow through the sample, under a small external head, is measured. From the results, empirical correlations of permeability and applied pressure are obtained (5). There is considerable doubt (8, 10) as to the applicability of compressibility data obtained in such cells to the conditions obtaining in cake-filtration, where the solids stress results from flow-induced drag. To the authors' knowledge, compression-permeability testing has not been used in the sewage sludge field.

The most widely used experimental indices of sludge filtration characteristics are the specific resistance to filtration (SRF) measured by the Buchner funnel method (11) and the instrumentally determined capillary suction time (CST)(12). The shortcomings of the Buchner funnel test for compressible materials such as highly flocculated activated sludge are demonstrated in the following section; the CST apparatus quantifies sludge drainability under very low hydraulic gradients by measuring the time required to withdraw a fixed volume of filtrate. It is thus a very convenient tool for the rapid comparison of conditioning agents, but does not model cake-filtration conditions, where steep hydraulic gradients and high drag forces exist.

4. EXPERIMENTAL TESTS ON CONDITIONED ACTIVATED SLUDGE

A series of tests were carried out on an aerobically stabilised sludge (of municipal oxidation ditch origin) to evaluate its filtration characteristics when conditioned by polyelectrolyte. The cationic polyelectrolyte Zetag 51, which was in use at the treatment plant, where the sludge was dewatered on drying beds, was used throughout the tests. The optimum polyelectrolyte dose was determined by CST measurement (13). The mean specific gravity of the sludge suspended solids was 1.4 and their average volatile fraction 0.71. The results of typical Buchner funnel SRF tests on the sludge, in its unconditioned state and after conditioning, are presented in Fig. 1 in the form of $\frac{t}{V}$ versus V plots. The linear correlation of these variables for the unconditioned sludge indicates that its filtration characteristics are satisfactorily modelled by equation (7). Its computed r value of 12 x 10^{15} $m.kg^{-1}$ is indicative of very low filterability (14). By addition of polyelectrolyte, the sludge was transformed to a highly flocculated condition, in which its filtration characteristics were no longer satisfactorily modelled by equation (7) as its non-linear correlation of $\frac{t}{V}$ and V, plotted in Fig. 1, shows. It is clear that the Buchner funnel test is of limited value for this type of sludge because of scale effects related to pressure, solids loading and time. In order to overcome these limitations, a scaled-up version of Buchner funnel system was devised, as shown in general outline in Fig. 2. A positive air pressure was used in place of a vacuum to impose a hydraulic pressure gradient on the test sample.

Fig. 3 shows typical correlations of reciprocal filtration rate and filtrate volume, derived from filtration tests using this apparatus. The shape of these curves corresponds with that reported by Tiller (5) as being characteristic of compressible filter cakes. In the early part of the filter run, the reciprocal filtration rate and hence, the overall cake resistance, are non-linearly related to filtrate volume, the relation becoming effectively linear after about three hours filtration time.

Fig. 4 shows the influence of filter solids loading on dewatering rate at given values of initial sludge solids concentration and applied pressure. Examination of these plots shows that dewatering time is very sensitive to filter solids loading i.e. to filter cake thickness. For example, an increase in solids loading from 2 to 4 $kg.m^{-2}$ increases the dewatering time to reach a specified solids concentration (test range 6 - 12%) by a factor of approximately 3.1.

Fig. 5 compares the filtration rates of two identically prepared test samples of conditioned activated sludge, one subject to gravity drainage and the other subject to a filtration pressure of 300 $KN.m^{-2}$ applied after an initial 15 minute period of gravity drainage. The gravity-drained sample had an initial total pressure head of about 1.4 $KN.m^{-2}$, corresponding to its own hydrostatic pressure, which decreased with time in direct proportion to the volume of filtrate discharged. Its maximum drainage driving force was therefore less than 0.5% that of the pressurised sample, which was subject to a constant pressure of 300 $KN.m^{-2}$. It is therefore remarkable that there was no significant difference in their drainage rates which could be attributed to the large pressure difference. The major part of the difference in the accumulated filtrate volumes occurred in the initial 15 minute period, when both samples were undergoing gravity drainage. This suggested a slight initial difference in filtration resistance, possibly due to a variation in sample handling. The medium resistance was relatively low, discharging a clean water volume, equal to that contained in the sludge samples in 35 seconds. The effectively zero response in filtration rate to applied pressure indicates the development of a cake resistance which would appear to be directly proportional to the applied pressure. Much additional testing is however, required to more fully define the influence of pressure on filtration resistance.

The porosity gradient across gravity and pressure-drained filter cakes is illustrated in Fig. 6, which shows the variation in the water content of slices cut from these cakes. As might be expected, there is a negligible porosity gradient in the gravity-drained cake. The results also indicate that porosity and porosity gradient in the pressure-drained cakes are maximum at the filter medium and minimum at the cake surface. It is interesting to note that Gale (15) found a similar water content profile in a conditioned raw sludge produced by pressure filtration at approximately 709 $KN.m^{-2}$ (pressing time and cake thickness not reported). Similar results have also been reported by Tiller (5) for compressible cakes such as those formed from fine silca and polystyrene latex.

5. DISCUSSION AND CONCLUSIONS

The degree of flocculation of activated sludge, which can be obtained with currently available polyelectrolytes, greatly enhances its filtration characteristics at low valves of hydraulic gradient and compressive stress. Increasing compressive stress, whether due to self-weight or of hydraulic drag origin, is accompanied by an increasing resistance to filtration. Thus, in dewatering by a filtration process, the desirable objective of increasing filtration rate by increasing the applied pressure is frustrated by the development of a cake layer on the medium which has a high hydraulic resistance with the result that the filtration rate is very little different from that obtainable by simple gravity drainage. The CST test provides an excellent index of sludge drainage characteristics at low hydraulic gradient. There is need, however, for the development of test procedures which would provide a more complete picture of the hydraulic gradient/filtration resistance correlation for highly flocculated compressible sludges. Such knowledge would facilitate the determination of the optimum combination of gravity and pressure filtration for dewatering of a particular sludge. It is clear that the Buchner funnel SRF test gives but a very limited insight into the mechanics of filtration of such materials. The test results presented in this paper indicate that the overall cake resistance varies non-linearly with time and hence the commonly used model of cake-filtration, based on a linear cake resistance/filtrate volume relationship, cannot be applied to the filtration of highly flocculated activated sludges.

Solids loading also has a strong influence on dewatering by filtration. The data plotted in Fig. 4 indicates that the output of dewatered sludge per unit area of filter, at a given solids concentration, increases, as the applied solids load decreases. In practice, however, the influence of downtime in batch filtration and the difficulties in removing thin cakes from the filter medium would have to be taken into account in determining the most productive loading rate.

Two factors, which may influence the dewatering of conditioned activated sludge and have not been examined experimentally in this study are the initial sludge water content and the effect of shear stress on filtration resistance. The application of shear stress to filter cakes has been shown (16) to reduce filtration resistance and is considered to be a significant factor in dewatering by filter belt presses (17). Since all the filtrate must flow through the compressed cake, it is clearly desirable that as much water as possible should be separated by thickening prior to filtration. However, highly conditioned activated sludges release free water very rapidly by gravity filtration and where the latter is provided prior to pressure filtration, the influence of initial water content on the overall process may not be significant.

The results presented in this paper are no more than generally illustrative of the filtration characteristics of highly flocculated activated sludges. Considerable additional work is needed to provide a basis for the better understanding of filtration mechanics and hence exploit the remarkable degree of flocculation which polyelectrolyte-conditioning can achieve.

6. ACKNOWLEDGMENT

The experimental studies described in this paper were carried out in the Department of Civil Engineering, University College Dublin with the aid of a grant from the National Board of Science and Technology.

List of Symbols

A	cross-sectional area, L^2
c	solids concentration, ML^{-3}
d_e	equivalent spherical particle diameter, L
K	Kozeny constant, dimensionless
K_d	Darcy permeability, L^2
p	pressure, FL^{-2}
r	specific resistance to filtration, LM^{-1} (SRF)
r	mean value of r
Rm	medium resistance, L^{-1}
t	time
v_x	volumetric discharge per unit area, LT^{-1}
V	volume, L^3
X	distance, L
ϵ	Porosity, dimensionless
μ	dynamic viscosity, $ML^{-1}T^{-1}$
ρ_s	**solids density, ML^{-3}**

(Dimensions: M = mass, L = length, T = time, F = force)

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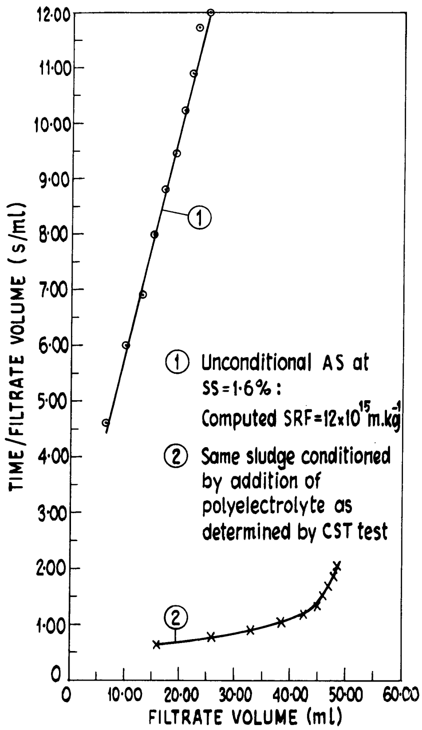

Fig. 1 – Mean reciprocal filtration rate as function of filtrate volume from Buchner Funnel SRF test

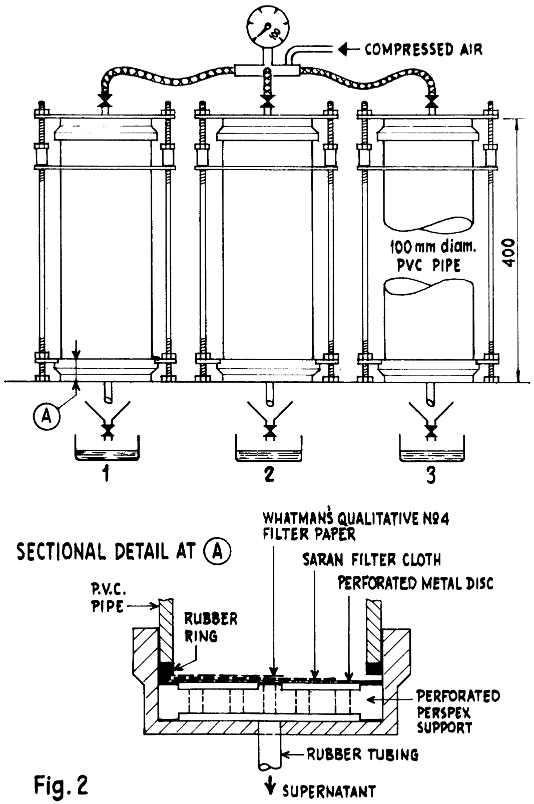

Fig. 2
FILTER COLUMNS (not to scale)

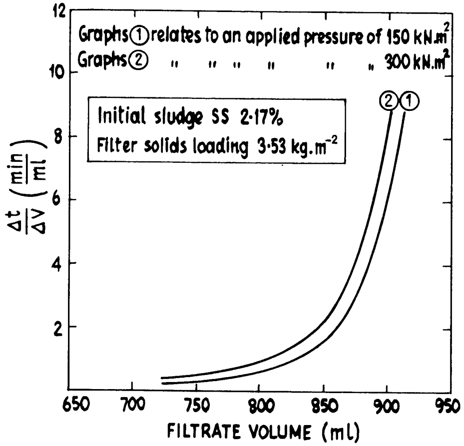

Fig.3 CORRELATION OF INVERSE FILTRATION RATE AND FILTRATE VOLUME

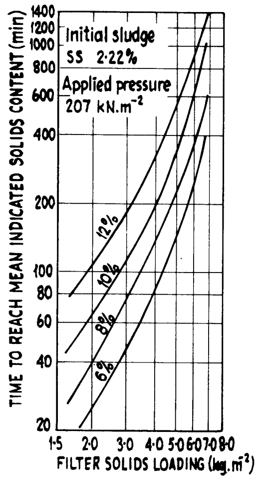

Fig.4 INFLUENCE OF FILTER SOLIDS LOADING ON DEWATERING RATE

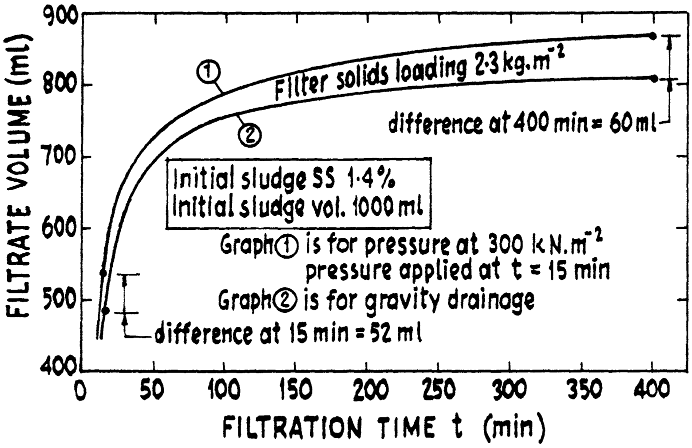

Fig.5 INFLUENCE OF PRESSURE ON FILTRATION RATE OF CONDITIONED ACTIVATED SLUDGE

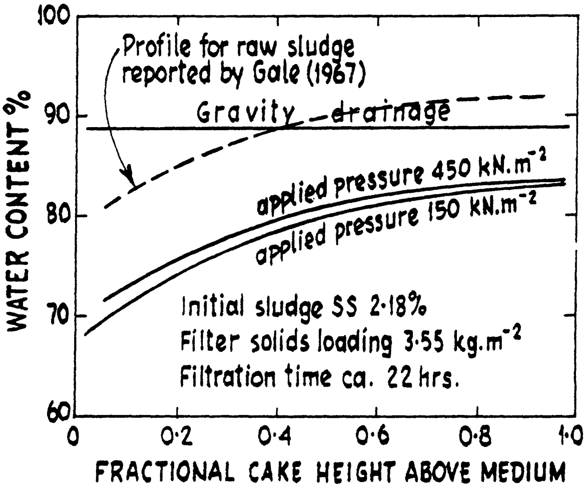

Fig.6 CAKE WATER CONTENT CONCENTRATION

DIE BEDEUTUNG VON KENNWERTEN ZUR CHARAKTERISIERUNG DER MASCHINELLEN FEST-FLUESSIG-TRENNUNG VON KLAERSCHLAMM

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Summary

Besides the general characterization of the dewaterability of sewage sludge, parameters are more and more used in the field of mechanical sludge dewatering for selection and dimensioning of sludge dewatering facilities. In this way large full scale trials can be reduced by the application of preliminary tests. This requires the exact knowledge of the medium sludge, especially the qualities which are relevant for dewaterability. In this context structure and quality of the sludge solids are primarily important as well as the water binding forces between the solid-liquid-components.

By laboratory investigations the influencing factors were found out which are of importance for the dewaterability and by which technique of measurement they can be determined sufficiently and finally which importance has to be attributed to these statements.

Besides dry residue and non volatile substance, the specific resistance of filtration, the compressibility, the capillary suction time and the particle size distribution were determined as the substantial parameters.

Whereas sludge parameters are used with success for the comparison of the dewaterability of different sludges and for estimation of the quantities of chemicals, which are necessary for a good conditioning, there is only a reduced information, dealing with the application of sludge parameters for dimensioning and control of sludge-dewatering facilities.

Relations between technical dewatering with full scale trials and the laboratory parameters of dewatering were elaborated.
Hereby it was necessary to take into consideration the basic conditions of the dewatering machine. To characterize the dewaterability in filter presses, the specific resistance of filtration proved to be an appropriate parameter, whereas for dewatering in centrifuges the particle size distribution, which was determined by sieve analysis, was used for evaluation of the flocculant quantities. The capillary suction time is a versatile purpose parameter, which on one hand can be used for documentation of the amelioration of dewaterability for the application of organic and non-organic chemicals and on the other hand for automatic control of the dewatering process.

Zusammenfassung

Sowohl bei der allgemeinen Kennzeichnung des Entwässerungsverhaltens als auch bei der maschinellen Fest-Flüssig-Trennung von Klärschlamm kommen Schlammkennwerte zur Anwendung. Durch labormäßige Voruntersuchungen können ohne größeren verfahrenstechnischen Aufwand Konditionierungsmittelmengen ermittelt und orientierende Bemessungswerte für die Aggregatauslegung erarbeitet werden. Ausgehend von der Kenntnis der für die Entwässerung relevanten Schlammeigenschaften und unter Berücksichtigung der verfahrenstechnischen Randbedingungen der einzelnen Entwässerungsaggregate konnten durch Untersuchungen die Anwendungsmöglichkeiten von Entwässerungskennwerten aufgezeigt sowie Zusammenhänge zur Entwässerung in Filterpressen ermittelt werden.

Neben Feststoffgehalt und Glührückstand wurden der spezifische Filtrationswiderstand, die Kompressibilität, der CST-Wert und die Teilchengrößenverteilung bestimmt. Bei der Filterpressenentwässerung hat sich der spezifische Filtrationswiderstand als geeigneter Kennwert zur Charakterisierung des Entwässerungsverhaltens erwiesen. In Abhängigkeit von der Schlammausgangsbeschaffenheit läßt sich die für eine ausreichende Konditionierung erforderliche Chemikalienmenge mit Hilfe des spezifischen Filtrationswiderstandes durch Vorgabe eines Zielwertes ermitteln. Zusammenhänge zwischen dem spezifischen Filtrationswiderstand des konditionierten Schlammes und dem erreichbaren Feststoffgehalt im Filterkuchen des entwässerten Schlammes konnten unter Berücksichtigung der Filtrationsdauer nachgewiesen werden.

1. Einleitung:

Im Zuge des wachsenden Klärschlammanfalles und der damit in Zusammenhang stehenden steigenden Anforderungen an Behandlung und endgültige Beseitigung, gewinnen geeignete Charakterisierungsparameter sowohl zur Bewertung und Einordnung von Schlämmen unterschiedlicher Art und Herkunft als auch bei der maschinellen Entwässerung vermehrt an Bedeutung. Aufgrund der Inhomogenität und der Komplexität des Mediums Klärschlamm ist jedoch die Beschreibung der im Hinblick auf die maschinelle Entwässerung relevanten Schlammeigenschaften mit nicht unerheblichen Schwierigkeiten verbunden, da neben der Menge vor allem die Beschaffenheit der in den einzelnen Verfahrensstufen anfallenden Schlämme starken Schwankungen unterliegt.

2. Allgemeines zu Entwässerungskennwerten und Möglichkeiten ihrer Anwendung

In Tabelle I sind die wichtigsten Kennwerte zusammengestellt, die für die Charakterisierung des Entwässerungsverhaltens von Klärschlamm eine Rolle spielen. Die Tabelle erhebt keinen Anspruch auf Vollständigkeit. Einen allgemeinen Überblick über Charakterisierung und Bewertung von Schlämmen gibt Leschber [1] .

Kennwert			Bestimmung
Trockenrückstand	TS	(%)	nach DEV und [2]
Glührückstand	GR	(%)	nach DEV und [2]
spezifischer Filtrationswiderstand	$r \cdot 10^{-12}$	(m/kg)	nach [2, 3, 4]
Capillary suction time	CST	(s)	nach [2, 5, 6]
Kompressibilität	s	(-)	nach [2, 3]
Teilchengrößenverteilung	-	-	nach [7]
Konditionierbarkeit	-	-	nach [2, 8]
dynamische Viskosität	η	(Ns/m^2)	nach [2, 9, 10]
Dichte	ϱ	(kg/m^3)	nach [2]
Absetzbarkeit	-	-	nach [2]
Abscheidegrad	-	-	nach [2]

Tabelle I: Zusammenstellung von Schlammentwässerungskenngrößen

Während Kennwerte zur Charakterisierung des allgemeinen Entwässerungsverhaltens von Schlämmen unterschiedlicher Art und Herkunft in der Praxis bereits Einigung gefunden haben, befindet sich die praxisorientierte Anwendung von Entwässerungskenngrößen bei der maschinellen Entwässerung noch am Anfang. Bei Kenntnis der stoffspezifischen Grundlagen und unter Berücksichtigung der daraus abgeleiteten entwässerungsrelevanten Einflußfaktoren sind bei Anpassung der Kennwert-Meßmethodik an die verfahrenstechnischen Randbedingungen des Entwässerungsaggregates folgende Anwendungsmöglichkeiten denkbar:

- Abschätzung der für die Entwässerung günstigen Chemikalienart und -menge bzw. der Konditionierungsbedingungen.
- Auswahl des Entwässerungsaggregates
- Erarbeitung von Orientierungshilfen bei der Aggregatauslegung
- Steuerung von Schlammentwässerungsanlagen

Über Bedeutung, Möglichkeiten und Grenzen der Anwendung von Schlammentwässerungskennwerten liegen bereits verschiedene Veröffentlichungen vor [6, 11, 12, 13] . Sie befassen sich überwiegend mit Untersuchungen im labor- und halbtechnischen Maßstab, weisen jedoch übereinstimmend auf die Problematik der Übertragbarkeit von im Laborverfahren ermittelten Aussagen auf großtechnische Entwässerungsaggregate hin.

3. Untersuchungen zur Anwendung von Entwässerungskennwerten

3.1 Vorüberlegungen

Die zur Beschreibung des Entwässerungsverhaltens von Klärschlamm wesentlichen Eigenschaften leiten sich aus den Grundlagen für Zwei-Phasen-Systeme ab, wobei in erster Linie der Größe, Beschaffenheit und Zusammensetzung der im Schlamm enthaltenen Feststoffpartikel sowie den damit in Zusammenhang stehenden Bindungsmechanismen zwischen den Fest-Flüssigkomponenten besondere Bedeutung zukommt. Mit kleiner werdendem Teilchendurchmesser ist durch die zunehmende spezifische Gesamtoberfläche ein Anwachsen der wirksamen Bindungskräfte und somit eine Verschlechterung der Entwässerungseigenschaften verbunden. Energetisch gesehen erfordert die Schlammwasserabtrennung die

Zuführung einer den im Stoffsystem herrschenden Bindungskräften äquivalenten Energiemenge [14] . Insofern zielen die der Entwässerung vorangehenden Vorbehandlungsmaßnahmen primär auf eine Aufhebung bzw. Reduzierung der Bindungskräfte ab.

Aufgabe von Entwässerungskennwerten ist es nun, das Schlammwasserabtrennungsvermögen und die Schlammwasserpartikelstruktur- und größe bzw. die durch Konditionierungsverfahren eintretenden Veränderungen der oben genannten Eigenschaften zu beschreiben. Sollen Kennwerte zur Aggregatauslegung bzw. -steuerung verwendet werden, genügt es jedoch nicht, nur die stoffspezifischen Eigenschaften auszudrücken, vielmehr müssen die verfahrenstechnischen Randbedingungen im Hinblick auf die unterschiedliche Schlammwasserabtrennungstechnologie der Entwässerungsaggregate berücksichtigt werden.

3.2 Versuchsdurchführung

Im Rahmen eigener Untersuchungen wurden im labortechnischen Maßstab Entwässerungskennwerte ermittelt und im halbtechnischen und technischen Maßstab Entwässerungsversuche durchgeführt. Folgende Kennwerte wurden nach den in der Literatur angegebenen Verfahren bestimmt:

- Trockenrückstand	TS in %
- Glührückstand	GR in %
- spezifischer Filtrationswiderstand	$r \cdot 10^{-12}$ in m/kg
- Capillary suction time	CST in s
- Kompressibilität	s
- Teilchengrößenverteilung	

Im Gegensatz zur üblichen Verfahrensweise wurde die Messung des spezifischen Filtrationswiderstandes mit Überdruck (10 bar) durchgeführt, um im Hinblick auf die Filterpressenentwässerung eine bessere verfahrenstechnische Übereinstimmung zu erzielen.

Die Untersuchungen bezogen sich auf zwei Faulschlämme und einen aerob stabilisierten Schlamm, deren Eigenschaften durch ausgewählte Kennwerte in Tabelle II beschrieben sind.

Schlammart	TS %	GR %	$r \cdot 10^{-12}$ m/kg	CST s	Fraktions-anteil < 63 µm %	s -
Faulschlamm Geiselbullach	2,7	45,5	464	600	68	0,93
Faulschlamm Dachau	4,1	47,6	339	381	62	0,89
Schlamm Haim-hausen, aerob stabilisiert	7,1	62,4	12	40	56	0,87

Tabelle II: Entwässerungskennwerte für die untersuchten Schlämme (Mittelwerte)

3.3 Beschreibung des Konditionierungsverhaltens

Der Nachweis der verbesserten Entwässerbarkeit infolge Konditionierung ist als erster Schritt beim Einsatz von Kennwerten bei maschineller Schlammentwässerung anzusehen. Neben einer Qualifizierung ist vor allem die Quantifizierung der Veränderung des Entwässerungsverhaltens im Hinblick auf die Konditionierungsmengenermittlung von Bedeutung.

Bei der Konditionierung im Labormaßstab, durchgeführt entsprechend dem Verfahrensvorschlag von Leschber und Niemitz [8], gelangte Eisenchlorid ($FeCl_3$ 6 H_2O) in Verbindung mit Kalk ($Ca(OH)_2$) sowie ein kationisches Polymerisat zur Anwendung. Um den Schwankungen der Schlammausgangsbeschaffenheit Rechnung zu tragen, empfiehlt es sich, die aus der Konditionierung resultierende Verbesserung des Entwässerungsverhaltens in Abhängigkeit von den Ausgangswerten darzustellen.

Organische Flockungsmittel bewirken neben einer Verminderung der Schlammwasserbindungskräfte vor allem die Ausbildung größerer Teilchenverbände und damit eine Verschiebung der Teilchengrößenverteilung. In Bild 1 ist die Abnahme des Fraktionsanteiles < 63 µm in Abhängigkeit von der zugegebenen Flockungsmittelmenge für die drei untersuchten Schlämme dargestellt. Ein Vergleich mit der Ausgangsbeschaffenheit (siehe Tabelle II) verdeutlicht den Zusammenhang zwischen dem Fraktionsanteil < 63 µm der ungeflockten Schlämme und der Flockungsfähigkeit, dargestellt als Abnahme des Feinstkornanteiles < 63 µm (Bild 1). Mit dem höchsten Feinstkornanteil weist der Geiselbullacher Faulschlamm bei zunehmender Flockungsmitteldosierung auch die geringste prozentuale Abnahme an Feinstbestandteilen auf. Diese Aussage läßt sich durch die CST-Messung bestätigen.

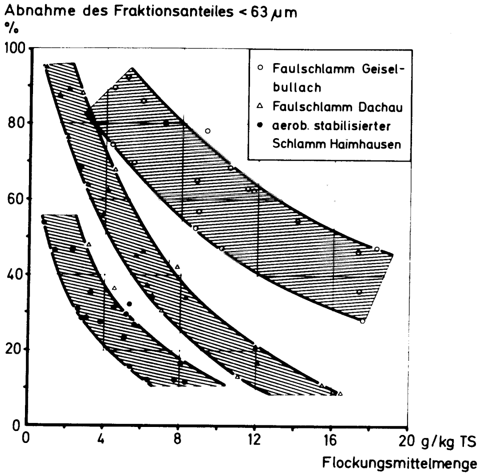

Bild 1: Abnahme des Fraktionsanteiles < 63 µm durch Zugabe organischer Flockungsmittel

Während durch das Naßsiebverfahren ausschließlich die infolge Flockungsmittelzugabe hervorgerufene Veränderung der Teilchengrößenverteilung dokumentiert werden kann, erfaßt die CST-Messung mehrere durch die Flockung hervorgerufene Eigenschaftsveränderungen. Zum einen das Schlammwasserabgabevermögen, zum anderen jedoch auch in gewissem Umfang die damit verbundene Partikelgröße, wie aus Bild 2 zu ersehen ist. Am Beispiel des Faulschlammes Dachau wird der Zusammenhang zwischen dem CST-Wert und dem Fraktionsanteil < 63 µm für Flockungsmittelzugabemengen von 0 - 600 g/m^3 verdeutlicht.

Der in Bild 2 dargestellte Zusammenhang läßt sich für jeden Schlamm ableiten, verliert jedoch bei Konditionierung mit anorganischen Chemikalien seine Gültigkeit, da es hierbei zu keiner durch die Naßsiebung nachweisbaren Beeinflussung der Teilchengrößenverteilung kommt.

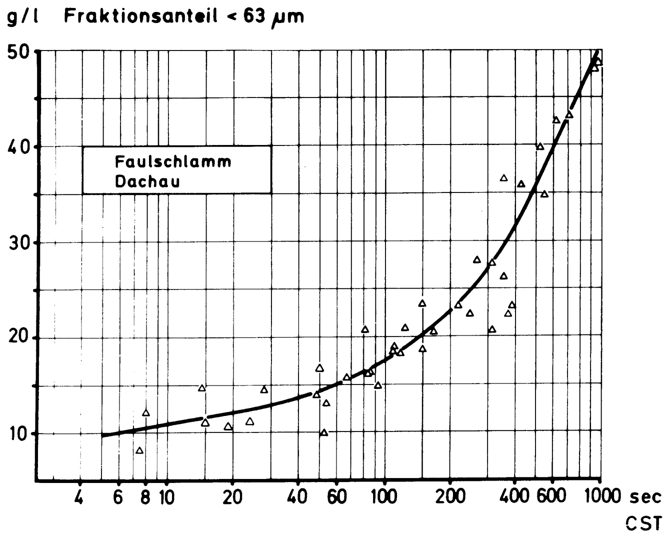

Bild 2: Zusammenhang zwischen dem CST-Wert und dem Fraktionsanteil < 63 µm

Während sich der mit Überdruck ermittelte spezifische Filtrationswiderstand zur Beschreibung des Konditionierungsverhaltens bei Verwendung organischer Flockungsmittel aufgrund der Instabilität der gebildeten Flocken gegenüber höheren Druckkräften nicht als geeignet erwiesen hat, läßt sich bei Konditionierung mit Eisenchlorid und Kalkhydrat die Verbesserung der Entwässerbarkeit zufriedenstellend beschreiben (Bild 3). Der Quotient des spezifischen Filtrationswiderstandes nach (r_k) und vor der Konditionierung (r_o) wird in Abhängigkeit von der Eisenchloridmenge aufgetragen, wobei zur Vereinfachung von einem konstanten Kalk-Eisenchlorid-Verhältnis ausgegangen wurde. Das optimale Verhältnis muß jeweils untersucht werden. In diesem Fall erwies sich ein Verhältnis von 3 : 1 als günstig. Nach Ermittlung dieser Eichkurve läßt sich in Abhängigkeit von r_o nach Vergabe eines Zielwertes r_k die benötigte Chemikalienmenge ablesen.

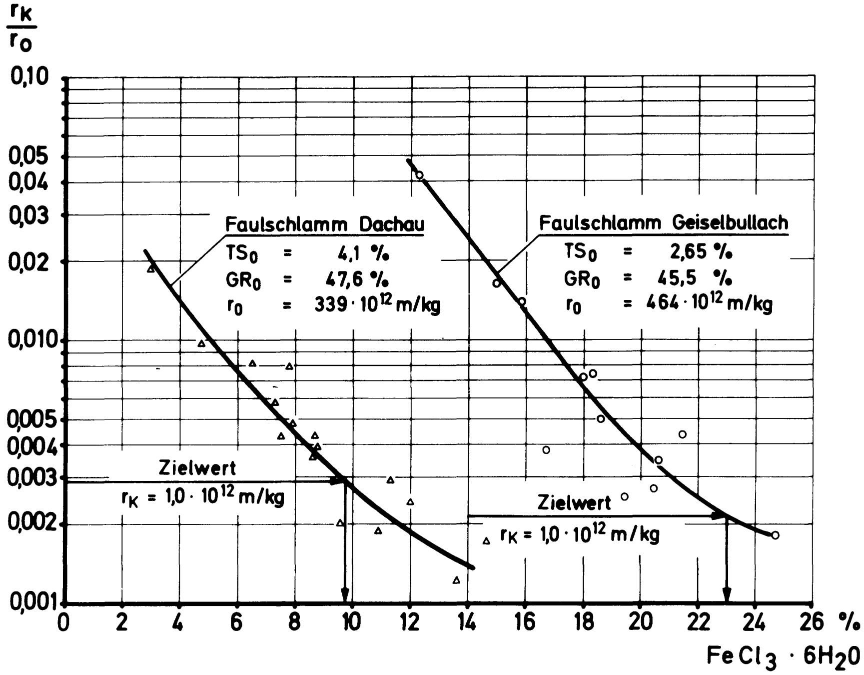

Bild 3: Ermittlung des Chemikalienbedarfs mit Hilfe des spez. Filtrationswiderstandes für $Ca(OH)_2/FeCl_3 \cdot 6H_2O$ ist 3/1

3.4 Zusammenhang zwischen Laborkennwert und maschineller Entwässerung

Am Beispiel der Filterpresse werden die Möglichkeiten der Kennwertanwendung im Hinblick auf die maschinelle Schlammentwässerung aufgezeigt. Bei der Filterpresse gliedert sich der Verfahrensablauf in Filtrations- und Entwässerungsvorgang, welche durch den spezifischen Filtrationswiderstand mit gewissen Einschränkungen beschrieben werden können. Aus Bild 4 ist zu entnehmen, in welchem Maß der erreichbare TS-Gehalt bei sonst konstanten Betriebsbedingungen vom spezifischen Filtrationswiderstand abhängt. Es bestätigt sich, daß Schlämme mit einem spezifischen Filtrationswiderstand kleiner $1{,}0 \cdot 10^{12}$ m/kg in einer Filterpresse gut zu entwässern sind [13]. Die in Bild 4 dargestellten Ergebnisse, gewonnen mit einer Modellfilterpresse (Filterfläche 0,5 m^2) konnten mit einer großtechnischen Presse (Filterfläche 300 m^2) verifiziert werden. Infolge der größeren Abmessungen des Aggregates ist eine längere Filtrationsdauer in Ansatz zu bringen (Bild 5).

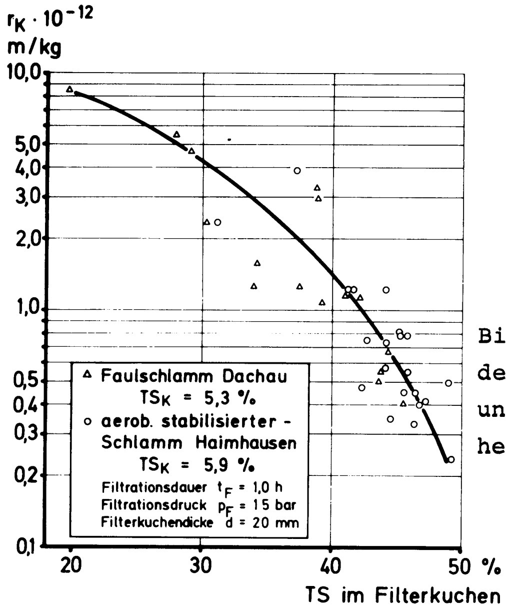

Bild 4: Zusammenhang zwischen dem spez. Filtrationswiderstand und der Filterkuchenbeschaffenheit (Modellpresse)

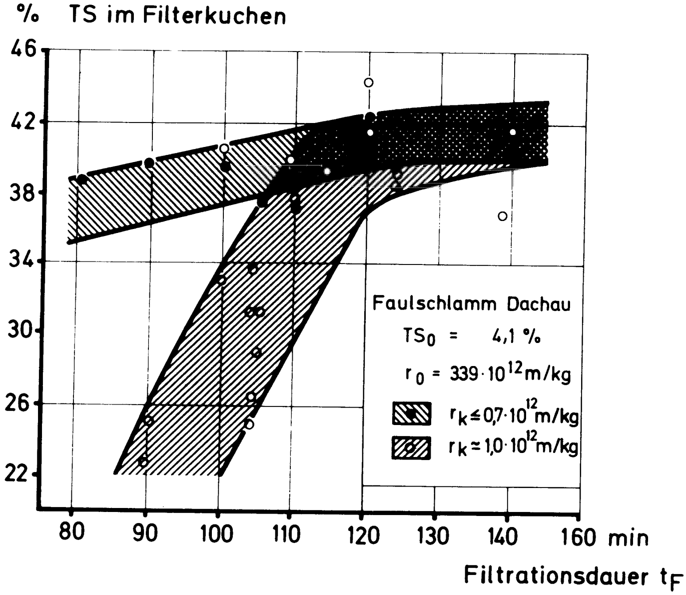

Bild 5: Einfluß der Filtrationsdauer und des spez. Filtrationswiderstandes auf die Filterkuchenbeschaffenheit (großtechnische Presse)

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INFLUENCE OF PRECIPITATION ON THE BEHAVIOUR OF SLUDGE IN THE CASE OF DEWATERING

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Summary

The influence of sludge from precipitation purification on the dewatering behaviour of sludges was examined in four comparative tests carried out in municipal sewage treatment plants. The same pilot plants were used in all cases for sludge dewatering: hydrostatic bag, belt filter and filter press. Pure precipitation sludge from postprecipitation is difficult to dewater. A mixture (1:1) of precipitation sludge and conventional digested sludge displays the same dewatering behaviour as natural mixed sludge, e.g. from simultaneous precipitation. Introduction of precipitation purification in the form of simultaneous precipitation increased the total solids content of the sludge and with that the absolute flocculant consumption; the specific consumption only increased in the belt filter in spite of the reduced volume of sludge produced. Iron III precipitants had a more favourable effect on flocculant consumption and dry matter content achieved than aluminium precipitants. This was not confirmed by the other dewatering units. Pre and simultaneous precipitation displayed similar results in sludge dewatering. Simultaneous precipitation is to be given preference on account of the smaller amount of sludge produced.

1. INTRODUCTION

The eutrophication control of stagnant and slowly flowing waters requires that these are kept free from phosphorus which is a plant nutrient. Phosphorus is eliminated from polluting sewage by means of precipitation purification. Approx. two thousand municipal sewage treatment plants all over the world work according to this process. Precipitation purification not only eliminates phosphates but also other substances found in sewage and is therefore used in particular to relieve sewage treatment plants. It can be introduced into existing sewage treatment plants at short notice and without structural alterations. The additional costs are relatively low.

A swift increase in the installation of precipitation purification must therefore be expected in the future. The sludge from sewage treatment undergoes changes due to precipitation purification; its solid matter content increases and its composition alters. The influence of this on the mechanical dewatering of sludge should be examined. Then the scope of sludge dewatering is increasing. It is necessary before depositing, incineration, composting and other sludge transformations. Environmental protection and the protection of raw materials are bringing new aspects in this respect.

2. INVESTIGATION PROJEKT

The investigation project comprised four comparisons (fig. I):

A Sewage treatment with and without precipitation purification.

B Pre and simultaneous precipitation.

C Aluminium and iron precipitants.

D Pure precipitation sludge and a mixture with conventional digested sludge.

Each part of a comparison was examined in the same sewage treatment plant. There was an interval of more than 50 days between two parts of a comparison. Within this period the contents of a digestion tank were generally replaced to approx. 90 %

Survey of investigations

INVESTIGATION	TREATMENT PLANT	PRECIPI-TATION	METHOD	PRECIPITANT	SLUDGE
1	Auenheim	WITHOUT WITH	SIMULTAN	AL	MIXED
2	Ravensburg	WITH	PRE SIMULTAN	//	//
3	Friedrichs-hafen	//	SIMULTAN	AL FE	//
4	Überlingen	//	POST	AL	MIXED SEPARAT

Fig. I	Influence of precipitation on dewatering of municipal sludge.	

Survey of treatment plants of investigations

TREATMENT	Auenheim	Ravensburg	Friedrichshafen	Überlingen
I.SEWAGE				
MECHANICAL	+	+	+	+
BIOLOGICAL	○	⧄	○	○
CHEMICAL	–	SIMULTAN.	SIMULTAN.	POST
II.SLUDGE				
ANAER.DIGEST.	+	+	+	⊠
DEWATERING	CENTRIF.	CENTRIF.	CENTRIF.	FILTER PRESS

○ aeration from surface; ⧄ aeration from bottom; ⊠ except chemical sludge

Fig. II	Influence of precipitation on dewatering of municipal sludge	

and more. This was not necessary in the case of comparison D.

Four well-operated municipal sewage treatment plants which were not overloaded were chosen for these investigations, and three of these in the region of Lake Constance work regularly with precipitation purification (fig. II). In all four sewage treatment plants the waste sludge is stabilised by means of digestion and then dewatered. In the sewage treatment plant in Überlingen post-precipitation sludge is not digested but dewatered directly in a filter press.

Three portable pilot plants were used in all cases for dewatering the sludge with which it was possible to carry out practice related tests:

A Belt filter, performance approx. 1,5 m^3/h

B Filter press, performance dependent on number of frames approx. 0,02 m^3/h

C Hydrostatic bag, performance approx. 0,1 m^3/h.

The results of the dewatering units in the four sewage treatment plants were taken into consideration in the evaluation of the investigations.

The sludges were examined with respect to total solids, volatile solids, pH-value, specific filter resistance, and capillary suction time. Flocculation tests were carried out in the laboratory with one liter of sludge in order to select suitable conditioning agents. There were 33 organic polymers and four inorganic electrolytes to choose from. Conditioning agents were added to the sludge which was then decanted ten times. The formation and settleablility of the flakes was observed. Stability of the flakes was tested by pressing a filter cloth bag filled with sludge by hand. The conditioning agents selected in this way were used in the pilot plants. Depending on the unit concerned and the expenditure of time between three and thirty tests were carried out per unit for each part of a comparison. Seven different measurements were generally taken on the sludge cake and the filtrate as a double test: dry matter, volatile solids, residue on evaporation, settleable solids after 2 hrs, pH-value, conductivity and turbidity.

3. PRELIMINARY EXAMINATION OF VARIOUS CONDITIONING AGENTS ON THE SLUDGE UNDERGOING INVESTIGATION

The nature of precipitation sludge can be observed most distinctly when treated separately. But this is not often possible in practice because precipitation sludge resulting from pre and simultaneous precipitation flows together with the sludges resulting from other methods. Even when it flows separately as in postprecipitation it is usually mixed with the other sludges before dewatering.

The other charge characteristic of precipitation sludge colloids is visible during treatment with cationic and anionic polymers. Precipitation sludge does not react or only poorly to cationic polymers; the same is true in part with combinations of anionic and cationic flocculants (fig. III). This is in contrast with a mixture of precipitation sludge and conventional digested sludge.

As expected, inorganic electrolytes such as $FeCl_3$ do not achieve a satisfactory dewatering structure of pure precipitation sludge. Lime which is used in practice together with polymers has a different effect. The reason for this is that the sludge has a high pH-value when lime is used, which weakens or reverses the electric charge of the colloids.

The comparison of digested sludge from mechanical-biological sewage treatment with and without simultaneous precipitation shows that these properties of precipitation sludge are no longer effective in mixed sludge (fig. IV); they are compensated by the colloids of the other sludges which are in the majority. Mixed sludge from precipitation sludge and conventional sludge can be best conditioned with cationic polyelectrolytes or combinations of anionic and cationic polyelectrolytes.

These observations are confirmed by the flocculation test in the comparison of simultaneous precipitation and preprecipitation. The flocculation properties were fair to poor in the

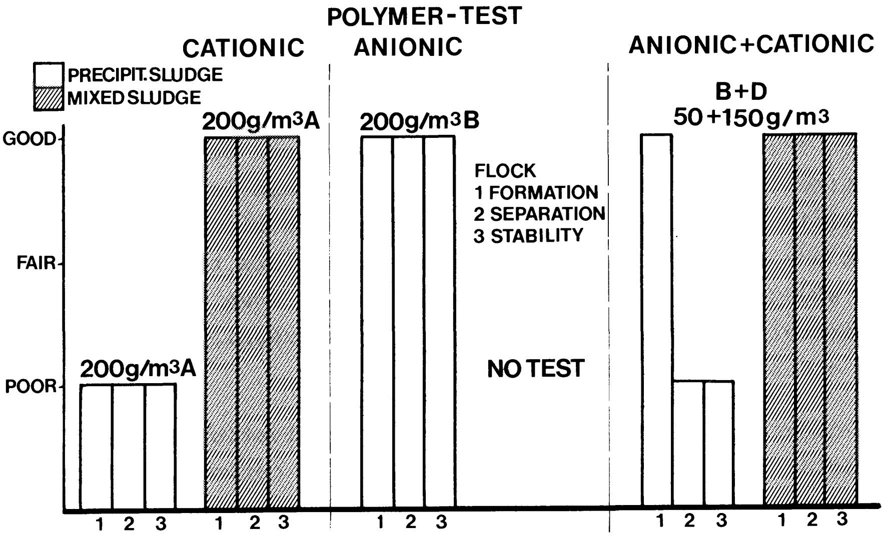

Fig. III	**Chemical sludge from postprecipitation** compared with mixture (1:1) of chemical sludge and digested conventional sludge; treatment by different polymers.	

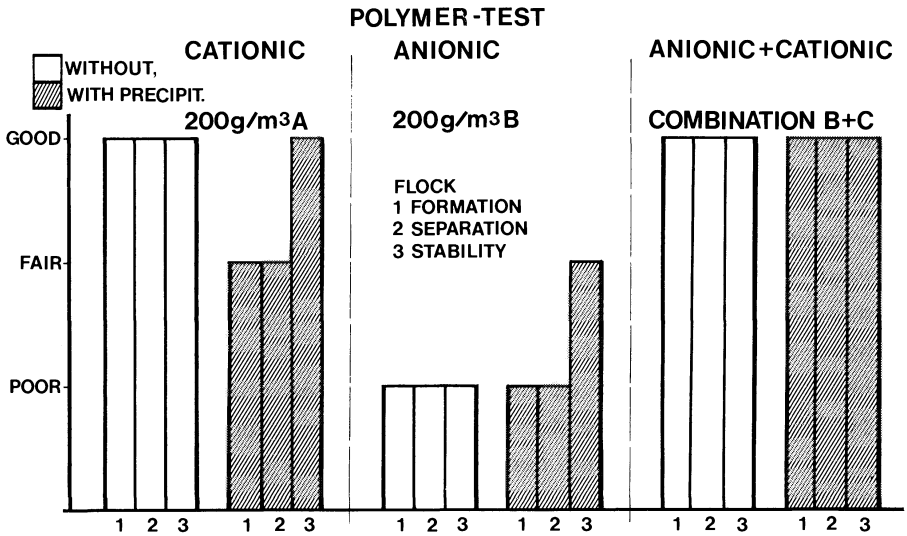

Fig. IV	**Sludge from mech.-biol. sewage treatment without and with simult. precipitation;** behaviour by application of different polymers.	

case of anionic polyelectrolyts fair to good in the case of cationic polyelectrolytes or combinations.

In the comparison of the aluminium precipitant with the iron III precipitant it was noticed that two cationic polymers were classified "good" in the case of Al, but "poor" or only "fair" in the case of Fe. A combination of precipitants achieved good results in both cases.

It is obvious that these results must not apply to the same extent in all cases.

4. DEWATERING RESULTS

4.1 PURE PRECIPITATION SLUDGE AND A MIXTURE WITH CONVENTIONAL DIGESTED SLUDGE

Pure precipitation sludge from postprecipitation with aluminium sulphate cannot be drained easily (Überlingen). In comparison with mixed sludge from pure precipitation sludge and conventional digested sludge only approx. 60 % of the dry matter content can be achieved in the centrifuge and the filter press (fig. V). Pure precipitation sludge conditioned with polymers could not be dewatered in the belt filter. It was only possible after adding large quantities of lime (7,8 - 31,5 kg/m^3). The specific flocculant requirement of pure precipitation sludge exceeded that of mixed sludge by 65 to 75 %. The dry matter content achieved for the artificial mixed sludge, which was produced in the ratio volume of 1:1, corresponded to that of natural mixed sludge, e.g. from simultaneous precipitation.

4.2 SLUDGE FROM MECHANICAL-BIOLOGICAL SEWAGE TREATMENT WITH AND WITHOUT PRECIPITATION PURIFICATION

The absolute coagulant requirement per cubic meter of sludge increase considerably by introduction of precipitation purification (fig. VI).

The arithmetic mean of all results concerning the centrifuge and the belt filter proved an absolute flocculant requirement which was more than twice as high whilst the mean dry matter

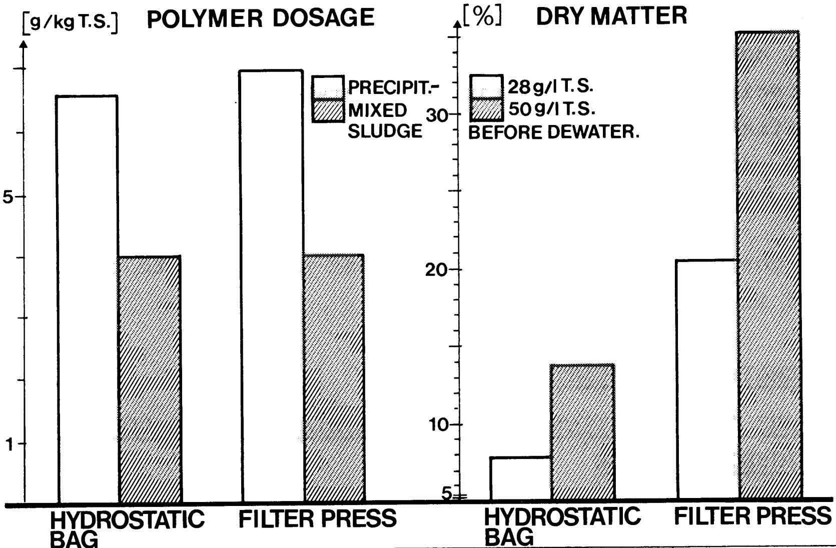

Fig. V	**Dewatering: Sludge from postprecipitation in comparison** with a mixture (1:1) of postprecipitat. sludge and digested sludge from mech.-biol. sewage treatment.	

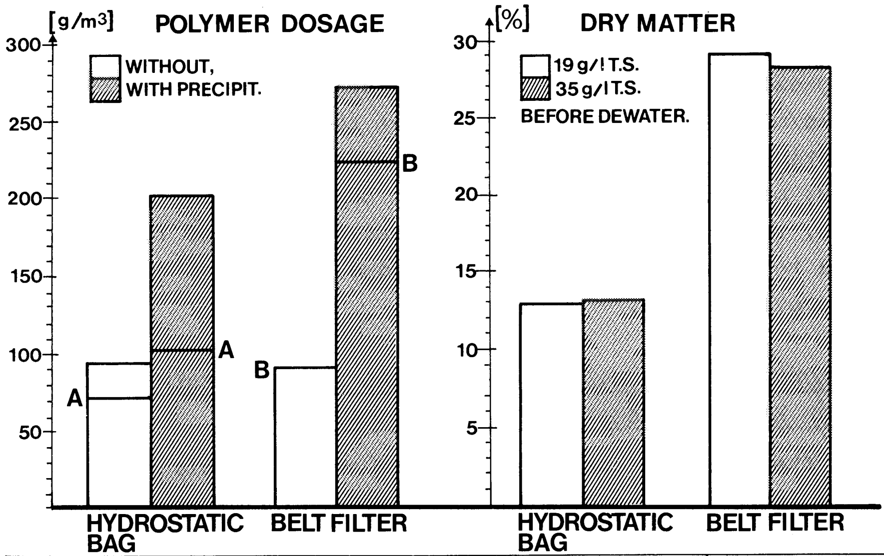

Fig. VI	**Dewatering of digested sludges** from mech.-biol. sewage treatment without and with precipitation; mean values and dosage of polymer A and B.	

contents were almost the same. A flocculant (A) which was used in comparison showed a considerably smaller difference in requirement with nearly the same dewatering result. The choice of suitable conditioning agents in the case of sewage treatment with precipitation must evidently be made with special care.

The higher flocculant requirement in the case of precipitation purification is due to the approx. 80 % higher total solids content of the sludge before dewatering. However the final analysis in the above mentioned cases averaged an increase in the relative flocculant requirement per kg solids. This does not apply to the above mentioned individual case.

The balance of conditioning agent in the case of precipitation purification is improved by the decrease in waste sludge volume, approx. 10 % less waste sludge occurred by introduction of precipitation purification (fig. VII). This more or less compensates the difference in specific flocculant requirement in the case of the centrifuge, but not quite for the belt filter dewatering.

4.3 COMPARISON OF THE INFLUENCE OF ALUMINIUM AND IRON PRECIPITANTS

The results of the tests made with the belt filter demonstrate on an average a higher dry matter content together with a much lower specific flocculant requirement when iron salt is used as compared with precipitation purification with aluminium salt (fig. VIII).

In the case of the centrifuge and the filter press the average specific flocculant requirement turned out to be reverse; but the differences were smaller and the average dry matter contents almost the same. The result of the test in the pilot belt filter are more important, because in this comparison it was possible to carry out a larger number of tests. The different properties of the sludge flocks in the different dewatering units can of course stand out here.

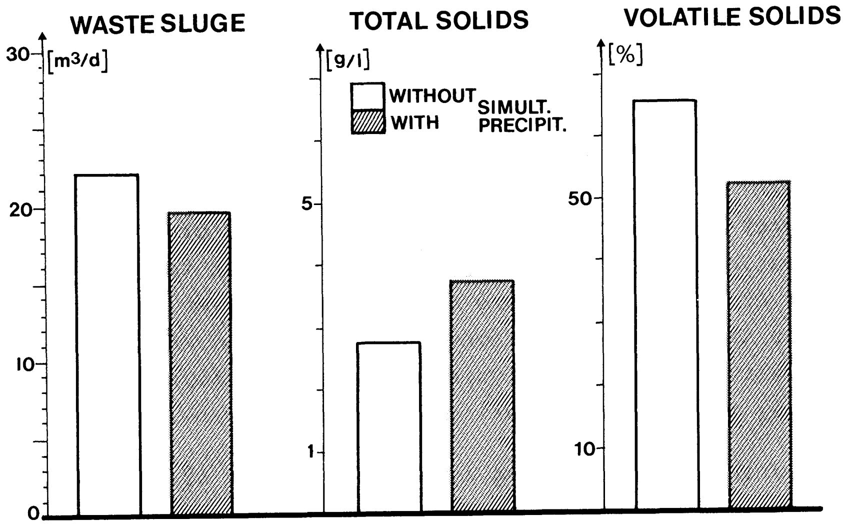

Fig. VII	**Influence of simultaneous precipitation** on waste sludge amount, total solids content and volatile solids percentage.	

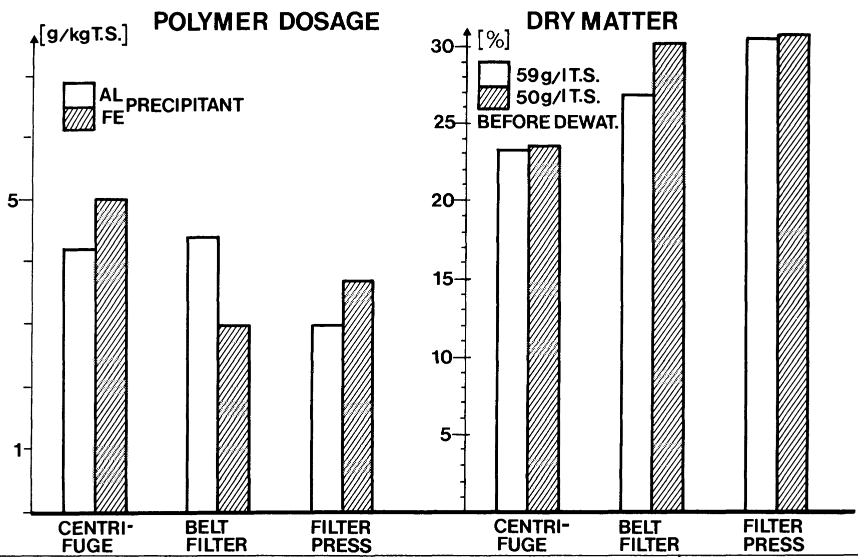

Fig. VIII	**Dewatering of digested sludges** from mech.-biol.-chem. sewage treatment; simultan. precipit. by Al-and Fe-precipitant.	

4.4 SLUDGE FROM SIMULTANEOUS AND PREPRECIPITATION

The average results of the comparison between simultaneous and preprecipitation show hardly any difference in the case of the centrifuge and the belt filter (fig. IX). In both cases the process in the centrifuge of the sewage treatment plant was operated with the same cationic flocculant and could not be optimised. In the hydrostatic bag the same addition of flocculant combinations resulted in the same dry matter contents in both parts of the comparison.

In consideration of the fact that the volume of sludge resulting from simultaneous precipitation is smaller than that from preprecipitation, simultaneous precipitation must be given preference over preprecipitation.

4.5 FILTRATE BEHAVIOUR

The comparison of mechanical-biological sewage treatment without and with precipitation, which was tested mainly in the belt filter, showed an increase in turbidity and settleable solids. Individual comparisons and tests in the other dewatering units did not always confirm this pattern.

5. DISCUSSION

This evaluation of the investigations was only concerned with conditioning with organic polyelectrolytes.

In spite of numerous conditioning tests dispersion of the dry matter contents reached was in most cases about $\pm$ 10 %.

Within the scope of these investigations which took over six months it was not possible to treat all influencing factors systematically or to optimise all dewatering processes. The aim of the investigations was not to compare dewatering units but to indicate the influence of precipitation purification on sludge dewatering, and this was basically successful. But there are still gaps in our knowledge. Above all the acquired results must be repeatedly supported and extended.

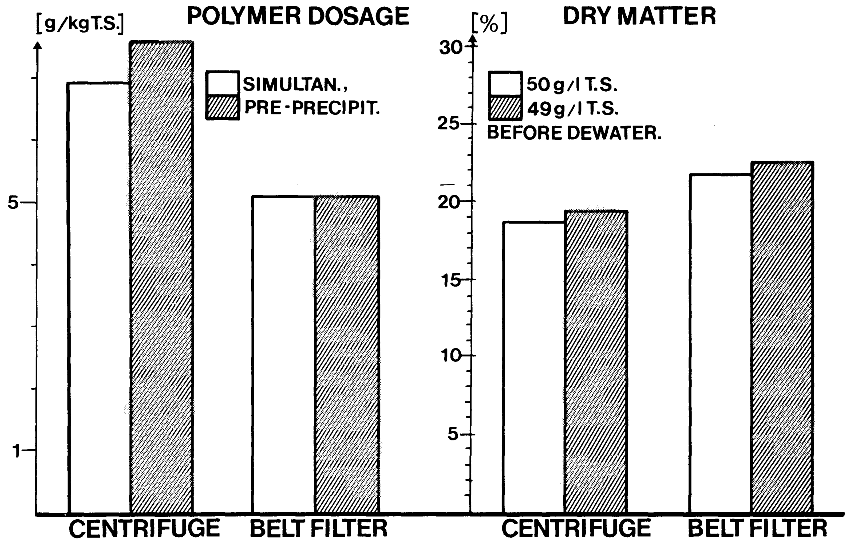

Fig. IX	**Simultaneous precipitation compared with** preprecipitation concerning sludge dewatering behaviour.	

AN APPLICATION OF NATURAL SLUDGE DEWATERING AT SMALL SEWAGE TREATMENT PLANTS IN FINLAND

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Summary

Increasing strict requirements for the quality of sludge are causing ever greater problems at small sewage treatment plants. Mechanical dewatering is not the answer, since costs and operational difficulties increase as the size of the plant decreases. Sludge drying beds are prone to failure in cold, damp climates. In 1977 a study was begun in Finland into various modifications of the sludge drying bed and application of the freeze-thaw effect to sludge dewatering. Laboratory, pilot-scale and full-scale experiments with peat-covered drying beds have been performed in conjunction with freeze-thaw experiments. The use of a peat layer as the filter medium has the advantage over a conventional sand filter that it is more economical and that the sludge and peat can be composted together. Average winter temperatures, even in the south of Finland, are sufficient to freeze the top sludge layer of about 50 cm, providing the insulating effect of the snow is minimised. Snow is no longer a problem if the sludge is allowed to freeze in thin layers, something which is possible in even the mildest winters. After thawing, the sludge is dry and porous enough to start composting on its own on the drying bed or after lifting it onto flat land. The water obtained from the sludge is at least as clean as that obtained by mechanical dewatering.

1. INTRODUCTION

Several different methods are available for the treatment of sewage sludge at sewage works catering for more than 5'000 inhabitants. The operation and efficiency of these methods have been investigated and are thus fairly well known. Sewage works catering for less than 5'000 inhabitants, on the other hand, often do not provide adequate sludge treatment due to high costs and lack of suitable methods.

Public health and water authorities set certain criteria on the heavy metal concentrations and treatment methods for sludge to be utilized in agriculture. The sludge from small sewage works has so far seldom been used. The reason for this is not heavy metals, which are present in such sludges at very low concentrations, but inadequate dewatering and stabilization.

Sludge treatment at small sewage works is not a significant problem in terms of total sludge quantity. The problem lies in the large number of these small plants. Three years ago about 85 % of Finland's 546 sewage works catered for less than 5'000 inhabitants. Seventy-nine per cent of these sewage works had no sludge dewatering at all and only 9 % had drying beds or basins. These statistics do not include several hundred of the smallest sewage works. The Finnish authorities intend to prohibit all disposal and utilization of liquid sludge in a few years time. Exceptions will be made only in well justified cases. Thus sludge dewatering will become a major undertaking at small sewage works.

2. AIM OF THE STUDY

The objective of the study was to seek and develop economical, easily operated, reliable and reasonably effective sludge dewatering methods so that the sludge from small sewage works can be used more in agriculture instead of going for disposal on sanitary landfills. Since the operators of small sewage works often work only half a day, special attention was given to the simplicity of a plant's operation.

Mechanical dewatering methods at small sewage works have proved expensive and unreliable. Conventional mechanical dewatering devices as well as filter bags and rotosieve-type concentrators have not been successful, either. Only small filter presses remain to be tried under Finnish conditions. The remaining alternative was the classical, almost forgotten sludge drying bed.

Sludge drying beds have been studied very little in Finland, although plenty of them were built at the end of 1960s and even at the beginning of 1970s. Their operation has not been satisfactory due to lack of operating and maintenance instructions, which led to the failure of measures that were essentially correct. The other common disadvantages - space requirement and odour - are not so pronounced at small sewage works. The study concentrated on improving the operation of sludge drying beds by utilising a peat filter bottom and sludge freezing.

3. METHODS

The study consisted of a literature review, laboratory experiments, pilot-scale and full-scale trials and planning examples of some full-scale applications. The study was performed in Oulu Water District in northern Finland under the management of the Technical Research Office of the National Board of Waters. The experiments were performed at Oulu University and at the sewage works of the participating municipalities.

The study deals with sludge drying bed dewatering by peat and the effects of freeze-thaw as independent phenomena, although the experimental arrangements were often the same. In full-scale praxis the methods can be used to supplement each other.

Preliminary experiments with peat as a filter medium were carried out in 1977 at the Ruukki sewage works. In summer 1978 two sludge drying beds with peat filter bottoms were constructed and operation began (Fig. 1). The total area of the beds was 135 m^2. Sludge was taken from the plant's pre-precipitation basin. The precipitation agent used was ferric chloride. An initial sludge layer of 60-70 cm was pumped onto the beds.

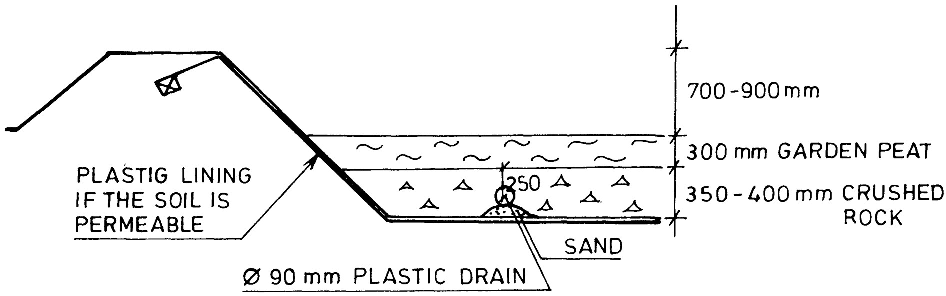

Fig. 1. The principle of a peat filter bottom sludge drying bed. The banks are constructed from the local soil.

The progress of dewatering and filtrate quality and quantity were monitored for three months. The dewatered sludge was removed manually using spades and mixed with peat to form a compost which was analyzed the following spring. In summer 1979 eight filters were constructed using 200 l barrels at Kempele sewage works. During the summer sludge from the pre-precipitation of sewage by lime was dewatered 2-4 times. The variables were the number of cycles, the thickness of the peat layer and the depth of the sludge layer. One barrel had a sand filter instead of a peat filter. The filter media were not changed during the experiments. In addition to these experiments the operation of two other drying beds with peat filter bottoms was monitored in summer 1979.

In summer 1978 sludge freezing and subsequent thawing were studied in the laboratory using ø 120 mm acrylic plastic cylinders and 40 l basins with insulated sides. Some vessels had a watertight bottom, some a filter bottom. The sludges tested were produced at existing treatment plants by direct precipitation with aluminium or iron salts or lime or by simultaneous precipitation with ferrous sulphate. During winter 1978-

1979 freezing of ferric chloride sludge was monitored on sludge drying beds with peat filter bottoms at two sewage works. Freezing of lime sludge in watertight basins was monitored at Oulu sewage works. Sludge temperatures were measured by thermocouples and the depth of frozen sludge by drilling the ice. Freezing in one deep layer versus several shallow layers, solids migration, the effect of snow cover on freezing, thawing and drying, the characteristics of the treated sludge and the sludge water quality were all monitored.

COD, SS, N, P and pH were determined from the sludge filtrate and from sludge water separated after thawing. The total solids (TS) content, and from time to time the content of volatile substances, macro- and micronutrients, and certain heavy metals were determined from sludge and compost. The C, N and P contents of the peat used in the filters were also determined.

The required weather observation data was obtained from weather observation stations nearby. Evaporation was measured by means of a CLASS A evaporation test.

4. RESULTS

Sludge was dewatered on the Ruukki drying beds from 4.6 % TS to 25-36 % TS. During this period the total evaporation was 127 mm and precipitation 46 mm. Most sludge water filtered during 2-3 weeks. Rain ran through the cracked sludge without wetting it. Initially some sludge escaped below the peat layer, as can be seen from the high filtrate concentrations shown in Table 1. Operating the sludge drying bed taught us practical measures such as sludge feeding, peat layer compaction and wetting. Table 2 shows the peat analysis. Table 3 shows the analysis of the peat-sludge compost. The same peat layer was left untouched for winter operation. The peat layer was replaced by a new one the following summer. However, at this time the drying beds were not operating satisfactorily because of clogging caused by sludge iron precipitation in the drains.

Table 1. Quality of sludge water from different dewatering methods (mg/l)

Sludge		Sewage works	Time	SS	COD	N	P
K_{Fe}	Peat filter	Ruukki	1978	19-460		87-140	1.9-8.0
K_{Ca}	"	Kempele	1979	14-43	190-710	27-140	0.4-3.4
K_{Ca}	Sand filter	Kempele	1979	12-37	160-280	62	0.8-1.0
K_{Al}	Frozen and thawed	Tyrnävä	1978	13-19	84-130	34-75	0.4-1.0
K_{Fe}	"	Kempele	1978	120	19-38	47-96	0.2-0.3
K_{Fe}	"	Ruukki	1979	36-120		360-410	2.6-3.1
K_{Ca}	"	Oulu	1978	5-77	40-160	23-89	9.2-1.1
BK_{Fe}	"	Muhos	1978	12	590-630	970-1200	2.2-6.0
K_{Al}	Belt press filter	Tyrnävä	1975	870	78	41	28
K_{Fe}	"	Kempele	1975	750	290	39	15
K_{Ca}	"	Oulu	1977	35000	2000		420
BK_{Fe}	"	Muhos	1975	5900	650	200	100

Table 2. Peat quality before and after use as a sludge filter medium

Place	Time	Peat	P (mg/l)	N (% of TS)	C (% of TS)
Ruukki	1978	Fresh	0.6	1.4	45
	1978	Used	0.4	0.9	22
Kempele	1979	Fresh	0.7-3.4	1.4-1.6	48-50
	1979	Used	0.8-4.0	1.6-1.9	44-55

Table 3. The quality of sludge composted together with peat versus frozen, thawed and composted sludge

Analysis	Peat-sludge compost	Frozen, thawed and composted sludge
pH	4.3	4.4
TS	55.4	48.6
Ash % of TS	68.2	40.6
C "	11.9	14.4
N "	0.8	2.4
P "	0.6	3.9
K g/kg of TS	1.0	1.2
Ca "	4.6	8.9
Mg "	1.9	1.0
Fe "	35.8	207
Pb mg/kg of TS	24.1	28.3
Cd "	0.7	4.5

The Kempele pilot-scale filtering tests required a dewatering period of less than one week for initial 70 cm sludge layers. Increasing the initial sludge layer to 100-140 cm prolonged the dewatering time to three weeks. The differences between this and the previous sludge dewatering times were due to the chemical used in sewage precipitation: sludge from lime precipitation dewaters more easily than that from ferric chloride precipitation. The sludge at Kempele was dewatered from 5-7 % TS to 27 % TS. The dewatering times were shorter for thinner filter medium layers. The sand filter operated in a way comparable to that of peat filters. In terms of filtrate quality it was not possible to make a clear list of the different filter media, their thicknesses or sludge layer thicknesses (Table 1). The filter media and sludge layers were easily separated by sludge removal. The topmost peat layers had compacted and decomposed and the sand layers had started to clog. It is obvious that thin filter layers do not last more than a few filtering cycles. The peat analyses were very heterogenous (Table 2).

Sludge freezing in the laboratory caused the expected gross migration of solids away from the freezing zone. Sludge water separated as crystal clear ice when freezing started. This also took place when freezing was by layers, resulting in the formation of clearly distinguishable water and solids layers. Thawing released the sludge water rapidly through the pores formed by the ice crystals. The porous structure of sludge also allowed effective evaporation of the remaining moisture. Water poured on the dry sludge no longer produced any permanent moistening. The sludge water could be removed through the filter bottom as well as decanted from the surface or sides of the vessels without any notable loss of sludge solids. The chemical and biological-chemical sludges tested dewatered in cylinders from 2-7 % TS to 20-33 % TS and in basins from 7-19 % TS to 31-37 % TS. After melting the sludge water was in general cleaner than the filtrates obtained from mechanical dewatering of the respective sludges (Table 1).

Sludge material ceofficients used to describe the progress of freezing were calculated from freezing and temperature observations at the sewage works and from weather observation data. Sludge freezing temperatures were -1.8 °C (sludge from ferric chloride precipitation) and -1.4 °C (sludge from lime precipitation). Soon after thawing the sludge dried to 31-49 % TS as a result of filtration and effective evaporation of the sludge water. Snow cover was found to have an insulating effect, and thus slowed down freezing. However, this is not a significant disadvantage in freezing by layers, provided that sludge is added frequently enough. The high concentration of sludge water solids is due to the pulverizing effect of frost on the peat layer.

The depths of the sludge layers which can be frozen in an average winter in different parts of the country were calculated from freezing indexes and sludge material coefficients for one layer freezing and for freezing of several layers.

Sludge dewatered on a peat bottom drying bed in summer and frozen and thawed sludge were so dry that they could be composted without additional support material. Frozen and thawed sludge even started to compost on the drying bed due to its suitable porosity and moisture. Sludge soon turned into odourless humus, which was much more valuable as a fertilizer than sludge dewatered in summer and composted together with peat (Table 3).

The total costs of full-scale sludge drying beds constructed in 1979 were 185 Fmk/tTS. Mechanical dewatering at such a small sewage works would have cost, according to the literature, at least 1'000 Fmk/tTS, and probably well over 1'600 Fmk/tTS.

5. DISCUSSION

A sludge drying bed with a peat bottom combined with natural sludge freezing and thawing proved more succesful than expected. In particular, sludge freezing and thawing and the subsequent composting gave good results. The treated sludge was dry and odourless. Freezing, long retention of sludge in the process and composting even ensure that the sludge contains relatively few pathogenic organisms. Separate stabilization after freezing becomes unnecessary. The frozen, thawn and subsequently composted sludge was five times more valuable as a fertilizer than sludge composted together with peat, the latter being most suitable for use on its own as a nutrient-rich topsoil.

Both peat and sand (# 0.5-5 mm) are suitable filtering materials for sludge drying beds. Local prices dictate the most economical choice. In the cases studied peat was clearly more economical on site. Laying a sand layer is easier than wetting and compacting peat. The filtrate obtained from sand filters contains slightly less organic matter than that obtained from peat, which contains dissolved humus. On the other hand, a 25-30 cm peat filter lasts longer than the comparable 15-20 cm sand filter. Moreover, peat can be composted together with sludge and does not cause a separate waste problem.

It must be remembered that operating a drying bed requires removal of dewatered sludge and replacement of the filter medium by a new one. The life-time of a filter medium is at most two years depending on the mode of operation. This is due to the clogging of sand and decomposition of peat, both of which reduce the efficiency of dewatering cycle by cycle. Flushing and maintenance of drains is necessary, especially with sludges containing iron precipitates. Otherwise fluctuating dry and wet conditions in drains leads to clogging in such cases.

Sludge freezing and thawing can be carried out either on drying beds or in separate watertight basins. In the latter case frozen sludge should be lifted onto flat land for thawing. The material coefficient of sludge in freezing was calculated to be 0.0230-0.0234 $m/\sqrt{d^{o}C}$ for ferric chloride sludge and 0.0256 $m/\sqrt{d^{o}C}$ for lime sludge. Thus the formula describing freezing can, with adequate accuracy, be presented in the form

$$d = c\sqrt{F}, \qquad (1)$$

where d = thickness of frozen layer (cm)

$c = 2.4\ cm/\sqrt{d^{o}C}$ and

F = freezing index ($d^{o}C$).

This formula does not take into account the effect of snow cover, which has to be removed. In an average winter a single sludge layer of 80 cm can be frozen in Oulu and one of 55 cm in Helsinki. Even during the mildest winter it is possible in theory to reach a total frozen depth of 200 m in Oulu and 70 cm in Helsinki, provided the sludge is frozen in 10 cm layers.

Both the filtrate and the water released from thawing chemical sludge were usually so clean that they could, in principle, be lead directly to the effluent from the sewage works. In case of any operational shortcomings they must naturally be lead to the influent. Sludges containing biological sludge produced much more polluted filtrates and thawing waters than plain chemical sludges. However, the thawing water and the filtrate obtained from the drying beds studied were always at least as clear as the water obtained from mechanical dewatering.

Detailed plans and dimensioning criteria for some new peat bottom sludge drying beds utilizing the freeze-thaw phenomenon were drawn up on the basis of the experience gained during the study. The aim now is to gain further experience with full-scale treatment units and to study the separate treatment of septic sludge by the same method. How efficient and economical this method is will be judged finally after the remaining experiments.

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KLAERSCHLAMMBEHANDLUNG IN OESTERREICH

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Summary

Presently about 500 sewage treatment plants are operated in Austria treating the sewage of approximately 6,4 mill inhabitant-equivalents. About 70 % of these plants treat the sewage biologically.

The sludge treatment of the plants with a capacity of more than 10.000 inhabitant-equivalents is performed mainly using one of the three following processes:

1 - In the majority of sewage plants sludge is treated by anerobic digestion, with gas utilization produced in digestors of 250 m^3 to 11.000 m^3 volume. Digestion gas engines between 80 kW and 750kW have been installed.

2 - In numerous plants sludge is treated by aerobic stabilization (even with a capacity up to 300.000 inhabitant-equivalents).

3 - The sludge of the main treatment plant of Vienna (2,5 mill inhabitant-equivalents) is burnt in a special waste incinerator.

The final storage of the sludge is mainly carried out by dumping it for sanitary landfill together with domestic solid waste; agricultural utilization of the digested sludge is of minor importance.

Zusammenfassung

Derzeit stehen in Oesterreich rd. 500 Kläranlagen in Betrieb, in denen die Abwässer von rd. 6,4 Mio EGW gereinigt werden. In rd. 70 % dieser Anlagen wird das Abwasser biologisch gereinigt.

Die Schlammbehandlung wird in den Anlagen mit Anschlussgrössen über 10.000 EGW im wesentlichen nach drei Verfahren durchgeführt:

1 - In der überwiegenden Anzahl in anaeroben Schlammfaulanlagen mit Klärgasverwertung in Faulräumen von 250 m^3 bis 11.000 m^3 Inhalt. Faulgasmotoren zwischen 80 kW und 750 kW sind installiert.

2 - In zahlreichen Anlagen (auch mit Anschlussgrössen bis 300.000 EGW) wird der Schlamm aerob stabilisiert.

3 - Der Schlamm der Hauptkläranlage Wien (2,5 Mio EGW) wird in einer Sonderabfallverbrennungsanlage verascht.

Die endgültige Unterbringung des Klärschlammes erfolgt hauptsächlich durch gemeinsame Deponie mit Hausmüll, untergeordnet wird die landwirtschaftliche Nassschlammverwertung angewandt.

SITUATION DER KLÄRSCHLAMMBEHANDLUNG IN ÖSTERREICH

Der folgende Bericht soll eine Übersicht über die Klärschlammbehandlung in Österreich geben. Von den derzeit in Österreich in Betrieb stehenden rund 500 Kläranlagen wird das Abwasser von ca. 6,4 Mio. EGW gereinigt, wobei der Anteil mit biologischer Reinigungsstufe etwa 70 % beträgt. Der Großteil dieser Anlagen hat allerdings Anschlußgrößen unter 10.000 EGW. Bei diesen Anlagen herrscht die anaerobe Schlammstabilisation vor. Eine untergeordnete Rolle spielen bei den kleinen Anlagen auch ältere Tropfkörperanlagen. Wegen der relativ kleinen Schlammengen wird im allgemeinen der Klärschlamm in der Landwirtschaft und Gartenbetrieben oder auf Mülldeponien anstandslos untergebracht.

Bei Anlagengrößen über 10.000 EGW werden im wesentlichen drei Verfahrensgruppen angewendet:

In der überwiegenden Anzahl erfolgt die Schlammstabilisierung in anaeroben beheizten Schlammfaulanlagen.

In mehreren größeren Anlagen erfolgt eine aerobe Schlammstabilisierung.

Der Schlamm der Hauptkläranlage Wien wird in einer Sonderabfallverbrennungsanlage verascht.

In etwa 50 Kläranlagen mit Anschlußgrößen über 10.000 EGW wird die anaerobe Schlammfaulung in beheizten Schlammfaulbehältern angewendet. Der kleinste Faulbehälter steht auf der Kläranlage Wiental mit einem Inhalt von 250 m3. Die größte Schlammfaulanlage ist mit drei Behältern und insgesamt 33.000 m3 Inhalt in der Regionalkläranlage Linz-Asten in Betrieb.

Die Beheizung der Faulräume erfolgt bei den älteren Anlagen durch innen liegende Wärmetauscher, in den neueren Anlagen durchwegs durch außen liegende Wärmetauscher. Die älteren Anlagen sind nach der deutschen Form mit kegelstumpfförmigem Unter- und Oberteil und zylindrischem Mittelstück errichtet. Die Umwälzung erfolgt bei den kleineren Anlagen durch Umpumpen, in Linz-Asten durch Schraubenschaufler und in einigen neueren Anlagen durch Gaseinpressung. Baulich wurden diese Behälter bis etwa 2.000 m3 Inhalt aus schlaff bewehrten Betonkonstruktionen hergestellt, darüber in vorgespanntem Beton, die größeren eiförmig.

Die Tabelle I gibt beispielhaft die Anschlußgröße und den Faulrauminhalt von den wichtigsten Kläranlagen in Österreich wieder.

Tabelle I

Regionalkläranlage Linz	1,000.000 EGW
Großkläranlage Graz	400.000 EGW
Kläranlage des WV. Wiener Neustadt-Süd	230.000 EGW
Kläranlage Innsbruck	230.000 EGW
Kläranlage Welser Heide	200.000 EGW
Kläranlage Klagenfurt	200.000 EGW
Kläranlage Leoben	100.000 EGW
Kläranlage Traunsee-Nord	75.000 EGW
Kläranlage Trattnachtal	65.000 EGW
Kläranlage Knittelfeld	50.000 EGW
Kläranlage Ternitz	32.000 EGW
Kläranlage Stockerau	30.000 EGW

Im Jahre 1967 ging auf der Kläranlage Klagenfurt der erste Faulgasmotor in Betrieb. Durch die Anwendung der Wärme-Kraftkopplung kann das Klärgas optimal ausgenützt und der Energieverbrauch der Anlagen minimiert werden.

Tabelle II

Mit Stand 1980 sind in Österreich folgende Faulgasmotorenanlagen in Betrieb:

	Gesamtleistung
Großkläranlage Graz	1.544 kW
Kläranlage Innsbruck	1.155 kW
Kläranlage Klagenfurt	338 kW
Kläranlage Traunsee-Nord	220 kW
Kläranlage Stockerau	120 kW

In weiteren ca. 15 Anlagen werden Faulgasmotoren installiert, wobei sich die größte Anlage auf der Regionalkläranlage Linz-Mitte mit einem Gesamtanschlußwert von 2.530 kW in Montage befindet.

Bei den bestehenden Anlagen ausnahmslos und bei den geplanten Anlagen mit einer Ausnahme werden die Faulgasmotoren zum direkten Antrieb der Druckluftgebläse für die biologische Reinigung verwendet.

Bei einer Anlage (Traunsee-Nord) ist eine Vorpasteurisierungsanlage installiert, die allerdings nur zeitweise in Betrieb steht.

Der Betrieb der Faulanlagen verläuft im wesentlichen problemlos. Durch industrielle Einwirkungen kam es zu etwa einem Dutzend Störfällen in den letzten 10 Jahren. In sechs größeren Kläranlagen stehen Faulgasmotoren in Betrieb, wobei die installierte Leistung in Stockerau bei 30.000 EGW Anschlußgröße 120 kW und in Graz bei 400.000 EGW rd. 1.500 kW beträgt. Rund 10 Kläranlagen erhalten Gasmotorenanlagen, wobei die installierte Leistung von 60 - 2.500 kW schwankt.

Bei der überwiegenden Zahl dieser Anlagen wird der Schlamm zumindest teilweise natürlich in Schlammtrockenbeeten oder Schlammteichen entwässert. Etwa 20 Anlagen haben Schlammentwässerungsmaschinen, meistens Siebbandpressen, in Betrieb. Die Anlagen verteilen sich auf drei Erzeuger mit 15, 3 und 2 Anlagen in Betrieb.

In jüngster Zeit geht die Bereitschaft von Bauherren und Planern, Schlammentwässerungsanlagen zu installieren, wieder leicht zurück, da bei einigen in Betrieb befindlichen Anlagen die Garantiewerte und die Standzeiten nicht erreicht werden konnten. Derzeit (Beginn 1980) ist eine Kammerfilterpresse ausgeschrieben (Feststoffgarantiewert 40 %).

In der Kläranlage Wien-Blumental (300.000 EGW), der Kläranlage des Abwasserverbandes Wulkatal im Burgenland und in den vier Kläranlagen des Mürzverbandes in der Steiermark wird der Schlamm aerob stabilisiert. Die Belüftung in den Stabilisierungsbecken erfolgt durch Oberflächenbelüfter. Beim Abwasserverband Wulkatal erfolgt die landwirtschaftliche Verwertung des Schlammes durch Ausbringung in flüssigem Zustand. Der Schlamm der Anlagen des Mürzverbandes wird zusammen mit Hausmüll zu Kompost verarbeitet. Der aerob stabilisierte Schlamm der Kläranlage Wien-Blumental wird wieder in den Hauptsammelkanal eingebracht und in Zukunft der Hauptkläranlage Wien zugeleitet.

Die Schlammverbrennung des auf der Hauptkläranlage Wien anfallenden Schlammes wird von der EBS - Entsorgungsbetriebe Simmering GmbH & Co KG, an welcher die Stadt Wien über die Wiener Allgemeine Beteiligungs- und Verwaltungs-GmbH und eine private Gesellschaft zu je rd. 50 % beteiligt ist, durchgeführt.

Der Unternehmensgegenstand der EBS ist vor allem Klärschlammverbrennung und -verwertung zum Zwecke des Umweltschutzes.

Die von der EBS in unmittelbarer Nähe der Hauptkläranlage Wien errichtete Anlage verbrennt auch Sonderabfälle. Der Anfall an Sonderabfall wird in Österreich auf rd. 300.000 bis 350.000 Jahrestonnen geschätzt. Der Jahresanfall an Frischschlamm in der Hauptkläranlage Wien wird auf rd. 1 Mio. Tonnen geschätzt.

Das Gesamtkonzept der Anlage der EBS sieht die Übernahme des Frischschlammes aus der Hauptkläranlage per Druckleitung in zwei Schlammstapler, die Entwässerung in 5 Dekantern, Typ KHD, mit einer Leistung von je 50 m3/h, die weitere Trocknung eines Drittels der entwässerten Schlammenge in 3 Mahltrocknern mit einer Verdampfungsleistung von je 4 to/h und die Verbrennung des wieder gemischten, entwässerten (25 % TS) und getrockneten Schlammes (93 % TS) in zwei Wirbelschichtofenstraßen mit einer Wärmeleistung von je 67,2 GJ/h vor.

Über die Funktionsweise der Anlage der EBS kann noch nichts ausgesagt werden, da diese Anlage erst im Juni 1980 in Betrieb gegangen ist.

Seit 1973 gibt es in Österreich rd. 10 kombinierte Müll-Klärschlammbehandlungsanlagen, in denen Kompost erzeugt werden soll. Es handelt sich dabei um Anlagen verschiedener Hersteller, Ausbaugröße und Qualität des angestrebten Endproduktes. Es konnten keine verifizierbaren Aussagen über die tatsächlich verarbeiteten Klärschlammengen erhalten werden. Bei allen Anlagen soll aber Klärschlamm meist in einwohneräquivalenter Menge zusammen mit Hausmüll verarbeitet werden. Es handelt sich dabei um folgende Anlagen:

Inbetriebnahme	Anlage	Kapazität in EW
1973	Pill in Tirol	120.000
1975	Attnang/Puchheim	180.000
1975	Lustenau	160.000
1976	Traiskirchen	80.000
1976	Ahrental	180.000
1978	Oberpullendorf	60.000
1978	Pöchlarn	70.000
1978	Zell am See	66.000
1978	Siggerwiesen	300.000
1978	Oberes Ennstal	70.000
1979	Allerheiligen (Mürzverband)	120.000

Es bleibt zu hoffen, daß bei all diesen Anlagen die projektierte Klärschlammenge tatsächlich zur Verarbeitung kommt und das Endprodukt zur Bodenverbesserung verwendet werden kann.

Das Rahmenkonzept 1976 des Österreichischen Bundesinstitutes für Gesundheitswesen empfiehlt:

- o Die Beseitigung der Rückstände - Klärschlamm, Rechengut, Sandfanggut - muß unter Beachtung aller hygienischen Erfordernisse erfolgen.
- o Der Verarbeitung des Klärschlammes in der Landwirtschaft ist großes Augenmerk zuzuwenden, wobei ständige Kontrollen über die Zusammensetzung geboten erscheinen.
- o Die gemeinsame Kompostierung von Müll und Klärschlamm soll als zweckmäßiges Verfahren im Rahmen der gegebenen Möglichkeiten angewendet werden.

Der jährliche Anfall an Dünger und Stallmist wurde für Österreich mit etwa 33 Mio. Tonnen errechnet. Ein großer Teil davon wird in der Landwirtschaft verwertet. Beseitigungsprobleme ergeben sich erst, wenn Tiere in Massentierhaltungen aufgezogen werden.

Es erscheinen folgende Maßnahmen notwendig:

- o Bei den Anlagen zur Massentierhaltung sind wirksame Einrichtungen gegen eine Geruchsbelästigung der Umgebung zu treffen.
- o Für einen geeigneten Abtransport und entsprechende Beseitigung der Abfälle ist unter Einhaltung der Erfordernisse des Umweltschutzes Sorge zu tragen.

In der zunehmend industrialisierten Landwirtschaft wird hin und wieder der Humusmangel in den Böden und die fortschreitende Verdichtung festgestellt. Die Folge sind schwerere Bearbeitbarkeit, die Notwendigkeit, Stoppelfelder abzubrennen und progressiv steigender Einsatz von Handelsdünger, um den Ertrag gleich hoch zu halten.

Bei weitgehender Einbringung der Klärschlammengen in unsere Böden könnte dieser negativen Veränderung entgegengewirkt werden. Dabei kann überhaupt nur die bodenverbessernde Eigenschaft des Klärschlammes von Bedeutung sein, da sein Nährstoffgehalt im Vergleich zu den in Österreich verwendeten Handelsdüngermengen verschwindend gering ist. Unter der Annahme, daß der gesamte Klärschlamm landwirtschaftlich verwertet wird, entspricht sein Düngegehalt, bezogen auf Reinnährstoff, nur ca. 2 % des Stickstoffverbrauches und nur ca. 2,5 % des Phosphorverbrauches in Österreich.

A BRIEF REVIEW OF METHODS FOR STABILISING SEWAGE SLUDGES

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Summary

The main purpose of stabilisation is to reduce the offensive odour and putrescibility of raw sludge in order to facilitate its disposal without causing nuisance. There may also be other beneficial effects of stabilisation but these are not usually essential.

Methods of stabilisation may involve either biological treatment, when the effects are permanent, or chemical treatment, when stabilisation is only temporary. There is a wide variety of feasible methods, some of which are widely used, others restricted to certain areas, and others still at an experimental stage. The relative usage of the 4 main methods of stabilisation varies from country to country in Europe but in all cases, mesophilic anaerobic digestion is the most important. Technical aspects of this method are considered and it is concluded that it will continue to be the major method of stabilisation at medium and large works for the foreseeable future. It may well also find greater use at small works.

The status of aerobic digestion, including autothermic thermophilic digestion, is considered and it is concluded that the latter process may prove the more widely applicable in future provided the energy costs are favourable. Composting of sludge is briefly considered and seen to be a process which will remain largely confined to certain countries. The use of lime in various ways for stabilisation is also reviewed.

Finally, a qualitative checklist is provided as a method of comparison of the main features of each of the major stabilisation methods.

INTRODUCTION

The prime purpose of all stabilisation methods is to render raw sludge less malodorous and reduce its putrescibility so that subsequent storage and disposal may be effected without odour nuisance. Some stabilisation processes may, of course, also bring about other significant changes - i.e. a reduction in the mass of sludge solids, reduction in numbers of pathogens, improved flow characteristics, improvement in availability of plant nutrients - but odour reduction is invariably the key objective. Indeed, it is unlikely that any of the processes would be employed for these other purposes if odour control was not required.

The methods which have been devised for stabilising sewage sludge may be broadly divided into:

(a) Biological processes - which usually effect permanent stabilisation, and

(b) Chemical treatments - which are generally only temporary in effect.

A classification listing virtually all the feasible (but not necessarily widely applicable) methods is presented in Table 1 together with an assessment of their current status in Europe. Only a few methods are in use everywhere; others are more or less confined to particular countries or regions, and some are in only very limited use or are still at the research and development stage.

The proportion of raw sludge produced which actually receives stabilisation before disposal varies from country to country in Europe as does the relative usage of the main methods and this is clearly seen in Table 2. In all countries, anaerobic digestion is the process of greatest importance in terms of mass of sludge solids treated. In the extreme case of the UK, anaerobic digestion is used for over 96% of the mass of sludge solids stabilised each year. Of the other methods of stabilisation, it is seen that aerobic digestion is particularly strongly featured in the Netherlands; composting processes are much more popular in the Federal Republic of Germany and Scandanavia than elsewhere. Lime stabilisation is also much more widely used in the Scandanavian countries than in the rest of Europe.

It may be noted that incineration is not included in the list of methods in Table 1. Although it could certainly be regarded as an extreme form of stabilisation, it is more conventional to consider it as a separate form of treatment (or disposal) and it will not be discussed further in this paper. Similarly, the addition of lime to sludge as a

Table 1. Possible methods of stabilisation of sewage sludge and the current status of each method in Europe

<table>
<tr><th>Type of stabilisation</th><th>Process</th><th colspan="3">Method</th><th>Status* of method</th></tr>
<tr><td rowspan="15">Biological</td><td rowspan="5">Anaerobic digestion</td><td colspan="3">Unheated (Lagoon or Tank)</td><td>B</td></tr>
<tr><td rowspan="4">Heated</td><td rowspan="3">Mesophilic ($25-35^{o}C$)</td><td>Single-stage</td><td>A</td></tr>
<tr><td>Two-stage</td><td>C</td></tr>
<tr><td>Two-phase</td><td>D</td></tr>
<tr><td colspan="2">Thermophilic ($45-55^{o}C$)</td><td>C</td></tr>
<tr><td rowspan="3">Aerobic digestion</td><td colspan="3">Unheated</td><td>B</td></tr>
<tr><td rowspan="2">Auto-thermic</td><td colspan="2">Using air</td><td>C</td></tr>
<tr><td colspan="2">Using commercial oxygen</td><td>C</td></tr>
<tr><td rowspan="5">Composting with a bulking agent or recycled material</td><td colspan="3">Windrowing</td><td>B</td></tr>
<tr><td colspan="3">Rotary drum</td><td>B</td></tr>
<tr><td colspan="3">Aerated vessel</td><td>B</td></tr>
<tr><td colspan="3">Aerated pile</td><td>C</td></tr>
<tr><td colspan="3">'Pressed brick'</td><td>C</td></tr>
<tr><td>Composite process</td><td colspan="3">Auto-thermic aerobic digestion + anaerobic digestion</td><td>D</td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="4">Chemical</td><td rowspan="3">Addition of lime to pH >12</td><td colspan="3">Hydrated lime to liquid sludge</td><td>B</td></tr>
<tr><td colspan="3">Quicklime to liquid sludge</td><td>C</td></tr>
<tr><td colspan="3">Quicklime to sludge cake</td><td>C</td></tr>
<tr><td>Addition of oxidising agent or bactericide</td><td colspan="3">Peroxides, organic oxidising agents</td><td>D</td></tr>
</table>

* Status

A = Well established and widely used in most countries

B = Well established but much more common in some countries than in others.

C = In limited use

D = Experimental or under development

Table 2. Approximate proportions of sludge stabilised before disposal in various European countries and relative usages of each stabilisation method

		Netherlands	Finland	FDR Germany	Norway	Sweden	Switzerland	UK
Proportion of all sludge stabilised before disposal (per cent)		65	42	75	25	90	81	60
Per cent use of each method	Anaerobic digestion (mesophilic or cold)	43	20	65†	10†	50	77 (some with pasteurisation)	58
	Aerobic digestion (cold)	21	13	7†	5†	18	2	<1
	Composting (windrow, pile or in-vessel)	*	<1	3 (>30 plants)	4 (5 plants)	7 (>20 plants)	2 (9 plants)	* 1 plant
	Lime stabilisation	*	8 (50 plants)	<1	5 (>30 plants)	15 (64 plants)	*	* (2 plants)

* Very small or none † Assumed percentages

method of conditioning it before dewatering to a cake may effect some degree of stabilisation but it is not principally intended as a stabilisation process.

The objective of this paper is to summarise the current situation in regard to each of the main methods of stabilisation with an indication of possible future developments. The criteria involved in selection of a stabilisation method for a particular scheme are also briefly considered and a check list is presented as a means of rapid qualititative comparison of alternatives.

BIOLOGICAL PROCESSES

Anaerobic Digestion

The general importance of anaerobic digestion in Europe has already been indicated. The process is likely to remain very much favoured as a method of stabilisation at medium and large works and it will become even more attractive wherever the value of digester gas as an energy source can be fully exploited. Use of anaerobic digestion at small, even rural, works may also become much more attractive in the future as a result of the recent developments in pre-fabricated digester design described in another contribution to this symposium[1].

Some 10-20 years ago, the anaerobic digestion process went through a period of unpopularity in a number of European countries. This was largely the consequence of significant numbers of cases of process failure caused by inhibition or through under-, or over-, loading inadequate mixing and heating or poor process control. There is now much fuller appreciation of the causes of inhibition and a better understanding of process requirements. This, together with the development of improved mixing and heating systems, has led to much reduced frequency of digester failure and an improved confidence in the anaerobic process. Energy considerations have also led to an increased interest in the anaerobic digestion process which, uniquely among stabilisation methods, is capable of yielding a surplus of usable energy.

Problems with anaerobic digesters do still occur, of course, particularly in regard to inadequate heating (resulting from inadequate gas yield) during cold weather when supplementary fuel may be required. However, improved design of plant (together with improved insulation techniques) have tended to reduce the occurrence of such difficulties.

By far the commonest form of anaerobic digestion employed in Europe is the heated process operated at 30-35°C (mesophilic digestion). Plants normally comprise a single stage of primary digestion in a closed tank (or tanks) provided with a mixing system (gas recirculation, pumping, or mechanical mixing) and a heating system (internal or external). The primary digestion stage is normally followed by a secondary consolidation stage in an open tank or lagoon. The use of two heated digesters in series ('two-stage' digestion) occurs at a few plants only and it is not thought to have any marked advantage over the conventional 'single-stage' mode of operation.

In all countries, the capacity of the heated stage of digestion is normally based on the provision of a hydraulic retention period of 20-25 days with an operating temperature of 30-35°C. Thermophilic digestion (45-55°C) is very rarely employed in Europe and it is clear that the potential advantages of the process (i.e. increased rate of digestion, greater solids reduction, greater pathogen destruction) are largely outweighed by the disadvantages (greater heat requirements, more delicate process stability, increased strength of sludge liquors, greater odour intensity of digested sludge).

The practice of unheated anaerobic digestion in open tanks or lagoons is confined to small sewage works and is probably more widespread in the UK than in other countries. It may be a very economical form of sludge stabilisation if earth-banked lagoons are employed but the reliability of the method, particularly during the winter, is often unsatisfactory and odour nuisance may occur. Methods of converting cold digesters to heated digesters at low cost are being developed in the UK[(2)].

Throughout Europe, the normal material of construction of digesters is reinforced concrete but steel has been used for some large plants[(3)], and it may well become more commonly used in the future for pre-fabricated digesters for small works[(1)]. There is an interesting difference between some countries in regard to the conventional configuration of primary digesters. In FDR Germany and in Scandanavia, the configuration is commonly ovoid with a high aspect ratio. This shape is considered to facilitate mixing and reduce grit deposition and scum formation. In the UK, by contrast, it is traditional to construct primary digesters as simple cylindrical tanks with relatively flat floors and usually with a rather low aspect ratio (height:diameter <1). Construction costs are undoubtedly much lower for the cylindrical-tank flat-flow configuration but the greater difficulty in achieving adequate mixing offsets this advantage to some extent.

Despite the differences in design of digester, grit deposition and accumulation is clearly a problem common to all countries. It reduces effective volume and necessitates periodic shut-down of the digester for grit removal. Some digesters are provided with scrapers which may be effective in preventing grit deposition. Imhoff[3] refers to a novel method of continuous grit removal which has been developed recently in FDR Germany. It is clear that improvement in mixing and grit removal is one potentially fruitful area for further research.

Future trends in the development of the anaerobic digestion process are likely to be:[4]

(i) A general reduction in design hydraulic retention periods to closer to 15 days than to 25 days with consequent reduction in capital cost of digesters. This would be accompanied by the development of more effective and efficient mixing systems to minimise grit deposition and facilitate process control.

(ii) Development of more efficient forms of heating system to conserve gas and improve the reliability of winter operation.

(iii) Increased use of pre-thickening to produce a high-solids feed sludge (5-7% dry matter) and thereby reduce heat requirements and digester volume requirements.

(iv) Development of more efficient and more economical gas-driven engines for generation of power from digester gas.

The future of more radical process developments such as 'two-phase' digestion[5] in which the acid-generating phase of the digestion process is separated from the methane-generating phase by operating two digesters in series, each with an 'optimum' retention period related to the microbial growth rate, is much less certain. It seems probable that it will remain in the experimental stage for the foreseeable future in Europe.

Aerobic Digestion

Two distinct methods of aerobic sludge digestion are now recognised:

(a) Ambient (cold) aerobic digestion

(b) Autothermic (thermophilic) aerobic digestion.

Both methods depend on aerobic microbial oxidation of degradable sludge solids.

Ambient aerobic digestion

The conventional aerobic digestion process operating at ambient temperatures involves aeration of sludge for 15-50 days to produce a stabilised end-product with about 40-50% reduction in organic and volatile solids. The process may be operated as an integral part of an extended-aeration activated-sludge plant or oxidation ditch (this accounts for its extensive use in the Netherlands), or as a separate system comprising a simple open tank or tanks with a suitable aeration/mixing system. Primary, secondary and mixed sludges may be stabilised by the process, using continuous or batch feeding and removal.

The 'cold' aerobic digestion process is simple and reliable in operation and is not susceptible to failure by inhibition. The degree of digestion achieved may, however, drop considerably under low-temperature conditions. Capital costs are low but operating costs - largely relating to power consumption for aeration and mixing - are very high in comparison with those for anaerobic treatment.

Aerobic digestion at ambient temperatures was introduced at a time when the anaerobic digestion process was in disfavour and energy costs in real terms were much lower than they are today. The picture has now changed considerably, and conventional cold aerobic digestion is no longer a serious contender as a stabilisation process for any but small works.

Autothermic thermophilic aerobic digestion

This form of stabilisation has been developed over the past 6-8 years[6]. It utilises the metabolic heat produced by microbial aerobic oxidation of organic matter in sludge to raise the temperature of the sludge to above 45^{o}C, and as high as 65^{o}C. It is basically therefore a "wet composting" process. As a result of the high temperature of operation, the rate of digestion is rapid and retention periods of only 3-5 days may be sufficient for full stabilisation of the sludge. This implies much smaller plant capacity requirements than for ambient aerobic digestion and thus lower capital costs. The high operating temperature also effects a high degree of pathogen removal. A further advantage is that the operating temperature will be more or less independent of ambient temperatures and the process will function without external heat even in very cold conditions.

The success of the autothermic thermophilic process is crucially dependent on (a) a sludge feed with a sufficiently high concentration of oxidisable organic matter to generate the heat requirements (for primary sludge, a solids content of 1.5-2% is required) and (b) providing adequate insulation and minimising as far as possible the loss of heat in exit gases from the digestion tank.

Two systems of operation have been developed,

(a) Oxygenation using commercial oxygen

This method has the clear advantage of minimal gas throughput and heat loss but it has the disadvantage of the high cost of providing commercial oxygen.

(b) Oxygenation using an aeration device

It has been clearly demonstrated[7] that it is possible to operate the process at high temperatures using an aeration system, but the efficiency of oxygen transfer must be at least 15% to reduce heat losses below the critical level for a heat balance. It is usual to employ the aspirating type of aerator for such purposes.

The prospects for autothermic thermophilic aerobic digestion look quite promising particularly for the types employing aeration devices other than commercial oxygen. Several full-scale plants are understood to be in operation in the Federal Republic of Germany, and at least one in the Netherlands and there is a good deal of experimental work proceeding in other countries. However, much more information is required about the actual energy requirements and other operating costs of thermophilic aerobic digestion processes, before a full economic evaluation can be made. A first assessment of the costs of the process using commercial oxygen has indicated that, in the UK at least, they would not be competitive with those for anaerobic digestion, assuming oxygen had to be bought in liquid form.

Composite Aerobic/Anaerobic Digestion

It has been claimed[8] that stabilisation of sludge by a combination of aerobic thermophilic digestion and anaerobic digestion has economic advantages over other systems of stabilisation. The system proposed involves partial destruction of sludge solids by autothermic thermophilic digestion, using oxygen, and the feeding of the hot partially-digested sludge to a second stage of anaerobic digestion. This process is being examined on an experimental scale in various countries, though its future application to full-scale operation seems very uncertain.

COMPOSTING

The composting of sludge in combination with domestic refuse or a bulking agent such as bark, sawdust, straw, wood chips or dry recycled compost is fairly well established as a stabilisation process, but its use is largely confined to certain countries. The Federal Republic of Germany is the centre of activity and development, with at least 30 plants for composting sewage sludge alone and 12 or more plants for composting sludge with domestic refuse(9). The mass of sludge solids composted, however, amounts to only a few per cent of the total mass of sludge stabilised in the country, since composting is employed mainly at smaller works (10-25,000 population equivalent). Scandanavia is another area where sludge composting is important and it is employed at some large works; there are some 20 plants in Sweden. Switzerland has about 9 composting plants.

The reason for the differing popularity of sludge composting among different countries is not clear but may relate to a varying demand for compost for agricultural use. In the UK, for example, where there is only one composting plant (processing sewage sludge + domestic refuse), it is broadly recognised that farmers, in general, prefer liquid sludge or sludge cake to compost. It is possible that the same situation applies in other countries and, if so, it would mean that any significant expansion in the use of composting for sludge stabilisation is unlikely.

The basic process requirements for composting of sludge are well established and described in the literature. A major potential advantage of the process is the fact that it is exothermic, and temperatures of up to 75°C may be obtained within the composting material. These conditions should effect complete destruction of pathogens. However there is evidence(9) that, in practice, composting is not a fully reliable means of disinfection and that much depends on operating conditions. A certain disadvantage of composting is that there is a significant loss of nitrogen during the process and this may reduce its fertilizer value compared with, say, liquid digested sludge.

The various methods for composting of sludge may be divided into the following broad categories.

A. Unconfined

(1) Windrow

(2) Aerated static pile

B. Confined

(1) Within vessel - open or closed tank

(2) Rotating drum

C. Pressed Brick

D. Fermentation cell

The unconfined systems, particularly windrows, tend to be low in capital cost and relatively high in operating cost while the confined systems are higher in capital cost. Must of the recently constructed composting plants in the Federal Republic of Germany are of the within-vessel type, in particular the open tank/BAV system. These have the advantage that the operating conditions are highly controllable.

CHEMICAL STABILISATION

Chemical treatment of sludge effects only temporary stabilisation but this is quite satisfactory provided disposal can be achieved before the sludge reverts to the putrescent condition. The general advantages of chemical stabilisation are simplicity of operation, reliability, and low capital cost. The only chemical of practical importance at present is lime (hydrated lime or quicklime) but there is a possibility that other chemicals - particularly oxidising agents - will find greater use for sludge stabilisation in the future.

Lime stabilisation of liquid sludge

Lime has been used for centuries to reduce the odour and offensiveness of putrescent substances but its use for sludge stabilisation is fairly recent. It is a particularly popular process in Norway where there are at least 20 plants and where a good deal of research and development on the process has been done[10]. The process essentially requires the addition of sufficient lime (usually hydrated lime) to liquid sludge to raise the pH value initially to above 12.0 and to maintain the pH value above 11.0 for a minimum period of time - usually 14-20 days. The raising of the pH to above 12.0 suppresses the malodour of sludge and also destroys pathogenic bacteria. The effect on the eggs of parasitic worms is less certain.

Raising the pH value of raw sludge to above 12.0 promotes the release of ammonia from the sludge, but this does not normally give rise to problems except perhaps in confined spaces. Some loss of nitrogen may occur in this way and reduce the fertilising value of the sludge. The dose of lime required to raise the pH value of raw primary sludge to above 12.0 and to maintain the pH above 11.0 for 14 days is usually in the range 150-200 g $Ca(OH)_2$ per kg dry sludge solids and the mass of solids to be disposed of therefore increases proportionately. In some cases quicklime rather than hydrated lime is used.

The equipment required for lime stabilisation comprises essentially a lime storage silo, a lime feed system, and a sludge/lime mixing vessel and storage tank. At some works, existing equipment installed for dosing lime to sludge for conditioning it before dewatering has been used, with an obvious saving in capital costs.

Despite its simplicity, the process of lime stabilisation still requires good supervision. Eikum[11] has described the operational problems experienced at a number of Norwegian works in the early days of the process. In some cases these were so severe that the lime-stabilisation process was stopped altogether.

Lime stabilisation of sludge cake

The addition of quicklime to dewatered sludge cake is practised at some works in Sweden and experience of this method in the Federal Republic of Germany is described in another contribution to this symposium[12]. The heat of reaction produced by the slaking of the quicklime within the sludge mass can be sufficient to raise the temperature to 60-70°C with consequent pathogen destruction. The hydration of the lime also effects partial further dewatering.

Other Chemicals

The use of chemicals other than lime for stabilising sludge is virtually unknown in Europe though for example, stabilisation by chlorination is practised to a limited extent in the USA. However, there is a great deal of research activity at present into the possibilities of using oxidising agents, including organic oxidising agents, and bactericidal agents, to achieve temporary stabilisation.

Table 3 - Qualitative comparisons of various methods of sludge stabilization

✓ = yes x = no

	ANAEROBIC DIGESTION			AEROBIC DIGESTION			COMPOSTING		LIME STABILISATION (pH >12)
	Cold (lagoon)	Heated		Cold	Thermophilic		Windrow or static pile	In-vessel	
		Meso-philic	Thermo-philic		Air	Oxygen			
Major component of cost of process									
Capital cost		✓	✓					✓	
Operating cost	✓			✓	✓	✓	✓		✓
Suitable for									
small works (<5000)	✓	?	x	✓	✓	✓	✓	x	✓
Large works (>100,000)	x	✓	?	x	?	?	x	✓	x
Suitable for									
Warm climate	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cold climate	x	✓	?	✓	✓	✓	✓	✓	✓
Effectiveness for removal of pathogens									
Pathogenic bacteria	variable	variable	good	poor	good	good	variable	variable	good
Worm eggs	poor	good	good	poor	good	good	variable	variable	poor
Preliminary treatment of sludge required	None (Thickening desirable)			None			Dewatering to cake		None
Effect on dewaterability of sludge	No improvement			No improvement			-		Improvement
Decrease in mass of sludge solids	✓			✓			x	x	x (increase)
Possible operational problems									
Inhibition	✓	✓	✓	x	x	x	x	x	x
Maintenance of temperature	✓	✓	✓	x	✓	✓	✓	✓	x
Odour nuisance	✓	x	x	x	?	?	✓		x
Mechanical		✓	✓	x	x	x		✓	✓
Stabilisation — permanent	✓	✓	✓	✓	✓	✓	✓	✓	
Stabilisation — temporary									x
Energy requirements	low	usually none (energy yield possible)		high	high	high	medium	high	low

PROCESS SELECTION

In selecting a method of sludge stabilisation for a particular works the designer may wish to use a large number of criteria on which to base a decision. Costs (both capital and operating) will obviously be a major consideration but there will also be various secondary criteria which may be used such as the suitability of method for the size of works, effects of climate, effectiveness of process for removal of pathogens, the preliminary degree of treatment of sludge required, effect on dewaterability of sludge, effect on mass of sludge solids, possible operational problems, permanence of stabilisation, and energy requirements. The relative importance of these secondary criteria will vary from site to site. It is obvious that a quantitative assessment will be required in each case but the qualitative comparisons given in Table 3 may serve as a preliminary checklist. It is emphasised that the assessments made are qualitative and very general and would require much more quantification in actual situations.

In regard to costs estimates it will be necessary to assess the cost of each stabilisation method in the context of the cost of whole sludge treatment and disposal "route" and comparisons can only safely be made on this basis. Estimates of the total costs of sludge treatment and disposal routes involving different methods of stabilisation and to be found in the contribution by Colin[12] to this symposium and in an earlier report relating to the situation in the UK.[13] It would be unwise to apply the costs data in these reports to other countries without extreme caution but they do give a useful general guide to the relative costs of different stabilisation methods and how these relative costs are influenced by the size of the treatment works involved.

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BEHANDLUNG VON KLAERSCHLAMM MIT BRANNTKALK

-VORAUSSETZUNGEN UND ABSATZMOEGLICHKEITEN-

A. THORMANN

Summary

Utilization of sewage sludge on land causes many difficulties particularly for large sewage treatment plants. Very often there is not enough arable land available near by the plants. Costs for tansportation of liquid sewage sludge can be prohibitive for longer distances.

An additional treatment process e.g. using caustic lime can produce a soil conditioner or fertilizer which has excellent properties for tansportation, handling and agricultural use. With regard to effects and handling this material is often better than now used kinds of lime.

A market for this material requires a garanteed quality comparable to other used types of lime. This requirement is being meet a good price can be garanteed taking into consideration the cost of landfill disposal, incineration or dumping at sea. Apart from good quality, trade organisation and technical assistance to the users are of prime importance In the Federal Republic of Germany are 14 plants working, using the method of lime stabilization. Most of them do not yet meet the above mentioned conditions.

A new model plant will be planned in a large German city which will produce a lime fertilizer which will fullfill all the requirements for agricultural use. Trade organizations already show high interest for this new fertilizer as they expect better handling conditions and lower costs for this new material.

Zusammenfassung

In grösseren Kläranlagen bereitet die Verwertung der Klärschlämme in flüssiger Form wegen der oft fehlenden Flächen im Umland der Kläranlage oftmals Schwierigkeiten. Bei weiteren Entfernungen werden die Transportkosten zu hoch.

Durch weitergehende Aufbereitung der Klärschlämme z.B. mit Branntkalk lassen sich lager- und transportwürdige Bodenverbesserungs- und Düngemittel herstellen, die bei richtiger Marktpflege und Anwendung mit vorhandenen Kalksorten vergleichbar sind. Bei garantierten Inhaltsstoffen lassen sich für diese Produkte auch entsprechende Preise erzielen, so dass die Verfahren im Vergleich mit Beseitigungsverfahren nicht teuer sein müssen.

In der Bundesrepublik werden zur Zeit 14 Anlagen zur Kalkstabilisierung von Klärschlamm betrieben. Die erzeugten Produkte entsprechen jedoch nicht voll diesen Ansprüchen und werden vielfach auf Deponien abgelagert.

Für eine Grosstadt in der Bundesrepublik wird derzeit eine Behandlungsan lage und eine Vertriebsorganisation geplant, die für dieses Verfahren Modellcharakter hat. Nach erster Beurteilung durch landwirtschaftliche Fachorganisationen hat dieser Kalk-Klärschlamm-Dünger gegenüber eingeführten Kalkdüngern arbeitstechnische und wirtschaftliche Vorteile.

1.) Einleitung

Die Verwertung von Klärschlamm ist in allen Teilnehmerstaaten an der Cop-Cost-68 ^{bis}-Aktion ein erklärtes Ziel der Arbeiten. Aus den bisher vorliegenden Erhebungen über die Verwertungsanteile am derzeit anfallenden Klärschlamm ist im Cadarache berichtet worden (Thormann, 1979). Dort wurde auch gezeigt, daß im allgemeinen Flächen für eine Verwertung zur Verfügung stehen. Bei Aufwandmengen von durchschnittlich 2,5 Tonnen Klärschlamm-Trockenmasse pro Jahr wären etwa 3,5 Prozent der landwirtschaftlichen Nutzfläche zur Verwertung des Klärschlammes notwendig.

Die erforderlichen Flächen stehen jedoch in Ballungszentren mit hohem Klärschlammanfall und wenig landwirtschaftlicher Nutzfläche oft nicht zur Verfügung.

Damit auch Klärschlämme aus dicht besiedelten Gebieten verwertet werden können, sind größere Anstrengungen und mehr technischer Aufwand erforderlich, um aus dem Klärschlamm handels- und transportwürdige Bodenverbesserungs- oder Düngemittel herzustellen. Damit diese Voraussetzungen geschaffen werden können, sind eine Reihe von Vorbedingungen zu erfüllen (Thormann, 1980):

a) Der Absatz von der Kläranlage muß ganzjährig gewährt werden. Es sind dafür Lagerkapazitäten zu schaffen.

b) Das Negativimage des Klärschlammes muß für den Anwender abgebaut werden. Es müssen ähnlich dem Mineraldünger Normen erstellt werden.

c) Eine Kontrolle muß die Einhaltung von Grenzwerten für Schadstoffe und bestimmte Nährstoffe garantieren.

d) Sowohl beim Kläranlagenbetreiber als auch beim Anwender muß durch Aufklärung und Beratung mehr Kenntnis und Verständnis für die gegenseitigen Belange geweckt werden.

Durch weitergehende technische Aufbereitung lassen sich viele dieser Vorbedingungen erfüllen. Dazu wird in der Regel eine Vorentwässerung der Schlämme nötig und es sind meist Geräte für eine Mischung und Trockung o.ä. erforderlich. In vielen Fällen werden auch Zukaufstoffe wie Kalk, Sägemehl, und Torf zur Verbesserung eingesetzt. Geräte und Verfahren sind hierfür bekannt.

2.) Verfahren der Kalkstabilisierung

Vorentwässerte Klärschlämme lassen sich durch Zumischung von Branntkalk (CaO) stabilisieren.
Dieser Prozeß beruht auf der exothermen Reaktion
(1) $CaO + H_2O \rightarrow Ca(OH)_2 + 1.152$ MJ/kg CaO
Dabei bindet 1 kg CaO 0,32 kg Wasser zu Löschkalk und zusätzlich verdampfen etwa 0,44 kg Wasser.
Der Trockenmassegehalt des Schlammes wird damit durch die Kalkzugabe selbst,durch die Wasserbindung und die Wasserverdampfung erhöht (Henze/1980).

Dieser Prozeß läßt sich berechnen, um z.B. bei einem bestimmten vorentwässerten Klärschlamm einen anzustrebenden Endtrockenmasse-Gehalt zu erreichen (Meyer und Ziess/1977)

$$(2) \qquad X = \frac{1000\,(Ts_2 - Ts_1)}{0{,}32\,CaO_{lf} + 100 - Ts_2}$$

Dabei bedeuten

X = kg Kalkzugabe zum Klärschlamm

Ts_2 = gewünschter Trockenmassegehalt (%) im Endprodukt
Ts_1 = Trockenmassegehalt (%) im vorentwässerten Klärschlamm
CaO_{lf} = löschfähiger CaO-Anteil (%) im Branntkalk

Die starke Anhebung des pH-Wertes führt zusammen mit der Wärmereaktion bei den entsprechenden Kalkmengen zu einer sicheren Entseuchung (Strauch u.a./1978) und zugleich zu einer deutlichen Reduzierung der Geruchsentwicklung. Bei dem Reaktionsprozeß tritt aufgrund der hohen pH-Werte der größte Teil des NH_4 als Ammoniak (NH_3) aus und verursacht eine Geruchsbelastung in der Nähe der Anlage.

Für die Herstellung von Klärschlamm-Kalk-Gemischen bieten sich verschiedene Geräte und Verfahren an, wie zum Beispiel Doppelwellenmischer, Paddelmischer, Pflugscharmischer, Granulatoren und ähnliches, mit denen je nach Ausgangswassergehalt des Schlammes, Kalkzugabe und Mischgerät krümlig, brockige bis gut gekörnte, granulierte Bodenverbesserungs- und Düngemittel hergestellt werden können (Henze/1980).
Dieses Material - gut aufbereitet - hat sowohl in Farbe, Geruch und Materialeigenschaften nichts mehr mit dem Ausgangsprodukt "Klärschlamm" gemeinsam.

Ein granuliertes "Kalk-Klärschlamm-Gemisch" mit definierten Gehalten an wert-bzw. typbestimmenden Bestandteilen von z.B. 30 % CaO in der Originalsubstanz könnte als Düngemittel in die Typenliste der Düngemittelverordnung in der Bundesrepublik aufgenommen werden.

Dieser Düngemitteltyp bietet für den Einsatz in der Landwirtschaft eine Reihe von Vorteilen, da neben dem Kalk sowohl der Phosphorgehalt als auch z.B. für die Forstdüngung der geringe Stickstoffgehalt vorteilhaft ist. Die Kalkwirkung dieses Materials entspricht der von nicht gebrannten Düngekalken, die Ertragswirkung ist zum Teil - nach ersten Versuchen - sogar etwas günstiger.

3.) Marktvoraussetzungen

Beim Einsatz des Verfahrens sind für das Klärwerk einzuhalten:

- ganzjährige, uneingeschränkte Abnahmegarantie
- zumutbare Verfahrenskosten
- sichere Verfügbarkeit des Verfahrens

Für den Abnehmer/Anwender:

- garantierte, gleichbleibende Produktqualität
- garantierte Gehalte (Minimum- oder Maximumwerte an wertbestimmenden oder bedenklichen Bestandteilen)
- Lager- und Transportfähigkeit des Produktes
- seuchenhygienische Unbedenklichkeit
- vorteilhafte Anwendbarkeit
- marktgerechter Preis
- ansprechendes Material-und Verpackungsbild

Der Vertrieb des Düngemittels sollte durch eine bereits bestehende Vertriebsorganisation erfolgen, die im landwirtschaftlichen Handel eingeführt ist und Erfahrung auf diesem Gebiet besitzt und damit

- das Produkt-Image unterstützt
- gezielte Produktpflege betreiben kann
- ausreichende Lagermöglichkeiten vorhalten kann
- das Produkt möglichst schnell auf dem Markt einführt
- über ausreichende Werbe- und Beratungsfachleute verfügt.

Die Absatzchancen für ein solches Produkt werden von den meisten landwirtschaftlichen Organisationen, die bisher diese Verfahren beurteilt haben, als gut eingestuft. Ausreichend leistungsfähige Landhandels-Organisationen haben am Vertrieb solcher Produkte ihr Interesse angemeldet. Die Absatzchancen sind von Henze (1980) beschrieben worden.

4.) Kosten

Auf den ersten Blick erscheinen die Aufbereitungsverfahren teurer als die heute gebräuchlichen Beseitigungsverfahren wie Deponie oder Veraschung (Verbrennung). Betrachtet man jedoch die zu realisierenden Verkaufserlöse einerseits und die verschärften Bedingungen für Beseitungsverfahren andererseits, so sind zum Teil die Vorteile auf Seiten der Verwertungsverfahren (Tabelle 1).

Bisher arbeiten in der Bundesrepublik etwa 14 Anlagen zur Kalkstabilisierung, für die Kassner (1980) die Kosten ermittelt hat. Für 100.000 E+EGW werden ca. 130.000,-- DM an Investitionen und 550.000,00 DM an Betriebskosten entsprechend ca. 10,-- DM je m^3 Klärschlamm mit 5 % Trockenmasse (TM) angesetzt. Nach Böhnke und Weiling (1980) würden für eine Aufbereitung zu einem Düngemittel mit ca. 30 - 35 % CaO etwa 10 bis 11,-- DM für einen Schlamm mit 5 % TM erforderlich. Die Kosten der Vorentwässerung sind dabei nicht berücksichtigt. Im Vergleich mit einer Entwässerung auf 35 % TM durch eine Kammerfilterpresse und anschließender Deponie liegen die Kosten nur um ca. 3,00 DM pro m^3 Naßschlamm höher. Sofern für das aufbereitete "Düngemittel" ca. 11,00 DM pro Tonne gezahlt werden, ist nach dieser Rechnung bereits ein Kostenvorteil gegeben.

Sofern Abfallwärme für eine Trocknung dieses - bereits lager- und streufähigen - Materials von ca. 65 % zur

Behandlungsform/ Schlammart	Kosten/DM pro Tonne TM ab Faulturm*	Volumen-reduzierung	Lager-fähigkeit	Transport-fähigkeit	Hygiene-ansprüche	Energie-bedarf	Verteilung/ Handhabung
Flüssig-schlamm ohne } Pateu-risierung mit	ca. 100 - 200 ca. 160 - 320	gering	schlecht	schlecht	schlecht gut	gering mittel	mittel
Kompos-tierung ohne } Verkaufs-erlös mit	ca. 240 - 700 ca. 190 - 650	mittel	mittel	mittel	gut	mittel	gut
Kalkbe-handlung ohne } Verkaufs-erlös mit	ca. 28o - 7oo ca. 200 - 620	mittel	gut	mittel	gut	mittel	gut
Trocknung ohne } Verkaufs-erlös mit	ca. 380 - 8oo ca. 300 - 7oo	hoch	gut	gut	gut	hoch	gut
Mischung mit Torf	ca. 260 - 750	mittel	mittel	mittel	mittel	mittel	gut
nur Ent-wässerung ohne } Ablage-rung mit (Kammerfilterp.)	ca. 12o - 450 ca. 250 - 580	mittel	mittel	mittel	mittel	mittel	mittel/ schlecht
Veraschung ohne } Ablage-rung mit	ca. 400 - 1000 ca. 440 - 1050	hoch	gut	gut	gut	hoch	----

* ab Faulturm bzw. gleichwertiger Vorbehandlung

Tabelle 1 : Bewertungskriterien für Klärschlammbehandlungs- und Aufbereitungsverfahren

Verfügung steht und auf ca. 88 - 90 % TM getrocknet werden kann, werden Preise von ca. 40,00 DM pro Tonne ab Kläranlage erwartet.

Erste Planungen zur Realisierung eines solchen Konzeptes werden zur Zeit in einer Großstadt des Bundesgebietes durchgeführt.

Sofern ein Markt nicht gegeben ist, kann nach Berechnungen von Böhnke und Weiling (1980) bei Reduzierung der Kalkmenge ein gut deponierfähiges Material hergestellt werden, das unter den Kosten der Entwässerung durch Kammerfilterpressen liegt.

5.) Beurteilung

Der auf einer Kläranlage anfallende Schlamm muß in jedem Fall schadlos beseitigt werden. Die Kosten für eine Beseitigung müssen einem Verwertungsverfahren gutgeschrieben werden. Sofern eine Aufbereitung als Dünge- und Bodenverbesserungsmittel mit garantierten bzw. definierten Gehalten angeboten wird, dürfte die Landwirtschaft auch bereit sein, eine solche Anwendungsquelle zu nutzen.

Etwa 40 % der Böden des Bundesgebietes sind kalkbedürftig. Die Anwendung von granuliertem Kalk- Klärschlamm - Dünger hat gegenüber der Anwendung von feingemahlenem Branntkalk eine Reihe von Arbeits- und Lagervorteilen. Kalk-Klärschlamm-Dünger staubt nicht, läßt sich als riesel- und schüttfähiges Material auch im Freien lagern und enthält neben Phosphor noch Stickstoff und zum Teil Spurennährstoffe - leider oft auch weitere Schadelemente.

Durch eine Verringerung der Aufbringungsmengen auf die für eine Kalkung benötigte Menge von ca. 6 dt pro ha und Jahr wird die Klärschlamm-Menge auf ca. 3 dt pro ha und Jahr reduziert und damit eine zu hohe Belastung der Böden mit Schadelementen weitgehend vermieden.

Henze (1980) schätzt, daß etwa 80.000 t Trockenmasse Klärschlamm über ein solches Düngemittel abzusetzen wären. Optimistische Schätzungen gehen von der doppelten bis mehrfachen Menge aus.

Es ist anzunehmen, daß durch die höheren Anforderungen an die Beseitigungsverfahren und durch den knapper werdenden Deponierraum Verfahren der beschriebenen Art erheblich zunehmen und bei Einschaltung des Landhandels die erzeugten Produkte auch absetzbar sind.

Vor allem lassen sich die Energieaufwendungen für dieses Material durch die exotherme Reaktion des sonst direkt ausgestreuten Branntkalkes in diesem Material gegenüber anderen Verfahren reduzieren.

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PREFABRICATED SYSTEMS FOR LOW-COST ANAEROBIC DIGESTION

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SUMMARY

This paper outlines the development of a low-cost anaerobic digestion plant which accrues the cost benefits of standardised components within a prefabricated structure. The examination of process and cost sensitivities has resulted in a revised plant design using non-conventional (within the U.K. Water Industry) materials and construction techniques. The development of such plants allow digestion provision for much smaller plants than previously considered, thereby reducing overall sludge tankering requirements.

The plant described shows two particular advantages over its conventional counterpart namely cost: at £6/person compared with £40/person and rapid construction: with erection and commissioning within 18 working days.

INTRODUCTION

The term 'prefabricated' as used by the authors of this paper refers to the accepted use of the term, namely; "Manufacture sections (of building, etc.) prior to assembly on site - produce in a standardised way".

The most important connection between the above definition and the term low-cost lies with the word 'standardised'. Whilst a plant item such as the conventional floating roof gas holder may be prefabricated off site, standardisation of panels etc. is not usually found and certainly not reflected in price.

Examination of many aspects of the process engineering of anaerobic sludge digestion continues [1,2,3,4] within the Severn Trent Water Authority and this short paper highlights some aspects of one study topic. The approach adopted throughout the studies has been the application of sensitivity analysis to both the processing and cost aspects. Early work was centred upon optimising operation of existing plant resources in an attempt to meet a shortfall of sludge treatment capacity in the light of the twin constraints of a very short time scale and shortage of capital for the conventional solution.

A critical survey of existing plants highlighted the "sensitivity" of process operation with respect to mixing and heating inadequacies of these plants. Further examinations have indicated other interlinked contributing parameters e.g. sludge feeding regime, reactor aspect ratio, etc. In the definition of an "order of sensitivities" then this is equivalent to a priority listing of process rate determining stages. Correction of mixing and heating inadequacies has afforded an extremely low-cost provision of additional digestion provision, as well as redefining the major design parameters for further 'new' plants.

The fundamental process design parameter of detention time has been reduced to approximately 15 days: (approaching half that previously adopted) all of which has a profound effect on the distribution of plant Capital Costs. Historically [1] some 70% of the plant costs were consumed within the civil structures, allowing 30% for provision of all processing equipment. In recent years this balance has been moving towards a larger share being allocated to processing equipment. However, a close analysis of current major cost items, when compared with a number of less conventional options, underlines a number of areas for "structural" cost savings. These include reactor vessel, housings for process equipment and gas holder provision.

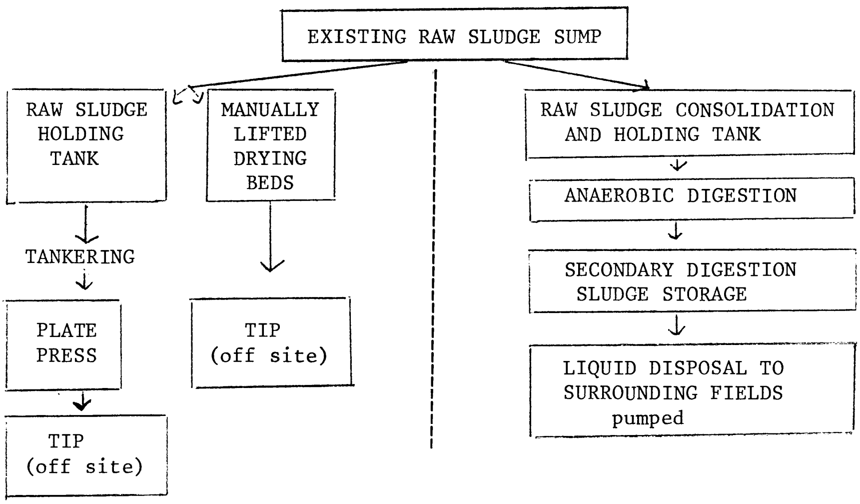
By way of illustration of the process and cost sensitivities, we will outline a recent collaborative exercise with Farm Gas Limited for the design and acquisition of a prefabricated package digestion plant. The plant was funded as a Research and Development evaluation plant to gain operating information for a standardised larger plant based on approximately 10,000 - 15,000 persons.

PITTS MILL WRW, GLOUCESTERSHIRE, LOWER SEVERN DIVISION, S.T.W.A.

This is a rural works currently serving a population of some 2,600 persons. The works flow is delivered via a number of pumping stations. The original sludge flow sheet allowed for raw sludge storage and/or use of manual drying beds. Prior to erection of the digestion plant, the works raw sludge (mixed primary/humus) was tankered to a filter press plant on a neighbouring works, a round trip of some 14 miles. This cake was then disposed of to tip. See Fig. 1.

The completed digestion plant allows for the following revised sludge flow sheet see Fig.2. Raw sludge to consolidation/storage tank on to Digester and then to the Secondary digester (previously the raw sludge storage tank) via a sump. The thickened liquid digested sludge is then disposed of 'over the fence' to the surrounding field which can receive all of the works sludge and remain within the U.K. guidelines for sludge disposal. Prior to this stabilisation (and inherent solids disposal) route, the sludge was not acceptable to the farmer.

Fig.1 Fig.2



The digestion plant has been erected on two of the existing twenty drying beds. The foundation requirement for the main reactor itself (a one foot square ring beam of reinforced concrete) was excavated through the existing concrete membrane. On inspection, this existing membrane would have been adequate for immediate erection of the reactor tank.

The package plant comprises two glass coated steel sectional tanks, a roofed reactor tank of $80m^3$ and a consolidation/sludge storage tank of $10m^3$, with a gas holder of $5m^3$ and a digested sludge sump of $5m^3$, each in glass fibre reinforced plastic, together with all associated process equipment. This process equipment has 100% standby of feed pump, gas compressor (for mixing), submersible digested sludge sump discharge pump, hot water circulating pump, with all process controls mounted within a single electrical panel. Details of the individual plant items are given below.

REACTOR/DIGESTER

The main digester is an $80m^3$ steel (glass coated) tank of 4.3m diameter and 6.5m height. The steel panels are bolted together and use a mastic sealant, see Fig.3. The tank base is of sloped concrete, insulated with block polyurethane and complete with a 150mm bottom drain gate valve. Also included are two full access hatches. Wall and roof ladders complete with safety rails, together with 4 off 100mm ports (for future developments) were also included.

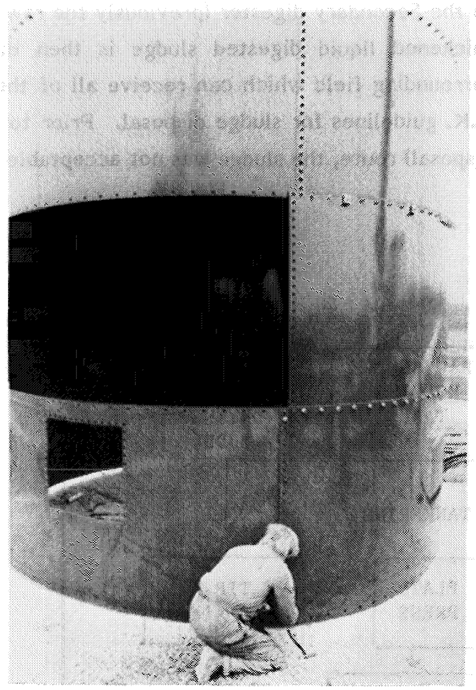


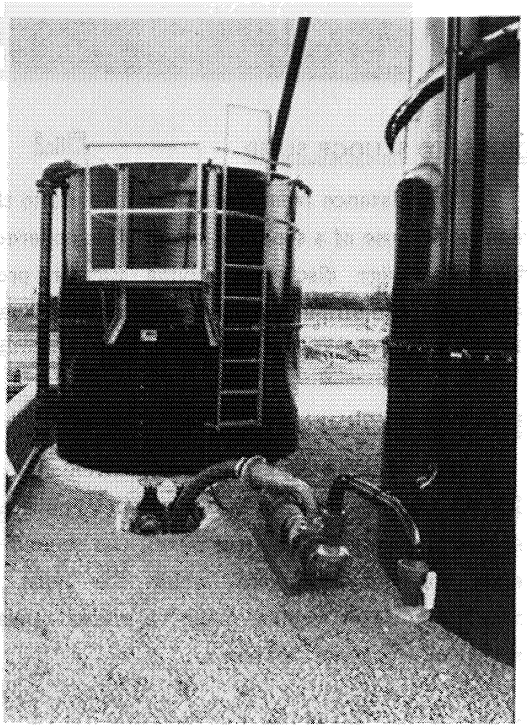
Fig.3

Great care was taken in providing low-cost anti-blockage sludge inlet and outlet arrangements. Outlet is provided to a sump by positive displacement and the roof fitments include a mechanical excess pressure relief valve, a solenoid operated gas release, together with inspection and lighting panels and splash trap serving the roof gas take off point.

One obvious drawback of a thin walled steel tank is its relatively high thermal conductivity compared with its conventional concrete counterpart. This drawback is remedied and, indeed, improved by an internal lagging of the digester using 100mm thick sprayed polyurethane on the walls and 50mm depth on the roof underside. Mechanical protection of the insulation is also provided.

The lagging integrity and performance has been established by Infra Red photographic and radiometric techniques. Current performance indicates a standing heat loss of approximately 50% of that norm found at plants within Severn Trent Water Authority.

SLUDGE HOLDING/CONSOLIDATION TANK



This glass coated sectional steel tank of $10m^3$ provides approximately two days sludge feed and is equipped with dewatering facilities mounted from a surface support. A concrete floor slope to a hopper bottom is included. Separate 150mm valved outlets to individual feed pumps are provided, see Fig.4.

GAS HOLDER

This is a bell over water type of $5m^3$ capacity prefabricated in G.R.P. of a double skinned insulated construction. Gas supply and delivery pipes enter from below, with the floating lid ballasted to provide a gas pressure of 125mm water gauge, see Fig.5. A patent sensing system provides waste gas release from the digester roof solenoid.

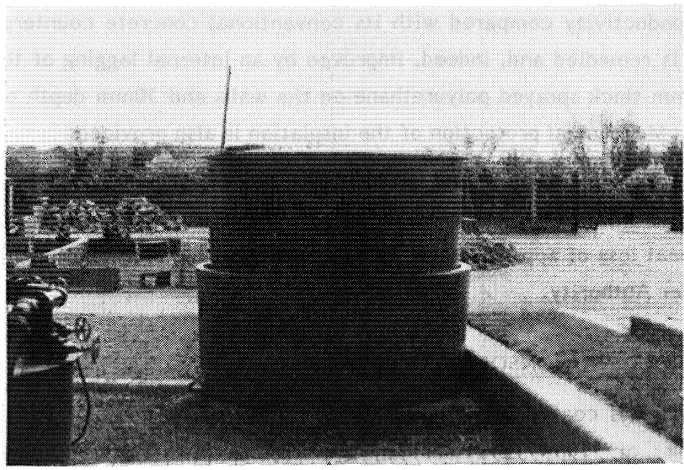


Fig.5

DIGESTED SLUDGE SUMP

The distance from the digester vessel to the re-allocated secondary digester requires the use of a separate sump. This covered sump in G.R.P. allows a vertical digested sludge discharge, giving further protection against digester outlet blockage. A multiple valving arrangement allows for either gravity discharge to the secondary digester or use of the duty or standby submersible sludge pump.

PROCESS EQUIPMENT HOUSINGS

For reasons of safety and convenience, three isolated housings (also in G.R.P.) are provided for the process equipment. One unit contains the primary electrical supply and control panel, the second contains the gas compression and mixer solenoid equipment, whilst the third includes the sludge gas boiler, circulating water pumps, make up water tanks and standby heating via in-line electrical immersion heaters.

PLANT ERECTION AND COMMISSIONING

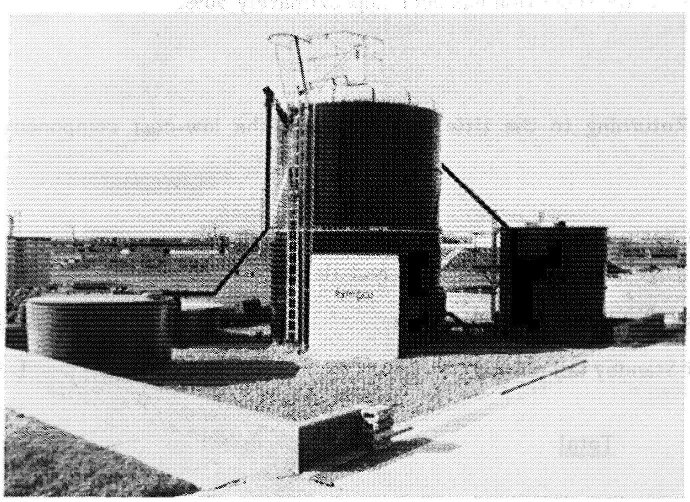
One of the more notable aspects of the use of prefabricated systems is the possible speed of erection. In the case of the plant described above, erection time as defined from a starting point of uncleared drying bed (also without electricity and water services) to digester gas in a fully charged gas holder took a total of some 18 working days. Were that period to be 18 weeks it would still be unapproachable for construction of a conventional plant.

The size of plant facilitated start up within a day by the importation of digesting sludge, although this plant was placed on full raw sludge feed within seven days of start up.

Within the overall 18 day erection period, site clearance to tank erection was completed within three days with internal insulation requiring two further days. These periods included the difficulties experienced in trying to penetrate the existing drying bed membrane for which any temptation to use this as the tank foundation was resisted.

All services within the package area, namely; water, gas and electricity are all suitably protected and buried under the original drying bed gravel now returned and augmented, see Fig.6.

Fig.6



DIGESTER OPERATION

Digester start up at half sludge feed was introduced to give a higher degree of process assurance in the event of a reduced monitoring staff availability which restricted the anticipated, very frequent monitoring of pH, Bicarbonate Alkalinity and Volatile Acid levels so critical on start up. Since that period, sludge loading has been increased by tankering sludge in from other works so that the population now served varies between 3,500 and 4,000 persons, with a detention period of approximately 17 to 20 days.

The plant has operated successfully from start up to date (6 months), although minor modifications and corrections to the plant have been made. These derived wholly from the different requirements of the contractors previous agricultural clients, and were restricted to items of detail which we were not able to totally eradicate during the design and construction stages. Plant operation is entirely automatic with current operator requirement restricted to reading of the hours run meters on the control panel and switchovers between duty and standby equipment.

PLANT INVESTIGATIONS

Availability of monitoring staff has greatly improved and a lithium trace of digester hydraulic performance has begun. Lagging monitoring is scheduled for two further examinations in this first year of operation. Whilst the monitoring period to date is rather short in digestion terms (approximately 6 retention periods) volatile matter reduction has been approximately 50%.

COSTS

Returning to the title of this paper, the low-cost component is now self evident.

Cost of Basic Plant (Digester, Gas holder, sump and all process equipment)	£14,655
Cost of Consolidation/holding tank	£ 2,085
Cost of Standby (all plants)	£ 3,850
Total	£20,590

CONCLUSIONS

This is one example of a low-cost prefabricated plant and embodies a number of aspects. Other areas of prefabrication are also being studied within Severn Trent Water Authority. At a population served of 3,500 persons, the capital cost per person is approximately £6, a figure which compares most favourably with conventional plants (up to £40/person) especially in view of inherent diseconomies of scale in this small plant. The 10,000 - 15,000 person plant would cost approximately £4/person. Although these tank types have been available within the U.S.A. for approximately 30 years, plant life is estimated at twenty years minimum (the known life of such tanks to date within the U.K.). Operational manpower requirements are drastically reduced in comparison with conventional plant, this resulting from the automatic cycle of feeding and mixing which repeats every 20 minutes throughout a 24 hour period.

ACKNOWLEDGEMENTS

We should like to express our thanks to all who have contributed to the work so far with special thanks to the Staff of Lower Severn Division S.T.W.A., to the enthusiasm of Farm Gas Limited, to Dr Harkness and colleagues of the Reclamation and Treatment Research Steering Group for the required financial assistance.

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ETUDE DE COMPARAISON TECHNICO-ECONOMIQUE DES FILIERES DE TRAITEMENT ET ELIMINATION DES BOUES RESIDUAIRES URBAINES

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Résumé :

L'Institut de Recherches Hydrologiques a entrepris en 1978 - 1979 une étude de comparaison technico-économique des filières de traitement et élimination des boues résiduaires urbaines. La comparaison a été effectuée pour des stations d'épuration desservant 5 000, 25 000, 75 000 et 300 000 équivalent-habitants.

Les coûts ont été reconstitués de façon synthétique en dimensionnant les différentes filières correspondant à chaque taille d'installation et en demandant à un bureau d'études d'évaluer leurs coûts d'investissement et de fonctionnement. Les résultats obtenus montrent les filières les plus intéressantes pour chaque taille de station, l'importance relative des coûts d'investissement et de fonctionnement, des coûts de traitement et d'élimination, des coûts de conditionnement et de déshydratation et enfin permettent de tirer des conclusions sur l'intérêt de certaines opérations unitaires dans la composition des filières de traitement.

Summary :

I.R.H. undertook 1978 - 1979 a study for a technical-economical comparison of treatment chains and disposal of urban sewage sludge. The comparison was made for treatment plants of 5 000, 25 000, 75 000 et 300 000 population-equivalents.

Costs were determined in a synthetical way, by dimensioning the treatment chains corresponding to the size of each plant and by asking an engineering office to evaluate their investment and operating costs. The obtained results indicate the most interesting chains for every important of treatment plant, the relative importance of investment and operating cost, and treatment and disposal costs, of conditioning and dehydration costs. They ending enable to draw conclusions concerning the relative interest of some united operations in structure of treatment change.

1. INTRODUCTION

L'Institut de Recherches Hydrologiques (I.R.H.) à Nancy a entrepris en 1978-1979 pour le compte du Ministère de l'Environnement et du Cadre de Vie, Direction de la Prévention des Pollutions, Service des Déchets, une étude de comparaison technico-économique des filières de traitement et élimination des boues résiduaires urbaines. Cet exposé décrit sommairement les résultats de cette étude et insiste sur les conclusions pratiques que l'on peut en tirer quant au choix des filières les mieux adaptées en fonction de la taille des installations.

2 . METHODOLOGIE D'ETUDE ET BASES D'EVALUATION :

Cette étude aurait pu être effectuée en réalisant une enquête sur les coûts d'investissement et de fonctionnement d'une large gamme de stations existantes en réactualisant les coûts d'investissement. Une telle démarche présente l'inconvénient majeur de comparer des coûts établis sur des bases non homogènes et ne permet pas de différencier les coûts élémentaires relatifs aux opérations unitaires. Pour éviter cet écueil, il a été décidé, pour la réalisation de l'étude, d'adopter une approche beaucoup plus synthétique consistant à définir 4 tailles de stations d'épuration : 5 000, 25 000, 75 000 et 300 000 habitants pour lesquelles un nombre important de filières possibles ont été définies, optimisées et dimensionnées à partir des données disponibles. Nous avons ensuite demandé à un bureau d'études indépendant, le Bureau d'Etude des Fluides et Structures (B.E.F.S.) d'effectuer l'évaluation économique de ces filières.

Les principales hypothèses et bases de dimensionnement retenues sont les suivantes :

- Coûts indiqués à la date du 1-6-1978
- Investissements : non prise en compte du coût du terrain qui est susceptible de varier très largement en fonction des conditions locales

. prise en compte forfaitaire d'une partie des aménagements généraux de la station : voirie, batiments d'exploitation, infrastructures

- Taux d'amortissement annuels :
  . batiment et génie civil : 6,7 %
  . équipements : 12,5 %
- Exploitation :
  . coût du kilowatt-heure : 0,243 F
  . coût de main d'oeuvre toutes charges comprises : 35 F/h
  . coût d'entretien annuel des batiments :1 % de l'investissement
  . coût d'entretien annuel du matériel : 3 % de l'investissement
  . coûts d'exploitation divers des traitements déterminés pour chaque opération unitaire après enquête auprès des exploitants
  . coût d'admission en décharge : dégressif de 15 à 5 F par tonne selon quantité
  . distance d'utilisation agricole des boues $d = 0,044\sqrt{P}$ avec d en km et P la population en habitants
  . non prise en compte de la valeur économique de la boue.

3 . FILIERES ETUDIEES ET RESULTATS DE L'ETUDE ECONOMIQUE :

Les filières et leurs variantes ayant donné lieu a étude de dimensionnement et évaluation économique sont décrites schématiquement sur les tableaux I, III, V, VII de l'Annexe. C'est ainsi que 49 options ont été considérées pour la taille 5 000 h, 67 options pour la taille 25 000 h, 59 pour la taille 75 000 h et 40 pour la taille 300 000 h.

Les coûts totaux annuels, incluant l'amortissement et le fonctionnement sont visualisés graphiquement sur les tableaux II, IV, VI et VIII de l'Annexe sous une forme qui permet des comparaisons immédiates de toutes les filières.

L'attention est attirée sur le fait que l'extrapolation de ces

TABLEAU I - Recapitulation des Filières Etudiées (Taille: 5.000 équivalent-habitants)

OPERATIONS UNITAIRES	FILIERES N°																																																
	1	2 a	2 b	2 c	3 a	3 b	3 c	4 a	4 b	4 c	5 a	5 b	5 c	6 a	6 b	6 c	8	13	14 a	14 b	14 c	15 a	15 b	15 c	16 a	16 b	16 c	17 a	17 b	17 c	18 a	18 b	18 c	25	26 a	26 b	26 c	27 a	27 b	27 c	28 a	28 b	28 c	29 a	29 b	29 c	30 a	30 b	30 c
DIGESTION AEROBIE																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																
DIGESTION ANAEROBIE																																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
EPAISSISSEUR GRAVITAIRE OU SILO CONCENTRATEUR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X																
PASTEURISATION																																																	
CONDITIONNEMENT PAR POLYELECTROLYTE					X	X	X	X	X	X	X	X	X	X	X	X						X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X	X	X	X	X
CONDITIONNEMENT PAR REACTIFS MINERAUX																																																	
CONDITIONNEMENT THERMIQUE AUTOCLAVAGE																																																	
FLOTTATION																																																	
STOCKAGE DE BOUES LIQUIDES	X																																																
SECHAGE SUR LIT		X	X	X				X	X	X									X	X	X				X	X	X								X	X	X				X	X	X						
SACS FILTRANTS											X	X	X															X	X	X														X	X	X			
CENTRIFUGATION					X	X	X															X	X	X														X	X	X									
FILTRATION SOUS VIDE																																																	
FILTRE A BANDES														X	X	X															X	X	X														X	X	X
FILTRE-PRESSE																																																	
COMPOSTAGE AVEC O.M.																																																	
INCINERATION COMBINEE AVEC O.M.																	X																																
INCINERATION BOUES SEULES – LIT FLUIDISE																																																	
INCINERATION BOUES SEULES – FOUR ROTATIF																																																	
INCINERATION BOUES SEULES – FOUR A SOLES																																																	
UTILISATION AGRICOLE DE BOUES LIQUIDES	X																	X																X															
STOCKAGE DE BOUES		X	X		X	X		X	X		X	X		X	X			X	X	X		X	X		X	X		X	X		X	X		X	X	X		X	X		X	X		X	X		X	X	
UTILISATION AGRICOLE EXCLUSIVE DE BOUES SOLIDES			X			X			X			X			X					X			X			X			X			X				X			X			X			X			X	
COMB. UTIL. AGRIC/MISE EN DECHARGE		X			X			X			X			X					X			X			X			X			X				X			X			X			X			X		
MISE EN DECHARGE EXCLUSIVE DE BOUES SOLIDES				X			X			X			X			X					X			X			X			X			X				X			X			X			X			X
EVACUATION DE COMPOST																																																	
EVACUATION DE CENDRES																	X																																

TABLEAU II (Taille: 5.000 équivalent-habitants)

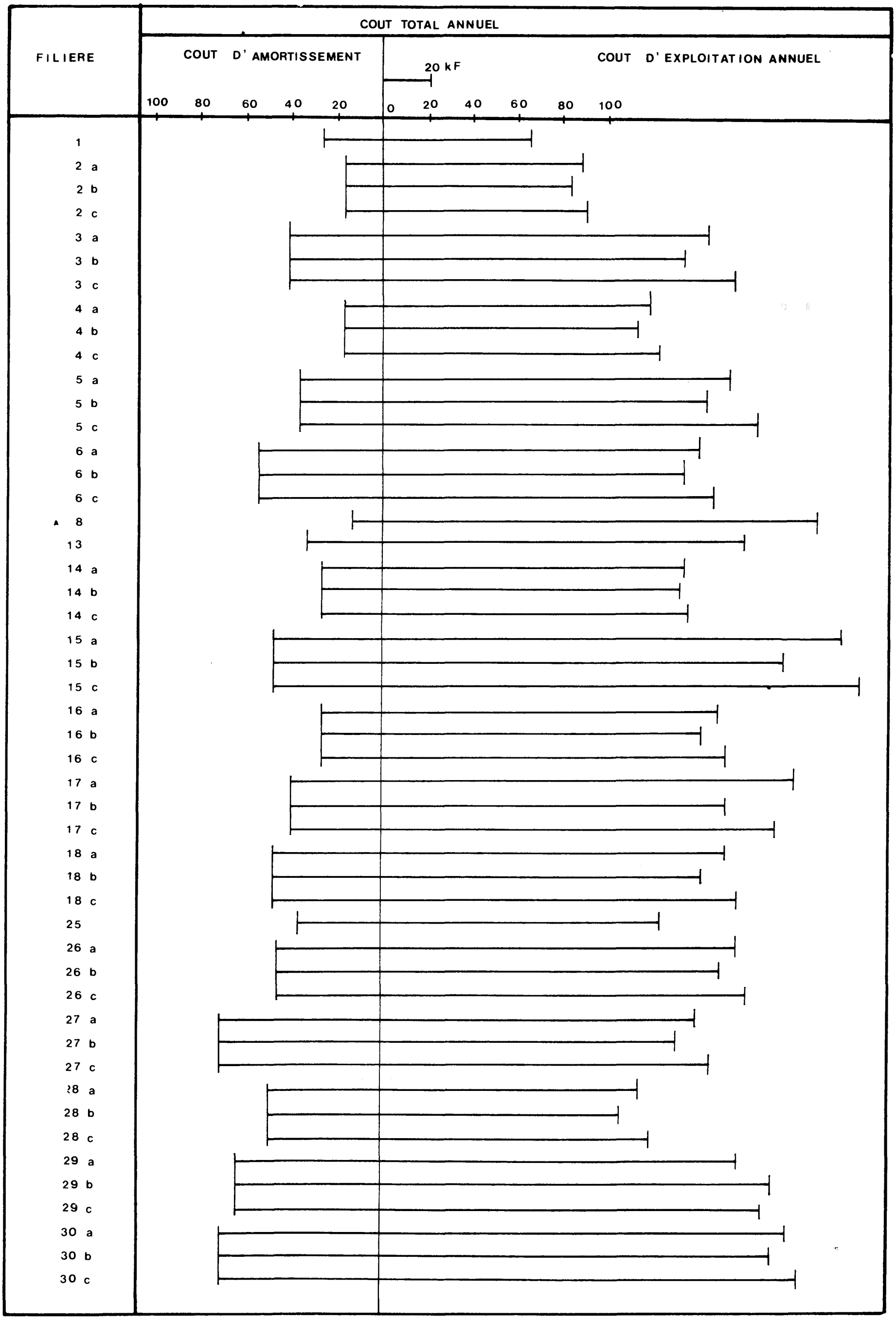


TABLEAU III - Recapitulation des Filières Etudiées (Taille: 25.000 équivalent-habitants)

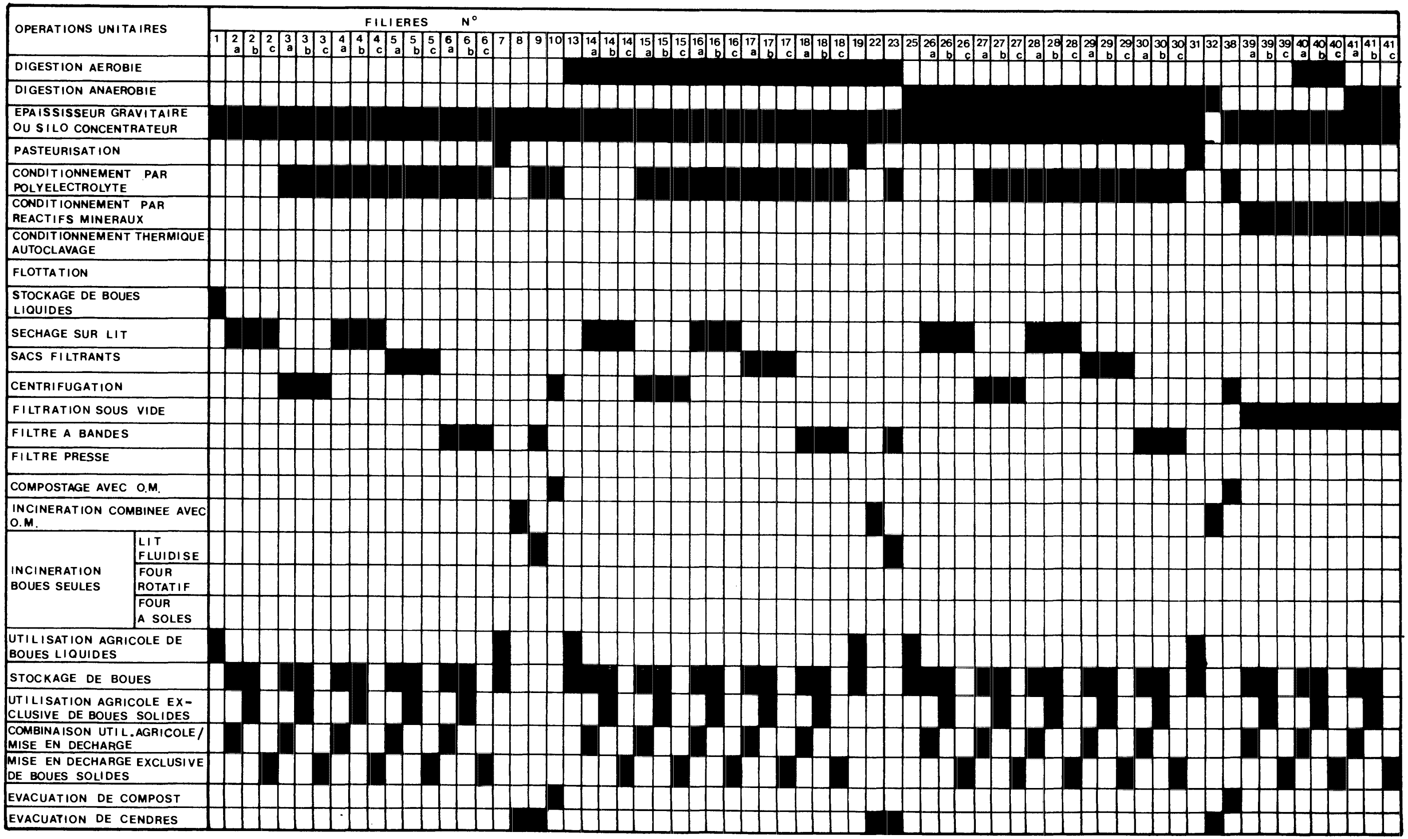


TABLEAU IV (Taille: 25.000 équivalent-habitants)

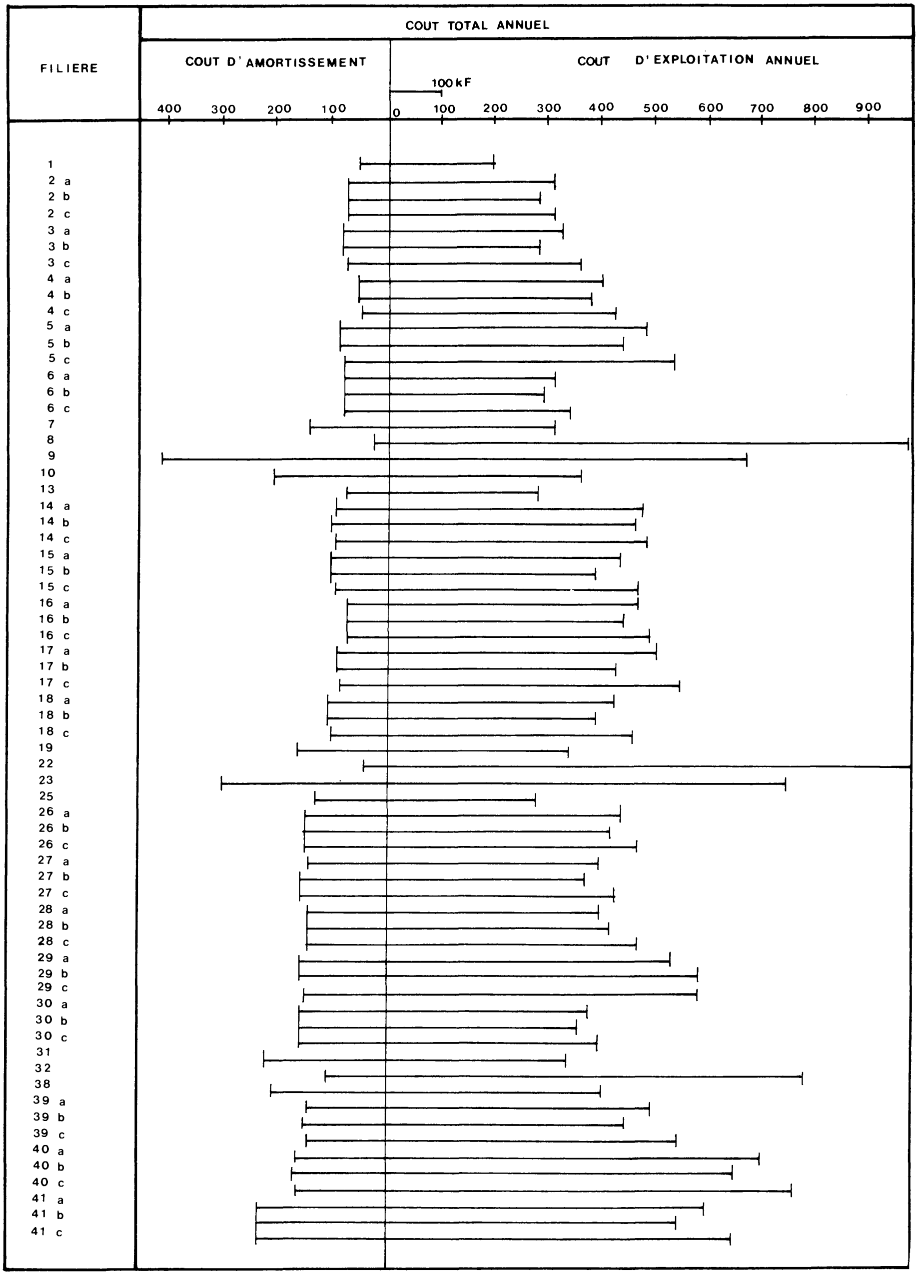


TABLEAU V - Recapitulation des Filières Etudiées (Taille 75.000 équivalent-habitants)

OPERATIONS UNITAIRES	FILIERES N°																																																										
	1	3 a	3 b	3 c	4 a	4 b	4 c	6 a	6 b	6 c	7	9	10	11 a	11 b	12 a	12 b	12 c	13	15 a	15 b	15 c	16 a	16 b	16 c	18 a	18 b	18 c	19	20	21	22	23	24	25	27 a	27 b	27 c	28 a	28 b	28 c	30 a	30 b	30 c	31	32	33	34	35	38	39 a	39 b	39 c	40 a	40 b	40 c	41 a	41 b	41 c
DIGESTION AEROBIE																			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																					■	■	■			
DIGESTION ANAEROBIE																																			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								■	■	■
EPAISSISSEUR GRAVITAIRE OU SILO CONCENTRATEUR	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■												■				■	■	■	■	■	■	■			
PASTEURISATION											■																		■																■														
CONDITIONNEMENT PAR POLYELECTROLYTE		■	■	■	■	■	■	■	■	■		■	■	■	■					■	■	■	■	■	■	■	■	■		■			■			■	■	■	■	■	■	■	■	■			■	■		■									
CONDITIONNEMENT PAR REACTIFS MINERAUX																■	■	■													■			■															■		■	■	■	■	■	■	■	■	■
CONDITIONNEMENT THERMIQUE AUTOCLAVAGE																																																											
FLOTTATION																																		■																									
STOCKAGE DE BOUES LIQUIDES	■																																																										
SECHAGE SUR LIT					■	■	■																■	■	■														■	■	■																		
SACS FILTRANTS																																																											
CENTRIFUGATION		■	■	■									■	■	■					■	■	■								■						■	■	■										■		■									
FILTRATION SOUS VIDE																																																			■	■	■	■	■	■	■	■	■
FILTRE A BANDES								■	■	■		■														■	■	■					■									■	■	■			■												
FILTRE-PRESSE																■	■	■													■			■															■										
COMPOSTAGE AVEC O.M.													■																																					■									
INCINERATION COMBINEE AVEC O.M.																																■														■													
INCINERATION BOUES SEULES – LIT FLUIDISE												■					■													■	■		■	■													■	■	■										
INCINERATION BOUES SEULES – FOUR ROTATIF															■			■																																									
INCINERATION BOUES SEULES – FOUR A SOLE														■		■																																											
UTILISATION AGRICOLE DE BOUES LIQUIDES	■										■								■										■						■										■														
STOCKAGE DE BOUES		■	■		■	■		■	■		■								■	■	■		■	■		■	■		■						■	■	■		■	■		■	■		■						■	■		■	■		■	■	
UTILISATION AGRICOLE EXCLUSIVE DE BOUES SOLIDES			■			■			■												■			■			■										■			■			■									■			■			■	
COMBINAISON UTIL. AGRICOLE/MISE EN DECHARGE		■			■			■												■			■			■										■			■			■									■			■			■		
MISE EN DECHARGE EXCLUSIVE DE BOUES SOLIDES				■			■			■												■			■			■										■			■			■									■			■			■
EVACUATION DE COMPOST													■																																					■									
EVACUATION DE CENDRES												■		■	■	■	■	■												■	■	■	■	■												■	■	■	■										

TABLEAU VI (Taille 75 000 équivalent-habitants)

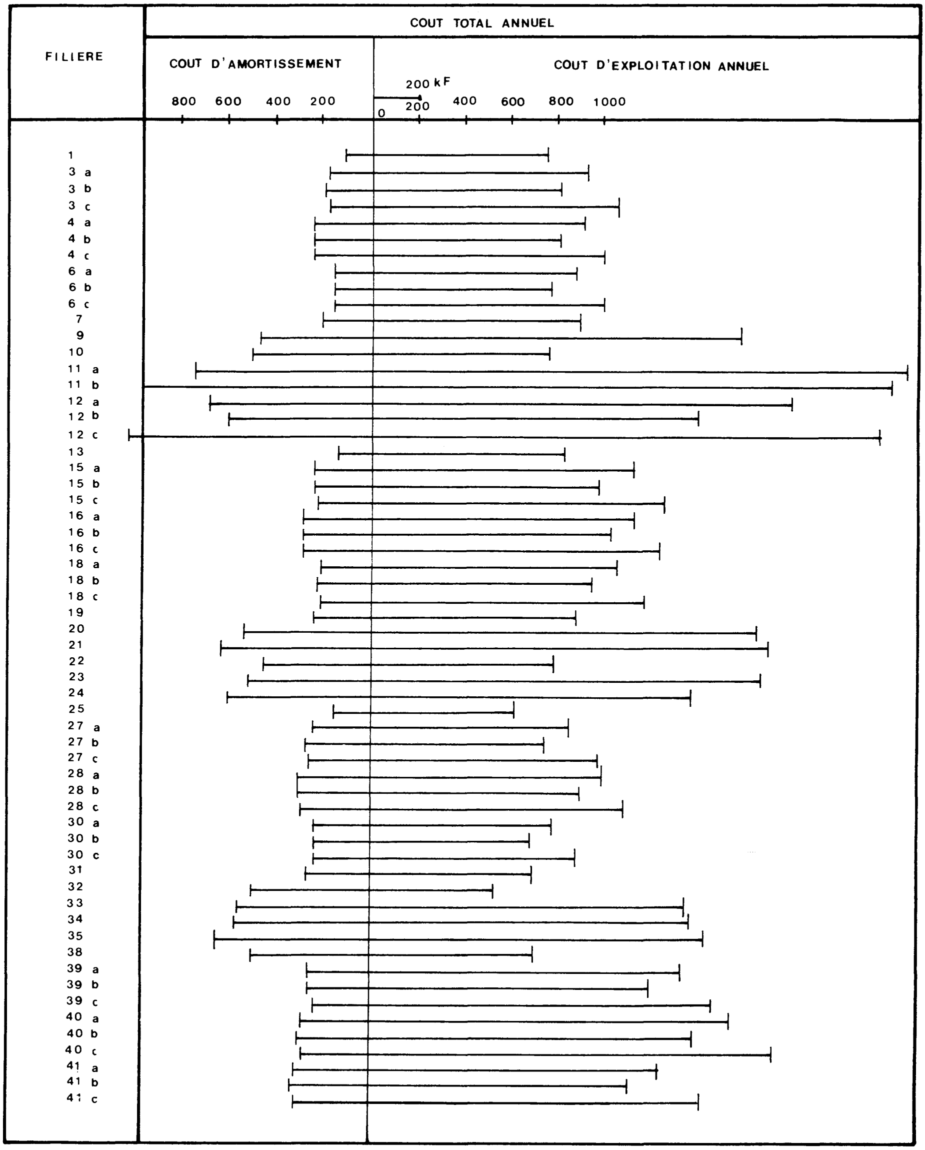
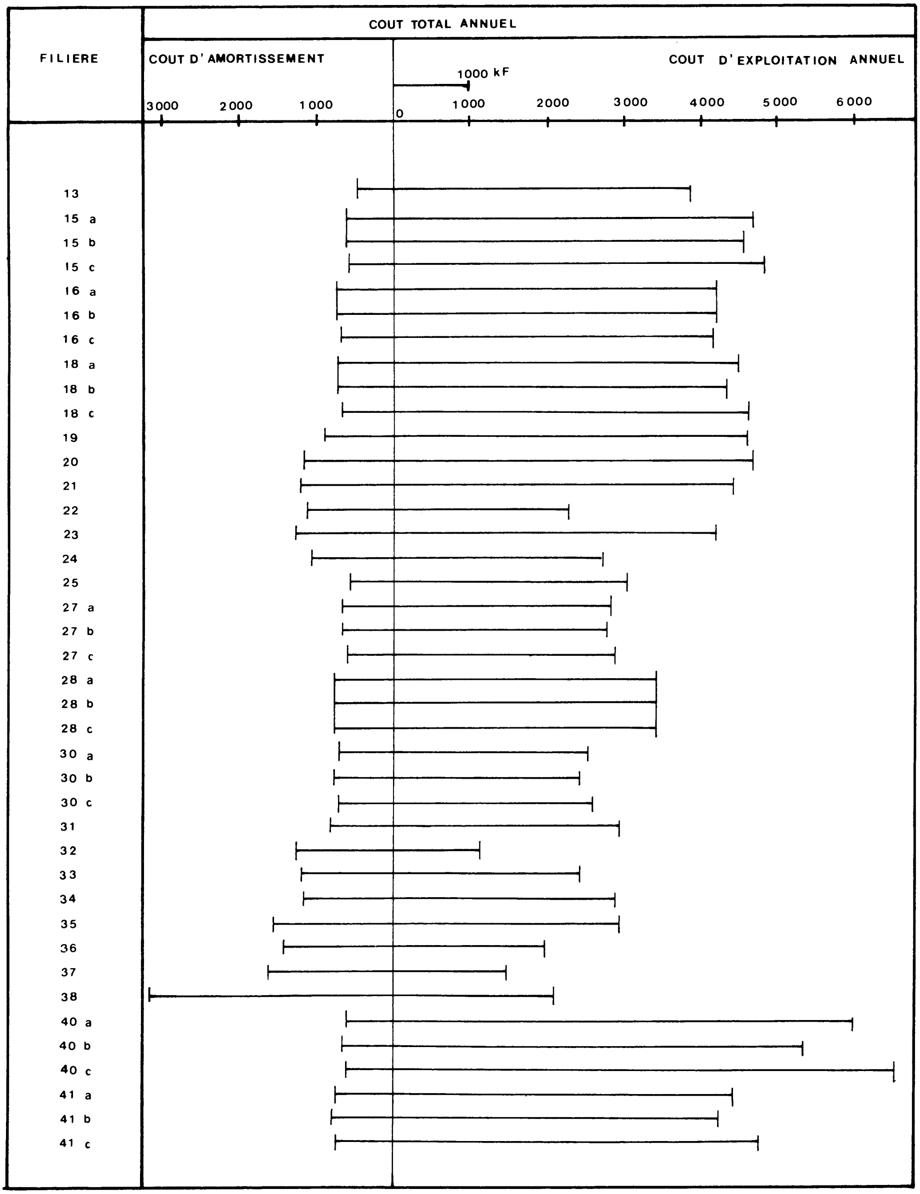


TABLEAU VII - Recapitulation des Filières Etudiées (Taille 300.000 équivalent-habitants)

OPERATIONS UNITAIRES	FILIERES N° 13	15 a	15 b	15 c	16 a	16 b	16 c	18 a	18 b	18 c	19	20	21	22	23	24	25	27 a	27 b	27 c
DIGESTION AEROBIE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
DIGESTION ANAEROBIE																	X	X	X	X
EPAISSISSEUR GRAVITAIRE OU SILO CONCENTRATEUR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
PASTEURISATION											X									
CONDITIONNEMENT PAR POLYELECTROLYTE		X	X	X	X	X	X	X	X	X		X			X			X	X	X
CONDITIONNEMENT PAR REACTIFS MINERAUX													X			X				
CONDITIONNEMENT THERMIQUE AUTOCLAVAGE																				
FLOTTATION																X				
STOCKAGE DE BOUES LIQUIDES																				
SECHAGE SUR LIT					X	X	X													
SACS FILTRANTS																				
CENTRIFUGATION		X	X	X								X						X	X	X
FILTRATION SOUS VIDE																				
FILTRE A BANDES								X	X	X					X					
FILTRE-PRESSE													X			X				
COMPOSTAGE AVEC O.M.																				
INCINERATION COMBINEE AVEC O.M.														X						
INCINERATION BOUES SEULES – LIT FLUIDISE												X	X		X	X				
INCINERATION BOUES SEULES – FOUR ROTATIF																				
INCINERATION BOUES SEULES – FOUR A SOLES																				
UTILISATION AGRICOLE DE BOUES LIQUIDES	X										X						X			
STOCKAGE DE BOUES	X	X	X		X	X		X	X		X						X	X	X	
UTILISATION AGRICOLE EXCLUSIVE DE BOUES SOLIDES			X			X			X										X	
COMB. UTIL. AGRI./MISE EN DECHARGE		X			X			X										X		
MISE EN DECHARGE EXCLUSIVE DE BOUES SOLIDES				X			X			X										X
EVACUATION DE COMPOST																				
EVACUATION DE CENDRES												X	X	X	X	X				

OPERATIONS UNITAIRES	28 a	28	28	30 a	30 b	30 c	31	32	33	34	35	36	37	38	40 a	40 b	40 c	41 a	41 b	41 c
DIGESTION AEROBIE															X	X	X			
DIGESTION ANAEROBIE	X	X	X	X	X	X	X	X	X	X	X		X					X	X	X
EPAISSISSEUR GRAVITAIRE OU SILO CONCENTRATEUR														X	X	X	X			
PASTEURISATION							X													
CONDITIONNEMENT PAR POLYELECTROLYTE	X	X	X	X	X	X			X	X				X						
CONDITIONNEMENT PAR REACTIFS MINERAUX											X				X	X	X	X	X	X
CONDITIONNEMENT THERMIQUE AUTOCLAVAGE												X	X							
FLOTTATION																				
STOCKAGE DE BOUES LIQUIDES																				
SECHAGE SUR LIT	X	X	X																	
SACS FILTRANTS																				
CENTRIFUGATION										X				X						
FILTRATION SOUS VIDE															X	X	X	X	X	X
FILTRE A BANDES				X	X	X			X											
FILTRE-PRESSE											X	X	X							
COMPOSTAGE AVEC O.M.														X						
INCINERATION COMBINEE AVEC O.M.								X												
INCINERATION BOUES SEULES – LIT FLUIDISE									X	X	X	X	X							
INCINERATION BOUES SEULES – FOUR ROTATIF																				
INCINERATION BOUES SEULES – FOUR A SOLES																				
UTILISATION AGRICOLE DE BOUES LIQUIDES							X													
STOCKAGE DE BOUES	X	X		X	X		X								X	X		X	X	
UTILISATION AGRICOLE EXCLUSIVE DE BOUES SOLIDES		X			X											X			X	
COMB. UTIL. AGRI./MISE EN DECHARGE	X			X											X			X		
MISE EN DECHARGE EXCLUSIVE DE BOUES SOLIDES			X			X											X			X
EVACUATION DE COMPOST														X						
EVACUATION DE CENDRES								X	X	X	X	X	X							

TABLEAU VIII (Taille 300.000 équivalent - habitants)



résultats à des pays autres que la France où les structures de coûts sont différentes ne doit être faite qu'avec la plus grande précaution. Néanmoins les tendances générales que l'on déduit, ci-après, de la comparaison des résultats peuvent être considérées comme valables pour l'Europe de l'Ouest.

4 . INTERPRETATION DES RESULTATS ET CONCLUSIONS GENERALES :

4.1. Mise en évidence des filières les plus intéressantes

4.1.1. Taille 5 000 habitants

Sur le plan de l'investissement, la filière la plus intéressante paraît être celle de l'incinération combinée avec les ordures ménagères, la boue étant admise à l'état liquide. Cependant, dans le cas des tailles de 5 000 et 25 000 habitants, il n'a pas été considéré de participation au coût de l'installation d'incinération.

En fait, les plus faibles coûts d'investissement sont rencontrés pour les filières où la boue issue du silo concentrateur d'une installation biologique à faible charge est admise sur lit de séchage. Vient ensuite l'option avec sacs filtrants, puis le séchage sur lits de boues digérées aérobies.

Pour toutes ces solutions, le coût d'investissement le plus faible correspond à la mise en décharge (pas d'investissement considéré pour cette opération) puis la combinaison mise en décharge/ utilisation agricole et enfin l'utilisation agricole seule. Ce classement révèle l'incidence des coûts de stockage.

En fait, la seule comparaison intéressante sera celle des coûts annuels/habitant.

En ce qui concerne les coûts d'exploitation, le coût le plus faible est celui de l'utilisation agricole de la boue de station à faible charge simplement épaissie gravitairement, puis vient alors celui des mêmes boues séchées sur lits. Le coût minimal correspond alors à l'utilisation agricole exclusive puis par ordre d'importance croissante correspond à la combinaison mise en décharge/utilisation agricole et enfin la mise en décharge exclusive. On trouve ici l'influence du coût de mise en décharge.

La comparaison des coûts totaux annuels rapportés à l'habitant raccordé qui sont les seuls qui puisse être valablement comparés s'établit comme suit :

- le coût minimal est rencontré pour les stations biologiques à faible charge avec utilisation agricole directe de la boue épaissie gravitairement (18 F/habitant),

- vient ensuite le cas des mêmes boues séchées sur lit sans conditionnement, avec stockage et utilisation agricole exclusive, puis le cas des mêmes boues avec combinaison utilisation agricole/mise en décharge pendant des durées annuelles sensiblement égales, puis enfin la mise en décharge exclusive,

En effet, nous avons considéré que les boues étaient admises dans une installation d'incinération d'ordures ménagères de taille suffisamment importante pour ne pas nécessiter de séchage préalable de la boue, ce qui correspond à un cas de figure peu fréquent. Le coût considéré comprend le coût marginal d'incinération. Le coût d'une filière identique avec séchage préalable de la boue n'a pas été envisagé.

- vient ensuite le cas des boues de même destination finale, préalablement séchées sur lit après conditionnement par polyélectrolyte,

- les solutions avec conditionnement et déshydratation mécanique des boues se révèlent évidemment les plus coûteuses (2 fois plus que la solution la moins onéreuse).

4.1.2. <u>Taille 25 000 habitants</u>

Sur le plan de l'investissement, les solutions apparemment les plus intéressantes sont celles avec incinération combinée des boues et des ordures ménagères, pour les raisons indiquées au paragraphe précédent. Si on en tient compte, on s'aperçoit que l'investissement minimal correspond, comme dans le cas de la taille 5 000 habitants au cas des boues de station à faible charge, épaissies gravitairement, floculées par polyélectrolyte,séchées sur lit et mise en décharge, et/ou utilisées dans l'agriculture.

En ce qui concerne les coûts d'exploitation, le coût le plus faible est encore obtenu pour l'utilisation agricole de la boue issue d'une station à faible charge simplement épaissie gravitairement. Vient ensuite le cas de la boue conditionnée par polyélectrolyte, passée sur filtre à bande et utilisée exclusivement dans l'agriculture, puis la boue liquide incinérée conjointement avec les ordures ménagères du fait des raisons déjà exposées et dans l'hypothèse où on peut construire une installation d'incinération d'ordures ménagères correspondant à une population équivalente plus importante que celle de la station d'épuration. Par ordre de coût d'exploitation croissant, nous trouvons ensuite les boues de station à faible charge non conditionnées, séchées sur lit, stockées et utilisées exclusivement dans l'agriculture, puis les mêmes boues conditionnées par polyélectrolyte, centrifugées, stockées et utilisées exclusivement dans l'agriculture.

Du point de vue du coût total annuel par habitant, la solution la moins coûteuse (10 F/habitant) est encore l'utilisation agricole directe de la boue de station à faible charge épaissie gravitairement. C'est un des coûts les plus faibles rencontrés au cours de l'étude. Vient ensuite le séchage sur lits de la même boue non conditionnée, son stockage et l'utilisation agricole exclusive (14 F/habitant). On peut recourir pour le même coût au conditionnement par polyélectrolyte et à la déshydratation par filtre à bandes presseuses avec utilisation agricole exclusive.

4.1.3. Taille 75 000 habitants

Les solutions les moins coûteuses en investissement sont celles qui utilisent un filtre à bande presseuse puis une centrifugeuse et éliminent les boues par mise en décharge et/ou utilisation agricole. L'utilisation directe de boue liquide épaissie gravitairement est encore bien placée du point de vue de l'investissement.

Pour les coûts d'exploitation, l'utilisation agricole directe de boue liquide digérée anaérobie et l'incinération conjointe avec des ordures ménagères se situent favorablement. Viennent ensuite la déshydratation par filtre à bandes de la boue digérée anaérobie conditionnée par polyélectrolytes suivie d'une utilisation agricole exclusive. Vient ensuite l'utilisation agricole de la boue digérée anaérobie pasteurisée liquide.

Au niveau du coût total annuel par habitant, les deux solutions les moins coûteuses sont l'utilisation agricole directe de la boue de station à faible charge épaissie gravitairement (11 F/habitant) ou de la boue de station à moyenne charge digérée anaérobie (11 F/habitant). Vient ensuite l'utilisation agricole exclusive de la boue de station à faible charge épaissie, floculée par polyélectrolyte et déshydratée par filtre à bandes presseuses (13 F/habitant) puis l'utilisation agriccle directe de la boue de station à moyenne charge digérée aérobie et liquide (13 F/habitant). On trouve ensuite les mêmes solutions dans le cas de la boue digérée anaérobie déshydratée par filtre à bande ou liquide pasteurisée utilisées dans l'agriculture.

4.1.4 <u>Taille 300 000 habitants</u>

Les solutions les plus intéressantes du point de vue du coût d'investissement sont :

- le conditionnement par polyélectrolyte puis la centrifugation de la boue digérée aérobie, la boue déshydratée étant mise en décharge,

- le conditionnement par réactifs minéraux puis la filtration sous vide et la mise en décharge de la boue digérée aérobie.

Viennent ensuite l'utilisation agricole directe de la boue digérée aérobie liquide et la combinaison utilisation agricole/ mise en décharge de la boue digérée aérobie conditionnée par polyélectrolyte et centrifugée.

En ce qui concerne le coût annuel d'exploitation, il est minimal pour l'incinération combinée de la boue digérée anaérobie liquide avec les ordures ménagères. Viennent ensuite l'incinération par four à lit fluidisé de la boue digérée anaérobie, autoclavée et déshydratée par filtre-presse, puis la même solution adoptée pour les boues mixtes fraîches.

Les solutions les plus intéressantes du point de vue du coût total annuel par habitant sont :

- l'incinération combinée de la boue digérée anaérobie liquide avec des ordures ménagères (sous réserve de validité du coût indiqué par le fournisseur du procédé spécifiquement adapté) (coût : 8 F/ habitant),

- l'incinération par four à lit fluidisé de la boue digérée anaérobie, autoclavée et déshydratée par filtre-presse (10 F/habitant),

- l'utilisation agricole exclusive de la boue digérée anaérobie, conditionnée par polyélectrolyte et déshydratée par filtre à bandes presseuses (11 F/habitant).

4.2. Observations et conclusions générales

4.2.1. Importance relative des coûts d'amortissement et exploitation

Nous avons calculé pour chaque taille de station d'épuration, la moyenne des coûts annuels d'amortissement et d'exploitation pour les 10 filières se révélant les plus intéressantes économiquement (coût total annuel par habitant le plus faible). Les valeurs obtenues sont regroupées dans le tableau ci-dessous :

Taille de station	Coût moyen d'amortissement (kF/an)	Coût moyen d'exploitation (kF/an)
5 000	21	108
25 000	74	358
75 000	226	732
300 000	923	2 308

Il s'avère que dans tous les cas, les coûts d'exploitation sont nettement supérieurs aux coûts d'amortissement puisque le rapport de ces deux grandeurs passe de 5 à 2,5 lorsque la taille de station passe de 5 000 à 300 000 habitants raccordés. En conséquence, le choix d'une filière doit en tenir le plus grand compte et ne pas privilégier systématiquement les solutions conduisant aux investissements les plus faibles.

4.2.2. Importance relative des coûts de traitement et d'élimination

Nous avons calculé pour chaque taille de station et en ne considérant, comme précédemment que les 10 filières économiquement les plus intéressantes dans chaque cas, les coûts moyens de l'ensemble traitement + élimination et d'autre part, de la phase d'élimination considérée isolément (transport et mise en décharge et/ou utilisation agricole, incinération). Les résultats sont regroupés dans le tableau suivant :

Taille de station	Coût moyen total annuel (kF)	Coût moyen annuel de l'élimination	% de l'élimination dans le coût total
5 000	144	18	12,5 %
25 000	352	111	31,5 %
75 000	957	421	44,0 %
300 000	3 231	1 752	54,2 %

Nous constatons que le coût de l'élimination finale qui est 7 fois plus faible que celui du traitement pour une station de 5 000 habitants voit son importance relative augmenter considérablement lorsque la taille de la station croît et le coût de l'élimination finale est supérieur au coût du traitement pour une station de 300 000 habitants. Cette constatation montre l'impérieuse nécessité d'optimiser l'ensemble traitement + élimination finale pour aboutir au coût minimal, cette démarche n'est malheureusement pas très fréquente et l'on ne se soucie souvent du devenir des boues qu'après la conception de la station d'épuration. On peut donc attendre des progrès d'une meilleure adaptation de la conception des stations en vue de minimiser les coûts globaux.

Si au lieu de considérer la moyenne des coûts des 10 filières les moins coûteuses, on ne considère qu'une seule filière, les pourcentages relatifs trouvés peuvent s'écarter considérablement de ceux qui figurent ci-dessus mais notre conclusion demeure valable.

4.2.3. Importance relative des coûts de conditionnement et déshydratation

Nous avons calculé pour chaque type de déshydratation (sacs filtrants, centrifugation, filtre-presse, filtre rotatif, filtre à bandes) l'importance relative du coût annuel total de conditionnement par rapport au coût annuel total de l'opération unitaire de déshydratation.

Type de déshydratation	Ratio : coût annuel total de conditionnement / coût annuel total de déshydratation
Sacs filtrants	0,31 à 0,47
Centrifugeuse	0,29 à 2,04
Filtre-presse	1,31 à 2,16
Filtre rotatif	1,50 à 3,02
Filtre à bandes	0,31 à 1,4

Ces chiffres mettent en évidence la non-validité de comparaisons entre procédés unitaires de déshydratation qui ne comportent pas la prise en compte des frais de conditionnement, particulièrement lorsque celui-ci est réalisé au moyen de réactifs minéraux.

Les coûts totaux annuels de conditionnement de la boue étant élevés par rapport aux coûts totaux annuels de la déshydratation considérée isolément, on devrait privilégier des procédés de déshydratation admettant un conditionnement moins coûteux, même s'ils correspondent à un investissement plus élevé.

4.2.4. Importance relative du coût de l'épaississement

Pour les 10 filières les mieux placées économiquement et pour chaque taille de station, nous avons calculé l'importance relative du coût total de l'épaississement par rapport au coût total de la filière incluant l'élimination finale. La proportion relative trouvée est la suivante :

Taille de station	Coût total de l'épaississement (% du coût total de la filière)
5 000	3 %
25 000	5 %
75 000	3 %
300 000	1,5 %

Il s'avère donc que le coût de l'épaississement gravitaire reste très faible par rapport au coût total et quand on connaît l'incidence de la concentration de la boue sur le dimensionnement des ouvrages de traitement, on ne peut qu'être amené à conseiller la généralisation des épaississeurs gravitaires en amont des filières de traitement des boues. D'une façon générale, des améliorations technologiques qui permettraient un accroissement des performances d'épaississement, auraient une incidence particulièrement importante sur le coût global du traitement des boues.

4.2.5. Influence du mode de stabilisation sur les coûts moyens de traitement et élimination

Nous avons calculé pour chaque taille de station et pour les filières directement comparables, qui ne différaient que par l'existence et la nature d'un traitement de stabilisation des boues, le coût total annuel par habitant.

Les résultats montrent si on se réfère aux valeurs moyennes que, dans presque tous les cas, les filières comportant une stabilisation séparée des boues sont plus coûteuses que celles qui n'en comportent pas (stations par aération prolongée). Il n'en serait évidemment pas de même si on comparait les coûts des filières de traitement des eaux correspondantes.

En dessous et pour 25 000 habitants, les filières avec digestion anaérobie sont plus coûteuses que celles avec digestion aérobie. L'inverse se produit au-dessus et pour 75 000 habitants. Pour une taille de 300 000 habitants, les filières avec digestion anaérobie semblent moins coûteuses que celles qui ne comportent pas de stabilisation.

4.2.6. Influence de la destination finale des boues sur les coûts moyens de traitement et élimination

Nous avons calculé pour chaque taille de station et pour l'ensemble des filières de traitement considérées dans l'étude les coûts totaux annuels moyens par habitant et les avons classés en fonction de la destination finale des boues :

Taille de station	5 000 hab.	25 000 hab.	75 000 hab.	300 000 hab.
Destination finale				
Compostage	-	22 à 25	16 à 17	18
Incinération boues seules	-	44 à 45	26 à 44	10 à 20
Incinération avec O.M.	42	36 à 45	17 à 26	8 à 12
Décharge	21 à 52	15 à 37	15 à 27	11 à 24
Epandage agricole	18 à 50	10 à 33	11 à 23	11 à 22

Il s'avère, en fonction de ces résultats que le coût total annuel par habitant est toujours plus faible pour les filières comportant l'utilisation agricole ou la mise en décharge des boues que pour celles qui comportent une incinération pour les stations de 5 000, 25 000, 75 000 habitants. Pour les stations de 300 000 habitants, les coûts sont du même ordre de grandeur dans tous les cas. (Il faut cependant remarquer qu'ils ne prennent pas en compte la valeur agronomique des boues).

4.2.7. Influence de la taille de station sur les coûts moyens de traitement et élimination

Nous avons calculé les coûts totaux annuels par habitant en faisant la moyenne des résultats des 10 filières les plus intéressantes par taille de station. Ces résultats montrent sans ambiguïté que le coût par habitant diminue quand la taille de station augmente et ceci bien que le traitement et l'élimination des boues des petites stations fasse appel à des techniques rudimentaires et très simples.

Taille de station	Coût total annuel par habitant (francs)
5 000	18 à 32
25 000	10 à 17
75 000	11 à 14
300 000	8 à 12

Cette constatation n'est pas suffisante pour promouvoir un traitement centralisé des boues ou la constitution de très grosses stations d'épurations, car elle ne prend pas en compte les coûts de collecte des effluents.

EXPERIENCES IN LARGE SCALE TREATMENT AND UTILISATION OF SEWAGE SLUDGE

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Summary

The role of the ten Water Authorities in England and Wales and the organisation of the Thames Water Authority are briefly described.

Of the 12 million population served by the Authority, some 7.5 million live within the Metropolitan Public Health Division's area - basically Greater London. The Division is responsible for sewerage and sewage treatment, including the control of trade discharges. Nearly all the effluent from the ten sewage treatment works is discharged to the tidal Thames.

The sewage sludge is digested and about 5 million tonnes at 3 % solids approximately are shipped to sea for disposal and some 3 million tonnes at 6 - 10 % solids are utilised on land for agricultural use or land reclamation. This sludge is stored in lagoons for up to 4 years for thickening and pathogen reduction.

Methods of meeting the constraints on land utilisation are described and also the means by which sludge quality may be improved.

1) Thames Water Authority is one of ten such organisations, based upon river catchments, in England and Wales responsible for all aspects of the water cycle (e.g. River management, pollution control, land drainage, Water resources, supply, treatment and distribution, sewerage and sewage treatment and disposal and trade effluent control).

2) The Metropolitan Public Health Division is one of nine divisions in Thames Water and is responsible for sewerage, sewage treatment and disposal, including trade effluent control, in the Greater London area. Of the 12 million population within the Authority area, 7.5 million reside within the Division's area. The total average daily flow received by the ten works in the Division is some 3 million cubic metres (700 m.g.d.)

3) The Authority was formed in 1974, taking over the responsibilities of the predecessor authorities. These, in the Division's area, included the Greater London Council and the West Kent Main Sewerage Board etc. Hence, the accrued experience of the Division in sewerage, sewage treatment and disposal extends back into the 19th century.

4) The greater part of the total flow is treated by the activated sludge process with the effluents fully nitrified. Nearly all sewage sludge is digested and disposed to sea or utilised on land.

5) Some 5 million tonnes at about 3% dry solids is disposed of to sea from four works. Sea disposal is licenced by the Ministry of Agriculture, Fisheries and Food under the Dumping at Sea Act (1974) which followed the London and Oslo Conventions (1).

6) The sludge is carried by a Fleet of five sludge vessels of an average capacity of 2.500 tonnes each. Each vessel has two crews of 12 who work one week on duty and one week off.

7) Subject to availability, the ships sail every tide to the dump ground, a round trip of about 150 Km taking 9 to 10 hours.

8) The areas of the dump are specified on the licence. The condition of the sea water in the area, the sea bottom and fish caught in the area are monitored independently by the Ministry as well as by the Authority.

9) The dumping operation of each ship takes about ten minutes. Strong currents and tidal action give excellent dispersion and, though disposal has been going on since 1890, there is no evidence of build up of material on the sea bottom.

10) The alternative of land utilisation and disposal for two of the four works from which sludge is taken to sea would pose problems of long hauls by a large number of road tankers through urban areas, adding to environmental pollution. Costs would also be appreciably greater as compared with sea disposal.

11) The 3 million cubic metres (wet) of digested sludge from the remaining sewage treatment works is, in the main, utilised on agricultural land in both liquid and dry form. Some of the lather has been utilised for land reclamation on tips and on motorway embankments.

12) Digested sludge intended for agricultural use is stored for two to four years after digestion in earth bank lagoons. During this period supernatant liquor is withdrawn and returned to the treatment works for full treatment. Thus the stored sludge is thickened, an average dry solids content of 6 to 10% being achieved. As capacity is made in the lagoons by removing the supernatant, the lagoon is topped up with thin digested sludge. During the final year no sludge is added, thus minimising the risk of pathogen, virus and parasite survival.

13) The largest installation is Perry Oaks Sludge Treatment Works adjacent to Heathrow (London) Airport and serving the Mogden Sewage Treatment Works (population 1.4 million). The treatment and disposal operations from this Works will be described as being generally typical for other works.

14) The operational area is 97 hectares and comprises 7 reception tanks, 11 lagoons varying in capacity from 75,000 cu.m. to 430,000 cu.m. and 30 hectares of drying beds of which 10 hectares are equipped with mechanical lifters, the remaining area having the dried sludge lifted by specially adapted excavators.

15) The whole site is sealed from water bearing strata by a clay layer.

16) The drying beds are formed of graded ash and clinker and underdrained, the drainage liquors being returned to the treatment works for full treatment.

17) The beds are filled with liquid digested sludge at about 3 - 4 % dry solids to a depth of 125 to 300 mm and lifted when dried, by atmospheric action, at between 40 - 70 % dry solids. At this time, the thickness is about 10 - 25 mm.

18) When lifted, the dried sludge may be stacked, where some further drying may occur, or taken direct to the site where it is to be utilised. A small quantity is heat treated, ground, bagged and sold locally.

19) Dried sludge is usually applied to agricultural land by tractor drawn farm machinery (e.g. moving floor manure spreaders).

20) The average quantity of sludge treated by air drying is 10,000 cu.m. per annum at an average dry solids content of 50%.

21) Liquid sludge is removed by pumping from lagoons to overhead tanks from which road tankers are loaded. As the level of sludge is lowered in the lagoon, because of its solids content and thixotropic nature, the sludge will not readily flow to the pumps situated at the side of the lagoon. At this stage, a tractor with blade is introduced to move the sludge to the pumps.

22) Care needs to be taken in the choice of tractor. The tracks of crawler tractors tend to lift stones from the bottom of the lagoon and mix them into the sludge thereby causing serious wear on the pumps. Once transported to site, the stones are likely to block valves or jam pumps on spreaders. They are also unacceptable to farmers on pasture land in large quantities. Tractors of the buoyant type are preferable (e.g. muskeg or swamp buggies). Alternatively, pumps mounted on pontoons may be used, but these are time consuming to erect and labour intensive in use because of the need to move them within the lagoon and to adjust the delivery hose to accomodate the movement.

23) The road tankers carry the sludge to farms where it is transferred to slurry spreaders for application to land. Several types of spreader have been used. Tractor drawn spreaders have proved satisfactory in dry weather and in wet weather on well drained land. At present, self propelled spreaders are being used which give a low ground loading. It is hoped that these will operate in winter conditions on most types of ground without damaging the soil structure or becoming bogged down.

24) This method of operation, detail of which is given later, has evolved over the years as sludge utilisation and disposal activities have been reviewed in the light of increasing knowledge or suspicions of environmental effects. The following commentary relates to Perry Oaks but is reasonably typical for other works.

25) From the mid 1930s when Perry Oaks, as the sludge treatment works for Mogden Sewage Treatment Works, became operational until about 1950, nearly all digested sludge was air dried and taken to agricultural land as a soil conditioner. (2)

26) However, treatment works' extensions to deal with increasing sewage loads and higher effluent standards led to increased sludge quantities and it was then that the system of earth banked lagoon storage and thickening was started to cope with the quantity of sludge in excess of the capacity of the drying beds.

27) The liquid sludge was also taken to local agricultural land as a soil conditioner. As quantities increased, at some times of the year, it would be laid thickly (up to 450 mm) and ploughed in when dry - which might take two to three years before the land was ready for cropping.

28) In the late 1960s planning authorities indicated that the sludge disposal method could not be considered "good agricultural practice" and hence fell under the provision of the Town and Country Planning Acts.

29) From this time, sludge was utilised on local horticultural and agricultural land and landfill sites by spreading at approx. 50 - 100 mm thickness. The sludge was applied direct from a road tanker, spread by a blade grader to give uniform thickness and then ploughed in. Sludge and soil samples were analysed periodically.

30) In 1971, the Agricultural Development and Advisory Service of the Ministry of Agriculture Fisheries and Food issued the results of research upon the effect of phyto-toxic metals (Zn, Cu, Ni) upon plant germination and growth. (3).

31) While this research was noted, the results of the pot experiments conflicted to such a degree with the practical experience that the predecessor authority continued to dispose of sludge in the manner discribed.

32) Interest was also being taken in the uptake of metals toxic to humans into crops. One source was considered to be from sludge from industrial areas applied to agricultural land. The predecessor Authority intensified its sludge and soil analysis programme and avoided those lands with high metal content.

33) In 1977, a Government working party reported with "Guidelines", on the addition of element to soils which might be found in sewage sludge (4).

34) Of the various metals referred to in the report, Cadmium was the only human toxic one which gave some cause for concern with respect to the sludges from Perry Oaks.

35) Thames Water designed a completely new operating method for the disposal of sludge to agricultural land from the Metropolitan Works under the title "Thamesgro". One works (Hogsmill) continued a direct labour operation but carried out to "Thamesgro" standards. (5)

36) The basic priciples were:-

1) The soil background levels for toxic metals upon which the maximum additions in the Guidelines were based must not be exceeded.
2) Sludge would be applied at such a rate as to provide the nitrogen requirement of the crop.
3) As far as practicable a service should be provided to Farmers and all operations must be in accordance with good agricultural practice.
4) Monitoring analysis of sludges, soils before and after sludge application and of crops should be greatly intensified and recorded in detail.

37) The consequences of this policy were that:-

1) Land had to be found which had not previously been sludged. Hence, haulage distances were increased with consequent increase in the number of road tankers.
2) Meeting the guidelines on metals required applying sludge at much lesser depth (10mm) than previously.
3) Long haulage distances required large capacity tankers and larger numbers because of the consequently longer turn round periods. These heavy tankers could not be used to apply the sludge to land, especially in wet weather.

4) Consequently, spreading machinery suitable for farm conditions was required.

5) To gain the optimum return on the heavy capital investment in tankers and plant all year round working was resorted to.

38) It was decided to let a two year contract with provision for some development of methods in operation as there was no previous experience on which to call.

39) As hauls up to 60 Km were involved articulated tankers were employed to obtain maximum return on the investment.

40) Agricultural plant was used for spreading. Initially experimentation was required to adjust jets and splash plates to obtain the correct doseage and even spread.

41) With the more arduous working of spreaders than in normal agricultural use, strengthening of chassis proved necessary.

42) The spreader initially used proved unsuitable for winter working except on very well drained soils. Two wheel drive tractors had to be replaced for this type of going with four wheel drive units.

43) A different type of spreader, suitably strengthened and having a single axle instead of tandem axles, proved more suitable for winter work.

44) A new organisation had to be set up to find farmers willing to accept sludge, manage the contract, ensure compliance with Thames Water policy and to monitor soils and sludge quality and to record the work done.

45) To this end

1. A Farmer Relations section was set up to find farmers, arrange that the farmer received his sludge when and where he required it and that the required dose of nitrogen for the crop was provided.

2. The Contracts Manager supervised the contract which was monitored on site by field Inspectors who were also charged with the duty of maintaining the continuity of the operation and output.

46) The results of sludge analysis, quantity of sludge applied, the results of analysis of soils before and after application together with the location were recorded. The volume of data involved required the use of a computer.

47) Whereas previously all operations had taken place within the Divisions' boundary, going further afield meant encroaching on other Divisions' Territory. A method of communication was set up to prevent conflict of interest and to ensure that River divisions could ensure that Water resources were not liable to contamination.

48) For Perry Oaks' sludge, cadmium was the limiting factor controlling the quantity of sludge to be applied. While this did not prevent the required nitrogen application being met it did mean that the "land resource" would be used up more rapidly than desirable.

49) Clearly, the higher the metal content of a sludge the smaller the quantity that can be spread over a given period on a field before the permitted background level in the soil is reached and new land has to be found, thus increasing, the haulage distance and hence the cost.

50) To ameliorate this situation as far as possible, a survey of the drainage circus areashas been made to locate the sources of cadmium and their respective loads.

51) The total quantity received at the Mogden Works was 9 kg per day, of which 2 kg was attributable to domestic sources.

52) An investigation was also carried out to discover what pre-treatment processes were available for metal removed and what lower limit in the effluent was reasonably attainable.

53) As a result a concentration of 1 mg/kg cadmium appeared attainable in trade effluent discharges.

54) Trade dischargers were visited by Trade Effluent Officers and the problem discussed. Traders were informed that a limit of 1 mg/kg would be included in their consent as soon as legally possible.

55) For forty years or more, the quality of trade effluents in the area have been licenced under legislation covering the drainage of trade premises. Consents to discharge are issued to all traders and quality limits set for the trade effluent.

56) Under the legislation, consents may be changed two years after issue by direction. Many traders have taken remedial action before the direction has been issued.

57) The result is that within three years of informing traders of the proposed limit, the cadium load received at Mogden has dropped to 5 kg per day of which 2 kg is of domestic origin.

58) CONCLUSION

1) . The choice of method for disposal of sludge in the Divisional area is matter of economics for each treatment Works. The works to the East send sludge to sea, at present the most economic for their situation.

2) To the West, utilisation on land is the most economic in the circumstances obtaining at these Works.

3) Sewage sludge is a valuable natural resource of nitrogen and phosphorus and, to a lesser degree, potash. It is also a soil conditioner.

4) Control of trade effluents should be used to reduce so far as practicable elements unacceptable for agricultural use.

5) Sewage sludges should preferably be digested and stored before application to minimise nuisance and risk from pathogems, viruses and parasites.

6) There is a serious lack of knowledge of the mechanism of the up take of metals into crops, the safe limits for human and animal intake and effects upon crop germination and growth.

7) Without reliable data, it is wise to set cautious limits on metals where human health is concerned but practical experience of many years should be taken into account where crops and animal health are concerned.

8) National - or preferably international - guidelines should be set at realistic but safe limits in the light of current knowledge- such as it is.

9) Authorities responsible for the utilisation of sludge on agricultural land should comply so far and as nearly as possible to those guidelines, especially if human health is likely to be affected. They should also, as quickly as possible, take steps to meet the guidelines fully (e.g. through the control of trade effluents)

10) The setting of guidelines which are unreasonable will be self defeating for no authority can afford excessive expenditure in meeting a limit for which there is little or no evidence for its justification.

11) Continuing research is required into the environmental impact of sludge on agricultural land. Ideally, this research should be carried out on agricultural land with sludges using agricultural practices - not in laboratories on pot plants using metal salts. Sludge/soil mixtures should be used in this work.

12) Monitoring of the application of sludge to agricultural land by analysis of sludges, soils before and after application and of crops grown will add to the knowledge of the impact of sludge utilisation.

13) Until more knowledge is obtained, the safest control is to set a maximum level of toxic metal in the soil and at the same time monitor the level in the crop.

ACKNOWLEDGEMENT

The views expressed in this paper are those of the Author. The paper is presented with the permission of the Director of Operations, Thames Water Authority. The Author thanks the members of staff who helped in the preparation of the paper.

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SLUDGE GENERATION, HANDLING AND DISPOSAL AT PHOSPHORUS CONTROL FACILITIES IN ONTARIO

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Summary

This paper identifies experiences in sludge quantity changes due to metal salts addition for phosphorus removal at primary and conventional activated sludge plants in Ontario. A survey of Ontario plants has shown that for P-removal to 1.0 mg $P.L^{-1}$ an average sludge volume increase of 60% for primary plants and 35% for secondary plants occurs.

The problem of sludge quantity estimation based on stoichiometry, bench scale and pilot scale data is illustrated.

The Ontario survey also shows that incineration, application to agricultural land and disposal to landfill are the three major prevailing sludge disposal practices, accounting for 40%, 34% and 23% of all sludge produced, respectively. Problems and beneficial effects of sludge disposal to agricultural land are summarized. Sludge application rates to 11 300 ha averaged 5 $t.ha^{-1}.a^{-1}$. For an average haulage distance of 10.4 km the 1975 cost averaged $47 per ton of sludge. The two most frequent problems related to sludge disposal on land were identified to be odour and sludge transport. Information obtained from farmers surveyed indicates that due to increased crop yield and cattle weight gain, the net benefit of sludge use on agricultural land approximates $2 and $3 million dollars per year.

Based on the average nutrient and heavy metal concentrations in the sludges surveyed, less than 50% of the Ontario sludges meet the criteria of the Ontario provisional guidelines for sludge utilization on agricultural lands.

Where, in the absence of any data, an estimate of sludge volume from a conventional activated sludge plant with phosphorus removal to 1 mg $P.L^{-1}$, using metal salt addition, is required, the rule-of-thumb that sludge volume approaches 0.5% of the influent hydraulic load is a good first approximation.

1. INTRODUCTION

The design of sludge handling and disposal facilities is generally the most neglected aspect of wastewater treatment facility design. This is not without reason. The most frequent excuse given is that we have no idea how much sludge will be produced and what the sludge characteristics may be. As well, in many instances no clear strategy concerning the final sludge disposal or utilization option to be pursued is identified. In general, the concern regarding sludge quantities, handling and disposal is proportional to population density, and the degree and complexity of industrialization.

This paper will focus on providing information on the effect of adding metal salts to existing wastewater treatment plants for phosphorus removal to 1 $mg.L^{-1}$ total and as it impacts on sludge quantity, handling and disposal/utilization.

2. SLUDGE QUANTITIES PRIOR TO ANAEROBIC DIGESTION

Waste treatment process design engineers are continually plagued by lack of information when it comes to designing sludge handling and disposal/utilization facilities. Sludge production is influenced by a number of variables.

For conventional primary plants influent solids, overflow rate, temperature and general waste characteristics influence the quantity of sludge which will require handling and disposal.

When chemicals are added to primary plants, additional factors such as type of chemical, chemical dosage and point of chemical addition influence the sludge quantities produced.

For biological sludge production, the type of process used in the conversion of substrate (hence SRT), the nature of substrate oxidized and nutrient availability, all affect the amount of biomass produced. Because the auto-oxidation rate depends on temperature, higher sludge volumes result in winter than in summer.

The total volume of sludge produced from biological and physical/chemical systems, or any combination thereof is also influenced by clarifier performance, sludge recycle and the degree of operator attention to the system.

A most useful method of sludge quantity estimation consists of performing a mass balance around various treatment process components and coupling this with process efficiency assumptions (1). Calculations to determine chemical sludge quantities based on stoichiometric relationships is another popular approach (2). Bench scale and pilot scale studies would appear to provide more specific information which can be used in the design of full scale sludge handling and disposal/utilization facilities.

Examples of data from bench scale, pilot scale and full scale treatment systems will illustrate some of the difficulties associated with sludge quantity determinations.

Much of the full scale data reported herein is taken from a 1975 survey of 185 Ontario wastewater treatment plants. Records of sludge production prior to the implementation of phosphorus removal technology were compared with plant records following the installation of phosphorus precipitation systems (3). Data concerning sludge characteristics and disposal/utilization practices are also summarized.

2.1 Conventional Primary Plants

Figure 1 summarizes the data from 15 conventional, primary plants (without precipitant addition) surveyed covering a range of hydraulic loadings from 1200 to 5000 $m^3.d^{-1}$. The data show that 50% of time approximately 2 m^3 of sludge are produced for each 1000 m^3 of wastewater treated. This translates to 114 kg dry solids for each 1000 m^3 treated (Figure 2). The total solids concentrations of the raw primary sludges varied from 3.5 to 8% with a mean of 5.7%.

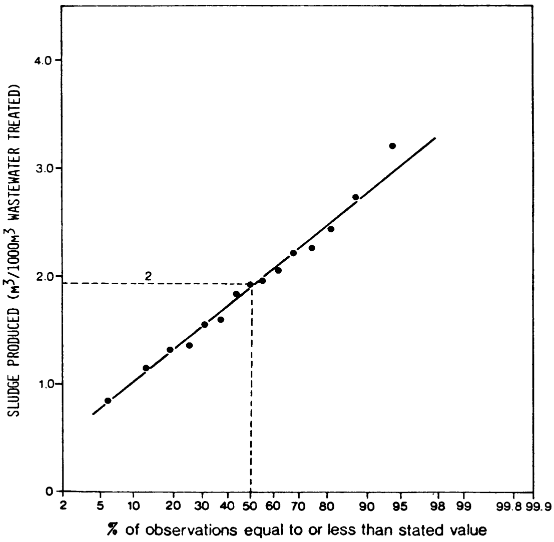

FIGURE 1. SLUDGE VOLUME PRODUCED AT CONVENTIONAL PRIMARY PLANTS (3).

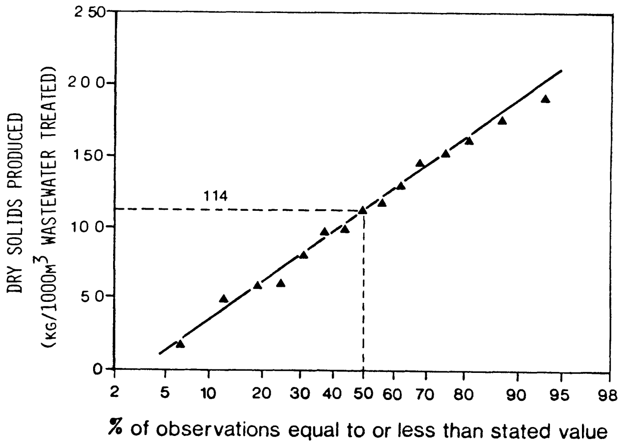

FIGURE 2. SLUDGE MASS PRODUCED AT CONVENTIONAL PRIMARY PLANTS (3).

2.2 Upgraded Primary-Plants

Upgraded plants are defined as those plants where chemicals are added for phosphorus removal to achieve an effluent total phosphorus concentration of 1.0 $mg.L^{-1}$. Influent total phosphorus concentrations are 6.8 $mg.L^{-1}$ (4).

2.2.1 Full scale - Camp Borden

A full scale phosphorus removal study was conducted at the primary wastewater treatment plant at Borden (5). The study lasted ten months and covered three phases of chemical addition for phosphorus removal using lime, alum and ferric chloride. While the major objective of that study was to determine the optimum phosphorus removal precipitant and its dosage to achieve an effluent P objective of 1 $mg.L^{-1}$, information on sludge production under various operational conditions was also collected. These data as summarized in Table I were compared to calculated sludge production values and are shown as a frequency distribution in Figure 3. In this case, the amount of sludge produced was overestimated by 28%, 50% of the time.

2.2.2 Full Scale - Ontario Survey Data

As effluent objectives become more stringent, treatment process complexity increases and sludge quantities increase as well.

For example, the impact of chemical addition for phosphorus removal at primary plants is illustrated in Figures 4 and 5 for seven upgraded plants. In these plants, the average sludge solids concentration decreased from 6.0 to 5.3% after chemical addition. The sludge volume increased by 60% whereas the sludge mass increased by 40%.

TABLE I CAMP BORDEN SLUDGE PRODUCTION - PRIMARY PLANT (5)

P-Removal Precipitant		Sludge Mass Produced				Ratio of Measured to Calculated Value
Chemical	Dosage	Calculated		Measured		
-	$mg.L^{-1}$	$kg.d^{-1}$	$g.m^{-3}$	$kg.d^{-1}$	$g.m^{-3}$	
Baseline	-	116	26	191	42	1.65
	151[1]	1186	261	1148	253	0.97
Lime	197	1389	306	1400	308	1.01
	275	3184	643	1697	343	0.53
	210	1876	386	1399	288	0.76
	4.4[2]	201	52	332	86	1.65
Alum	7.5	385	102	283	75	0.74
	14.8	645	173	253	68	0.39
	18.5	604	160	294	78	0.49
	9.6[3]	290	76	304	80	1.05
Ferric	14.6	321	87	307	83	0.96
Chloride	19.0	502	133	312	83	0.62
	26.6	515	138	343	92	0.67

[1] as $CA(OH)_2$
[2] as Al^{3+}
[3] as Fe^{3+}

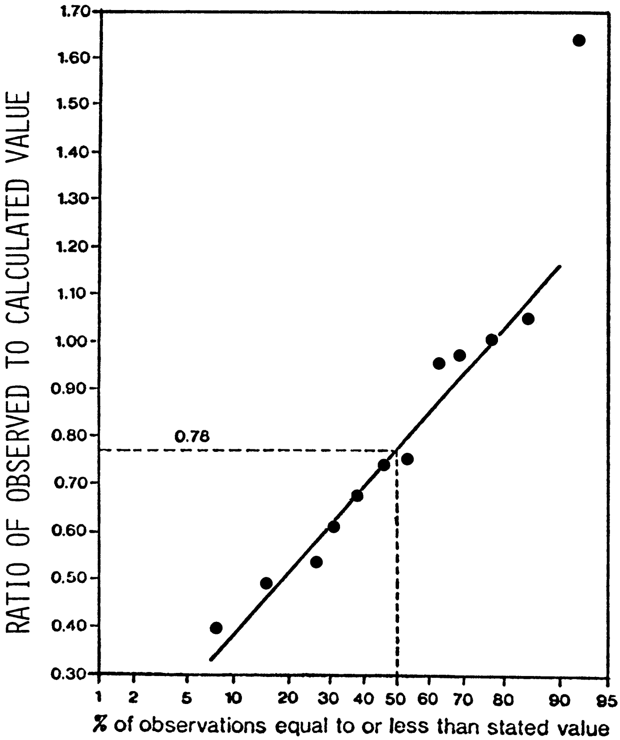

FIGURE 3. OBSERVED TO CALCULATED SOLIDS PRODUCTION RATIO - PRECIPITANT ADDITION TO A FULL SCALE PRIMARY PLANT (5)

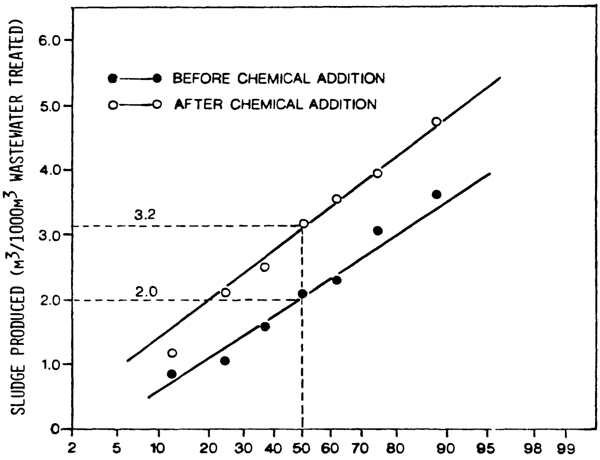

FIGURE 4. SLUDGE VOLUME PRODUCED AT PRIMARY PLANTS PRIOR TO AND AFTER METAL SALT ADDITION (3)

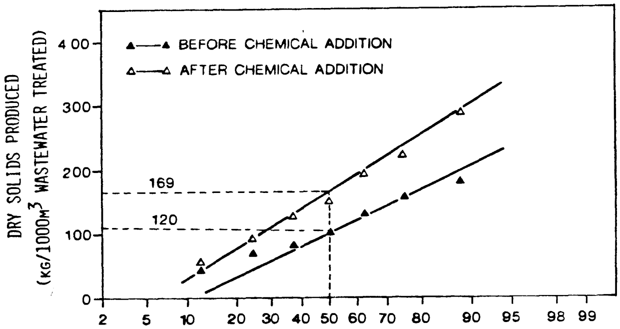

FIGURE 5. SLUDGE MASS PRODUCED AT PRIMARY PLANTS PRIOR TO AND AFTER METAL SALT ADDITION(3).

2.2.3 Use of lime

Because few Ontario plants practice P removal using lime, no substantive data base for sludge quantity estimation exist. However, based on past experience at a number of pilot and full scale facilities practicing P removal using lime, reasonable estimates of sludge production can be made.

The mass of sludge produced will depend largely on the wastewater alkalinity and the lime dosage required to attain a specific pH at which target P effluent level is achieved.

Figure 6 illustrates that, having determined the pH at which the P effluent target will be achieved, the correlation will predict the required lime/alkalinity ratio. Knowledge of the wastewater alkalinity enables calculation of the required lime dosage (6). Another correlation (7) for raw wastewaters from 20 Ontario municipalities indicating lime dosage requirements to attain pH 10 and 11 for various alkalinity values is shown in Figure 7.

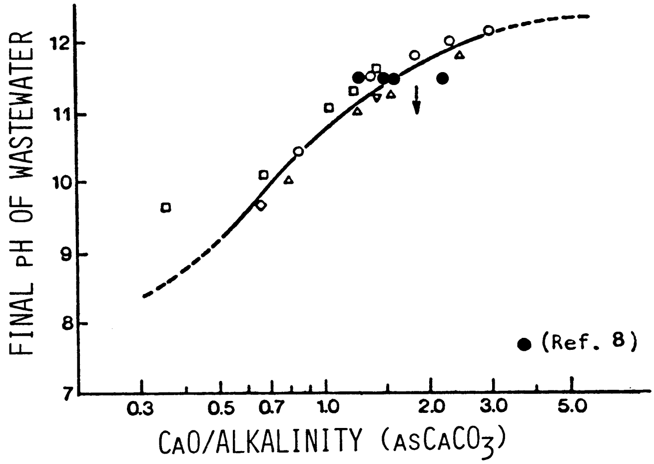

FIGURE 6. LIME DOSAGE - ALKALINITY, pH RELATIONSHIP (6).

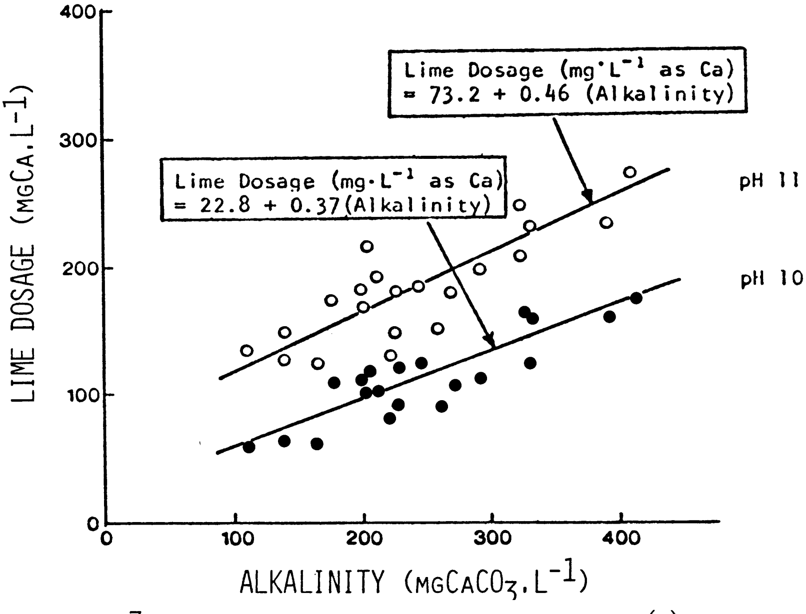

FIGURE 7. LIME DOSAGE VS. WASTEWATER ALKALINITY (7).

Brouzes (8) in his bench scale experiments examined the use of lime in the treatment of municipal wastewaters and also monitored sludge production. Figure 8 illustrates sludge production as a function of pH for the municipal

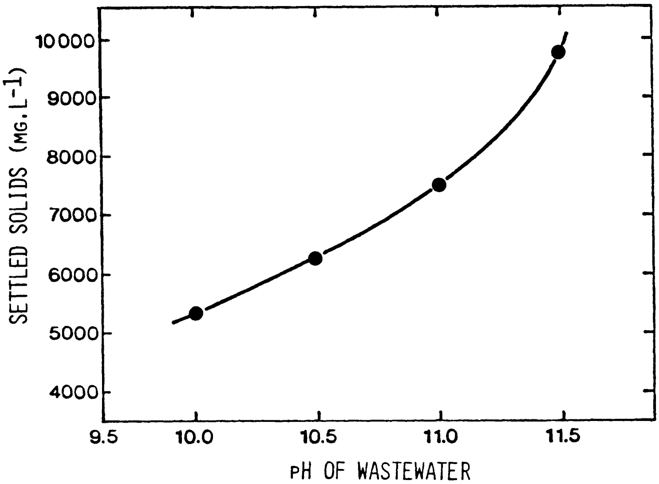

FIGURE 8. SLUDGE VOLUME AS A FUNCTION OF PH DURING LIME ADDITION FOR PHOSPHORUS REMOVAL (8)

sewage from Beaconsfield, Quebec.

At a tertiary treatment facility for P removal at Ely, Minnesota, the sludge volume due to lime addition for P removal to extremely low levels (0.05 $mg.L^{-1}$ at pH 12) increased by 700% (9).

The available information in the literature quite clearly demonstrates that for lime treatment systems sludge volumes are many times greater than for any other treatment process. This may not necessarily result in a disposal problem inasmuch as lime can be recovered from the sludge and reused in the process. In this case it would be more of a materials handling problem.

2.2.4 Summary - Sludge quantities from primary plants

The information as it relates to full scale plant data previously presented is summarized in Table 11. Chemical addition for total phosphorus removal to 1.0 $mg.L^{-1}$ using metal salts resulted in a 60% sludge volume increase.

TABLE II SLUDGE PRODUCTION DATA FROM PRIMARY PLANTS (3)

Description	Units	Sludge Production		
		Prior to Chemical Addition	After Chemical Addition	Percent Change
Volume	$m^3/1000m^3$	2.0	3.2	+ 60
	$L.capita^{-1}.d^{-1}$	1.3	2.1	-
	% of influent Q	0.20	0.32	-
Mass	kg/1000 m^3	120	169	+ 40
	$g.capita^{-1}.d^{-1}$	77	109	-
Solids	percent	6.0	5.3	|-0.7|
Number of Plants	-	7	7	-

2.3 Principles of Biological Sludge Production

Sludge quantities can be estimated from bench and pilot scale data when considering biological principles. Figure 9 shows that normally micro-organisms experience a growth history which consists of 3 phases. A logarithmic (a - b) a declining growth (b - c) and an auto-oxidation (c - d) phase. The net accumulation of sludge due to this synthesis and oxidation can be expressed by:

$$\text{kg VSS produced/day} = a(\text{kg BOD}_5 \text{ removed/day}) - b(\text{kg MLVSS}) \qquad (1)$$

where:

a = the fraction of BOD_5 removed and synthesized to new sludge

b = the mean rate of auto-oxidation (endogenous respiration) as a fraction per day

MLVSS = kg of MLVSS under aeration

In addition there are usually non-oxidizable volatile solids present. These and the inert particulate solids leaving the primary sedimentation tank are assumed to be trapped in the sludge and hence, must be taken into account when calculating the total amount of sludge production.

It is convenient to express equation (1) in the general format of:

$$y = mx - b \qquad (2)$$

$$\frac{\text{kg VSS produced/day}}{\text{kg MLVSS}} = a \, \frac{\text{kg BOD}_5 \text{ removed/day}}{\text{kg MLVSS}} - b$$

Data obtained from bench and pilot scale studies is arranged and plotted as shown in Figure 10. This then facilitates the calculation of constants a and b. Constants a and b are only constant for a particular wastewater under

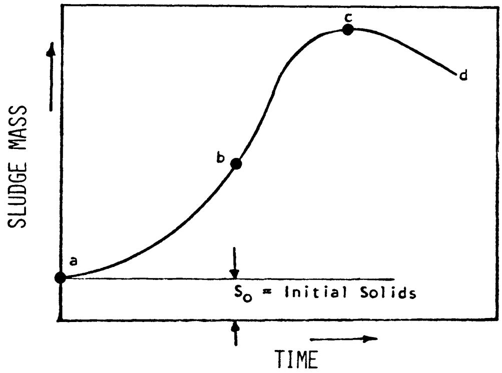

FIGURE 9. SLUDGE GROWTH

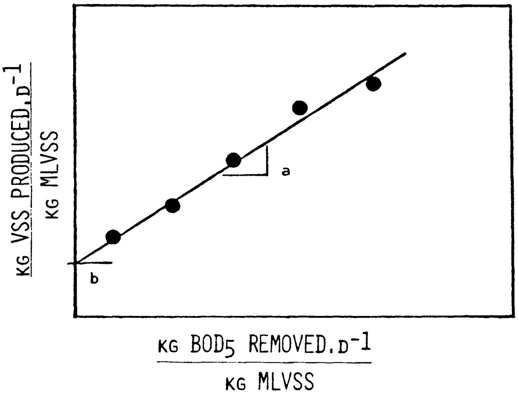

FIGURE 10. SYNTHESIS AND ENDOGENOUS RESPIRATION CONSTANTS

specific process conditions, and must be derived for each design situation. Past experience has shown that a may vary from 0.5 to 0.7 and b from 0.04 to 0.1 day^{-1}.

It was noted earlier that the amount of sludge produced is very much dependent on the SRT. The SRT being defined as:

$$SRT = \frac{\text{amount of volatile solids in the aeration tank}}{\text{amount of volatile solids removed daily from the system}} \quad (3)$$

$$SRT = \frac{VC_1}{Q_w C_2 + QC_3} \quad (4)$$

where:

V	= aeration tank volume	m^3
Q_w	= sludge wastage rate	$m^3.d^{-1}$
Q	= influent flow	$m^3.d^{-1}$
C_1	= MLVSS	$mg.L^{-1}$
C_2	= underflow VSS	$mg.L^{-1}$
C_3	= effluent VSS	$mg.L^{-1}$

Experience has shown that the activated sludge process is best controlled by attempting to maintain a constant SRT. Generally speaking the SRT may be anywhere between 3 and 12 days. Figures 11 and 12 show examples of solids

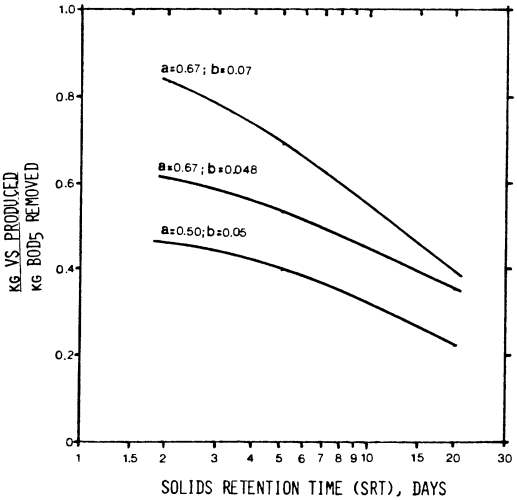

FIGURE 11. SLUDGE PRODUCTION FOR DIFFERENT WASTEWATERS (10).

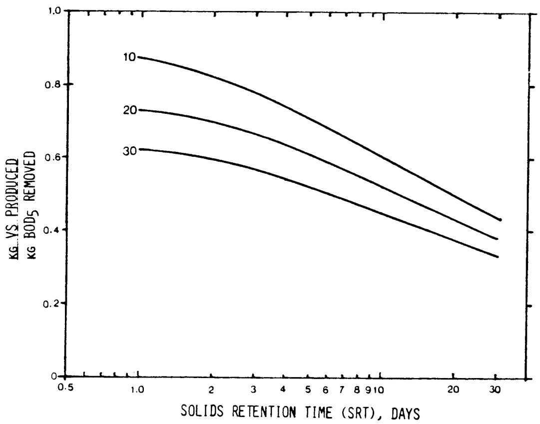

FIGURE 12. SLUDGE PRODUCTION AT DIFFERENT TEMPERATURES (10).

production as a function of SRT for different wastes and as affected by temperature, respectively.

2.4 Conventional Biological Plants

The literature abounds with sludge production data from biological treatment plants. Figure 13 is just one example for municipal sludges and illustrates the degree of variability, which can be in excess of 100%. In this case sludge production for various aerobic biological treatment processes is shown.

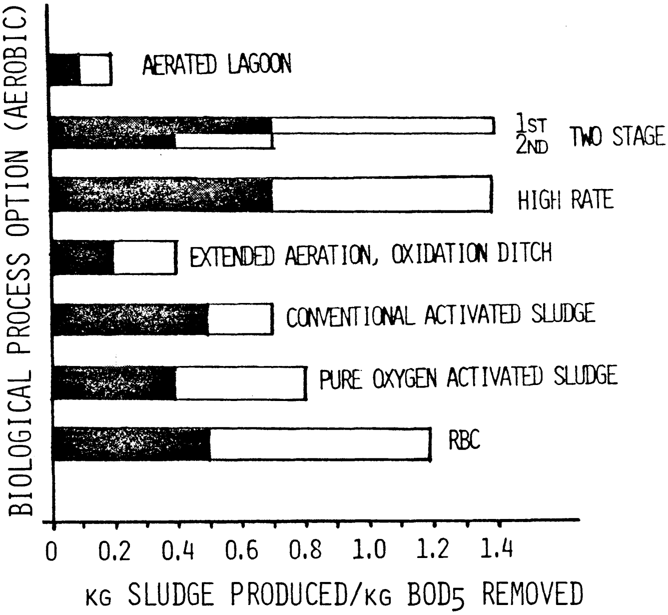

FIGURE 13. BIOLOGICAL SLUDGE PRODUCTION (11)

Sludge production data from 42 secondary plants in Ontario using the conventional activated sludge process were analyzed. The plants have flow capacities ranging from 1400 to 770 000 $m^3.d^{-1}$. The raw sludge produced consists of both primary and waste activated sludge. In the case of conventional activated sludge plants, Figure 14 shows that 50% of the time at least 3.9 m^3 of sludge are produced per 1000 m^3 treated. Solids concentration varied from 2 to 7%, with a weighted average of 4.6%. Similarly, the dry weight of solids produced at conventional activated sludge plants was equal to or less than 179 kg dry solids per 1000 m^3 of wastewater treated, 50% of the time (Figure 15).

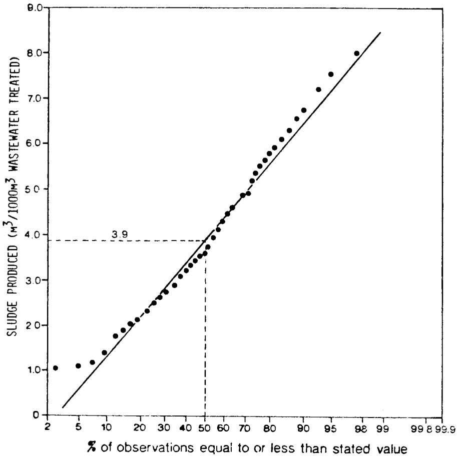

FIGURE 14. SLUDGE VOLUME PRODUCED AT CONVENTIONAL ACTIVATED SLUDGE PLANTS (3)

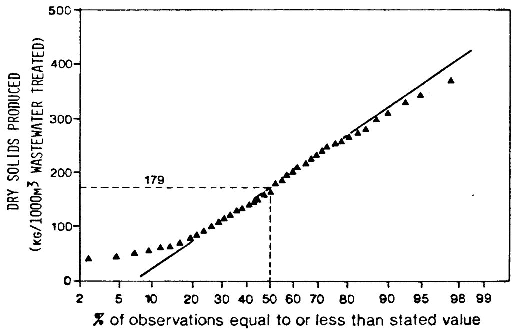

FIGURE 15. SLUDGE MASS PRODUCED AT CONVENTIONAL ACTIVATED SLUDGE PLANTS (3)

2.5 Upgraded Biological Plants

As with the primary upgraded plants, upgrading is defined as chemical addition of metal salts to attain an effluent total phosphorus objective of 1.0 $mg.L^{-1}$. In the case of biological plants this involves simultaneous precipitation.

2.5.1 Observed vs stoichiometric results - pilot scale

A long-term pilot scale study for the removal of phosphorus and nitrogen (12) was conducted at the Wastewater Technology Centre (WTC). Sludge production was monitored over a 16-day consecutive period. Comparing the observed to calculated sludge production values for ferric iron addition based on stoichiometric relationships shows that the actual sludge production was underestimated by 65%, 50% of the time. This point is illustrated in Figure 16.

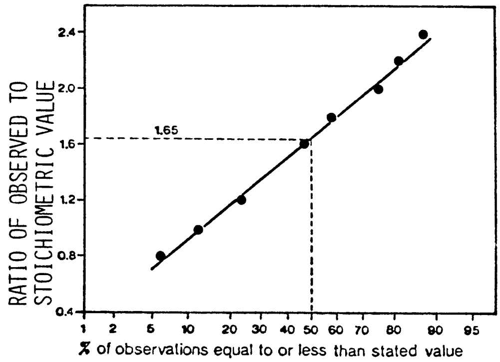

FIGURE 16. OBSERVED TO STOICHIOMETRIC SOLIDS PRODUCTION RATIO - FERRIC IRON ADDITION AT A NITROGEN AND PHOSPHORUS REMOVAL ACTIVATED SLUDGE PLANT (11)

2.5.2 Full scale - Ontario survey data

Sludge production data were obtained from a 1975 survey of Ontario wastewater treatment plants. In a number of instances, it was possible to compare sludge production prior to phosphorus removal to sludge production following installation of phosphorus precipitation systems (3).

Sludge production data for 15 secondary biological plants, upgraded to include phosphorus removal, (primary + waste activated + chemical sludge) are illustrated in Figures 17 and 18.

Fifty percent of the observations showed a solids production equal to or less than 173 kg dry solids per 1000 m^3 before chemical addition. This increased to 217 kg of dry solids per 1000 m^3 after chemical addition and represents a 26% increase in sludge mass. The sludge volume increased by 35%. Following precipitant addition, the average total solids concentration decreased from 4.5 to 4.2%.

While in Ontario metal salts are generally added to the aeration tanks, data analyzed from four installations where metal salts were added to the primary settling tank showed a decrease in solids produced. In this in-

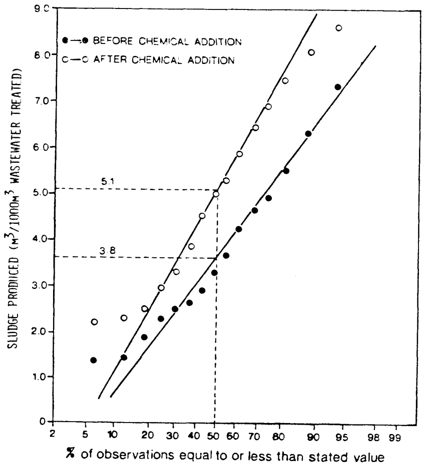

FIGURE 17. SLUDGE VOLUME PRODUCED AT CONVENTIONAL ACTIVATED SLUDGE PLANTS PRIOR TO AND AFTER METAL SALT ADDITION TO AERATION TANK(3).

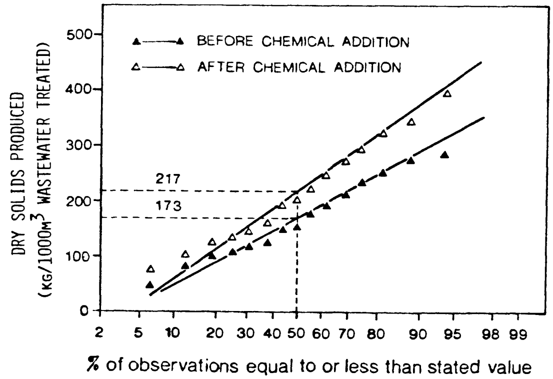

FIGURE 18. SLUDGE MASS PRODUCED AT CONVENTIONAL ACTIVATED SLUDGE PLANTS PRIOR TO AND AFTER METAL SALT ADDITION TO AERATION TANK (3).

stance, the lower organic loading to the aeration tank due to additional organics removed in the primary, resulted in reduced biosynthesis.

It must be recognized that aside from reduced phosphorus concentrations in the effluent, there are additional benefits when chemicals are added.

In the case of metal salt addition these benefits would consist of lower SS, lower BOD_5, lower heavy metal and lower toxics levels. When lime is added similar benefits are realized. As well, additional advantages consist of a disinfected effluent, enhanced sludge dewatering characteristics and tie-up of heavy metals in the sludge flocs. On the other hand, the disposal/utilization of this sludge now concentrated with some of the undesirable constituents may pose a problem.

2.5.3 Summary - Sludge quantities from activated sludge plants

Sutton (12) underestimated sludge production by 65% when using stoichiometric relationships for a biological system with chemical addition.

From our experience, the best data base for sludge production exists in the Ontario survey of full scale treatment plants (3). The data presented in earlier figures are summarized in Table III for activated sludge plants.

TABLE III SLUDGE PRODUCTION DATA - FROM ACTIVATED SLUDGE PLANTS (3)

Description	Units	Sludge Production		
		Prior to Chemical Addition	After Chemical Addition	Percent Change
Volume	$m^3/1000m^3$	3.8	5.1	+ 35
	$L.capita^{-1}.d^{-1}$	2.5	3.4	-
	% of influent Q	0.38	0.51	-
Mass	$kg/1000m^3$	173	217	+ 26
	$g.capita^{-1}.d^{-1}$	114	145	-
Solids	percent	4.5	4.2	|- 0.3|
Number of Plants		15	15	-

2.6 Sludge Quantity Prediction for Lower Than 1 $mg.L^{-1}$ Effluents P Targets

The aforenoted information does not address the question of "how much more sludge would be generated when imposing point source controls for effluent total phosphorus concentrations of 0.5 $mq.L^{-1}$?" Or for that matter for BOD_5 and SS concentrations of 3 to 5 mg. L^{-1}.

A recent document (13) made a first attempt at answering this question by reporting on a computer simulation of required process modifications to meet various point source P control scenarios and the resulting sludge quantities. Figure 19 is a typical illustration of the dramatic increases in sludge mass over baseline conditions of no phosphorus removal. The example shows a simulation for 17 Canadian plants in the Lake Ontario drainage basin and represents a total flow of 2.6×10^6 $m^3.d^{-1}$ for a sewered population of 3.8 million persons. The simulation predicts a sludge mass increase of 34% over baseline conditions (no chemical addition) for an effluent total phosphorus concentration target of 1.0 $mg.L^{-1}$.

This prediction compares favourably with the 1975 Ontario sludge survey data (3) indicating a 26% sludge mass increase. Treatment process modification required to attain an effluent objective of 0.1 $mg.L^{-1}$ total phosphorus predicts a 108% increase in sludge mass over baseline levels (no chemical addition).

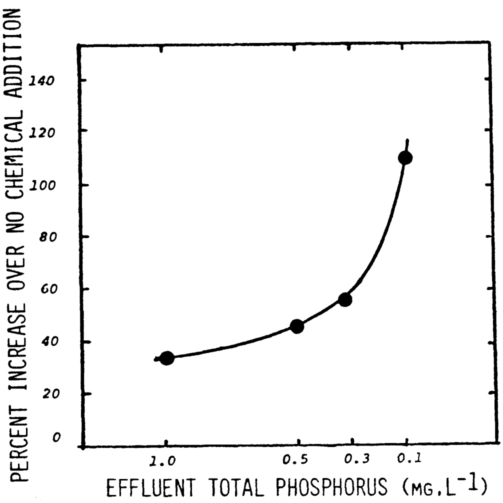

FIGURE 19. INCREASE IN SLUDGE MASS DUE TO CHEMICAL ADDITION TO MEET VARIOUS EFFLUENT TOTAL PHOSPHORUS TARGETS

3. SLUDGE DIGESTION

Before sludges can be disposed of in Ontario, they are digested. In general, sludges from Ontario phosphorus removal facilities have been found to be readily digestible in both existing aerobic and anaerobic digesters. Initial digester problems which were experienced could be related to the increase in sludge loading rather than the nature of the sludge itself. This increased digester loading resulted in inadequate heat exchanger capacity leading to operational problems caused by reduced digester temperature. Digester (primary) foaming due to increased volatile solids loading and inadequate gas/liquid separation has in some cases led to further operational problems.

Inhibitive effects due to accumulated metal salts have never been experienced. In one case (14), digester operation was completely disrupted due to erratic lime dosing for phosphorus removal during start-up. This resulted in periodic massive doses of high pH sludge being pumped to the digester until the digester's buffering capacity was exceeded.

Later, under continuous operation, the digester was found to operate very effectively provided a sludge blanket of 30-50 cm was maintained in the clarifier. This partially neutralized the raw sludge to a pH of 8.5-9.0.

Phosphorus resolubilization within the digester has been found to be insignificant in relation to the total plant loading, regardless of the chemical used.

4. SLUDGE QUANTITIES AFTER ANAEROBIC DIGESTION

The sludge production data summarized earlier, facilitates the design of sludge handling and volume reduction facilities. When designing facilities for ultimate disposal, the sludge volume after digestion must be known. Such data are difficult to obtain. In many instances, this can be attributed to incomplete records concerning volume of sludge disposed of, as well as problems associated with solids concentration determinations.

4.1 Conventional Primary Plants

The Ontario survey (3), while incomplete, provides the best, currently available data base on this subject. The data relating sludge volumes disposed from standard primary plants practicing anaerobic digestion to population served were subjected to regression analysis (Figure 20).

The equation expressing this relationship in m^3 per year for 17 plants is shown as:

$$\text{Sludge Disposed } (m^3.a^{-1}) = 76.73 \text{ (population x } 10^{-3})^{1.131} \quad (5)$$

Figure 20 illustrates the fact that digester problems will result in substantial increases in sludge volumes requiring disposal.

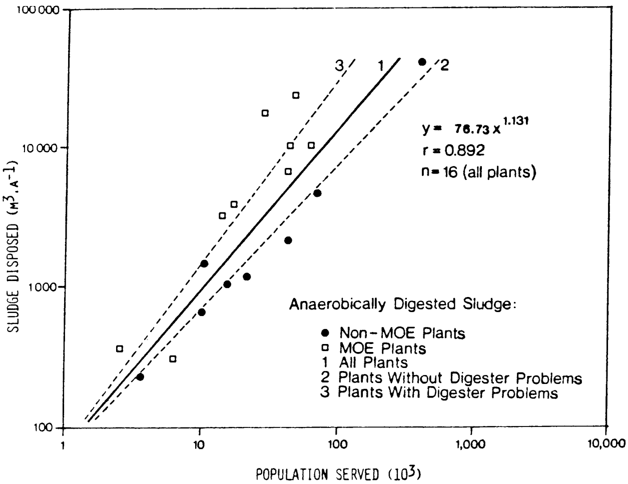

FIGURE 20. SLUDGE VOLUME DISPOSED AT CONVENTIONAL PRIMARY PLANTS (3)

4.2 Upgraded Primary Plants

The data base for upgraded primary plants and the resulting sludge quantities after anaerobic digestion was inadequate for analysis.

4.3 Conventional Biological Plants

Figures 21 and 22 illustrate from the available Ontario data (3) relationships between volume or mass of sludge to be disposed of as a

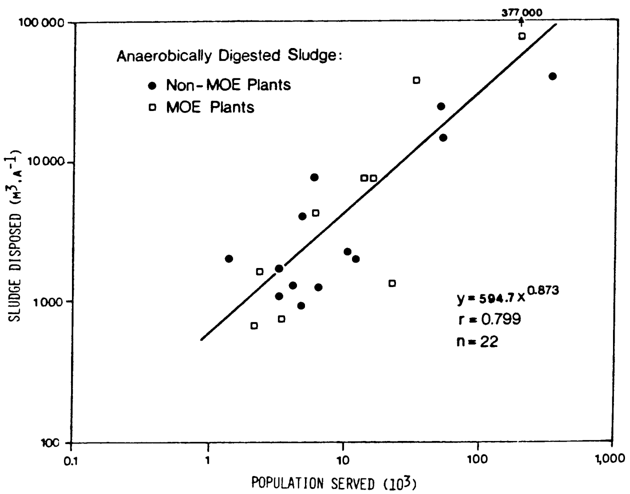

FIGURE 21. SLUDGE VOLUME DISPOSED AT CONVENTIONAL ACTIVATED SLUDGE PLANTS (3).

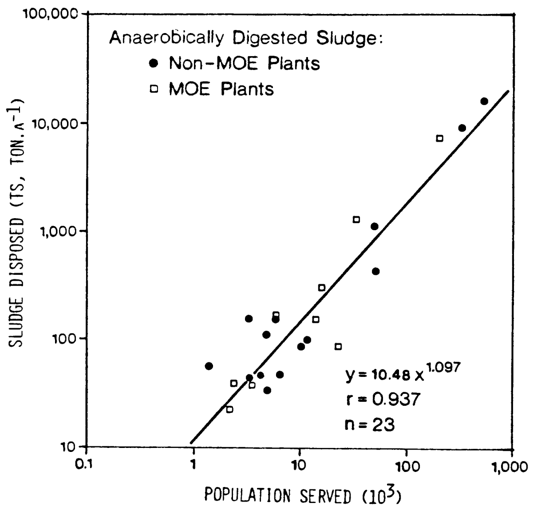

FIGURE 22. SLUDGE MASS DISPOSED AT CONVENTIONAL ACTIVATED SLUDGE PLANTS (3).

function of population served. The data pertain to sludge from conventional activated sludge plants after anaerobic digestion.

4.4 Upgraded Biological Plants

Similarly, Figure 23 and 24 show sludge volume and mass as functions of population served after anaerobic digestion of sludge from conventional activated sludge plants upgraded for total phosphorus removal to 1.0 $mg.L^{-1}$.

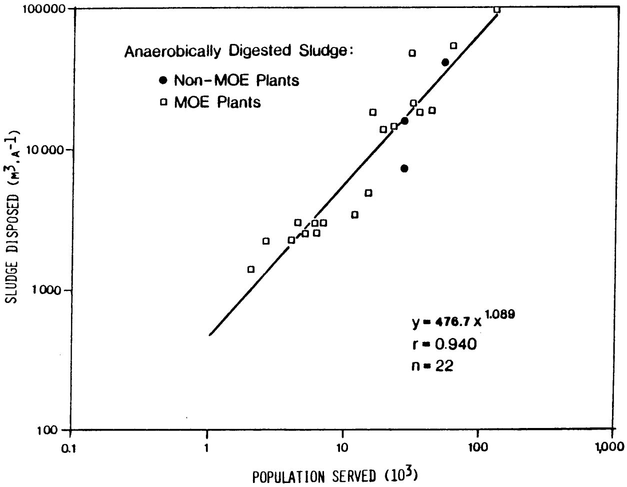

FIGURE 23. SLUDGE VOLUME DISPOSED AT CONVENTIONAL ACTIVATED SLUDGE PLANTS UPGRADED FOR P REMOVAL TO 1 $MG.L^{-1}$ (3)

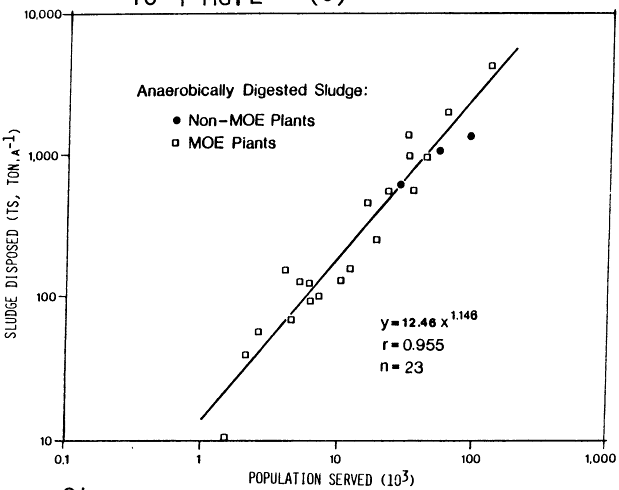

FIGURE 24. SLUDGE MASS DISPOSED AT CONVENTIONAL ACTIVATED SLUDGE PLANTS UPGRADED FOR P REMOVAL TO 1 $MG.L^{-1}$ (3)

The equations for the various functions shown in Figures 21 to 24 are summarized in Table IV.

TABLE IV SUMMARY OF ANAEROBICALLY DIGESTED SLUDGE DISPOSAL - RELATIONSHIPS WITH POPULATION SERVED (3)

Standard Activated Sludge Plants			
n = 22	Sludge disposed ($m^3.a^{-1}$) = 594.7	(Population x $10^{-3})^{0.873}$	(6)
n = 23	Sludge disposed ($ton.a^{-1}$) = 10.48	(Population x $10^{-3})^{1.097}$	(7)
Upgraded Activated Sludge Plants			
n = 22	Sludge disposed ($m^3.a^{-1}$) = 476.7	(Population x $10^{-3})^{1.089}$	(8)
n = 23	Sludge disposed ($ton.a^{-1}$) = 12.46	(Population x $10^{-3})^{1.146}$	(9)

5. SUMMARY-SUGGESTED DESIGN DATA

Based on the results of the Ontario survey (3), some generalizations concerning sludge production design data are shown in Tables V and VI.

TABLE V SLUDGE PRODUCTION - SUGGESTED DESIGN DATA*

Plant Type		Sludge Quantity		
		$g.capita^{-1}.d^{-1}$	Volume % of Influent	kg d.s./1000m^3
Primary	Conventional	77	0.20	120
	Upgraded	109	0.32	169
Activated Sludge**	Conventional	114	0.38	173
	Upgraded	145	0.51	217

* based on Q = 658 $L.capita^{-1}.d^{-1}$
d.s. = dry solids
**primary + waste activated

5.1 Sludge Quantities Prior to Anaerobic Digestion

The rule-of-thumb that sludge volume approaches 0.5% of the influent hydraulic load to a conventional plant is a good approximation. By using this estimate, the apparent margin of safety would allow upgrading of a conventional plant to include chemical phosphorus removal to 1.0 $mg.L^{-1}$ total phosphorus using metal salts without major expansion of sludge handling facilities.

5.2 Sludge Quantities After Anaerobic Digestion

Figure 25 summarizes all the pertinent water pollution control plant data from the Ontario survey (3). More specifically these data illustrate

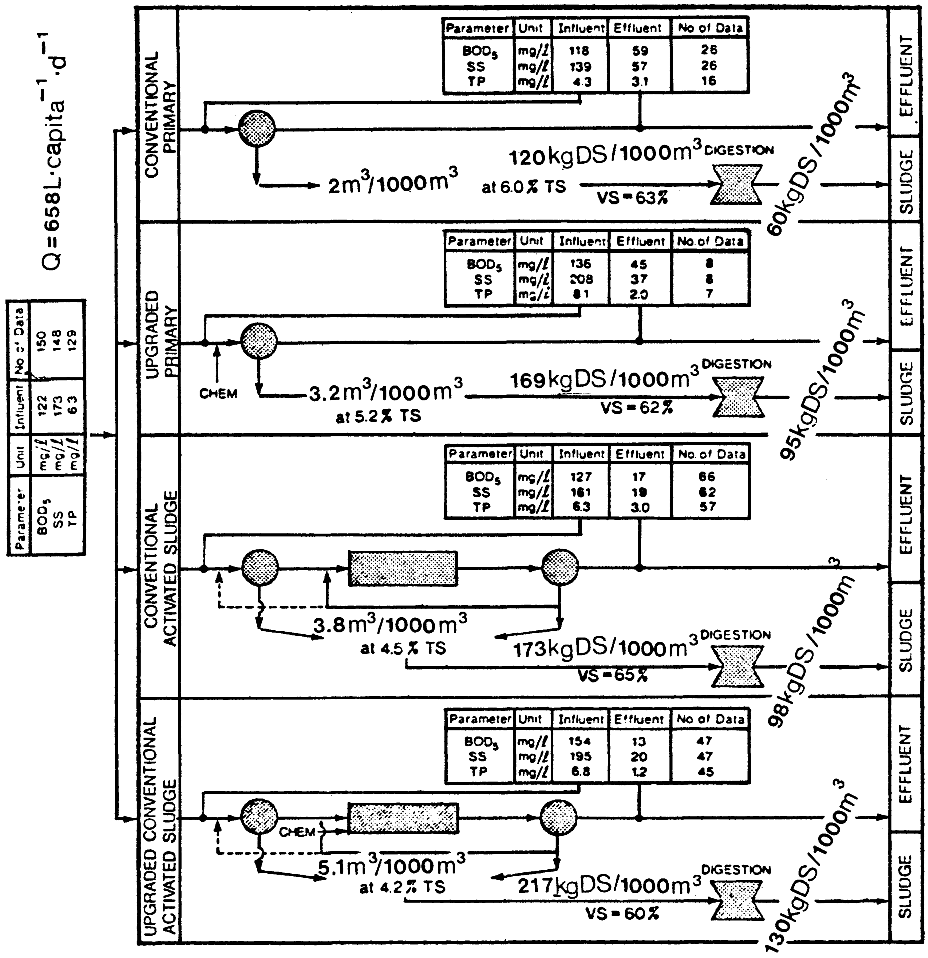

FIGURE 25. SUMMARY OF ONTARIO WATER POLLUTION CONTROL SLUDGE PRODUCTION AND DISPOSAL DATA (3)

that in Ontario's case anaerobic digestion will reduce the total solids generated at primary plants by as much as 50% on the average. When phosphorus removal to 1.0 mg.L^{-1} is practiced, anaerobic digestion will reduce the total solids generated by 44% on the average.

The data for anaerobic digestion of solids from Ontario conventional activated sludge treatment facilities show that on average a total solids reduction of 43% is achieved. With simultaneous chemical addition for phosphorus removal to 1.0 $mg.L^{-1}$ this drops to an approximate 40% reduction in total solids after anaerobic digestion.

These data are within the range of 25 - 58% TS reduction normally found in the literature (10).

Insofar as sludge production data for conventional and upgraded primary and activated sludge plants are concerned, this can best be summarized as shown in Table VI for the cases of before and after anaerobic digestion.

TABLE VI SLUDGE QUANTITIES SUMMARY

Plant Type		Anaerobic Digestion ($g.capita^{-1}.d^{-1}$)	
		Before	After
Primary	Conventional	77	40
	Upgraded	109	63
Activated Sludge	Conventional	114	64
	Upgraded	145	86

Clearly properly designed and well operating anaerobic digestion facilities will greatly reduce the sludge quantity requiring ultimate disposal.

6. SLUDGE HANDLING

Experience has demonstrated that metal salt addition to wastewater treatment processes for P removal not only results in increased sludge volumes and mass, but reduced solids concentration. The increased inorganic content due to chemical addition has the additional effect of lowering calorific values if incineration is selected as the volume reduction process. More ash is produced.

With regard to sludge dewatering, waste activated alum sludges, because of their gelatenous nature, are generally not dewatered by themselves but mixed with primary sludge, thickened and then dewatered. Table VII illustrates the effects of implementing phosphorus removal at two Ontario treatment plants on sludge dewatering. The West Windsor Treatment Plant is a primary facility which upon chemical addition showed reduced filter yield and cake solids concentration. Filtrate solids and conditioning costs increased. These effects were more pronounced with alum than ferric chloride. The North Toronto Sewage Treatment Plant experience using ferric chloride also showed a decrease in filter cake solids and increases in sludge conditioning requirements. No decrease in filter yield was noted.

Similar experiences are related by Farrell (6), Campbell (15) and others (16).

TABLE VII FULL SCALE VACUUM FILTRATION OF SLUDGES FROM PHOSPHORUS REMOVAL FACILITIES (15)

Description	West Windsor[1]			North Toronto[1]	
Phosphorus Removal Chemical	None	Fe^{3+}	Al^{3+}	None	Fe^{3+}
Type of Sludge	primary			digested elutriated	
Solids Concentration (%)	11.9	8.6	7.9	8.1	7.6
Conditioning Chemicals (% lime)	9.9	15.9	24.0	9.5	11.8
(% ferric chloride)	1.3	0.1	1.2	0	6.6
Conditioning Cost[2]	1.00	1.67	1.84	Not Recorded	Not Recorded
Filter Yield ($kg.m^{-2}.h^{-1}$)	60.6	46.9	32.8	18.6	19.1
Filter Cake Solids (%)	31	21	17	23	19
Filtrate SS ($mg.L^{-1}$)	2 830	3 660	13 900	5 550	7 690

[1]Campbell et al (15) [2]Cost relative to no chemical conditioning

Lime based sludges have invariably superior dewatering characteristics than metal salt based sludges. This is well documented in the literature (8, 17, 18).

7. SLUDGE UTILIZATION AND DISPOSAL

7.1 Sludge Chracteristics

One of the factors impacting on potential sludge utilization schemes is that of sludge characteristics.

Sludge characteristics are modulated not only by the type of waste treatment processes employed but are a function of the constituent inputs to municipal sewerage systems. More specifically, industrial discharges to municipal sewers may contain heavy metals, nitrogenous compounds, phosphates, a diversity of complex organic compounds, etc. In biological and physical/chemical treatment systems, most of these compounds are complexed, broken down and/or sorbed by sludge flocs. In most instances, additional chemicals such as lime and/or iron salts are added to enhance the dewatering characteristics of the sludge. Furthermore as phosphorus removal is practiced, sludges not only contain appreciable amounts of phosphorus, the precipitant used to complex the phosphorus, but higher metal concentrations.

As shown in Table VIII, the most common method of sewage sludge disposal in Ontario is land application of liquid digested sludge to agricultural lands.

TABLE VIII SLUDGE DISPOSAL METHODS PRACTICED IN ONTARIO (3)

Method of Disposal	No. of Plants	Percent of Total Plants	Wt of Sludge (dry tons.a^{-1})	Percent of Total Wt
Application to Agricultural Lands	98	63.2	48 100	34.0
Incineration	3	2.0	56 400	39.8
Landfill Application	17	11.0	31 800	22.5
Dumpsite	14	9.0		
Storage Lagoon	7	4.5	5 300	3.7
Drying Beds	16	10.3		
Total	155	100	141 600	100

In sludge application to land, a number of factors must be considered. For instance, the heavy metal concentration in the sludge will dictate the total amount of sludge that can safely be applied over the lifetime of a site. The "total" metals are generally considered as an indicator of the likely ultimate effect and is used by many to calculate sludge application rates. If an "immediate" effect needs to be ascertained, then this is represented by the "available" fraction of the metal(s) as determined using suitable reagents for extraction. It is important to recognize the potential cumulative and thus, long term effects of metal addition to soil in excess of the small amounts taken up by plants and that lost due to leaching.

The nitrogen content of a sludge will dictate the annual application rate and should be consistent with use of nitrogen by agronomic crops. This will reduce the potential for nitrate pollution of groundwater.

In Ontario the application of sludge to agricultural lands is governed by Provincial Guidelines (19). Every effort is made to dispose and at the same time utilize the sludge for its potential nutrient value and soil builder characteristics. The Guidelines take cognizance of this potential nutrient value but at the same time ensure that no appreciable metal build-up in the soil will occur. Details concerning Ontario's experience have been reported on elsewhere (21).

7.2 Sludge as a Source of Pollutants

As noted earlier, the major problem in the area of sludge utilization on land concerns the content of potentially toxic substances. However, the level and nature of the substance(s) will also dictate the choice of land utilization alternative. More specifically, sludge may be used as a soil builder and/or organic fertilizer, for land reclamation or application to agricultural land.

Sludge from wastewater treatment facilities practicing chemical phosphorus removal contains almost all of the metals which are discharged into sewers. In the case of heavy metals occurrence in Ontario sludges, Table IX summarizes this information from 40 Ontario water pollution control plants (10 primary, 30 secondary).

TABLE IX ONTARIO FLUID SLUDGES - HEAVY METAL CONCENTRATIONS (3)

Component	Primary Plants* Anaerobically Digested Sludges			Secondary Plants** Anaerobically and Aerobically Digested Sludges		
	Range $mg.L^{-1}$	Mean*** $mg.L^{-1}$	Stand. Dev. $\pm\sigma$ $mg.L^{-1}$	Range $mg.L^{-1}$	Mean $mg.L^{-1}$	Stand. Dev. $\pm\sigma$ $mg.L^{-1}$
Zinc	2.8 - 130	74.3	48.3	4 - 225	55.5	57.4
Copper	4.6 - 150	54.5	46.9	7 - 148	34.8	30.2
Nickel	0.7 - 15	4.4	4.7	0.26 - 16.8	6.5	14.9
Chromium	2 - 68	16.5	20.9	2 - 430	41.6	51.7
Lead	11 - 86	40.9	30.3	3.7 - 60	21.8	25.1
Cadmium	0.2 - 2.6	0.7	0.7	0.1 - 8.7	1.4	2.0
Cobalt	<0.6 - 1.4	1.0	0.3	0.3 - 3.6	0.8	0.8

* No. of Plants = 10
** No. of Plants = 30
*** Arithmetic Mean

The concentrations of heavy metals in digested sludges from primary and secondary plants are similar except for chromium which is three times lower in primary digested sludges.

In 1975, approximately 34% (48 100 tons dry weight) of the sludge produced in Ontario was applied to agricultural land. This resulted in annual, heavy metal loadings as shown in Table X.

TABLE X ANNUAL HEAVY METAL LOADINGS TO SLUDGED ONTARIO SOILS (1975 ESTIMATE) (3)

Metal	Average mg/kg soil	Average $kg.ha^{-1}$	Total tons
Zn	3.4	6.9	76.7
Cu	2.2	4.4	48.9
Ni	0.4	0.8	8.5
Cr	2.4	4.8	53.1
Pb	1.4	2.8	31.4
Cd	0.1	0.2	1.8
Co	0.05	0.1	1.1

7.3 Sludge as a Fertilizer

Major plant nutrients, nitrogen, phosphorus and potassium are contained in sewage sludge. Typical concentrations are 3% nitrogen, 2.5% phosphorus and 0.5% potassium on a dry weight basis. The nutrients in sludge are at a level of 1/5 of the usual chemical fertilizers.

Sludge quality data from the Ontario sludge survey (3) were obtained for 43 water pollution control plants (10 primary, 33 secondary). Forty of these plants disposed of sludge in fluid form, two disposed of sludge cake and one disposed of composted sludge. Table XI summarizes data on TS, VS, ammonia nitrogen, Total Kjeldahl Nitrogen (TKN) and phosphorus for digested sludges at primary and secondary plants.

In applying 890×10^3 m^3 (48 100 dry wt tons) of digested sludge to agricultural land in Ontario, the amount of nutrients applied during one year are summarized in Table XII. The data also indicate a relationship between TKN and total solids for anaerobically digested sludge from 23 secondary plants practicing metal salt addition for P removal (Figure 26). This relationship can be used to calculate the TKN loading to farmland as follows:

$$\%TKN = 16.6\ (\%\ TS)^{-0.799} \qquad (10)$$

The survey data showed an ammonia nitrogen to TKN ratio varying between 12 and 57% (average 30%). The ammonia nitrogen loading to farmland can thus be approximated by using this average value.

By making a number of assumptions it is possible to estimate the poten-

TABLE XI ONTARIO FLUID SLUDGES - NUTRIENT CHARACTERISTICS (3)

Constituent	Primary Plants* Anaerobically Digested Sludge			Secondary Plants** Anaerobically Digested Sludge			Secondary Plants*** Aerobically Digested or Waste Activated Sludge		
	Range $mg.L^{-1}$	Mean $mg.L^{-1}$	Stand. Dev $\pm\sigma$ $mg.L^{-1}$	Range $mg.L^{-1}$	Mean $mg.L^{-1}$	Stand Dev $\pm\sigma$ $mg.L^{-1}$	Range $mg.L^{-1}$	Mean $mg.L^{-1}$	Stand Dev $\pm\sigma$ $mg.L^{-1}$
Total Solids - TS%	2.8 - 12.5	8.8	2.9	2.0 - 12	4.1	1.8	2.2 - 4.5	2.75	0.95
Volatile Solids - VS%	24 - 61	43.4	10.5	36 - 70	41	8.5	41 - 69	55.8	9.9
Ammonia Nitrogen - N	100 - 590	326	78	250 - 1200	628	245	20 - 180	110	24.8
Total Kjeldahl Nitrogen - N	950 - 2900	1736	913	1600 - 3000	2114	495	650 - 2300	1358	576
Total Phosphorus - P	240 - 2600	713	399	390 - 2900	975	603	440 - 1200	730	303

* No. of Plants = 10
** No. of Plants = 25
*** No. of Plants = 8

TABLE XII SLUDGE NUTRIENTS APPLIED ANNUALLY TO ONTARIO FARMLAND (ESTIMATE) (3)

Constituent	Amount tons.a^{-1}
TKN	2,800
NH_4 -N	810
Total P as P	1,280
K	270
TS	48,100
VS	27,300

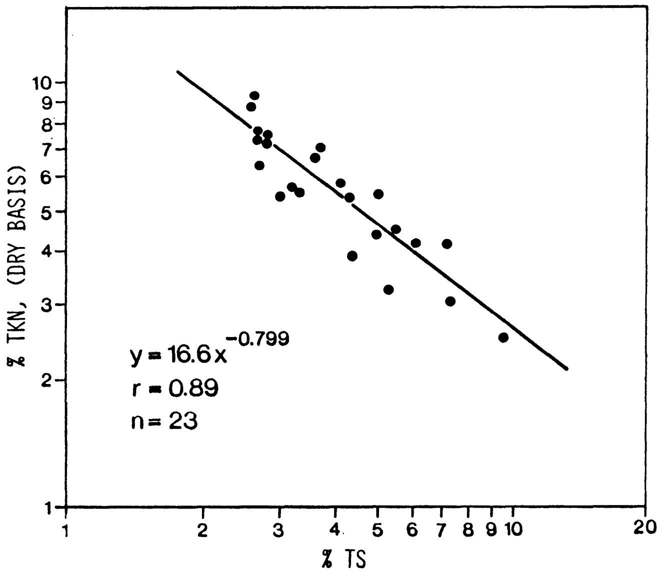

FIGURE 26. TKN VS. TOTAL SOLIDS IN ANAEROBICALLY DIGESTED SLUDGE AT STANDARD ACTIVATED SLUDGE PLANTS (3)

tial nutrient value of sludge when applied to farmland in Ontario:

1. the 'available' nitrogen in fluid sludge is equal to the soluble nitrogen (NH_4-N) (a conservative estimate);
2. only one-half of the total phosphorus in liquid sludge is potentially plant available (20) (a conservative estimate);
3. the 'available' potassium in fluid sludge is equal to the total potassium;
4. based on commercial fertilizer prices (November, 1979) the prices for nitrogen, phosphorus and potassium are \$0.59, \$1.50 and \$0.35 per kg respectively.

Using the amounts of nutrients applied to farmland as shown in Table XII and the aforenoted assumptions, the sludge fertilizer value can be calculated as follows:

$$NH_4\text{-}N = 810 \text{ tons.a}^{-1} \times 1000 \text{ kg.ton}^{-1} \times \$0.59 \text{ kg}^{-1} \simeq 477\ 900$$

$$P = 1280 \text{ tons.a}^{-1} \times 1000 \text{ kg.ton}^{-1} \times 0.5 \times \$1.50 \text{ kg}^{-1} \simeq 960\ 000$$

$$K = 270 \text{ tons.a}^{-1} \times 1000 \text{ kg.ton}^{-1} \times \$0.35 \text{ kg}^{-1} \simeq 94\ 500$$

$$\text{TOTAL} \simeq 1\ 531\ 400$$

This analysis shows that the fertilizer value of the sludge now applied to farmland is approximately \$1 500 000 per annum (\$133.ha^{-1}). This excludes any other potential benefits such as the presence of calcium, magnesium or the considerable amount of organic matter in the sludge. If the farmer required organic matter to improve soil structure (and moisture retention capacity) sludge could have a value of approximately \$20./ton. Based on the volatile solids applied to farmland, the sludge would be worth \$500 000 per annum.

The farmers interviewed for the Ontario survey (3) attempted to quantify yield increases due to sludge application. The average increase in hay yield was estimated at 8 tons.ha^{-1} and in corn yield at 1 ton.ha^{-1}. Benefits resulting from cattle weight gain were also noted. A reasonable estimate of the benefits of sludge use on agricultural land in Ontario lies somewhere between \$2 000 000 and \$3 000 000 per annum (21). At this time, the farmers receive sludge free of charge with the transportation costs charged against disposal costs, borne by the municipalities. In 1975, sludge haulage to farmland costs were approximately \$2 250 000.

To date, no negative effects on crop yields were reported by farmers applying sludge for periods in excess of five years. However, long term studies are required to assess whether heavy metals will have negative effects on plants, soil or leachate.

Field monitoring of soil, plants and leachate quality at selected sites where sludges containing high concentrations of heavy metals have been applied for extended periods, has just been completed (22).

7.4 Continuing Studies

Investigations concerning sludge/soil interactions at laboratory greenhouse, field trial and lysimeter scale have been in progress since 1973 at the University of Guelph (23 - 29) and the Wastewater Technology Centre (30 - 34). Some of the more significant conclusions from these studies are:

- Sewage sludges supplied nitrogen and phosphorus for crop production but were low in potassium. Sludges produced crop yields at least as high as were obtained with chemical fertilizers.

- Sewage sludge application did not result in marked increases in runoff of nutrients, heavy metals or bacteria on 2% and 6% slopes except when heavy rain occurred immediately after sludge application.

- Soil salinity was not a problem in the field under Ontario conditions. It might pose a problem in less humid areas. Boron levels in some sludges tested would also be expected to pose a problem in arid regions.

- Re-application of the sludges between crops did not lead to increased metal concentrations in the plant materials.

- Large amounts of metals were added to soils in some sludges and their removal by crop uptake or leaching was very limited.

- The organic nitrogen in sludges was mineralized gradually and the mineralization rate varied from one sludge to another. As with other sources of nitrogen, applications in excess of crop requirements lead to high levels of nitrate in the soil solution.

- The average NH_4^+-N content of sludges studied was 1.3% on a dry weight basis or 27% of the total nitrogen. In two experiments 40% and 48% of the NH_4^+-N was lost by volatilization from sewage sludge applied to the soil surface. This loss occurred in five and eight days, respectively.

- Salmonella were isolated from five of 207 sludge samples tested. If vegetables are not grown and animals not grazed immediately following sludge application and if reasonable care is exercised in spreading, digested sludge does not pose a serious health hazard.

- At least twice as much nitrogen must be applied in fluid sludge as in commercial fertilizer to obtain equivalent yields.

- The Cd, Cr, Cu, Ni, Pb and Zn concentrations in orchard grass and wheat plant materials have not exceeded suggested maximum "tolerance" or "toxic" levels.

- The maximum concentrations of Cd, Cr, Cu, Ni, Pb and Zn in leachates have not exceeded drinking water standards.

- Soluble P in the leachates from fluid sludge treatments ranged as high as 10 $mg.L^{-1}$ during summer 1977. Soluble P from the air-dried sludge treatments never exceeded 2 $mg.L^{-1}$. Subsequent leachate P levels have returned to their normal values of < 1.0 $mg.L^{-1}$

- Total organic carbon in leachates from both the fluid and air-dried sludge experiments were greater than 50 $mg.L^{-1}$ in 1976 at the highest sludge loading rates. Static bioassay toxicity tests using Daphnia showed no toxicity in these leachate samples.

7.5 Ontario Guidelines for Sludge Utilization on Agricultural Land

The amount of NH_4-N applied to Ontario farmland in 1975 was 810 tons (Table XII). Combining this information with the data on heavy metal application to farmland (Table X) allows for an assessment as to whether or not Ontario sludge is generally suitable for land application if the criteria of the Provisional Guidelines for Sewage Sludge Utilization on Agricultural Land (19) are applied. This assessment is summarized in Table XIII and shows that the sludge is generally suitable for agricultural land application. The exception is the cadmium content. Sources of high cadmium content sludges are few and isolated. It is important to stress that average values are extremely misleading and that it is imperative that each sludge source be characterized separately in order to determine its limits of suitability for application to farmland.

TABLE XIII SUITABILITY OF ONTARIO SLUDGE FOR UTILIZATION ON FARMLAND (3)

Constituent[1]			NH_4-N:Heavy Metal		Suitability
NH_4-N	Heavy Metal		Actual Ratio	Minimum Required Ratio[2]	
810					
	Zn	76.7	11	4	Yes
	Cu	48.9	17	10	Yes
	Ni	8.5	95	40	Yes
	Cr	53.1	15	15	Yes
	Pb	31.4	26	15	Yes
	Cd	1.8	450	500	No
	Co	1.1	736	50	Yes

[1]in $tons.a^{-1}$ (Tables 10 and 12)

[2]Provisional Guidelines for Sewage Sludge Utilization on Agricultural Land(19)

8. CLOSING REMARKS

The information presented represents a summary of Canada's experience in the Province of Ontario with increased sludge production due to removal of total phosphorus to 1.0 $mg.L^{-1}$ when using metal salts. It was found that:

- Sludge production estimates based on stoichiometric relationships can fluctuate by at least ± 50%. The rule-of-thumb that for biological treatment plants using metal salt addition for phosphorus removal 0.5% of the influent wastewater winds up as sludge is supported by data from the Ontario survey.
- Metal salt addition for phosphorus removal to 1.0 $mg.L^{-1}$ total phosphorus at primary and secondary activated sludge plants has increased sludge volumes by 60 and 35%, respectively.
- Lime treatment of municipal sewage to total phosphorus concentrations of <0.1 $mg.L^{-1}$ can result in sludge volumes up to 700% greater than normally experienced.

Ontario's current sludge management strategy consists of applying the most cost-effective and environmentally acceptable solution. Sludge utilization for its nutrient value on agricultural land is one such management strategy followed by an increasing number of municipalities who, as well as the farmers, are concerned about potentially long-term harmful impacts on soils due to heavy metal addition.

While technological solutions to phosphorus point source control to 0.1 $mg.L^{-1}$ are available, the impact on sludge quantities generated, handling and disposal still remains to be more closely defined. Only with information on relative costs between alternatives to achieve these goals can an effective point source phosphorus control management strategy be proposed.

Computer simulation is one approach to assess potential management strategies. It may well turn out that point source control to levels substantially lower than currently practiced will cause more problems elsewhere.

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COMPUTER CONTROL OF SLUDGE FERMENTATION : PROCESS MONITORING AND DATA TREATMENT.

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Summary

The process monitoring and data treatment systems of a pilot fermentor unit are described. The main purposes of the data system are : acquisition of experimental data, their reduction in a easily and quickly understandable form, development of computerized control systems for waste treatment.
The fermentor unit consists of three separate vessels with individual sensors and control elements. The following elements compose the system : a multiplexer, a desktop computer and a printer plotter. The multiplexer is interfacing the system to the fermentor both for data input and control output. The desktop computer acts as a system controller. Hardcopy output is from the printer plotter.
Following features are highlighted :

- Scanning of up to 36 data channels either sequentially or selectively;
- Software smoothing of noisy signals;
- Foreground-background operation due to a local microprocessor at multiplexer level;
- Live keyboard allowing operator intervention during fermentation run

Programms referenced are :
"Input" : data acquisition and continuous display on CRT
"Output" : data deduction and logging
"Opern" : a programfragment that derives control parameters from the response of the system to small induced changes
"System" : supervision program fragment checking system status and some error conditions
"Plottn" : providing graph output, with autoscaling and labelling.

Current research is directed to software development for the optimisation of fermentation processes on a heuristic basis.

1. INTRODUCTION

For research and development in the field of fermentation of sludge and primary waste materials, our laboratory was equiped early 1980 with a BIOLAFITTE pilot fermentor. In addition to the hardware analog control units which are standard on this equipment, we linked a computer controlled data system to the basic instrumentation.

The following elements, purchased from HEWLETT PACKARD compose the system : a 9835 A desktop computer as controller, a 6242 Multiprogrammer as multiplexer and a HP 7245 A Printer plotter for hardcopy output.

The main purposes of the data system are :

- It performs automatic data acquisition and reduction into a quickly and easily understandable form.
- A second objective is the development of computerized control systems for waste treatment, system supervision routines being an integral part of this application.

2. THE FERMENTOR.

The pilot fermentor unit consists of two 100 litres vessels and of a smaller one of 25 liter total volume. Each of these can be operated in batch or continuous mode and 2 or 3 vessels can be cascaded. Each vessel has individual sensors for temperature, dissolved oxygen, pH, agitator motor speed, applied voltage, and induced current. A sensing probe is used either for a foam level control switching or level monitoring in continuous or fed batch fermentators.

In order to monitor reagent consumption, calibrated sensing probes are used in the storage vessels for acid, base and foam controlling agent. Position transmitters on the admission valves for compressed air, oxygen and nitrogen allow the data system to define the control range still available at each moment during the process.

In its standard version the pilot unit is controlled (fixed setpoints) by hardware analog devices (AFSC mode). For each control variable, two control elements are present either acting on low or high values. Control elements are switched on or off through fast relays by a train of pulses of known amplitude and frequency. On our behalf Direct Digital Control was provided by a set of three additional relays : the first one selects the DDC or AFSC mode. The control circuits "LOW" and

"HIGH", each are serviced by one of the remaining relays.

3. THE DATA SYSTEM

3.1. The interface

3.1.1. DATA INPUT

From the fermentor unit, parameter and control variables are transmitted to the computer system, as standardized 4-20 mA current signals, through screened double wired channels. The D.S. interfacing is performed by the 6242 Multiprogrammer. At input level the current signals are transformed to 1 - 5 V voltage signals. These are scanned either sequentially or under program control through a set of 69 730 A Relay output Cards. Digitization of the voltage signals is performed by a High Speed AD Convertor 69751 A which stores its outputs on a 69790 A Memory Card (1024 16 bits digital words capacity). Readings are taken under program control. Bursts of up to 1024 sequential readings from one channel can be integrated. This feature allows "software smoothing" of noisy signals and signal wave form analysis. In the triggered mode, the AD Convertor is controlled through a 69735 Pulse train output Card. A second AD convertor wired, as far as triggering is concerned, in parallel to the first one allows simultaneous reading on two channels. The feature permits calculation of the adsorbed power of the agitator motor from applied voltage and induced current values but is also valuable in tracing down system interferences.

3.1.2. CONTROL OUTPUT

Also on the control side, the 6242 is interfacing the data system to the fermentor unit. In DDC mode a 69735 Pulse train output card is dedicated to the circuit control. Pulse rate and pulse length of this cards output can be modified under program control. In the low state, the output circuit sinks up to 37 mA, which is amply sufficient to drive the control relays based in the fermentor unit.

3.2. The controller

The controller function is performed by the computer 9835 A. This unit integrates keyboard, memory, central processor, tape unit and CRT display. In the standard version, 64 Kbytes of Read/Write Memory (RMW are present above and beyond the 112 Kbytes operating system contained in Read only

Memory (ROM). Some 14 Kbytes RWM are dedicated to the CRT back-up system, 48962 Kbytes of memory being still available for program and data storage. Due to the integrated tape unit, additional 216 Kbytes of overlay program and data storage are available. An overlay environment is supported by the operating system, with the use of common parameters, pass parameters and local variables.

There is no support for multitasking on the CPU level. But as array operations are supported, parallel computation, on stored variables can be performed. On the other hand, as the multiprogrammer has its own memory and processing capability, multitasking on a system level is supported. Due to a system of interrupts and priority levels, foreground-background operation is possible within the combination of controller and multiprogrammer.

Operator intervention is possible during the run due to the live keyboard feature. Execution of keyboard operations are delayed untill the end of the current program line or untill the completion of a current input/output operation. Execution of a keyboard instruction causes the program to pause momentarely.

3.3. Input/Output devices

Basically the multiprogrammer-controller combination as described contains all necessary input/output devices for system management. To provide print-out on a larger scale than possible on the 9835 internal printer and to have the possibility of graphic output the 7245 A printer plotter was linked into the system through the HPIB bus interface.

4. THE SOFTWARE

4.1. Programming language

An enhanced version of ANSII BASIC is used, with beyond standard minimal BASIC supports array operations, debugging tools, subprograms, multi-character identifiers, formated output and the possibility of program anotation.

4.2. The programs

A minimal monitor is permanently resident in the RWM. A number of subprograms are stored on tape and called to RWM. At power on, the monitor is loaded and calls an initializing program which prompts the operator to load all informations to identify the experiments run. This same program supports if necessary, the recalibration of the sensors mounted on the fermentors. On completion, the initializing program is replaced in the overlay region. Next fragment called is by "Input" a data acquisition subprogram which continuously scan either all, or selected data channels. This program offers continuous display of all scanned parameters on the CRT display after data conversion. At predetermined intervals, it switches to a second program resident in RWM "Output" : a program fragment which checks if any of the scanned variables has significantly changed during the reference period. If so, the current program fragment provides data storage and hardcopy output of the detected variation, along with timing an identifiing information, afterwards returning control to the acquisition program. If no changes are detected, control is returned to the acquisition program immediately. When one or more variables are brought under system control a third program fragment is made resident : "Contrl" part of this program contains the control routines which are not dependent on one particular experiment, another part is dedicated to optimization strategies which are dependent from the experimental conditions.

In the start up phase, we now, at the present time, concentrate on the first group of routines : Among others on "Opern" a program fragment which derives control parameters from the response of the system to small induced changes.

"Opern" allows a fermentor to recover quickly from surges in feed rate or feed composition which are frequent on units running in continuous mode on sludge or waste materials.

Program fragment "System" is checking system status as well to hard ware error conditions as to noisy lines or failing sensor elements. On detection of one of the referenced errors, notification is send to the operator on screen and hardcopy data logger. To prevent system hangup, switched off sensor elements are defaulted to zero output and for noisy lines a smoothing routine is called which is put to work on the data collected on the noisy lines only. On keyboard control explorative routines e.g. a routine for the analysing of the noise wave form can be made resident. Hardcopy graphic output is provided by "Plottn" a sub program that can be co-resident with "Input" and "Contrl", but not with "Output" as the latter

program is accessing the same input/output devices. As "Output" is accessed at predetermined intervals (typically once each fifteen minutes) this restriction does not prohibit plotting of results during a fermentation run.
Either for selected parameters or for all parameters sampled on a one at a time basis, "Plottn" is generating graphs of parameter vs time or vs any other parameter which stands into an unabiguous relation to time. (eg. dissolved oxygen vs time or dissolved oxygen vs base consumption). Scaling and labeling of the graphs are fully under program control. A table of the lay-out parameters is presented to the operator before execution of each graph allowing lay-out modifications. Even when the graph has been drawn, post-editing is possible, an incorporated "zoom" routine allowing to enhance selected features of the graph.

Conclusion

Computer data treatment and proces control of sludge fermentation offers the following features :

- Continuous logging restricted to usefull data, operator intervention and information about mass memory management;
- Automated graph output with possibility for operator intervention in editing an postediting, as well as enhancement of selected data fragments;
- Overall system control and selective treatment of signals, depending of their signal to noise ratio;
- Optimized control to fixed objectives allowing quick recovery after surges in feed rate of composition.

Current research is directed to development of software for the optimization of fermentation processes on a heuristic basis.

SESSION II - CHEMICAL POLLUTION OF SLUDGE

ACTIVITIES OF WORKING PARTY 2 "CHEMICAL POLLUTION OF SEWAGE SLUDGE"

INTRODUCTORY REMARKS

by

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A review of the problems of analytical determination and evaluation of harmful effects of heavy metals and some other contaminants during the two years period of work till summer 1980 is given. It includes the difficulties of carrying out the first interlaboratory comparison during the winter of 1978/79 and the corresponding results. This led to a second collaborative study which was performed in the winter of 1979/80 with the aid of a large number of participating laboratories of nearly all countries involved in the work of W.P. 2.

After having finished work on the determination of total heavy metals in amounts not difficult to determine now a second programme has been set up to determine total amounts of heavy metals in a sludge-amended soil and their mobile fraction due to given pH values.

In a further programme, the analysis of heavy metals in plants grown on polluted soils will be carried out in cooperation with a programme on standardized pot trials which was worked out by Working Party 5 in coordination with a similar action of the United Nations Food and Agriculture Organization called "European Research Network on Trace Elements".

The importance of other contaminants in sludges of municipal origin is under discussion e.g. chlorinated compounds for setting up future analytical programmes, if there is a need.

SCHWERMETALLE IN KLÄRSCHLAMM UND MÜLLKOMPOST

Ergebnisse des 2. Ringversuchs
der konzertierten Aktion Cost 68^{bis}, Arbeitsgruppe 2

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Summary

Heavy metals in sewage sludge and garbage compost

Results of the 2^{nd} interlaboratory comparison of concerted action COST 68^{bis}, working party 2

On the basis of the results of the 1st Interlaboratory Comparison (IC) of Working Party (WP) 2, presented already at the 1st European Symposium in Cadarache, the reasons are given why a 2nd IC had to be carried out.

Moreover, the experiences made under a similar programme of the Food and Agriculture Organisation (FAO) of the UN (European Research Network on Trace Elements) were used when preparing the 2nd IC, since some of the laboratories involved in COST 68 activities have been participants in the FAO programme.

This led to the conclusion that the analytical investigation of a "Test Solution" of pure metal salts had to be a necessary step of this IC. The test samples distributed by the Joint Research Centre Ispra consisted of a dried sewage sludge and a garbage compost sample in addition to the above-mentioned test solution. The latter had to be used for testing the accuracy of the methods, apparatus and laboratory standards of the participating laboratories. The participants were also supplied with operating procedures in respect of the pretreatment of samples and the methods of digestion that should, if possible, be used in addition to the preferred laboratory method.

These precautions turned out to be justified. It was seen from the results received from 38 laboratories in 9 countries that the instructions given had been essentially adhered to. However, there were some unexplained deviations from reference values for the test solution. Likewise, some of the results communicated did not admit of interpretation. At the session of WP 2 where the preliminary evaluation of the collaborative study was discussed, it was thus decided to circulate among the participants a questionnaire inquiring about details of the methodology used, in parti-

cular with regard to the method(s) of digestion. The answers are to provide more information on the techniques used and to permit a detailed interpretation of results. This will, in turn, enable an evaluation of the methods applied that goes beyond the scope of results generally obtained from collaborative studies. The experience gained in the present IC may be useful when having to make recommendations on the selection of suitable methods for the analysis of heavy metals in sludges and composts and thus contribute to the field of evaluation of the heavy metal contamination of such materials if used in agriculture.

Vorgeschichte

Auf dem 1. Europäischen Symposium "Charakterisierungm Konditionierung und Verwendung von Klärschlamm" im Februar 1979 in Cadarache/Frankreich war von J.C. Tjell (1) über die Ergebnisse des 1. Ringversuchs der Arbeitsgruppe 2 "Chemische Verunreinigung" der Aktion COST 68^{bis} berichtet worden. Tjell schloß aus den Ergebnissen, daß die Untersuchung sog. normaler Klärschlämme auf ihren Schwermetallgehalt keine besonderen Probleme mit Ausnahme der Bestimmung von Quecksilber bereitet. Er beurteilte die Aufschlußmethoden hinsichtlich ihrer Wirksamkeit als gleichwertig, abgesehen von der bekanntermaßen nur wenig aggressiven Kaltextraktion mit 2N HCl und dem Verfahren, bei dem mit den drei Säuren HNO_3, $HClO_4$ und H_2SO_4 gearbeitet wurde. Die Streuung der Ergebnisse zwischen den einzelnen Laboratorien wurde von ihm als akzeptabel angesehen. Er betonte jedoch die Notwendigkeit einer ständigen Eigenkontrolle der Laboratorien mit Hilfe von Referenzmaterial.

Zum Zeitpunkt dieser Beurteilung lagen noch nicht alle Untersuchungsergebnisse vor. Als das aber im späten Frühjahr 1979 der Fall war, wurde die Auffassung von Tjell im wesentlichen auch von den übrigen Mitgliedern der Arbeitsgruppe geteilt. Man kam dabei überein, in einem weiteren Ringtest mit ähnlichem Material zu versuchen, durch entsprechende Planung der Versuchsdurchführung und Ausweitung des Teilnehmerkreises weitergehende Informationen zu sammeln, die zu einer Verbesserung der Bestimmung von Schwermetallen in Klärschlämmen und ähnlichem Material führen sollten.

Dies geschah nicht zuletzt aufgrund der Ergebnisse, die bei einem Ringversuchsprogramm des "European Cooperative Research Network on Trace Elements" erhalten worden waren (2). Bei diesem vom Europäischen Büro der Welternährungsorganisation FAO koordinierten und von drei sog. Liaison

Centres als Koordinierungsstellen organisierten Programm hatte sich ebenfalls gezeigt, daß bei einer Vielzahl von Methoden und laborspezifischen Variationen zur Bestimmung von Schwermetallen in Schlamm-, Kompost- und Bodenproben eine statistisch gesicherte Aussage sowohl über die Zuverlässigkeit der angewandten Aufschlußmethoden als auch über die Genauigkeit des Analysenverfahrens nur recht unvollkommen möglich war.

Vorbereitung und Durchführung

Die Mitglieder der Arbeitsgruppe 2 der Aktion COST 68^{bis} beschlossen deshalb hinsichtlich der Durchführung des 2. Ringversuchs folgendes:

1. Es sollte nur eine begrenzte Zahl von Aufschlußverfahren zur Wahl gestellt werden, von denen mindestens eines von jedem der beteiligten Laboratorien angewendet werden sollte. Es waren dies die Aufschlüsse mit

   A. Königswasser,

   B. Salpetersäure,

   C. Salpetersäure/Wasserstoffperoxid und

   D. Trockenveraschung.

   Darüber hinaus sollte es den Laboratorien freigestellt werden, eine davon abweichende eigene Methode vergleichend anzuwenden und die Ergebnisse mitzuteilen.

2. Mit jedem der angewandten Aufschlußverfahren sollten fünf parallele Mineralisationen durchgeführt werden, um Aussagen über die Reproduzierbarkeit des Verfahrens zu erhalten.

3. Um die Genauigkeit der Laboratorien zu testen, sollte eine synthetische Lösung (Testlösung) analysenreiner Metallsalze in verdünnter Salpetersäure ohne Aufschluß untersucht werden.

Die Proben für den Ringversuch wurden vom gemeinsamen Forschungszentrum (JRC) Ispra Ende November 1979 an etwa 40 Laboratorien in 9 Ländern versandt, die sich auf Bitten der Mitglieder der Arbeitsgruppe zur Teilnahme bereit erklärt hatten. Es handelte sich um die schon erwähnte Testlösung, die in Ampullen eingeschmolzen verschickt wurde, eine Klärschlammprobe und ein Müllkompostpräparat, beides trockene Präparate in Glasflaschen. Um Komplikationen zu vermeiden, war die Konzentration der Metallsalze in der Testlösung so gewählt, daß sie etwa derjenigen entsprach, die beim Aufschluß von 2 g des Klärschlammpräparates entsprach. Um sicherzustellen, daß die Testlösung bis zum Zeitpunkt der Untersuchung keine Veränderungen ihrer Zusammensetzung erlitten hatte, wurden 8 Ampullen nach einem Zufallsraster vom JRC ausgewählt und zurückbehalten und der Metallgehalt nach den klassischen Methoden der Gravimetrie etwa zur Zeit der Untersuchung in den übrigen Laboratorien zur Prüfung ermittelt. Es ergab sich kein Anhalt für etwaige Veränderungen.

Beim Klärschlamm handelte es sich um ein relativ stark mit Schwermetallen kontaminiertes Präparat, so daß zu erwarten war, daß die Untersuchungen nicht durch Schwierigkeiten beeinträchtigt werden würden, die mit der Bestimmung sehr geringer Metallkonzentrationen in derartigen Präparaten verbunden sind. In der Kompostprobe lagen die Schwermetalle in recht ähnlichen Konzentrationen, jedoch in anderen Verhältnissen zueinander vor. Beide natürlichen Präparate waren in ihrer Zusammensetzung dem JRC aufgrund eingehender früherer Untersuchungen sehr genau bekannt, wenngleich eine Zertifikation noch nicht erfolgt war. Den am Ringversuch beteiligten Laboratorien wurde mit der Arbeitsanleitung, die im wesentlichen nur allgemeine Hinweise enthielt, aufgegeben, den Feuchtigkeitsgehalt der Präparate an einer 2 g-Probe durch Trocknen über Phosphorpentoxid zu bestimmen und die bei den Aufschlüssen und nachfolgenden Analysen erhaltenen Werte für die Schwermetallkonzentrationen entsprechend zu berichtigen. Zur Erleichterung der Auswertung wurden Vordrucke versandt, in die die erhaltenen Ergebnisse einzutragen waren.

Erfahrungen und Ergebnisse allgemeiner Art

Die Einsendung der Vordrucke mit den Untersuchungsergebnissen erfolgte nicht so rechtzeitig, daß auf der im Frühjar 1980 in Ispra durchgeführten Sitzung der Arbeitsgruppe schon eine abschließende Beurteilung möglich war. Dafür waren folgende Faktoren verantwortlich:

Zum einen war der Probenversand wegen Schwierigkeiten während der Vorbereitungen relativ spät erfolgt, so daß die Laboratorien, die sich größtenteils aus freien Stücken neben ihrer normalen Routinearbeit und Forschungstätigkeit am Ringtest beteiligten, diese zusätzlichen Untersuchungen nicht sofort in ihr Programm aufnehmen konnten und zum anderen ließ sich in einigen Fällen der durch die Untersuchung der Testlösung und zweier natürlicher Präparate erforderliche erhebliche Aufwand nicht zeitgerecht bewältigen.

Die vorläufige Auswertung eines Teils der eingegangenen Ergebnisse und deren Diskussion auf der Arbeitsgruppensitzung ergab, daß unerwarteterweise in einigen Fällen bereits die Untersuchung der Testlösung und die Auswertung der dabei erhaltenen Ergebnisse Schwierigkeiten bereitet hatte. Zum Teil konnte dies mit Rechenfehlern erklärt werden, zum Teil schienen aber auch Fehler bei der Eichung für mangelhafte Ergebnisse verantwortlich zu sein. Derartige Fehler mußten Auswirkungen auf die Untersuchungsergebnisse der Schlamm- und Kompostprobe haben und die Beurteilung der Brauchbarkeit der angewandten Aufschlußmethode erschweren.

Da zudem in einigen Fällen die Vordrucke nicht benutzt oder aber mißverständlich ausgefüllt worden waren, wurde beschlossen, durch eine Fragebogenaktion zusätzliche Informationen von den Untersuchern einzuholen. Hierzu wurde am 8. Juni 1980 ein Fragebogen mit 17 Fragenkomplexen und insgesamt fast 100 Einzelfragen an die Teilnehmer versandt. Die Rücklaufquote betrug 81%.

Diskussion

Erfahrungsgemäß zeigen Interlaboratoriumskampagnen, ausgeführt von einer großen Zahl von Laboratorien aus vielen Ländern (Tabelle 1) mit unterschiedlichen analytisch-methodologischen Traditionen, bedeutende Datendispersionen, und der vorliegende Ringversuch bildet insofern keine Ausnahme.

Die Verwendung von Standardproben mit bekanntem Homogenitätsgrad ($\leq$ 2% für die untersuchten Elemente), sowie die parallele Analyse einer Standardlösung eliminierte alle mit dem untersuchten Material assoziierten Unsicherheiten und lieferte Informationen über die jeweilige Sicherheit der Endbestimmung durch AAS.

Tabelle 2 faßt die Ergebnisse der Standardlösungsanalyse zusammen.

Table 1

List of participating laboratories

ACEPSA, Oulens, CH
Amt für Wasser- und Energiewirtschaft, St! Gallen, CH
Anstalt Gewässerschutz, Dübendorf, CH
Bayerische Landesanstalt Bodenkultur, München, D
Bayerisches Landesamt Umweltschutz, München, D
Bundesanstalt Geowissenschaften, Hannover, D
Bundesgesundheitsamt Berlin, D
Bureau de Recherches Géologiques et Minières, F
CEA Cadarache, F
CERCAR, F
Chemisches Laboratorium Kanton Graubünden, Chur, CH
Ecole Polytechnique Fédérale Lausanne, CH
Eidg. Forschungsanstalt Liebefeld, CH
Hessische Landesanstalt für Umwelt, Wiesbaden, D
INRA Bordeaux-Pont-de-la-Maye, F
Institut de Recherches Hydrologiques, Nancy, F
Institut du Génie de l'Environnement, Lausanne, CH
Institut Fresenius, Wiesbaden, D
Instituut voor Bodemvruchtbaarheid, Haren, NL
IRCHA, Vert-le-Petit, F
Kantonales Laboratorium Zürich, CH
KFA Jülich, D
Laboratoire de Controle et d'études des eaux, Le-Pecq, F
Landesamt Nordrhein-Westfalen, Düsseldorf, D
LUFA Augustenberg, Karlsruhe, D
LUFA Münster, D
Niedersächsisches Landesamt, Bremen, D
Rijksuniversiteit Gent, B
Rijks Instituut voor de Volksgezonheid Bilthoven, NL
Ruhrverband, Essen, D
Statens Landbrukskemiska, Uppsala, S
Statens Naturvårdsverk, Solna, S
Tech. University Lyngby, DK
The Agricultural Institute, Wexford, GB
Universität Stuttgart, D
Waterschap de Dommel, Boxtel, NL
Wessex Water, Poole, GB
Westab, Duisburg, D

Table 2

Material: TEST SOLUTION (Values expressed in ppm)

LABORATORY No.	Pb $\bar{x}$	Pb s	Pb Δ	Cd $\bar{x}$	Cd s	Cd Δ	Co $\bar{x}$	Co s	Co Δ	Ni $\bar{x}$	Ni s	Ni Δ	Cu $\bar{x}$	Cu s	Cu Δ	Zn $\bar{x}$	Zn s	Zn Δ	Cr $\bar{x}$	Cr s	Cr Δ	Hg $\bar{x}$	Hg s
1	84	1.1	+ 2	9.3	0.14	+1.1	35	1.3	+2	79	0.9	- 4	78	1.1	+ 6	238	1.1	+ 41	62	0.6	- 4	2.5	0.1
2	84	2.0	+ 2	8.0	0.20	-0.2	-	-	-	82	4.7	- 1	76	5.5	+ 4	261	12	+ 19	73	2.9	+ 7	-	-
3	80	0.8	- 2	8.4	0.10	+0.2	-	-	-	76	0.6	- 7	71	0.4	- 1	201	2.4	- 41	47	1.3	-19	2.8	0.1
4	82	1.6	0	8.5	0.05	+0.3	34	0.4	+1	91	0.9	+ 8	73	0.8	+ 1	252	1.5	+ 10	65	0.8	- 1	-	-
5	81	0.7	- 1	8.0	0.17	-0.2	-	-	-	83	1.1	0	72	0.7	0	247	3.6	+ 5	84	2.1	+18	-	-
6	83	0.7	+ 1	8.5	0.17	+0.3	34	1.0	+1	83	1.1	0	75	0.7	+ 3	265	3.9	+ 23	77	4.2	+11	2.3	0.1
7	83	10.6	+ 1	8.3	0.12	+0.1	33	0.4	0	84	0.4	+ 1	71	3.3	- 1	250	34	+ 8	66	0.5	0	-	-
8	79	0.4	- 3	8.3	0.09	+0.1	33	0.3	0	69	1.1	-14	73	0.3	+ 1	260	1.9	+ 18	61	0.4	+ 5	2.8	0.04
9	81	1.0	- 1	8.2	0.07	0	32	0.1	-1	85	0.2	+ 2	73	0.1	+ 1	190	1.7	- 52	66	0.4	0	2.0	0.06
10	83	0.4	+ 1	8.3	0.05	+0.1	38	0.4	+6	85	0.4	+ 2	74	0.5	+ 2	257	1.9	+ 14	64	0.3	- 2	2.7	0.04
11	80	1.3	- 2	8.1	0.03	-0.1	-	-	-	76	0.7	- 7	74	1.4	+ 2	254	1.9	+ 12	-	-	-	-	-
12	78	0.7	- 4	7.9	0.18	-0.3	31	0.6	-2	77	1.5	- 6	74	0.8	+ 2	222	2.0	- 20	64	1.0	- 2	1.3	0.04
13	83	0.7	+ 1	8.2	0.10	0	-	-	-	80	0.1	- 2	70	0.1	- 2	251	1.2	+ 9	67	6.1	+ 1	2.6	0.1
14	75	0.3	+ 7	8.2	0.14	0	30	0.3	-3	75	0.3	- 8	70	0.5	- 2	252	1.8	+ 10	63	0.5	- 3	4.9	0.08
15	80	2.9	- 2	8.2	0.32	0	35	1.0	+2	79	0.7	- 4	71	0.9	- 1	251	3.7	+ 9	72	1.5	+ 6	3.5	0.29
16	150	-	+68	9.0	-	+0.8	42	-	+9	-	-	-	-	-	-	345	-	+103	100	-	+34	1.9	0.07
17	90	1.5	+ 8	9.1	0.11	+0.9	34	0.5	+1	77	3.5	- 6	71	3.7	- 1	252	5.2	+ 10	66	1.3	0	2.3	0.15
18	85	1.1	+ 3	8.1	0.14	-0.1	33	0.5	0	76	0.7	- 7	68	1.4	- 4	200	11	- 42	54	1.3	-14	3.0	0.11
19	77	2.4	- 5	8.6	0.6	+0.4	32	0.8	-1	76	2.3	- 7	70	1.1	- 2	250	10	+ 8	-	-	-	2.7	0.004
20	89	1.3	+ 7	8.8	0.2	+0.6	37	0.8	+4	80	8.0	- 3	75	0.6	+ 3	254	4.9	+ 12	75	1.1	+ 9	2.5	0.23
21	86	0	+ 4	7.8	0.03	-0.4	34	0.3	+1	80	0.4	- 3	73	0.2	+ 1	264	0.8	+ 22	62	0	- 4	-	-
22	73	5.8	+ 9	-	-	-	-	-	-	80	3.0	- 3	71	0.8	- 1	323	5.8	+ 81	-	-	-	-	-
23	81	1.1	- 1	8.2	0.15	0	34	0.9	+1	80	1.1	- 3	82	1.2	+10	235	1.1	- 7	59	1.4	- 7	-	-
24	83	1.7	+ 1	8.4	0.08	+0.2	33	0.2	0	76	1.0	- 1	71	0.6	- 1	249	2.7	+ 7	-	-	-	12.8	1.2
25	79	0.3	- 3	8.1	0.04	-0.1	31	1.0	-2	77	0.14	- 6	72	0.3	0	250	1.4	+ 8	68	0.1	+ 2	2.6	0.06
26	80	2.1	- 2	8.2	0.25	0	-	-	-	77	1.3	- 6	70	1.8	- 2	242	9.0	0	71	0	+ 5	-	-
27	91	0.9	+ 9	7.6	0.09	-0.6	36	0.6	+2	72	0.6	-11	85	0	+13	287	0.9	+ 45	68	0.8	+ 2	1.5	0.21
28	79	0.2	- 3	8.1	0.07	-0.1	33	0	0	79	0.1	- 4	71	0.2	- 1	246	0.9	+ 4	60	0.8	- 6	2.2	0.13
29	83	4.0	+ 1	8.0	0.50	-0.2	31	0	-2	84	7.0	+ 1	76	3.0	+ 4	251	0	+ 9	63	3.0	- 3	2.0	0.40
30	84	2.6	+ 2	8.3	0.21	+0.1	-	-	-	80	1.5	- 3	74	1.3	+ 2	252	18	+ 10	69	2.5	+ 3	2.8	-
31	75	0.5	- 7	7.5	0.55	-0.7	34	0.4	+1	82	0.1	- 1	59	1.1	-13	234	4.7	- 8	63	0.7	- 3	-	-
32	83	0.4	+ 1	8.6	-	+0.4	-	-	-	76	2.3	- 7	68	-	- 4	259	0.8	+ 17	60	-	- 6	2.3	0.08
33	79	0.9	- 3	7.2	0.07	-1.0	30	0.3	-3	69	1.9	-14	65	1.3	- 7	251	7.1	+ 9	62	1.4	- 4	-	-
34	89	1.3	+ 7	2.6	0.06	-5.6	-	-	-	73	1.0	-10	77	1.0	+ 5	-	-	-	-	-	-	2.5	0.04
35	81	0	- 1	8.2	0.08	0	33	0.2	0	83	0.9	0	72	0.8	0	242	4.1	0	63	0.5	- 3	-	-
36	80	0.3	- 2	9.0	0.10	+0.8	31	0.2	-2	80	0.4	- 3	73	0.1	+ 1	255	2.6	+ 13	33	0.2	-33	2.8	0.16
37	-	-	-	-	-	-	-	-	-	97	8.9	+14	76	2.4	+ 4	246	13.0	+ 4	59	8.3	- 7	2.0	0.06
$\bar{\bar{x}}^*$	81.0			8.3			-			78.89			-			249.10			65.10			2.48	
$\bar{\bar{x}}$	83.7			8.1			33.6			79.4			72.6			252.35			65.19			2.95	
$s_{Interlab.}$	12.06			1.04			2.63			5.42			4.40			28.82			10.88			2.15	
$s^*_{Interlab.}$	4.08			0.43			-			4.57			-			17.90			7.00			0.41	
RSD*	5.04%			5.18%			-			5.79%			-			7.19%			10.75%			16.53%	
RSD	14.41%			12.84%			7.83%			6.59%			6.06%			11.42%			16.69%			72.88%	

* Corrected for outliers

Die hohen Konzentrationen der zum Versand gekommenen Originallösung erlaubten eine genaue Analyse der Lösung mit Hilfe von hochpräzisen gravimetrischen und titrimetrischen, störungsfreien Verfahren. Tabelle 3 zeigt die erhaltenen Sollkonzentrationen, ihre Standardabweichung und die eingesetzten Methoden, bereits auf die Bedingungen der "Testlösung", d.h. zwanzigfache Verdünnung mit 2M HNO_3, bezogen. Lediglich Hg konnte, in Ermangelung geeigneter Methoden nicht mit vergleichbarer Genauigkeit bestimmt werden. Der in Tabelle 3 genannte "Referenzwert" basiert auf der Messung durch Atomfluoreszenzspektroskopie und könnte mithin mit systematischen Fehlern unbekannter Größe belastet sein.

Die zur Analyse der "Testlösung" notwendigen Manipulationen durch die Teilnehmerlaboratorien waren somit auf ein Minimum beschränkt: Öffnen der Ampulle, Verdünnung des Inhalts auf 1 L, Analyse.

Eine Betrachtung des systematischen Fehlers Δ zeigt jedoch, daß nur wenige Laboratorien alle Elemente richtig bestimmen.

Die Streuung der Analysendaten hält sich jedoch, nach Eliminierung einiger grober Ausreißer, im Rahmen der im Allgemeinen in Routinelaboratorien für erforderlich erachteten Genauigkeit, mit Ausnahme der Elemente Hg und Cr.

Während sich beim Chrom die auch von anderen Autoren beobachtete Fehleranfälligkeit in der AAS bestätigte, liegt beim Quecksilber die Hälfte der Laboratorien in dem wahrscheinlich richtigen Konzentrationsbereich 2.5 - 3.0 ppm, und nur wenige Messungen erscheinen grob falsch. Hier spiegelt sich offensichtlich ein im Gange befindlicher Entwicklungsprozess mit guter Perspektive.

Tabellen 4 und 5 zeigen die für die beiden eingesetzten Testmaterialien erhaltenen Ergebnisse. Neben der Totalvarianz für alle Analysenwerte wurden getrennte Auswertungen für den Königswasseraufschluß und die Trockenwaschung durchgeführt. (Tabelle 6 und 7).

Die absoluten Konzentrationswerte liegen, mit wenigen Ausnahmen, für den Königswasseraufschluß höher. Die Ausnahmen bilden Zink, das mit großer Konstanz mobilisiert wird und Kobalt. Bei letzterem steht zu vermuten, daß die enorme Streuung der Daten, wohl verursacht durch mangelnde Praxis für dieses Element, andere Tendenzen maskiert.

Table 3

Test solution reference concentration values

Element *	Method	$\bar{x}$ [ppm]	s [ppm]	RSD [%]
Pb	Gravimetry (Leadchromate)	82	0.35	0.43
Cr	Oxidimetry	66	0.25	0.38
Ni	Gravimetry (Dimethylglyoxim)	83	0.40	0.48
Cd	Electrogravimetry	8.2	0.05	0.61
Co	Gravimetry (α-Nitroso-βNaphthol)	33	0.35	1.06
Cu	Electrogravimetry	72	0.55	0.76
Zn	Gravimetry ($Zn_2P_2O_7$)	242	0.71	0.29

* Due to the low concentration the establishment of a mercury reference value was found impossible. By atomic fluorescence spectroscopy a concentration value of 2.75 ppm was found.

Material 1 Table 4 (Values expressed in ppm)

Laboratory No.	Pb $\bar{X}$	Pb S	Cd $\bar{X}$	Cd S	Co $\bar{X}$	Co S	Ni $\bar{X}$	Ni S	Cu $\bar{X}$	Cu S	Zn $\bar{X}$	Zn S	Cr $\bar{X}$	Cr S	Hg $\bar{X}$	Hg S
1 (Dry ashing)	349	0	21	0	14.5	2.1	42	0	432	73	3311	115	81	11		
1 (HNO_3; $HClO_4$)	179	-	26	-	29	-	81	-	481	-	3537	-	134	-		
1															9.5	1.2
2 Aqua regia	344	4.9	20.2	0.13			45	6.3	426	5.2	2580	38	93	3.0		
2 Aqua regia mod.	353	6.0	20.2	0.13			54	4.0	436	4.9	2639	21	98	2.5		
3 Aqua regia	309	15	14.3	1.0			66	13	754	33	2292	78	76	3	6.0	1.2
3 HNO_3	311	7.6	16.8	0.9			71	9.7	768	6	2273	23	70	4	6.6	0.3
3 Dry ashing	286	7	15.0	1.5					545	11	1682	28	55	2	2.2	0.2
3 Aqua regia	321	7	15.6	0.3			57	6.3	769	11	2270	25	74	1	11.0	0.8
4 HNO_3	323	40	18.8	0.4			56	1.3	468	9	2872	16	67	5		
5 Aqua regia	398	4.5	20	0			53	0.7	467	3.4	2967	85	155	1.2		
6 HNO_3(Pressure)	96	0.07	17.5	0.17	4.4	0.77	35	1.3	467	10.4	3192	73	64	1.1	7.6	0.4
7 Aqua regia	322	11	18.3	0.12	14.9	0.44	45	0.35	415	3.3	2798	34	61	0.53		
8 HNO_3;H_2O_2	256	4.7	15.3	0.13	10.7	0.51	38	0.37	389	5.0	2476	18	57	1.1	7.6	0.4
9 HNO_3;H_2O_2	340	5.6	17.7	0.84	5.6	0.29	41	0.81	425	7.5	2298	55	63	1.3		
10 Test solution only																
11 Dry ashing	314	4.9	16.7	0.36			38	2.0	353	5.0	2761	33				
12 HNO_3:H_2O_2	380	7.8	19.4	1.6	20.9	1.7	50	4.4	409	11	1658	19	37	2.2	6.8	0.5
12 HNO_3(Pressure)	366	5.7	19.1	0.62	18.5	0.43	50	1.4	403	7.4	2634	64	34	1.7	6.6	0.6
13 Aqua regia	350	2.2	17	0			52	0	403	1.5	2884	19	75	1.1	9.6	1.2
13 Dry ashing	335	4.2	16.4	0.2			29	2.9	340	1.7	2833	12	51	1.0		
14 Aqua regia	380	10	28	2			60	10	430	11	3030	20	80	0	16	1
15 No information	319	12	17	0.8	5.7	0.8	34	1.1	445	5.6	3250	213	77	7.3	16.2	1.1
16 Aqua regia	474	21	16.2	0.8			34	1.8	364	7.1	2774	302	85	5.0	3.3	3.5
17 Dry ashing	345	17	17.9	0.9	7.9	0.17	39	1.6	426	4.7	3010	24	119	6.3	3.9	1.1
18 Aqua regia	458	33	24.4	2.1	11.6	1.3	57	6.2	588	55	3380	345	90	7.3	7.2	1.2
19 HNO_3:H_2O_2	294	6	18.8	1.3	6.9	0.09	36	1.9	380	13	2719	101			6.0	0.8
19 HNO_3;$HClO_4$			19.8	1.1	9.4	1.1	42	6.7	396	21	2919	333				
20 HNO_3;H_2SO_4	339	14	19.0	0.6	13.0	1.4	43	4.0	415	5.0	2792	222	72	5.3	8.9	0.5
21 Dry ashing	344	2.2	16.9	0.2	17.1	0.5	45	1.0	389	2.8	2814	58	75	2.1	27.6	0.8
22 Dry ashing	318	1.3					53	0.6	346	11	4070	140				
22 Aqua regia	327	31					60	1.7	409	1.5	4210	32				
22 HNO_3	310	1.2					52	1.2	400	1.5	4120	30				
22 HNO_3;H_2O_2	311	0.6					57	1.6	399	4.0	4220	1.2				
23 HNO_3	368	8.4	17.8	0.8	27	4.5	45	1.0	453	5.1	3126	55	64	1.2		
23 Dry ashing	337	4.2	18.5	0.12	29	1.2	47	0.6	430	2.1	3093	31	65	1.7		
24 Dry ashing	334	12	19.0	0.72	6.8	0.68			398	8.1	2928	24				
25 Aqua regia	341	3.0	18.7	0.18	10.4	0.21	44	0.71	420	3.7	2828	8.3	80	1.2	7.8	0.47
25a HNO_3-$HClO_4$	356	3.3	19.1	0.34	17.3	1.08	47	1.08	408	5.5	2865	54.5	113	6.2	8.5	-
26 HNO_3;HNO_3-$HClO_4$-H_2SO_4	347	19	17.5	1.1			41	1.0	434	4.0	2926	88	146	4		
27 HNO_3-H_2O_2	378	11.6	17.0	1.39	9.6	0.89	36	0	431	4.5	2541	23	64	4.9	0.17	0.05
28 Aqua regia	328	3	16.0	0.5	6.2	0.3	35	0.6	404	3.0	2910	19	69	0.8	8.4	0.2
29 HNO_3(Pressure)	330	20	16.0	1.0	5.0	0.4	30	1.0	440	40	2720	90	81	5.0	8.0	1.0
30 HCl-H_2O_2	368	6.9	16.8	0.45			33	1.3	469	11.5	2806	220	84	5.6	8.0	-
31 H_2O_2-HNO_3	221	14.5	15.7	0.34	9.9	0.40	43	1.4	322	12.4	2297	85.4	67	0.90		
31a $HClO_4$-HNO_3	256	10.3	16.1	0.32	9.5	0.58	43	1.38	240	14.6	2340	45	95	1.6		
32 Aqua regia	326	8.5	18.3	0.6			48	0.9	320	19.6	2931	74.7	78	0.3	7.4	0.7
32a $HClO_4$-HNO_3	343	42.0	18.9	0.3			42	4.0	433	8.7	3023	56	77	0.3		
33 Dry ashing																
34 HNO_3(Pressure)	350	4.7	20.1	0.16			52	0.77	454	2.8					8.5	0.31
35 HNO_3 1:1	391	16.1	18.0	0.42	16.2	0.95	53	6.9	463	12.5	2940	72	141	10.3		
36 HNO_3	329	8.3	19.0	0.37	6.5	0.38	37	2.0	426	1.9	2890	7.9	86	3.4	13.0	0.15
36a Aqua regia	348	3.1	18.9	0.20	5.7	0.40	36	0.39	435	7.8	2880	9.4	88	8.0		
37 Aqua regia							53	4.6	446	5.5	2770	253	101	9.1	9.2	0.30
38 Non-destructive	345	-	14.5	-	6.7	-	42	..	413	-	3080		128	-		

Material 2 Table 5 (Values expressed in ppm)

Laboratory No.	Pb $\bar{x}$	Pb s	Cd $\bar{x}$	Cd s	Co $\bar{x}$	Co s	Ni $\bar{x}$	Ni s	Cu $\bar{x}$	Cu s	Zn $\bar{x}$	Zn s	Cr $\bar{x}$	Cr s	Hg $\bar{x}$	Hg s
1 Dry-Ashing	1589	38.6	9.4	0.40	29	2.1	239	3.5	673	11.3	1884	16.4	220	3.7	—	
1 HNO_3; $HClO_4$	1332	244	11.7	0.53	41	1.6	282	5.0	732	3.7	2036	12.6	289	18.2	—	
1	—		—		—		—		—		—		—		10.5	0.66
2 Aqua regia	1427	62	10.1	0.27	—		228	3.3	597	6.7	1630	12.5	202	1.7	—	
2 Aqua regia mod.	1442	112	10.1	0.27	—		244	4.7	615	5.5	1669	11.9	214	3.4	—	
3 Aqua regia	1512	29	6.0	0.43	—		311	20.4	1115	40	1993	12	183	4	5.6	0.27
3 Aqua regia	1571	33	5.2	0.37	—		366	21	1249	46	1894	15	124	4.6	9.5	0.56
3 HNO_3	1569	36	5.9	0.23	—		208	16	1189	32	1883	13	70	4.2	5.3	0.75
3 Dry-Ashing	562	42	1.95	0.44	—		72	4	591	33	534	18	115	1.6	1.6	1.50
4 HNO_3	1662	17	6.0	0	22.4	0.5	262	0.9	704	7	1870	14.1	149	1.6	—	
5 Aqua regia	1794	12	8.0	0.08	—		271	2.24	714	8.1	1796	14.2	326	1.8	—	
6 HNO_3	1740	56	5.8	0.25	10.7	0.6	169	5.0	708	23	1986	66	75	5.0	7.0	0.73
7 Aqua regia	1488	54	7.3	0.08	19.1	0.4	265	0.8	640	4	1790	14.1	121	0.7	—	
8 HNO_3; H_2O_2	1284	43	5.0	0.13	15.7	0.5	168	0.89	610	9.3	1652	11	77	4.6	7.3	0.47
9 HNO_3; H_2O_2	1643	5.2	5.3	0.4	10.2	0.8	206	6.8	668	3.2	1386	42	112	9.2	6.3	2
10 Testsolution only	—		—		—		—		—		—		—		—	
11 Dry-Ashing	1326	59	5.75	0.26	—		170	6.2	520	42	1556	46	—		—	
12 HNO_3; H_2O_2	1668	24	7.0	0.79	23.1	1.5	242	3.4	672	26	1688	41	251	8.3	5.1	0.26
12 HNO_3	1752	38	7.7	0.80	21.8	1.7	234	3.1	662	26	1696	23	251	8.2	5.1	0.58
13 Aqua regia	1696	23	5.2	0	—		241	7.1	616	5.7	1799	2.9	183	0.6	8.5	0.5
13 Dry-Ashing	1582	26	5.2	0	—		176	3.6	543	5.7	1697	21	94	1	—	
14 Aqua regia	1700	11	—		—		260	0	630	13	1840	26	190	0	13.2	1
15 No information	1492	85	5.3	0.44	9.5	1.0	172	5.6	670	27	2101	162	93	7.4	10.2	0.53
16 Aqua regia	1750	74	4.2	0.6	—		201	4.3	631	11	1833	124	173	2.6	6.9	0.79
17 Dry-Ashing	1778	26	5.9	0.21	15.2	0.9	206	20	663	7.3	1907	35	264	7.3	7.7	0.46
18 Aqua regia	1592	49	6.0	0.04	15.5	0.4	241	1.5	593	6.3	1490	51	108	6.8	8.0	0.41
19 HNO_3; H_2O_2	1431	69	9. 0	1.2	12.8	0.6	155	6.8	614	14	1742	78	—		6.0	0.9
19 HNO_3; $HClO_4$	—		8.6	0.5	13.0	1.0	200	12	596	24	1802	122	—		—	
20 HNO_3; H_2SO_4	1550	14	9.2	0.7	19.5	2.4	184	13	632	10	1722	22	94	2.8	7.4	0.31
21 Dry-Ashing	1561	13	6.7	0	22.9	1.2	237	5.2	623	7.6	1751	13	219	2.8	—	
22 Dry-Ashing	1328	30	—		—		210	12	641	4.5	2603	30	—		—	
22 Aqua regia	1537	17	—		—		247	11	671	12	2654	35	—		—	
22 HNO_3	1517	18	—		—		217	12	655	1.1	2620	24	—		—	
22 HNO_3; H_2O_2	1496	23	—		—		231	2.5	646	12	2601	33	—		—	
23 HNO_3	210	7.1	8.0	0.7	41	1.1	179	1.6	686	7.6	1904	15	64	0.9	—	
23 Dry-Ashing	192	3.5	3.6	0.4	40	0.6	245	15	650	4.6	1976	32	169	3.1	—	
24 Dry-Ashing	1627	26	8.5	0.35	11.4	1.2	238	3.2	630	12	1801	13	—		—	
25 Aqua regia	1602	6.06	7.7	0.24	17.3	0.32	206	5.3	644	3.1	1768	12.1	152	8.4	7.3	0.30
25a HNO_3-$HClO_4$	1684	20.0	3.4	0.09	25.9	0.37	237	3.2	633	12.3	1777	10.6	289.3	7.9	—	
26 HNO_3;HNO_3-$HClO_4$-H_2SO_4	1651	52	5.8	0.35	—		253	8	650	4	1816	13	320	7.0	—	
27 HNO_3-H_2O_2	1630	26	5.0	0.57	—		246	8	670	7	1891	40	316	9.0	—	
28 Aqua regia	1665	57	7.1	1.02	14.8	0.89	147	3.3	643	26.3	1762	39	76	2.2	0.19	0.1
29 HNO_3 (Pressure)	1641	17	5.1	0.24	12	0	222	2.2	645	6.1	1769	25	166	1.8	6.9	0.08
30 HCl-H_2O_2	1700	50	5.0	0.5	9.0	1.0	160	10	680	30	1780	30	112	5	7.0	1.0
31 H_2O_2-HNO_3	1682	31.4	5.8	0.34	—		179	6.6	639	37.3	1710	86	122	11.0	8.3	-
31a $HClO_4$-HNO_3	1242	199	7.9	0.26	14.7	0.74	217	5.0	556	44.1	1560	53	132	5.5	—	
32 Aqua regia	1058	80	6.4	0.26	15.7	0.38	224	6.0	574	12.9	1525	34	229	3.8	—	
32a $HClO_4$$HNO_3$	1684	31	6.2	0.1	—		268	1.4	633	3.2	1819	13.9	181	6.8	5.5	0.2
33 Dry-Ashing	1385	128	6.8	0.84	10.8	0.45	140	0	495	15.2	1295	20.9	257	29.9	8.6	0.85
34 HNO_3 (Pressure)	1901	43.1	7.0	0.18	—		241	7.0	540	6.9	—		—		7.5	0.29
35 HNO_3 1 : 1	1936	18	6.5	0.46	23.1	0.96	211	15.5	711	10.9	1759	13	155	27	—	
36 HNO_3	1659	2.9	5.9	0.17	9.6	1.0	201	16.6	657	2.3	1723	6.6	110	34.6	11.0	0.91
36a Aqua regia	1653	13.1	6.0	0.19	9.9	0.28	204	20.8	650	6.1	1749	23.9	145	45.8	—	
37 Aqua regia	—		—		—		270	16	684	15	1750	43	246	34	7.1	0.21
38 Non-destructive	1530	-	4.3	-	14	-	226	-	612	-	1920	-	297	-	—	

Table 6

	Min.-Max.	$\bar{x}_{All}$	RSD_{All}	$\bar{x}_{Aqua\ regia}$	$RSD_{Aqua\ regia}$	$\bar{x}_{Dry\ ashing}$	$RSD_{Dry\ ashing}$
Pb	96 - 474	332	17.5%	359	13.8%	331	6.1%
Cd	14.3 - 28	18.3	14.3%	19.0	19.0%	17.8	12.0%
Co	4.4 - 29.0	12.4	56.8%	9.8	39.3%	16.9	54.5%
Ni	29 - 81	46	22.8%	50	19.0%	43	20.7%
Cu	240 - 769	438	21.9%	467	27.3%	411	16.8%
Zn	1658 - 4220	2886	17.8%	2884	15.4%	2962 (2777)*	24.1%
Cr	51 - 155	86	28.9%	87	25.0%	65	19.6%
Hg	0.17 - 27.6	9.0	55.1%	9.2	32.1%	-	-

*Omitting 1 outlier (4070 ppm)

Table 7

	Min.-Max.	$\bar{x}_{All}$	RSD_{All}	$\bar{x}_{Aqua\ regia}$	$RSD_{Aqua\ regia}$	$\bar{x}_{Dry\ ashing}$	$RSD_{Dry\ ashing}$
Pb	192 - 1936	1524	20.9%	1609	6.7%	1228	44.4%
Cd	1.95 - 11.7	6.7	26.7%	6.6	27.1%	6.6	36.1%
Co	9 - 41	18.3	49.0%	14.2	26.1%	21.3	60.1%
Ni	72 - 366	220	21.5%	253	16.6%	196	29.6%
Cu	495 - 1249	667	20.6%	705	26.0%	612	9.7%
Zn	534 - 2634	1811	18.1%	1816	13.1%	1716	32.6%
Cr	64 - 326	176	42.9%	177	31.4%	191	35.1%
Hg	0.19 - 13.2	7.3	35.9%	8.3	29.2%	-	-

Die Totalvarianz scheint im Regelfall zugunsten des Königswasseraufschlusses zu sprechen, obwohl in einigen Fällen maskierende Effekte auftreten, die leider aufgrund des zu knappen Datenmaterials nicht statistisch quantifizierbar sind.

Die den Trockenveraschungsverfahren nachgesagten Defekte scheinen sich zu bestätigen, wenn man die absoluten Konzentrationen der Königswasseraufschlüsse (Ausnahme Kobalt; siehe oben) vergleicht.

Elemente mit der Neigung zur Bildung flüchtiger, sublimierbarer Chloride (eingeschlossen Chromylchlorid in Gegenwart von Chromaten) können mit negativem Bias belastet sein. Die Richtigkeit der Analyse nach Trockenaufschluß scheint sowohl von der Tüchtigkeit des Laboranten, wie manche Daten der Tabellen 4 und 5 zeigen, wie auch von der Konzentration begleitender Elemente (Chloride, Ammoniumsalze und anderer Kosublimate) abzuhängen.

Zusammenfassend läßt sich feststellen, daß ungeachtet lokaler Traditionen und im Interesse fortschreitender Harmonisierung, dem einfacheren und relativ biasfreien Königswasserverfahren der Vorzug vor Trockenveraschung und anderen Säureaufschlüssen gegeben werden sollte.

Schlußbetrachtung

Die Leistungsfähigkeit von Laboratorien und analytischen Methodologien ist selbstredend einem Utilitätsprimat unterworfen.

Bei der Beurteilung der Resultate dieses Interlaboratoriumsvergleichs sollte mithin unterschieden werden zwischen dem Ausspruch der reinen analytischen Doktrin und den praxisorientierten Anforderungen an eine Schadstoffanalyse.

Vom Standpunkt der reinen Analytik und unter Berücksichtigung der Heterogenitätsdaten von 0.5 bis 2% für die untersuchten Standardmaterialien, bezogen auf die bestimmten Elemente, sind die Ergebnisse ohne Zweifel stark verbesserungsfähig.

Wie hoch jedoch die Ansprüche an eine, durch ein Routinelaboratorium ausgeführte Schadstoffanalyse von Klärschlämmen tatsächlich sein müssen, wird weitgehend von den in kommenden Direktiven noch festzulegenden Ana-

<u>Table 8</u>

ANALYTICAL METHODOLOGIES USED FOR THE DETERMINATION OF Cd, Cr, Co, Cu, Pb and Zn

Laboratory-Code	Analytical methodology	
	Sample digestion	Determination
1	Dry ashing: 5h at 480°C and dissolution in HCl	AAS
1a	Wet ashing: HNO_3, $HClO_4$	AAS
2	Wet ashing: Aqua regia	AAS
2a	Wet ashing: Aqua regia ("modified")	AAS
3	Wet ashing: Aqua regia	AAS
3a	Wet ashing: HNO_3	AAS
3b	Dry ashing: 0,5 h at 55°C	AAS
3c	Wet ashing: Aqua regia (reflux)	AAS
4	Wet ashing: HNO_3	AAS
5	Wet ashing: Aqua regia	AAS
6	Wet ashing: HNO_3 1:1 pressure digestion(120°C; h)	AAS
7	Wet ashing: Aqua regia	AAS
8	Wet ashing: HNO_3-H_2O_2	AAS
9	Wet ashing: HNO_3-H_2O_2	AAS
10	Test solution only	AAS
11	Dry ashing: h 4 at 450°C	AAS
12	Wet ashing: HNO_3-H_2O_2 pressure digestion at 170°C, 4 h	AAS
12a	Wet ashing: HNQ_3 pressure digestion(170°C, 4 h)	AAS
13	Dry ashing: 5 h at 480°C	AAS
13a	Wet ashing: Aqua regia	AAS
14	Wet ashing: Aqua regia (reflux)	AAS
15		
16	Wet ashing: Aqua regia (reflux)	AAS
17	Dry ashing: In presence of toluol-sulphonic acid at 450°C. Dissolution on HCl and dissolution of the residue by H_2F_2/H_2SO_4	AAS
18	Wet ashing: Aqua regia	AAS

Table 8 (continued)

ANALYTICAL METHODOLOGIES USED FOR THE DETERMINATION OF Cd, Cr, Co, Cu, Pb and Zn

Laboratory Code	Analytical methodology	
	Sample digestion	Determination
19	Wet ashing: HNO_3-H_2O_2	AAS
19a	Wet ashing: HNO_3-$HClO_4$	AAS
20	Wet ashing: HNO_3-H_2SO_4 (reflux)	AAS
21	Dry ashing: 2,5 h at 55°C and dissolution in HCL	AAS
22	Dry ashing: 3 h at 540°C and dissolution in HCL	AAS
22a	Wet ashing: Aqua regia	AAS
22b	Wet ashing: HNO_3	AAS
22c	Wet ashing: HNO_3-H_2O_2	AAS
23	Dry ashing: 2 h at 650°C and dissolution in HCl	AAS
23a	Wet ashing: HNO_3	AAS
24	Dry ashing: 1 h at 500°C and dissolution in HCl	AAS
25	Wet ashing: Aqua regia	AAS
25a	Wet ashing: HNO_3-$HClO_4$	AAS
26	Wet ashing: HNO_3(Pb,Cd) and HNO_3-$HClO_4$-H_2SO_4 (Ni, Cu, Zn, Cr)	AAS
26a	Wet ashing: HNO_3	AAS
27	Wet ashing: HNO_3-H_2O_2	AAS
28	Wet ashing: Aqua regia	AAS
29	Wet ashing: HNO_3 pressure digestion	AAS
30	Wet ashing: HCl-H_2O_2	AAS
31	Wet ashing: H_2O_2-HNO_3	AAS
31a	Wet ashing: $HClO_4$-HNO_3	AAS
32	Wet ashing: Aqua regia	AAS
32a	Not described	AAS
33	Dry ashing: 2.5 h at 425°C Dissolution $HClO_4$-HF-HNO_3	AAS
34	Wet ashing: pressure digestion with HNO_3	AAS
35	Wet ashing: HNO_3 1:1; 8 h	AAS
36	Wet ashing: HNO_3 (reflux)	AAS
36a	Wet ashing: Aqua regia (reflux)	AAS
37	Wet ashing: Aqua regia	AAS
38	Non destructive	XRF

lysentoleranzen bestimmt werden, und dabei wird eine Reihe von wissenschaftlichen, aber auch volkswirtschaftlichen und nicht zuletzt politischen Faktoren eine Rolle spielen.

Neben vereinzelten Eichproblemen in einigen Laboratorien sind die Fehlerquellen in der Schwermetallbestimmung in Klärschlamm und ähnlichen Produkten im Probenaufschluß zu suchen. Eine Harmonisierung der Analysenvorschriften in dieser Richtung ist zweifellos aussichtsreicher als eine Fortsetzung der methodologischen Forschung an vielen verschiedenen Aufschlußsystemen.

Königswasser ist nach den bisherigen Erfahrungen, bei Einhaltung einiger elementarer Verfahrensregeln, als Aufschlußmittel, immer mit dem Ziel vergleicbarer Daten, gut geeignet (Muntau, 1979). Ob die unter Königswasseraufschlußbedingungen im Klärschlamm verbleibenden Schwermetallreste im Boden aktivierbar wären, ist zum gegenwärtigen Zeitpunkt eine Frage von akademischem Interesse.

Ein periodisch-stichprobenartiger Aufschluß des Königswasserrückstandes mit Flußsäure bei einer routinemäßig erfolgenden Schwermetallbestimmung im Königswasserauszug unter standardisierten Bedingungen und eine regelmäßige und möglichst häufige Überprüfung der vollständigen analytischen Prozedur durch Standardreferenzklärschlämme sollte geeignet sein, die zur Begrenzung der Schwermetallbelastung von landwirtschaftlichen Nutzflächen notwendige Information zu liefern.

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MOBILITY OF HEAVY METALS IN SLUDGE AMENDED SOIL

An interlaboratory comparison

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Summary

A polluted soil sample has been used for a ring test in view of the determination of total and mobile contents of heavy metals. With very few exceptions the results for total contents are sufficiently well grouped and no systematic deviations were observed between a suggested method using aqua regia and some personnal methods.

The mobility test for heavy metals presented some difficulties due to the special characteristics of the soil under study and since only one sample was distributed, there was no alternative for comparison. In spite of this the results are sufficiently indicative for the situation of this particular soil.

Recommendations for eventual further work concern the laboratory apparatus and the proposal to compare different soils, rather than excluding such comparison by using only one sample.

1. PRINCIPLE

The agricultural, biological and environmental effects of trace elements and heavy metals in soils are determined by their "reactivity", this means by the fraction which is chemically and biologically active. This fraction is variable and depends on several factors such as pH, redox potential, fixation phenomena, active organic matter. It may be considered as the amount of elements which can be transferred from the solid to the liquid phase under the influence of changing conditions.
In this context one can distinguish between

- a fraction which is soluble at the actual soil conditions. This corresponds with the so-called nutrient intensity, in the case of essential elements
- a "mobilizable" fraction, being the amount which can pass into the solution when soil conditions are changed.

Since the pH influences directly or indirectly the equilibrium reactions, governing the distribution of trace elements between the different forms in which they are present, this factor can be used as a variable in estimating their mobility.
Indeed, by acidifying progressively a soil-water suspension and analyzing the solution-phase, a mobilization pattern is obtained, which is characteristic for the behaviour of the elements under study.

2. INTERLABORATORY COMPARISON - METHODS

A soil sample was provided by the Research Centre Euratom - ISPRA (Dr. Muntau). The participants were asked to make a total analysis of the heavy metals and to carry out a mobility test as described in the following paragraphs.

2.1. Determination of the total metals content by aqua regia digestion (suggested method)

Weigh 1 g of dry soil into a 100 ml round-bottom flask and add a small amount of distilled water (approx. 2-3 ml) to obtain a slurry. To the latter add 10 ml aqua regia. Place a reflux condenser (Dimroth-type or similar) of approx. 40 cm length on top of the flask. Boil mixture in the flask under reflux for 2 h. Cool slightly and add, through the condenser, approx. 30 ml of distilled water to wash residual amounts into the flask. Filter the diluted solution through an acid-resistant paper filter and take up the filtrate in a calibrated 100 ml flask. Wash filter with residue with warm 2 N

HNO_3 to take up residual amounts and repeat several times. When solution has cooled down to room temperature complete volume to the mark with 2 N HNO_3. Onward dilutions, if necessary for analysis, are obtained by using 2 N HNO_3.

Remark : The same method is applicable for sewage sludge. Prior to analysis determine the moisture content of the original sample by storing over P_2O_5 in an exsiccator until constant weight. Correct values.

2.2. Procedure for the mobility test

Analytical procedure

Weigh 10 g air-dry soil in a 150 ml beaker. Add 40 ml distilled water and adjust the pH of the suspension to the desired value while using a magnetic stirrer (see below). For steps B, C and D, this is achieved by adding controlled volumes (V ml) of HNO_3. The normality of the HNO_3 varies from 0.1 to 2 N in function of the desired pH decrease of the suspension and of the nature of soil used. The total volume of added HNO_3 should not exceed 10 ml. The pH of the continuously stirred suspension is kept constant by suitable means for 30 minutes. After equilibration the final volume is brought to 50 ml by adding (10 - V) ml of distilled H_2O. The soil suspension is filtered, pH of the filtrate is determined and entered into the table. The filtrate is analyzed for Cd, Cu, Ni and Zn and if possible, also for Pb, Cr and Co.

Experience has shown that it is recommendable to use 2 N HNO_3 solutions when determining the metals by atomic absorption spectrometry, so that for necessary dilutions of the filtrate, 2 N HNO_3 is used.

For purposes of this Intercomparison Study, it is recommended to observe the following pH steps

A. Original pH of the soil-water suspension (= pH soil)

B. pH 4.0

C. pH 2.0

D. pH 0.5

For each step, a fresh soil-water suspension is prepared. If the mass of the sample is too small, the original quantities used should be less (e.g. 5 g soil + 20 ml distilled water ...)

3. EXPERIMENTAL RESULTS

The results of 15 laboratories were received in due time.

3.1. Total contents

Nine participants have used the proposed method, nine applied a personnal method and three made parallel determinations with both proposed and personnal methods (see table 1 and fig. 1 to 3).

There are no systematic differences between the results obtained by the different methods being used. The deviations are rather accidental and the analytical figures are relatively well grouped around the mean value.

3.2. "Mobilizable" fractions and mobility

In applying the proposed method several difficulties were encountered. Due to the characteristics of the soil sample it was necessary to add higher concentrations of HNO_3 in order to lower the pH of the soil suspensions sufficiently. Thus in stead of 2 N as proposed, nitric acid solutions of 4 N, 5 N and 6 N have been added.

The major problem was the pH control of the soil suspensions. Indeed after the pH was brought to the desired value of 4, 2 or 0.5 it progressively raised again so that the filtrates finally showed the following pH ranges :

pH-soil	: 6.60 to 7.7
after bringing to pH 4	: 4.0 to 5.5
after bringing to pH 2	: 2.0 to 4.0
after bringing to pH 0.5	: 0.5 tc 2.2

With regard to this observation the following remarks may be made :

a.- there is always a slight pH difference between the suspension and the filtrate and this is known as suspension effect

b.- the pH raise during equilibration is due to the presence of lime and alcaline particles reacting slowly in function of surface properties, effect of coating etc. The dissolving power of the added acid is therefore acting progressively in time. Another reason for pH variation is the phenomenon of selective ion exchange, due to which added H^+-ions are exchanging different adsorbed ions in successive steps

c.- the effect of heavy metals in the soil is strongly influenced by its cation exchange capacity, lime and organic matter content. Thus light and acid soils are much more affected than heavy and calcareous soils.

d.- the actual mobility test was originally conceived for light and medium soils. With the aid of a "pH-Stat" instrument, acid is added with an automatic buret in order to maintain the pH at any preset value.

The experimental results are given in tables 2 to 4.

In spite of the occurring variations the soil sample is characterized in a quite specific way. This can be illustrated by comparing the ISPRA test soil with other non polluted soils, as shown in the same tables for Cu and Zn.

4. GENERAL REMARKS AND CONCLUSION

The mobility test for heavy metals in the one distributed soil sample presented some difficulties due to its high CEC and lime content.
In spite of this all participants have obtained results which are quite indicative for the situation of the polluted ISPRA-soil sample under study. Since only one single sample was distributed no comparison with other occurring situations was possible. Facing the figures determined on the ISPRA-sample with those for other soils reveals the type of distinction which can be obtained by the analysis of soils in different conditions.

A more detailed and fundamental discussion of the method shows that the effect of an existing pollution is quite well reflected by the slope of the mobilization curve in combination with the total content of the element under study. Furthermore, since a certain fraction of the total content is strongly fixed or immobilized, it may be sufficient to consider the amount being mobilized at pH 0.5 instead of total values.

For eventual further work it is recommended to make use of an appropriate instrument for keeping the pH of the soil suspension more constant while the test should be carried out on different samples in order to permit comparison of their situation.

5. ACKNOWLEDGEMENT : thanks to Prof.R.LESCHBER, coordinator of Working Party 2 of the CEC Concerted Action COST 68bis and to all participants having carried out the proposed analysis.

Table 1. Total contents of heavy metals (ppm in the soil)

Lab nr.	Cd	Cu	Ni	Zn	Pb	Cr	Co
proposed method							
1	35.3	268	103.5	1381	1380	176	14.6
2	32	230	100	1275	1306	200	13.1
3	34	260	104	2560	1400	219	28
4	35	234	115	1301	1378	243	14.7
6	21.8	235.3	102	1281.2	723	209.2	17.4
8	29	222	91	1210	1360	165	16
9	31.6	241	84.5	1259	1392	191	16.1
10	34.68	262.9	116.7	1358	1382	221	16.76
14	33.5	236	105.1	1275	1391	202	20.5
$\bar{x}$	31.9	243.2	102.4	1433	1301	202.9	17.4
σ	4.3	16.3	10.2	426	219	23.8	4.4
personnal method							
3	31	225	109	2300	1331	205	-
4	36	235	115	1302	1395	244	14.7
5	27	210	89	1230	1250	210	-
7	31.2	238	105	1283	1367	375	14.2
9	35.2	234	78.8	1273	1405	172	12.1
11	34.8	240	86	1487	1373	134	20
12	29.2	218	60	1060	1195	200	-
13	30.4	238	93	1325	1355	183	12.5
16	31.4	232	92.6	1246.2	1323.2	189.1	11.6
$\bar{x}$	31.8	230	92	1390	1333	212.5	14.2
σ	3.0	10.3	16.7	359	69	67.9	3.1
general mean value	31.8	236.6	97.2	1412	1317	207.7	16.1
general σ	3.6	14.8	14.4	382	158.2	49.6	4.2

Lab nr.	ppm Cd found after the following pH adjustments				ppm Cu found after the following pH adjustments			
	pH-H_2O of the soil	± 4	± 2	± 0.5	pH-H_2O of the soil	± 4	± 2	± 0.5
1	0.05	3.75	17.24	25.36	0.46	1.67	12.17	121.7
2	0.03	3.6	18.4	32	2.0	2.5	8.2	153
3	1.22	3.68	14.3	17.2	0.82	1.23	2.87	165
4	0.1	3.5	20.3	29.9	1.68	1.88	9.40	95.8
5	0.5	4.0	18	28	1.0	1.8	13	120
6	-	3.85	10.8	13.8	-	0.96	26.5	153
7	0.25	4.70	18.0	29.8	1.6	2.2	7.6	135
8	0.01	3.5	11	25	1.0	1.9	4.3	62
9	-	3.48	22.7	29.3	0.99	2.18	22.1	145
10	0.01	4.80	19.1	31.1	0.5	0.98	11.0	132
11	-	5.47	24.6	34.3	-	3.1	29	169
12	0.02	4.1	12.4	19.7	1.9	2.6	25.3	125
13	0.05	3.6	13.3	21.0	1.2	2.0	9.2	94.5
14	-	-	-	-	-	-	-	-
16	0	3.2	27.5	31.8	0.8	1.5	52.9	158
Range	0 - 1.22	3.2 - 5.47	10.8 - 22.7	13.8 - 34.3	0.46 - 2.0	0.96 - 3.1	2.87 - 52.9	62 - 169
$\bar{x}$		3.95	17.7	26.3	1.2	1.89	16.7	131
median		3.70	18.0	28.5		1.89	11.6	134

light soil (pH 5.60)	0.5	0.55	1.80	8.7
medium soil (pH 5.65)	0.12	0.37	4.50	13.6
heavy soil (pH 7.10)	trace	trace	trace	4.4

Table 3. Ni and Zn mobilization patterns

Lab nr.	ppm Ni found after the following pH adjustments				ppm Zn found after the following pH adjustments			
	pH-H_2O of the soil	± 4	± 2	± 0.5	pH-H_2O of the soil	± 4	± 2	± 0.5
1	0.46	3.8	15.21	38.03	0.61	152	517	781
2	0.39	6.4	18.5	52	0.55	145	621	1000
3	1.60	5.8	16.4	54	1.64	132	573	1167
4	1.42	6.3	17.5	42	1.83	136	654	918
5	<0.5	3.8	15.0	38	<1	170	580	930
6	-	6.9	19.5	40.8	-	248.2	758.7	991.9
7	0.3	5.7	19.9	49.0	0.71	197	687	1101
8	0.25	4.5	11.1	34.3	0.30	227	454	833
9	0.79	5.5	19.1	47.8	0.65	198.6	698	996
10	0.14	5.9	16.8	44.0	0.83	234	680	1098
11	-	5.1	19.9	50	-	256	847	1248
12	0.25	3.7	11.9	28.9	2.2	200	625	800
13	<0.2	3.5	10.9	30.0	3.1	170	500	750
14	-	-	-	-	-	-	-	-
16	0.06	6.2	44.7	52.4	0.3	119.5	1050.3	1268.2
Range	0.06 - 1.6	3.5 - 6.9	10.9 - 44.7	28.9 - 54	0.3 - 3.1	119.5 - 256	454 - 1050	750 - 1268
$\bar{x}$		5.2	18.3	42.9		185	660	992
median		5.6	16.6	43		180	640	995
				light soil (pH 5.60)	0.22	2.20	8.30	9.75
				medium soil (pH 5.65)	0.05	7.70	12.50	12.50
				heavy soil (pH 7.10)	trace	0.50	4.50	13.30

Lab nr.	ppm Pb found after the following pH adjustments				ppm Cr found after the following pH adjustments				ppm Co found after the following pH adjustments			
	pH-H_2O of the soil	± 4	± 2	± 0.5	pH-H_2O of the soil	± 4	± 2	± 0.5	pH-H_2O of the soil	± 4	± 2	± 0.5
1	<0.5	0.71	35.5	882	<0.05	0.25	1.52	28.4	<0.05	0.25	1.27	4.26
2	<0.5	1.0	23.0	1040	0.12	0.12	0.81	47	<0.2	0.25	1.8	5.10
3	0.8	2.8	11.2	1180	0	0.41	1.23	38.5	1.22	2.86	4.1	11.5
4	0.97	1.12	26.9	770	0.41	0.61	2.29	28.8	<0.1	0.25	1.42	4.12
5	<1.0	<1.0	45	900	<1	<1	3	43	-	-	-	-
6	-	2.27	72.6	583.5	-	0.1	4.3	48.1	-	0.5	1.60	4.40
7	<0.5	1.5	26.1	1040	<0.25	<0.25	1.01	49.3	<0.25	0.45	1.91	5.3
8	0.05	1.7	8.2	475	0.13	0.25	0.55	15	0.05	0.30	1.10	3.70
9	trace	trace	113	1139	0.21	0.68	4.43	50.5	trace	trace	3.03	9.09
10	0.22	2.24	35.1	960	0.1	0.32	1.89	20.8	0.06	1.00	1.90	6.53
11	-	2.0	138	1255	-	0.50	3.4	45	-	1.8	4.0	9.9
12	0.37	2.25	110	1085	0.16	0.30	3.5	54	-	-	-	-
13	0.30	0.50	28.5	735	<0.2	0.65	2.1	21	<0.2	<0.2	0.7	2.7
14	-	-	-	-	-	-	-	-	-	-	-	-
16	0	0.7	466.7	1235.7	0.05	0.5	13.7	71.9	0	0.8	4.9	5.2
Range	0-0.97	0.5-2.8	8.2-467	475-1255	0-0.41	0.1-0.68	0.55-13.7	15-72	0-1.22	<0.2-2.86	0.7-4.9	2.7-11.5
$\bar{x}$		1.6	81.4	949		(0.4)	3.1	40		(0.85)	2.31	6.0
Median		1.6	40	1000		(0.41)	2.2	46		(0.65)	1.85	5.25

Fig. 1. Total Cd and Cu

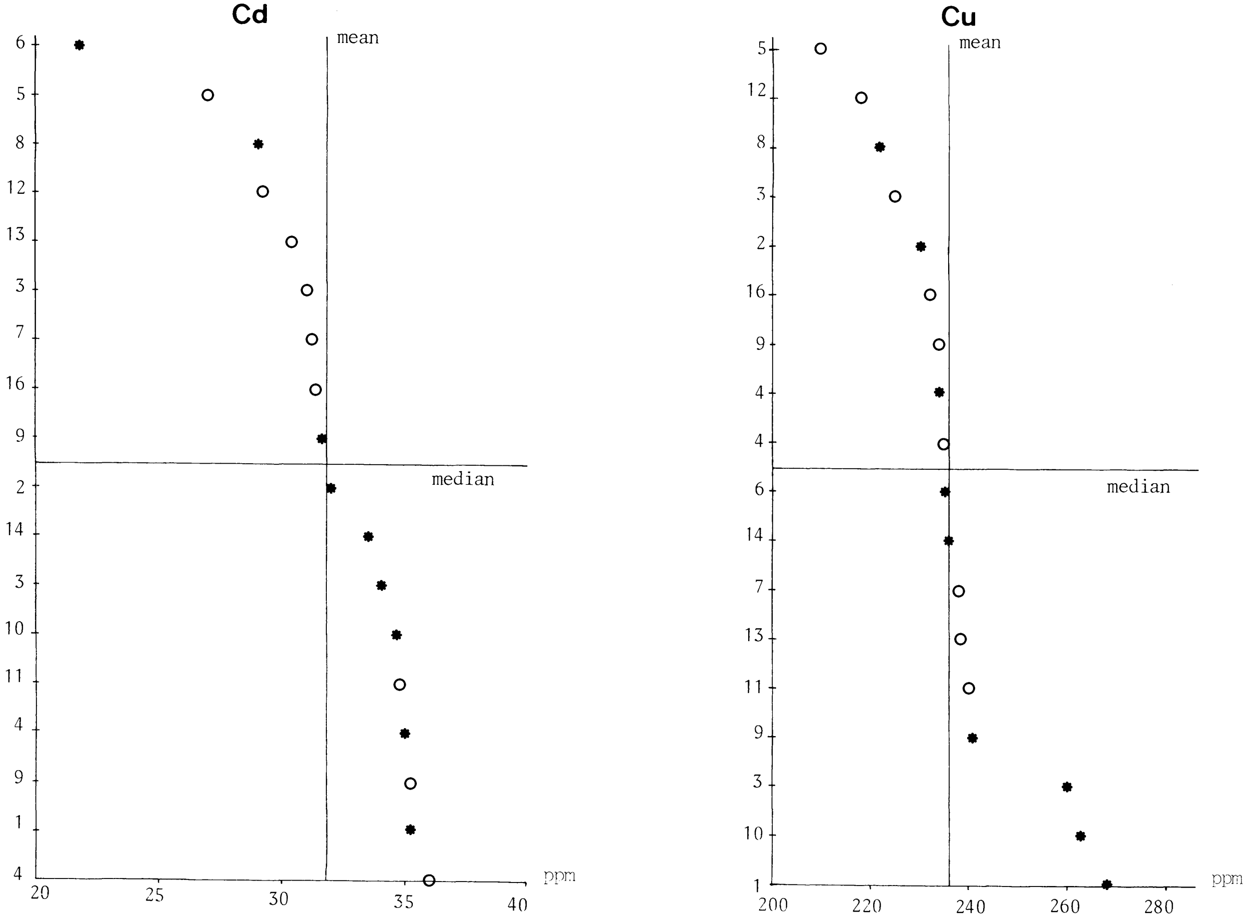


Fig. 2. Total Ni and Zn

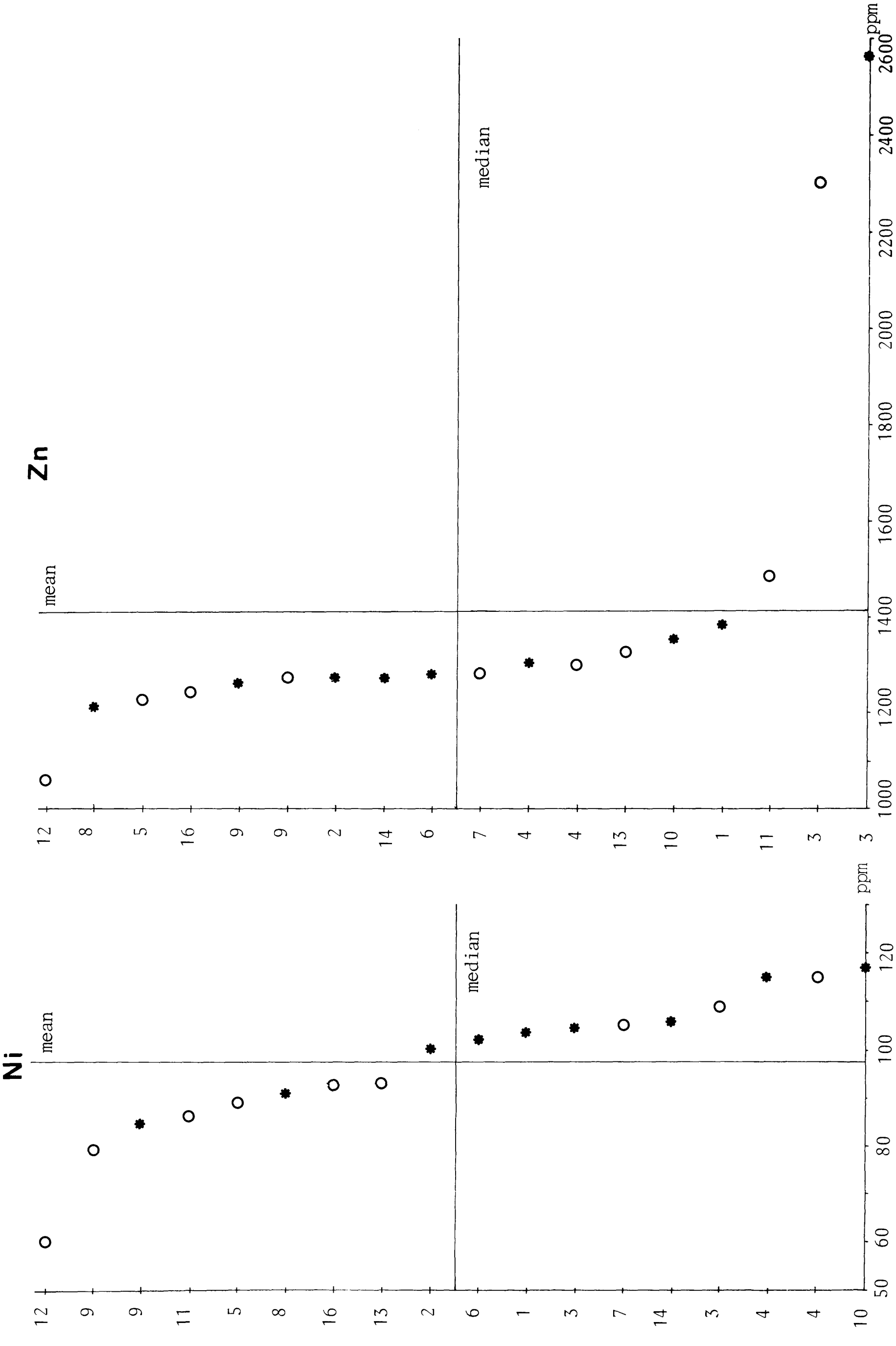
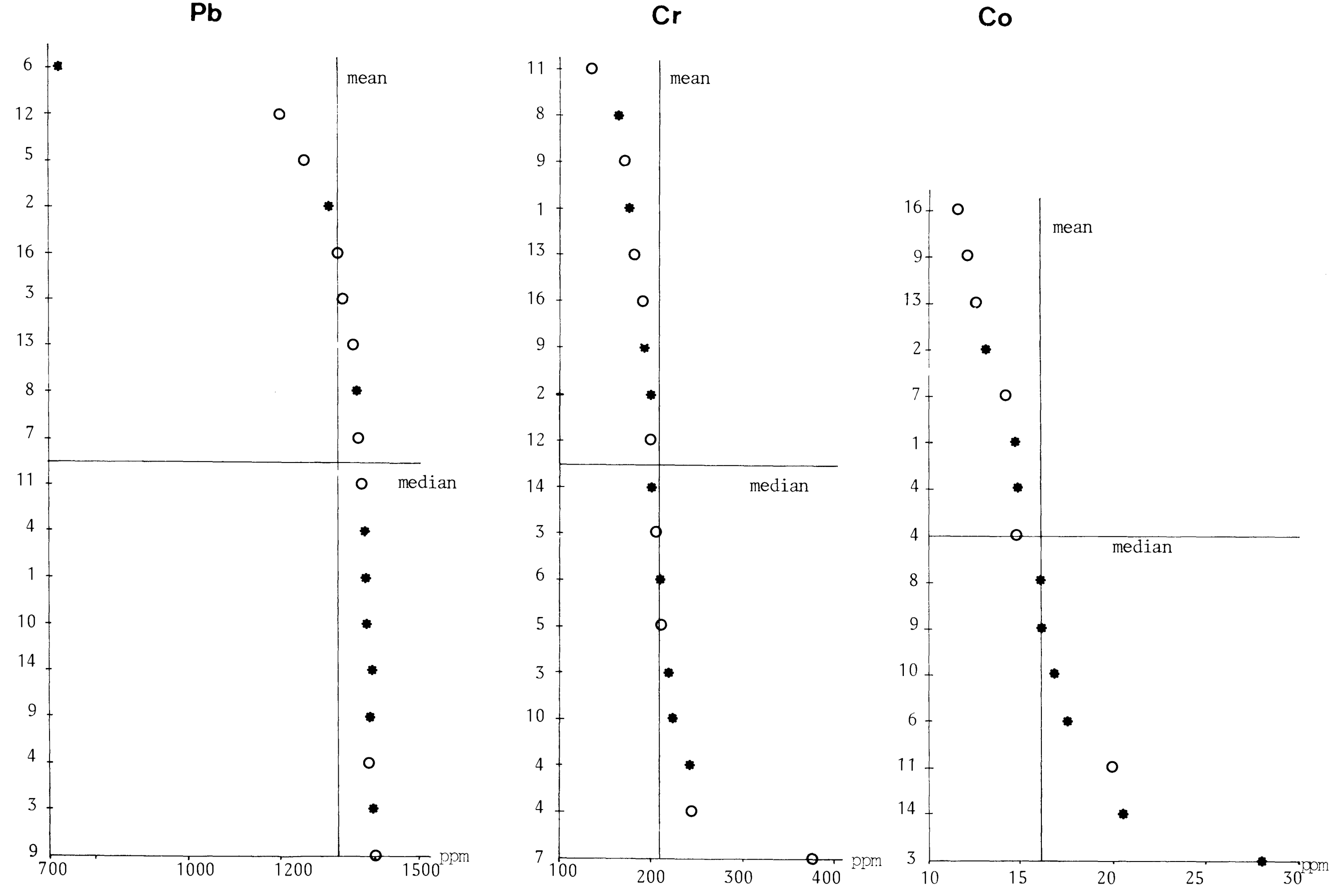


Fig. 3. Total Pb, Cr, Co



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PCB DANS LES BOUES DE QUELQUES STATIONS D'EPURATION DE SUISSE

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Résumé

L'étude des PCB dans le lac Léman et leur concentration dans une chaîne alimentaire (du sédiment aux oiseaux) a montré que les teneurs en PCB dans les sédiments voisins des stations d'épuration sont significativement plus élevées que les teneurs en PCB observées dans les sédiments non influencés par des rejets d'eaux usées.

Cet état de fait a incité l'institut du génie de l'environnement de l'école polytechnique fédérale de Lausanne a entreprendre des études sur la contamination des stations d'épuration par les PCB et plus particulièrement d'étudier les composés organohalogènés présents dans les boues d'épuration.

Une étude préliminaire des boues de 9 stations d'épuration communales et industrielles permet de penser que les PCB, voire même dans un sens plus large les composés organohalogènés, posent des problèmes réels quant à l'élimination et l'utilisation de ces boues.

Summary

A study on the PCB's in the lake of Geneva and on their concentration in a food chain (from the sediment up to the birds of prey) showed that the PCB amounts in the sediments are appreciably higher at the outlet of a treatment plant as in other areas which are not under the influence of sewage waters.

This fact led to the study of the PCB problem at the level of the treatment plant and more specifically to the analysis of the organohalogenated compounds in the sewage sludges.

A preliminary study covering 9 communal and industrial treatment plants allows us to assume that the PCB problem in the sewage sludges does really exist.

A study on the PCB data at out disposal in Switzerland is at the present time on hand in order to allow the elaboration of a national reseach program on PCB's

1. INTRODUCTION

Une étude préliminaire de la pollution du lac Léman par les PCB effectuée en 1979 à l'institut du génie de l'environnement de l'école polytechnique fédérale de Lausanne,a montré l'importance de la pollution du milieu lacustre par les PCB.

Cette étude a permis de mettre en évidence l'influence des activités humaines sur la contamination des sédiments par les PCB et plus particulièrement l'existence de zônes à fortes teneurs en PCB(160 à 540 ppb) à proximité des rejets de stations d'épuration.

Des analyses de PCB dans des poissons du Léman,effectuées par l'institut d'hygiène du canton de Genève entre 1972 et 1978,semblent indiquer que la contamination du milieu par les PCB augmente.

D'autre part,des analyses de PCB effectuées dans d'autres lacs suisses par divers laboratoires de Suisse et d'Allemagne,laissent supposer que la pollution de l'environnement par les PCB s'étend à l'ensemble du territoire hélvétique.

Enfin,des études faites par BERG et PEOPLE et DE COK,montrent que les stations d'épuration(STEP) jouent un rôle important de concentrateurs de PCB.

Il nous a donc semblé intéressant de vérifier ces suppositions par l'analyse de PCB dans les boues de quelques STEP de Suisse.

2. METHODOLOGIE

Pour cette étude,quatre types de STEP ont été choisis:

- STEP de grandes villes (Zürich,Genève,lausanne)
- STEP de villes industrielles (Baden,Winterthur,La Chaux-de-Fonds)
- STEP de petites villes (Morges)
- STEP industrielles (Fabrique de papier Utzenstorf,Fairtec)

Pour des raisons pratiques,seuls des échantillons de boues déshydratées ont été prélevés(sauf Baden,boue liquide).

La préparation des échantillons pour l'analyse comprend en principe 5 étapes:

- lyophilisation
- extraction à l'hexane
- Attaque à l'acide sulfurique à 7% de SO_3
- séparation des phases
- purification de la phase organique(élimination du S)

L'analyse proprement dite est effectuée par chromatographie en phase gaseuse avec détection par capture d'électrons et comparaison avec un standard PCB constitué d'un mélange à parts égales d'AROCLOR 1242 (42% Cl),1254(54% Cl) et 1260(60% Cl).

3. RESULTATS

Les concentrations de PCB dans les boues d'épuration sont présentées sous trois formes:

a) teneurs en PCB dans des boues à 95.5% d'eau

b) teneurs en PCB dans les gâteaux de boues

c) teneurs en PCB dans les matières sèches lyophilisées

Les résultats obtenus ont ensuite été extrapolés de manière à obtenir les quantités annuelles de PCB contenues dans les boues,la production spécifique par habitant et par an et les quantités de PCB introduites dans les sols après épandage de 50 tonnes de boues à 95.5% d'eau par hectare et par an.

Les chiffres présentés en annexe montrent que toutes les boues analysées contiennent des PCB et bien que les extrapolations soient quelque peu hardies les ordres de grandeur obtenus sont intéressants.

Les boues des STEP de Baden,Genève et Zürich présentent les teneurs en PCB les plus élevées.Ces valeurs sont comparables à la valeur moyenne du mercure observée dans les boues des STEP de Suisse(5ppm).

Les quantités de PCB introduites dans les sols après épandage de 50 tonnes par hectare et par an,varient entre 0.8 et 17 g/ha.an.

4. CONCLUSION

Les chiffres étant établis,il s'agit maintenant d'essayer d'évaluer l'ampleur du phénomène et ceci plus particulièrement dans le cas de l'utilisation des boues en agriculture.

Comparativement à des études effectuées en 1972 au Canada,où des valeurs moyennes de PCB dans les matières sèches des boues varient entre 5 et 10 ppm,les boues analysées en Suisse présentent les même taux de contamination.

Selon une étude américaine,les boues de la ville de Georgetown présentant des teneurs en PCB de 7.4 ppm sur les matières sèches,ont été utilisées comme engrais.Après un épandage unique,les horizons superficiels du sol montraient des teneurs en PCB de 7 à 10 ppb et les céréales cultivées sur ces sols contenaient 28 ppb de PCB dans les grains.

Des études effectuées en Europe par DE COK ont montré que les boues d'épuration concentrent les PCB.Des valeurs de 0.1 à 10 ppm de PCB sur les matières sèches ont en effet été observées dans les boues d'une STEP recevant des eaux usées contenant entre 1 et 30 ppb de PCB.

Enfin dans le but d'évaluer l'importance du problème posé,une dernière extrapolation a été effectuée.En se basant sur les quantités des PCB trouvées dans les boues analysées,il est possible d'estimer la quantité totale de PCB se trouvant chaque année dans les boues des STEP de Suisse à quelques centaines de kilogrammes,voire plus d'une tonne.

On constate donc,après ces quelques chiffres et considérations que la contamination des boues d'épuration par les PCB pose un problème réel et que bien des connaissances font encore défaut dans ce domaine.

Actuellement,une étude bibliographique sur l'état des connaissances en matière de PCB est en cours en Suisse,dans le but de permettre l'élaboration d'un programme national de recherche sur les PCB.

STEP	Equivalents habitants (1979)	Est. quant. annuelle boue à 95.5% (t)	Conc.PCB des boues (ppm)			Extrapol.quantité PCB annuelle		Extrapol. quantité PCB en g/ha 5o t/an de boues à 95.5%
			boues à 95.5%	gâteau	MS lioph	(kg/an)	(mg/hab.an)	
Zürich-Werdh.	345'000	235'000	0.13	1.8	2.8	31	90	6.5
Genève	268'000	183'000	0.34	2.9	7.6	62	231	17
Lausanne	2o9'000	143'000	0.038	0.48	0.85	5.4	26	1.9
Baden	48'000	33'000	0.11		2.4	3.6	75	5.5
Winterthur	100'000	68'000	0.045	0.30	1.0	3.1	31	2.3
La Chaux-de-Fonds	36'000	25'000	0.016	0.14	0.36	0.40	11	0.8
Morges	25'000	14'000	0.054	0.36	1.2	0.76	38	2.7
Fabrique de papier Utzenstorf	43'000	30'000	0.11	0.85	2.5	3.3	150 *)	5.5
Fairtec Turgi			0.022	0.21	0.48			

*) mg/t de papier recyclé

Concentrations de PCB dans les boues des stations d'épuration analysées

ANNEXE

SCHADSTOFFE IM KLÄRSCHLAMM AUS ÖSTERREICHISCHER SICHT

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Summary

During the last ten years the construction of new central sited sewage plants resulted in a strong accumulation of sludge. The partly rural structure of Austria allow the application of sludge as fertilizer. This application also requires the continuous control of the heavy metal content.

The disintegration techniques used in the determination of the heavy metals varies from laboratory to laboratory. The determination itself was carried out by thermic or flame-less AAS methods.

The limit values of heavy metals were exceeded in 38 cases out of 120 examinations. The origin of the contamination, the coordination of examination methods, and the standardization of limit values are discussed.

Der vermehrte Ausbau von zentralen Kläranlagen in den letzten 10 Jahren hat nunmehr auch in Österreich das Problem der Beseitigung des Klärschlammes akut werden lassen. Bedingt durch die stark landwirtschaftlich geprägte Struktur Österreichs wird vornehmlich die Verwendung des Klärschlammes zu Düngezwecken ins Auge gefaßt.

Im Zusammenhang damit ergab sich die Notwendigkeit der Untersuchung der chemischen Verunreinigungen, wobei besonders den Schwermetallen das Augenmerk zugewandt wurde.

Auf Grund der fehlenden behördlichen Regelung wurden als Richtwerte für Schwermetallverunreinigungen jene der Österreichischen Düngerberatungsstelle in Wien als Beurteilungsschema zugrundegelegt, welche auf ausländischen, vornehmlich bundesdeutschen Erfahrungen basieren. Die Richtlinien sind so ausgelegt, daß auch bei langjähriger Klärschlammdüngung eine Schwermetallanreicherung im Boden mit großer Sicherheit verhindert werden kann.

Tabelle I Richtwerte der Österreichischischen Düngerberatungsstelle, Wien.

Element	tolerierbare Menge im Klärschlamm in ppm
Zink	2000
Cadmium	10
Nickel	200
Quecksilber	10
Kupfer	500
Kobalt	100
Molybdän	50
Blei	500
Chrom	500
Arsen	100
Selen	20

Hinsichtlich der angewandten Untersuchungstechnik unterscheiden sich die bisher vorliegenden und erfaßbaren wenigen Untersuchungsergebnisse. Bei Untersuchungen in der Steiermark wurde 1974 der Naßaufschluß im Autoklaven bei 110°C durch 15 min, 1975 in verschlossenen Röhrchen mit Königswasser 4 Std, im Wasserbad und 1976 im Veraschungsautomaten schritt weise bis 150°C durch 35 min durchgeführt. Nach den Angaben der Untersucher ERTL, POPP und SCHWINGHAMMER ergaben Vergleichsuntersuchungen weitgehende und gute Übereinstimmung der gewonnenen Meßwerte.

In Vorarlberg wurden die Methoden der Eidgen. Anstalt für Wasserversorgung, Wasserreinigung und Gewässerschutz sowie der International Solid Wastes and Public Cleansing Assoc. zur Untersuchung des Schwermetallgehalts des Klärschlammes herangezogen, wobei die Mineralisierung der Schlämme durch Naßaufschluß mit Salpetersäure 75% : Perchlorsäure 25% = 3 : 1 erfolgte.

Das gleich Aufschlußverfahren wurde im Institut f. Landwirt schaft der Österr. Studiengeselschaft für Atomenergie, Seibersdorf angewendet.

Zur Bestimmung der Schwermetalle wurde allgemein die Atomabsorptionsspektroskopie eingesetzt, wobei sowohl die thermische Anregung mit Luft-Acetylen oder die flammenlose Methodik in der Graphitrohrküvette zur Verwendung gelangte.

Da noch nicht alle Bundesländer sowie deren einschlägige Laboratorien auf die Untersuchung von Klärschlamm eingerichtet sind, sind ausgedehnte Ringversuche zur Abstimmung der Methoden nur vereinzelt erfolgt. Die Ergebnisse waren jedoch nicht zugänglich.

Auf Grund einer Umfrage in Österreich zur Erstellung dieses Referats wurden aus vier Bundesländern Ergebnisse übermittelt, welche in Tabelle 2 hinsichtlich der Überschreitung der Richtwerte bezogen auf die Gesamtzahl an Untersuchungen ausgewertet wurden.

Tabelle II Überschreitungen der Richtwerte bezogen auf die Gesamtzahl an Untersuchungen.

Bundesland	Anzahl der Untersuchungen	Cd	Cr	Hg	Ni	Pb	Zn	Cu
Steiermark	96	4	2	3	0	8	13	4
Vorarlberg	13	1	0	0	0	0	1	0
Oberösterreich	10	0	1	0	0	1	0	0
Niederösterreich	1	0	0	0	0	0	0	0
Insgesamt	120	5	3	3	0	9	14	4

Lediglich für die in der Steiermark erhobenen Werte liegen auch Hinweise auf den Grund der Überschreitungen vor. Für Cadmium und Quecksilber wird in einem Fall das Abwasser einer Krankenanstalt verantwortlich gemacht, die anderen Werte konnten hinsichtlich ihrer Herkunft nicht geklärt werden, weil entsprechende Industrie-betriebe fehlen.

Blei wird vornehmlich den Abwässern aus Gewerbe und Industrie, aber auch den Abschwemmungen von Verkehrsflächen in Siedlungsgebieten sowie Garagen- und Tankstellenabwässern (Überwässer aus Mineralöl- und Benzinabscheider) zugeordnet.

Soferne es sich bei den überhöhten Zinkwerten nicht um solche aus gewerblichen Unternehmungen handelt, sind in den anderen Fällen verstärkte Korrosionen in den Trinkwasser-Versorgungsnetzen als Ursache der Überschreitung anzusehen.

Für überhöhte Kupfer- und Chromwerte sind ausschließlich Industriebetriebe verantwortlich.

Im Hinblick auf die Anreicherung von Schwermetallen im Klärschlamm sowie deren Bedeutung bei Anwendung in der Landwirtschaft ist eine einheitliche Regelung der Grenzwerte und der Untersuchungsmethoden sowie auch eine generelle Festlegung der Zahl der Untersuchungen pro Jahr unter Berücksichtigung der Herkunft der Abwässer dringend erforderlich, wenn man sich vor Augen hält, daß in nächster Zukunft Tausende von Tonnen an Klärschlamm in ganz Österreich anfallen werden und beseitigt werden müssen.

Die chemische Untersuchung von Klärschlämmen im Hinblick auf die Verwertung in der Landwirtschaft wird aber auch im vermehrten Maß hinsichtlich der Methodik auf die Pflanzenverfügbarkeit Rücksicht nehmen müssen.

BILAN DE METAUX LOURDS DANS LE BASSIN VERSANT D'UNE STATION D'EPURATION

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Summary

Waste water of Switzerland are treated in approximatively 763 treatment plants. Sewage sludges which have been anaerobically or aerobically stabilized are, due to their amount of fertilizing elements, used as much as possible as agricultural manure or composted with garbage.

Nowadays, about 70 % of the producted sewage sludges, that is to say 1 680 000 m^3/year are spread in agriculture.

Controls made by the FAC (Forschungsanstalt für Agrikulturchemie und Umwelthygiene - Liebefeld) showed that the concentration of heavy metals in these sewage sludges can sometimes be considered as alarming.

In order to collect more information on the importance, the distribution and the causes of the heavy metal pollution of waste water, a study has been carried out on the drainage basin of a middle-size treatment plant (25 000 eq).

Industrial and waste water as well as rain water have been analyzed during one year in order to determine the amount of Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn and Hg. The concentration of Zn has been in particular pointed out. The different parameters which have been analyzed as well as the measured or estimated fluxes made it possible to establish a balance of heavy metals in the drainage basin of a treatment plant. This balance has been controled through analyses of the sewage water arriving in the treatment plant as well as through the digested sludges.

1. INTRODUCTION

Les eaux usées de Suisse sont traitées aujourd'hui par près de 763 stations d'épuration (STEP) mécanobiologiques. Environ 37% sont équipées pour déphosphater les eaux usées.

Les boues d'épuration stabilisées, soit par digestion anaérobie, soit par traitement aérobie, sont du fait de leur teneur en éléments fertilisants, essentiellement phosphore et azote, utilisées autant que possible comme engrais en agriculture ou compostées avec des ordures ménagères.

Actuellement, environ 70% des boues produites sont épandues en agriculture (1'680'000 m^3/an). Boues d'épuration et composts de gadoues, étant assimilés aux produits auxiliaires de l'agriculture, sont soumis au contrôle de qualité effectué par la Station Fédérale de Recherche en Chimie Agricole et en Hygiène de l'Environnement de Liebefeld (FAC).

Une première enquête entreprise par la FAC en 1975-1976 sur 68 STEP a montré la nécessité d'un contrôle régulier de la teneur en métaux lourds des boues d'épuration. Une étude récente de la FAC a également mis en évidence l'importance du problème des métaux lourds dans les composts de gadoues et les composts mixtes gadoues/boues de STEP.

Afin de protéger les sols, les plantes et les consommateurs de produits de la terre, il est absolument indispensable de tout mettre en oeuvre pour diminuer les rejets de produits toxiques dans l'air et dans les eaux superficielles et les eaux usées.

La méthode la plus efficace permettant d'atteindre ce but consiste à traiter les problèmes, autant que faire ce peut, aux sources du mal; encore faut-il les connaître.

Dans le but d'élargir les connaissances sur l'importance, la répartition et les causes de la pollution des eaux usées par les métaux lourds provenant de sources diffuses, l'Office Fédéral de la Protection de l'Environnement (OFPE) a demandé à l'Institut du Génie de l'Environnement (IGE) de l'Ecole Polytechnique Fédérale de Lausanne (EPF-L) d'établir le bilan des métaux lourds dans le bassin versant de la station d'épuration de l'Association intercommunale pour l'Epuration des eaux usées de la Région Morgienne (ERM). Cette étude a fait l'objet d'un premier mandat de l'OFPE à l'IGE (EPF-L) suivi d'un deuxième entre l'Office Fédéral de l'Education et de la Science (OFES) s'inscrivant dans le cadre du projet CEE COST 68 bis, tous deux destinés à la financer partiellement.

2. STRUCTURE DU BASSIN VERSANT ETUDIE

Le bassin versant de la station d'épuration étudiée regroupe les territoires de 11 communes, totalisant environ 30 km^2. La surface étudiée peut être divisée en deux zones: une zone à haute densité de population avec des activités industrielles et artisanales importantes (fonderies, électrotechniques, galvanoplastie, alimentaire, hôpital de district), et l'arrière pays agro-viticole.

La population résidente est d'environ 22'000 habitants, dont près de 13'000 habitent la ville où est située la station d'épuration.

3. RESEAU D'EGOUTS ET STATION D'EPURATION

Le réseau collecteur d'égouts est mixte. Il mesure environ 35 km et est équipé de 44 déversoirs d'orages. La station d'épuration mécano-biologique avec déphosphation (décantation primaire rectangulaire, bassin à boues activées combiné et précipitation simultanée) traite près de 5 millions de m^3 d'eaux usées par an. La proportion des eaux de pluies est estimée à environ 34%.

Les boues fraîches sont stabilisées par voies anaérobie, puis utilisées en agriculture soit, sous forme liquide (67%), soit sous forme deshydratée à 20% de matières sèches.

Les boues d'épuration produites par la STEP ont montré les teneurs en métaux lourds suivantes (valeurs du contrôle officiel):

Cd	20	mg/kg MS
Cu	444	
Cr	189	
Pb	267	
Ni	86	
Zn	1581	

4. METHODOLOGIE

Afin d'estimer les charges en métaux lourds provenant des diverses sources ponctuelles et diffuses, des prélèvements et des mesures de débits ont été effectués, soit à la sortie des usines, soit en des points regroupant environ 1'500 habitants de zones immeubles locatifs ou zones villas soit, sur des eaux claires. Les prélèvements ont été effectués à diverses époques de l'année et durant plusieurs jours consécutifs (5 à 12 jours) à l'aide d'échantillonneurs spécialement conçus à cet effet.

Dans le but d'établir l'influence de la corrosion des conduites de distribution d'eaux de consommation (conduites internes aux immeubles) dans la pollution des boues d'épuration par le zinc, des prélèvements ont été effectués dans des immeubles d'âges différents (constructions avant 1965, 1965 à 1975, après 1975).

Des eaux usées à l'entrée de la STEP et des boues digérées ont été prélevées durant toute l'année dans le but de contrôler le bilan de métaux lourds et d'établir les variations de teneurs en métaux lourds au cours de l'année. Tous les échantillons prélevés sont des échantillons moyens sur 24 heures. Les métaux Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn et Hg ont été analysés par spectrophotométrie d'absorption atomique avec flamme (à l'exception du Hg) après minéralisation nitro-perchlorique sur les échantillons bruts (teneur totale) et filtrés sur membrane 0.45 μ (fraction dissoute).

5. BILAN DE METAUX LOURDS

Le bilan annuel de métaux lourds sur le bassin versant de la STEP a été conçu de la manière suivante:

les valeurs annuelles de charges de métaux lourds de sources industrielles ont été extrapolées à partir du total des valeurs individuelles des diverses campagnes de prélèvement pondéré par un facteur de correction tenant compte du débit total durant les campagnes de prélèvement et du débit annuel. En d'autres termes la charge rejetée durant les diverses campagnes a été ramenée à l'unité du mètre cube d'eau rejeté durant la même période et multipliée par le débit annuel.

Dans le cas de l'hôpital et accessoirement pour le nickel dans celui d'une petite industrie utilisant des procédés de traitement de surface où des mesures "in situ" ont fait défaut les valeurs obtenues dans des cas semblables, contrôlées par des mesures effectuées en d'autres circonstances, ont dû être utilisées en relation avec les débits respectifs de l'hôpital et de cette industrie.

Les données sur les eaux usées domestiques en réseau séparatif (quartier grands locatifs) ont servi à estimer la charge provenant des foyers domestiques. Les charges obtenues durant les diverses campagnes de prélèvement ont été totalisées et ramenées à des charges spécifiques par habitant et par an en divisant les charges totalisées par le nombre d'habitants branché sur le réseau étudié et par le nombre de jours de prélèvement et en multipliant par 365 jours.

La charge annuelle totale amenée par les eaux usées domestiques a ensuite été calculée en multipliant la charge par habitant et par an, par le nombre d'habitants effectivement raccordés. Pour chaque point de rejet trois valeurs sont présentées: la première est calculée sur la base de valeurs moyennes ou médianes et les deux autres sur la base de des valeurs minimales et maximales observées.

Cette méthode de calcul a été utilisée pour tous les métaux à l'exception du zinc et du cuivre.

Les valeurs obtenues lors de l'analyse des eaux potables effectuées sur des eaux provenant de types d'habitats différents et d'âges différents, ainsi que les données statistiques de logements et de densité de population par logement ont permis d'une part de stratifier la population en trois groupe,à savoir:

a) population résidant dans des immeubles construits avant 1965

b) population résidant dans des immeubles construits entre 1965 et 1975

c) population résidant dans des immeubles construits après 1975

et d'autre part de classer les valeurs de concentrations des eaux potables en fonction des mêmes critères(-1965,1965-1975,1976-)

Année de construction	Concentration en zinc (ppb)	
	Total	Dissous
Avant 1965	80 (10 - 600)	10 - 590
1965-1975	93o (200 - 1840)	755 (140 - 1750)
1976-1979	340 (110 - 670)	190 (100 - 650)

En multipliant les concentrations par les débits annuels d'eau consommée,il a été possible de calculer les charges annuelles en zinc rejetées par les diverses strates:

avant 1965	61	(45 - 450)	7.8%
1965-1975	714	(608 - 1398)	91.5%
1976-1979	5	(3 - 10)	0.7%
Total en kg/an	780	(656 - 1858)	100 %

Les 91.5% du zinc provenant des eaux potables disrtibuées dans les foyers domestiques proviennent des conduites galvanisées posées entre 1965 et 1975(période de haute-conjoncture).

La teneur en cuivre des eaux potables est en général faible(10-20 ppb), malgré quelques cas de contamination isolés(270 ppb).

Teneur en cuivre : 50 (20 - 270) ppb

L'apport en cuivre par les eaux potables distribuées dans les ménages s'élève ainsi à:

74 (30 - 396) kg/an

Le plomb et le cadmium dans les eaux potables n'ont pas été dosés.Par contre,il est possible d'estimer les concentrations et les charges dues à l'eau potable en tenant compte que le zinc utilisé pour le galvanisage des conduites contient en moyenne

1.06 % de Pb (0.83 - 1.52%)

0.68 ‰ de Cd (0.01 - 2.65‰)

Les teneurs en Pb et Cd ainsi estimées sont de:

	Pb (ppb)	Cd
Avant 1965	0.85(0.1 - 6.4)	0.05 (0.01 - 0.40)
1965 -1975	8.50(2 -20)	0.54 (0.14 - 1.25)
1976 -1979	2.30(1.3 - 7.1)	0.15 (0.08 - 0.46)

Les rejets spéciphiques de métaux lourds par les habitants(g/hab.an) dans les eaux usées domestiques sont les suivantes:

Cd	0.41	(0.37 - 3.95)
Cu	3.50	(1.40 -19)
Cr	0.87	(0.47 - 1.70)
Fe	40	(30 -58)
Mn	2.17	(1.92 - 4.10)
Ni	1.40	(1.20 - 1.90)
Pb	3.25	(2.63 - 5.48)
Zn	37	(31 -88)
Hg	0.028	

L'ensemble des résultats obtenus peut être reproupé comme suit:

Métaux totaux	Cd	Cu	Cr	Fe	Mn	Ni	Pb	Zn	Hg
					(%)				
Industries	11	13	36	5	4	47	3	3	30
Ruissellement	51	66	50	84	82	38	80	32	37
Foyers domestiques	38	21	14	11	14	15	17	65	33
					100 %				

Métaux dissous	Cd	Cu	Cr	Fe	Mn	Ni	Pb	Zn	Hg
					(%)				
Industries	4	4	11	17	5	25	4	5	ND *)
Ruissellement	74	78	77	32	69	53	75	25	ND *)
Foyers domestiques	22	18	12	51	26	22	21	70	ND *)
					100 %				

*) ND = non déterminé

Ensemble des résultats du bilan des métaux lourds dans les boues des stations d'épuration analysées

Les métaux lourds peuvent être classés en deux groupes en fonction de leurs sources dans le bassin versant.

Le premier groupe comprenant le Cu,Fe,Mn,Pb et le Zn est caractérisé par des apports provenant essentiellement de sources diffuses peu maîtrisables et par des apports industriels modestes,bien que certaines concentrations observées à la sortie des entreprises dépassent parfois les normes en vigueur(Pb,Zn,Cu).

Le deuxième groupe,comprenant le Cd,Cr,Ni et le Hg,montre des apports industriels plus importants.Les rejets les plus élevés(Ni,Cr) ont été évidemment observés à la sortie d'usines de traitement de surfaces. Des dépassements des valeurs-limites ont été observés dans 70 à 80 % des échantillons galvaniques analysés.

Le Cd a été placé dans les métaux de provenance industrielle,après avoir constaté que la charge en Cd des eaux de ruissellement est,dans le cas étudié,le fait de rejets atmosphériques industriels(fonderie).

Ces chiffres montrent que les eaux de ruissellement,essentiellement les eaux de lessivage des routes,et les eaux usées domestiques contiennent des quantités importantes de métaux lourds.Les apports industriels de métaux lourds représentent,pour le cas étudié,une proportion relativement faible par rapport au total observé à l'entrée de la STEP,avec quelques exceptions pour le Ni et le Cr en particulier. Bien que ces charges soient faibles,leur impact négatif sur le fonctionnement de la STEP a pu être observé à maintes reprises.De plus,du fait de l'irrégularité de ces rejets,il est fort possible que les charges industrielles effectives soient plus élevées que celles mentionnées ici.

Ces rejets irréguliers ont une incidence certaine sur les teneurs en métaux lourds des boues d'épuration.Le cas le plus marquant a été celui du Cd,où la valeur-limite de 30 ppm de Cd sur la matière sèche a été dépassée durant plus de 7 semaines(max.68 ppm).
Les autres métaux ont montré des variations plus ou moins importantes sans pour autant dépasser les valeurs-limite prescrites.

Les métaux lourds extraits par les boues ont présenté les pourcentages suivants de la charge en métaux à l'entrée de la STEP:

Cd	55%	Pb	40%
Cu	46%	Zn	45%
Cr	93%	Hg	100% ~
Ni	30%		

6. CONCLUSIONS

L'étude des métaux lourds dans le bassin versant d'une station d'épuration a montré l'importance des sources diffuses dans le bilan global de ces métaux.
Parmi ces sources,la corrosion interne des conduites de distribution d'eau de consommation et les eaux de lavage des routes(trafic,pollution atmosphèrique) tiennent une place prépondérante;mais bien que ces apports soient considérés comme diffus,les sources de contamination sont bien établies.
Il est donc possible,à plus ou moins court terme,d'intervenir aux sources effectives des problèmes.

Enfin,en considérant les variations de concentrations en métaux lourds au cours de l'année,il semble que le système de contrôle des boues d'épuration existant en Suisse(à savoir 4 échantillons de boues par an, et par STEP et analyse des métaux lourds sur un homogénat de ces 4 échantillons à la fin de l'année)soit suffisant.

METHODE DE DOSAGE DES METAUX LOURDS DANS LES BOUES, REPARTITION SELON LEUR ORIGINE ET DANS LE TEMPS.

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Résumé

Le dosage des métaux lourds dans les boues a été effectué d'après la méthode de référence du "Comité Inter Institut" modifiée en fonction de la nature des échantillons. Les éléments suivants ont été déterminés sous leur forme totale après calcination et traitement à l'HNO_3 : Cu, Mn, Zn, Cd, Co, Cr, Ni et Pb ; Cu, Mn et Zn ont été dosés par spectrophotométrie d'absorption atomique dans la flamme, les autres par spectrophotométrie d'absorption atomique muni d'un four à graphite.

Les divers métaux lourds étudiés ont été dosés dans 4 boues d'origine différente. L'échantillonnage a été fait mensuellement de façon à suivre la variation des teneurs dans le temps.

Une comparaison est faite entre les normes expérimentales A.F.N.O.R. et les teneurs maximales obtenues ainsi qu'entre les apports de métaux lourds par application modérée de boues (100 m^3/ha) et par les produits courants utilisés en agriculture.

Summary

The dosage of heavy metals in sewage sludges has been done following the method of "Comité Inter Institut" modified according to the nature of the samples. The following heavy metals have been determined on their total form after calcination and treatment with HNO_3 : Cu, Mn, Zn, Cd, Co, Cr, Ni and Pb ; Cu, Mn and Zn by atomic absorption spectrophotometry in flame and the other elements by atomic absorption spectrophotometry by means of carbon rod.

The heavy metals studied have been measured in four sewage sludges from different origin. The sampling has been done monthly to follow the variability of concentrations versus time.

A comparison is made between the experimental norms A.F.N.O.R. and the maximum values obtained in the different sludges.

An other comparison is made between heavy metals brought by application of sewage sludges and by mineral and organic fertilizers used in agriculture.

1. INTRODUCTION

Les boues de stations d'épuration sont des matériaux relativement complexes dont la matière sèche est constituée en moyenne de 50 à 70 % de matière organique et de 30 à 50 % de matière minérale, toutefois ce ne sont ni des matériaux végétaux ni des sols. Il est donc nécessaire d'utiliser, pour libérer les éléments liés à la matière organique et à la matière minérale, des techniques reprises pour chacune des deux matières et qui soient compatibles l'une avec l'autre sans négliger le fait d'un dosage possible des métaux lourds au four à graphite. En effet pour ce type de dosage, il est recommandé d'éviter les acides halogénés qui peuvent provoquer la formation d'halogénures susceptibles de se volatiliser durant la phase d'atomisation donnant ainsi des valeurs sous estimées; dès lors il est conseillé d'éviter l'utilisation de HCl, HF et $HClO_4$.

Diverses méthodes ont été testées, telles la minéralisation par HNO_3 et dosage direct des éléments, la calcination à 425 °C avec attaque par $HNO_3/HClO_4$, la calcination basse suivie d'une attaque à l'eau régale etc... La méthode qui a été choisie consiste en une minéralisation par voie sèche suivie d'une attaque H_2SO_4/HF dont le résidu est repris par HNO_3. Cette méthode est décrite ci-dessous.

2. METHODOLOGIE

2.1. Attaque : Méthode "Comité Inter Institut" modifiée

- porter la poudre de boue à l'étuve à 70 - 80 °C pendant 16 h
- laisser refroidir en dessicateur pendant 30 min.
- introduire, dans une capsule ou un creuset en platine, 2 g de poudre de boue et placer au four froid.
- porter la température à 500 °C en 2 h et la maintenir pendant 2 h (on doit obtenir des cendres claires qu'on laisse refroidir)
- reprendre les cendres par 2 gouttes de H_2SO_4 concentré et 10 ml HF.
- porter la capsule (ou le creuset) sur bain marie puis sur plaque chauffante et évaporer à sec le contenu de la capsule avec précautions (le bain de sable n'est pas conseillé car susceptible d'amener des contaminations).
- reprendre le résidu par 4 ml HNO_3 conc.
- porter à nouveau la capsule sur bain marie et évaporer à sec son contenu.
- reprendre le résidu par 1 ml HNO_3 conc. et de l'eau déminéralisée

chaude.

- filtrer la solution obtenue sur filtre sans cendre (SS 589/3 bande blanche).
- recueillir le filtrat dans une fiole jaugée de 50 ml.
- compléter au volume après lavages du filtre et refroidissement.

N.B. : 1) dans chaque série d'échantillons soumis à l'attaque, introduire un blanco et un ou des témoins des éléments étudiés.

2) l'eau utilisée pour les lavages et les dilutions est toujours de l'eau bidistillée.

2.2. Dosage

Le dosage de Cu, Mn et Zn a été effectué sur un spectrophotomètre d'absorption atomique VARIAN TECHTRON AA4 simple faisceau dans la flamme avec un mélange gazeux air-acétylène.

Caractéristiques des cathodes :

	Cu	Mn	Zn
fente	50 μ	150 μ	300 μ
amp.	6 m A	6 mA	6 mA
λ	3 247 Å	2 794 Å	2 136 Å
Concentrations	2 - 20 ppm	2 - 20 ppm	0,5 - 5 ppm

Aucune interférence n'a été notée pour Cu et Zn, celle de Si sur le dosage de Mn a été supprimée par l'attaque à HF qui provoque la volatilisation de Si pendant la durée de l'atomisation.

Le dosage de Cd, Co, Cr, Ni et Pb a été effectué par un spectrophotomètre d'absorption atomique VARIAN AA 175 simple faisceau muni d'un four à graphite CRA 90 avec injecteur automatique de 5 μ l.

Caractéristiques des cathodes et du four à graphite

Cd λ = 2 288 Å — four : séchage 100° 30"
fente = ouverture circulaire — calcination 500° 30"
amp. = 5 mA — atomisation 1900° 3" 350°/sec
concentrations : 0 - 15 ppb

Co λ = 2 407 Å — four : séchage 100° 30"
fente = ouverture circulaire — calcination 800° 25"
amp. = 10 mA — atomisation 2200° 2" 400°/sec

concentrations : 0 - 200 ppb

Cr λ = 3 579 Å	four :	séchage	100°	45"	
fente = ouverture circulaire		calcination	700°	20"	
amp = 5 mA		atomisation	2300°	2"	400°/sec
concentrations : 0 - 50 ppb					

Ni λ = 2 320 Å	four :	séchage	100°	60"	
fente = ouverture circulaire		calcination	800°	25"	
amp = 5 mA		atomisation	2200°	2"	400°/sec
concentrations : 0 - 400 ppb					

Pb λ = 2 171 Å	four :	séchage	100°	30"	
fente = ouverture circulaire		calcination	400°	30"	
amp = 5 mA		atomisation	1500°	3"	400°/sec
concentrations : 0 - 100 ppb					

2.3. Problèmes rencontrés lors des différents dosages

Le dosage de Cu, Mn, Zn dans la flamme n'a pas donné lieu à des mises au point longues et difficiles, ainsi que pour Co, Cr et Ni au four à graphite. Il n'en a pas été de même pour le passage de Cd et Pb. En effet pour le cadmium, quelques difficultés sont apparues lors du passage des échantillons. Après de nombreux essais, il s'est avéré que le passage initial d'un extrait de boue permettait une lecture plus constante des absorbances. Il nous semble que la nature de la boue a une grande influence sur l'obtention des résultats, cependant nous n'avons pas encore pu vérifier cette hypothèse.

Le dosage du plomb a posé d'autres problèmes, notamment dans la mise au point des caractéristiques du four, les données théoriques préconisées par le constructeur ont dû être fortement modifiées : une calcination plus longue et une température d'atomisation plus élevée avec une montée en température plus rapide. L'effet mémoire constaté après passage des points de l'échelle et des extraits de boue a pu ainsi être supprimé. De plus, dans le cas du plomb, on observe une variabilité de la réponse qui dépend nettement de la fraîcheur de l'extrait, ce que nous n'avons constaté pour aucun autre élément étudié.

3. COMPARAISON AVEC LES NORMES EXPERIMENTALES A.F.N.O.R.

Le tableau I ci-dessous établit ces comparaisons pour les différents éléments concernés.

TABLEAU I : Comparaison entre les valeurs maximales obtenues et les normes expérimentales A.F.N.O.R.

Origine*	Cu	Mn	Zn	Cd	Co	Cr	Ni	Pb
Bastogne	1473	719	2997	8,7	13,2	2086	2158	295
Fleurus	329	679	2854	10,1	6,3	93	94	292
Rhisnes	147	263	2199	6,0	3,5	84	63,9	92
Saive	198	297	2972	11,5	5,8	70	54,1	212
Normes A.F.N.O.R. U44 - 041	1500	500	3000	15	20	300	100	200

____ valeurs dépassant les normes A.F.N.O.R.

---- valeurs voisines des normes A.F.N.O.R.

Commentaires

En général, les valeurs observées pour les différents éléments sont inférieures aux normes expérimentales. La station de Bastogne se distingue par des maximums dépassant les normes pour plusieurs métaux "lourds" : le manganèse, le chrome, le nickel et le plomb. Les 3 stations urbaines plafonnent la limite préconisée par la norme pour le zinc.

4. COMPARAISON ENTRE LES QUANTITES DE METAUX LOURDS APPORTEES PAR DES EPANDAGES MOYENS DE BOUES ET D'AUTRES PRODUITS COURANTS UTILISES EN AGRICULTURE (Kg/ha)

Le tableau II ci-après mentionne ces diverses quantités pour quatre boues d'origine différente et pour d'autres produits utilisés couramment en agriculture.

Commentaires

Dans le cas où un épandage de boues ne dépasse pas 100 m^3/ha et en excluant de la comparaison la station de Bastogne, les apports en métaux lourds des boues est du même ordre de grandeur que ceux obtenus par d'au-

* 3 stations sont des stations urbaines : BASTOGNE, FLEURUS et SAIVE.
1 station traite les eaux d'une industrie agro-alimentaire RHISNES.

Tableau II: Quantités de métaux lourds apportées par des épandages moyens de boues et d'autres produits courants utilisés en agriculture (kg/Ha)

Elément	Boue Bastogne 100 m^3/Ha	Boue Fleurus 100 m^3/Ha	Boue Rhisnes 100 m^3/Ha	Boue Saive 100 m^3/Ha	Lisier Bovin 60 m^3/Ha	Lisier Porc 40 m^3/Ha	Lisier Volaille 20 m^3/Ha	Scories Thomas 780 kg/Ha
Cu	1.39	0.97	0.53	7.90	0.26	1.08	0.37	0.13
Mn	3.31	1.66	0.82	4.45	0.73	0.77	2.16	39.05
Zn	12.57	18.43	10.52	17.87	0.77	1.96	2.43	-
Cd	0.04	0.07	0.03	0.06	-	-	-	-
Co	0.02	0.03	0.01	0.08	-	-	-	0.02
Cr	0.37	0.40	0.35	10.09	0.04	0.02	0.13	0.86
Ni	0.30	0.30	0.25	11.85	-	-	-	0.05
Pb	0.97	0.93	0.22	1.14	0.04	0.02	0.02	-

\- pas de chiffres.

tres produits utilisés en agriculture, sauf pour le Zn où les doses apportées sont nettement plus importantes. Notons que, malgré des apports faibles en Cd, il y a lieu de ne pas les négliger, compte tenu de la toxicité de cet élément.

5. CONCLUSIONS

En raison de la nature complexe des boues des stations d'épuration, la mise au point d'une technique de dosage des métaux lourds a nécessité l'utilisation de réactifs employés pour l'extraction des matières organiques et minérales. Cette technique a permis de déceler la présence de métaux lourds étudiés dans toutes les boues. Toutefois, un usage raisonnable de celle-ci n'apporterait pas plus de métaux lourds que les produits utilisés couramment aux doses habituelles.

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CARACTERISATION DE LA FRACTION ORGANIQUE ET DE LA FRACTION MINERALE CRISTALLINE DES BOUES D'EPURATION (°)

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Resumé

Suivant la méthode proposée par Stevenson, on a fractionné la matière organique de dix boues d'épuration de la Toscane en: graisses, cires et huiles; résines; polyoses solubles dans l'eau; hemicellulose; cellulose; protéines acide-resistantes et "lignine-humus". La fraction organique présente en quantité la plus élevée est la fraction appelée "lignine-humus"; la teneur des autres fractions organiques résulte assez variable, sauf celle de l'hemicellulose.

Les diffractogrammes-X de la fraction minérale cristalline indiquent la constante presence de quartz, calcite, dolomite, feldspaths, kaolinite, micas et chlorites. En general on trouve aussi des faibles quantités de talc, d'halite et de montmorillonite et/ou vermiculite et, parfois, de l'opale et du gypse.

Summary

The organic matter of ten sewage sludges from Tuscany was fractionated, according to Stevenson's procedure, in: fats, waxes, oils; resins; water soluble polysaccharides; hemicellulose; cellulose and protein plus "lignin-humus". The largest amount of the organic matter is recovered in the group of "lignin-humus". The other organic components result rather variable, with the exception of the hemicellulose.

The X-ray diffraction investigation of the inorganic crystalline fraction shows the general occurrence of quartz, calcite, dolomite, feldspars, kaolinite, micas and chlorites. Small amounts of talc, montmorillonite and/or vermiculite, and halite are nearly always present. Other components of definitely more rare occurrence are opal and gypsum.

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1. INTRODUCTION

Conformément aux prescriptions de la Loi italienne sur la protection de la qualité des eaux, les stations d'épuration des eaux usées sont, et elles seront, toujours plus nombreuses. Le problème de l'utilisation des boues que ces stations produisent est à l'ordre du jour dans de nombreux pays; pour se débarasser de ces sous-produits on pense à les utiliser en agriculture. Ainsi, pour ne pas laisser au hasard leur utilisation, plusieurs auteurs ont éffectué des recherches concernantes leur teneur en éléments nutritifs et en métaux lourds. Au contraire, les études intéressant la caractérisation des matières organiques (11-82%) restent limitées (1-7) tandis que ceux qui concernent les matières minérales (8, 9) analysent surtout leur composition élémentaire.

L'étude suivante a pour but de mieux définir la composition de la fraction organique et de caractériser la fraction minérale cristalline des boues d'épuration.

2. MATERIEL ET METHODES

Les dix échantillons utilisés pour cette étude représentent des stations d'épuration qui suivent des différentes technologies et qui se trouvent sur des territoires avec des différentes caractéristiques; les échantillons de boue ont été prélevés avant la phase finale de décantation. On connaissait déjà la composition des mêmes échantillons en éléments nutritifs et en métaux lourds (10).

A - Caractérisation de la matière organique. Sur les échantillons sechés à une température de 60°C on a déterminé la matière organique en multipliant par 1,724 la teneur en carbone oxidable par attaque avec $K_2Cr_2O_7$. La matière organique a été fractionnée, selon la méthode proposée par Stevenson (11) pour le sol, en: 1) graisses, cires et huiles; 2) résines; 3) polyoses solubles dans l'eau; 4) hemicellulose; 5) cellulose; 6) protéines acide-résistantes et 7) "lignine-humus".

B - Caractérisation de la fraction minérale cristalline. Les analyses ont été éffectuées par diffraction-X sur des poudres non orientées des échantillons globaux (a) et traitées avec H_2O_2 (b); sur des poudres orientées, saturées par K^+, a température ordinaire (c) et chauffées à 550°C (d); et enfin sur des poudres orientées, saturées par Mg^{++} et traitées au glycérol (e). Les diffractogrammes relatifs aux poudres orientées ont été tous éffectués sur des échantillons dont la matière organique avait été détruite avec H_2O_2 ou, parfois, avec NaOH 0,1 N.

3. RESULTATS ET DISCUSSION

A - Fraction organique. En tableau 1 on rapporte les résultats du fractionnement de la matière organique qui, dans nos échantillons, varie de 42 jusque 63% de la matière sèche, avec une moyenne de 48 et un coefficient de variation peu élevé (CV = 18).

La méthode d'analyse que nous avons utilisée nous a permis de fractionner, à peu près, le 95% de la M.O., avec un minimum de 91% et un maximum de 104% et un CV = 5, particulièrement peu élevé.

Les fractions solubles en éther et en alcool entrent, globalement, en raison de 21% dans la composition de la matière organique;elles présentent à peu près les mêmes quantités moyennes et le même coefficient de variation (CV = 29), mais leurs teneurs peuvent être très différentes, l'une auprès de l'autre, dans chaque échantillon. La fraction soluble en éther constitue environ le 10% de la M.O., en très bon accord avec les teneurs obtenues par Rebhun et al. (2), Chawla et al. (4), Duncan (6), Gehm et al. (7), Desbaumes (12), tandis que nous avons trouvé les résines en quantités plus élevées que les autres auteurs (1, 3).

D'ailleurs il faut remarquer que les deux fractions ainsi extraites, et en particulier la première, comprennent aussi, sans doute, des graisses animales et végétales, surtout d'origine domestique, et des hydrocarbures d'origine industrielle.

Les glucides constituent, tous ensemble, en moyenne le 38% de la M.O.

TABLEAU 1 - Répartition des matières organiques des boues.

Echantillon N.	Ville	M.O. % de la M.S.	Graisses, cires, huiles	Résines	Polyoses hydrosolubles	Hemicellulose	Cellulose	Protéines acide-résistantes	Lignine-humus	Total
			% de la M.O.							
1	Ponsacco	44	12	9	17	11	9	10	24	92
2	Livorno	42	6	15	26	11	6	8	19	91
3	Chiesina U.	44	14	12	8	8	15	10	29	96
4	Massa	65	12	7	24	7	13	7	34	104
5	Viareggio	47	9	15	18	10	9	10	20	91
6	Camaiore	42	10	13	14	9	14	8	26	94
7	Pistoia	42	7	6	18	18	12	10	27	98
8	Montecatini T.	50	10	13	9	9	25	6	31	103
9	Forte dei M.	43	9	13	24	10	4	7	25	92
10	Pescia	63	16	8	6	8	15	6	35	94
VM		48	10	11	16	10	12	8	27	95
CV %		18	29	29	43	30	48	21	20	5

Parmi eux la quantité la plus élevée (VM = 16%), et assez variable (CV=43), constitue la fraction soluble en eau qui, cependant, contient, sans doute, d'autres matières organiques hydro-solubles; elle représente la fraction la plus disponible comme source d'éléments nutritifs et d'énergie pour les microorganismes. L'hemicellulose constitue, en moyenne,le 10% de la M.O. et, parmi les glucides, elle représente la fraction la moins variable. Le

12% de la M.O. est constitué, en moyenne, par la cellulose, qui montre des variations élevées, avec un taux minimum de 4% et un taux maximum de 25%. La teneur globale en glucides est en accord avec la quantité determinée par Berger et al.(5), tandis qu'elle est plus élevée que celle obtenue par Duncan (6) - 25% - et,surtout, par Rebhun et al. (2) - 11,5% - et moins élevée que celle rapportée par Gehm et al. (7) - 50%.

La fraction organique présente en quantité la plus élevée est la fraction appelée "lignine-humus" (VM = 27%, CV = 20); elle n'est pas bien définie et on l'obtient en soustrayant à la matière organique résistante aux solutions acides la teneur de la même en protéines. Cette fraction est assez constante dans les différentes boues; elle est plus abondante dans les échantillons des stations d'épuration N. 4,8 et 10 qui utilisent des traitements complètement, ou partiellement, anaérobiques; on sait bien que la dijestion en anaérobiose favorise la perte des fractions plus hydrolisables et, en conséquence, la persistance de celles moins hydrolisables. Néanmoins, la valutation de la fraction "lignine-humus" est un peu imparfaite parce que la détermination des protéines sur laquelle elle se base, est, elle aussi, source d'erreurs; en effet l'azote organique n'est certainement pas tous protéique. En tout cas les protéines résiduelles représentent, en moyenne, le 8% de la M.O. et constituent une fraction moins facilement hydrolisable et, pourtant, moins disponible pour les microorganismes.

La répartition des matières organiques des boues indique que les fractions moins biodégradables, telles que la cellulose et la lignine, se trouvent en teneurs environ équivalentes dans la matière organique des boues et du fumier, tandis que les fractions solubles en éther des boues sont presentes en quantité à peu près deux fois plus élevée que dans le fumier (13).

B - Fraction minérale. La composition de la fraction minérale cristalline resulte, qualitativement, assez uniforme (tableau 2). Des minéraux fréquents dans le milieu naturel, tels que la calcite, la dolomite, les feldspaths, la kaolinite et les micas, ou même ubiquistes, tel que le quartz, sont présents dans tous les échantillons, bien qu'en proportions relatives différentes; il n'est donc pas facile établir l'origine, ou les origines, des constituants cette fraction, en particulier celle des mineraux plus abondants dans le milieu naturel ou plus souvent utilisés par l'homme et, par conséquence, présents dans les résidus et les déchets.

Dans les échantillons de boue le quartz est toujours abondant, ce qui est à rattacher à sa fréquence dans le milieu naturel et à sa stabilité chimique.

La calcite est, en général, très abondante, liée ou à la fraction détritique inorganique des boues, ou à la dureté naturelle des eaux. Elle résulte plus variable que le quartz; les échantillons N. 7 et 10 n'en contiennent que très peu, tandis qu'elle est abondante, ou très abondante, dans les échantillons N. 2, 4 et 5. Cette variabilité reflète évidemment la fréquence du minéral dans les roches du bassin versant, ou même la

TABLEAU 2 - Composition minéralogique semi-quantitative de la fraction minérale cristalline des boues.

Echantillon N.	1	2	3	4	5	6	7	8	9	10
Quartz	++++	+++	+++	++++	++++	++++	++++	++++	+++	+++
Calcite	++++	+++++	+++	++++	++++	+++	++	+++	++++	++
Dolomite	+++	+	+++	++++	+++	+++++	+++	++++	+++	++
Feldspaths	++	+	+++	++	+	++	+++	++	+++	+
Halite	+	++++	-	-	+++	-	-	++	-	-
Kaolinite	+++	tr.	+++	+++	+++	++	++	++++	++	+++
Mica	++	tr.	+++	+++	+++	++	++	+++	+++	++
Talc	++	-	++	+++	+	+	+	+++	-	+
Chlorite	+	tr.	++	+++	++	tr.	++	tr.	++	++
Montmorillo-nite et/ou Vermiculite	-	-	++	+++	-	+++	tr.	-	-	+++
Opale	-	-	-	++++	-	++	-	-	-	+++
Gypse	+	-	-	-	-	-	-	-	-	+++

+++++ très abondant; ++++ abondant; +++ commun; ++ présent; + présent en quantités très faibles; tr. traces; - absent.

différente dureté des eaux, ou même, encore, la différente agressivité des boues vis-à-vis ce carbonate. Cette dernière hypothèse semble confirmée par l'abondance imprévue de la dolomite qui, généralement moins fréquente que la calcite dans le milieu naturel, résulte, au contraire, presque toujours abondante dans les échantillons étudiés, parfois même plus abondante que le carbonate de calcium. Ce fait s'esplique par une concentration préferentielle de la dolomite consequente une moins facile solubilisation de ce minéral; cela est surtout évident dans les boues des régions plus riches de roches carbonatiques (échantillons N.4 et 6), en correspondance avec l'origine toujours détritique de la dolomite.

Sauf que dans trois échantillons, en général les feldspaths sont présents en quantités faibles ou très faibles; sans doute ils sont liés, eux aussi, aux fractions détritiques,sableuse et limoneuse.

L'halite est liée à la salinité des boues et depend surtout de l'utilisation domestique et industrielle du chlorure sodique; pour les échantillons particulièrement riches en NaCl de Livorno et de Viareggio, villes de mer, on peut penser à un enrichissement d'origine marine.

On trouve aussi, bien qu'en faibles quantités, des phyllosilicates liés à la fraction argileuse détritique. Parmi eux les plus fréquents sont la kaolinite et la mica, minéraux assez répandus dans l'environnement sédimentaire. Dans le milieu naturel la première est moins abondante que la deuxième,au moins dans nos conditions pédoclimatiques, mais, pour sa relative résistance à l'action des agents chimiques, elle peut se concentrer aussi dans des milieux agressifs tels que les boues d'épuration. Les minéraux micacés résultent, au contraire, très dégradés puisqu'ils apparaissent abondamment interstratifiés avec des minéraux à couches expansibles. Aussi les chlorites, moins abondantes et fréquentes que les micas, sont, probablement, partiellement dégradées, puisqu'elles présentent une faible résistance à la déshydroxylation lors du traitement thermique. En effet, le chauffage a 550°C, bien qu'en entraînant dans presque tous les échantillons un renforcement de la réflexion d 001, la fait aussi déplacer vers 13,90 Å, ce qui est caractéristique de chlorites avec des feuillets gibbsitiques (ou brucitiques) plus ou moins discontinus, qui peuvent même faire transition à des vrais "intergrades" chloritiques.

Une autre phase revenante aux minéraux argileux est représentée par un minéral caractérisé par la présence d'une raie aux alentours de 15,5 Å dans les échantillons naturels; le minéral, saturé par Mg^{++} et traité au glycérol, ne montre aucune expansion, même dans les échantillons dont la matière organique avait été extraite avec la méthode la plus énergique, mais après chauffage à 550°C il résulte se contracter vers 10 Å. Il pourrait s'agir d'une vermiculite, bien que la distance interfoliaire soit, peut-être, un peu trop élevée; ou bien il pourrait représenter un "intergrade" chloritique issu d'une smectite (ou, aussi, d'une vermiculite) dont la couche octaédrique, bien que discontinue, soit difficilement extractible; ou, encore, il pourrait s'agir d'un complexe smectite - matière organique particulièrement résistant aux traitements minéralisants. Par conséquence nous nous sommes bornés à indiquer cette phase comme "montmorillonite et/ou vermiculite".

Parmi les phyllosilicates on trouve presque toujours le talc; puisque dans le milieu naturel ce minéral se rencontre essentiellement dans les roches métamorfiques qui présentent des affleurements très limités, ou même qui sont complètement absentes dans les régions des stations d'épurations étudiées, sa présence dans les boues est probablement à rattacher aux pratiques hygiénique-sanitaires et aux activités industrielles.

Les larges bandes aux alentours de 4,3-4,1-3,9 Å, surtout évidentes dans les diffractogrammes des échantillons N. 4 et 10, out été attribuées à l'opale, en accord avec Jones et al. (14), bien qu'elles peuvent indiquer aussi des effets de diffraction de matières organiques plus ou moins condensées (15). En effet la présence de l'opale est confirmée par la persistance de ces bandes aussi dans les spectres des échantillons où l'on avait détruit la matière organique et, surtout, par la présence, dans certains diffractogrammes, du pic le plus intense de la tridymite de basse température superposé à ces bandes. De plus, dans les diffractogrammes des matériaux chauffés à 550°C paraît le pic le plus intense de la cristobalite de basse température, tandis que celui de la tridymite va baisser remarquablement, en accord avec les observations de Jones et al. (14) pour les opales, surtout d'origine végétale.

On a enfin identifié le gypse à l'aide de la réflexion à 7,6 Å qui est parfois visible déjà dans les spectres des échantillons naturels, comme, par exemple, dans celui de la boue de Pescia, mais qui, le plus souvent, apparaît seulement dans les spectres des échantillons orientés, où elle peut être suivie par quelques autres raies très faibles.

4. CONCLUSIONS

En ce qui concerne la matière organique des boues, nous nous sommes bornés à la fractionner en sept grands groupes, tout en comprenant que pour connaître avec certitude l'origine des différentes fractions organiques il faudrait procéder à une analyse plus détaillée et spécifique. On peut sans doute affirmer, en général, que les différentes fractions organiques des boues sont, évidemment, d'origine mixte, animale et végétale, et qu'elles y parviennent à travers la purification d'effluents domestiques et industriels. En outre la caractérisation de la M.O. indique qu'elle est constituée par des fractions analogues aux fractions du fumier et pourtant qu'on peut utiliser les boues en agriculture en tant que riches en M.O., en accord avec Johnston (16); néanmoins une analyse plus spécifique peut être necessaire lorsqu'on suspecte la présence de substances organiques toxiques telles que détergents, pesticides, benzopyrênes, etc. (12), bien que, probablement, elles soient détruibles par les microorganisme et les enzymes.

La composition de la fraction minérale cristalline, enfin, ne pose pas de limitations à l'épandage des boues sur le sol; seulement leur teneur en sulfates et, surtout, en chlorures, s'oppose, peut-être, à l'utilisation agricole des boues. Néamoins, seulement pour les échantillons N. 2 et 5, qui se distinguent pour une teneur très élevée en chlorure de sodium, on peut effectivement penser à une limitation de leur emploi.

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SESSION III - BIOLOGICAL POLLUTION OF SLUDGE

ACTIVITIES OF WORKING PARTY 3 "BIOLOGICAL POLLUTION OF SLUDGE"

INTRODUCTORY REMARKS

by

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At the I. meeting of the Concerted Action Committee (13 Dec. 1977) it was decided to establish a number of working parties. Among the objectives for these working parties were the quality of sludge and derived products for agricultural use and harmonisation of rules or recommendations with regard to sludge application on soil concerning content of pollutants and pathogens.

At the second meeting (28 Febr.1978) 5 working parties were suggested and full agreement was reached on three of them. Among these three was the working party on " biological pollution of sludge " dealing with the characterization of bacteria, viruses, parasites and all aspects of disinfection.

The working party has concluded its work up to now with a report dealing with various aspects mentioned in the terms of reference. On some aspects the opinions within the group have varied considerably, but what is mentioned in the report is what the group has agreed unanimously.

1. Risk Assessments

Because of increase in the amount of waste water, the amount of treatment given and the efficiency of the treatments, the amount of sludge produced in various countries is increasing quite considerably. It is of importance to utilize the sludges for agricultural purposes, but the health risks must be evaluated, and suitable practices must be used to prevent spread of infection. The value of the product will be influenced by the type of treatment applied.

Economically and practically a no-risk level cannot be obtained, although it might be technologically possible.

Definitions of levels of treatment of sludge that may provide reasonable safety are not easy to obtain, and they cannot be expressed in absolute terms, but would depend on a number of economical, political and geographical factors. In a situation where probably half of the sludge produced is applied on land, legally or illegally, the Working Party has found it important to review the situation and make suggestions so that some obviously unsafe procedures could be omitted bearing in mind, that if too strict rules are suggested, it may become quite impossible to place sludge on agricultural land.

2. The Pathogens

A number of pathogens (bacteria, viruses, parasites, fungi) have been discussed regarding their possible significance for the use of sewage sludge. The report contains lists and special remarks. It is concluded that it would be advisable to have special treatments of wastes from slaughterhouses, tanning industries and certain laboratories for microbiology and hospitals dealing with special communicable disease. This would reduce the treatment that had to be given to the combined municipal sludge.
Stormwater may contain a number of pathogenic parasites excreeted with faeces, but it is not indicated that this plays an important role in the dissimination of parasitic diseases. The following agents are identified, which should be considered especially in connection with sludge application or studies should be promoted to investigate their importance : Salmonellae, Yersinia enterocolitica, antibiotic resistant E.coli , Mycobacteria group, the human enteric viruses, Taenia saginata, a number of nematode eggs especially ascaris eggs.

3. The various treatments

The report contains attemps to define the various methods.

4. Sludge Treatment and Suggested Possible Land Application

It has been attempted to evaluate the material collected by working party 5 together with a number of other materials ;
these the following suggestions have emerged.

Treatment	Pathogen Reduction	Application
No treatment	Primary raw sludge has a higher concentration of pathogens than the untreated waste water	Limited and localized usage allowable under appropriate conditions with the approval of competent authorities
A Stabilized sludge whether liquid, dewatered or naturally dried I)	Important reduction of pathogens, especially of vegetative bacteria. The effects on cysts and eggs and bacterial spores will be a time temperature effect.	Arable land during vegetation rest periods, vineyards and orchards. Pasture and forage land after harvest and until the end of the year 2)
Composting I 3)		No crops used uncooked for human consumption
B Lime conditioning Low dose irradiation (<500 K rad)	Reduction of pathogens except for parasites and bacterial spores. Vegetative bacteria destroyed .	Less restrictions on the period of application than indicated for A.
Pasteurization Lime treatment Quick lime treatment Composting II 4) Irradiation with high dosage (> 500 K rad) Aerobic thermophilic stabilization 5) High temperature treatment 6)	Sanitized 7)	No restrictions

I. Would apply also to chemically conditioned, stabilized sludge (except for lime conditional, but the concentrations of e.g. virus may become higher than it was in the only stabilized sludge.

2. Possible grassland application should be considered.
A restriction period of 6 months would seem reasonable depending on the climatic conditions (temperature and precipitation).

3. By this is understood a composting which could be used as a method equivalent to stabilization by e.g. anaerobic digestion. The composting could operate at 40 ° C for at least 5 days, with the temperature exceeding 55°C for at least 4 hours.

4. A composting giving results equal to pasteurization.
A process where the temperature is raised above a minimum of 55°C for several days.

5. Temperature and time like composting II.

6. At least equivalent to pasteurization.

7. Regrowth or recontamination in liquid sludge by bacteria must be considered. Parasite eggs and cysts may be very resistant even for prolonged periods at high pH.

The report contains a short section (5) on the resistance of residual pathogens and on the indicator problems (6) and finally (7) a number of identified research needs.

SEUCHENHYGIENISCHE PROBLEME BEI DER ENTSORGUNG VON KLÄRSCHLAMM IN ÖSTERREICH

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Summary

Until 1970 no problems existed with municipal sewage sludge in Austria. With the increasing number of sewage plants during the last decade, in Austria, too, problems were arising concerning the unobjectionable hygienic disposal of sewage sludge. This led to intensive investigations of the theoretical background as well as to applied investigations of University institutes.

In Austria the sludge from smaller plants is first stabilized under either anaerobic or aerobic conditions and then utilized for agricultural purposes. In a few cases the sludge is deposited or piled up in sludge lagoons. Pasteurization is mainly applied to infectious sludge while heat treatment is not used. In Vienna the sewage sludge is burnt.

Concerning the hygienic aspects of the treatment of sewage sludge there are no legal regulations in Austria.

1. EINLEITUNG

Wie SUPERSBERG in seinem Referat zur Arbeitsgruppe V ausführt, gab es in Österreich bis 1970 mit kommunalem Klärschlamm kaum Schwierigkeiten. Der anfallende Schlamm konnte bis dahin in den Kläranlagen gespeichert oder an die Landwirtschaft abgegeben werden. Mit der Zunahme der Zahl der Kläranlagen traten allerdings zwischen 1970 und 1980 Probleme bei der seuchenhygienisch einwandfreien Entsorgung von Klärschlamm auf.

Mit diesem vermehrten Anfall an Klärschlamm setzte dann auch eine intensivere Forschungstätigkeit ein. Am Hygiene-Institut der Universität Wien hatte man bereits Mitte der 60er-Jahre mit Grundlagenforschung begonnen. Diese Untersuchungen wurden dann gemeinsam mit dem Institut für Wasserversorgung, Abwasserreinigung und Gewässerschutz der Technischen Universität Wien fortgeführt und erstreckten sich über mehr als 10 Jahre. Derzeit laufen im Hygiene-Institut auch noch Untersuchungen über die gemeinsame Kompostierung von kommunalem Klärschlamm und Hausmüll.

Am Hygiene-Institut der Universität Innsbruck werden mit mikrokalorimetrischen Methoden Untersuchungen über Schlammaktivitäten vorgenommen sowie Prüfungen an Rotten durchgeführt. Fragen der Klärschlammhygienisierung wurden am Forschungszentrum Seibersdorf der Österreichischen Studiengesellschaft für Atomenergie geprüft. Im Institut für Wasserwirtschaft der Universität für Bodenkultur Wien wurden nach der Beschlammung landwirtschaftlicher Flächen auch bakteriologische Grundwasseruntersuchungen vorgenommen.

Nachfolgend eine kurze Übersicht über die Ergebnisse durchgeführter und laufender wissenschaftlicher Untersuchungen.

2. ABGESCHLOSSENE PROJEKTE

2.1. Experimentelle Studien mit Bakteriophagen an mechanisch-biologischen Kläranlagen mit Emscherbrunnen, Tropfkörper und Nachklärbecken

(Hygiene-Institut der Universität Wien, Vorstand o.Univ.Prof. Dr.med.H.Flamm)

Im Zusammenhang mit der Frage, wie sich pathogene Viren im Zuge der Abwasserreinigung in mechanisch-biologischen Kläranlagen verhalten und mit welcher Virusverminderung während des Reinigungsvorganges zu rechnen ist, wurden Kläranlagen mit einer bekannten Menge von Viren beimpft und diese Agentien während ihrer Passage quantitativ verfolgt. Pathogene Viren konnten wegen der Verseuchung der belebten Umwelt allerdings nicht herangezogen werden. Als Virusmodell wurden daher Staphylokokkenphagen eingesetzt, die sich in Vorversuchen (1) als geeignet erwiesen hatten. Die notwendige Information über die Durchströmungsverhältnisse in den Kläranlagen wurde durch Markierung mit radioaktivem Natrium (Natrium-24) erreicht.

Die chemisch-bakteriologischen Analysen ließen die Abwässer als dünn bzw. nur mäßig konzentriert erkennen. Die mikrobiologischen Untersuchungen zeigten, daß der Kläranlagenablauf etwa 1/3 weniger Viren enthielt, als eingesät worden waren. Die größte Viruseliminierung aus dem Abwasser wurde im Absetzbecken beobachtet, in Tropfkörper und Nachklärbecken waren nur kleine Eliminationsraten nachweisbar. Der Großteil der aus dem Abwasser eliminierten Viren fand sich im Schlamm wieder und erwies sich als virulent.

Die mechanisch-biologische Abwasserreinigung mittels Tropfkörper ist wegen der geringen Viruseliminationsrate aus dem Abwasser und der Virusanreicherung im Schlamm vom seuchenhygienischen Standpunkt aus als unbefriedigend zu beurteilen (2).

2.2. Experimentelle Studien mit Modellviren beim Belebungsverfahren

(Hygiene-Institut der Universität Wien, Vorstand o.Univ. Prof.Dr.med.H.Flamm, und Institut für Wasserversorgung, Abwasserreinigung und Gewässerschutz der Technischen Universität Wien, Vorstand o.Univ.Prof.Dipl.Ing.W.v.d.Emde)

Aufbauend auf den Erfahrungen an Tropfkörperanlagen wurden mit gleicher mikrobiologischer Methodik Untersuchungen zur Virusinaktivierung an Belebungsanlagen durchgeführt (3), (4), (5). Bei diesen Untersuchungen war für die seuchenhygienischen Belange das Hygiene-Institut der Universität Wien verantwortlich, für den technischen Teil das Institut für Wasserversorgung, Abwasserreinigung und Gewässerschutz der Technischen Universität Wien. Die Untersuchungen gliederten sich in Standversuche im Labor und Durchlaufversuche an Kläranlagen im Raum von Wien und dienten der Überprüfung der verschiedenen Parameter, die die Viruseliminierung bei Belebungsverfahren beeinflussen.

Standversuche

Bei Versuchen, die mit Asbestflocken gefahren wurden, war zu erkennen, daß mit Zunahme des Feststoffgehaltes die Viruseliminationsrate in der flüssigen Phase ansteigt und die Viren an die Asbestflocken adsorbiert werden. Weiters zeigten die Versuche, daß eine Beeinflussung der Modellviren durch Belüftung in inertem Leitungswasser nicht nachweisbar war. Wurde hingegen Abwasser als Medium angewandt und mit Luft begast, war eine Phagenreduktion über 4 log festzustellen, während unter gleichen Versuchsbedingungen eine Stickstoffbegasung praktisch keine Virusreduktion erbrachte. Daraus ergibt sich, daß bei der Eliminierung der Viren auch biologische, Sauerstoff benötigende Vorgänge von Bedeutung sind. Bei intermittierender Viruseinsaat werden idente Reaktionskurven erhalten, es zeigt sich demnach, daß sich die Biozönosen immer wieder adaptieren. Bei der Untersuchung von Schlämmen aus unterschiedlich belasteten Kläranlagen konnte nachgewiesen werden, daß die

Eliminierungsrate für die Viren aus dem Abwasser mit steigender Schlammkonzentration zunahm, die Überprüfung der Schlämme ergab, daß sich die Viren hier angereichert hatten. Ebenso ließen die Standversuche erkennen, daß bei geringerer Schlammbelastung (ausgedrückt in kg BSB_5/d) nicht nur ein weitgehender Abbau von organischen Substanzen, sondern auch eine wesentlich höhere Viruseliminationsrate aus dem Abwasser zu erreichen ist. Bei Belastungsversuchen, die bei unterschiedlichen Temperaturen (5°C, 15°C) liefen, konnte beobachtet werden, daß bei höherer Temperatur die Eliminationsrate größer war. Dies kann mit einer höheren Reaktionsaktivität der Belebtschlammbiozönosen bei höherer Temperatur erklärt werden.

Durchlaufversuche

Für die Durchlaufversuche wurden Pilotanlagen (mit Belebungs- und Nachklärbecken) in den Klärwerken aufgebaut. Über Dosierpumpen wurden die Anlagen mit frischem Abwasser und Viren kontinuierlich beschickt. BSB_5, COD, TOC und Trockensubstanz wurden laufend überprüft und ergaben idente Werte mit den Hauptkläranlagen, sodaß die gefundenen Resultate als repräsentativ angesehen werden können. Es zeigte sich, daß nach kurzer Einarbeitungszeit bei mittel belasteten Anlagen eine Reduktionsrate von 97,7% und bei schwach belasteten Anlagen von 99,9% zu erzielen war. Bei konstantem Abwasserdurchsatz und stufenweiser Steigerung der Viruskonzentration stellte sich nach relativ kurzer Zeit eine für die jeweilige Belastung charakteristische Abbaurate ein. Sie nahm im Hinblick auf die Einsaat wohl prozentuell ab, absolut war jedoch eine Leistungssteigerung des Systems nach jeweiliger Einarbeitung zu erkennen. Schließlich wurden noch über längere Zeit Durchlaufversuche mit synthetischem Abwasser mit geringem Anteil an frischem Abwasser gefahren, die schwach, mittel und stark belastete Anlagen simulieren sollten. Bei gleicher Viruskonzentration konnte man auch hier an der schwach belasteten Anlage den besten Wirkungsgrad beobachten.

Die Untersuchungen ließen eindeutig erkennen, daß Belebungsanlagen den Tropfkörperanlagen im Hinblick auf die Viruseliminierung wesentlich überlegen sind. Die besten Erfolge sind bei schwach belasteten Anlagen zu erzielen, sodaß diesen - soweit es möglich ist - der Vorzug gegeben werden sollte. Für den Hygieniker ist im Gegensatz zum Techniker nicht allein die prozentuelle Reduktion von Krankheitserregern von Interesse, sondern vielmehr, ob und inwieweit die Infektionsdosis überschritten wird. Es wird daher gelegentlich erforderlich sein, eine weitere Aufbereitung des Abwassers, aber insbesondere der Schlämme, vorzunehmen.

2.3. Inaktivierung von T_4-Bakteriophagen durch Wärme- und γ-Strahlenbehandlung in Hinsicht auf Klärschlammhygienisierung

(Österreichische Studiengesellschaft für Atomenergie, Forschungszentrum Seibersdorf)

Die Versuche wurden mit dem Bakteriophagen T_4 und dem E.coli Stamm K12D10 durchgeführt, zur Anwendung gelangte die Plaque-Technik. Die Versuche ergaben, daß eine Kombination von Hitzeeinwirkung und Bestrahlung wegen synergistischer Effekte die höchste Inaktivierungsrate erbrachte (6).

2.4. Einfluß von Beschlammung auf Grundwasser

(Institut für Wasserwirtschaft der Universität für Bodenkultur Wien, Abteilung Landwirtschaftlicher Wasserbau, Vorstand o.Univ.Prof.Dr.H.A.Supersberg)

In den Jahren 1972/1973 wurden in der Umgebung von Wien Beschlammungsversuche vorgenommen, bei denen auch bakteriologische Prüfungen erfolgten. Die Ergebnisse von Proben aus Grundwassersonden im Einflußbereich der Beschlammung zeigten stark erhöhte Keimzahlen, typische Darmkeime wurden jedoch nicht nachgewiesen. (6a).

2.5. Demonstration of Heterotrophic Activities in Primary Sludge, Activated Sludge and Anaerobic Sludge by Microcalorimetry

(Hygiene-Institut der Universität Innsbruck, Vorstand o.Univ.Prof.DDr.J.Benger, Arbeitsgruppe für Techn.Hygiene)

Vom Hygiene-Institut der Universität Innsbruck gemeinsam mit dem Labor für Thermochemie der Universität Lund (Schweden) und den Chäpalla-Abfallwerken Stockholm durchgeführte Untersuchungen ergaben, daß mikrokalorimetrische Arbeitsmethoden im aeroben, mikroaerophilen und anaeroben Berich gute Aussagen über die Schlammaktivität gestatten (7).

2.6. Inhibition of Sludge Activities in Waste-Water Systems by Microcalorimetric Methods

(Hygiene-Institut der Universität Innsbruck, Vorstand o.Univ.Prof.DDr.J.Benger, Arbeitsgruppe für Techn.Hygiene)

Bei Störungen in einer Belebungsanlage konnte mit Hilfe vom mikrokalorimetrischen Methoden - besser als mit konventionellen - eine Schlammvergiftung nachgewiesen werden(8).

2.7. Determination of Hydrolytic Activities in Waste-Water-Systems by Microcalorimetry

(Hygiene-Institut der Universität Innsbruck, Vorstand o.Univ.Prof.DDr.J.Benger, Arbeitsgruppe für Techn.Hygiene)

Ergebnisse von mikrokalorimetrischen Untersuchungen über hydrolytische Aktivitäten von Schlamm nach Zusatz verschiedener Substrate (9).

3. PROJEKTE IN ARBEIT

3.1. Hygienische Aspekte bei der gemeinsamen Hausmüll-Klärschlamm-Kompostierung

(Hygiene-Institut der Universität Wien, Vorstand o.Univ. Prof.Dr.med.H.Flamm)

Es ist Ziel dieser Untersuchungen, hygienisch befriedigende Resultate bei der gemeinsamen Kompostierung von Hausmüll und Klärschlamm zu erreichen. Die getestete Anlage arbeitet wie folgt: Aussortierter und zerkleinerter Hausmüll wird mit Klärschlamm gemischt, gelangt über eine Fermentierungstrommel (1-2 Tage, Temperaturen bis 55°C), 4-6 Wochen in eine statische Rotte (belüftete Reifeplatte), in der eine "Hygienisierung" erfolgen soll. Der so erhaltene Kompost wird vor Verwendung ein Jahr gelagert. Bis jetzt zeigten die Prüfungen, daß im Rohschlamm, in der Fermentierungstrommel und auch in den äußeren Zonen der Reifeplatte reichlich Fäkalkeime und auch Salmonellen nachweisbar waren. Lediglich in der Kernzone der Reifeplatte, in der die höchsten Temperaturen erreicht wurden, waren der Gehalt an Fäkalkeimen nur mehr niedrig und Salmonellen nicht nachweisbar. Der ein Jahr gelagerte Kompost zeigte eine weitere Abnahme der Fäkalkontamination.

3.2. Sickerwasseruntersuchungen zur Charakterisierung des Rotteablaufes bei der aeroben Rotte in Mieten

(Hygiene-Institut der Universität Innsbruck, Vorstand o.Univ.Prof.DDr.J.Benger, Arbeitsgruppe für Techn.Hygiene)

Ziel dieser Untersuchungen ist die Erfassung der in aeroben Trapezmieten ablaufenden mikrobiellen Prozesse, um den Rottezustand zu charakterisieren und den Rottevorgang zu beschleunigen.

3.3. Gemeinsamer anaerober Abbau von Klärschlamm und Hausmüll

(Hygiene-Institut der Universität Innsbruck, Vorstand o.Univ.Prof.DDr.J.Benger, Arbeitsgruppe für Techn.Hygiene)

Ziel der Arbeit ist die Erfassung der mikrobiologischen Grundlagen kleinräumiger Systeme.

. SITUATION IN ÖSTERREICH

Eine bundeseinheitliche Regelung zur Seuchenhygiene von Klärschlamm fehlt. Diverse Richtlinien und Regelblätter für die

Einleitung von Abwässern in Kanäle und Vorfluter liegen wohl bereits vor, darunter sind aber keine Unterlagen, die sich speziell mit dem Schlamm, insbesondere mit den hygienischen Aspekten befassen. Die notwendigen Entscheidungen werden durch die jeweils zuständigen Sanitätsbehörden entsprechend den lokalen Verhältnissen getroffen. Als Entscheidungshilfe wird in vielen Fällen das Merkblatt Nr. 7 (10) des Bundesgesundheitsamtes in Berlin "Die Behandlung und Beseitigung von Klärschlämmen unter besonderer Berücksichtigung ihrer seuchenhygienisch unbedenklichen Verwertung im Landbau" herangezogen.

Allgemein ist zu beobachten, daß die Tendenz von Tropfkörperanlagen zu Belebungsanlagen führt.

Zur Verwertung bzw. Beseitigung von Klärschlamm konnten von Herrn Prof.v.d.Emde, Vorstand des Institutes für Wasserversorgung, Abwasserreinigung und Gewässerschutz der Technischen Universität Wien, folgende Angaben erhalten werden. Der Schlamm kleinerer kommunaler Anlagen - und das sind die meisten Anlagen in Österreich - wird meist landwirtschaftlich verwertet. Zur Anwendung gelangt kein Rohschlamm, sondern nur aerob oder anaerob stabilisierter Schlamm. Dieser wird in dünner Schicht (etwa 10 mm pro Jahr) auf landwirtschaftliche Flächen außerhalb der Vegetationsperioden aufgebracht. Bis zur landwirtschaftlichen Nutzung bleibt der Schlamm in den Kläranlagen.

Gelegentlich wird der Schlamm auch auf Deponien gelagert, für den Grundwasserschutz wird, wie es auch sonst bei Deponien üblich ist, vorgesorgt. Vereinzelt wird der Schlamm auch in Schlammteichen gestapelt, auch hier ist man um einen ausreichenden Grundwasserschutz bemüht. Der Weg einer gemeinsamen Kompostierung von Hausmüll und Klärschlamm wird ebenfalls in Österreich beschritten. Gerade auf diesem Sektor laufen - wie bereits ausgeführt - wissenschaftliche Untersuchungen, um seuchenhygienisch befriedigende Verhältnisse zu erreichen. Schlamm wird nur ganz vereinzelt pasteurisiert, vor allem dann, wenn es sich um Abwässer handelt, deren Kontamination mit Krankheitserregern bekannt ist, wie z.B. Abwässer von Lungenheilstätten. Schlämme und Abwässer werden auf das Vorhandensein von Tuberkelbakterien in solchen Fällen meist routinemäßig durch Hygiene-Institute oder durch dem Bundesministerium für Gesundheit und Umweltschutz unterstellte Bundesanstalten kontrolliert. Eine thermische Konditionierung von Schlamm wird bisher in Österreich nicht vorgenommen, obwohl dieses Verfahren vom Standpunkt der Hygiene aus große Sicherheit bietet. Vereinzelt, so wie z.B. im Fall der Großstadt Wien, wird der Schlamm nach vorheriger Entwässerung verbrannt.

Eine befriedigende Regelung der seuchenhygienischen Belange bei der Entsorgung von Klärschlamm wird durch die Hygieniker des Landes angestrebt, Vorschläge sind allerdings noch nicht erarbeitet. Bei allen Regelungen wird auf jeden Fall zu berücksichtigen sein, daß es sich bei den Österreichern im allgemeinen um eine stark mit Hepatitisviren, vor allem Typ A, durchseuchte Bevölkerung handelt. Mit dem Vorhandensein dieser Viren muß daher im kommunalen Abwasserschlamm gerechnet werden, und alle Maßnahmen müssen unter Berücksichtigung dieser Tatsache gesetzt werden.

Ergänzend soll noch bemerkt werden, daß an der Veterinärmedizinischen Universität Wien Fragen des Überlebens von Krankheitserregern in Flüssigmist und bei Biogasverfahren, die Beeinflussung der Biogasgewinnung durch Futteradditive und Desinfektionsmittel sowie das Schicksal von Resistenzplasmiden in Flüssigmist, kommunalem Abwasser und in Kläranlagen bearbeitet wird.

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THE CONTROL OF SALMONELLOSIS IN THE USE OF SEWAGE SLUDGE ON AGRICULTURAL LAND

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Summary

Salmonellosis is a very widespread disease of man and food animals. Because salmonellae are excreted by active cases and carriers, and can be detected in sewage, sludges and effluents, there is concern that a cycle of infection between man and food animals could be caused by the use of sludge on land as a fertilizer. The European information has been critically examined and shows that the major causes of salmonellosis in food animals exist within agriculture as self-contained cycles, that human salmonellosis takes the form of food poisoning caused by faulty food hygiene involving poultry, meat and dairy products, and that transmission from man to farm animals will occur by discharge of sewage or partly treated effluents to grazing areas and by passive carriage by seagulls from infected garbage to pasture. The transmission of salmonellosis to cattle by use of sludge on grazing land cannot be ruled out, although it would appear to be a minor cause, except in areas where there is limited land available for disposal of sludge and where animal populations are dense and the content of salmonellae in the sludges is high.

Salmonellae are considerably removed during full biological treatment of sewage. The numbers of salmonellae in sludge are very variable depending upon season, size of community, and locality. Anaerobic mesophilic or aerobic digestion, in practice, will give incomplete removal of salmonellae; complete inactivation will be achieved only by lime at pH >11 or by processes involving heating to at least 45-50^{o}C or by irradiation. The effects of heating may be nullified by regrowth on storage. When sludge is spread on land, crops or grass, salmonellae will decay exponentially. The philosophy for control of disease is examined and it is considered that the best and most economic policy for minimizing hazard to farm animals is one of operational guidelines determined from local expert advice, rather than universal uniform emission standards. Such guidelines would specify practices which impose real barriers to infection. The cost of routine microbiological monitoring of sludge is likely to be high and cannot be justified.

1. SALMONELLOSIS

The term salmonellosis describes the illnesses in man and animals caused by Salmonella species. These bacteria are primarily enteric pathogens and about 1800 species can be identified by serology. They are released into the environment, often in very large numbers, in the faeces of infected animals. After recovery from acute salmonellosis, it is common for various organs of the body to become chronically infected. Such carriers of the organisms will continue to excrete salmonellae, usually in faeces.

Certain host-adapted serotypes tend to attack man or specific animals more or less exclusively. The cycle of infection with host-adapted serotypes is usually well-defined, being from animal to animal by direct or indirect contact. Other serotypes, typified by S. typhimurium, tend to attack man and vertebrate animals indiscriminately, with the result that cross-infection between man and animals occurs. This type of disease relationship is termed a 'zoonosis' and the causes of zoonoses are often difficult to trace epidemiologically, because complex cycles of infection and widespread environmental contamination may exist.

Highly sensitive, though imprecise, methods are now available for isolating salmonellae from soil, sludge and aquatic environments. Estimation of count requires replicate culture of specific amounts of sample to yield a 'most probable number' estimate. To obtain quantitative information upon numbers is therefore tedious and expensive, but the data are more meaningful than 'presence/absence' records. With either type of data, the limits of detection must be specified. This must be emphasised, as conclusions cannot otherwise be drawn upon severity of environmental contamination or upon survival rates. In general micro-organisms in a hostile environment exhibit rates of death, as idealised in the exponential model, where the ratio of survivors to initial count, N_t/N_o, is related to time elapsing ($t - t_o$) by

$$\log_{10} (N_t/N_o) = k(t - t_o) \tag{1}$$

and where k is a death-rate constant. The time taken for a 90% decrease in count, T_{90}, is given by

$$T_{90} = 1/k. \tag{2}$$

2. INCIDENCE AND TRANSMISSION OF SALMONELLOSIS

Salmonellosis is a major bacterial disease of animals and man. In England, of 11 281 cases of human food poisoning reported by local authorities, 66.9% were caused by salmonellae - a case rate of about $16.3/10^5$ population (1). The distribution of serotypes (11 240) reported in 1978 (2) show nearly equal incidences of S. typhimurium (24.2%) and S. hadar (21.6%). In 333 outbreaks in 1973-1975, meat was incriminated in 34.8%, poultry in 39.0%, and dairy products in 9.6% (1). Meat, poultry, and dairy products are the main source of salmonellosis in man, and direct transmission from animals is uncommon. Table I shows that a high proportion of bovine salmonellosis is attributable to S. typhimurium and to exotic serotypes, in addition to the host-specific S. dublin. It also indicates an increase

Table I. Percentage involvement of different serotypes in bovine salmonellosis in various countries

Country	Years	S. dublin	S. typhimurium	Other serotypes	Comments and reference*
England, Wales	1958-74	74.4	21.0	4.6	29 294 incidents recorded (6)
England, Wales, Scotland	1978	39.2	47.9	12.9	1428 incidents (7)
Germany	1961-65	49.3	36.5	14.2	Isolations, Bulling and Pietzch (1968)
Lower Saxony	1959-60	76.4	8.9	14.7	2131 isolations (8)
Holland	1969-71	35.9	62.9	11.2	From 1686 cattle at slaughter, Edel et al. (1974)
Sweden	1968-72	59.7	30.0	10.3	Incidents recorded, Gunnarson et al. (1974)
USA	1933-73	7.5	72.2	20.3	Isolates, Morse et al. (1976)

* Source of references cited by Wray and Sojka (6), except where given

in disease by the first two classes in the United Kingdom, so that there has been much concern to determine the causes and reservoirs of infection in food animals, including compulsory reporting of outbreaks under the Zoonoses Order (3).

Table II shows considerable evidence for self-contained cycles of salmonellosis within agriculture. However, unlike transmission from animals to man, caused by faulty food hygiene, there is less evidence for

Table II. Factors influencing salmonellosis in food animals

Factors	Comments and references
Intensive rearing of calves, movement of calves	Animal to animal transmission, stress of marketing and transport. Peak incidence in autumn corresponds to sales (6,9). Cause of general outbreaks on farms (9).
Infected animal feed	UK survey (6) -587/2801 raw foods positive but only 8/1459 pelleted foods. Epidemiological evidence incriminating dairy cake (10). Pipe-line feeding of pigs (11). Animal feed responsible for introducing *S*. 4,12:d:-, *agona*, *indiana* into UK (11).
Rough pasture, wet lands, liver fluke	Predispose to *S. dublin* in cattle; geographical relationship in UK (6) and Lower Saxony (8).
Pasture contaminated with faeces of excreters	Adult cattle and *S. dublin*. Circum-stantial evidence for salmonellosis in cattle, since related to grazing season in UK (11) and Switzerland (12).
Infected poultry breeding stock	In UK, *S. hadar* in turkey poults (13).
Transmission by seagulls	Epidemiological evidence: from nearby rubbish tips (14).
Wild animals	Not significant in UK survey of wild mammals (15).
Contamination of pasture with sewage, septic-tank effluents	Documented cases (16,17) including septic-tank wastes from households with a carrier. Endemic salmonellosis in cattle attributed (18) to discharge of settled sewage to streams in a marshy area (Schleswig-Holstein).
Use of animal slurry on land	Recognised mode of transmission (6) controllable by interval between application and grazing.
Use of sewage sludge on land	No confirmed evidence in UK but circumstantial evidence from Switzerland (12), Germany (19), Holland (20).

transmission of salmonellosis from man to animals. It is sufficiently well-documented that this can occur by contamination of pastures with sewage or septic-tank liquors, and by transmission by sea birds feeding on domestic refuse, but there is no evidence in the United Kingdom that sludge is a vector, if it is applied in accordance with official recommendations (4,5).

3. EVIDENCE FOR USE OF SLUDGE IN AGRICULTURE AS A VECTOR OF BOVINE SALMONELLOSIS

The contradiction between the lack of evidence in the UK and positive evidence reported from three other countries (Table III) requires critical study, either in terms of national differences in agricultural practices and demographic factors and in community health and sewage treatment on the one hand, and on the other, an assessment of the validity of the association observed between salmonellosis and agricultural use of sludge. Some of the

Table III. Evidence for transmission of salmonellosis to farm animals by sewage sludge applied to pastures

Country	Details, comments (and reference)
England and Wales	No case evidence (3,4). Failure to infect clinically heifers, 10-12 months old when fed raw sludge, infected naturally or artificially (*S. dublin*) with up to $10^5/1$ (23).
Switzerland	Salmonella isolated from 32/600 cattle from regions using treated sludge, 0/83 from area where no sludge was applied (24) - association statistically significant (P = 0.0142). Four individual cattle found to be infected after grazing on land, sludged 1-4 months earlier (12). Nine cases infected with rare *S. tokoin* in a herd, 6 days after eating grass from pasture sludged 4 weeks earlier; identical serotypes isolated from grass 7 weeks after sludging (12). Relationship between rises in seasonal incidence of salmonellosis in cattle (1969-1974, 13 877 cases) in May and August to sludging of land in winter and shortly before second grass cut respectively (12,26).
Germany	Two infections of herds with *S. paratyphi* B grazing on land irrigated with digested sludge (Strauch, 1965; cited 19).
Netherlands	Large dairy herd grazed on land receiving regular doses of digested sludge. Herd returned to land 8-21 days after sludging. *S. panama* present in 3 faeces samples from animals grazing; sludge applied 43 days earlier had contained *S. panama*. Proportion of salmonella-positive faeces samples (11/250) in excess of that (3/602) in a national survey; difference is highly significant ($P<0.01$), incidence of clinical illness not recorded (20).

former factors are assessed in Table IV. This shows that the agricultural land available for sludge disposal and for grazing cattle is least in Switzerland, whereas the proportion by weight of sludge disposed to land is highest in Switzerland and the UK (which has the most agricultural land per

Table IV. National differences in population densities and facilities for treatment and disposal of sewage and sludge

Country	Population density (ha^{-1})*		Population (%) served by main drainage†	Sewage flow (%) receiving full biological treatment†	Sludge (% by weight) to agricultural land‡
	Human / arable + pasture	Cattle / pasture			
German FR	4.8	2.7	79	35	30
Netherlands	6.5	4.0	54	90	45
Switzerland	31.0	22.4	?	?	70
UK	4.5	2.9	92	c.100§	74

References: *(27), †(28), ‡(29) - papers by Thornmann, A., Scheltinga, H. M. J., Obrist, W. and for UK, Ref (4).

§ In UK, about 12% of sewage flow is discharged to sea; apart from this, the proportion of sewage not receiving full biological treatment is negligible.

head of human population). The proportion of population served by main drainage and of that sewage receiving full biological treatment is highest in the UK. It is not considered that these are the only factors responsible for the differences in national experience, but they are consistent with the view that high population densities encourage spread of pathogens by direct and indirect means, and with the knowledge that full biological treatment of sewage is capable of removing a high percentage (99-99.9%) of vegetative enteric bacteria, including salmonellae (21).

There are considerable difficulties in proving a causal relationship between disease and an operation, such as using sludge on land, as opposed to merely demonstrating an association or, at the lowest level, making an argument of the post hoc - ergo propter hoc nature. Nine criteria for measuring the strength of proof have been stated by Bradford Hill (22) and include strength of association, frequency of reporting, lack of association of the disease with other environments, or of that environment with other diseases, and demonstrations that disease follows exposure after an expected incubation period and does not occur before exposure, that a positive dose-response relationship exists, that the association is compatible with and not in conflict with the known biology or natural history of the disease, that experiments support the causal relationship and that there is a fair analogy with some parallel context. These criteria may be used to assess the evidence presented in Table III, which demonstrates strength of association (4,20,23) or occurrence of disease (12,10) or excretion (20) a suitable time after exposure. A serious drawback to proof is that there is a very strong relationship between salmonellosis in cattle and agricultural practices (Table II) and that, in areas where it is endemic (17,25), there is widespread environmental contamination by salmonellae, so that the association with sludge is weakened. The seasonal incidence of salmonellosis in Swiss cattle (12,26), although relatable to seasonal practices in applying sludge to grass, nevertheless is similar to the seasonal incidence of salmonellosis in British cattle, where cattle movements and marketing are probably responsible (6,9,11) and to that observed in humans, which is probably a reflection of the more rapid deterioration of infected foodstuffs in the warmer months of the year. The results of feeding salmonellae to healthy cattle (6) suggest that large numbers are required to establish clinical infection (calves; 10^6-11^{11} S. dublin, 10^4-10^{11} S. typhimurium). Feeding of infected raw sludge to young cattle (23) at rates of up to 10^5 salmonellae (in 1-l/animal-day) failed to establish clinical infection after 28 days, although in the case in which sterilized sludge was fed, to which 10^5 S. dublin/l had been added, 3/4 animals were found to be sub-clinically infected. The authors concluded that although it was not possible to say that salmonellae in sludge do not infect cattle, the results suggested that it was unlikely to occur except under prolonged exposure to heavy contamination or when the susceptibility of the cattle might be unduly high. This, too, appears to be the conclusion to be drawn from the evidence considered in this Section.

4. THE FATE OF SALMONELLAE IN TREATMENT OF SEWAGE AND SLUDGE

It should be realized that full biological treatment of sewage (e.g. that reducing the BOD_5 to at least 20 mg/l), far from acting as a source for disseminating pathogens into natural waters, represents a barrier to the spread of infection. The removal of faecal bacteria in biological treatment is largely caused by the feeding activity of ciliated protozoa and varies inversely with the hydraulic or surface loading rates of the plant (21). Table V shows that less removal occurs in the primary sedimentation stage than in biological treatment and that removal of at least 98% of salmonellae can occur in a treatment works. No data apparently exist to enable the salmonella content of primary sludge to be related to the proportion of solids removed, although the data from Guildford and Woking (28) suggested that the proportion of salmonellae and suspended solids removed were approximately equal.

Table V. Removal of salmonellae in sewage treatment*

Works, treatment, stage (and reference)	Salmonella count/l		Per cent remaining	Notes
	Influent	Effluent		
Epping; primary treatment, biological filtration (21)	1800	4.3	0.24	S. paratyphi B; quarterly samples 1953-1961
Guildford (30); primary sedimentation	1300	350	27	23 samples
activated sludge	250	1	0.40	15 samples
Woking (30); primary sedimentation	1700	200	12	23 samples
biological filtration	250	35	14	13 samples

* Counts are medians for matched pairs of influent and effluent samples

In biological treatment, death or inactivation of vegetative bacteria occurs and, for this reason, the count of salmonellae in the sludge will be less than that expected from physical removal of these bacteria from the sewage.

The numbers of salmonellae found in sewage and in the sludge will depend upon the level of infection in the community and this will vary seasonally, being greatest in the warmest months, and with location and the size of the population served. Thus, in the large Swiss survey (19), median counts in raw and digested sludge were 10^4 and 10^2/100 ml respectively, compared with values of 22 and 370 in a national survey in England and Wales (31), of >194 and >171 (averages) in Thames Water Authority (32), and geometric mean values of 250/100 ml for raw sludge fed to animals (23) and of 139/100 g for digested sludge spread on a Dutch farm (20). These data suggest that the general counts for digested sludges may be about 10^2/100 ml, whereas for raw sludges, counts may vary widely according to source. For one Water Authority in England (31), with a large number of small works, 87% of 260 samples of raw sludge were free of salmonellae in 100 ml and the estimated geometric mean count was only 8/100 ml. It is more usual, for reasons of economy in analysis, to study presence/absence of salmonellae rather than to estimate the count. It should be realized that the two types of result require different interpretation, since the relationship of count to frequency of occurrence is complex and not linear. Thus salmonellae will be more frequently detected in sludges and effluents from large works, compared with small works, although they appear to be most numerous in sludges from medium-sized works (31).

The effects of sludge treatments on salmonellae have been reviewed (33) and studied (31). In general, treatment with lime to pH values of 11 or over, and by processes involving heating to at least 45-50°C (as in heat-conditioning, pasteurization, irradiation, hot-air drying, thermophilic aerobic or anaerobic digestion) are lethal to salmonellae. With composting, efficiency of inactivation depends upon raising the whole contents of the pile to at least 45°C for a reasonable part of the composting cycle. Salmonellae are, however, able to multiply in previously autoclaved or heat-treated liquid sludges and animal slurries, because of the elimination of microbial competition and predation. Pasteurization of sludge before digestion, rather than after, would avoid this problem, which arises from cross-contamination at the plant (24).

Anaerobic mesophilic or aerobic digestion appear, in practice to give only partial inactivation of salmonellae and by no more than 90-99% (31). Some of the reasons for this have been discussed (34), the most important being that digesters are operated as batch-fed or incompletely-mixing reactors, whereas maximum efficiency of inactivation can occur only in plug-flow reactors. Experimental anaerobic digesters reactors at WRC, fed with 1/15 and 1/20 of their working volume daily or raw sludge containing added (1.5 x 10^5/100 ml) resting-stage cells of S. duesseldorf have, at 35°C, removed respectively 98.5% amd 99.37% of these bacteria.

5. THE FATE OF SALMONELLAE IN THE ENVIRONMENT

There is considerable evidence that salmonellae can be detected in water and soil and on grassland and that these can be traced to discharges of treated effluent from sewage works (17,25), to use of sludge or animal slurries as fertilizers (18-20,25,26), or to contamination with faeces of infected animals or birds (14) acting as vectors, and the implication is that, when salmonellosis is endemic in farm animals and man, there will be widespread environmental contamination. There have been many attempts to measure the degree of survival of salmonellae in the environment. However, caution is needed in interpreting findings for several reasons. Examinations only for presence do not give any indication of death rate, but merely measure the presence of resistant survivors and the end-point of detection (the mis-named "survival time") depends upon initial dose. Experiments at WRC suggest that the rate of death depends upon the physiological state of cells, so that experiments inoculated with pure cultures may not show inactivation kinetics characteristic of indigenous salmonellae.

In Table VI, published data have been recalculated to obtain values of T_{90}, the decimal reduction time (Equations 1 and 2), for salmonellae applied to soil and crops. In all the trials given, the model (Equation 1) was fitted with high statistical significance, although in two trials (Holland, ref. 20; Ohio, 1976, ref. 35) salmonellae persisted at a reduced level. The pot experiments (36) show that inactivation is greatest on sand and is least under wet conditions; further work demonstrated a lethal effect of light.

Table VI. Rates of inactivation of salmonellae calculated from experiments upon survival

Experimental regime	Decimal reduction time, T_{90} (d)	Notes (and reference)
Soil in pots, S. typhi culture added		Respectively, for simulated rainy, rainy, dry, dry seasons (rainfall: 257, 81, 51, 18 mm). California, USA (36)
Adobe	20, 7.8, 3.6, 4.7	
Adobe peat	21, 8.6, 5.4, 6.3	
Loam	18, 9.0, 3.9, 6.2	
Sand	3.1, 1.1, 0.47, 1.1	
Peat	13, 19, 0.17, 2.7	
Digested sludge applied to grazing land (10 Sept 1972); residue of sludge sampled weekly, 10-99 d after application	13	For 0-36 d after application. Initial count 920/100 g. From 36 to 99 d, geometric mean count 4.2/100 g. Holland (20)
Mesophilically digested sludge, applied to arable land, weekly sampling for 9 weeks after application	28, 32, 21	Respectively for sandy soil April-July 1976, sandy soil May-July 1977, rich loam April-June 1977, North West England (37)
S. typhimurium culture added to sewage effluent or sludge, weekly sampling of lettuce crops and soil after application:		Ohio, USA (35)
Sludge/lettuce	8.9	- 1976, 4-8 weeks
Soil/sludge	15, 4.4	) For 1976 and 1975) respectively. All) data (5-9 weeks from) application, except) 1976 soil/sludge -) first 5 weeks only) and for weeks 5-12,) geometric mean was) 50/g
Soil/effluent	12, 12	
Lettuce/sludge	9.1, 8.8	
Lettuce/effluent	15, 5.7	

In the Dutch study (20), sludge samples, and the grassland soil to which the sludge had been applied 8 or 12 d earlier, were examined quantitatively for counts and serotypes of salmonellae. The data of their Table III, when examined statistically (by Yates' X^2 test or Fisher's exact test for 2 x 2 tables) show significant association between incidence of serotypes originally present or absent in sludge and incidence of those present or absent after 8 d in soil ($0.05 > P > 0.01$), but no significant association ($P > 0.05$) after 8 or 12 d on grass or 12 d on soil. One interpretation of this is that the serotypes originally present in the sludge died out after application and that after 8 d on grass or 12 d on soil they had largely been replaced by serotypes derived from other sources of environmental contamination.

The conclusions to be derived from this Section are that salmonellae in sludge applied to grass, soil or crops will decline in count according to the exponential decay model (Equation 1), that their rate of decline in soil will be accelerated by dry conditions, sandy soil, and exposure to sunlight, but that after periods of many weeks they may still be detectable by the sensitive methods available, although in low numbers, in cases where nutrient levels are high enough to support them, or where the initial numbers were very high or because of the sensitivity of the method used to count them.

6. CONTROL OF SALMONELLOSIS AND POLICIES FOR USE OF SLUDGE ON LAND

The control of disease requires expenditure of money, either from public funds or by increasing the cost or complexity of industrial or other operations. Since public or industrial funds for improving human or veterinary health or the quality of the environment are limited, priorities are applied in practice. The priorities are governed by such considerations as whether the disease can be controlled at all, the benefits to be gained in relation to the cost of control, the most effective point in the transmission cycle in terms of cost-benefit for applying control and whether there are greater benefits to be gained from controlling other diseases. Monitoring of pathogens will represent a continuous additional cost of control. Treatment and disposal of sludge represents a major part (about 40%) of the cost of full sewage treatment, so that additional requirements for processing to remove pathogens or reductions in the availability of land for disposal will exert a disproportionate effect upon the costs of sewage treatment.

The literature on salmonellosis and use of sludge on land contains many opinions, not all of which can be substantiated by scientific information. An attempt has been made in this paper to re-examine critically what information is available and what could be used in advising on policies for minimising risk from salmonellosis. It is realized however that policy decisions may be taken on grounds other than scientific; if so, these grounds should be clearly stated.

This paper has revealed a number of key factors which could be considered in formulating policy. These are listed as follows:

1. Salmonellosis is a major and widespread diseas of man and food-producing animals. In man, the cause is faulty food hygiene, and cooked meat and dairy products are incriminated. In rearing of food animals, the major causes are cycles of infection which are self-contained in agriculture.
2. Transmission from man to food animals is proven in the case of contamination of pasture with sewage or partly-treated effluent or the activities of gulls feeding on refuse. Full treatment of sewage is a major barrier to disseminating infection.
3. The evidence for use of sludge on grazing land as a cause of bovine salmonellosis is not universal and is sparse. Critical examination suggests that an absence of risk cannot be assumed, although infectivity is probably low and that the risk is highest with prolonged or intensive exposure and where densities of animal or human populations are greatest.
4. There is considerable local, national and seasonal variability in the salmonella content of raw sludge and this is related to incidence of disease in the human population.
5. Only processes involving treatment with lime, heat or irradiation can inactivate salmonellae completely, but with heat treatment regrowth on storage can nullify its value.
6. Anaerobic mesophilic or aerobic digestion will partially remove salmonellae.
7. When sludge is applied to soil, grass or crops, salmonellae are inactivated according to the exponential decay model, although they may appear to persist for long periods because of re-contamination, or sensitivity of the methods used to count them.
8. Very sensitive methods are available for detecting salmonellae in the environment and their presence in sludge is primarily an indication of

disease in the human population and not of risk to agriculture, for which rigorous proof is required.

Factors 1 and 2 suggest, that, unless national or local information indicates a causal relationship between salmonellosis and use of sludge on land, the major effort in controlling the disease should be directed towards improvements in agricultural management, food hygiene or sewage treatment, and that risks from use of sludge could be minimized most economically by a policy of local or national guidelines relating the character of the sludge to the use of land and of controlling the way that sludge is applied. Such operational policies would impose barriers to infection. No case can be made for uniform microbiological emission standards for sludge, owing to the difficulty in relating count to infectivity because of variations in sensitivity and the low precision of methods and because of regional and national differences in the aetiology of salmonellosis, in agricultural practices, in the densities of population, and in the nature and area of land available for receiving sludge. The cost of routine microbiological examination for salmonellae is likely to be very high nationally and would add significantly to the national cost of sludge disposal.

Since microbiological monitoring of itself, without operational control, will not reduce hazard, the proper role of microbiology would appear to be one of research to determine which treatments and practices are effective in destroying salmonellae.

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PARASITOLOGICAL PROBLEMS ASSOCIATED WITH LAND APPLICATION OF SEWAGE SLUDGE

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Summary

The risk to man and animals arising from the use of sewage sludge for agricultural purposes is reviewed. The biological characteristics of each of the parasites likely to be present in sewage sludge in Europe are outlined. Those parasites such as *Ascaris* and *Taenia* which produce eggs that are very persistent are referred to in greater detail. The parasites that may be in sewage sludge vary from country to country. The various methods that are used in processing sludge are evaluated with regard to their efficiency in rendering the sludge free from infective pathogenic parasites. At present the heat treatment of sludges would appear to be the only practical method that will ensure that the product is free from infective parasites.

Ascaris eggs are the indicator of choice for the presence of parasites in sludges and current research may provide a better method for their isolation from this product that can be used in smaller laboratories. With regard to the persistance of pathogenic parasites on land further work is required in different ecological conditions.

1. INTRODUCTION

Some parasites which are commonly found in sewage sludges are pathogenic for man and animals, the eggs of some remain viable for long periods and they are capable of surviving most of the conventional procedures used to process sludge except those involving heat. For these reasons the land application of infected sludges must cause concern.

In this paper the more common pathogenic parasites found in sewage sludge under European conditions are discussed. The parasites fall into three categories, viz. (1) those for which there is convincing evidence that the land application of sludge is a factor in their spread, (2) those that may very well be spread by sludge used in this manner but for which there is as yet no evidence, and (3) those that are present in sewage but because of their limited capacity to remain viable for long periods outside the host, are of lesser concern.

The task of evaluating the possible role of sewage sludge in the transmission of pathogenic parasites is complicated by the fact that, as many of the symptoms of the diseases they cause in man are not specific, these conditions are not always diagnosed. Furthermore, even when a parasitic disease is diagnosed, the alternative modes of transmission of the parasite which must be considered, are many.

2. PATHOGENIC PARASITES IN SLUDGE

The parasites that commonly may be present in sewage sludge under European conditions are listed in Table I :

Table 1. Some Parasites of public health importance likely to be present in sludges in Europe

A. Protozoa	*Entamoeba histolytica*
	Giardia lamblia
	Toxoplasma gondii
	Sarcocystis spp.
B. Cestodes.	*Taenia saginata*
	Taenia solium
	Diphyllobothrium latum
	Echinococcus granulosus
C. Nematodes.	*Ascaris lumbricoides*
	Ancylostoma duodenale
	Toxocara canis
	Toxocara cati
	Trichuris trichiura

PROTOZOA

ENTAMOEBA HISTOLYTICA

The trophozoite of this protozoan parasite is found in man's large intestine and oocysts are passed out in the faeces. It has a direct life cycle. The cycle of infection is continued when these cysts are ingested on contaminated food or in water. Cysts in faeces are sensitive to temperatures above 40°C or below -5°C (13). Although they survive for several weeks in cool water with a minimum of bacterial contamination, they are not likely to live more than 20 days in sewage (14). For these reasons sludge, after the minimum of storage, is not likely to be a factor in the spread of *Entamoeba histolytica*.

GIARDIA LAMBLIA

This parasite has a wide geographical distribution. The life cycle is direct. The trophozoite lives in the small intestine and cysts are passed out in the faeces. The increased incidence of Giardiasis in holiday makers and other travellers has focussed attention on this parasite and the disease has been the subject of a recent review by Meyer and Radulescu (28). Large scale outbreaks are usually traced to the contamination of water supplies by sewage and occur in populations in which the prevalence and immunity is low. The parasite may cause infection in animals which may act as reservoir hosts (28). The thermal death point of the cyst is 62^{o}C; 2 - 5% phenol or lysol, and 3 g of ammonium per 100 g faeces are also reported as being lethal to the cysts (28). Because large numbers of cysts can be passed by infected persons and because the cysts are very infective, some concern exists with regard to their presence in sewage sludge when it is applied to land (18).

TOXOPLASMA GONDII

Toxoplasma gondii is now considered a coccidian parasite, with the genera Felis and Lynx being the definitive hosts; the intermediate hosts include man and a wide range of domestic and wild animals (2). It has a wide geographical distribution. Infection in man may have serious consequences, such as death or lesions of the central nervous system, in new-born children.

Oocysts excreted in the faeces of cats could be washed into the domestic sewage supplies by rainwater run-off. The cysts sporulate to an infective stage within a few days and they may then survive in moist soil for up to 18 months (2). They are killed quickly by boiling water or by 10% formaldehyde solution in 24 hours. Arthropods and earthworms may act as a mechanical vector for the oocysts. As the consumption of raw or undercooked meat or meat products is now considered the major source of human infection, contaminated sewage sludge, when spread on land, might act as a vehicle for the passage of oocysts to meat-producing animals grazing the treated pasture and so transmit the infection back to man.

SARCOCYSTIS SPP.

Man can be the final host or an intermediate host for *Sarcocystis* species. For example, man is now considered the final host for one *Sarcocystis* species of cattle and for another of pigs (2). When meat from domestic animals is infected and eaten uncooked by man he can then start to excrete sporocysts. However any possible role that sewage sludge may have in the spread of sarcosporidiosis to meat-producing animals requires further study. A recent report (2) concludes that "control measures to prevent human infection with the cyst stage will depend on further elucidation of the parasitic life cycle".

CESTODES

TAENIA SAGINATA

LIFE CYCLE AND EPIDEMIOLOGY

Human infection is acquired by the consumption of infected raw or under-cooked beef. Cattle generally become infected by grazing land polluted with human faeces. There is considerable evidence that the land application of sewage sludge (digested or undigested) can cause outbreaks of bovine cysticercosis (35, 10, 37, 26, 15).

The tapeworm in man is large (four to five metres in length with 1000 to 2000 segments) and is frequently responsible for disturbances in the normal function of the intestinal tract (13). The widespread distribution of bovine cysticercosis in Europe is shown in Table II :

Prevalence of bovine cysticercosis in some European Countries *

Country	Prevalence %	Period	Source*
Austria	2.26	1960	Kleibel (1961)
Czechoslovakia	1.18	1961-70	Mour (1971)
Denmark	0.56	1972	Biering-Sorengen (1974)
Finland	0.03	1971	Salmi (1972)
France	3.00	1969	Bressou (1972)
East Germany	3.9	1969	Muller (1970)
West Germany	1.69	1967	Triantafillu (1970)
Ireland	0.68	1970	Shafai (1975)
Italy	3.15	1961-67	Ceetto & Panizza (1967)
The Netherlands	2.69	1970	Reiningh (1972)
Poland	1.33	1970	Kozakiewicz (1973)
Sweden	0.39	1970	Lundstrom (1972)
Switzerland	1.6-3.2	1967-71	Konz (1972)
England & Wales	0.18	1970	Beynon (1972)
Yugoslavia	0.86	1969	Kazi (1973)

* After Shafai (38).

Since man is the only known source of the eggs which produce bovine cysticercosis it can be assumed that the parasite is widely dispersed in the European population. In the absence of treatment infection, usually with a single tapeworm, may persist for several years (2). The current method of control includes the treatment of infected persons and the prevention of human infection by the inspection of meat before it is allowed for sale, as well as adequate sewage treatment and disposal. Because of the difficulty of identifying infected persons and arranging for their treatment, little progress has been made in that direction. Meat inspection cannot be relied upon to prevent human disease because of the difficulty in detecting lightly-infected carcases (11, 38).

The ability of the eggs of this tapeworm to persist in the environment and their resistance to external factors must be considered when contemplating the application of non-heat-treated sewage sludge to land. The literature on the survival of eggs under natural and experimental conditions has been reviewed recently by a number of authors (10, 14, 16, 18).

LONGEVITY OF EGGS

Some eggs can be hatched after storage at 4°C for 11 months (39) and Penfold *et al.* recorded that eggs stored in saline were infective for calves up to three months later (33).

EFFECTS OF HIGH TEMPERATURE

Eggs maintained at 59°C for 10 minutes failed to hatch *in vitro* (39). In our Laboratory Shafai found that eggs exposed to a moist heat 60°C for 5,10,15 and 30 minutes could be hatched but the hatching rate decreased as the exposure time increased. However when eggs were exposed to a moist heat of 60°C for 15 minutes and then fed to susceptible calves the eggs were found not to be infective (38).

EFFECTS OF LOW TEMPERATURE

After storage for two months at -4°C eggs were still viable (42) and in *in vitro* studies, Lucker found that eggs were infective after a similar period at the same temperature(24).

EFFECTS OF DESICCATION

Desiccation for 14 days is lethal to eggs, irrespective of the relative humidity (39).

SURVIVAL OF EGGS UNDER FIELD CONDITIONS

Arkhipova recorded that on soil irrigated with sewage, eggs survived for 77 to 93 days in spring, 35 to 45 days in summer, 80 to 97 days in autumn and 128 to 147 days in winter (3). Penfold et al. concluded that, in Australia, eggs stored at 2 to 5°C and then spread on pasture were viable for two months (32,33). In Kenya it was suggested that eggs survive on pasture for 12 months or more (12). The work of Jepsen and Roth in Denmark suggests that eggs survive at least five months under winter conditions in that country and for 58 days in summer (21). In concluding his review on the effects of weather on tapeworm eggs and its epidemiological implications Gemmell writes that "weather effects can only be defined in each ecological situation by appropriate grazing trials" (16).

SURVIVAL IN ANIMAL FODDER

Lucker and Douvres recorded that the survival period for eggs in hay can be more than 3 but less than 10 weeks (25). Brylez & Wikerhauser reported that eggs were not viable after being kept in grass silage at 40 - 50°C for 37 days (4). However some current systems of making silage using formaldehyde, propionic acid and other additives may not allow fermentation to cause a temperature rise which would be lethal to eggs (31).

EFFECTS OF CHEMICALS

The published literature on the effects of chemicals on the eggs of *Taenia saginata* has been reviewed by Shafai (38). It is evident that eggs can withstand exposure to a wide range of chemical disinfectants. Hays in her review on the land application of sewage sludge, concludes that disinfection procedures as used in treating sewage effluent do no harm to eggs (19). However the use of some chemicals for the treatment of sludges containing the parasite are being investigated further by Crewe and Owen and show some promise (10).

SURVIVAL IN SEWAGE AND SEWAGE SLUDGE

The recent epidemiological evidence that the eggs survive in the sludge has been cited earlier in this paper.

Glassborow has summarised the published experimental information on the type and duration of sewage treatment required to kill *Taenia* eggs (18). According to Newton *et al*.activation of sludge has no effect on *Taenia* eggs (30) and they also considered that at least six months storage is required to kill these eggs.

SPREAD BY BIRDS AND FLIES

Glassborow has reviewed the literature on this subject (18). There is ample evidence that both birds and flies can transport eggs and perhaps segments of the tapeworm. The part that these agents play in spreading the pathogen from infected sludge and in cross contamination within a sewage treatment system, should be considered.

MONITORING OF CYSTICERCUS BOVIS

The monitoring of the prevalence of the cysts of *Cysticercus bovis* in the carcases of cattle which have grazed on land on which sewage sludge has been spread is a useful surveillance system and often gives the first indication that viable pathogens are still present on the land.

TAENIA SOLIUM

Man is the usual host for this tapeworm and inadequately heated pork containing the cystic stage of the parasite is the major source of human disease. Pigs become infected by ingesting the eggs shed by human carriers. In addition man may also become infected with the cystic stage by ingesting the eggs of the tapeworm and this may lead to serious muscular or neuromuscular disease (13).

In areas where *Taenia solium* is endemic the spreading of unheated sludge on land where pigs feed may propagate the parasite. There is also the possible hazard of the eggs being carried back to man on crops grown on such land if the food is consumed raw.

DIPHYLLOBOTHRIUM LATUM

Man, along with other fish-eating mammals, can harbour this parasite. The adult worm lives in his small intestine for decades and sheds more than one million eggs per day. Crustaceans are the first intermediate host and freshwater fish are the second; man acquires infection by the ingestion of raw infected fish. The parasite is commonest in Europe in countries bordering the Baltic Sea but also exists in French, Irish, Italian and Swiss lakes (2). In Sweden, eggs of this parasite were recovered in the sludge and effluent at 38 out of the 40 waste water treatment plants examined (36). It is evident from the same report that chemical treatment, which complemented mechanical and biological treatment, reduced the outflow of eggs considerably. Lapage, when discussing control measures for this parasite, states that sewage in endemic areas should be treated with formaldehyde, chlorine or heat to kill the eggs (22).

ECHINOCOCCUS GRANULOSUS

Man acts as an intermediate host for the cystic stage of this parasite, the dog being the host of the egg-shedding tapeworm. Sewage sludge is only likely to become contaminated by run-off from urban and city streets in endemic areas. Because of the possible role that sludge, when it is contaminated in this way, might play in disseminating the eggs to reservoir hosts such as cattle and sheep and, less likely, to man, this parasite should be considered when sewage sludge is to be applied to pasture.

NEMATODES

ASCARIS LUMBRICOIDES

LIFE CYCLE AND EPIDEMIOLOGY

This parasite is the most cosmopolitan and most common of all parasites of man (13). The adult worm lives in the intestine with an estimated daily output of 200,000 eggs for each female worm. The life cycle is completed when, after a period of incubation, fertilized eggs are ingested. The ingested egg liberates a larva which migrates through the liver and lungs before reaching the intestine, its final destination. The thick shell of the *Ascaris* egg and the ability of the larvae to become metabolically inactive when they reach the infective stage, are factors put forward to explain their great longevity; periods recorded range from 11 months to 5 years (41).

LETHAL FACTORS

Desiccation is the most lethal condition for eggs. When exposed to direct sunlight they are killed within a few weeks and under conditions of bright sunlight and desiccation in one to two hours. In wet soil the eggs may live for 2 years at temperatures of 5 to 20°C and, at these temperatures, in water for 20 months. They are also resistant to cold temperatures surviving at -20 to -30°C for three months (41).

In anaerobic digesters Reyes *et al*. found that *Ascaris* eggs failed to survive 30 days at 38°C, 20 days at 45°C or 20 minutes at 55 - 60°C (34). Cram reported that some eggs could survive for 6 months at 20°C (9). Hogg found that in order to kill any *Ascaris* eggs present, sludge had to be dried to less that 5% of its original dry matter (20). Faechem *et al*. (14) concluded that suitable time: temperature conditions for the destruction of *Ascaris* eggs were as follows:

(i) at least 62°C for 1 hour;
(ii) at least 50°C for 1 day;
(iii) at least 46°C for 1 week;
(iv) at least 43°C for 1 month;
(v) at least 42°C for 1 year.

RECENT REPORTS OF LETHAL FACTORS

Crewe and Owen assessed the effects of irradiation on *Ascaris* eggs (10). They report that there are definite indications that irradiation is effective to some degree against the eggs but at both 0.4 and 1.2 Megarads, the irradiation was less effective than against bacteria (10). They also comment that the particles of sludge may shield the eggs from irradiation. Alexandre states that irradiation is economically acceptable but that there are political and psychological disadvantages to its use (1).

Chefranova tested anhydrous ammonia on *Ascaris* eggs in sludge and reported that at a concentration of 2.5% it was lethal for the eggs in 10 days (6). Chilikin found that ammonium hydroxide at a concentration of 5% killed all *Ascaris* eggs in sludge in 20 days and that carbathion at a concentration of 5 to 7% was also lethal for the eggs in 5 days (7). Crewe and Owen in a preliminary report on the effects of lime on the development of *Ascaris* eggs found that at a pH of 12.25 the development of the eggs was halted but whether or not it was lethal awaits a further report (10). They also stated that the chemical "SX-1" (produced by Imperial Chemical Industries) shows some promise for the treatment of sludges. Recently Sokhrokov reported that ultrasound at 50 volts per cm^2 at a frequency of 24 kilohertz for 10 minutes killed all *Ascaris* eggs in sewage at a pH 12.9 to 13.4 with the addition of added ferromagnetic substances at 50 mg per litre (40).

ASCARIS LUMBRICOIDES AS A PATHOGEN INDICATOR IN SLUDGES

Because *Ascaris* eggs are so resistant it has been proposed that in areas where *Ascariasis* is endemic, if there are no viable *Ascaris* ova present in sewage sludge, then other pathogens are absent as well. Viable ova of this parasite would therefore appear to be the pathogen indicator of choice available for sewage sludge (14). Meyers *et al.* also advocated the use of *Ascaris* eggs as an indicator for helminth eggs because they are common and because they are more resistant to adverse external conditions than other enteric organisms (27). These authors also describe a modification of the zinc sulphate concentration method using hypochlorite and an anionic detergent to improve recovery of eggs from sewage sludge. Crewe and Owen also report on techniques for the recovery of *Ascaris* eggs from sludge using sugar solutions of very high specific gravities and also on the use of anionic detergents and sodium hypochloride (10).

TOXOCARA CANIS

TOXOCARA CATI

There is growing concern about toxocariasis in man (2). Man becomes infected by the ingestion of infective eggs which then release larvae which can migrate to any part of the body, with most serious consequences when the eye or brain in involved. The thick-shelled eggs are produced by round worms in dogs at a rate of 10,000 or more per gramme of faeces. Infection of dogs is worldwide, with a prevalence rate of 20% in Britain (45). In that country there is evidence that 2 to 3% of the population have been exposed to the parasite (2).

The eggs are capable of long periods of survival in soil, and so the contaminated environment is considered to be a significant reservoir of infection. The sewage system in cities and towns receive *Toxocara* eggs from the washing of streets and roads and hence eggs are commonly present in sewage sludge (36,43). Therefore sludges if not adequately treated before they are applied to land, can contribute to further contamination of the environment.

ANYLOSTOMA DUODENALE

This is essentially a parasite of, amongst other places, Southern Europe and it does not normally occur in northern latitudes above 52° (29).

The adult worm lives in the small intestine and fertilised eggs, which have thin shells, are passed out in the faeces. In warm, moist and shady conditions the eggs hatch to larvae in one to two days. The larvae, after about three days of feeding on organic matter, become infective for man and can remain viable in the soil under suitable conditions for several weeks. They infect by penetration of the skin where they cause creeping eruptions before they finally migrate back to the intestine. Infection can also take place by ingestion of the infective parasite (29). Miller has presented a comprehensive review on the subject of hookworm infection in man (29). There is evidence that the eggs of this parasite are present in sewage (19) but there appears to be none linking the land application of sludge with disease in man. The larvae survive six weeks in faeces (14) and the ova 60 - 80 days in drying sludge (9). Other hookworms that infect dogs may also cause skin lesions in man when the larvae are present in soil. Although it is theoretically possible that the eggs of these parasites, when shed by dogs, could be present in sludge, there is no evidence of the disease in man having been traced to this source.

TRICHURIS TRICHIURA

These helminths, also known as "whipworms", live in the lower part of man's intestine. Eggs are passed in the stool and require a period of about two to three weeks to become infective. Estimates for the output of each female of eggs are about 6,000 per day. The parasite is cosmopolitan in distribution and it has been estimated that about 34 million people in Europe are affected. Infection results from ingestion of eggs obtained directly or indirectly from the soil. The eggs are much less resistant to desiccation and heat than *Ascaris* eggs and will not survive direct sunlight, putrefaction or many chemicals (13). Faust *et al.* concluded that, in a moist atmosphere, the eggs in a moderately dry film of faeces will not survive for more than two weeks (13).

3. PREVALENCE OF PARASITES IN SEWAGE SLUDGES

Hays (1977) has reviewed the literature on this subject. The number and type of parasites present appear to be influenced by the infection rate of the local population. For example in a recent report on helminth ova in sludges from twelve urban areas in the United States of America, Theis and Storm (43) found that *Ascaris lumbricoides* was the most frequent ova recovered. It was found in 25.8% of all sludge samples examined; 19.3% contained *Toxocara* species. Whereas in Sweden Roneus and Dalborg (36) examined the sludges of 40 waste water treatment plants and found egg of *Diphyllobothrium* in 38 plants, *Ascaris* eggs in 24, *Toxocara* eggs in 12, *Trichuris* eggs in 6, *Taenia* eggs in 3 and *Capillaria* eggs in 3. They considered that the *Toxocara* eggs originated from dogs and cats.

The sludge's load of parasites will also depend on the amount of animal waste reaching the sewage system. Liebmann is of the opinion that in temperate climates of Europe, about 10% of the ova in waste-water is of human origin (23).

4. SURVIVAL OF PARASITES IN SEWAGE SLUDGE AND SOIL

Feachem *et al.* have recently reviewed the literature on this subject and conclude that in sewage, protozoan cysts are unlikely to survive for long: 20 days is the likely maximum for the cysts of *Entamoeba histolytica*. Helminth ova vary considerably in their ability to survive in this medium, the most persistant being *Ascaris* ova, with a capacity to survive for a year or more (14).

On soil the same authors conclude that protozoan cysts are unlikely to survive for more than 10 days, with variable survival periods for helminth ova, the greatest being for *Ascaris* ova, with a survival time of several years. On crops they estimate that protozoan cysts survive for usually less than 2 days and helminth ova for usually less than one month.

5. EFFECTS OF THE VARIOUS TREATMENT OF SLUDGES ON THE SURVIVAL OF PARASITES

Feachem *et al.* (14) concluded that the activation sludge process has little effect on parasites, that protozoa will survive none of the digestion procedures and that the only digestion process that will provide helminth-free sludge is batch thermophilic digestion for 13 days at 50°C. With regard to the drying of sludges, protozoan cysts can be expected to be killed but eggs of *Ascaris*, *Trichuris* and *Taenia* spp. will survive conventional treatments.

The destruction of pathogens in sewage sludge by composting has been reviewed by Burge *et al.*,(5). They conclude that composting is the only process that greatly reduces pathogen levels and stabilises the sludge so that it can be applied to land. They also consider that the destruction of pathogens by forced air composting is much faster than windrow composting and, furthermore, is not adversly affected by rainfall.

6. USE OF SLUDGE FOR AGRICULTURAL PURPOSES

Restrictions on the use of sludge vary greatly from country to country and some of the restrictions arise because of the hazard of transmission of human parasites (8). In Sweden, for example, sludge may be used for agricultural cultivation provided it is mixed with soil by ploughing, but unpasteurized sludges may not be spread on hay fields, grazing land or any other crop-growing area (4.4). In Britain raw sludge may be applied to grassland provided there is a waiting period between application and grazing. It may also be applied to arable land if it is immediately ploughed (8).

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MONITORING SEWAGE SLUDGE SANITATION BY BACTERIAL INDICATORS

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Summary

Sanitation of sewage sludge may be obtained by different processes like pasteurization, radiation and composting. In order to ascertain that the end-product has been sufficiently treated, microbiological monitoring may be used. A discussion is given of the suitability of various, commonly used indicator groups for this purpose.

The resistance against heat and radiation of enterobacteria and subgroups thereof (total and thermotolerant coliforms) is too low to provide an adequate margin of safety. Faecal streptococci appear to be useful for monitoring all types of sanitation discussed, and possibly also coliphages are well suited. Bacterial endospores generally are too resistant, so that neither spore-counts nor total counts will give information about the process conditions applied. In the composting process, special problems arise due to the regrowth of certain indicator-bacteria.

1. INTRODUCTION

It has been well established in the literature that high numbers of pathogenic micro-organisms are usually found in sewage sludge. The use of sludge in agriculture therefore adds to the dissemination of pathogens in the environment, thus creating an indirect or a direct risk to human or animal health. Indirect risks may occur by the intensification of cycles of pathogenic micro-organisms, as have been shown to exist for instance for *Salmonella* (Kampelmacher, 1977) and *Clostridium botulinum* (Notermans *et al.*, 1980). Direct risks may result from the consumption of contaminated foodstuffs, grown on sludge-treated land. For this reason, it has been commonly accepted that sludge should not be applied to land used for growing crops that are intended for human consumption, especially if the crops are eaten raw.

Considerable amounts of raw or digested sludge however, are applied to pasture in all countries of the European Community. Usually, a minimum period of time is specified before animals can be introduced to the grounds. This will not always result however in a sufficient inactivation of pathogens because climatological conditions show great variation, and moreover, most sludge is applied in the cooler season when environmental inactivation is comparatively low. It has been demonstrated for instance by McPherson *et al.* (1978) that 36 out of 40 cows acquired cysticercosis after being introduced to pasture that had been treated with "slurry" from a sewage treatment plant one month earlier (September 15). As a result of these and other findings, there is an increasing tendency towards in-plant inactivation of pathogens, thus reducing both indirect and direct health risks.

Working Party 3 of the EEC Concerted Action Committee "Treatment and Use of Sewage Sludge" (COST 68 bis) has reviewed the possible treatment processes and has given indications as to the acceptable use of differently treated sludge. No restrictions are specified for the use of so-called sanitized sludge, that has undergone a treatment aimed at complete inactivation of vegative bacterial cells and parasitic ova and cysts. By these processes, many viral species will also be killed. The desired effect can be reached by a number of processes: pasteurization, radiation, composting, lime treatment, aerobic thermophilic stabilization or high temperature treatment (under pressure above boiling point). Apart from a direct control of process parameters (temperature, pH, radiation dose), microbiological analyses are necessary to ascertain that the desired effect has been reached and also that no recontamination has occurred.

Demonstration of the absence of specified pathogens in the end-product appears to be the obvious way of monitoring the sanitation process, but unfortunately this is hindered by a number of facts. Enumeration of pathogens is either not possible at all or laborious and expensive and only within the reach of specialized laboratories. In addition most pathogens are only present in sewage sludge in low numbers. Furthermore, the possible number of pathogenic species present in sludge is quite large, so that many tests should be carried out.

A more practical approach is based on the enumeration of indicator organisms. Their absence in the end-product (in a specified amount) or a reduction by at least a certain factor should indicate that the process has worked satisfactorily. In the following, a number of candidate indicator organisms will be discussed with regard to their microbiological characteristics, occurrence in sludge and enumeration techniques. Subsequently, a discussion will be given of the suitability of these organisms for monitoring some sanitation processes as specified above.

2. INDICATOR ORGANISMS

In general a number of criteria is applied for the selection of appropriate indicator organisms. For monitoring sewage sludge sanitation, the following criteria apply:

- presence in high numbers in raw sludge
- cultivation and enumeration in the laboratory possible by reliable but rapid, simple and inexpensive methods
- resistance sufficiently high to demonstrate underprocessing, but inactivated if the process is applied correctly.

On the basis of the first two criteria a number of commonly used groups of organisms can be selected. They are listed in Table 1, together with an indication of their numbers in raw sludge. Data on the occurrence of indicator organisms in sludge are scarce and scattered in the literature and show great variability. Therefore, the numbers shown in the table should be regarded as a guidance only. The data have been derived mainly from the following sources: Kampelmacher and Van Noorle Jansen, 1972; Farrel *et al.*, 1974; Cooke *et al.*, 1978; Berg and Berman, 1980; Breer, 1980 and unpublished data from our own laboratory.

Table 1. Indicator organisms in raw sewage sludge

Indicator group	No. of organisms/g wet sludge
total aerobic count 37°C	$10^6 - 10^8$
enterobacteria	$10^6 - 10^8$
coliforms	$10^6 - 10^8$
thermotolerant coliforms	$10^5 - 10^7$
group D (= faecal) streptococci	$10^4 - 10^6$
sulphite-reducing clostridia	$10^3 - 10^5$
aerobic spores	$10^3 - 10^5$
coliphages	$10^3 - 10^5$

The total aerobic count at 37°C, as determined on a non-selective medium, is for the larger part made up of enterobacteria as can be seen from a comparison of the numbers of these two groups. The enterobacteria as counted by the conventional techniques, based on glucose-fermentation and bile-tolerance are mainly found in the *Enterobacteriaceae*-family but in addition some members of the *Vibrionaceae*-family will contribute to the count. All are gram-negative, rod shaped bacteria and are normal inhabitants of the intestinal flora of humans and animals. In addition, certain species can also multiply in other habitats. In water microbiology, where the attention is mainly focused on faecal pollution, more specific subgroups of the enterobacteria are usually analyzed therefore. Coliforms, defined by their capability of fermenting lactose to acid and gas at 37°C are universally applied. As can be seen from Table 1, the coliforms constitute the majority of the enterobacteria in sludge. Members of the coliform group can be found among the genera *Escherichia*, *Enterobacter*, *Citrobacter*, *Klebsiella* and *Aeromonas*. Of these genera, only *Escherichia coli* can be considered a specific faecal indicator. A differentiation between *E.coli* and other members of the coliform group is generally made by carrying out the lactose-fermentation test at 44°C instead of 37°C. Bacteria capable of performing this reaction are called thermotolerant (or faecal) coliforms. Usually, *E.coli* will constitute the majority of the thermotolerant coliforms, but in certain cases thermotolerant *Klebsiella*- and *Enterobacter*-species can be found (Talbot and Seidler, 1979; Huntley *et al.*, 1976). The bacteria can be distinguished from

E.coli by the indole-test. This test must be performed at 44°C instead of the usual 37°C because certain species (*Klebsiella oxytoca, Enterobacter gergoviae, Enterobacter sakazakii*) can produce indole at 37°C but do not grow at 44°C. The numbers of thermotolerant coliforms are generally one order of magnitude smaller than those of the total coliforms. When monitoring the efficiency of sludge sanitation processes, there is no need for a specific faecal indicator, so in this respect all three groups (enterobacteria, total and thermotolerant coliforms) are equally useful. Problems may arise however due to the different behaviour of the bacterial species included in these groups.

Group D (or faecal) streptococci are also found in high numbers in sludge. Apart from low numbers of certain species being present on plants, they can be considered specific faecal indicators. Like other gram-positive cocci, they are in general more resistant than enterobacteria against adverse environmental conditions.

Sulphite-reducing clostridia can be considered ubiquitous, but the main species in sludge *Clostridium perfringens*, occurs mainly in faeces. The value of this group as indicator lies mainly in the production of highly resistant endospores. In sewage sludge, the spore-form dominates the vegetative cells in numbers.

Spores of aerobic bacteria are also highly resistant. They can be counted by performing a total count after heating the sample at a temperature of 70°C for 10 min. This treatment will kill all vegetative cells.

Bacteriophages are viruses of bacteria, those of *E.coli* (coliphages) being most widely analysed. Like animal and human viruses, the phages may be comparatively resistant against inactivation but this may vary considerably in a natural population. As *E.coli* does not multiply in sludge, multiplication of the coliphages also is unlikely to occur for this only can take place in an actively growing host.

3. MONITORING OF SANITATION PROCESSES

In the following the applicability of the candidate indicator organisms for monitoring the effect of pasteurization, composting and radiation will be discussed.

3.1 Pasteurization

It is generally accepted that the pasteurization process should be carried out at a temperature of 65-70°C for 30 min or more. An unsatisfactory end-product may arise from under-pasteurization (i.e. the desired temperature is not reached or not maintained for a sufficient period of time) or from recontamination of the pasteurized sludge. Especially in order to demonstrate under-pasteurization very strict demands should be met by the indicator. No inactivation must occur at temperatures below ca 60°C but complete inactivation must take place at temperatures of ca 70°C, all within the time scale of the process.

Data on the heat inactivation of specific bacterial groups can be found mainly in the literature on food microbiology. It has become clear that the inactivation process is influenced by a number of factors so that comparisons of experimental data are very difficult, as are interpolations of these results to the processing of sewage sludge. In general, the following conditions increase the heat-resistance of micro-organisms: low water activity, high organic matter content (proteins, fats, carbohydrates) and neutral pH. Also, resting cells are more resistant than actively growing cells. Thus, the decimal reduction time D (the time needed to inactivate the population by a factor of 10 at a given temperature) has been reported to range from 4,8 to 35 min at 55°C and from 0,2 to 9,5 min at 60°C for *Salmonella senftenberg* (Jay, 1978). These data are based on laboratory experiments using pure cultures and non-selective media for counting. When investigating sludge however, selective media must be exployed. One should realise that bacteria surviving heat treatment have become more sensitive to such factors as salt concentration, selective agents etc. in the cultivation media (sublethal injury). The measured death rate under practical conditions therefore also depends on the counting procedure. For our present purpose however, an approximation of the heat resistance of the candidate indicators is sufficient.

The enterobacteria are relatively heat-labile, most species being killed within a few minutes at temperatures between 55 and 60°C (Jay,1978). Consequently, a complete kill of enterobacteria (or subgroups thereof) does not imply that the pasteurization process has been performed within the limits as discussed above. This should be better reflected by analyses of the numbers of faecal streptococci. These organisms are able to survive for a considerable time at 60°C but will be rapidly inactivated at 65°C. Spores of clostridia (anaerobic) and bacilli (aerobic) are highly heat-resistant and will not be killed by temperatures normally applied for pasteurization. Therefore, spore-counts but also total counts (to which spores will contribute) will not be useful for monitoring pasteurization processes. The thermal resistance of bacteriophages is less documented than that of bacteria. Inactivation of a number of species takes place in the range of 65-70°C (Adams, 1959) so that this indicator may most critically reflect under-pasteurization.

The above theoretical considerations have been tested in some laboratory experiments, the results of which are shown in Table 2. In these experiments, anaerobically digested sludge was submerged in a water bath in small, screw-capped tubes that were removed after certain periods of time.

Table 2. Thermal inactivation of different indicator organisms in sewage sludge (decimal reduction values)

Temperature (°C)/ time (min.)	Enterobacteria[1)]	Faecal strept.	Sulphite-red. clostridia	Total count 37°C	Coliphages
60/15	> 4	1,4	< 1	1,5	< 1
60/30	> 4	2,1	< 1	1,5	< 1
60/45	> 4	3,1	< 1	1,5	1,1
70/15	> 4	> 4	< 1	-[2)]	1,7
70/30	> 4	> 4	< 1	1,6	2,0
70/45	> 4	> 4	< 1	1,5	2,1
80/15	> 4	> 4	< 1	-	3,9
80/30	> 4	> 4	< 1	1,8	3,9
80/45	> 4	> 4	< 1	1,5	> 4

1) the same reduction was found for coliforms (total and thermotolerant)

2) - : not tested

As can be seen from these data, inactivation of enterobacteria and subgroups took place very rapidly at all temperatures investigated. In all cases, the bacteria were absent from 1 g of sludge after treatment. The inactivation of faecal streptococci on the other hand was relatively slow at

60°C but virutally complete within 15 min at 70°C. Sulphite-reducing clostridia (spores) were not inactivated and the reduction of the total count at 37°C amounted ca 1,5 decimals, irrespective of temperature and time. All of the surviving bacteria were spore-formers, so this reduction factor reflects the ratio between vegetative cells and spores in the sample instead of the process conditions applied. The data on the reduction of coliphages indicate that their thermal resistance as a group is intermediate between that of the vegetative bacterial cells and that of bacterial spores. It must be borne in mind however that the coliphage-group is composed of many different species that may have a different thermal resistance. Nevertheless, the group seems to be well suited to monitor the pasteurization process.

3.2 Radiation

Sanitation of sludge can be obtained by a radiation dose of 300-1000 krad depending on the properties of the sludge and other factors (Alexandre, 1978). Working Party 3 of COST 68 bis suggests treatment with a dose of at least 500 krad while American regulations require at least 1000 krad (Anon, 1979). It may therefore be assumed that a suitable indicator should survive a dose in the order of 100 krad but that a substantial reduction should take place by doses between 500 and 1000 krad.

The radioresistance of micro-organisms depends mainly on the same factors as the thermal resistance and in addition the presence of oxygen increases the kill rate. Again, a comparison of literature data is a difficult task. In general, D-values of enterobacteria are reported to be comparatively low, ranging from 10 to 100 krad. *E.coli* appears to be more sensitive to radiation than other members of the coliform group, i.e. *Klebsiella* (Alexandre, 1978). It may therefore be concluded that monitoring enterobacteria or subgroups thereof does not detect under-processing. Faecal streptococci are more resistant to radiation and probably large differences between strains exist. D-values reported in the literature are between 100 and 300 krad, i.e. five times those of enterobacteria (Brandon, 1976; Stettmund von Brodorotti und Mahnel, 1980). According to the last authors, artificially contaminated *S.faecalis* was reduced by three orders of magnitude at a radiation dose of 1000 krad. The radioresistance of bacterial spores parallels the thermal resistance (Jay, 1978) so that spore counts and total counts cannot be used to monitor the effect of radiation doses at the specified level. No data are available on the radioresistance of bacteriophages in sludge. According to Adams (1959) D-values in broth cultures are in the order of 500 krad or more.

3.3 Composting

The inactivation of micro-organisms during composting takes place by a combination of temperature, time and microbial interactions. Further details depend strongly on the type of process applied. One of the major factors that can result in insufficient inactivation of pathogens is caused by the fact that the outer-layers of a compost-heap will not reach the high temperatures generated in the centre, so that the heap must be frequently mixed.

As thermal inactivation is the major sanitizing mechanism, the comparative resistance of micro-organisms as discussed for pasteurization also applies for composting. Generally, microbial inactivation by composting is better and even spores may be reduced to a low level during the initial, high temperature phases of the process. In later stages, the temperature may drop to 30-40^{o}C and regrowth of bacteria may take place. Löfgren, Tullander and Hovsenius (1978) noted a rise of aerobic sporeforming bacteria (e.g. *Bacillus cereus*) and coliforms, but not of faecal streptococci and *Clostridium perfringens*. The species constituting the coliform group behaved differently during the process. *E.coli* was present in the raw material and disappeared completely in the high temperature phase. Regrowth was mainly caused by *Klebsiella* and to a lesser extent by *Enterobacter*. These data imply that the numbers of coliforms and of spores of aerobic bacteria (and consequently also total counts) in the end-product bear no relationship to the inactivation of pathogens. Based on the data of Löfgren *et al.* (1978) faecal streptococci and also *C.perfringens* could be used for judging the hygienic quality of compost. No data on coliphages are available but it may be hypothesized that also these organisms may provide valuable information.

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DETECTION DES VIRUS DANS LES BOUES

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Résumé

Expérimentalement, diverses substances solides sont capables d'adsorber des virus : précipités minéraux (Al $(OH)_3$, Fe_2O_3 etc...) poudre et fibre de verre, substances organiques (cellulose, fibres naturelles ou synthétiques...), tissus ou cellules (levures, feuilles de laitues...) ; dans les eaux usées la plus grande partie des virus est naturellement adsorbée sur la boue. L'adsorption est favorisée par un pH acide, une force ionique optimale, la présence de cations polyvalents ; les facteurs favorisant le relargage sont le pH alcalin, la présence de protéines ou de substances organiques solubles et de détergents, l'action d'ultrasons. Tous ces facteurs sont interdépendants : nous ne pouvons jamais maitriser tous les paramètres du phénomène dans un milieu aussi complexe et variable tel que la boue. De plus, les mêmes facteurs agissent sur l'agglutination des virus et la capacité des cellules a adsorber et multiplier les virus qui conditionnent le titrage des virus. Les meilleurs méthodes d'extraction des virus des boues sont l'élution dans un milieu albumineux à pH alcalin (8,5 à 11,5), combinée à la chelation des cations, l'agitation avec des solvants (ex : fluorocarbone) et sonication. Les évaluations quantitatives sont peu reproductibles ; avec des souches virales choisies et dans des conditions expérimentales définies elles sont assez fidèles pour étudier la dénaturation des virus ; mais elles ne permettent pas de donner une image réelle de la pollution dans les conditions naturelles.

Summary

Different solid materials may absorb viruses in experimental conditions : mineral precipitates (Al $(OH)_3$, Fe_2O_3 etc...), glass powder of bibers, organic substances (cellulose, natural or synthetic fibers...), biological tissues or products (yeasts, lettuce leaves...) ; in sewage sludge most ot the viruses are naturally linked to sludge components. Favourable factors for experimental adsorption are : low pH, optimal ionic strenght, presence of polyvalent cations ; factor for desorption are high pH, presence of proteins or organic soluble substances, detergents and ultrasonication. They are interacting so that we cannot control each parameter of the pnenomenon in a so complex and changing medium as sewage sludge. Nevertheless the same environmental parameters act on viral aggregation and adherence to cells, and cell ability to adsorb viruses and developp viral multiplication, which are the conditions of the viral titration. The most suitable for the extraction of virus from sludge are : elution by high pH (from 8,5 to 11,5) albuminous medium combined with chelation of cations, agitation with solvents (ex : Fluorocarbon) and sonication. Quantitative evaluations are inaccurate ; with appropriate test-viruses in clearly defined conditions they may be sufficiently accurate for experiments on viral denaturation ; they are not enough reproductible to simulate the natural conditions and to select different strains of viruses.

1. RAPPEL

Peut-être est-il utile, pour ceux d'entre vous qui ne sont pas virologistes, de rappeler brièvement ce que sont les virus ; car, nous le verrons ensuite, la plupart des difficultés techniques qui vont apparaître, sont liées justement à la nature même de l'objet de nos recherches : les virus.

Les virus sont des agents pathogènes très répandus, très nombreux, très divers qui ont pour cibles et pour victimes les hommes, les animaux, les végétaux, les bactéries. Ce ne sont pas des être vivants, car ils n'ont aucune capacité personnelle de multiplication puisqu'ils ne possèdent aucun des systèmes enzymatiques capables de mettre en oeuvre les synthèses nécessaires à leur reproduction ; mais ce sont des êtres doués de continuité génétique puisqu'ils portent en eux le message codé permettant de reproduire leur matériaux de structure ; ils apportent, dans la cellule infectée, leur programme de synthèse mais les outils de fabrication et l'énergie nécessaire sont le fait de la cellule atteinte.

En somme un virus, c'est un message-programme (sous forme soit d'ADN, soit d'ARN) enfermé dans une enveloppe protéique simple (capside) ou double (capside + peplos).

Si l'enveloppe arrive à la bonne adresse -la cellule réceptive-, celle-ci extrait le message, et quitte à en mourir, fabrique de nouveaux virus programmés par le message.

Mais cette "adresse" est extrêmement précise. Tel virus se développe sur tel type de cellule et pas sur un autre ; souvent même un virus connu est observé chez un hôte humain, animal ou végétal, mais ne peut se développer que sur cet hôte, voire même sur cet hôte placé dans certaines conditions de réceptivité (un exemple tout à fait typique est celui des phages à RNA de E. coli qui ne peuvent se développer que sur des formes particulières cette bactérie possédant un pilus sexuel).

Cette présentation simplifiée nous permet de comprendre que :

- Pour mettre en évidence un virus il faut nécessairement le mettre en présence d'un système cellulaire réceptif (la bonne adresse) où il va se développer et se manifester : on ne trouvera jamais que le ou les virus que l'on cherche selon les moyens que l'on a choisi d'utiliser.

- Le primum movens du développement viral, et donc de sa détection et des moyens de dénombrement, est sa pénétration dans une cellule, suivi de la mise en route par celle-ci du programme de synthèse d'un unique message viral. Une seule particule suffit à engendrer un foyer infectieux : c'est la "loi de la particule unique" qui conduit à des modèles de titrage différents des titrages toxicologiques. Il est admis que la pénétration de plusieurs particules virales dans la même cellule, a les mêmes chances de succès que la pénétration d'une seule.

- Lorsque plusieurs messages incomplets (du fait de l'action d'agents dénaturants par exemple) pénètrent dans la même cellule, celle-ci peut reconstituer un message complet et fabriquer des virus de 2ème génération parfaitement normaux. Ce phénomène de "réactivation par multiplicité d'infection", très particulier au monde des virus, est une sorte de "résurrection" : on peut dire, par goût du paradoxe, que la meilleure preuve que les virus ne sont pas des êtres vivants est qu'ils peuvent réssusciter.

- L'universalité des virus, capables d'infecter tous les membres du monde animal, végétal et microbien, fait que les problèmes qu'ils posent et les dangers qu'ils représentent sont très divers et intéressent la santé publique (virus humains), l'élevage (virus animaux), l'agriculture (virus végétaux), l'industrie et le génie biologique (bactériophages).

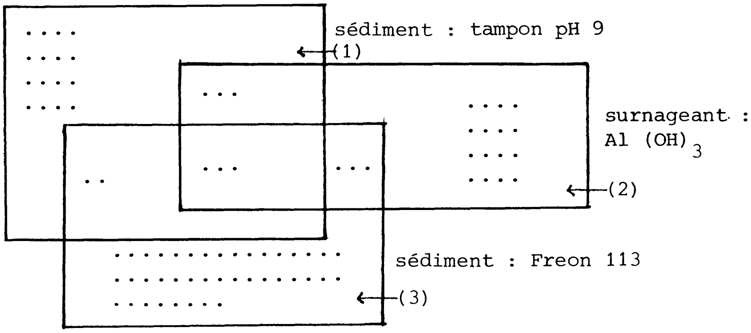
Nous allons voir successivement :

. que les particules virales s'adsorbent sur les boues
. leurs conditions d'adsorption et de désorption
. les procédés utilisés pour les mettre en évidence
. le problème des évaluations quantitatives
. le choix des méthodes selon les objectifs.

2. ADSORPTION DES VIRUS

H.L. MOORE, E. LUND, G. BERG et après eux tous les virologistes sont d'accord pour constater que les virus présents dans les eaux usées sont en beaucoup plus grand nombre liés aux particules de boues en suspension que dispersés dans la phase liquide *(1, 2, 3, 13, 17, 19)*. En séparant boue et surnageant par centrifugation (E. LUND) ou par simple décantation (nous mêmes) on isole plus fréquemment des virus dans la phase solide que dans le surnageant (figure 1).

Cette propriété des virus de se lier aux substances solides en suspension dans l'eau est connue depuis longtemps : elle est à l'origine de méthodes anciennes de prélèvement et de recherche des virus (méthode de gazes flottantes mise en oeuvre par MOORE, MELNICK, KELLY etc...) et des méthodes de concentration des virus par adsorption-élution *(13)*.



Résultats :

(1)	24	souches isolées
(2)	25	- -
(3)	48	- -
1 ∩ 2	6	- -
1 ∩ 3	5	- -
2 ∩ 3	6	- -
1 ∩ 2 ∩ 3	3	- -

Total : 83 souches isolées dans 48 essais.

FIGURE 1 - COMPARAISON DE L'EFFICACITE DE DIFFERENTES TECHNIQUES D'EXTRACTION DES VIRUS

Les substances insolubles expérimentalement capables d'adsorber les virus sont nombreuses et variées *(7)*.

Substances minérales : hydroxyde d'alumine, phosphate d'alumine, oxydes de fer, phosphate de calcium, poudre et fibre de verre, charbon.

Substances organiques : esters de cellulose, résines synthétiques, polyélectrolytes divers...

Substances naturelles minérales : argile, talc, celite, sable...

Substances naturelles organiques : fibres de coton, feuilles de laitue, levures...

L'adsorption est favorisée :

. par un pH acide (3,5 à 5)

. par une force ionique suffisante (au voisinage de l'isotonie)

. par la présence de cations divalents et trivalents (Mg^{++}, Al^{+++}) et inhibée par une forte concentration en protéine, inhibée par la présence de produits mouillants (tween, détergents...).

La désorption est favorisée :

. par un pH alcalin (8 et au delà)

. par une forte teneur en protéines (albumine bovine, sérum de veau, lait écrémé, extraits de viande de boeuf...)

. par la chelation des cations di ou trivalents

. par l'action de certains solvants (fluorocarbone)

. par l'action des ultrasons.

3. METHODE DE RECHERCHE DES VIRUS

Les méthodes de recherche des virus dans les boues sont de 3 types :

3.1 - Méthodes directes : les virus adsorbés sont, tels quels, capables de pénétrer dans les cellules sensibles et de s'y développer. Les boues sont pulvérisées, décontaminées pour détruire les microbes qui rendraient impossible la culture cellulaire, et mises en contact de la culture cellulaire sensible, souvent après traitement par ultrasons.

La décontamination est faite à l'éther *(18)* ou au chloroforme.

Il est important de réaliser cette recherche sans délai pour éviter l'action dénaturante spontanée des boues *(4, 18)*.

3.2 - Méthodes d'élution : elles sont nombreuses et variées.

Elles combinent plus ou moins les divers facteurs de désorption cités plus haut :

. pH 11,5 (tampon glycine) et neutralisation rapide
GERBA et All (14, 16), SOBSEN, WALLIS et MELNICK (23), WELLINGS et All (26), SARRETTE et All (20), SCHWARTZBRODT et All (22)

. pH 11,5 + chélateur (EDTA)
GERBA et All (15)

. pH 9 ou 9,5 + caséine isoélectrique ou lait écrémé — *BITTON (8)*
ou extrait de boeuf
STEVEN GLASS et All (24), CHARRIER et All (10)
ou sérum de veau
EISENHARDT et All (12), SABRAMANYAN (25)

. pH 7 à 7,5 + extrait de boeuf + chélateur
STEVEN GLASS (24)

. pH 7 à 7,5 sérum de veau + fluorocarbone
BEYTOUT (5)

. pH 7 à 7,5 sérum total de veau
SATTAR et All (21)

3.3 - <u>Elution suivie d'une concentration secondaire de l'éluat, utile pour la détection des faibles pollutions.</u>

3.4 - Les méthodes d'élution ont été mises au point par leurs auteurs sur des modèles artificiels : ils ajoutent, à des eaux ou à des suspensions de boues stérilisées ou tyndalisées un ou des virus-tests en quantité connue ; après un temps plus ou moins long de contact, l'adsorption du virus est évaluée par titrage des virus restés dans la phase liquide, puis la récupération du virus par élution est exécutée et son rendement évalué. Il faut bien reconnaitre que ce ne sont pas très exactement les conditions naturelles. Les virus utilisés dans ces expériences sont choisis pour leur maniabilité expérimentale : virus dont la caractérisation et le titrage sont faciles et reproductibles, résistants aux substances et au pH appliqués pour l'élution (les poliovirus vaccinaux ou sauvages, des entérovirus de culture facile, et les phages d'Escherichia coli sont pratiquement les seuls utilisés).

Dans ces conditions, pour tous les auteurs cités ci-dessus, le rendement de la méthode décrite est bon (supérieur ou égal à 50 %) et reproductible ; mais ceci, vrai pour le virus pris comme modèle, est souvent plus incertain pour d'autres virus essayés secondairement (écho virus par exemple ou adénovirus...), ou les résultats sont moins satisfaisants ou moins reproductibles, ou les techniques d'élution les dénaturent.

Le rendement dans les conditions naturelles, par définition, ne peut être connu. Comme le remarque E. LUND *(18)* si l'on essaie de comparer plusieurs méthodes, la meilleure (donnant l'évaluation la plus proche de la réalité) est celle qui donne le résultat le plus élevé et le plus constant.

Remarquons aussi que les virus sont très divers et que l'on ne peut déceler que ceux qui sont capables de se développer sur le ou les systèmes sensibles utilisés (cellules réceptives à tel type de virus et non à tel autre) : il ne peut exister aucun système universel de détection et on ne peut absolument jamais avoir une représentation de la souillure virale totale d'une eau ou d'une boue.

C'est pourquoi les évaluations quantitatives d'une pollution virale dans les conditions naturelles sont difficiles et sujettes à caution ; à l'inverse on peut espérer suivre le devenir d'une pollution artificielle expérimentale en utilisant un virus dont on maitrise bien les méthodes d'élution, de détection et de titrage.

4. EVALUATIONS QUANTITATIVES

Il est très généralement admis que la méthode des plages, lorsqu'elle est possible, est la meilleure méthode de dénombrement des virus, donnant la plus grande précision, que l'on emploie une méthode classique de Dulbecco avec dénombrement exhaustif ou une méthode miniaturisée avec troncature *(6, 9)*.

Mais il faut reconnaitre que si sa précision théorique est plus grande que celle des méthodes en tout ou rien (quelle que soit l'interprétation en dose infectante 50 % ou en nombre le plus probable), sa sensibilité est généralement moindre : lorsqu'on cherche à mettre en évidence "tous les virus" susceptibles de se développer sur un système cellulaire utilisé, on sait que certains d'entre eux donnent des plages peu visibles, voire n'en donnent pas du tout ; que dans le même prélèvement certains virus donnent des plages d'apparition précoce et extensives, empêchant l'apparition de plages de virus à développement plus lent et à plages peu visibles et tardives ; que certains effets toxiques peuvent donner de fausses plages virales. Les méthodes en tout ou rien se prêtent à la réalisation de "passages aveugles" permettant de mettre en évidence des virus non décelés sur une primo-culture. Dans une récente expérience multicentrique réalisée, sous les auspices du Ministère de l'Environnement français par VILAGINES et Coll., BLOCK, HARTMAN et Coll. et nous-même, les méthodes en tout ou rien ont permis de façon régulière de donner des titres de virus significativement plus élevés que les méthodes de dénombrement de plages en ce qui concerne les entérovirus naturellement présents dans des eaux polluées susceptibles de se développer sur les deux systèmes cellulaires utilisés.

Le reproche généralement fait aux méthodes en tout ou rien est leur imprécision ; ceci est vrai parce-que l'on utilise le plus souvent un nombre trop faible de répétitions (3 à 5 tubes par dilution) et une raison de dilution trop importante (dilutions décimales) ; les semi microméthodes de culture en boite à 96 alvéoles sont assez économiques en cellules pour permettre d'utiliser 96 répétitions. On sait en effet que l'écart type du logarithme du titre

$$s_{\log m} = 0,55 \sqrt{\frac{\log d}{n}} \qquad (11)$$

est inversement proportionnel à la racine carré de n (nombre de répétitions). L'utilisation de ces matériels permet donc d'utiliser des méthodes en tout ou rien, plus sensibles, en obtenant une précision théorique suffisante par une augmentation importante du nombre de répétitions *(BLOCK, PLISSIER, communications personnelles)*.

L'imprécision des techniques de titrage en matière de virus, tient aussi au fait que ceux-ci sont souvent agglutinés en amas comportant un nombre plus ou moins grand de virions qu'ils soient encore adhérents à leur support ou qu'ils en aient été élués : on ne peut jamais donner, même pour un virus aisément révélable, un nombre de virus présents mais simplement un nombre d'unités formant plage ou d'unités de virulence révélées, et n'avons pas la possibilité de savoir à combien cela correspond de virions virulents puisque nous ignorons tout de la loi de composition des agglutinats viraux. Cette lacune de nos connaissances peut encore compliquer les choses lorsqu'on veut étudier la dénaturation des virus du fait que les phénomènes de réactivation par multiplicité d'infection dépendent beaucoup de ces phénomènes d'agglutination (Cf. introduction).

5. ADAPTATION DES METHODES AUX OBJECTIFS

Même si nos techniques sont imparfaites il est nécessaire :

- d'une part de détecter les pollutions virales dans les boues et d'en apprécier l'intensité, la fréquence. Ne pouvant pas détecter tous les virus, nous pouvons être amenés à chercher des virus particuliers ou éventuellement à choisir des virus tests de contamination.

- d'autre part d'évaluer des actions de décontamination (l'aspect quantitatif est alors nettement plus important puisqu'il faut définir une cinétique de décontamination) et, dans cette optique, nous sommes amenés à choisir des virus tests de décontamination.

Dans le second cas, dans la mesure du possible, soucieux d'avoir des mesures de pollution reproductibles et comparables et ayant le choix du virus ou des virus tests, nous opterons pour la précision plutôt que pour la sensibilité : nous prendrons les virus les plus maniables et les méthodes les plus précises (s le plus petit possible) par exemple poliovirus ou bactériophage peu affectés par les méthodes d'élution et aisément titrables en plage ou à la rigueur en tout ou rien.

Dans le premier cas, notre choix d'un ou de virus tests dépend beaucoup moins de nos commodités expérimentales que du ou des dangers épidémiologique, épizootologique ou autre qu'il(s) représente(nt) et notre souci est de détecter la plus petite quantité possible de virus : nous préférons donc la sensibilité à la précision. Notre choix se porte donc sur les méthodes d'inoculation en milieu liquide avec passages aveugles possibles, et, s'il doit y avoir évaluation quantitative, sur des méthodes de titrage en tout ou rien.

6. CONCLUSION

Les méthodes d'étude de la pollution virale de boues ont fait, les dernières années, des progrés suffisants pour qu'elle soient utilisables. Elles ont un certain nombre de limites, que des recherches ultérieures reculeront sans doute et, nous sommes limités à l'étude de certains virus pour lesquels il existe des méthodes de culture actuellement au point.

Devant l'impossibilité d'inventaire exhaustif des virus polluants, on est amené à choisir des virus tests. Les uns, test de décontamination, sont choisis pour leurs commodité d'emploi et la précision de leur titrage ; les autres, test de contamination, sont choisis en fonction de leur intérêt épidémiologique et de la sensibilité de leur détection. Le choix de ces virus tests est encore à faire.

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THE PROBLEMS OF ASSESSING POSSIBLE HAZARDS TO THE PUBLIC HEALTH ASSOCIATED WITH THE DISPOSAL OF SEWAGE SLUDGE TO LAND: RECENT EXPERIENCE IN THE UNITED KINGDOM

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Summary

Part of the revolutionary improvement in the public health of developed countries during the last century was due to the construction and use of adequate sewage treatment facilities. The production of sewage sludge is an unavoidable consequence of sewage treatment, and the development of satisfactory guidelines for the application of sewage sludge to land is an important public health concern. Sewage sludge contains a wide variety of human pathogens, which have variable resistances to sludge treatment. The sludge applied to land certainly contains viable pathogens. Not all these represent a hazard to human health, for example they may be present in too small numbers, or they may die off rapidly after the sludge is applied to land. These factors, together with the limited routes for the pathogens in sludge to infect man, lead to the conclusion that the risk to health is small, and can be controlled by guidelines of good practice, based on adequate scientific evidence. In the United Kingdom the occasional transmission of Taenia saginata can be attributed to sewage sludge, but no other definite evidence exists for a role in the transmission of other infectious diseases. Surveillance of the incidence of human infectious disease, and the investigation of outbreaks is essential, and more cost-effective in protecting the public health than microbiological monitoring of sludge.

INTRODUCTION

In a publication in 1977 Menzies (1) said:

"The return to the land of organic wastes generated by living organisms is part of the natural cycle. In 'uncivilised' nature the soil decomposes these residues for recycling and decontaminates them of any disease organisms that they may contain. One does not need to be a dedicated organic farmer to recognise the fundamental importance of both these functions. No system of waste management that either avoids or abuses this cycle can be considered permanent".

This is an important perspective to retain when considering the public health implications of the disposal of human and animal wastes to land. We are discussing a process which has been carried out for centuries, and which is natural to primitive man and to animals in the wild.

This view, however, does not take the observer far enough. The outpourings of modern sewage works are far from "natural". They represent a concentration of the wastes of perhaps hundreds of thousands of humans, together with a certain amount of animal waste. These liquid and solid wastes may contain a wide variety of micro-organisms, a small proportion of which are pathogenic for man. The variety and concentration of these pathogenic organisms will vary with the size and state of health of the population producing the wastes. Simply because of this process of accumulation and concentration in one place these wastes represent a hazard to human health that is far from "natural" in the primitive sense. Of course this hazard must be kept in perspective. One of the hall-marks of primitive societies was a high mortality from infectious, including diarrhoeal, diseases. In developed societies such a burden of mortality is not seen. McKeown (2) regards this improvement as a response firstly to improved nutrition; secondly to improved social and environmental circumstances, particularly the provision of clean water supplies and adequate sewage disposal systems; thirdly to the understanding of hygienic infant feeding practices, including the pasteurisation of milk; and lastly to immunisation and therapy. When we talk about the hazards to public health in developed countries presented by the disposal of concentrated sewage wastes, we are talking about a hazard that is tiny compared with the hazard of not having the complex sewage collection and disposal systems that are characteristic of our developed urban society. The risk I am discussing today - the risk to the public health of the disposal of sewage sludge to land, is a consequence of efforts that have been made to reduce a much larger risk - that represented by not collecting and treating the sewage from populous areas.

This paper is then specifically concerned with the risk to the public health posed by the disposal of sewage sludge to land. That risk is small, and can be contained within acceptable limits by careful attention to guidelines describing good practice in sludge disposal to land. Equally important is a system for monitoring the true incidence of the infectious diseases which might theoretically be transmitted by sludge disposal, and for investigating any outbreaks of such diseases. Only in this way can the true size of the risk to human health posed by sludge disposal to land be estimated, and unnecessary and expensive restrictions on this practice be avoided.

PATHOGENS WHICH MAY OCCUR IN RURAL WASTE WATER

Human sewage can only present an identifiable hazard to human health if it contains pathogens. In fact the list of pathogens of man which conceivably could be present in rural waste water is extremely long. The list divides, however, into four broad groups: bacteria, protozoa, helminths and viruses.

Table I presents a list of those bacteria which might be expected in waste water; Table II a list of viruses that are released from the gastrointestinal tract of man, and which appear in waste water; and Table III enumerates the parasites which might be expected to occur in sewage, at least in countries with temperate climates such as the United Kingdom.

These lists are formidable, and will be familiar to all those concerned with the microbiology of sewage and sewage sludges. Before considering the implications for the public health of the application of such sludge to land it is necessary to consider how the process of sludge sedimentation, and the various treatment procedures to which freshly sedimented sludge can be subjected, affect both the variety and concentration of these microbial agents in sludge.

TABLE I

SOME BACTERIAL PATHOGENS WHICH MIGHT BE EXPECTED IN RAW WASTE WATER

Salmonellae	eg typhi paratyphi other
Shigellae	
Vibrios	eg cholerae other
Mycobacterium	eg tuberculosis bovis other
Bacillus anthracis	
Clostridium	eg botulinum perfringens
Yersinia enterocolitica	
Campylobacter	
Pseudomonas	
Leptospira	
Listeria monocytogenes	
Escherichia coli (including pathogenic types)	

TABLE II

VIRUSES IN WASTE WATER

Poliovirus

Cocksackie virus A and B

Echovirus

Adenovirus

Reovirus

Parvovirus

Hepatitis A virus

TABLE III

PARASITES WHICH MIGHT OCCUR IN SEWAGE IN THE UNITED KINGDOM

Protozoa

- Amoebae
  - Entamoeba histolytica
- Flagellates
  - Giardia intestinalis

Helminths

- Cestodes
  - Echinococcus granulosus
  - Hymenolepsis nana
  - Taenia saginata
- Trematodes
  - Fasciola hepatica
- Nematodes
  - Ascaris lumbricoides
  - Enterobius vermicularis
  - Strongyloides sp
  - Trichuris trichiura
  - Toxocara canis
  - Trichostrongyles

TABLE IV

REMOVAL OF PATHOGENS FROM WASTE WATER DURING SEWAGE TREATMENT

Pathogen	Reported Removal Efficiency (Per Cent)		
	Primary Treatment	Activated Sludge	Trickling Filters
Salmonella	15	96-99	84-99.9
Mycobacterium	48-57	Slight to 87	66-99
Amoebic cysts	Limited	None	11-99.9
Helminth ova	72-98	None	62-76
Virus	3 to extensive removal	76-99	0.82

After Engelbrecht

The literature on this subject is vast, and there have been some excellent reviews published (3). Some valid generalisations can be made. Bacterial pathogens can be, although they are not entirely, removed from waste water by primary sedimentation, producing a sludge which may constitute a hazard if not subsequently treated. The eggs of helminths and the cysts of protozoa are usually considered to be effectively removed by primary treatment (4), with a correspondingly high density being found in primary sludge. The removal of virus particles from waste water during primary treatment has been varyingly estimated, but it seems clear that many virus particles are associated with waste water solids (5) and show a tendency to sediment with sludge during sewage treatment (6).

Secondary or biological treatment also removes many waste water pathogens, with a corresponding concentration of these agents in the resulting biological sludges. Table IV shows the reported efficiency of the removal of various pathogens from waste water by primary and secondary treatment. It is obvious that after primary sedimentation and full biological treatment of waste water the population of pathogenic bacteria, helminth ova and viruses in primary and secondary sludges may be large. These sludges may also contain a relatively smaller population of amoebic cysts.

THE EFFECTS OF SLUDGE TREATMENT

Raw primary and secondary sludges may be treated further: to control odour, to reduce bulk and thereby ease handling and transport difficulties, and, largely incidentally, to reduce the population of pathogens. Various attempts have been made to compare the population of pathogens in primary sludge and in sludge following treatment. This is, in fact, difficult to do because of the large day to day fluctuation in the population of pathogens in the sludge within a single works. Attempts to assess the effects of treatment on the population of pathogens in sludge by comparing different sludges from different works are, for this reason, unsatisfactory. Some generalisations can, however, be made.

Mesophilic anaerobic digestion, when efficiently carried out, achieves a very substantial (over 99 per cent) reduction in the bacterial population in sludge during a 30 day digestion period (7). Most pathogenic bacteria die within 7 to 10 days of digestion, although the reduction in the population of mycobacteria during digestion is substantially less, and both primary and digested sludge may have a significant population of mycobacteria (8). At least one month's digestion at 30°C is thought to be necessary for the destruction of helminth ova (9), although Ascaris ova are particularly resistant. Cysts are thought to be readily destroyed by mesophilic digestion.

The effect of digestion on the population of viruses in sludge is difficult to determine. The available methods for recovering virus from sludge are not quantitative: some may recover more virus than others. It is usually considered, however, that mesophilic anaerobic digestion does achieve a substantial reduction in the population of infectious virus particles. Even so viable virus does occur in digested sludge, due either to failure of the full treatment process to inactivate the virus, or to the passage of sludge from the digester which has not been retained for a sufficiently long time to have received a full treatment: the result of the twin problems of inadequate mixing and short circuiting within the digestion chamber which often cause problems in digester operations.

This brief review leads to the conclusion that although the population of pathogenic agents in either primary or secondary sludges may be substantially reduced by anaerobic digestion, digested sludge may still contain the full range of pathogenic bacteria, ova, cysts and viruses referred to earlier. Does this matter? If sludge, even digested sludge, is placed on land is there a hazard to human health?

THE RISK TO HEALTH

To answer these questions requires far more than a simple demonstration that the sludge applied to land contains pathogenic microbes. According to Bernarde (10) (1973):

> "One must be chary of the type of microbiological thinking that equates the mere presence of microbes with illness or the potential for illness. The fact is that illness is an unusually complex phenomenon that does not have a 1:1 relationship to microbes".

For a public health problem to exist pathogens must be present in the sludge, and they are. They must also be virulent, and be present in sufficient numbers to cause infection in a susceptible host. The organisms must survive and retain their virulence in soil, again in sufficient numbers to cause disease. There must be a known biological pathway by which a particular pathogen in sludge may cause disease in humans, and this pathway must be important in comparison with any known alternative pathways by which the same pathogen may cause human disease. Lastly, and vitally, there must be historical or current evidence that particular human disease has or is being caused by the application of sewage sludge to land. All these factors are depicted in Figure 1, adapted from a recent review (11). Usually for any particular pathogen insufficient knowledge is available for every question to be answered satisfactorily. In particular the question of the virulence of micro-organisms applied to land in sewage sludge has been little studied. Three factors have received particular attention: the survival times of pathogenic organisms applied in sludge to soil or onto growing vegetables; the possible routes by which surviving organisms could infect man; and the availability of epidemiological evidence that human ill-health from a particular pathogen has been caused by the practice of sewage sludge disposal.

THE SURVIVAL OF PATHOGENS IN SLUDGE APPLIED TO LAND

Table V shows a representative list of the observed survival times of a number of different organisms in soil and on vegetables. This table is an over simplification, since many factors are known to affect pathogen survival, including climate, soil type, moisture, temperature and the possibility of biological antagonism. A more important deficiency of this table is that it gives no guide to the rate of death of pathogens applied to the land in sludge. Simply to say, for example, that salmonellae applied to land in sludge could be detected after a certain number of days does not exclude the possibility that the percentage survival of the organism after that period was so small as to pose no threat to human health.

This point can be illustrated with quantitative data on the survival of salmonellae obtained in the United Kingdom by the North Western Water Authority (12). The rate of death of salmonellae in a sewage sludge/soil mixture was determined after the application of digested sludge to arable land, under a variety of environmental conditions. During one four month period the population of salmonellae per kilogramme of wet sludge/soil mixture was seen to fall from 3×10^2 to 0 in six weeks. By plotting the

TABLE V

SURVIVAL TIMES OF VARIOUS PATHOGENS IN SOIL AND ON PLANTS

Organism	Medium	Survival time
Coliforms	Soil	30 days
	Tomatoes	35 days
Salmonella typhi	Soil	2-85 days
	Vegetables	7-53 days
Shigella	Tomatoes	2-7 days
Vibrio cholerae	Spinach, lettuce Non acid vegetables	2 days
Tubercle bacilli	Soil	up to 2 years
	Radish	3 months
Entamoeba histolytica	Vegetables	3 days
	Soil	8 days
Taenia saginata ova	Pasture	3 months to 1 year
Ascaris ova	Soil	up to 7 years
	Vegetables	27-35 days
Poliovirus	Soil	100 days
	Radish, lettuce	36 days

After Engelbrecht

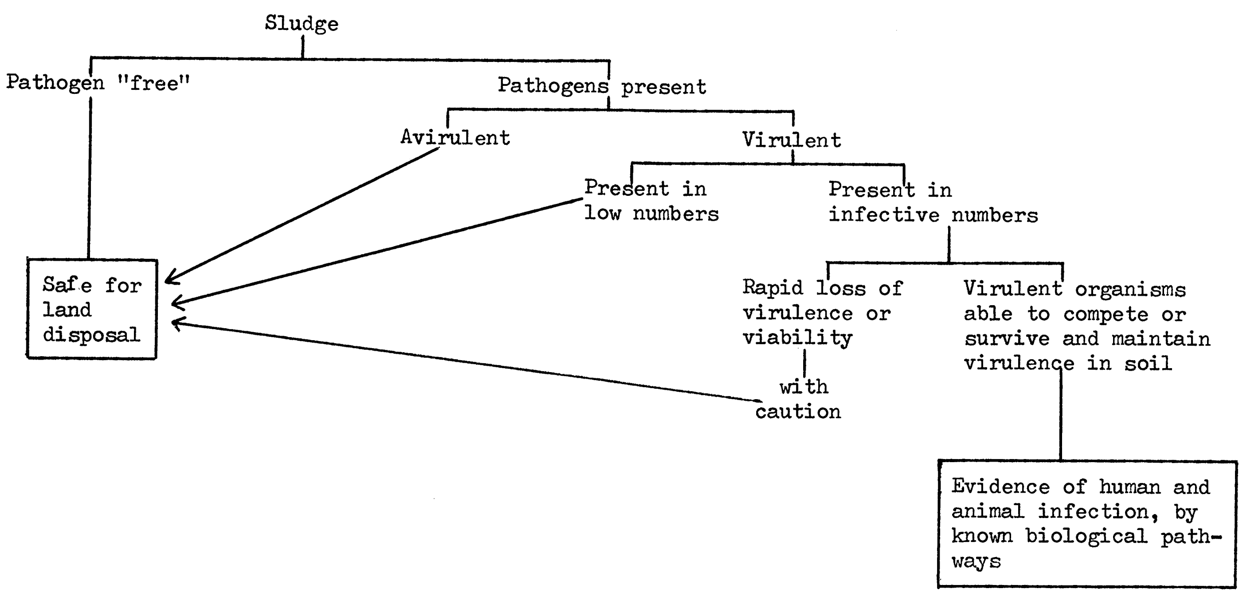
TABLE VI

ISOLATIONS OF VARIOUS INFECTIOUS AGENTS BY PHLS DURING 1978

Infectious Agent	
Escherichia Coli (infants under 3)	4,146
Shigellas	4,635
Salmonella typhi	286
paratyphi	121
other	10,833
Campylobacter	6,346
Leptospira	22
B. anthracis	0
M. bovis	25
Entamoeba histolytica	339
Giardia intestinalis	3,367
Ascaris lumbricoides	995
Hookworms	1,847
Taenia saginata	76
Trichuris trichiura	1,177

FIGURE 1

FACTORS NECESSARY FOR LAND APPLICATION OF SLUDGE TO PRESENT A HEALTH HAZARD



After Elliott and Ellis

Most Probable Number (MPN) of salmonellae per kilogramme sample against time, an approximation to a straight line graph was obtained showing a logarithmic die off of the organisms with a decimal reduction time (T90) of 16 days.

Data such as this places into perspective, and supports, the view of Gerba et al (13) (1975) that between 2-3 months in soil is sufficient to reduce most bacterial pathogens to negligible numbers.

ROUTES BY WHICH SURVIVING MICRO-ORGANISMS MIGHT INFECT MAN

Firstly it is possible that pathogens surviving in soil might contaminate edible crops. Table V shows representative survival times for various pathogens on edible plants. Rudolfs et al (1951), after applying sewage effluent and faecal suspensions to fruit and leaves concluded that if irrigation or night soil application is terminated one month before harvest it is unlikely that fruit would transmit human bacterial enteric diseases (14). Salmonellae and shigellae will not survive on vegetable surfaces for more than one week. Root vegetables eaten raw could be grown without health hazard in soils receiving sewage applications the year before (15). Rudolfs may, however, have underestimated the capacity of mycobacteria and Ascaris ova to survive in field conditions.

Polio virus has been observed to survive on mature lettuce and radish for as long as 36 days following irrigation of these crops with inoculated sludge or effluent (16). There is a possibility that virus may be mechanically transmitted when crops are harvested or consumed, and that when there is surface damage viruses may penetrate plant tissues (17).

Secondly, pathogens might cause human illness by infecting food animals allowed to graze on sludged land. A variety of experiments have documented the size of this risk. Raw sewage, treatment plant effluent and sludge was fed to pigs and cattle for six months without apparent harm (18). Grass was sprayed with 4.3×10^7 tubical bacilli/metre squared and fed to guinea-pigs with no apparent ill-effects, although at heavier inoculations they died (19). In the United Kingdom 10-12 month old heifers were fed raw sludge infected naturally or artificially with salmonella Dublin at populations up to 10^5/litre, without any evidence of clinical infection being noted (20).

However animals can become infected. When human sewage overflowed onto an area where milk cows were grazing, 30 out of 90 cows became infected with salmonella Aberdeen (21). In a recent outbreak of milk borne salmonellosis in Scotland the same serotype of Salmonella typhimurium was isolated from the affected individuals, from the milk cattle, and from a sludge well containing sludge which had been sprayed onto the fields two months before. The sludge was known to contain a proportion of effluent from a poultry processing establishment.

Animals might also become inapparent or chronic carriers of salmonellae, or act as physical transporters of the organisms into milking parlours or food processing establishments. Birds, particularly sea-gulls, have also been implicated as physical transporters of salmonellae.

Lastly, pathogens might cause human illness by contaminating surface waters by run off and perculation. Again this subject has an extensive literature. It appears that pathogen movement in soil is related directly to the hydraulic infiltration rate and inversely to media particle diameter; in general pathogens do not travel to any great extent in soils and are removed principally in the upper layers. Such pathogens will, of course, be concentrated near the soil area where crops will be grown. Soil contamination may also be passed above ground by flies or dust.

PUBLIC HEALTH HAZARD POSED BY SEWAGE SLUDGE APPLIED TO LAND

Sewage sludge contains a wide variety of pathogenic organisms although the processes of sludge treatment, and the natural decay and degradation which occur when pathogenic organisms are removed from their preferred environment and placed onto soil under a variety of environmental conditions, substantially reduce both the variety and numbers of pathogens remaining. Even so a number of routes exist by which individual pathogens might reach humans, and if present in infective numbers cause human ill-health. Even if originally present in small numbers, pathogens may contaminate foodstuffs and multiply in suitable conditions to give rise to later food poisoning.

In this situation the challenge is an epidemiological one: to determine whether any evidence exists that individual pathogens in sludge have, or could, cause episodes of human ill-health; and of deciding which particular pathogens are of importance, and the transmission of which need to be controlled. This epidemiological task is an extremely difficult one. The number of cases of human ill-health possibly associated with sewage sludge disposal may be small, and geographically scattered. To trace sewage sludge disposal as a key aetiological factor in human disease, and to isolate its effect from the other known aetiological pathways, is a formidable epidemiological challenge. Where relatively large numbers of individuals are made ill within a small geographical area the task is much simpler. A system for the routine monitoring of illness, and for the investigation of such outbreaks, is, however, a prerequisite for this epidemiological approach.

Such a system of routine surveillance provide knowledge of the incidence of infectious diseases amongst the population. A precise understanding of the epidemiology of each disease is also essential. Table VI shows the number of isolations of various infectious agents reported to the Communicable Disease Surveillance Centre in 1978 from the laboratories of the Public Health Laboratory Service. These figures certainly underestimate the numbers of infections experienced by our population, but give an indication of which are, and which are not, numerically significant infections. In the United Kingdom epidemiological investigation of episodes of illness caused by all these infectious agents has shown that, with the exception of Taenia saginata, and possibly salmonellosis, sewage sludge is not an important route of infection. Many of these infections, for example E.coli in infants, shigellas or the parasitic infections, are transmitted by the faecal-oral routine within households or institutions. Campylobacter is thought to be transmitted to man by direct contact with farms or domestic animals, or by unpasteurised milk. Leptospira is transmitted in the course of occupational exposure to contaminated water. With the single specific exception of hepatits A (23) there is no epidemiological evidence for the transmission of viral infections in temperate zones where effluent is spread on land. With the exceptions already mentioned, no direct evidence exists to implicate the disposal of sewage sludge to land as a significant vector in the aetiology of the human infectious diseases.

The possibility that sewage sludge spread to land is a significant vector in the cyclical maintenance of salmonellosis in animal and human populations has been fully discussed in another contribution to this conference (paper by Dr E B Pike). It should be remembered in this discussion that the public health may always be protected by adequate cooking of contaminated food, together with proper temperature control and good hygienic practices in the kitchen. Individual instances of the transmission of Taenia saginata have certainly occurred in the United Kingdom, probably because of its indirect mode of transmission, with the ova found in sludge being infective to cattle rather than to man. By this means the parasite achieves faecal-oral transmission in man by an indirect route, and circumvents the safeguards imposed by the usual prohibition on the direct consumption of sludge to vegetables and fruits which protect humans from other parasitic infection. The risk of transmission may, however, be minimised by strict adherence to the published guidelines.

This paper has traced a series of steps by which what at first seems to be a frightening list of pathogens in sludge posing a formidable public health hazard may be reduced in practice to much more manageable proportions. It is unjustified to regard every one of the pathogenic agents in sludge as a public health hazard, although it is certainly useful to be in a position to estimate the population of significant pathogens in sludge. Once the usual population of pathogens in the sludge produced by any one works is known, however, such estimations need only be intermittent. In the United Kingdom routine methods are being employed by some Water Authorities to estimate the population of salmonellae and Taenia saginata eggs in the sludge they put to land.

It is in our view quite inappropriate to concentrate on devising and enforcing microbiological standards to be met by the sludge being applied to land. The imposition of any such standards would certainly not be cost-effective as public health measures. Certainly the use of indicator organisms in a standard for sludges cannot be justified, for example to count the number of E.coli in sludge tells you little apart from the known fact that you are dealing with a faecally derived material. Nor is it helpful to count organisms such as Campylobacter or clostridial spores which are ubiquitous in the environment. There is no good evidence that indicator organisms and pathogens behave in the same way during sludge treatment or after application to land.

What certainly will protect the public health are sensible and applied guidelines on good practice in sludge disposal to land, which are backed up by convincing scientific evidence. The current guidelines in the United Kingdom provide guidance on which type of sludges are suitable for particular agricultural purposes, and recommend intervals between the application of sludge and crop harvesting or the grazing by animals of the land to which sludge has been applied. Untreated sludge should be applied to land only if the land is used for the production of animal feed crops or for the production of crops which are always cooked before human consumption. Grazing by cattle should not be perimtted within six months as a protection against the transmission of Taenia saginata eggs. Digested sludge may be placed to land and cattle allowed to graze after 3 weeks, or five weeks if they produce milk which will not be subject to pasteurisation. Salads or other crops which may be eaten raw should not be sown until 12 months after the application of treated sludge to land. To protect water supplies application rates should be adjusted to crop requirements, soils underlain by fractures or fissures possibly leading to ground water supplies should be avoided. These guidelines are currently being revised to take into account scientific evidence which has only recently become available.

Lastly it is emphasised that the only evidence of the transmission of disease associated with sewage effluence disposed to land has arisen when raw wastes have been placed on crops eaten too soon after waste application, or when the area has been grazed too soon after such application. No incidence of disease in humans has ever been convincingly demonstrated to be caused by the application of anaerobically digested sludge to land (1).

The removal of all risk from any practice is never a feasible proposition. This paper suggests that the risk to human health posed by the application of sewage sludge to land is small, and manageable by ahherence to guidelines of good practice which are based on sound scientific evidence. Further advances in understanding and controlling this hazard are more likely to follow an extension of epidemiological surveillance and investigation than the increased microbiological monitoring of sludge.

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ASPECT SANITAIRE DES EPANDAGES DE BOUE RESIDUAIRE : CINETIQUE DE REGRESSION SUR TERRAINS AGRICOLES DE QUELQUES GERMES TESTS

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Résumé :

L'utilisation croissante des boues de stations d'épuration urbaine rend indispensable une évaluation des risques sanitaires consécutifs aux épandages. Un pré et un champ ont été traités deux fois, successivement en automne et en hiver. Les prélèvements de terre et d'herbe ont permis de dénombrer une microflore bactérienne aérobie, coliformes et streptocoques fécaux ; lorsque les résultats sont similaires dans les parcelles témoins et traitées, on suppose que la décontamination bactérienne s'est réalisée. La disparition des germes fécaux étudiés diffère légèrement suivant la saison et le couvert végétal : pour le champ, il faut 4 mois en épandage d'automne et 3 mois en épandage d'hiver ; pour le pré, chaque fois 3 mois. Cette expérimentation permet d'apprécier les effets de l'écosystème sur une microflore fécale étudiée. La disparition de ces germes est bien observée ; elle ne permet pas, par contre, une extrapolation rigoureuse aux divers germes pathogènes présents éventuellement dans les boues. Le risque sanitaire pour l'homme ou l'animal ne pourra être évalué qu'en faisant intervenir les facteurs suivants : survie des germes fécaux étudiés et de germes pathogènes, doses minimales infectantes pour ces derniers, données zootechniques.

Abstract : SANITARY ASPECTS OF SLUDGE SPREADING : RATE OF RETROGRESSION OF SOME BACTERIAL POPULATION IN SOIL.

Owing to the fact that municipal sludges are getting more and more used, it is necessary to evaluate hasards for health associated with sludges spreading. A meadow and a field were twice treated during two different seasons, i.e. autumn and winter. Samples of soil and gras were taken to make counting of bacterial aerobic, fecal coliforms and fecal streptococci population. When results of counting are similar in treated and control samples, we suppose that sanitary purification is performed. The decreasing rate of the fecal population slightly differs according to season and culture as far as the field is concerned, 4 months are necessary in autumn and 3 in winter, but for the meadow, always 3 months. The experience allowed us to appreciate the effects of soil ecosystem on the fecal bacterial population. The decreasing of this population is observed but doesn't allow us to speak in a decisive way about pathogenic bacteria contaminating sludges. The health hasards for human or animal may only be evaluated in comparison with survival time of well known fecal bacteria and those of pathogenic microorganisms, in respect of minimal dosis of infection and zootechnical data.

INTRODUCTION -

Devant l'augmentation constante de l'utilisation des boues de station d'épuration urbaine en milieu agricole, il apparaît indispensable de mieux cerner le devenir des germes pathogènes contenus souvent en grande quantité par ces boues. L'objet de ce travail est d'étudier la survie de germes apportés par épandage de boues urbaines dans des conditions se rapprochant le plus possible de celles correspondant à une utilisation normale en agriculture.

Nous avons étudié deux groupes de germes, bien connus de spécialistes de l'eau, et généralement considérés comme non pathogènes : ce sont les *Coliformes fécaux* et les *Streptocoques fécaux*. Ces germes sont toujours présents dans les boues urbaines à des teneurs assez importantes, et sont d'excrétion fécale comme beaucoup de micro-organismes dont la présence constitue un risque sanitaire.

Nous avons suivi leur régression sur le sol nu d'un champ, sur le sol et l'herbe d'un pré après un épandage de boue effectué d'abord en automne, puis en hiver.

La boue d'hiver renfermant également des *Salmonelles,* nous avons pu suivre la régression de ce germe dans la deuxième phase de l'expérimentation.

Ce travail présente donc un intérêt sanitaire vis-à-vis des herbivores susceptibles de consommer de l'herbe souillée par un épandage : l'herbe peut être lavée par les pluies, mais porter beaucoup de germes fécaux. L'expérimentation essaye d'indiquer les délais minima à respecter avant la remise au pré du bétail.

MATERIELS ET METHODES -

1. - Terrain d'expérimentation :

Deux parcelles juxtaposées ont été utilisées : l'une est un pré, l'autre est un ancien champ de plantes médicinales en friche, labouré et hersé juste avant le premier épandage de boue.

2. - Caractéristiques de la boue :

La boue provient de la station d'épuration d'une partie de l'agglomération lyonnaise ; elle résulte de l'épuration d'eaux urbaines, mais aussi d'eaux industrielles. Cette boue, prélevée après épaississement, présente les caractéristiques suivantes au moment de l'utilisation :

	matière sèche	matière organique
- boue d'automne (11.10)..........	5,5 %	3,8 %
- boue d'hiver (14.01)............	8,7 %	6,3 %

3. - Modalités d'épandage :

Nous avons fait varier les doses d'épandage suivant la nature de la parcelle et la saison d'épandage :

- automne (11.10) : 5 l/m^2 sur champ n° 1 à 4 et 10 l/m^2 sur pré n° 1 ;
- hiver (14.01) : 10 l/m^2 sur champ n° 3 et 4 et 20 l/m^2 sur pré n° 1.

Les épandages ont été réalisés à l'aide de jerricans préalablement remplis à la station.

4. - Analyses bactériologiques :

En plus des *Streptocoques fécaux* et des *Coliformes fécaux,* nous avons étudié la microflore aérobie pour pouvoir repérer des conditions climatiques exceptionnellement favorables ou défavorables aux bactéries et, par assimilation alors, aux germes fécaux définis précédemment. Nous n'avons dénombré les Salmonelles que lors du deuxième épandage car l'analyse n'a pas permis de les déceler dans la boue du premier épandage.

4.1. Techniques de prélèvement :

La périodicité des prélèvements a été fixée de la façon suivante : à partir du jour de l'épandage, prélèvements après 15 jours, 1 mois, 2 mois, 3 mois.

Les prélèvements s'effectuent avec du matériel préalablement stérilisé ; la terre est prélevée avec un cylindre métallique sans fond et placée dans des bocaux en verre. L'herbe est prélevée à plus de 5 cm de la surface du sol à l'aide d'une pince et d'une paire de ciseaux.

Dans le champ, nous avons prélevé un échantillon moyen de terre traitée (carrés n° 1 à 4) et un échantillon moyen de terre témoin (carré n° 5). Dans le pré, nous avons prélevé un échantillon moyen de terre et un échantillon moyen d'herbe, respectivement dans les carrés traité (n° 1) et témoin (n° 2).

Après le deuxième épandage, le prélèvement est exactement le même pour le pré, mais diffère pour le champ : nous constituons un échantillon moyen de terre des carrés traités pour la seconde fois (n° 3 et 4), un échantillon moyen de terre des carrés préalablement traités (n° 1 et 2) et un échantillon moyen de terre témoin (n° 5).

4.2. Techniques d'analyse au laboratoire :

Les échantillons de terre ou d'herbe sont immédiatement portés au laboratoire et analysés sans préparation préalable telle que séchage et broyage. Par la méthode des suspensions-dilutions, nous réalisons les dilutions nécessaires.

4.2.1. Microflore bactérienne aérobie :

- Plate Count agar, ou Tryptone glucose yeast agar.
- Lecture après 72 heures à 30°C.

4.2.2. Coliformes fécaux :

- Bouillon lactosé au vert brillant, 48 heures à 44°C.
- Confirmation par le test de MacKenzie, 48 heures à 44°C.

4.2.3. Streptocoques fécaux :

- Milieu de Rothe-Litsky, 48 heures à 37°C.
- Confirmation par le milieu de Litsky à l'éthyl violet, 24 heures à 37°C.

4.2.4. Salmonelles :

- Nous utilisons ici le milieu déshydraté en utilisant la boue, diluée ou non, ou la suspension de terre ou d'herbe pour reconstituer le milieu ; la limite de détection est de 5 Salmonelles pour 100 g d'échantillon analysé.
- Milieu au sélénite, 24 heures à 42°C.
- Confirmation par le milieu de Hektoen, 24 heures à 37°C.

4.3. Expression des résultats :

Les résultats correspondant aux premier et deuxième épandages sont regroupés respectivement dans les tableaux 1 et 2.

RESULTATS ET DISCUSSION -

Le premier épandage (voir tableau 1) a été réalisé au mois d'octobre pendant une période pluvieuse (précipitations mensuelles de 191 mm). Malgré les quantités importantes de boue épandue, 5 et 10 l/m^2, la boue avait pratiquement disparu au bout de 15 jours ; seuls subsistaient quelques minces fragments épars.

A partir des données de l'épandage et l'analyse de la boue, et en supposant une imprégnation homogène du sol sur 5 cm d'épaisseur, nous avons évalué la teneur en chacun des deux germes fécaux étudiés à 3.10^4/g de terre. Les valeurs indiquées par l'analyse au bout de 15 jours sont similaires ou inférieures à cette valeur théorique.

Le tableau fait apparaître des différences minimes dans le comportement des germes étudiés :

- au champ, les *Coliformes* résistent mieux au départ que les *Streptocoques*, mais disparaissent en même temps ;
- au pré, dans la terre le comportement est identique, mais sur l'herbe les *Streptocoques* résistent beaucoup mieux au départ et persistent plus longtemps ;
- les germes étudiés persistent moins bien dans la terre du pré que dans celle du champ ;
- la microflore n'apporte aucun renseignement interprétable par rapport au but poursuivi.

La disparition des germes se fait en 3 mois pour le pré et 4 mois pour le champ.

Le deuxième épandage (voir tableau 2) a été réalisé en période froide et sèche (précipitations mensuelles de 36 mm) sur un sol gelé. Du fait des doses importantes épandues, de l'absence momentanée d'infiltration ou de ruissellement, une couche continue de boue a subsisté pendant plus d'un mois avant de commencer à se fragmenter très partiellement. En fonction des données de l'épandage, il est possible d'évaluer la teneur en *Streptocoques fécaux* à $1,2.10^5$/g et celle des *Coliformes fécaux* à 2.10^4/g, toujours sur 5 cm d'épaisseur de terre.

Les *Streptocoques*, au pré ou au champ, ont un comportement similaire, alors que les *Coliformes* résistent un peu mieux au pré qu'au champ. L'herbe du pré n'a été analysée qu'au bout de 2 mois, lorsque la gangue de boue qui la recouvrait avait presque disparu : les germes fécaux semblent s'y comporter de la même façon que dans la terre du pré.

La disparition des germes étudiés est acquise en 3 mois au champ et moins de 3 mois au pré. La microflore totale aérobie, en baisse constante entre janvier et avril, montre que le climat a peut-être joué un rôle plus important que lors du premier épandage : un épandage en automne sec aurait peut-être montré une régression moins rapide ?

Les *Salmonelles*, présentes théoriquement à la dose de 57/100 g de terre, disparaissent en 15 jours dans tous les prélèvements, sauf dans la croûte (1 mois) ; d'autre part, celle-ci semble ne plus renfermer les deux germes étudiés au bout de 2 mois. Paradoxalement, cette croûte qui aurait pu être un réservoir de germes est épurée plus rapidement que la terre.

CONCLUSION -

L'expérimentation permet de proposer un repos sanitaire de 3 mois avant la remise au pré du bétail ; elle montre quelques différences entre les possibilités de survie des trois germes étudiés. Les conditions climatiques pourraient notablement affecter la survie des germes, le froid sec étant défavorable aux germes et l'humidité étant favorable. La succession de deux épandages à 3 mois d'intervalle ne semble pas défavorable. L'expérimentation présente surtout un intérêt pour les prés car les produits de la grande culture sont consommés cuits ou traités.

L'expérimentation, en faisant apparaître des différences de comportement entre les germes étudiés, montre les limites de la méthode : les délais indiqués, 3 mois, sont fondés sur une plus grande sensibilité des germes pathogènes par rapport aux germes de référence aux conditions du milieu, ce qui est certainement vrai pour beaucoup d'entre eux, comme les Salmonelles, mais pas pour tous ; cette différence, si elle était méconnue, pourrait être la cause de graves problèmes sanitaires.

Il sera donc indispensable d'établir, en fonction des conditions d'utilisation, une échelle comparée de sensibilité entre des germes dits "témoins", facilement analysables et toujours présents, et les germes à haut risque parmi les virus, bactéries, champignons, protozoaires et métazoaires. En associant cette possibilité de survie à la notion de dose minimale infectante (DMI) et à des notions zootechniques, on pourra établir des délais sanitaires correspondant mieux aux risques réels.

Actuellement, il serait prudent de rechercher périodiquement les germes à haut risque dans les boues, d'en interdire l'utilisation en cas de présence et, d'une façon générale, de recommander l'hygiénisation des boues.

TABLEAU 1 : *Premier épandage.*

Dates	*Coliformes fécaux*					*Streptocoques fécaux*					*Microflore totale aérobie*				
	Champ		*Pré*			*Champ*		*Pré*			*Champ*		*Pré*		
	T	*tr*	*T*	*tr*	*h*	*T*	*tr*	*T*	*tr*	*h*	*T*	*tr*	*T*	*tr*	*h*
11.10	<4	-	5.10	-	<4	10	-	5.10	-	4	3,5	-	12,0	-	10,9
26.10	50	5.10^4	5.10	5.10^2	5.10^3	<4	5.10^2	5.10^3	5.10^2	5.10^5	29	67	6,0	4,2	-
19.11	<4	5.10	<4	5.10	<4	5.10	5.10^2	50	5.10	5.10^2	60	27	83	5	450
14.01	<4	5.10	<4	<4	<4	<4	5.10^3	<4	<4	<4	44	310	24	18	11
29.01	23	4,3.10	-	-	-	9	43	-	-	-	15	30	-	-	-
18.02	23	<4	-	-	-	<4	<4	-	-	-	13,8	23	-	-	-
07.03	<4	<4	-	-	-	<4	<4	-	-	-	4,7	6	-	-	-
08.04	<4	<4	-	-	-	<4	<4	-	-	-	2,5	20	-	-	-

Abréviations
- *T* = *témoin*
- *tr* = *traité*
- *h* = *herbe*

Boue d'automne
- *Coliformes fécaux* = 5.10^5/g *de boue brute*
- *Streptocoques fécaux* = 5.10^5/g *de boue brute*
- *Salmonelles* = < 5/100 g *de boue brute*

Expression
- *en germes/g de terre ou d'herbe brute*
- *microflore en* 10^5 *germes/g de terre ou d'herbe brute*

TABLEAU 2 : *Deuxième épandage.*

Dates	*Coliformes fécaux*					*Streptocoques fécaux*					*Microflore totale aérobie*				
	Champ		*Pré*			*Champ*		*Pré*			*Champ*		*Pré*		
	T	*tr*	*T*	*tr*	*h*	*T*	*tr*	*T*	*tr*	*h*	*T*	*tr*	*T*	*tr*	*h*
14.01	<4	5.10	<4	<4	<4	<4	5.10^3	<4	<4	<4	44	310	24	18	11
29.01	2,3.10	2,3.10	2,3.10	$4,3.10^2$	souil-lée	9	$1,5.10^3$	<4	$4,3.10^3$	souil-lée	15	60	12	200	souil-lée
18.02	2,3.10	<4	<4	1,5.10	"	<4	4,3.10	<4	4,3.10	"	13,8	41	7	9	"
07.03	<4	<4	<4	4	<4	<4	9	<4	4,3.10	$4,3.10^2$	4,7	72	4	320	40
08.04	<4	<4	<4	<4	<4	<4	<4	<4	<4	<4	2,5	6,2	1,8	33	3;9

Dates	*Croûte*			
	Coliformes fécaux	*Streptocoques fécaux*	*Microflore*	*Salmonelles*
14.01	-	-	-	-
29.01	2,3.10	$2,3.10^4$	1.300	5-50/100 g
18.02	2,3.10	$4,3.10^2$	160	< 5/100 g
07.03	<4	<4	970	"
08.04	<4	23	510	"

T = *témoin*

tr = *traité*

h = *herbe*

Boue d'hiver
- *Coliformes fécaux* = $1,5.10^5$
- *Streptocoques fécaux* = $9,3.10^5$
- *Salmonelles* = *430/100 g*

ENTEROVIRUS INACTIVATION IN EXPERIMENTALLY SEEDED SLUDGE AND SOIL SAMPLES

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Summary

Poliovirus I and Coxsackie B3 have been experimentally seeded into sludge supernatant, sludge and soil. Virus particles seeded into sludges showed rapid inactivation at 37°C. Enteroviruses seeded into soild samples, however, survived at the same temperature for several days.

Current studies indicate that land disposal of sewage plant products for soil enrichment purposes may constitute a possible threat to public health, because of the presence of enteric viruses still present in sludge after anaerobic digestion process.

The objective of the present laboratory study is to assess the relationship between temperature and detetion time-infectivity of two Enteroviruses, namely Polio I and Coxsackie B3.

The objective of the present laboratory study is to assess the relationship between temperature and detetion time-infectivity of two Enteroviruses, namely Polio I and Coxsackie B3, incubated at differnt temperatures (20 , 28 , 37 C) in different mediums (digested sludge supernatant, digested sludge and soil samples), tested for infectivity assay at different times (3 h, I,2,3,4,5 days).

The first series of experiments was designed to assess the relationship between temperature and virus reduction in anaerobically digested sludge supernatant and sludge.

The reduction of Poliovirus I in sludge supernatant and in control salt solution is shown in figure I. The rate of inactivation is much more rapid at 37° C. It is also apparent that the sludge supernatant is inactivating the virus because Polio I held in control Medium Eagle survives longer.

Figure 2 shows the inactivation rates of polio I seeded into sludge, incubated at the same conditions, then eluted by glicyne pH II. The table on the left shows the results of virus titration determined in supernatant before the elution phase: it is apparent the mechanism of virus binding to the particulate matter present in sludge. Table on the right shows virus reduction rate in sludge after the elution phase. By 24 h at 37°C Polio I is likewise entirely inactivated even though virus particles adsorbed to the sludge solid fraction show a slightly better percent survival at the low temperatures. The early curve slop which shows a sudden fall of virus titres by 3 h, likely indicates poor reliability of the methods employed to elute viruses from the solid fraction.

It is likewise apparent from figure 3, that sludge is somehow inactivating the virus, because Polio I held in control Medium has been detected after 5 days incubation at 37° C.

The inactivation rate of Coxsackievirus B4 seeded into sludge supernatant is shown in figure 4. In general the data are similar to those shown for Polio I; results indicate a more rapid inactivation rate at the highest temperatures.

Figure 5 shows the results concerning Coxsackie B3 reduction in digested sludge. Table on the left shows the results of virus assay in sludge supernatant before elution. Detection of virus particles until the 3rd day indicate that the Coxsackie B3 slightly binds to sludge solid fraction. Rate of inactivation in sludge eluate is shown on the right figure: the curve are similar to those of polio I, even though the high virus titres seeded, are considerably lowered by 24 h even at the low temperatures.

A second series of experiments was designed to assess the relationship between temperature and Enteroviruses inactivation rate in soil samples. Polio I and Coxsackie B3 have been incubated at the same temperatures, virus assays were performed after elution by glycine pH II.

Results for Polio I are shown in figure 6. The table shows a lower inactivation rate at the different temperatures, compared to virus recovery from sludge.

In figure 7 are shown the inactivation rates of Coxsackie Virus B3; in general, the data are similar to those shown for Polio I.

Results of current laboratory study indicate persistence of infectious viruses in soil samples until the 9th day even at the highest temperatures; to date, results concerning the fate of viruses from the 10th through the 21st day are missing.

In previous studies Lund E. et al. (I) report that a virucidal agent, possibly of biochemical nature is produced during sludge digestion.

Bertucci et al. (3), in 1979 report that waste water sludge bacterial by-products do not contribute to inactivate virus, while the rate of Polio I inactivation is enhanced in proportion to the ammonia concentration.

According to previous studies reported by Lund E. et al. (I) and Ward R.L., Ashley C.S. (2), in the present report the rate of Enterovirus inactivation was found to be faster in sludge anaerobically digested than in salt solution and in soil samples.

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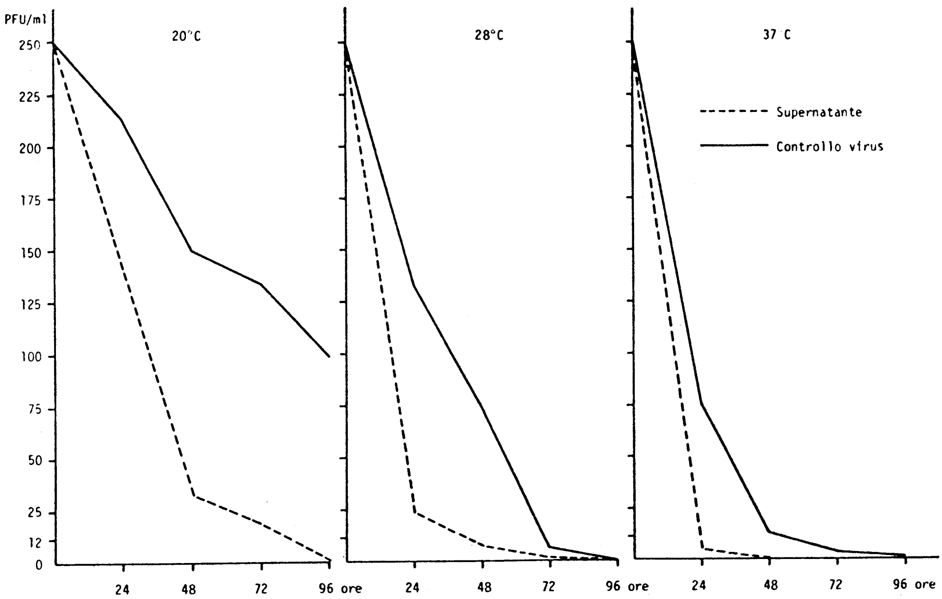

Fig. I - Rates of inactivation of Poliovirus I in digested sludge supernatant

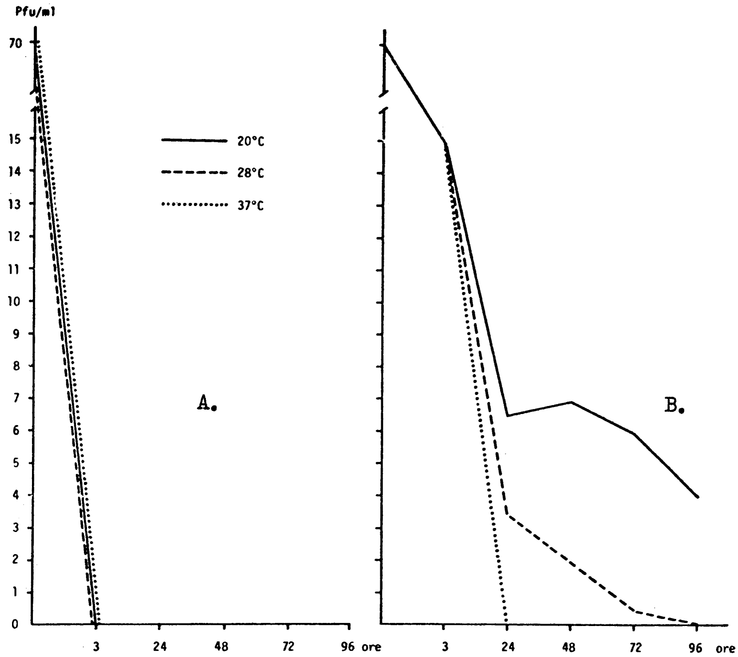

Fig. 2 - Rates of inactivation of Poliovirus in digested sludge:
A. Virus persistence in supernatant
B. Virus persistence in sludge eluate

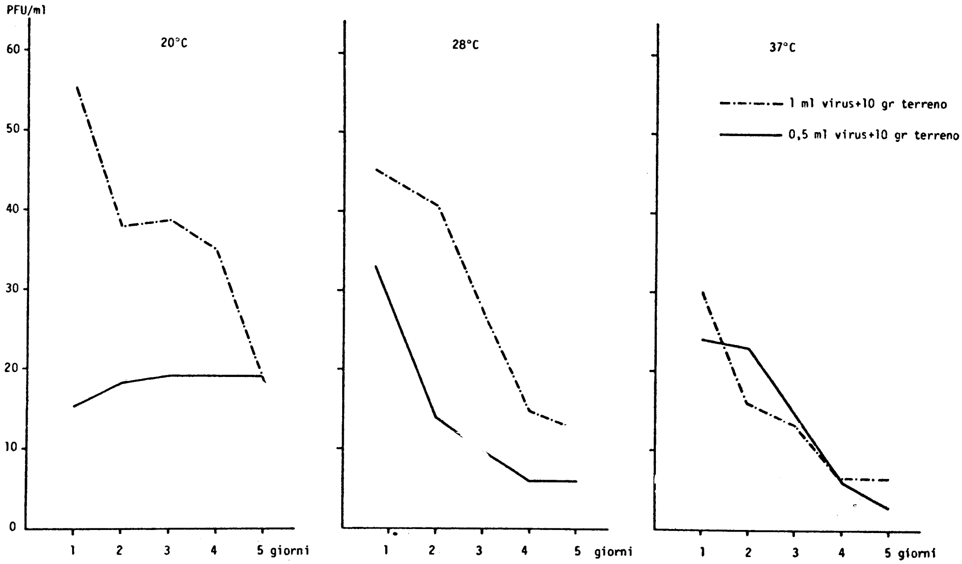

Fig. 3 - Rates of inactivation of Poliovirus I in Medium Eagle

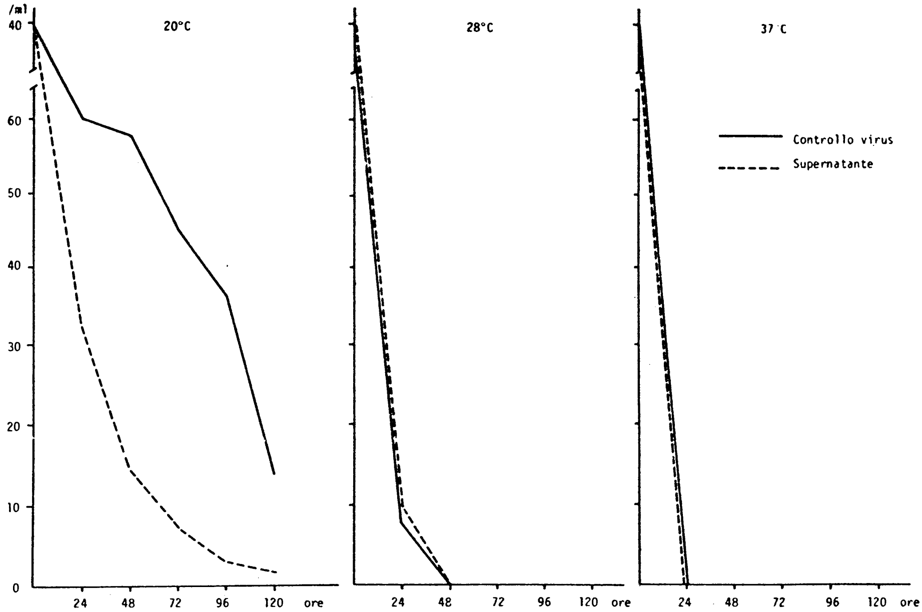

Fig. 4 - Rates of inactivation of Coxsackievirus type B3 in sludge supernatant

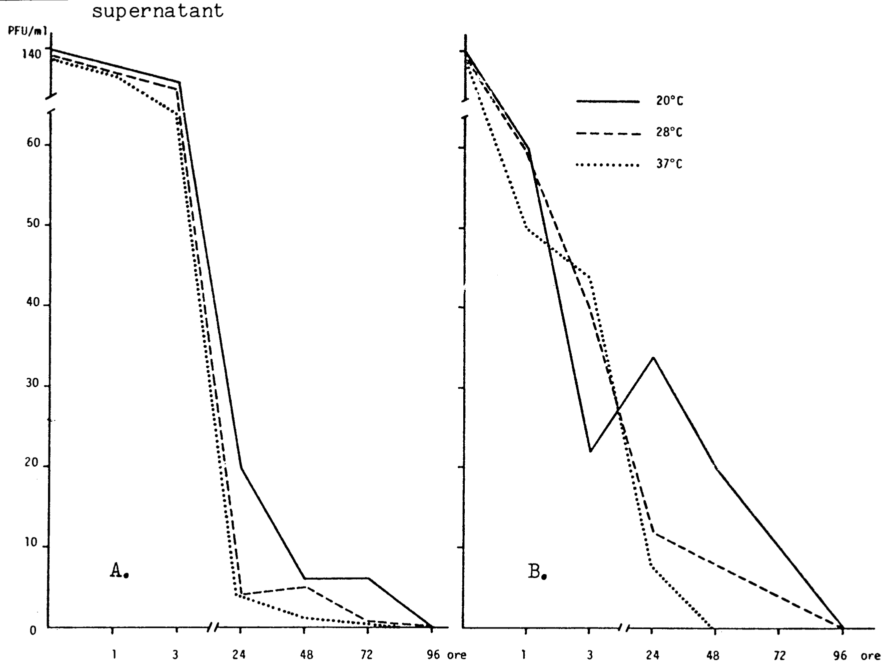

Fig. 5 - Rates of inactivation of Coxsackievirus type B3 in digested sludge: A. Sludge supernatant
B. Sludge eluate

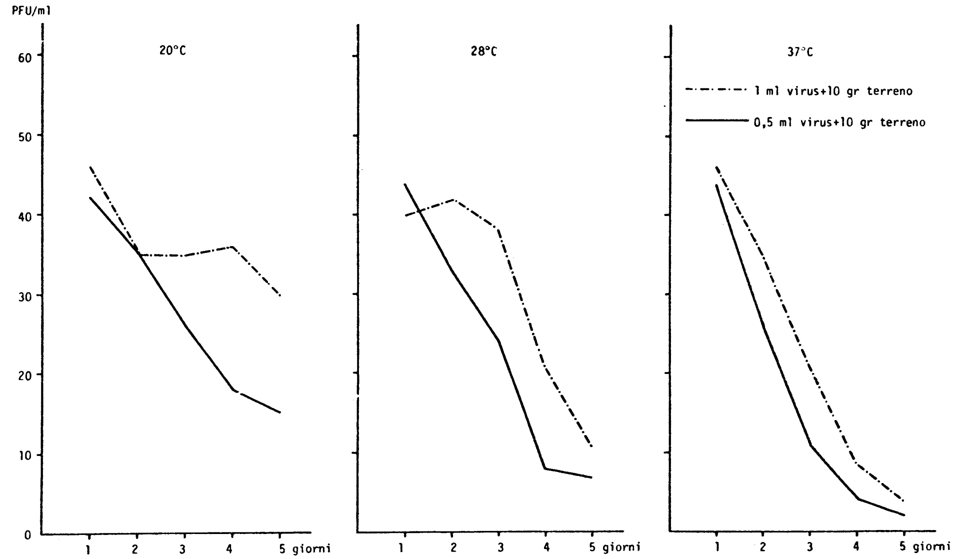

Fig. 6 - Rates of inactivation of Poliovirus I in soil samples

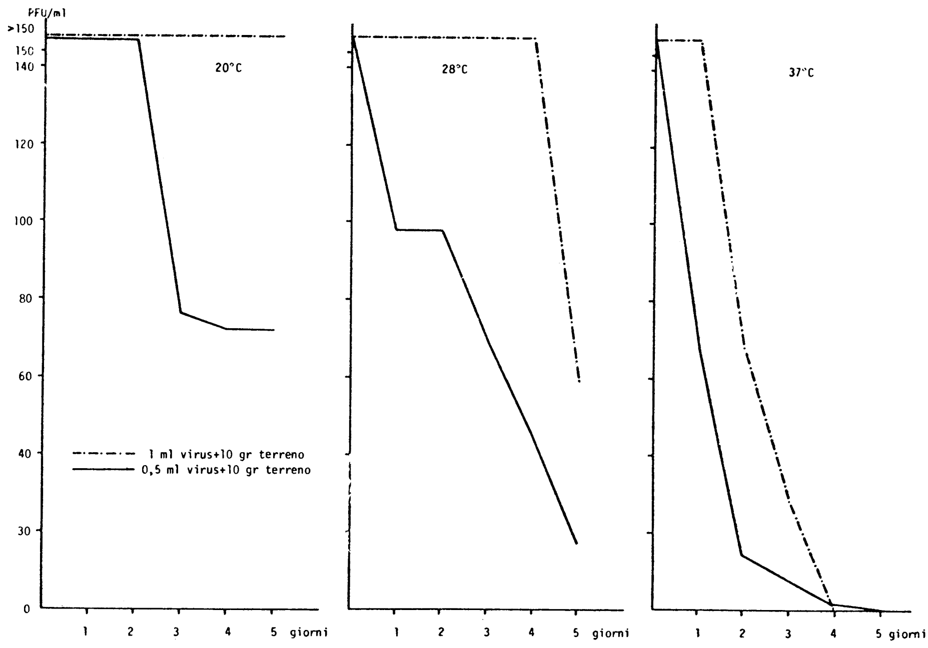

Fig. 7 - Rates of inactivation of Coxsackievirus type B3 in soil samples

SALMONELLEN IM KLAERSCHLAMM

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Summary

By bacteriological examination of sewage sludge we found Salmonellae in 150 of 151 sewage plants. We isolated between two and 10^6 Salmonellae per liter sewage sludge provided for fertilizing purposes.

Moreover we found that Salmonellae in sewage sludge spread on grass may survive up to 61 weeks. Fertilizing with unsanitized sludge may therefore lead to their transmission from plants to animals.

In several bovine herds we were able to demonstrate an epidemiological connection between manuring with unsanitized sludge and outbreaks of Salmonellosis. Inapparent infections are even more frequent. We isolated Salmonellae in 2,5 % of 2'500 apparently healthy cattle from 5 different slaughter houses. The number of Salmonella carriers accumulated during the grazing period. This is in contrast to the situation in swine fattening herds in confinement, where seasonal variations of the infection rate could not be noticed.

Zusammenfassung

Wir haben Klärschlamm aus 151 Anlagen untersucht und, mit einer einzigen Ausnahme, immer Salmonellen nachgewiesen. Dabei wurden jeweils zwischen zwei und 10^6 Salmonellen pro Liter Schlamm isoliert.

Bei Düngung von Grasflächen mit unhygienisiertem Klärschlamm besteht ein Infektionsrisiko für den Viehbestand, weil Salmonellen in angetrocknetem Schlamm an der Grasnarbe bis 61 Wochen überleben können.

In mehreren Rindviehbeständen haben wir den epidemiologischen Zusammenhang zwischen Klärschlammdüngung und manifesten Salmonelleninfektionen nachgewiesen. Ungleich häufiger sind die inapparenten Infektionen. Bei 2'500 klinisch gesunden Kühen und Rindern aus 5 verschiedenen Schlachthöfen haben wir eine Infektionsrate von 2,5 % festgestellt. Die Zahl der Salmonellenisolierungen beim Rind kulminierte in den Sommermonaten. Derartige saisonale Schwankungen konnten bei den Schweinebeständen mit Intensivhaltung nicht beobachtet werden.

Als Abwasserkonzentrat enthält Klärschlamm regelmässig pathogene Mikroorganismen. Von epidemiologischer Bedeutung sind in unseren Regionen vor allem die Salmonellen und die Eier von Taenia saginata.

Wir haben Proben aus 151 Kläranlagen untersucht und, mit einer einzigen Ausnahme, bei allen Schlämmen, die an die Landwirtschaft abgegeben wurden, Salmonellen isoliert.

Voraussetzungen für diesen praktisch lückenlosen Salmonellennachweis in Klärschlamm waren:

1. Repräsentative Proben, d.h. Entnahme nach vollständiger Umwälzung des gestapelten Schlammes.
2. Voranreicherung von 6 mal je 100 g Schlamm in gepuffertem Peptonwasser während 72 Stunden bei 30 °C.
3. Anreicherung in Tetrathionat-Bouillon in hoher Schicht während mindestens 36 Stunden bei 43 °C.
4. Umzüchtung der Anreicherung (nach Verdünnung im Verhältnis 1:60 und optimaler Homogenisierung in Peptonwasser) auf Brillantgrün-Phenolrot-Agar DIFCO Nr. 0285-01. Anschliessende Bebrütung während 24 Stunden bei 43 °C.

Mit dieser Technik erreichen wir eine eindeutige Selektion vorhandener Salmonellen.

Quantitativ fanden wir nach dem MPN-Verfahren zwischen zwei und 10^6 Salmonellen pro Liter. Bei Annahme eines Trockensubstanzgehaltes von 5 % entspricht das einer Menge von maximal 20'000 Salmonellen pro Gramm Feststoff.

Damit ist die Hypothese, wonach die pathogenen Keime durch konventionelle Schlammbehandlung eliminiert werden, widerlegt, weil es sich bei den untersuchten Proben zur Hauptsache um Faulschlamm handelte. Noch überzeugender lässt sich das beweisen durch quantitative Bestimmung von Indikatorkeimen vor und nach der Schlammbehandlung.

Wir haben aus einer repräsentativen Anzahl von Stichproben den durchschnittlichen Gehalt an E. coli ermittelt. Der Mittelwert sank von 10^9 pro Liter Frischschlamm auf 10^8 im aerob stabilisierten Schlamm und nur auf 10^7 im ausgefaulten Schlamm (1).

Die epidemiologische Bedeutung der Salmonellen sollte auch deshalb nicht bagatellisiert werden, weil die Keime im angetrockneten Klärschlamm eine erhebliche Tenazität aufweisen. Bei Düngeversuchen haben wir Ueberlebenszeiten von 61 Wochen an der Grasnarbe bzw. 58 Wochen in der oberen Humusschicht nachgewiesen (2).

Aus diesen Feststellungen geht hervor, dass die Verwendung von unhygienisiertem Klärschlamm zur Düngung von Grasland mit einem Infektionsrisiko für den Viehbestand verbunden ist.

Wir haben tatsächlich Infektketten: Klärschlamm - Futterpflanze - Rind nachgewiesen. So erkrankten in einer Milchviehherde 4 Wochen nach Klärschlammaustrag 9 Tiere an fieberhaftem Durchfall mit abruptem Milchversiegen. Wir isolierten Salmonella tokoin aus dem Darminhalt aller 9 Patienten. 7 Wochen nach Klärschlammdüngung gelang uns der Nachweis von Salmonella tokoin auch noch aus der Grasnarbe der betreffenden Weide. Der ursächliche Zusammenhang zwischen Klärschlammdüngung und Bestandes-Enzootie ist in diesem Fall offensichtlich, weil Salmonella tokoin vorher in der Schweiz noch nie nachgewiesen worden war.

In zwei Mastbeständen von Jungrindern, die ebenfalls an akuter Salmonellose erkrankt waren, gelang die Isolierung von Salmonella dublin bzw. Salmonella typhimurium aus dem Darminhalt der Tiere und aus Gras. Die betreffende Grünfläche war zuvor mit Klärschlamm gedüngt worden.

In vier weiteren Betrieben diagnostizierten wir nach Klärschlammdüngung sporadische Salmonellen-Infektionen (2).

Ungleich häufiger als die erwähnten klinisch manifesten Ausbrüche sind stumme Infektionen. Die Verseuchungsrate in unseren Rindviehbeständen ist innerhalb der letzten 14 Jahre um ein Mehrfaches angestiegen. Neuerdings haben wir in 5 Schlachthöfen bei 2,5 % von 2'500 klinisch gesunden Schlachtrindern und -kühen Salmonellen isoliert.

Dass die Verseuchungsdichte in Gebieten mit Klärschlammdüngung während der Grünfütterungsperiode jeweils signifikant ansteigt, haben wir an einem Untersuchungsmaterial von über 20'000 Proben bewiesen. Der Prozentsatz infizierter Schlachttiere kulminierte in den Monaten August und September. Die hochsommerliche Spitze führen wir auf den zeitlich massierten Austrag von unhygienisiertem Klärschlamm im Anschluss an die Heuernte zurück, vor allem aber auf das besonders kurze Intervall zwischen Düngung und Weidegang bzw. Grasschnitt z.Z. der Periode intensivsten Wachstums. Bezeichnend ist, dass wir bei unseren Mastschweinen mit permanenter Stallhaltung keine derartige saisonale Häufung der Salmonelleninfektionen feststellten.

Von Abwasserfachleuten wird immer wieder behauptet, die Salmonellenbelastung von Klärschlamm sei mit derjenigen von Hofgülle vergleichbar. Deshalb haben wir Gülle aus 502 bäuerlichen Betrieben ohne Klärschlammverwendung untersucht. Wir isolierten Salmonellen nur aus 6 Gülleproben, d.h. in 1,2 % (3). Das Infektionsrisiko durch Düngung mit Hofgülle ist also zu vernachlässigen, verglichen mit demjenigen bei Verwendung von unhygienisiertem Klärschlamm.

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SURVIVAL OF SALMONELLAS AND ASCARIS EGGS DURING SLUDGE UTILIZATION IN FORESTRY

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Summary

Sludge utilization in forestry is increasing because many municipal sewage treatment plants have difficulties to dispose of their sludge. If it cannot be incinerated or dumped and if it is not accepted by farmers the utilization in forestry is often the ultimate solution. This is especially true for such communities who are in possession of own forest areas where they can act own their own discretion. This of course creates hygienic problems because usually it is not possible to till the sludge into the soil between the trees. Therefore contacts of man and animals with infected sludge in forests are most likely.

Experiments with salmonella - and ascaris eggs - infected sludge at 11 different habitats in a large wooded area were made to get information about the tenacity of these pathogens. If the sludge was spread in June the salmonellas survived up to 2 years, after spreading in December the survival time was only up to 1 year. Ascaris eggs survived for 60 and 76 days, respectively.

From these results it can be concluded that spreading of infectious sludge in forests may be highly dangerous for man, stray animals and game as well. It is therefore necessary to make use of protective measures to avoid infections.

1. INTRODUCTION

According to an estimation of the Federal Government in 1985 about 50 million tons of municipal and 30 million tons of industrial sewage sludges will be produced in the Federal Republic of Germany per year. These considerable amounts have to be disposed of by the municipalities and the various industries. Possible methods for sludge disposal are: utilization in agriculture, horticulture, forestry and landscape architecture, storing in sanitary landfills or incineration.

It is well documented that raw municipal sludges as well as anaerobically digested sludges usually contain considerable amounts of pathogenic agents like bacteria, viruses and parasites which may cause infectious diseases of man and animals under certain circumstances (1). Therefore all these sludges are to be considered as infectious agents as long as they are not treated by disinfecting methods prior to their use in agriculture, horticulture and forestry.

Small communities with sewage treatment plants have sometimes difficulties to dispose of their sludge when the farmers do not accept them for utilization in agriculture because they are afraid of possible infections of the chains soil-plant-animal-consumer or soil-plant-consumer. Many of these communities are in possession of own forest areas which they use for the disposal of their surplus sludges, unfortunately very often without any consideration of hygienic and epidemiological aspects.

Based on the knowledge about the occurrence and viability of pathogens in municipal sludges we made some experiments in a large forest area near Stuttgart (Schönbuch) on plots of 11 different habitats with infected sludge. It was studied how long salmonellas and eggs of ascaris suis survive in these different habitats when the sludge was distributed on the plots either in the summer (June) or in the winter (December).

2. MATERIALS AND METHODS

In the area of the State Forest Office Weil im Schönbuch 11 plots in different habitats were selected according to the following contrast and comparing couplings:

- broad-leaved/coniferous forest,
- closed/open forest stand/free area (culture),
- high biological soil activity (mull)/ inhibited biological soil activity (raw humus). Different pH-ranges,
- sandy/loamy/clayey substrate.

A summary of the 11 experimental plots is given in Table 1. All of them are located in the zone of triasic sandstone and bulbous marl. The average temperature through the year is ca. 8.3°C, the average precipitation 739 mm. The plots were fenced (3 x 4 m) to avoid contact of the infected sludge with man and game and are far away from frequently used ways.

Within the fences infected municipal sludge (Salmonella senftenberg 10^7 ml) was spread on marked areas. In addition small patches of leather infected with dried salmonellas and small bags from silk gauze with 2 millions of eggs of Ascaris suis each were distributed on the plots. Ascaris suis from pigs is very similar to Ascaris lumbricoides of man so that they hardly can be differentiated.

Before the sludge was spread, on each plot a layer of leather patches and silk gauze bags was given which was then covered with infected sludge. On top of this another layer of leather patches was given. On each plot one maximum thermometer was put into the soil and one layed on the sludge.

Experiment No. 1 started in June (summer), No. 2 in December (winter). The layer of sludge spread on the plots was 1 cm/m^2 in exp. No. 1 and 2 cm/m^2 in exp. No. 2 which corresponded to 100 m^3/ha and 200 m^3/ha.

Samples were collected from each plot once a month: 1 leather patch from ground and surface,1 silk gauze bag from the ground and 1 sample of sludge. After a certain time the sludge was washed out by rain- and snowfall. In that case samples were taken from foliage, plant growth or the surface of the soil, depending on the circumstances.

The samples were investigated in the laboratory: salmonellas with pre-enrichment (18 h 37°C) in peptone-water and enrichment (15 min water-bath 45°C, 24/48 h 43°C) in tetrathionatebroth (Müller-Kaufmann). The ascaris eggs were resuspended in water and incubated for 40 days at 29°C.

Table 1: Location Of The Experimental Plots Classified According To Forest Stand, Lighting, Humus And Chemical Reactions

Substrate / Forest Stand	Broad-Leaved Forest	Coniferous Forest		Culture (Open Area)
Sand	5 Beech, Oak, ca.100 Years, Muck/Raw Humus, Coarse Sand From Triasic Sand-stone pH 3.8 (H_2O) 3.3 (KCl)	1 Fir, ca. 80 Years Raw Humus, Coarse Sand From Triasic Sandstone pH 3.6 (H_2O) 3.1 (KCl)	4 Fir, Pine, ca.110 Years, Raw Humus, Coarse Sand pH 3.9 (H_2O) 3.1 (KCl)	
Loamy Sand		10 Pine, Beech, ca. 90 Years, Open, Raw Humus, Loamy Sand pH 3.8 (H_2O) 3.1 (KCl)	9 Pine, Fir, ca.90 Years, Closed, Mull/Muck, Loamy Sand pH 4.7 (H_2O) 4.0 (KCl)	11 Fir, New Culture, Muck (Decaying), Loamy Sand pH 4.2 (H_2O) 3.5 (KCl)
Fine Sandy Loam	2 Beech (Oak) ca. 100 (160) Years, Mull-Humus, Fine Sandy Clay, Fine Loamy Covering pH 5.2 (H_2O) 4.4 (KCl)	8 Fir, ca.80 Years, Mull/Muck-Humus Fine Sandy Poor Loam pH 4.3 (H_2O) 3.6 (KCl)	3 Fir, ca. 40 Years, Closed Stand, Muck-Humus, Fine Sandy Loam-Loamy Clay, pH 4.5 (H_2O) 3.6 (KCl)	
Clay	6 Beech (Oak), ca. 130 Years, Mull/Muck-Humus, Clay pH 5.0 (H_2O) 4.2 (KCl)	7 Fir, ca.110 Years, Muck-Humus, Clay pH 4.8 (H_2O) 4.1 (KCl)		

If larvae II had developed they were fed to mice which were sacrificed after 48 h to investigate the livers.

3. RESULTS

Salmonella senftenberg

The tenacity of the salmonellas on leather patches from the surface (O), the ground (U) and in the sludge or the soil (K) of the 11 plots in the summer experiment is shown in Figure 1. The range of survival is between 270 and 640 days.

The results of the winter experiment are given in Figure 2. The survival range in this experiment is between 47 and 350 days.

For a quick survey the results of the summer and the winter experiment are summarized in Figure 3.

The control cultures of S. senftenberg which were stored in the refrigerator at 4°C survived during the summer experiment for 270 days and during the winter experiment for 258 days.

Ascaris suis

The results of the 2 experiments are summarized in Figure 4. The range of their survival is between 17 and 76 days.

The dry matter content of the sludge was 5.5% in the summer and 3.1% in the winter experiment. The maximum ambient temperatures in the first 2 months of the experiments were 41°C in the summer and 11°C in the winter.

4. DISCUSSION

The results show that salmonellas survive for a long time when they occur in municipal sludge which is spread in forest areas. This is apparently not substantially influenced by the habitats of the 11 different experimental plots.

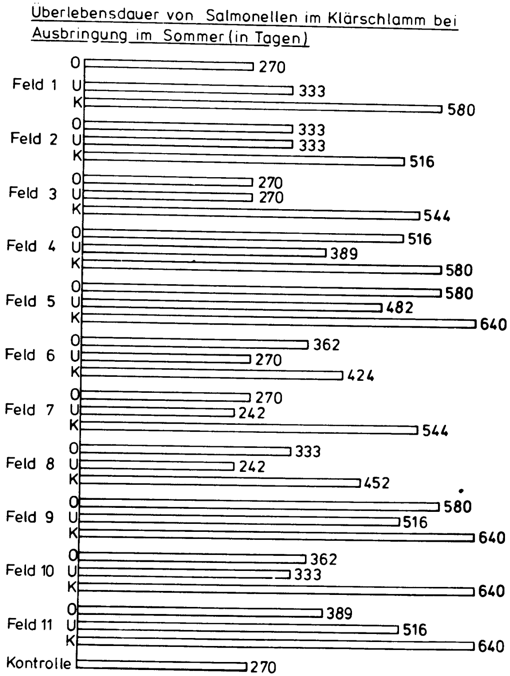

Figure 1: Survival of salmonellas in sludge after spreading in summer

0 = Leather patches on the surface
U = Leather patches on the ground
K = Sewage sludge
Feld = Field, exper. plot

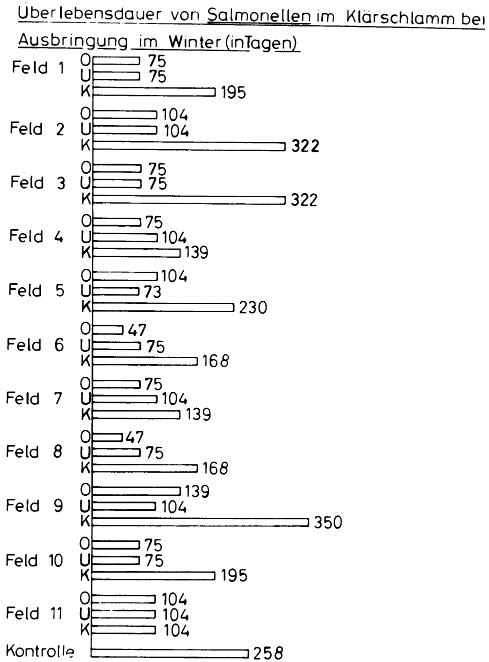

Figure 2: Survival of salmonellas in sludge after spreading in winter

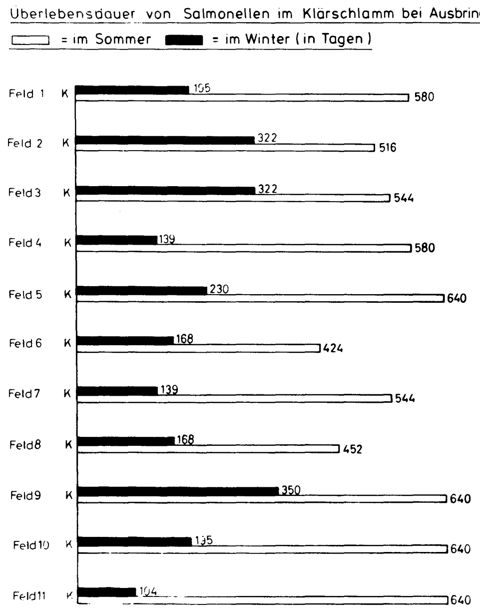

Figure 3: Survival of salmonellas in sludge after spreading in summer or in winter

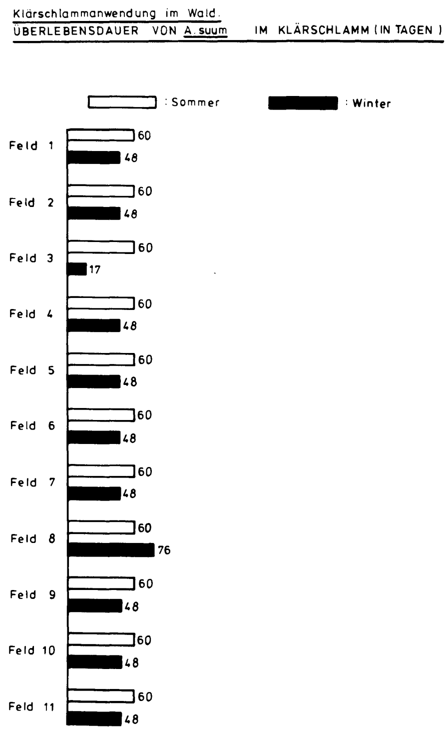

Figure 4: Survival of ascaris eggs in sludge after spreading in summer or in winter

On the other hand there seems to be a significant difference when the sludge is spread into the wooded area in the summer or the winter period. When the sludge was spread in June the maximum survival time of the salmonellas was 640 days. When it was spread in December the salmonellas survived only for 350 days. A possible explanation for this phenomenon is that the salmonellas could adapt themselves in the summer to their ambiente or they could even multiply stimulated by the high temperatures (41°C) so that they better could resist the unfavourable influences during the coming winter period. The salmonellas spread in December had none of these chances and therefore were exposed to the winter condition without any protection or resistance.

In both of the experiments the salmonellas usually survived much longer when they were suspended in the sludge than when they were adsorbed to the leather patches of the surface or on the ground of the plots. This also is an indication that the chances for survival are best within the sludge than on germ carriers.

The eggs of Ascaris suis showed no great differences of their viability during the summer or winter period. They are unable to multiply even during the summer outside of a host and therefore the results are very much the same in the 2 experimental periods: 60 days in summer and 48 days in winter. Only in fields No. 3 with 17 days and No. 8 with 76 days were minor differences in the winter experiment.

These results confirm our opinion, which was already published several years ago (2, 3, 4), that municipal sewage sludge which is not disinfected should not be used in forestry because a constant health hazard for man and game results from this utilization. In the wooded areas it is not possible to plough or till the sludge into the soil as it can be done on arable land. Therefore there is not much contact with the biologically active substrate of the upper soil layer which results in the fact that pathogens spread in wooded areas with sewage sludges remain viable and infectious for a longer time than on arable land.

Sewage sludge therefore should in principle be disinfected before it is used in forestry. If this is not possible due to local reasons, the areas where infectious sludge has been used must be fenced in to avoid contacts of man and animals with this infectious material.

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HYGIENIC EFFECTS OF SLUDGE PASTEURIZATION PRIOR TO ANAEROBIC DIGESTION (PRE-PASTEURIZATION)

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Summary

Pasteurization of sludge after anaerobic digestion resulted under practical conditions in many cases in recontamination of the stored sludge caused by using contaminated tubes for sludge transport or by infections with bird droppings or, possibly, by infected aerosols from the biological treatment processes. In Switzerland the pasteurization plants were closed down for a certain time to find out the reasons for these recontaminations.

Comparing experiments with salmonella-contaminated raw sludge, pasteurized before it was digested or stored without digestion, showed that recontamination can be reliably avoided. In none of these experiments salmonellas could be isolated. Salmonella-contaminated digested sludge was pasteurized after the digester and stored. Also in these cases recontamination was never found. There was a tendency towards multiplication of the total bacteria and the coliforms in pre-pasteurized sludge and in sludge pasteurized after digestion wheras salmonellas never could be isolated.

The results show that pre-pasteurization is a good means to avoid recontamination of digested sludge with salmonellas. But on the other hand it is also possible to avoid recontamination of digested sludge which is pasteurized and stored after the digestion process provided that exacting hygienic standards are applied. If these cannot be assured it is recommended to use the method of pre-pasteurization.

1. INTRODUCTION

Pasteurization of digested sewage sludge was considered to be a reliable method to obtain a hygienically safe sludge for use in agriculture. But very thorough investigations in Switzerland have shown that in 15 sewage treatment plants the pasteurized digested sludge was recontaminated with enterobacteriaceae and in 5 cases even with salmonellas during storage in open basins (1, 2, 3). As causes for this recontamination the authors mentioned that in none of the controlled plants the tubes for not-pasteurized and pasteurized sludge were consequently separated; some of the plants used biologically treated sewage for cleaning the tubes after pasteurization and they suspected recontamination in the storage basins by aerosols which are generated by nearby situated aeration tanks.

Stimulated by the Swiss results we started a research programm together with the Institute for Water Quality Management and Sanitary Engineering of the Technical University in Munich about the influence of pasteurization of raw sludge before digestion on technical and hygienic parameters. The following paper is restricted on the description of the bacteriological investigations.

2. MATERIALS AND METHODS

For the investigations 2 digesters with a volume of 500 liters each and 2 pasteurizers with a volume of 30 liters each were used (Fig. 1). One of the pasteurizers was mounted directly on the digester I to avoid recontaminations after pasteurization by directly filling the pasteurized raw sludge into the digester. Digester II was filled with raw sludge which was pasteurized after digestion.

At the beginning of the investigations the digesters were supplied daily with 25 l of pasteurized and raw sludge, respectively, and the total digestion time was 20 days. These data were changed in the following experiments that the daily sludge volume for the digesters was increased over 50 l to 75 l thus reducing the digestion time from 20 days over 10 days down to 7 days.

The pasteurization was done at 70°C for 30 minutes and the digestion temperature was held constantly at 33°C.

The raw sludge was infected with 250 ml of a suspension of Salmonella senftenberg W 775 containing 10 x 10^7 salmonellas/ml. The following bacteriological investigations were made: colony count, enterobacteriaceae count, salmonella isolation. Samples were taken at the following points (Fig. 1): P_1 raw sludge, P_2 after pre-pasteurization (VP), P_3 after digestion with pre-pasteurization, P_4 after digestion without pre-pasteurization, P_5 after digestion and pasteurization of digested sludge (NP).

To get informations about possible recontaminations and the biological stability tanks with pasteurized raw sludge, pre-pasteurized digested sludge and digested sludge pasteurized after digestion were placed in the experimental hall of the institute and close to a biological treatment basin in the experimental sewage treatment plant of the institute in Garching/Munich. The same bacteriological counts were made with these sludges as mentioned above.

3. RESULTS

Figure 2 shows the results in digester I (P_3). Colony count 73 x 10^5/ml, enterobacteriaceae 20.000/ml, salmonellas negative.

The results of digester II are given in Figure 3 (P_4). Colony count 85 x 10^5/ml, enterobacteriaceae 110.000/ml, salmonellas always positive. In Figure 4 the results of digester I and II are compared.

Comparing the pasteurization of raw sludge before digestion (P_2) with pasteurization of digested sludge (P_5) there are no significant results as far as enterobacteriaceae are concerned (less than 10/ml). The colony count in P_5 (Ø 21 x 10^4/ml) was slightly higher compared to P_2 (Ø 77 x 10^4/ml). In both samples salmonellas never could be isolated.

Storage of pre-pasteurized sludge showed that it had a biological stability. On the other hand there was a tendency for an increase in the numbers of colonies and enterobacteriaceae in the pasteurized digested sludges of both digesters. This observation was more evident in the digested sludge which was pasteurized after digestion than in the pre-pasteurized digested sludge.

Recontaminations of the stored sludges with salmonellas never occured.

4. CONCLUSIONS

Pre-pasteurization of raw sludge prior to digestion is a safe method to avoid salmonellas in the effluent of the digester. The disposition for recontamination of pre-pasteurized digested sludge seems to be less than that of not or only after digestion pasteurized sludges. So far our results confirm those of the Swiss working group (1). As far as the tendency for the increasing numbers of the colony counts and the enterobacteriaceae in the digested sludges is concerned our results do not correspond to those of the Swiss group. To find an explanation for this, more experiments are necessary.

Using exacting technical and hygienic conditions it is also possible to avoid recontamination with salmonellas of digested sludge which is pasteurized only after digestion. Under practical conditions it seems very difficult to achieve this demand (1). If these conditions cannot be ensured it is recommended to use the method of pre-pasteurization.

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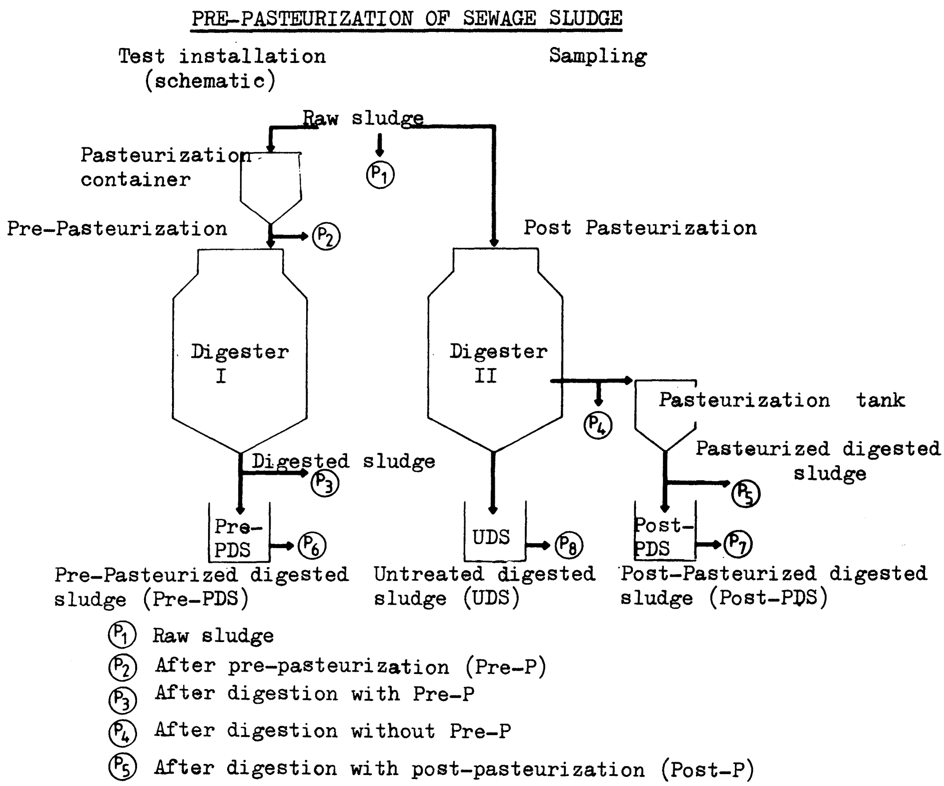

Figure 1: Scheme of the installations for the pre-pasteurization experiments

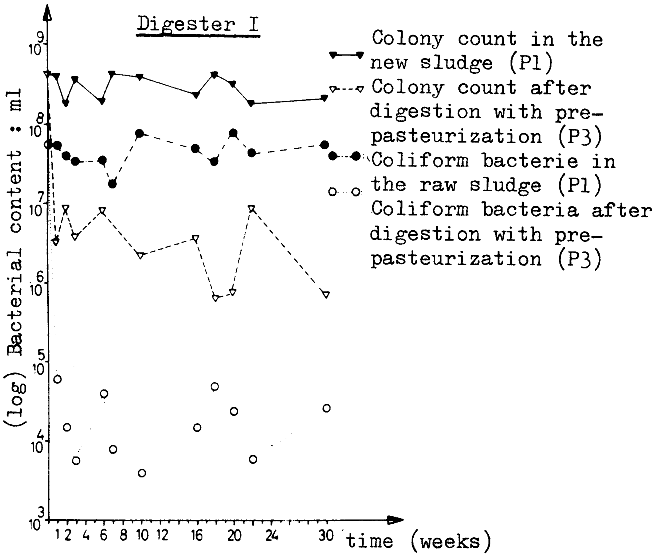

Figure 2: Colony count and entero-bacteriaceae in digester I

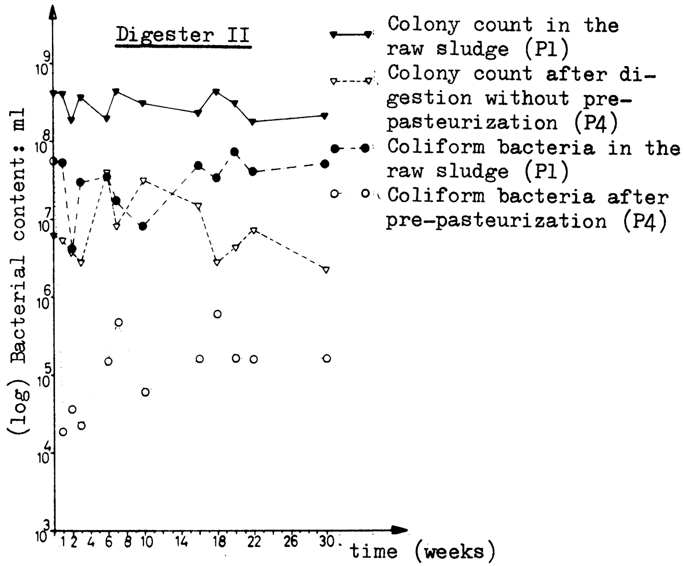

Figure 3: Colony count and entero-bacteriaceae in digester II

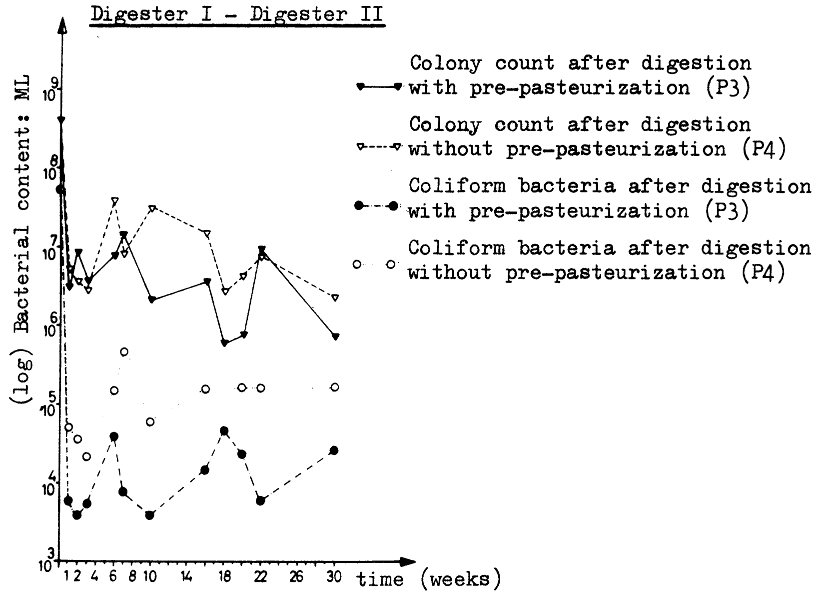

Figure 4: Comparison of the results in digester I and digester II

DIE PASTEURISATION VON FRISCHSCHLAMM

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Summary

In a pilot plant with an amount of about 160 tons of sewage sludge per day, we tested the effect of the pasteurization of raw sludge followed by anaerobic digestion. By weekly bacteriological examinations during one year of operation, we could demonstrate, that in the final product Enterobacteriaceae were not able to regrowth in case of recontamination. In two additional sewage disposal plants, we confirmed these findings and demonstrated, that the number of Enterobacteriaceae in the digestion rooms decreased within about 8 to 13 weeks from 10^4/g and 10^5/g respectively to less than 10 Enterobacteriaceae per gram. Beside this, Salmonellae could never be isolated in adequate pasteurized and subsequently digested sludge, which is therefore recommanded as a fertilizer for grassland.

Zusammenfassung

In einer Kläranlage mit einem täglichen Schlammanfall von rund 160 Tonnen untersuchten wir die Möglichkeit, Frischschlamm vor dem Faulprozess einer Pasteurisation zu unterziehen. Durch wöchentliche bakteriologische Kontrollen während eines Jahres konnten wir nachweisen, dass sich Enterobacteriaceen im pasteurisierten und anschliessend ausgefaulten Schlamm nicht mehr vermehren konnten. In zwei weiteren Kläranlagen liessen sich diese Befunde bestätigen. Hier konnte gezeigt werden, dass die Zahl der Enterobacteriaceen in den Faultürmen auch unter Praxisbedingungen innerhalb von 8 bis 13 Wochen von durchschnittlich 10^4/g bzw. 10^5/g auf weniger als 10 Enterobacteriaceen pro Gramm abnahm. Da wir ausserdem nie Salmonellen in derartig behandeltem Klärschlamm nachweisen konnten, kann der pasteurisierte und nachfolgend ausgefaulte Schlamm als Dünger von Grünland empfohlen werden.

Die Pasteurisation von Frischschlamm war ursprünglich vorgeschlagen worden, weil der Faulprozess im zuvor erhitzten Schlamm schneller und intensiver abläuft (4,5,7). Wir suchten in diesem Verfahren eine Alternative zur Faulschlammhygienisierung. Erhitzter Faulschlamm neigt nämlich zur Anreicherung von Rekontaminanten, namentlich von Enterobacteriaceen, die während der Lagerung in den behandelten Schlamm gelangen (1). Zudem unterbleibt bei der Frischschlammpasteurisierung die ständige Beimpfung der Faultürme mit Enterobacteriaceen-haltigem Rohschlamm, sodass mit einer langsamen Verarmung dieser Keime im ausgefaulten Schlamm zu rechnen war. Da ausserdem der völlig geschlossene Nachfaulraum als Stapelbehälter zur Verfügung steht, ist die Gefahr einer Rekontamination weitgehend gebannt.

Für unsere Untersuchungen standen uns zunächst in einer Kläranlage zwei vollständig getrennte Achsen mit je einem Vor- und Nachfaulraum (Fassungsvermögen jeweils 1'800 m^3) zur Verfügung. Der Frischschlamm für die Achse I wurde vor dem Ausfaulen in einem Chargenpasteur auf 70 ^{o}C erhitzt und während 30 Minuten bei dieser Temperatur heissgehalten. Anschliessend kühlten wir den pasteurisierten Schlamm in einem Wärmeaustauscher so weit ab, dass die Temperatur im Vorfaulraum - ohne zusätzliche Heizung - durchschnittlich 34,6 ^{o}C betrug. Der Schlamm im ungeheizten Nachfaulraum hatte im Mittel 32 ^{o}C. Parallel zu dieser Achse I wurde die gleiche Menge Rohschlamm in der Achse II ohne vorherige Pasteurisierung ausgefault. Die Temperaturen betrugen hier im Durchschnitt 32,7 ^{o}C im Vorfaulraum II und 30,8 ^{o}C im Nachfaulraum II.

Täglich fielen durchschnittlich 160 m^3 Schlamm an, wobei der Trockenrückstand des Frischschlammes im Mittel 4,96 % mit einem organischen Gehalt von 1,97 % betrug. Sein pH-Wert schwankte zwischen 5,8 und 6,4. Der anfallende Frischschlamm wurde zunächst in einem Voreindicker aufgefangen und von dort gleichmässig auf beide Achsen verteilt. Nach jeder Füllung der 5 m^3 fassenden Pasteurisierungsanlage in der Achse I wurde auch dem Vorfaulraum II die gleiche Menge Frischschlamm eingespeist. Auf diese Art war gewährleistet, dass beide Achsen gleichartigen Schlamm enthielten und die so gewonnenen Resultate vergleichbar waren. Vor Beginn der Versuche waren beide Vorfaulräume mit nicht pasteurisiertem Faulschlamm gefüllt. Auf eine Leerung der Faultürme wurde im Hinblick auf die spätere Praxis verzichtet.

Die bakteriologische Stufenkontrolle umfasste den Frischschlamm im Voreindicker sowie in beiden Achsen den Vorfaulraum, den Nachfaulraum und die Abgabestelle. In Achse I kontrollierten wir zusätzlich zwei Proben aus der Leitung zwischen Pasteur und Vorfaulraum, eine unmittelbar nach dem Pasteur und eine kurz vor Einmündung in den Faulturm. Als Indikatoren für ausreichende Hygienisierung des Klärschlammes diente uns die Gesamtzahl der Enterobacteriaceen.

Die Enterobacteriaceen-Zahl sank im Vorfaulraum der Achse I innerhalb von 3 Wochen nach Aufnahme der Frischschlamm-Pasteurisierung kontinuierlich von 109'000/ml auf 500/ml. Nach weiteren 10 Wochen lag ihre Zahl unter 10/ml und blieb während der ganzen Versuchsdauer, mit Ausnahme von 2 absichtlichen Betriebsunterbrüchen in der Pasteurisierungsanlage, auf diesem Wert. Salmonellen waren im Vorfaulraum nur während der ersten 2 Wochen nach Beginn der Untersuchungen nachweisbar, alle nachfolgend erhobenen Proben erwiesen sich als negativ. Im Nachfaulraum fiel der Enterobacteriaceen-Gehalt mit einer Verzögerung von etwa einer Woche gegenüber dem Vorfaulraum ebenfalls rasch ab. Zu Beginn der Versuche betrug er 9'000/ml, nach 5 Wochen 80/ml. Nach 13 Wochen wurde der Wert von weniger als 10 Enterobacteriaceen pro ml erreicht und dann, mit Ausnahme der erwähnten Unterbrüche, gehalten. An der Abgabestelle für den ausgefaulten Schlamm lagen ab der 12. Versuchswoche alle Werte unter 10 Enterobacteriaceen pro ml.

Im Vorfaulraum der Vergleichsachse II schwankte der Enterobacteriaceen-Gehalt stark, da dort ständig Frischschlamm zugemischt wurde, der zwischen 10 und 30 Millionen Enterobacteriaceen pro ml enthielt. Der Mittelwert lag im Vorfaulraum II während der ganzen Versuchsdauer bei 111'000 Enterobacteriaceen pro ml. Salmonellen waren in 69,8 % der 86 untersuchten Proben à 10 ml nachweisbar. Die Enterobacteriaceen-Zahlen im

Nachfaulraum II variierten wie im Vorfaulraum II ziemlich stark. Sie lagen schliesslich mit einem Mittelwert von 2'270/ml rund 3 Zehnerpotenzen höher als die Vergleichswerte aus der Achse I. Zudem konnten im Nachfaulraum II regelmässig Salmonellen nachgewiesen werden.

Mit zwei absichtlichen Betriebsunterbrüchen wollten wir feststellen, wie rasch die Enterobacteriaceen-Zahl nach einem Ausfall der Pasteurisation wieder auf den Ausgangswert von weniger als 10/ml absinken würde. Wir beschickten hierzu den Vorfaulraum I mit einer Charge (5 m^3) unpasteurisiertem Frischschlamm. In der Folge stieg der Enterobacteriaceen-Gehalt im Vorfaulraum sofort auf 6'500/ml an. Nach Wiederaufnahme der Pasteurisation sank die Zahl der Enterobacteriaceen innerhalb einer Woche wieder auf den Ausgangswert von weniger als 10/ml. Ein anschliessend simulierter zweiter Ausfall der Pasteurisierung hatte eine neuerliche Vermehrung der Enterobacteriaceen auf 4'600/ml zur Folge. Aber auch dieses Mal war ihre Zahl innerhalb von 2 Wochen nach Wiederbeginn der Pasteurisation auf den ursprünglichen Wert zurückgegangen. Im Nachfaulraum der Achse I stieg die Enterobacteriaceen-Zahl nach beiden Unterbrüchen ebenfalls an und fiel mit einer zeitlichen Verzögerung von ca. 3 Tagen gegenüber dem Vorfaulraum wieder auf unter 10/ml.

Die von Staab (6) in Modellversuchen beobachtete Verbesserung der Faulung liess sich bei unseren Vergleichsuntersuchungen nicht vollumfänglich bestätigen. In bezug auf die produzierte Gasmenge und den Heizwert des Gases fanden wir kaum nennenswerte Differenzen. Auch in der Gaszusammensetzung konnten wir keine Unterschiede feststellen. Dagegen war die Trübwasser-Abscheidung im pasteurisierten Frischschlamm besser. Die durchschnittliche Menge des Trübwassers lag in der Achse I nach Abzug des Kondensates rund 8 % höher als im herkömmlich ausgefaulten Schlamm. Demzufolge war auch der Trockenrückstand im Abgabeschlamm der Achse I mit 7,09 % entsprechend höher als in der Achse II mit 6,42 %. Der Anteil der Schwebestoffe war im Trübwasser des Nachfaulraumes I gegenüber den Vergleichswerten um rund 50 % geringer.

In zwei weiteren Kläranlagen konnten wir die in den Vergleichsuntersuchungen gewonnenen Erkenntnisse überprüfen und unter Beweis stellen. Bei beiden Anlagen handelte es sich um Pasteurisierungseinrichtungen, die den anfallenden Frischschlamm ebenfalls chargenweise erhitzten. In einem Fall betrug der mittlere Frischschlammanfall 127 m^3 pro Tag, im anderen rund 10 m^3 pro Tag.

Die bakteriologischen Reihenuntersuchungen ergaben in beiden Anlagen, dass der Gehalt an Enterobacteriaceen im Vorfaulraum innerhalb von 8 bis 13 Wochen von ursprünglich durchschnittlich 10^4/ml bzw. 10^5/ml auf unter 10/ml abfiel. Dieser Wert wurde anschliessend konstant beibehalten. Kleinere Pannen im Pasteurisierungssystem, wie sie nach Inbetriebnahme der Einrichtung gelegentlich auftraten, hatten keinen Einfluss auf die Keimzahl im Faulraum. In den Nachfaultürmen sank die Zahl der Enterobacteriaceen mit geringfügiger zeitlicher Verschiebung parallel zum Keimgehalt in den Vorfaulräumen. Auch hier wurde der Grenzwert von weniger als 10 Enterobacteriaceen pro ml nicht mehr überschritten. Da nach Aufnahme der Frischschlammpasteurisierung im ausgefaulten Abgabeschlamm der beiden Anlagen auch nie wieder Salmonellen nachgewiesen werden konnten, ist derartig behandelter Schlamm ohne weiteres als Dünger von Grünland zu verwerten.

Da die beiden Pasteurisierungseinrichtungen mit Wärmeaustauschern ausgestattet waren, die über einen ausreichenden Wirkungsgrad verfügten, liessen sich auch Untersuchungen über den Energieverbrauch anstellen. In beiden Kläranlagen lag der Gesamtenergieaufwand für die Frischschlammpasteurisierung nur unwesentlich höher als bei der vorgängig praktizierten Faulung ohne Pasteurisierung (2,3). Zu berücksichtigen ist allerdings, dass folgende Bedingungen eingehalten werden müssen:

- Möglichst weitgehende Eindickung des zu behandelnden Frischschlammes.
- Optimale Wärmerückgewinnung.
- Weitgehende Isolierung der gesamten Anlage, wenn möglich auch des Faulturmes.
- Angepasste Faulraumtemperatur.

Die Erfahrungen in den drei Kläranlagen haben gezeigt, dass das Prinzip der Frischschlammpasteurisierung als vertretbare Lösung für die ganzjährige Klärschlammhygienisierung empfohlen werden kann.

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COMPORTEMENT DES SPORES DE *CLOSTRIDIUM* SULFITO-REDUCTEURS APPORTEES AU SOL LORS DES EPANDAGES DE BOUES

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RESUME

Peu de publications, traitant des problèmes d'hygiène relatifs à l'épandage des boues sur les sols, considèrent le cas des *Clostridium*. Cependant ces bactéries sporulées, dont divers représentants sont pathogènes, abondent dans les boues à raison de $\pm\ 10^5$/ml.

En appliquant au sol 50 à 100 m^3 de boues liquides par hectare, on observe un accroissement important des spores. Cette situation persiste pendant de nombreux mois, en surface, car la migration est faible en raison de la formation d'une croûte assez stable qui retient les spores.

Huit mois après épandage sur prairie, la partie inférieure des graminées portent $\pm\ 10^5$ spores par gramme de matière fraîche alors que sur les plantes témoins on en trouve moins de 100.

Divers essais, réalisés en serre et en conditions naturelles montrent que le problème des *Clostridium* mérite de retenir l'attention, d'autant plus que les traitements d'hygiénisation affectent peu la population des *Clostridium* des boues.

SUMMARY

Only a few papers, dealing with the sanitary problem linked to the spreading of sludges on the soils, consider the case of *Clostridia*.

Though, these sporulating bacteria, some of which are pathogens, are currently founded in the sludges ($\pm\ 10^5$/ml).

When spreading 50 to 100 m^3/ha, the clostridial population of the soil surface rises considerabily, owing to the formation of a stable crust. The situation persists for a long time. The migration in depth is very slow.

Eight months after the treatment of a meadow with sludges, the lower part of the grass bears $\pm\ 10^5$ spores per gram of fresh matter whereas less than 10^2 spores are founded in the controls.

Several trials carried on in the greenhouse and in the fields show that the problem of *Clostridium* must be examined because spores are resistant to sanitary treatments.

1. INTRODUCTION

Il existe de nombreuses publications traitant des risques liés à la présence de *Salmonella* dans les boues. Il en est peu qui considèrent le cas des *Clostridium*, dont la résistance aux traitements d'hygiénisation est pourtant plus grande, en raison de leur aptitude à sporuler. Le groupe des *Clostridium* rassemble cependant quelques espèces redoutables qui méritent, à nos yeux, de retenir l'attention. C'est pourquoi notre groupe réalise actuellement un programme d'étude concernant les dangers éventuels tenant à l'épandage de boues fraîches (5 à 10 % de M.S.). Ces boues, d'origine urbaine, contiennent presque toujours quelques centaines de milliers de spores de *Clostridium* sulfito-réducteurs par ml.

Le programme prévu est le suivant :

a) Contamination de l'air lors des épandages par aspersion

b) Contamination du sol : - en surface
- en profondeur

c) Contamination des herbages et des animaux

d) Contamination des légumes

e) Contamination des eaux de surface

f) Contamination des nappes aquifères

Dans tous les cas, une tentative d'identification des espèces est prévue.

Dans ce papier, nous nous limiterons à décrire et à commenter les premiers essais concernant la migration des spores dans la profondeur du sol ainsi que leur persistance dans les sols et sur les herbages.

2. EXPERIMENTATION

2.1. Persistance et migration en profondeur des spores de *Clostridium* sulfito-réducteurs apportées au sol par les boues

2.1.1. Essai en champ

A. Conditions expérimentales :

a) le sol : l'expérience est réalisée dans la région de Gembloux, sur limon hesbayen. La zone considérée ne présente pas de pente.

b) <u>les parcelles</u> : trois parcelles carrées de 16 m^2 sont situées côte à côte. Une parcelle extérieure reçoit l'équivalent de 100 m^3 de boue par hectare, l'autre sert de témoin. La parcelle médiane sert de tampon, empêchant les interférences entre parcelles extrêmes qui servent pour les dénombrements de *Clostridium*.

c) <u>la boue</u> : provient d'une station d'épuration traitant des eaux usées urbaines. Elle contient 450.000 spores de *Clostridium* par ml. Son pH est de 6.5 et sa teneur en matières sèches vaut 6,5 %. Quelques jours après l'épandage, la terre est traitée à l'extirpateur sur 10 cm de profondeur afin de briser la croûte qui s'est formée. Malgré cette tentative d'homogénéisation, la quasi-totalité de la croûte reste en surface sous forme de fragments nettement visibles.

d) <u>les prélèvements</u> : périodiquement, deux échantillons de sol sont prélevés aseptiquement dans chacune des deux parcelles à l'aide d'une sonde électrique flambée, sur 90 cm de profondeur. Pour les analyses, la carotte prélevée est découpée en trois parties : 0 - 30 ; 30 - 60 et 60 - 90 cm.
Dans la parcelle traitée à la boue, un des deux prélèvements passe systématiquement par un fragment de croûte de surface tandis que l'autre évite d'emporter un tel fragment. Ceci vise à contrôler si les croûtes constituent des refuges à bactéries. Dans le tableau des résultats, les prélèvements avec croûte sont marqués d'un astérisque.

e) <u>entretien du sol</u> : pendant la durée de l'essai, les parcelles sont maintenues sans végétation.

f) <u>les comptages</u> de *Clostridium* sont réalisés en tubes de MILLER-PRICKET (1939), sur milieu de MOSSEL (1959). Les suspensions-dilutions sont chauffées dix minutes à 80°C avant les ensemencements. Il s'agit donc d'un comptage de spores.

B. Résultats (voir tableau I)

Nombre de semaines après épandage	Profondeur en cm	*Clostridium* par gr. de M.S.			
		Parcelle traitée		Parcelle traitée	
		Echant. 1	Echant. 2	Echant. 3	Echant. 4
2	0 - 30	7.060°	1.300	1.960	1.060
	30 - 60	280	0	160	265
	60 - 90	65	25	150	540
4	0 - 30	5.000°	1.600	190	10
	30 - 60	380	120	280	0
	60 - 90	100	90	10	85
6	0 - 30	40.500°	2.150	330	480
9	0 - 30	4.100°	6.300	850	350
	30 - 60	600	120	1.000	100
	60 - 90	180	20	200	220
12	0 - 30	1.000°	1.000	200	100
	30 - 60	160	240	70	-
	60 - 90	100	50	230	-
16	0 - 30	-	5.000	1.200	-
	30 - 60	-	40	20	-
	60 - 90	-	20	0	-

Tableau I : Effet d'un apport de boue sur la teneur en *Clostridium* d'un sol (résultats par g. de M.S.)
(°) échantillons avec fragment de croûte de surface.

C. Commentaires :

a) l'effet croûte : l'examen visuel des parcelles révèle que les fragments de boue séchée persistent pendant un peu plus de 6 semaines. Après celà, ils se délitent et deviennent difficilement repérables.
Il est intéressant de noter que pendant les 6 premières semaines, les échantillons de surface prélevés dans une plage porteuse d'une croûte sont généralement les plus chargés en *Clostridium*.

b) la persistance en surface : en dépit d'une certaine hétérogénéité des résultats, l'apport de boue se traduit par un accroissement sensible du nombre de spores dans les 30 premiers cm.

c) la migration en profondeur : est manifestement faible ou nulle. Tout se passe comme si les spores étaient emprisonnées dans les croûtes même lorsqu'elles sont réduites à de plus faibles dimensions. La poursuite de l'essai montrera si une libération se produit à la longue.

2.1.2. Essai en vase de végétation

A. Conditions expérimentales :

il s'agit de colonnes émaillées de 30 cm de hauteur et de 25 cm de diamètre. Ces colonnes s'adaptent par la base, qui est percée de trous, à un récipient hermétique destiné à récolter les percolats. Pour éviter que des fragments de sol passent dans le filtrat, une toile de nylon garnit le fond des vases.

Les vases sont remplis de sable stérile sur une hauteur de 20 cm et la moitié d'entre eux reçoit une dose de boue liquide correspondant à peu près à 100 m^3/ha (0,5 l par vase) et contenant 535.000 spores de *Clostridium* par ml. La teneur en matières sèches et de 6,6 %.

Des dénombrements périodiques de *Clostridium* sont effectués sur 2 vases sacrifiés : à 3 profondeurs dans le sable, sur un fragment de croûte et sur une aliquote du percolat.

L'essai a débuté en serre, pendant une période de gel qui s'est maintenue pendant un mois. Pendant ce temps, 5 arrosages de 250 ml d'eau stérile ont été appliqués. Au dégel, les vases ont été enterrés au 2/3 au voisinage de l'essai précédent, les plaçant ainsi dans des conditions de pluviosité naturelle. A noter que les vases témoins sont restés vierges de *Clostridium*.

B. <u>Résultats</u> (voir tableau II)

Nombre de semaines après épandage	Nature des prélèvements	*Clostridium* /g. M.S.		Percolats récoltés (en ml)
		Répétition 1	Répétition 2	
2	Croûte	12.000.000	7.400.000	
	Sable : 0- 6cm	0	10	
	6-12cm	0	0	
	12-18cm	0	0	
	Percolat	0	0	840
4	Croûte	4.800.000	3.900.000	
	Sable : 0- 6cm	380	420	
	6-12cm	220	90	
	12-18cm	0	50	
	Percolat	0	0	956
8	Croûte	7.200.000	5.900.000	
	Sable : 0- 6cm	580	790	
	6-12cm	70	360	
	12-18cm	60	70	
	Percolat	18	17	1.230
12	Croûte	6.200.000	6.350.000	
	Sable : 0- 6cm	380	480	
	6-12cm	10	120	
	12-18cm	70	30	
	Percolat	18	15	3.230

Tableau II : Persistance et migration des *Clostridium*

C. <u>Commentaires</u> :

Pour faciliter l'interprétation des résultats, il est intéressant de dresser, après chaque prélèvement, le bilan des *Clostridium* assorti de leur répartition dans les horizons considérés.

Nous indiquons ci-après les résultats calculés à partir des données de la douzième semaine (résultats moyens).

Rappelons les données utilisées pour les calculs (tableau III) :

Boue : 535.000 spores/ml

Matière sèche : 6,6 %

Chaque vase reçoit 500 ml de boue fraîche

Sable sec : il pèse 2.500 grammes par tranche de 6 cm

Percolat récolté : 3.230 ml.

On formule en plus l'hypothèse qu'aucune perte ni transit de matière sèche n'a eu lieu à partir de la croûte c'est-à-dire que le poids sec de la croûte est toujours de 33 grammes.

Horizons	Nombre de *Clostridium*	%
Croûte de départ	267.500.000	100
Croûte après 12 semaines .	207.075.000	77.41
Sable après 12 semaines :		
0 - 6 cm	1.075.000	0.40
6 - 12 cm	162.500	0.06
12 - 18 cm	125.000	0.05
Percolat	53.295	0.02

Tableau III : Répartition des *Clostridium* après 12 semaines

Conclusions :

1) la survie des *Clostridium* dans la croûte est grande. Elle est de plus de 77 % après 12 semaines.

2) la migration au départ de la croûte est faible et lente. Après 12 semaines seulement 0.53 % de spores vivantes se retrouvent dans le sable sous-jacent ou dans le percolat. D'autre part (tableau II), il faut entre 4 et 8 semaines pour que des spores vivantes traversent les 18 cm de sable.

2.2. Persistance des spores de *Clostridium* dans des parcelles de Ray-Grass (*Lolium perenne*)

A. Conditions expérimentales :

Un champ d'essai comprenant 3 parcelles de Ray-grass ayant reçu 51 m^3 de boue à l'hectare et 3 parcelles témoins a été mis à notre disposition.

Huit mois après l'application des boues et alors que deux coupes avaient été effectuées, nous avons remarqué, après la deuxième repousse, la présence persistante au pied des plantes traitées, d'une fine croûte de boue. C'est pourquoi nous avons procédé à des dénombrements comparatifs de *Clostridium* chez les plantes traitées et chez les témoins.

Les parties de plantes prélevées vont du ras du sol à l'aisselle de la première feuille. Pour les parcelles traitées, on a prélevé deux échantillons par parcelle. 25 grammes de matière fraîche sont soumis à l'analyse.

B. Résultats (voir tableau IV)

Parcelles n°	Nombre de *Clostridium* par gramme de matière fraîche		
	Parcelles traitées		Parcelles témoins
	Echantillon 1	Echantillon 2	
1	2.900	37.000	30
2	140.000	460.000	50
3	190.000	490.000	30

Tableau IV : Persistance des *Clostridium* sur des pieds de Ray-grass, 8 mois après l'application des boues

C. Conclusions :

Une nouvelle preuve de la persistance des *Clostridium* dans les croûtes desséchées est fournie par cet essai. Le fait constitue, ici, un danger potentiel de contamination du bétail que nous vérifierons prochainement.

2.3. Conclusions générales

L'épandage de boues liquides sur les terres agricoles accroît la teneur en spores de *Clostridium* de celles-ci.

L'effet porte sur la zone superficielle du sol (0 - 30 cm) car la migration est faible, pendant plusieurs mois, à la suite de la formation de croûtes desséchées qui ne se délitent que lentement et dans lesquelles la survie des spores est importante.

Si les dangers de contamination des nappes aquifères semblent faibles, il n'en est pas de même de la surface des sols et plus particulièrement des herbages où les pieds des graminées restent porteurs, pendant plus de 8 mois, d'une croûte à forte concentration de spores. Sachant que certains *Clostridium* sont des germes redoutables, on peut se demander s'ils ne réclament pas plus d'attention qu'on ne leur en accorde généralement lors des épandages de boues.

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LES *CLOSTRIDIUM* ET L'HYGIENISATION DES BOUES DE STATIONS D'EPURATION PAR LES RAYONS GAMMA

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RESUME

Si l'on considère l'aspect économique de l'irradiation des boues, la dose de 300 Krad semble intéressante. Elle est très efficace sur les bactéries non sporulées mais a peu d'effet sur les bactéries sporulées comme les *Clostridium* dont 60 % à peu près échappent au traitement.

Afin d'améliorer ces résultats, nous avons cherché à obtenir un effet synergique entre irradiation à 300 Krad et apport de peroxyde de calcium. Les résultats sont prometteurs.

SUMMARY : *CLOSTRIDIA* AND SLUDGES HYGIENISATION WITH GAMMA RAYS

If we consider the economical aspect of sludges irradiation, the dosis of 300 Krad seems quite satisfactory, at least for unsporulated bacteria. But, at this level, sporulating bacteria such as *Clostridia* didn't disappear : more than 60 percents of spores escaped the treatment.

In order to ameliorate the results, we have tried to obtain synergistic effect between gamma rays and calcium peroxyde. In definite conditions, the results were promising.

. INTRODUCTION

L'irradiation par les rayons γ est une manière d'hygiéniser les boues avant leur emploi en agriculture. Une dose reçue de l'ordre de 300 Krad est opérante vis-à-vis des *Salmonella* et des indicateurs de contaminations fécales (LESSEL et al., 1975; SUESS et LESSEL, 1977; BRAKEL et al., 1978; LESSEL et SUESS, 1978). Par contre le même traitement a peu d'impact sur des bactéries sporulées comme les *Clostridium* sulfito-réducteurs (BRAKEL et al., 1978) dont les apports massifs aux sols pourraient être inopportuns. Comme des impératifs économiques limitent les doses aux environs de 300 Krad, nous avons envisagé de renforcer l'action des rayons γ par un apport de peroxyde de calcium au moment de l'irradiation. On sait en effet que l'oxygène est susceptible d'agir en synergisme avec les rayons γ (WOODBRIDGE et al., 1975; HOLL et SCHNEIDER, 1975; SINSKEY et al., 1975; ALEXANDRE et GEVAUDAN, 1977).

2. MATERIEL ET METHODES

Le dénombrement des *Clostridium* sulfito-réducteurs s'effectue sur le milieu de MOSSEL (1959) en tubes de MILLER-PRICKET (1939). Les suspensions-dilutions de boues sont chauffées à 80°C pendant 10 minutes avant les ensemencements : les comptages concernent donc exclusivement les formes sporulées. Les incubations se font à 37°C et seules les colonies noires ou grises sont prises en considération.

Dans certains essais, les Coliformes et les Streptocoques fécaux sont considérés à titre de comparaison. Les Coliformes sont dénombrés sur gélose au désoxycholate tandis que les Streptocoques sont comptés en milieu liquide (milieux de ROTHE et LITSKY).

Les irradiations sont réalisées sur 400 ml de boue dans un irradiateur GAMMIR I. Il s'agit d'un dispositif classique au ^{60}Co. Les variations de dose à l'intérieur de la cellule sont de l'ordre de 10 %.

Le pH des boues utilisées se situe entre 6.8 et 7.0 et le pourcentage en matières sèches est proche de 5 %. Il s'agit de boues d'origines urbaines.

Tabl. I - Action de doses croissantes d'irradiation sur diverses populations bactériennes d'une même boue

Doses en Krad	*Clostridium*/ml			Coliformes/ml			Streptocoques fécaux/ml		
	N	log N	% résiduels	N	log N	% résiduels	N	log N	% résiduels
0	330.000	5,52	-	6.200.000	6,79	-	95.000	4,98	-
300	203.000	5,31	61,5	170	2,23	0,003	25.000	4,40	26,3
500	190.000	5,28	57,60	1	0,00	0,00002	2.500	3,39	2,7
750	125.000	5,10	37,90	0	-	0	450	2,65	0,5
1000	56.000	4,75	16,9	0	-	0	45	1,65	0,05

Tabl.II - Effet de 300 Krad sur les Clostridium, les Coliformes et les Streptocoques fécaux

Echantillon n°	*Clostridium*/ml			Coliformes/ml			Streptocoques fécaux/ml		
	0 Krad	300 Krad	% résiduels	0 Krad	300 Krad	% résiduels	0 Krad	300 Krad	% résiduels
1	330.000	203.000	61,5	6.200.000	170	0,0027	95.000	25.000	26,3
2	200.000	140.000	70,0	2.300.000	10	0,0004	150.000	25.000	16,7
3	410.000	230.000	56,1	630.000	13	0,0021	450.000	7.500	1,7
4	180.000	130.000	72,2	680.000	36	0,0053	95.000	25.000	26,3
5	390.000	250.000	64,1	240.000	9	0,0037	250.000	4.500	1,8
6	320.000	200.000	62,5	250.000	270	0,1080	250.000	4.500	1,8
7	340.000	230.000	67,6	950.000	-	-	450.000	4.500	1,0
8	243.000	209.000	86,0	193.000	220	0,1140	450.000	4.500	1,0
9	257.000	200.000	77,8	109.000	56	0,0514	95.000	9.500	10,0
10	300.000	240.000	80,0	290.000	11	0,0038	75.000	4.500	6,0
11	310.000	185.000	59,7	370.000	121	0,0327	95.000	9.500	10,0
Moyennes	298.200	201.500	67,6			0,0324			9,3

. EXPERIMENTATION

Elle comprend actuellement trois parties :

- irradiations à doses croissantes, sans CaO_2
- irradiations à 300 Krad, sans CaO_2
- irradiations à 300 Krad, en présence de CaO_2

3.1. Action de doses graduées d'irradiation, sans CaO_2

Le tableau I indique les résultats obtenus pour les *Clostridium*, les Coliformes et les Streptocoques fécaux de quatre échantillons d'une même boue soumis à 300, 500, 750 et 1000 Krad.

Commentaires : Les *Clostridium* résistent mieux que les Streptocoques, eux-mêmes moins sensibles que les Coliformes.

A 300 Krad, la population des *Clostridium* est peu altérée tandis que les Coliformes régressent de plus de quatre unités logarithmiques ce qui les amènent à un niveau dérisoire. Les Streptocoques fécaux perdent à peu près 75 % de leur effectif. A 1 Mrad, la D_{10} n'est pas encore atteinte pour les *Clostridium* alors que les deux autres groupes sont pratiquement éliminés.

3.2. Etude plus détaillée des irradiations à 300 Krad

Comme la dose de 300 Krad est souvent utilisée pour l'hygiénisation des boues, nous avons traité onze échantillons différents afin de mettre en évidence d'éventuelles variations liées à l'origine des boues (voir tableau II.).

Commentaires : les conclusions dégagées précédemment restent valables. Les écarts tenant à l'origine de la boue sont de peu d'importance.

On peut considérer qu'un ml de boue contient à peu près 300.000 spores de *Clostridium* sur lesquelles 300 Krad ont très peu d'impact (32,4 % de disparition). Comme le groupe des sulfito-réducteurs comprend des germes redoutables (*Cl.tetani*, *Cl.botulinum*, *Cl. perfringens*), il a paru intéressant d'essayer de renforcer l'action de 300 Krad en ajoutant du CaO_2 dont on pouvait attendre un effet synergique.

3.3. Recherche d'un synergisme rayons γ-oxygène

L'oxygène est apporté par du CaO_2 à 60 %. Selon les indications du fabricant, la libération de l'oxygène au pH des boues considérées (6.8 à 7.0) a lieu en 15 à 20 minutes, ce qui correspond à peu près à la durée d'exposition aux rayons γ pour atteindre une dose reçue de 300 Krad dans nos conditions d'activité.

Deux méthodes sont testées. La première consiste à mélanger le CaO_2 à la boue, immédiatement avant l'introduction dans la chambre d'irradiation. Pour la seconde, l'ensemble boue + CaO_2 est agité pendant l'irradiation, à l'aide d'un agitateur magnétique.

3.3.1. Essais sans agitation pendant l'irradiation

Le tableau III. montre que la présence de CaO_2 renforce légèrement les effets de l'irradiation, sans pouvoir conclure à la plus grande efficacité d'une des concentrations utilisées.

Traitements		Nombre de spores de *Clostridium*	
Krad	CaO_2 (ppm)	Boue n° 1	Boue n° 2
0	0	390.000	320.000
300	0	250.000	200.000
300	200	100.000	110.000
300	500	110.000	140.000
300	1000	112.000	99.000

Tableau III : Effet, sur les *Clostridium*, de la présence de CaO_2 lors d'irradiations à 300 Krad, sans agitation.

3.3.2. Essais avec agitation pendant l'irradiation

a) Apport de 200 mg de CaO_2/l de boue

Selon le producteur de CaO_2, la quantité d'oxygène libérée pendant l'opération serait de l'ordre de 62,5 mg d'O_2 par litre de boue.

Le tableau IV. rend compte des résultats de trois essais dont l'un comporte trois répétitions.

Traitements			Essais n°		
Krad	CaO_2 (ppm)	Agitation	1	2	3
0	0	+	410.000	180.000	257.000
300	0	+	230.000	130.000	200.000
300	200	-	110.000	-	186.000
300	200	-	-	-	189.000
300	200	-	-	-	179.000
300	200	+	90.000	80.000	144.000
300	200	+	-	-	132.000
300	200	+	-	-	126.000

Tableau IV : Effet sur les *Clostridium* de la présence de 200 mg de CaO_2 par litre lors d'irradiations à 300 Krad, avec agitation.

b) <u>Apport de 1000 mg de CaO_2/l de boue</u> (tableau V)

Dans ce cas, la quantité d'O_2 libérée serait de l'ordre de 125 mg/l de boue.

Traitements			Essais n°		
Krad	CaO_2 (ppm)	Agitation	1	2	3
0	0	+	340.000	243.000	320.000
300	0	+	230.000	209.000	240.000
300	1000	-	110.000	187.000	220.000
300	1000	-	123.000	203.000	220.000
300	1000	-	119.000	178.000	210.000
300	1000	+	75.000	69.000	59.000
300	1000	+	68.000	80.000	82.000
300	1000	+	85.000	82.000	50.000

Tableau V : Effet sur les *Clostridium* de la présence de 1000 mg de CaO_2 par litre lors d'irradiations à 300 Krad, avec agitation.

<u>Commentaires</u> : On trouvera ci-après une appréciation en % de l'effet des différents traitements (tableau VI).

Traitements			% de germes résiduels
Krad	CaO_2 (ppm)	Agitation	
300	0	+	70,1
300	200	-	51,5
300	200	+	44,5
300	1000	-	54,7
300	1000	+	24,5

Tableau VI: *Clostridium* résiduels en % du nombre initial.

L'ensemble des essais préliminaires réalisés permettent les conclusions suivantes :

- la présence de CaO_2 renforce les effets de l'irradiation
- l'agitation pendant l'irradiation améliore l'action du CaO_2
- dans les conditions de nos essais, le traitement 300 Krad + 1000 ppm de CaO_2 avec agitation est le meilleur. Il réduit les *Clostridium* d'environ 75 % ce qui correspond à une dose d'irradiation, sans CaO_2, comprise entre 750 et 1000 Krad (voir tableau I.).

  Du point de vue de l'hygiénisation, on ne peut prétendre à un effet très accusé car la réduction n'atteint même pas une unité logarithmique. Toutefois, on peut espérer obtenir des résultats plus favorables en cas d'agitation plus vigoureuse comme ce pourrait être le cas dans un irradiateur industriel.

  C'est pourquoi les essais seront repris avec l'irradiateur pilote dont nous disposerons prochainement.

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SESSION IV - VALORIZATION OF SLUDGES

ACTIVITIES OF WORKING PARTY 4 "VALORIZATION OF SLUDGE"

INTRODUCTORY REMARKS

by

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A l'heure où le coût des engrais ne cesse d'augmenter, où l'on parle de plus en plus de valoriser la biomasse végétale et les déchets pour produire de l'énergie, ce qui ne manquera pas de déséquilibrer le bilan humique des sols, l'Agriculture se doit de considérer attentivement toutes les possibilités d'utilisation des déchets qui lui sont proposées.
Parmi ceux-ci, les boues résiduaires urbaines tiennent une place bien particulière, du fait qu'elles sont produites régulièrement, et localement en quantité notable, mais surtout parce qu'elles sont difficilement valorisables autrement qu'en Agriculture.

Quels sont les effets recherchés par l'Agriculture lorsqu'elle utilise des boues résiduaires ? C'est en premier lieu l'effet azote qui est recherché, même si les boues ne sont généralement que des engrais azotés à faible teneur. Mais c'est aussi l'effet matière organique qui attire l'Agriculteur, le taux de matière organique de nombreux sols cultivés ayant tendance à décroître depuis plusieurs décennies. Enfin, l'effet phosphore, bien que moins apparent, est souvent pris en compte.
Les communications qui vont suivre tenteront de faire le point sur ces différentes questions ainsi que sur les aspects pratiques relatifs à l'utilisation agricole des boues, aspects pratiques qui conditionnent souvent le succès d'une opération de valorisation des boues en Agriculture.

VALEUR FERTILISANTE AZOTEE DES BOUES RESIDUAIRES

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Summary

The author summarizes studies dealing with nitrogen fertilizing value of sewage sludges. Various field trials, greenhouse studies and laboratory experiments (as well inside the E.E.C. as outside) are considered in order to estimate the amount of nitrogen released from different kinds of sludges.

It is shown that the results are mainly depending on their total and mineral nitrogen content and also on available carbon content.

Nevertheless, the methods proposed for prediction are still very approximative.

Résumé

L'auteur rapporte différents travaux, réalisés aussi bien à l'intérieur de la C.E.E. qu'à l'extérieur, qui se sont donnés pour but d'estimer au champ, en serre ou au laboratoire la valeur fertilisante azotée des boues résiduaires. Il apparait que l'efficacité azote des boues est liée principalement à leur teneur en azote total, à la proportion d'azote initialement sous forme ammoniacale, et également à leur richesse en carbone organique dont il ne faut pas négliger l'influence sur les phénomènes de minéralisation-réorganisation et dénitrification.

Les "formules" proposées jusqu'ici ne permettent cependant que des prévisions très approximatives.

INTRODUCTION

Une utilisation agricole optimale des boues résiduaires exige une bonne connaissance de l'évolution dans le sol de l'azote qu'elles contiennent. Cet élément, qui affecte fortement les rendements des cultures peut aussi présenter un danger pour la qualité des eaux (enrichissement en nitrates). Aussi, la plupart des pays qui ont édicté des recommandations à propos de l'épandage des boues résiduaires préconisent -ils (pour le court terme) de limiter les apports aux besoins en azote des cultures. Dans certains pays particulièrement sensibilisés à l'enrichissement des sols en phosphates, la dose de boues à épandre sera peut-être limitée par l'apport de phosphore, mais il faudra quand même savoir déterminer avec précision l'équivalence engrais azoté des boues afin de pouvoir calculer le complément minéral nécessaire.

La détermination de la valeur fertilisante azotée des boues résiduaires a toujours été une priorité de l'Action Concertée Européenne, et si les nombreux travaux effectués sur ce sujet - aussi bien au champ qu'au laboratoire - ont permis d'accomplir d'importants progrès, c'est aussi grâce à la possibilité de confrontation et de discussion des résultats au sein du Groupe 4 à Oxford, Paris, Cadarache et Dijon.

Nous arrivons maintenant à une étape importante de ces recherches; il nous a donc semblé utile de faire le point des connaissances accumulées jusqu'ici et de proposer quelques éléments de réflexion pour l'avenir.

1. L'AZOTE DANS LES PRINCIPAUX TYPES DE BOUES RESIDUAIRES

Le premier facteur déterminant la valeur azotée des boues résiduaires est bien sûr leur composition chimique. Plusieurs enquêtes portant sur un grand nombre de stations ont été effectuées dans plusieurs pays (SOMMERS, 1976; De HAAN, 1978; BOVAY et coll., 1979; etc).

Les boues contiennent en moyenne 4 % d'azote total, mais ce chiffre recouvre en fait des situations très diverses puisque les teneurs réelles s'étendent de 1 à 8 % selon les caractéristiques des effluents traités, ainsi que les procédés et éventuels traitements complémentaires utilisés.

Les principaux types de produits susceptibles d'être employés en agriculture sont les suivants (voir caractéristiques moyennes tableau 1) :

Boues liquides

- boues mixtes fraîches : mélange de boues de décantation primaire et de boues activées en excès. Usage agricole toléré dans certains pays et sous certaines conditions.

- boues digérées "anaérobies" : la digestion peut s'effectuer à température ambiante (10-20 ° C) ou être chauffée (30-35 °). Près de la moitié des matières organiques sont détruites et une fraction importante de l'azote est transformé en ammonium. Ce traitement peut s'appliquer aux boues de décantation primaires seules.

- boues digérées "aérobies" : l'oxydation à l'air des boues fraîches détruit environ 1/3 des matières volatiles. Ces boues sont donc un peu plus riches en matières organiques que les boues anaérobies, mais nettement plus pauvres en azote minéral.

- boues d'aération prolongée : proviennent de petites stations sans décantation primaire. Souvent confondues avec les précédentes sous le vocable de boues aérobies, elles sont typiquement moins concentrées et plus minéralisées, la dégradation des matières organiques y étant beaucoup plus poussée.

Boues solides ou pâteuses

- boues séchées sur lit : les boues stabilisées biologiquement (ci-dessus) sont mises à sécher sur lit jusqu'à l'état " pelletable ". En fonction des conditions atmosphériques, cela nécessite quelques semaines à plusieurs mois. Elles peuvent perdre jusqu'à la moitié de leur azote par rapport au produit de départ.

- boues conditionnées chimiquement et deshydratées : le conditionnement par réactifs minéraux utilise fréquemment la chaux et le chlorure ferrique. L'élèvation du pH jusqu'à 11 entraîne des pertes d'azote par volatilisation d'ammoniac. Il y a aussi un effet de dilution car la chaux apportée représente jusqu'à 30 % de la matière sèche du produit final.

  Au contraire, le conditionnement par polyélectrolytes ne modifie pratiquement pas la composition des boues. Mais la deshydratation ultérieure élimine de grandes quantités d'azote soluble (POMMEL et TETART, 1976) pouvant représenter 20 % de l'azote total.

- boues autoclavées et deshydratées : le traitement thermique hydrolyse les matières organiques les plus labiles. La majeure partie de l'azote est solubilisée et évacuée avec le filtrat (le gâteau de filtre n'en contient plus que 1 à 2 %) et le C/N, initialement inférieur à 10, dépasse alors 20.

D'autres types de boues résiduaires peuvent donner lieu à une valorisation agricole; nous nous sommes limités à ceux concernant les tonnages actuellement les plus importants. Ils représentent pourtant des produits fort différents les uns des autres, et ont certainement des caractéristiques agronomiques très diverses.

Par ailleurs, des analyses effectuées périodiquement sur les boues issues d'une même station indiquent des fluctuations considérables tout au long de l'année : l'azote total peut varier du simple au double, et la proportion d'azote ammoniacal davantage encore. S'appuyant sur un exemple concret, ROD (1973) montre qu'en épandant 100 m^3 / ha des boues d'une même station l'agriculteur peut apporter 110 à 240 kg d'azote total, dont 23 à 128 kg d'azote ammoniacal.

2. METHODES D'APPRECIATION DE LA VALEUR AZOTEE ET PRINCIPAUX RESULTATS OBTENUS

La diversité des produits que recouvre l'appellation générique de " boues résiduaires ", les variations et fluctuations que nous venons de rappeler, soulèvent un réel problème agronomique. La solution passe nécessairement par :

- la connaissance précise de la composition du produit à épandre,
- la connaissance de la valeur fertilisante azotée des différents types de boues, c'est-à-dire efficacité des différentes formes d'azote qu'elles contiennent, compte-tenu des conditions d'utilisation (climat, sol, culture...)

Le premier point impose de procéder à des mesures fréquentes des principales caractéristiques du produit.

Pour le deuxième point, différentes approches sont possibles.

La méthode la plus employée est le classique " essai au champ " où la valeur fertilisante azotée d'une boue est estimée en comparant les rendements qu'elle permet à ceux obtenus avec un engrais minéral (généralement le nitrate d'ammonium). Cette méthode peut être qualifiée de semi-empirique car elle intègre un grand nombre de paramètres non contrôlés ou mal contrôlés. Elle est parfaitement adaptée à l'évaluation d'une boue dans des conditions de climat, de sol et de culture donnés. Mais il est exclu que chaque station d'épuration mette en place des expérimentations au champ, ne serait-ce qu'en raison de leur coût et du temps nécessaire entre l'implantation des essais et l'utilisation possible des résultats. D'autre part, ces derniers ne peuvent être transposés à d'autres boues dans d'autres conditions.

Un autre type d'approche consiste à contrôler un maximum de paramètres pour essayer d'isoler celui que l'on souhaite étudier, puis tenter de dégager une loi générale. Pour ce qui nous concerne, il s'agit essentiellement de rechercher l'influence du type de produit et de sa composition sur son évolution dans le sol (minéralisation - nitrification) et l'influence des conditions de l'environnement (température, humidité, nature du sol) sur cette même évolution.

Ces essais peuvent être menés en serre ou au laboratoire. Les essais de laboratoire permettent une approche plus fine des mécanismes, mais ils négligent le végétal et les effets que celui-ci peut exercer (en prélevant tout ou partie de l'azote minéralisé, ou éventuellement en stimulant ou modifiant les activités microbiennes dans le sol).

Enfin, l'extrapolation au champ des résultats ainsi obtenus est hasardeuse voire impossible, en raison du caractère plus ou moins artificiel des conditions expérimentales et en raison des problèmes d'échelle (Par contre, l'accélération de l'échelle-temps au laboratoire peut être un avantage appréciable).

Les résultats obtenus d'après ces différentes approches ne sont pas à mettre sur le même plan mais peuvent concourir à améliorer nos connaissances et nos méthodologies.

2.1. Expérimentations au champ

Nous ne prendrons que quelques exemples parmi les expérimentations - établies spécialement pour déterminer la valeur azotée des boues, - où ces dernières sont parfaitement caractérisées (nature, composition), - et où, si possible, une comparaison de certains facteurs (types de boues, doses, dates d'apport, etc) permet de préciser leur influence.

- Types de boues

COKER (1966) a étudié les effets d'une boue digérée anaérobie sur trois cultures différentes. Ce produit aux caractéristiques assez particulières (plus des 2/3 de l'azote se trouve sous forme minérale) a une efficacité très élevée lorsqu'il est comparé à un engrais minéral apportant la même quantité d'azote total.

- la quantité d'azote prélevée par un Ray Grass à partir de boues est à peu près la même qu'à partir de l'engrais.
- sur prairie permanente, l'azote prélevé à partir des boues équivaut à 84 % de l'azote prélevé à partir d'ammonitrate.
- sur orge, pour un apport identique de 90 kg N/ ha, le rendement en grain est presque aussi élevé avec les boues qu'avec l'engrais.

L'efficacité azote des boues, mesurée par les exportations de cet élément est estimée à 81 % de celle de l'engrais.

A partir de ces résultats, et compte-tenu d'autres travaux antérieurs, COKER estime la disponibilité de l'azote par la formule :

$$\text{N disponible} = \text{N-NH}_4 + 1/6 \text{ N organique}$$

Pour des boues séchées sur lit, ne contenant pas plus de 8-10 % d'ammonium, COKER cite des efficacités voisines de 25 % par rapport au nitrate d'ammonium, 16 à 18 % de l'azote organique étant utilisable.

FURRER (1979) rapporte les résultats d'un essai au champ sur maïs, comparant 3 boues et un filtrat obtenus à différents stades dans une même station. On remarque (tableau 2) que l'efficacité azote par rapport au témoin engrais minéral diminue lorsque la proportion $N\text{-}NH_4$ / N total décroit, que le rapport C/N croît et que la teneur en matière sèche augmente.

LARSEN (1979), comparant 2 boues digérées anaérobies dont l'une est séchée sur lit et l'autre deshydratée par centrifugation, estime leur efficacité azote à 30 % et 15 %, respectivement, de celle de l'engrais ($NH_4 NO_3$). Il est difficile de savoir si la différence entre les deux boues doit être attribuée au C/N plus élevé ou/ et à la plus forte contamination par les métaux lourds de la seconde boue.

SOON et al. (1978) observent que le rendement en maîs obtenu avec 200 kg/ ha d'azote total de boues anaérobies conditionnées chimiquement est comparable à celui fourni par 100 kg N/ha de nitrate d'ammonium. La nature du réactif minéral de conditionnement ne semble pas influencer la valeur azotée des boues.

- Arrière-effet

D'autres estimations, qui ne semblent pas toujours appuyées par des expérimentations rigoureuses, chiffrent non seulement l'azote disponible la première année, mais aussi les années suivantes.

En Allemagne fédérale, les doses d'apport recommandées par le Niersverband reposent sur l'azote " disponible ", évalué pour la 1ère année à environ 20 % de l'azote total. Ce chiffre tient certainement compte des pertes d'azote, volatilisation d'ammoniac notamment, car il semble faible pour des boues digérées anaérobies (selon SUSS, l'efficacité globale serait plus proche de 30 %). La 2ème année, 8 % de l'azote est disponible, et 3 % la 3ème année.

En Californie, PRATT et al. (1973) estiment que 35 % de l'azote total d'une boue digérée anaérobie (contenant 2,5 % N) sont utilisables la 1ère année, 10 % de l'azote résiduel étant disponible la 2ème année et 5 % de l'azote restant minéralise la 3ème année.

Dans le Wisconsin, KEENEY et al. (1975) définissent l'azote " disponible " la 1ère année par la formule :

$$\text{N disponible} = 15\ \%\ \text{N organique} + 50\ \%\ \text{N-NH}_4 + 100\ \%\ \text{N-NO}_3$$

6 %, 4 % et 2 % des fractions azotées résiduelles sont disponibles les 2ème, 3ème et 4ème années.

COKER (1966) observait que sur Ray Grass l'azote prélevé la deuxième année ne représentait que 3 % de l'azote total apporté, soit 5,5 % de l'azote restant. Pour l'ammonitrate, les chiffres correspondants étaient respectivement de 1,6 et 3 %. Il n'est pas exclu que pour des boues moins minéralisées l'arrière effet soit plus important mais dans ce domaine les résultats fiables sont encore trop rares.

- Autres facteurs

Comme pour l'efficacité globale et la mesure des arrière-effets, les essais au champ sont irremplaçables pour évaluer l'effet-dose, l'influence de la date d'apport et la réponse de différentes cultures.

En général l'efficacité diminue lorsque la dose augmente, mais trop souvent cette relation est établie en apportant des quantités excédant considérablement les possibilités d'absorption des cultures (STEWART et al. 1975; KELLING et al. 1977).

Date d'apport et type de culture sont partiellement liés dans la mesure où l'efficacité-azote des boues est fonction de la durée pendant laquelle les cultures peuvent prélever l'azote, la fraction organique minéralisant progressivement. LARSEN (1979) rapporte qu'en moyenne, pour 2 boues et 3 sols différents, 10 % de l'azote des boues est utilisé par les cultures dont la durée de végétation est inférieure à 5 mois, contre 13 % pour les cultures dont la durée de végétation dépasse 5 mois.

Enfin, le cas le plus complexe où un maximum de paramètres interviennent (avec leurs interactions) est celui d'un épandage estival ou automnal. L'efficacité azote sur la culture suivante, qui peut être établie plusieurs mois après, a été peu étudiée.

2.2. Expérimentations en serre et au laboratoire

Les résultats obtenus au champ attribuent aux boues résiduaires une valeur fertilisante azotée qui peut aller, selon les cas, de 0 à 100 %.

Des expérimentations plus rapides et plus légères peuvent contribuer à élucider les raisons de cette variabilité.

- Types de boues

FURRER et BOLLIGER (1979) ont comparé 13 boues apportant des quantités identiques d'azote total à du Ray Grass cultivé en pots sur 3 sols différents. L'efficacité des boues est estimée en comparant les rendements en matière sèche et les exportations d'azote à ce qui est obtenu avec des doses croissantes d'azote minéral (NH_4 NO_3). Une régression linéaire multiple attribue le rendement aux fractions minérale et organique selon les formules suivantes :

N disponible = 91 % $N-NH_4$ + 25 % N organique

(d'après les rendements en matière sèche)

N disponible = 95 % $N-NH_4$ + 32 % N organique

(d'après les exportations d'azote).

Les boues utilisées par FURRER et BOLLIGER sont principalement des boues anaérobies très riches en azote ammoniacal (31 à 72 % du N total pour les boues liquides) et dont le rapport C/N est exceptionnellement bas (1,9 à 5,2). Les boues présentant ces caractéristiques ont une efficacité élevée : 40 à 80 % du nitrate d'ammonium. Une deshydratation appauvrissant le produit en azote ammoniacal, ou un défaut de stabilisation laissant une quantité importante de carbone organique (le cas limite étant les boues fraîches) diminuent la valeur azotée des boues.

Effectivement, en Norvège où de nombreuses stations d'épuration n'ont pas d'étape de stabilisation, VIGERUST a observé que les boues fraîches provoquent un effet dépressif pendant 1 à 3 mois avant de libérer de l'azote. L'effet dépressif est moins marqué au champ qu'en pots. Dans ce dernier cas, MARTINSEN (1976) a montré que l'effet dépressif était dû à une immobilisation de l'azote minéral du sol : les boues fraîches, avec un rapport C/N de 10 à 15 sont très riches en carbone assimilable et entraînent des phénomènes de réorganisation.

Au laboratoire, CHAUSSOD et al. (1978) ont également remarqué une immobilisation temporaire de l'azote du sol après apport de boues fraîches (C/N 13,5) ou de boues activées (C/N 10). L'effet dépressif disparaît après un mois à 20 ° C. Il peut durer 2 mois pour des boues non ou mal stabilisées particulièrement riches en carbone assimilable (C/N 14-15), ou même plus de 6 mois dans le cas de boues traitées thermiquement et deshydratées au filtre presse (C/N 20). Finalement, les résultats obtenus au laboratoire dépendent de la température et de la durée de l'incubation, aussi la plupart des auteurs ont-ils opté pour une étude cinétique qui permet de mieux rendre compte des phénomènes observés.

EPSTEIN et al. (1978) incubent pendant 15 semaines à 35 ° C 2 boues prélevées dans la même station, avant et après digestion. La boue digérée (2,9 % N total, 23,6 % C) libère de fortes quantités d'azote minéral pendant la première semaine puis la vitesse de dégradation diminue. Au contraire, la boue fraîche (3,55 % N total, 39,6 %C) provoque la première semaine un blocage partiel de l'azote minéral du sol, après quoi la vitesse de minéralisation augmente et dépasse celle de la boue digérée. Des résultats comparables ont été obtenus par YONEYAMA et YOSHIDA (1978).

3. VERS UNE APPROCHE PLUS UNIVERSELLE D'ESTIMATION ET DE PREVISION DE LA VALEUR FERTILISANTE AZOTEE DE DECHETS ORGANIQUES

Il est difficile de faire une synthèse des résultats que nous venons de rapporter. Leur diversité, voire leurs apparentes contradictions, s'expliquent en partie par la variété des conditions expérimentales; et bien souvent la validité des résultats est limitée à un type de boue donné, dans des conditions données. Cela n'enlève rien à leur valeur mais restreint plus ou moins les possibilités de leur utilisation.

Au contraire, une approche plus générale, comme celle proposée par SLUIJSMANS et KOLENBRANDER (1977) pour les effluents d'élevage, serait plus susceptible de faire progresser nos connaissances. Cette approche devrait procéder en deux temps. D'abord, déterminer la valeur azotée potentielle des boues résiduaires. Ensuite, déterminer dans quelle mesure cette valeur doit être corrigée, compte tenu des facteurs de l'environnement.

3.1. Valeur azotée potentielle des boues résiduaires

La matière organique des boues résiduaires est encore mal caractérisée d'un point de vue biochimique (tableau 3). Plutôt que d'entreprendre des analyses longues et complexes, il est plus réaliste de ne distinguer que 3 fractions azotées :

- Nm Azote minéral
- Nd Azote disponible, correspondant à la fraction organique qui est normalement minéralisée dans l'année
- Nr Azote résistant, qui ne minéralise que partiellement au cours des années qui suivent l'épandage.

Si la détermination de Nm ne pose aucun problème, la séparation de l'azote organique en Nd et Nr est très délicate car elle ne repose pas vraiment sur une réalité biochimique. Les méthodes biologiques donnent des résultats d'autant meilleurs qu'elles sont longues à mettre en oeuvre. Quant aux méthodes chimiques, CHAUSSOD (1979) n'a pas observé de corrélation satisfaisante entre l'azote extrait par autoclavage ou par action de $KMnO_4$ en milieu alcalin et la valeur fertilisante azotée des boues estimée en incubations aérobies de laboratoire ou sur Ray Grass en pots. Par contre, la connaissance de la teneur en azote et en carbone des boues autorise déjà une prédiction qualitative. De HAAN (1978) simplifie le problème en estimant que la fraction d'azote utilisable d'une boue est directement fonction de sa richesse en azote total (Kjeldahl),sans distinguer azote minéral et azote organique et sans tenir compte du carbone. Mais cette approche ne peut permettre que des prévisions très approximatives.

En fait, il reste à mettre au point une technique de séparation dont les résultats soient en bonne concordance avec ceux obtenus par les méthodes de référence. Pour les effluents d'élevage, SLUIJSMANS et KOLENBRANDER (1977) ont proposé une hydrolyse acide. Ces auteurs émettent l'hypothèse que la teneur en azote de la matière organique résistante ($M.O._r$) est la même que celle de la matière organique décomposable ($M.O._d$). Et ils estiment que la matière organique resistante est liée par une relation simple à la matière organique non hydrolysable, mesurée par perte au feu du produit après digestion par H_2SO_4. Mais, plus particulièrement pour les boues résiduaires, la M.O. non hydrolysable ne représente pas forcément la $M.O._r$ et surtout rien n'indique que la teneur en azote des deux fractions soit identique et donc que l'on puisse estimer des quantités d'azote en mesurant des quantités de matière organique.

Si l'extraction directe d'une quantité d'azote proportionnelle à l'azote "minéralisable" n'a pas donné satisfaction jusqu'ici, un fractionnement de la matière organique peut s'avérer plus fructueux à condition qu'il permette la détermination du rapport C/N des différentes fractions. Cela est nécessaire aussi bien pour transformer des quantités de matière organique en quantités d'azote que pour estimer le carbone " assimilable " dont la teneur commande les phénomènes de minéralisation-réorganisation de l'azote, et les pertes éventuelles par dénitrification.

3.2. Paramètres liés à l'environnement

Ces paramètres peuvent affecter différemment les 3 fractions définies ci-dessus. Aussi, plutôt que de multiplier la valeur azotée potentielle par un coefficient k (< 1) apprécié globalement en fonction des facteurs externes, il est plus rigoureux de considérer que les boues résiduaires apportent un supplément d'azote minéral, d'azote organique et de carbone organique à un cycle de l'azote dont on connaît la sensibilité des principaux maillons aux conditions de l'environnement (HUNT, 1977). Cette approche est schématisée par la figure 1.

Volatilisation d'ammoniac. Ce phénomène intéresse presque exclusivement la fraction Nm. BEAUCHAMP et al. (1978) observent qu'au champ 60 % de l'ammonium apporté peut être perdu en 5 à 7 jours dans le cas d'une application en surface; la concentration en ammonium et la température de l'air seraient déterminantes. Au laboratoire, RYAN et KEENEY (1975) ont trouvé que la volatilisation était affectée par le type de sol (proportion d'argiles, capacité d'échange en cations).

Bien entendu, un pH alcalin favorise les pertes, mais même dans ce cas elles sont très réduites par un enfouissement : c'est surtout le mode d'application qui est déterminant.

Minéralisation de l'azote organique. La vitesse de minéralisation de l'azote organique (fraction Nd) est influencée surtout par la température et l'humidité, et semble relativement indépendante des caractéristiques du sol (MILLER, 1974).

Pour l'azote " minéralisable " du sol, SMITH et al. (1977) déterminent la constante de vitesse K_t pour une température donnée et l'extrapolent en fonction des températures observées ou attendues en considérant que le Q_{10} est proche de 2. Cette constante de vitesse est corrigée en fonction de l'humidité par un facteur k_h égal à 1 en conditions optimales (0,33-0,1 bar) et diminuant linéairement lorsque l'humidité relative diminue. Le modèle plus complet de BHAT et al. (1980) reprend ces hypothèses. Bien entendu, cette approche très sophistiquée n'est pas directement utilisable dans la pratique. Par contre, elle peut déboucher sur des conseils concernant la date d'épandage en fonction de la culture qui sera implantée, ou le choix de la culture pouvant le mieux valoriser l'azote organique apporté.

Réorganisation. Lorsque la boue est très riche en carbone assimilable (boue fraîche ou mal stabilisée) de l'azote minéral peut être immobilisé par réorganisation. Ce phénomène passe souvent inaperçu au champ car il est généralement transitoire. Mais les boues dont le C/N de la fraction minéralisable dépasse 20 peuvent provoquer des effets dépressifs marqués sur la végétation.

Nitrification-dénitrification. Sauf cas exceptionnels (pH trop acide ou doses d'apport excessives) l'azote nitrifie correctement. Mais les nitrates formés et/ ou ceux préexistants dans le sol peuvent être perdus par dénitrification.

Ce phénomène strictement anaérobie se produit en sols saturés d'eau et est très sensible à un apport de matière organique. L'intensité de la dénitrification est directement fonction de la quantité de carbone assimilable apportée par les boues (CHAUSSOD, 1980).

Enfin, on peut également observer des pertes par dénitrification en sol non saturé (surtout de texture fine) après apport de fortes doses de boues ou de boues riches en carbone assimilable (EPSTEIN et al, 1978).

CONCLUSION

De nombreux essais au champ, en serre ou au laboratoire se sont donnés pour but d'estimer la valeur fertilisante azotée des boues résiduaires, et nous avons tenté de rapporter quelques uns des résultats les plus significatifs. Les éléments déterminant l'azote minéralisé la première année sont la teneur en azote et en carbone total des boues, la proportion d'azote ammoniacal par rapport à l'azote total et le degré de stabilisation, c'est-à-dire le carbone assimilable résiduel. Celui-ci règle l'évolution immédiate de l'azote (minéralisation ou réorganisation) mais influence aussi fortement les phénomènes de dénitrification.

Sous certains aspects nos connaissances sont encore insuffisantes, notamment à propos de l'évaluation des arrière-effets de différents types de boues, et les effets d'applications répétées. Pour ces recherches à effectuer au champ, l'harmonisation de certaines conditions expérimentales serait de nature à faciliter les comparaisons.

Enfin, des recherches sont encore nécessaires pour mieux déterminer la valeur azotée des boues épandues en automne sur la culture de l'année suivante. Ce problème, qui intègre les aspects sol, climat, cultures, déborde le cadre spécifique des boues résiduaires mais nos données sont encore insuffisantes pour répondre aux questions que nous pose la pratique de l'épandage. A cet égard, des tentatives de bilans, en lysimètres par exemple, seraient d'une grande utilité.

Des lacunes existent encore dans le domaine de la caractérisation biochimique de la matière organique des boues résiduaires et de l'appréciation de leur biodégradabilité en fonction de ces caractéristiques. Là encore, des méthodes standardisées seraient souhaitables.

Dans l'immédiat, il est nécessaire de coupler aussi souvent que possible des essais au champ donnant une valeur azotée globale avec des tests de laboratoire caractérisant le produit étudié. Cette démarche débouche sur une méthode plus universelle d'estimation et de prévision de la valeur fertilisante azotée des boues résiduaires, qui est également applicable à d'autres déchets organiques (d'origine industrielle par exemple, ou effluents d'élevage).

Tableau 1.

	M.S. en % produit brut	M.O. en % m.s.	N total en % m.s.	$N-NH_4$ en % N total	C/N
boues mixtes fraîches	3-5	60-80	3-5	$\leqslant$ 10	10-14
boues digérées anaérobies	5-10	40-60	2-7	20-40	5-10
boues stabilisées aérobies	4-8	50-70	3-8	5-10	5-8
boues d'aération prolongée	2-5	40-60	2-6	5-15	4-8
boues séchées sur lit	35-50	35-50	2-4	$\leqslant$ 10	8-12
boues conditionnées et deshydratées mécaniquement	20-30	40-60	2-6	$\leqslant$ 5	5-10
boues autoclavées et deshydratées	40-50	50	1-2	< 5	20

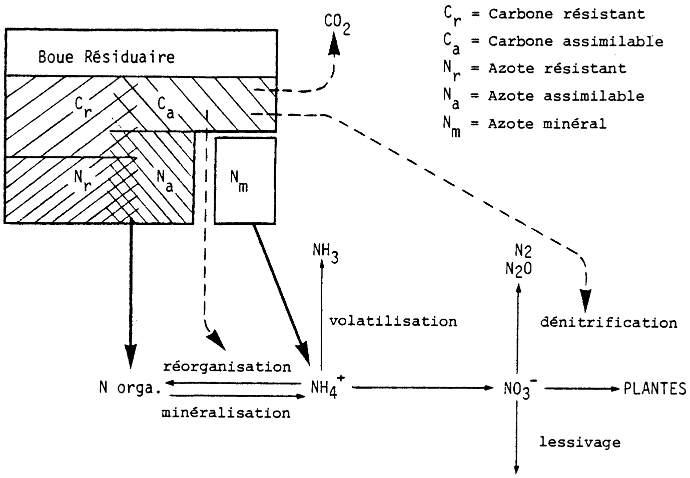
Tableau 2 : (d'après FURRER, 1979)

	M.S. en % produit brut	C/N	NH_4 en % de N total	efficacité N (sur maïs) NH_4NO_3=100
filtrat	0,8	2	74	83
boue anaérobie	6,3	5,2	39	54
boue deshydratée	22	6,5	13	35
boue séchée	97	8,4	7	30

Tableau 3 : (d'après GALWARDI et al., 1974)

	boues activées	boues fraîches	boues digérées
Matière organique	65 - 75	60 - 80	45 - 60
Azote organique	6,2	4,5	2,25
Graisses (extractibles à l'ether)	5 - 12	7 - 35	3,5 - 17
Hemicelluloses	7,0	3,2	1,6
Cellulose		3,8	0,6
Lignine		5,8	8,4
Pentosanes	2,1	1,0	1,5
Protéines	37,5	22 - 28	16 - 21

Fig. 1 - Influence d'un apport de boues résiduaires sur l'évolution de l'azote dans le sol



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EVOLUTION DANS LE SOL DES DIFFERENTES FORMES D'AZOTE PRESENTES DANS LES BOUES

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Résumé

Un essai visant à étudier l'évolution des différentes formes de N présentes dans les boues au cours du temps a été installé en se rapprochant le plus possible des conditions naturelles de la pratique agricole tout en s'assurant des possibilités de contrôle satisfaisantes. Il a été poursuivi pendant une durée de 12 mois en assurant 6 arrêts bimestriels. Les différentes formes de N (N org, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$) ont été déterminées sur les substrats et sur les percolats à chaque arrêt. Les résultats montrent qu'en une période de temps de 10 mois, ± 50 % du N org apporté par la boue s'est minéralisé, tandis qu'en une période de temps de 6 mois, seulement ± 20 % l'a fait, ce qui assure après ces périodes de temps des soldes de N org encore minéralisable respectivement de 50 et de 80 %.

Summary

An experiment intended to study the evolution of the different forms of N present in the sludge over a length of time has been set up, reproducing as faithfully as possible the natural conditions of agricultural practice whilst of course offering the possibility of frequent controls. It was carried out over twelve months, with six bi-monthly pauses. The different forms of N (org. N, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$) were determined at each pause on the substrata and on the percolated products. The results show that org. N supplied by the sludge was mineralized at about 50 % over a then monthly period, and only at about 20 % over a six monthly period, which leaves a remaining amount of org. N to be mineralized of respectively 50 and 80 %.

1. INTRODUCTION

L'azote a été déterminé sous diverses formes dans des boues produites par 4 stations d'épuration situées en Wallonie (3). Il s'y est révélé être présent principalement sous la forme organique ($\pm$ 2/3 de N total). La forme $N - NH_4^+$ y représentant $\pm$ 1/3 de N total. La forme $N - NO_3^-$ n'y a été présente qu'à l'état de trace. L'azote total s'est élevé à $\pm$ 3 % de N/MS, teneur qui mérite d'être prise en considération.

Toutefois les deux formes de N les mieux représentées ne sont pas accessibles telles quelles pour les plantes. Pour qu'elles le deviennent, elles doivent subir soit une nitrification, soit une minéralisation plus complexe.

Des essais ont été réalisés en vue de préciser l'importance de ces - phénomènes (cf. travaux de RYAN, KEENEY et WALSH (6,7) de PREMI et CORNFIELD (5), de KING (4), de FURRER et BOLLINGER (2)).

Il nous a semblé aussi intéressant de pouvoir quantifier ces phénomènes dans des conditions se rapprochant le plus possible des conditions réelles d'utilisation. A cette fin, un essai de longue durée (12 mois) a été mis en place en plein champ en s'assurant des possibilités satisfaisantes de contrôle.

2. CARACTERISTIQUES DE L'ESSAI

2.1. Méthodologie

De la terre et de la boue ont été mises en présence et le mélange a été suivi pendant une période de 12 mois au niveau des diverses formes de N, en présence d'un témoin.

Les 2 formes minérales de N ont été déterminées par la méthode de BREMNER (1). Le N org. résulte de la différence entre le N KJELDHAL et le $N\text{-}NH_4^+$.

Les substrats ont été placés dans des montages tels que celui représenté sur la figure 1. De plus l'ensemble du protocole a été recouvert d'une cage en toile moustiquaire.

Le protocole expérimental (cf. fig 2) a été prévu pour une durée de 12 mois avec 6 arrêts bimestriels. Il a été assuré 5 répétitions des 2 objets par arrêt.

Figure 1

MONTAGE EXPERIMENTAL

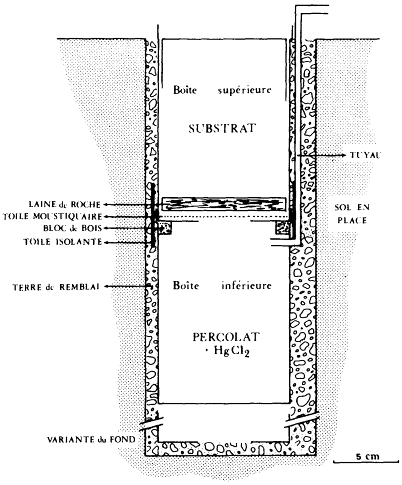
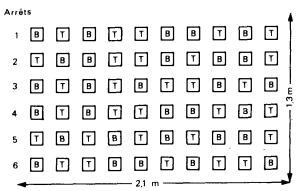


Figure 2

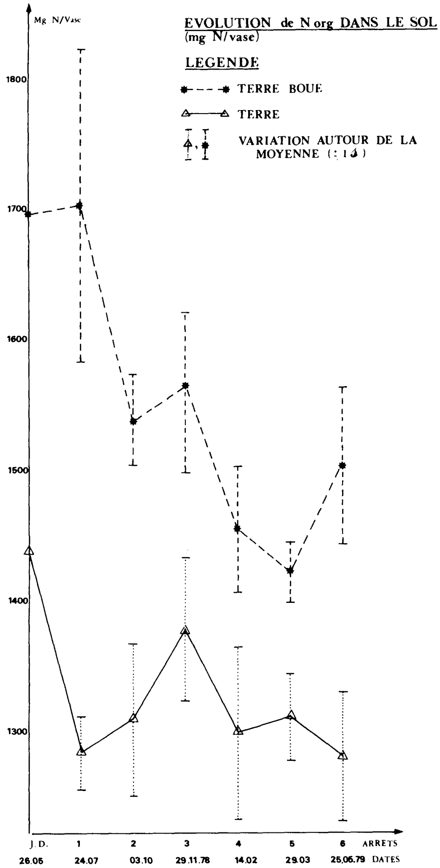
PLAN EXPERIMENTAL



LEGENDE T : Terre

B : Terre + Boue

Figure 3



2.2. La terre

Elle provient de la couche arable d'un sol de culture de la région de Gembloux (Hesbaye), limitée à 15 cm de profondeur. Son humidité est de 16,03 % et son pH H_2O de 7,1 .

Les teneurs suivantes en les différentes formes de N y ont été observées, exprimées en ppm N/MS : N org : 1146, $N\text{-}NO_3^-$: 14,2, $N\text{-}NH_4^+$: 4,2.

2.3. La boue

Elle provient de la Station de Rhisnes et accuse une teneur en M.S. de 4,2 %. Son pH H_2O est de 6,4.

Les teneurs suivantes en les différentes formes de N y ont été observées, exprimées en % de N/M.S. : N org : 3,12 % (=94,5 % de N tot.), N-NO_3^- : 0 %, N-NH_4^+ : 0,18 % (= 5,5 % de N tot.).

2.4. Installation de l'essai

Les récipients ont été remplis de 1,5 kg de terre fraîche. Ceux destinés au traitement avec boue ont reçu 200 ml de ce produit (200 m^3/ha), épandus en surface, tandis que les témoins recevaient 200 ml d'eau distillée. Aucune culture n'a été pratiquée et aucun produit phytosanitaire n'a été utilisé. L'essai a été mis en route le 26/05/78 et poursuivi jusqu'au 25/05/79. Les différentes séries ont été arrêtées respectivement aux dates mentionnées dans les figures 3, 4, 5 et 6.

2.5. Conditions climatiques survenues pendant l'essai

Les observations faites relatives à la température du sol et à la pluviométrie sont en accord avec les valeurs considérées comme normales par les météorologistes sauf en ce qui concerne les pluies des mois d'août, octobre et novembre 1978 qui ont été de l'ordre du 1/4 des précipitations normales (± 20 mm/± 75-80 mm).

2.6. Les mesures effectuées

A chaque arrêt d'une série, les volumes de percolats ont été mesurés et analysés au niveau des 3 formes de N. Il en a été de même pour les substrats.

3. RESULTATS ET DISCUSSION

3.1. Evolution de N org.

Celle-ci est renseignée dans le tableau I qui ne mentionne que les résultats relatifs au sol, les teneurs en N org. des percolats s'étant toujours révélées insignifiantes. La figure 3 met en image les variations observées.

Tableau I : Evolution de N org. au cours du temps dans le sol (mg N/vase)

Arrêts	Terre + Boue			Terre		
	V.A.	CV %	$\overline{X}_{J.D.,1,2...6}$	V.A.	CV %	$\overline{X}_{J.D.,1,2,..6}$
J.D.	1.699 (1439 + 260)	-		1.439	-	
1.	1.704	7,0		1.285 ★	2,1	
2.	1.539 ★	2,2	$\overline{X}_{2,3}$ = 1.552	1.310 ★	4,4	$\overline{X}_{2,3}$ = 1.345
3.	1.565	3,6		1.379	4,0	
4.	1.456 ★	3,3	$\overline{X}_{4,5}$ = 1.440	1.300 ★	5,1	$\overline{X}_{4,5}$ = 1.306
5.	1.423 ★	1,6		1.312 ★	2,5	
6.	1.505 ★	3,9		1.282 ★	3,8	

Notes : J.D. = jour de départ

CV % = coefficient de variation en % (= 100 x $\sigma/\overline{X}$)

\- = moyenne calculée sur deux résultats analytiques

$\overline{X}_{J.D., 1,2, ...6}$ = moyenne de 2 ou plusieurs arrêts repris en indice

★ = valeur significativement différente de celle du jour de départ

On observe que dans les 2 objets, la quantité de N org. diminue et ce d'une façon significative par rapport à celle de l'état initial. Cet N org. disparu n'a pas été retrouvé au niveau des percolats.

3.2. Evolution de N - NH_4^+

Le N - NH_4^+, quoique présent le jour de départ (20 mg N/vase dans le traité et 5 mg N/vase dans le témoin) ne se retrouve plus lors du 1e arrêt ni au cours d'aucun des 5 arrêts suivants. Cet N - NH_4^+ peut s'être soit volatilisé, soit nitrifié partiellement ou totalement. On peut admettre que 25 % de celui-ci s'est nitrifié et que 75 % s'est volatilisé (°)

3.3. Evolution de $N - NO_3^-$

Elle est renseignée dans le tableau II et dans la figure 4.

Tableau II : Evolution de $N - NO_3^-$ au cours du temps (mg N/vase)

Traitement	Arrêts	Sol		Percolat		Total (Sol + percolat	Gain (+) et perte(-) de $N - NO_3^-$	
		V.A.	CV %	V.A.	CV %			
Terre + Boue	J.D.	17,83	-	-	-	17,83	-	
	1	13,18	50,0	8,75	30,6	21,93	+ 4,10	Σ 1+2+3 =
	2	42,56	41,8	3,05	74,4	45,61	+23,68	+ 58,63
	3	76,46	11,4	-	-	76,46	+30,85	
	4	28,50	13,0	4,57	29,1	33,07	-43,39	Σ 4+5+6 =
	5	18,08	10,1	0,61	32,3	18,69	-14,38	- 64,25
	6	11,68	12,5	0,53	39,5	12,21	- 6,48	
Terre	J.D.	17,83	-	-	-	17,83	-	
	1	13,06	26,0	5,07	70,5	18,13	+ 0,30	Σ 1+2+3 =
	2	21,72	25,0	0,13	65,6	21,85	+ 3,72	+ 11,17
	3	29,00	11,9	-	-	29,00	+ 7,15	-
	4	19,59	12,5	1,79	41,4	21,38	- 7,62	Σ 4+5+6 =
	5	13,43	17,2	0,29	50,6	13,72	- 7,66	- 21,14
	6	7,41	6,5	0,45	90,0	7,86	- 5,86	

(°) Perte nette de $N - NH_4^+$ provenant de la boue : 15 mg N/vase - gain net de $N - NO_3^-$ provenant de la boue pendant la 1e période (cf. tableau II) ± 4 mg N/vase. Si on fait l'hypothèse extrême que ces ± 4 mg N/vase ne proviennent que de la nitrification de $N - NH_4^+$ et pas de la minéralisation de N org., on enregistre une perte de $N - NH_4^+$ de ± 11 mg N/vase (= 75 % de 15).

Au niveau des substrats, on observe dans les 2 objets, un enrichissement en $N - NO_3^-$ jusqu'au 3e arrêt et un appauvrissement au cours des 3 arrêts suivants. L'enrichissement, beaucoup plus accentué dans le traité que dans le témoin, peut être mis en parallèle avec la disparition de N org. L'appauvrissement ne peut résulter que d'une dénitrification du $N - NO_3^-$ qui était présent lors du 3e arrêt. La figure 4 montre également l'absence d'influence de l'humidité et de la température du sol sur l'évolution de $N - NO_3^-$.

Figure 4

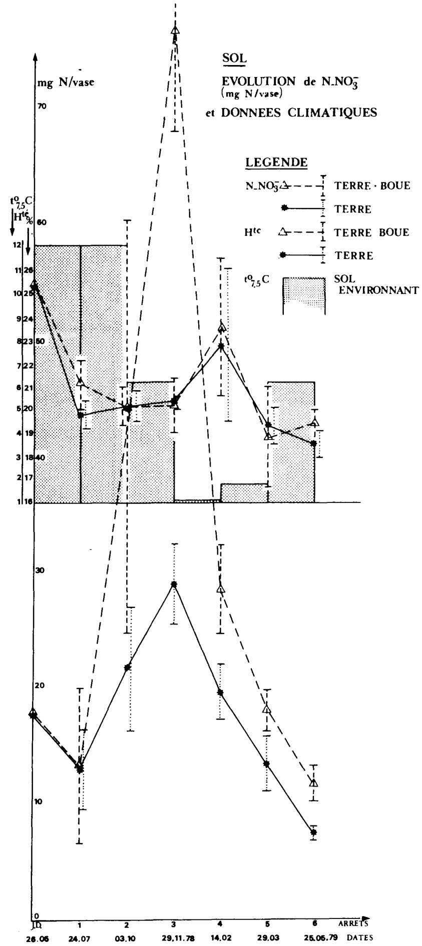
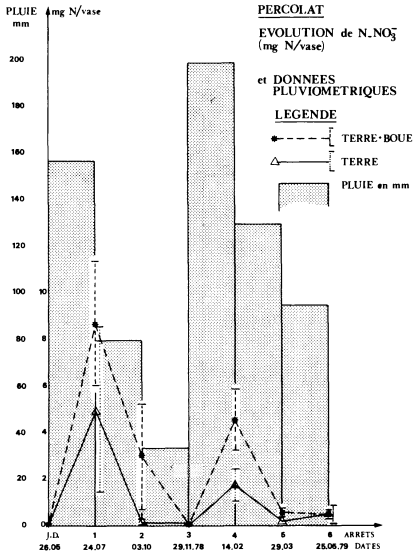


Figure 5



Au niveau des percolats, la figure 5 montre qu'une certaine quantité de N - NO_3^- y apparait et que cette quantité est dépendante de la pluviométrie.

3.4. Estimation de la valeur fertilisante du N des boues

Compte tenu des variations observées dans l'évolution de N org. et du N - NO_3^-, 2 espaces de temps ont été considérés dans cette estimation en les limitant aux 10 premiers mois d'observation et en établissant pour chacun d'eux un bilan. En effet, au cours des 2 derniers mois, on a assisté à un enrichissement du substrat du traitement "terre + boue" difficilement explicable. Les chiffres expriment des mg N/vase.

- Espace de temps J.D. → 3e arrêt ou ± 6 mois

	N org.		$N - NO_3^-$	
	Terre + Boue	Terre	Terre + Boue	Terre
J.D.	1.699	1.439	17,83	17,83
2e + 3e a./2 pour N org. 3e a. pour $N-NO_3^-$	1.552	1.345	76,46	29,00
	- 147	- 94	+ 58,63	+ 11,17
	$\neq$ = - 53 ou ± 20 % de l'apport initial		$\neq$ = + 47,46 ou 90 % du N org. disparu	

- Espace de temps 3e arrêt → 5e arrêt ou ± 4 mois

	N org		$N - NO_3^-$	
	Terre + Boue	Terre	Terre + Boue	Terre
2e et 3e a./2 pour N org. 3e a. pour $N-NO_3^-$	1.552	1.345	76,46	29,00
4e et 5e a./2 pour N org. 5e a. pour $N-NO_3^-$	1.440	1.306	18,69	13,72
	- 112	- 39	- 55,77	- 15,28
	$\neq$ = - 73 ou ± 35 % du solde du 1e espace de temps		$\neq$ = - 40,49	

Au cours de ce second espace de temps, la perte de $N-NO_3^-$ enregistrée pourrait correspondre à une dénitrification de celui apparu au cours du premier. La perte de N org., quant à elle, n'ayant pas été compensée, n'est explicable que par sa minéralisation suivie d'une perte de N par volatilisation. Le taux de minéralisation à admettre ici serait donc de 100 %. Il se peut que la forme minérale apparue ait été du $N-NO_3^-$ dont l'évolution, n'aurait pas été, pour sa totalité, une dénitrification si des plantes avaient été présentes pour le prélever. Des essais d'épandage de boue à des dates différentes de la date arbitraire choisie dans cet essai permettront de confirmer ou d'infirmer cette hypothèse.

On a dès lors estimé la valeur fertilisante du N des boues en considérant soit une période couvrant le 1e espace de temps (± 6 mois), soit une période couvrant les 1e et 2e espaces, soit ± 10 mois.

Ainsi, le N efficace de la boue serait de 18 % pour une période de 6 mois (90 % de 20 %) et de 47 % pour une période de 10 mois (90 % x 6 mois) + (100 % x 4 mois)/10 = 94 %, N org. disparu = 53 + 73 = 126, soit ± 50 %

de l'apport initial, et 94 % de 50 % = 47 %), en ne perdant pas de vue qu'au bout de la 1e période, on dispose toujours de 80 % de N org. minéralisable et de 50 % à la fin de la 2e période.

4. CONCLUSIONS

Les expériences réalisées ont révélé une efficacité très faible du $N - NH_4^+$ contenu dans les boues, mais une aptitude marquée à la minéralisation de la forme N org. qui peut, dès lors, être considérée comme une pourvoyeuse potentielle de $N - NO_3^-$. Chiffrer cette aptitude est une démarche encore prématurée qui dépendra, plus que probablement, de l'époque d'application de la boue.

La boue peut donc être considérée, entre autres finalités, comme un engrais azoté à part entière, dont l'usage dans la pratique agricole doit être subordonné à son homogénéisation et à une identification précise de ce qu'elle contient, compte tenu, que parmi tous les éléments biogènes qui y sont présents, c'est N qui accuse la plus grande variabilité de station à station, au cours du temps dans une même station et au sein d'un même lot de boue reconnu comme homogène.

Elle offre de plus l'avantage, en tant qu'engrais azoté, de "débiter" son $N - NO_3^-$ progressivement, ce qui assure à la fois une nutrition minérale azotée des cultures régulières et une protection efficace contre le lessivage des ions NO_3^-.

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COMPARATIVE STUDIES OF NITROGEN MINERALIZATION IN FOREST SOILS FERTILIZED WITH FLUID AND DEWATERED SEWAGE SLUDGE

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Summary

A pine forest on poor sandy soil in middle Sweden was fertilized with fluid (4 % dry weight) and dewatered (20 % dry weight) sewage sludge. Three amounts of sludge, 3 kg dry wt/m^2, 2 kg dry wt/m^2 and 1.5 kg dry wt/m^2, were used. Ammonium- and nitrate concentrations increased in all fertilized areas. The immediate increase of ammonium was most pronounced in areas fertilized with dewatered sewage sludge, probably mainly due to the added nitrogen from the sludge. The highest increase in nitrate concentration during the first year after fertilization was found in areas irrigated with fluid sludge.

Incubation studies showed that the nitrogen mineralization rate was strongly increased after fertilization. The effects showed good correlation to the applied amounts of sludge. The effects seemed to be delayed one year on areas fertilized with dewatered sludge reching the maximum increase in soil samples from the second and third year. Visible effects on biomassproduction in the herblayer and shootlength increment also indicated that the fertilizing effects were most rapid when the forest was irrigated with fluid sludge.

1. INTRODUCTION

Increasing amounts of sewage sludge have become a problem in most industrialized countries. Estimates from the United States indicate that the volume of sludge in the middle of the 1980´s will have increased with about 65 % compared with ten years earlier (6). About 40 % of the produced sewage sludge is used in agriculture while about 50 % is dumped on landfills (2). Sewage sludge is rich in nutrients, especially nitrogen which is an essential limiting factor for biomass-production in most terrestrial ecosystems. A better utilization of sludge as soil improvement would decrease the need for artificial fertilizers produced by energy consuming industrial processes. At present sewage sludge is mostly used on agricultural lands and in horticulture. In some areas in the United States, for example around Seattle in Washington and in Pensylvania, sewage sludge fertilization of forest ecosystems is carried out in a practical scale (7, 11).

Fertilization with sewage sludge in forests probably leads to less leaching of nutrients than with artificial fertilizers, as nutrients are bound to organic substances and are slowly released during mineralization processes. Addition of organic substances to poor forest soils further increases the waterholding capacity of the soil.

Surviving of patogenic organisms and viruses as well as contaminating heavy metals are problems connected with sewage sludge potentially limiting the usefulness of sludge as fertilizer.

The potential distribution of heavy metals to the forest ecosystem as a result of sewage sludge fertilization is another risk which could limit the usefulness of sewage sludge as soil improvement. Sludge with extremely high concentrations of heavy metals should not be used as fertilizer.

Most sewage plants have techniques to decrease the water concentration in sewage sludge in order to reduce transportation costs. The water is pumped back to the sewage treatment process. Bramryd (1) has shown that the major fractions of nitrogen and other nutrients are retained in the semi-solid organic residue. This paper presents investigations concerning the difference in effects on nitrogen balance in soil and on vegetation in a mid-swedish poor pine forest.

2. MATERIAL AND METHODS

The investigations were carried out in an approximately 50 - 60 years old Scotch pine forest (Pinus silvestris) in Jädraås outside Gävle in middle Sweden. The experiment site has a mean temperature of about +3^{o} C and a mean precipitation of about 550 mm. The humidity is around 300 mm (12) and the snow cover lasts for about 130 days per year. The research area is dominated by a sandy till soil formed during deglaciation under the water. The highest shore limit reached 205 - 220 m above present sealevel. The area has a well developed podzol with a bleached layer of approximately 5 cm. The age-structure of the pines is uniform but colonization of Norway spruce (Picea abies) occurs. The ground vegetation is dominated by Vaccinium vitis idaea, V. myrtillus, Calluna vulgaris, Pleurozium schreberi and Cladonia rangiferina.

Three plots (25 x 25 m) were fertilized with fluid sludge (4 % dry matter) with dewatered sludge (20 % dry matter), corresponding to the amounts of 1.5 kg dry wt/m^2, 2 kg dry wt/m^2 and 3 kg dry wt/m^2 respectively. Three reference areas were unfertilized.

The sludge derived from sewage plants with biological treatment of mixed domestic and industrial waste water and contained approximately 40 g nitrogen per kg dry wt of which approximately 15 g per kg dry wt was inorganic. The fluid sludge was irrigated from a tank lorry while the dewatered sludge was homogeniously spread by hand over the areas.

Soil samples were taken before fertilization and once a year the following years using a borer with 5 cm diametre. From each experiment plot 2 x 20 soil cores were randomly sampled and mixed together in four soil samples; two for the organic layer (about 5 cm thick) and two for the first 10 cm of the underlaying mineral layer. In order to compare the nitrogen mineralization rate soil samples were incubated during 10 days under aerobic conditions in constant temperature (20^{o} C) and moisture. The difference between ammonium- and nitrate concentrations before and after incubation indicated the mineralization rate. Ammonium- and nitrate concentrations in soil extracts were analysed with an Orion digital ammonium electrode (3). Nitrate concentrations were determined after reduction to ammonium with Devarda´s alloy powder as an oxidant. Kjeldahl - N concentrations were analysed with a destillation procedure after digestion with conc. H_2SO_4 (5). The total carbon concentrations were determined according to Nömmik (9). pH was analysed in watersolution using a Metrohm digital pH-metre.

3. RESULTS AND DISCUSSION

The increase in ammonium- and nitrate concentrations was rapid after sludge fertilization (figure I). A clear correlation could be found between the increase and the amount of sludge applied to the area. The ammonium concentrations reached higher concentrations during the first year in the areas fertilized with dewatered sludge (20 % dry wt) than in areas with fluid sludge (4 % dry wt). This can be explained by the fact that much of the dewatered sludge is retained at the surface of the litter layer during the first year and is thus included in the organic layer sample. During the second year however the semi-solid sludge had been dispersed into the moss- and litterlayer. The typical dark green colour of the vegetation indicating a good nitrogen supply appeared during the first year after fertilization, when sludge was irrigated to the research plot, but was delayed until the second year in the case of the semi-solid sludge. Measurements of the annual increment of Vaccinium vitis idaea, V. myrtillus and other ground vegetation species as well as pine- and spruce shoots also indicate that the fertilizing effects were delayed when dewatered sludge was used.

The uptake in vegetation can also explain a relatively low increase in ammonium- and nitrate concentrations in the mineral layer. The nitrate concentrations increased significantly during the first year after fertilization but decreased the second year. The decrease was most rapid in the areas with dewatered sludge. After the first year nitrate concentrations were higher in areas fertilized with fluid sludge than in areas where semi-solid sludge was applied. This can be explained with a better distribution of sludge particles within the ground vegetation and the organic layer which probably will create a more aerated and favourable milieu for nitrifying bacteria.

The increases of inorganic nitrogen in deeper layers of the soil profile are very limited and have only been found in the upper 20 - 30 cm. This is probably due to the rather rapid uptake of nitrogen in the vegetation. Johnson and Urie (8) found that about 48 % of the added nitrogen from sewage sludge applied to agricultural lands was incorporated into the herbaceous vegetation during the first growing season. Edmonds (7) also found very small nitrogenlosses from sewage sludge applied to forest ecosystems. The high moisture content in the sludge during the first 9 months may inhibit nitrification and the lack of leaching from the sludge means that few nutrient elements move downwards in the soil profile during the first year. Herbs growing in aggregations of solid sludge particles have a much better biomass production than plants of the same species growing close by.

Soil samples taken one year after fertilization from the organic layer in areas irrigated with fluid sludge and incubated in vitro during 10 days produced a rapid increase in ammonium- and nitrate concentrations (figure II). The increase was less the second and third year. Probably the high initial mineralization rate to some extent depends on the microbial activity in the sludge itself. At pH values around 4.5 - 5.0 conditions are favourable for nitrifying bacteria which may explain the marked increase in nitrate during incubation of soil samples from the first year. However nitrate immobilization by ammonificativ bacteria might be an important factor which can explain low increases or even decreases of nitrate concentrations during incubation.

Denitrification of nitrogen can also be of importance to explain low net mineralization values. Recent theories (10) indicate that sludge fertilization often stimulates denitrification. This can especially be found in soil samples having high water content due to for example heavy rains before sampling. This fact together with immobilization of nitrogen might explain the decrease in nitrogen concentrations after the first year in incubated soil samples from areas fertilized with dewatered sludge. The nitrogen mineralization rate however seems to reach its maximum later in areas fertilized with dewatered sludge than in the case with sludge irrigation.

The C/N ratio in the organic layer decreased during the first two years in fertilized areas due to addition of nitrogen and thus an accelerated oxidation of organic matter (table I). Earlier investigations have shown similar results (7, 4).

Table I. pH and C/N ratio in the organic layer in relation to time

	Unit[1]	C/N ratio Year[2]				pH Year[2]			
		0	1	2	3	0	1	2	3
Areas fertilized with sludge; 4 % dry wt	A_1	59	34	22	33	4.1	4.5	4.3	4.4
	B_1	69	30	29	35	4.0	4.4	4.2	4.3
	C_1	42	25	39	40	4.1	4.6	4.3	4.4
	R_1	47	53	44	47	4.0	4.1	4.0	4.1
Areas fertilized with sludge; 20 % dry wt	A_2	40	34	26	32	4.1	4.6	4.9	4.7
	B_2	35	16	29	33	4.1	4.6	4.7	4.5
	C_2	44	27	25	30	4.1	4.3	4.7	4.7
	R_2	38	35	42	46	4.1	4.0	4.2	4.2

1) Units A_{1-2}, B_{1-2}, and C_{1-2} are fertilized with 3, 2, and 1.5 kg dry wt/m^2 of respectively. R_{1-2} are control areas.

2) Year 0, 1, 2, and 3 indicate time of sampling. Year 0 is before fertilization.

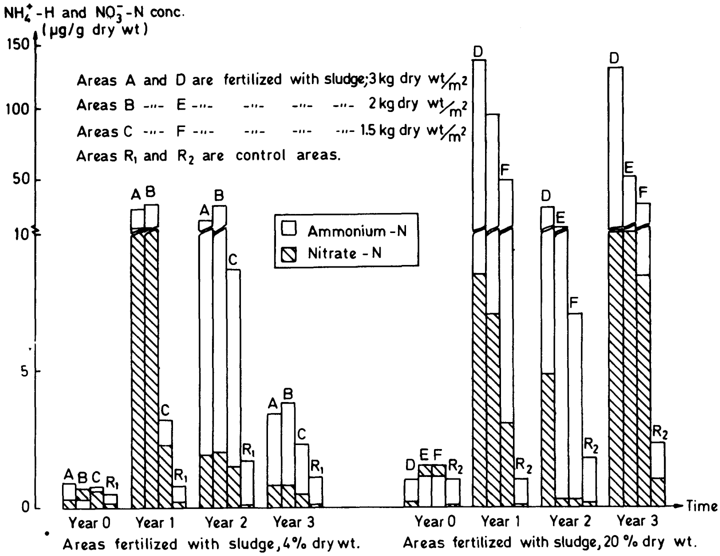

Figure I. Ammonium- and nitrate concentrations in the organic layer before sludge fertilization and 1, 2, and 3 years after fertilization.

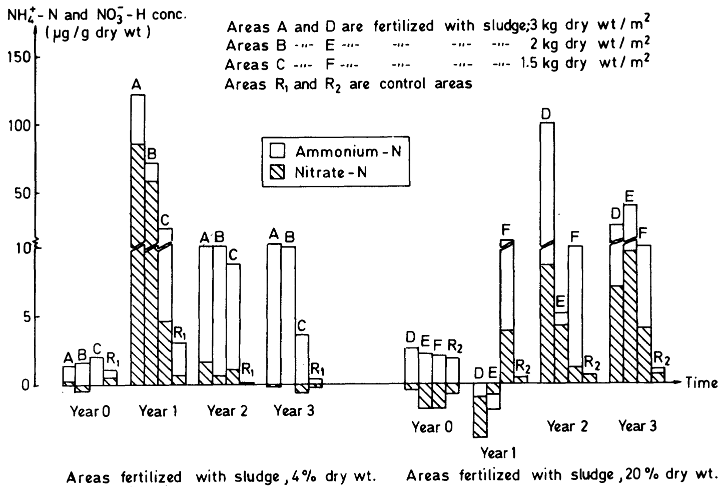

Figure II. Changes in ammonium- and nitrate concentrations in the organic layer during incubation. Samples taken before and 1, 2, and 3 years after fertilization.

pH increases in areas treated with fluid sludge with approximately 0.2 units while the increase is more pronounced, about 0.6 - 0.8 pH units, in areas fertilized with dewatered sludge. The maximum values are however reached during the second year in the case of dewatered sludge, while the process is faster when fluid sludge is used (table I).

Conclusions can be drawn from the investigations that sewage sludge fertilization increases the amounts of available soil nitrogen, due both to a direct supply from the sludge and to an increased nitrogen mineralization rate in soil. The effects are evident both in areas fertilized with dewatered sludge and in areas being irrigated with fluid sludge, but the effects on the mineralization rate can be seen earlier with fluid sludge. Most visible effects, as for example increased growth of the herblayer vegetation, seem to be delayed approximately one year when the sludge is dewatered before fertilization.

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EFFECT OF COMPOSTED SEWAGE SLUDGE ON MINERALIZATION OF ORGANIC CARBON, AMMONIFICATION AND NITRIFICATION IN SOIL

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Summary

The use of composted sewage sludge on agricultural land might reduce some environmental risks connected to the utilization of liquid sludge, nevertheless frequencies and levels of applications can adversely affect some soil biological properties.

Mineralization of organic carbon and nitrogen as well as nitrification in soil amended with different quantities of composted raw sewage sludge have been investigated in order to define the influence of treatment on these microbial activities.

1. INTRODUCTION

It is beyond doubt that the application of sewage sludge to agricultural land may affect chemical, physical and biological properties of soil.

A large number of studies are concerned the effects of sewage sludge on chemical contents of soil; some Authors have studied effects on physical characteristics (4, 5, 8); only few researches have been carried out about the influences that repeated treatments with sewage sludge may exert on soil microorganisms and their activities (3, 12, 13). Nevertheless within the ultimate expression of soil fertility, the admirable disposition of soil to produce is considered as consequence of the concurrence of chemical, physical and biological qualities too.

Sewage sludge can directly affect soil microflora by means of massive supplies of new and different viable cells. However other important effects on soil microorganisms are certainly caused by chemical and physical changes of the environment produced by sludge application. These last widely depend on sludge type and characteristcs.

Sludge compost appeares very suitable to agricultural use: it may be stored and utilized at appropriate times; application can be carried out as well as other solid fertilizers; organic matter is stabilized and partially humified; hygienic risks are very reduced or absent; smaller areas can be employed to disposal of sludge coming from a determinate water treatment plant. Notwithstanding this, frequencies and levels of addition of compost to soil do not need to remain indefinite and soil conditions after the treatment are to be verified.

This paper reports results showing the effect of different treatments with composted sewage sludge on mineralization of organic carbon and on ammonifier and nitrifier organisms in soil.

2. MATERIALS AND METHODS

Sludge compost was produced by the pilot-plant of the Station for Industrial Microbiology of the University of Naples, composting raw sewage sludge with wood-chips by the forced aeration system. Compost was characte rized from a moisture content of 55 per cent and, as dry matter, 50% of organic matter, 2% of nitrogen (of which about 10% in inorganic forms), 1.7% of phosphorus, 1.1% of potash, 2,000 ppm of Zn, about 200 ppm of Cu, 38 ppm of Ni, 7 ppm of Cd and 180 ppm of Pb.

Experiments were carried out with a fine texured sandy loam soil, volca nic, widely present in the Province of Naples and in other areas of Campania. This soil is neutral and its organic content amounts to about 1.7 per cent. Sludge compost has been applicated to soil at three different per cent levels: 1.25, 2.5 and 5.0. The first quantity corresponds to about 550 quintals x ha^{-1}. The total biological activity of sludge amended soil samples as well as control soil has been monitored during several months measuring the CO_2 release, by the barium peroxide method (2). After 100 days since sludge treatment the abilities of soil samples to mineralize organic carbon and nitrogen as well as to oxidize NH_4^+-N have been verified. Microbial counts of heterotrophic, ammonifier and nitrifier microorganisms have also been carried out. Microbial activities have been studied at room temperature, by the apparatus shown in the figure 1. Each soil sample (100 g dry matter) was amended with 5 g of wheat straw, 5 mg of ureic nitrogen and 5 mg of nitric nitrogen in order to study the mineralization of organic carbon. Water content was carefully brought to 50% saturation. The gas-wa shing-bottle 1 of the set was supplied with 30% NaOH solution to eliminate the CO_2 from the air forced into the system; the gas-washing-bottle 2 contained the solution to titrate CO_2 released. Ammonification was studied by adding to soil 5 g per cent of Bacto-Casaminoacids from Difco Lab., Detroit, U.S.A. GWB 1 contained water to humidify air and GWB 2 was supplied with 0.1N H_2SO_4 to titrate NH_3 released. In nitrification studies soil sam ples were added with 1 ml of 4% $(NH_4)_2SO_4$ solution (corresponding to 8.47 mg of NH_4^+-N), 1 ml of 2% $Ca(H_2PO_4)_2$ solution, 0.3 g of $CaCO_3$ and water up to 50% saturation. Only GWB 1 was utilized supplied with water to humidify the air. Each week small aliquots of soil were extracted by shaking with N NaCl and filtrate analysed for NH_4^+-N (Nessler reagent), NO_2^--N (Griess reagent) and NO_3^--N ($AgSO_4$-phenoldisulphonic method).

Viable counts of heterotrophic microorganisms were carried out on soil-extract-agar plates inoculated with gradual suspensions of the sample in steril water with 0.5 ml per cent (v.:v.) of sodium silicate (3°Bé) and 0.5 ml of saturated solution of sodium oxalate (incubation at 30°C for 10 days). The most probable number of ammonifier microorganisms was determined according to Pochon and Tardieux (9).Nitrifiers were counted in liquid medium according to Coppier and De Barjac (1) as well as on double-layer-silica gel plates according to Soriano (12).

3.RESULTS AND DISCUSSION

Mineralization of composted sewage sludge when added to soil at increasing levels can be argued from the figure 2, where the cumulative release of CO_2 as final event of the process is reported.Epstein et al. (6) have already found out that sludge composted with wood-chips is not easily mineralized in the soil and that mineralization rates depend on the quantity of amendment added. Results obtained within this research show that of course the biological activity of soil is directly correlated to the quantity of compost applicated. Nevertheless it seems to be of some interest to notice that the lowest level of application promotes respiratory activity according to a normal pattern, with reduced increases after about one month of incubation; whereas the highest levels show progressive increases probably corresponding to overcoming adverse conditions that trend to lessen the process. The rate of this appeares very favourable in the first case and its completion results rather advanced after about three months.

Unfavourable conditions produced by the heaviest treatment with sludge compost are confirmed for mineralization and ammonification rates in amended soil. About 100 days after the compost application, these microbial activities resulted as reported in figg. 3 and 4. The mineralization of organic carbon in soil appeares stimulated by 1.25 and 2.5 per cent application of composted sludge, but adversely affected by 5.0%. This last soil sample has shown the highest value of microbial counts: $1.5x10^9$ heterotrophic microorganisms x g^{-1} of soil whereas $1.0x10^8$, $2.6x10^8$ and $6.0x10^8$ respectively resulted in the control, in 1.25% and 2.5% sludge amended soil samples. Nevertheless microbial enzyme activities responsible for the breakdown of glucidic materials turn out adversely affected. This result is partially in contrast with data of Cornfield, Beckett and Davis (3), who have found out that also higher levels of organic matter do not depress the mineralization of organic carbon in soil, when applicated as consolidated activated sludge, secondary digested sludge or vacuum filter cake.

As far as the effects on ammonification, the influence of sludge compost is more severe and only the lowest level of application appears to preserve this activity. The soil treated with 5.0% of compost is resulted as rich as the control soil in ammonifiers ($1.2x10^7$ microorganisms X g^{-1}). Therefore also in this case organic and/or inorganic inhibitors of enzymes hydrolysing C-N bonds rather than of microbial viability can be easily hypothesized. The studies of Tyler (13) on the effect of some heavy metals on nitrogen mineralization in acidic forest soils should be extended to other soil types in order to define the influence of the sludge heavy metals on these actions and new researches should be devoted to organic inhibitors.

Nitrification in soils treated with composted sewage sludge is reported in fig. 5. This microbial activity does not appear very affected. The oxidation of NH_4^+-N reaches the best value in soil amended with 1.25% of compost, but the contro soil and the sample treated with 5.0% of compost at the end of the experiment paradoxically show alike quantities of nitrate nitrogen. Microbial counts have evidenced similar values for the different samples: about $1.0x10^4$ NH_4^+-oxidizers and about $5.0x10^2$ NO_2^--oxidizers x g^{-1} of soil (MPN); $1.0x10^4$ nitrifiers x g^{-1} of soil are equally resulted by plate-counts, without statistical significance.

Studies on nitrification of digested sludges added to soil carried out by Premi and Cornfield (10) have shown a temporary immobilization of ammonium nitrogen when the highest levels of sludge were applicated. Lees (7) reports several organic acids and other organic substances as specific inhibitors of Nitrosomonas as well as of Nitrobacter. From this point of view composted sewage sludge results definitively stabilized and probably lacking in such inhibitors. On the other hand the improvement of soil structure can generically promote nitrification.

In conclusion, the overall data from experiments reported show that also for composted sewage sludge only rates of application inspired to correct practice of fertilization guarantee the preservation of soil biological properties. Within these quantities, applications can occur enough frequently and allow a more intensive agricultural use of sewage sludge.

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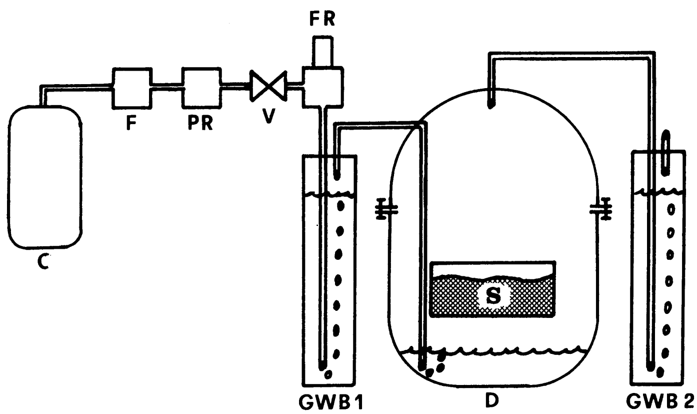

C:air compressor; F:air filter; PR: pressure regulator;
V:valve; FR: flowrate regulator; GWB: gas washing bottles;
D: desiccator (utilized as incubation tank); S: soil sample.

Figure 1 - Experimental set up for mineralization studies

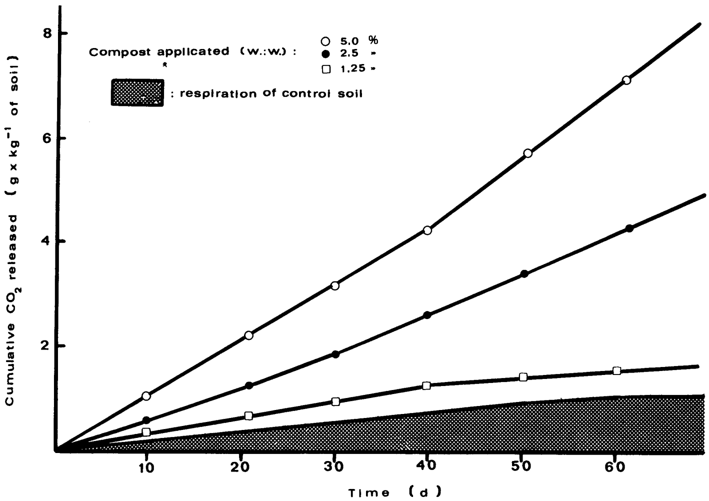

Figure 2 - Mineralization of composted sewage sludge in the soil

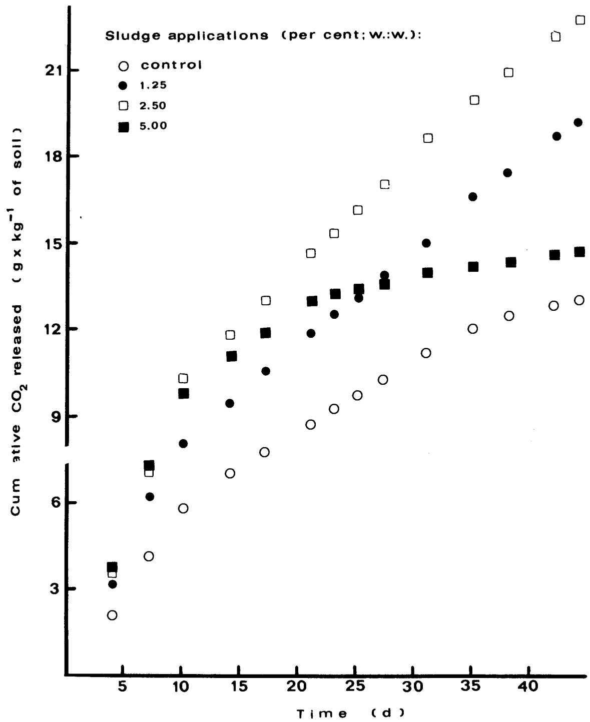

Figure 3 - Mineralization of organic carbon

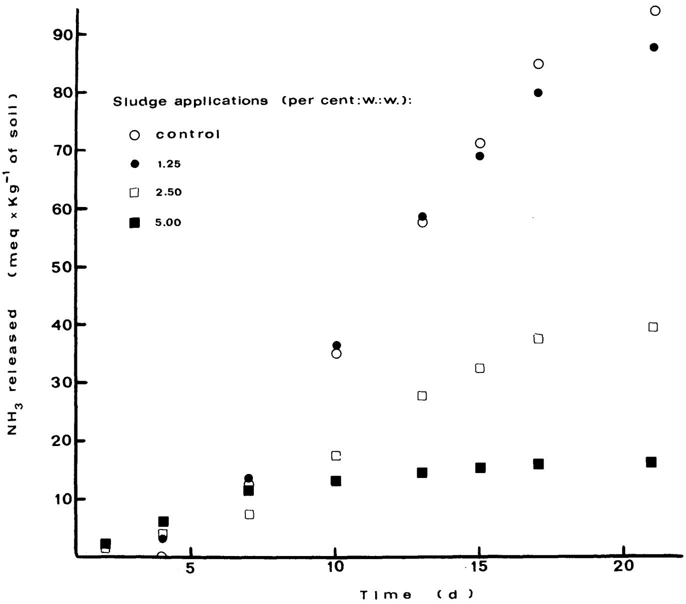

Figure 4 - Ammonification

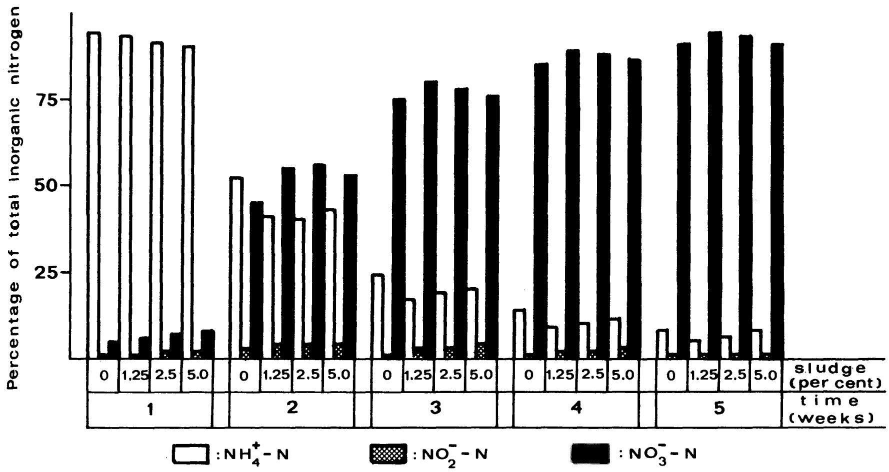

Figure 5 - Nitrification in soils treated with composted sludge

EIGENSCHAFTEN UND NUTZWERT EINES DURCH SCHNELLKOMPOSTIERUNG ERZEUGTEN TROCKENEN KLÄRSCHLAMMDÜNGERS

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Zusammenfassung

In der Bundesforschungsanstalt für Landwirtschaft wurde eine spezielle Schnellkompostierung von teilentwässertem Klärschlamm entwickelt. Das Verfahren basiert auf einer 4 - 5tägigen Kurzrotte von pelletiertem Material bei 70 - 75° C und benötigt keine weiteren Zusätze. Das erzeugte Produkt ist frei von pathogenen Keimen und weist eine krümelige Struktur auf.

Hauptnachteil dieser Heißrotte sind die damit verbundenen hohen Abbauverluste an Kohlenstoff und Stickstoff bis zu 40 bzw. oder sogar 50 %. Der ausgeprägten Abnahme von laugelöslichen Kohlenstoff- und Stickstoffverbindungen steht eine beträchtliche Vermehrung der hydrolysierbaren Anteile gegenüber, verbunden mit einer beachtlichen Ammonifizierung des im Produkt verbliebenen Stickstoffs. Infolgedessen werden von dem Schnellkompost im Boden ähnlich große Stickstoffmengen freigesetzt wie von dem ursprünglichen Klärschlamm, so daß sich die Stickstoffverfügbarkeiten im Gefäßversuch nicht wesentlich unterscheiden. Durch eine zusätzliche Nachrotte von mehreren Wochen wird die Zusammensetzung dieses Produktes nicht mehr wesentlich verändert. Der erzeugte Schnellkompost ist ein guter und leicht zu handhabender Dünger, sofern dessen Wert nicht durch hohe Schwermetallgehalte beeinträchtigt wird.

Summary

A special process has been developed for the short-time composting of partly dewatered sewage sludge. Its characteristic features are a fermentation of pelletized material during 4 - 5 days at 70 - 75° C in a solid-state composter. This process does not require the addition of external materials and yields a crumbly end-product free of pathogens.

The main disadvantage of this hot fermentation process are carbon and nitrogen losses of up to 40 or even 50 % respectively. There is a pronounced decrease in alkali soluble carbon and nitrogen compounds during the fermentation, but the hydrolisable proportion and the percentage of ammonium nitrogen is strongly increased. The percent of nitrogen released from the final product in soils is similar to that of the original sludge material, so that in pot experiments the nitrogen supply to plants from both materials does not differ very much. An additional open-air composting of the fermented material over several weeks does not considerably change its composition any more. Unless its heavy metal content is high, the composted material is an effective fertilizer which can be conveniently handled and used.

1. EINLEITUNG

Gewöhnliche Klärschlämme enthalten in der Regel höchstens 5 % Trockenmasse und werden daher ähnlich wie Jauche und Gülle vorwiegend flüssig auf den Feldern ausgebracht. Vom wirtschaftlichen Gesichtspunkt ist dieses Verfahren deshalb nachteilig, weil hierbei eine große Menge von Verdünnungswasser kostspielig transportiert und verteilt werden muß. Ähnliches gilt auch für den Transport von Klärschlämmen zur Deponie, ganz abgesehen davon, daß derart große Flüssigkeitsmengen gar nicht ordnungsgemäß deponiert werden können.

Zahlreiche Gemeinden pflegen daher ihren Klärschlamm vor dessen Beseitigung zu entwässern, wozu neben Trockenbeeten und Zentrifugen in jüngerer Zeit zunehmend Kammerfilter- oder Siebband-Pressen in Verbindung mit Flockungs- bzw. Fällungsmitteln verschiedener Art eingesetzt werden. Die Produkte enthalten je nach Verfahren zwischen 15 und 35 % Trockensubstanz und stellen eine stichfeste zähe Masse dar.

In der landwirtschaftlichen bzw. gartenbaulichen Pflanzenproduktion werden derartige entwässerte Klärschlämme nur sehr begrenzt eingesetzt. Hierfür sind u. a. eine Reihe von negativen Eigenschaften verantwortlich: der Besatz an pathogenen Organismen, der unangenehme Geruch, das Aussehen und die schwierige Handhabung. Teilentwässerter Klärschlamm ist zäh und schmierig, weder pump- noch rieselfähig und daher auch nur sehr schlecht zu verteilen bzw. zu dosieren.

In einem speziellen Forschungsvorhaben des Institutes für Technologie der FAL wurde daher versucht, diese negativen Eigenschaften von teilentwässerten Klärschlämmen zu verbessern bzw. hieraus ein leicht zu handhabendes organisches Düngemittel herzustellen. Diesem Zweck diente ein besonderes Kompostierungsverfahren, zu welchem bereits entsprechende Erfahrungen unter Verwendung tierischer Exkremente vorlagen (1, 2).

Im Institut für Pflanzenernährung und Bodenkunde der FAL wurden diese Produkte analytisch charakterisiert und ihre Düngewirksamkeit in Gefäßversuchen mit verschiedenen Pflanzen festgestellt. Das Herstellungsverfahren, das erzeugte Düngemittel und dessen Düngewert werden nachfolgend im einzelnen beschrieben.

2. HERSTELLUNGSVERFAHREN

Abbildung 1 zeigt schematisch den Ablauf des verwendeten "Feststoffverfahrens": teilentwässerter Klärschlamm "m_0" mit einer Ausgangsfeuchtigkeit von 65 - 85 % wird in einem Paddelschneckenmischer mit trockenem, zerkleinertem Rückgut "m_4" vermengt. Dieses Rückgut soll überschüssige Feuchtigkeit binden und dem erzeugten Gemisch eine porenreiche Struktur vermitteln. Für den weiteren Verfahrensablauf hat sich ein Wassergehalt von 40 - 45 % als optimal erwiesen, weil das Gemenge "m_1" dann in einer krümeligen Form vorliegt. Mit einer Schneckenpresse werden hieraus röhrenförmige Preßlinge "m_2" hergestellt, die einen Außendurchmesser von 50 mm, einen Hohlkern von 10 mm und eine mittlere Länge von 50 - 100 mm aufweisen.

Diese Preßlinge werden anschließend in eine wärmeisolierte Rottezelle eingefüllt, in der sich ohne Zusatzbelüftung innerhalb von 1 - 2 Tagen durch Selbsterhitzung Temperaturen von 70 - 75^{o} C entwickeln. Diese Schnellkompostierung wird nach einer 4 - 5tägigen Fermentationsdauer abgebrochen. Das so erzeugte Rotteprodukt "m_2" kann anschließend in Mieten gelagert werden, wobei eine weitere Nachrotte eintritt.

Wegen ihrer hohen Luftdurchlässigkeit trocknen diese Preßlinge in den Mieten allerdings rasch weiter aus. Für eine ungestörte Nachrotte ist daher unter Umständen eine nochmalige Befeuchtung erforderlich. Andererseits werden durch diese natürliche Austrocknung an der freien Luft Energiekosten eingespart. - Ein weiterer Teilstrom des Rottegutes "m_3" wird im Kreislauf als "Rückgut" zurückgeführt, thermisch getrocknet und gemahlen. Die Feuchtigkeit dieses getrockneten Rückgutes "m_4" liegt zwischen 10 und 15 %.

Das Verfahren beruht also im wesentlichen auf einer Kompostierung von Klärschlamm-Preßlingen und zeichnet sich insofern durch seine Unabhängigkeit von fremden Zuschlagstoffen aus (5). Eine Anhäufung derartiger Preßlinge weist zwar insgesamt mit etwa 45 % fast das gleiche Hohlraumvolumen wie ungepreßte Krümel auf, aber einen deutlich geringeren Strömungswiderstand und eine wesentlich bessere Luftdurchlässigkeit. Hierdurch tritt auch bei Schütthöhen von 3 - 4 m noch ein ausreichender und gleichmäßiger Luftaustausch ein, ohne daß hierfür eine Zwangsbelüftung notwendig wäre.

Das Produkt kann dank der in diesem Prozeß erreichten Rottetemperaturen von über 70^{o} C als hygienisch einwandfrei gelten. Die erzeugten Preßlinge sind schütt- und streufähig. Nach einer mehrwöchigen Nachrotte hat der so behandelte Klärschlamm auch seinen lästigen Geruch verloren und auch in dieser Hinsicht Komposteigenschaften angenommen.

3. PRODUKTEIGENSCHAFTEN

Aus der Tabelle I geht hervor, daß sowohl die Kohlenstoff- als auch die Stickstoffgehalte in der Trockenmasse während der Heißrotte beträchtlich ab-, und die Aschegehalte entsprechend zunehmen. Insgesamt gehen während der 4 - 5tägigen Schnellkompostierung bis zu 40 % des im Klärschlamm enthaltenen Kohlenstoffs und von dessen ursprünglichem Stickstoffgehalt sogar bis zu 50 % verloren. Derartige Stickstoffverluste lassen sich bei Substraten mit engen C/N-Verhältnissen ganz allgemein kaum vermeiden. Sie sind jedoch bei der hier durchgeführten Heißrotte deshalb besonders hoch, weil das durch mikrobielle Umsetzung entstandene Ammonium durch die intensive Belüftung des alkalischen Materials bei vergleichsweise hohen Temperaturen besonders leicht ausgetrieben wird.

Dessen ungeachtet bleibt festzustellen, daß der Gehalt an Ammoniumstickstoff in den Rotteprodukten ganz wesentlich höher ist als in dem ursprünglichen Klärschlamm und von dort 2 - 3 % auf ungefähr 20 % des gesamten in diesen Komposten enthaltenen Stickstoffs ansteigt. Man kann also bei diesen Produkten mit einem vergleichsweise hohen Anteil an leicht verfügbarem Stickstoff rechnen. Eine Nachrotte von 2 - 6 Wochen führt erwartungsgemäß zu weiteren Substanzverlusten, die aber im Vergleich zu der vorangegangenen Heißrotte verhältnismäßig gering bleiben. Insgesamt sind diese Rotteverluste natürlich auch von der Art des jeweiligen Klärschlamms abhängig, wobei es durchaus vorkommen kann, daß ein ascheärmeres Material wie der Schlamm Nr. 2 sogar weniger Substanz verliert als der aschereichere Schlamm Nr. 1.

Daß in diesem Klärschlamm Nr. 2 umsetzungshemmende Konzentrationen an Schadstoffen vorlagen, ist nach den Schwermetallanalysen der Tabelle II nicht zu erwarten. Sehr wahrscheinlich ist dagegen ein hemmender Einfluß auf die mikrobielle Umsetzung des Klärschlammes Nr. 3, weil dessen Cadmium- und Zinkgehalte bei 70 bzw. 8000 ppm lagen. Nach SINGHANIA und SAUERBECK (6) ist bei Zinkkonzentrationen über 2000 ppm in der Trockenmasse bereits mit einer deutlichen Blockierung der anaeroben Umsetzungen und bei mehr als 6000 ppm auch der aeroben Zersetzungsvorgänge zu rechnen.

Die Tabelle III macht deutlich, daß durch die Heißrotte vor allem die laugelöslichen Kohlenstoff- und Stickstoffverbindungen vermindert wurden. Die Zunahme von nicht hydrolysierbaren Anteilen ist dagegen vermutlich nur auf die absolute Verminderung des Gehaltes an organischen Substanzen und die hierdurch hervorgerufene relative Anreicherung schwerer zersetzlicher Reste zurückzuführen. Stark zugenommen haben aber auch die hydrolysierbaren Anteile, insbesondere an Stickstoff. Hieraus wäre zu folgern, daß die in dem Schnellkompost verbliebenen bzw. neu entstandenen Stickstoffverbindungen großenteils noch relativ leicht zersetzlich und demnach auch im Boden mineralisier- bzw. nachlieferbar sind.

4. DÜNGEWERT

Abbildung 2 zeigt die Ertragswirkung der beiden Kompostierungsprodukte im Vergleich zu dem unbehandelten Klärschlamm Nr. 1 auf 2 verschiedenen Böden. Die mineralische Stickstoffsteigerung von 0 auf 1,8 g je 6,5 kg Boden ergab die übliche Mitscherlich'sche Ertragskurve, bei einer stark von den Bodeneigenschaften abhängigen Düngerwirkung. 80 bzw. 100 g Trockenmasse aus Klärschlamm oder Rotteprodukten entsprachen den in den Säulen angegebenen Stickstoffmengen in g je Gefäß, von denen etwa 20 % als pflanzenverfügbar angenommen wurden.

Die Erträge der Erstfrucht Senf zeigen, daß tatsächlich mit rund 3 g Gesamtstickstoff aus dem Schlamm und den beiden Komposten ein Effekt erzielt wurde, der demjenigen von etwa 0,6 g Mineraldüngerstickstoff entsprach. Die relativ geringen Ertragsunterschiede zwischen Schlamm, Schnellkompost und nachgerottetem Kompost sind offensichtlich auf die nicht ganz gleiche Stickstoffzufuhr durch diese 3 Substanzen zurückzuführen. Auf jeden Fall läßt sich aus diesen Ergebnissen folgern, daß durch die Schnellkompostierung bzw. Nachrotte von Klärschlamm zwar eine beträchtliche Menge an Stickstoff verloren geht, die Pflanzenverfügbarkeit des in diesen Produkten noch enthaltenen Stickstoffs durch die Heißrotte aber nicht beeinträchtigt, sondern eher noch vermehrt worden ist.

Nach den in Tabelle II gemachten Angaben kann diese hohe Ertragswirkung der beiden Klärschlammkomposte auf deren relativ hohen Anteil an Ammonium-N in Höhe von etwa 20 % des gesamten noch vorhandenen Stickstoffs zurückgeführt werden. Aber auch der unbehandelte Klärschlamm hat trotz geringer Ausgangsgehalte an mineralischem Stickstoff während seiner Umsetzung im Boden kaum weniger pflanzenverfügbaren Stickstoff freigesetzt als die beiden Komposte. Darüber hinaus haben offensichtlich der Klärschlamm ebenso wie dessen Komposte auch späterhin ziemlich ähnliche Stickstoffmengen für den als Zweitfrucht angebauten Mais nachgeliefert. Die hier geprüften Substanzen sind also auch hinsichtlich ihrer längerfristigen Effekte weitgehend vergleichbar.

Wie bei allen stickstoffhaltigen Düngemitteln, so muß allerdings auch hier vor einer Überdosierung gewarnt werden. Steigert man die Zufuhr dieser Substanzen nämlich über 80 bzw. 100 g je Gefäß hinaus, so ist bei der Erstfrucht Senf keine weitere Ertragszunahme, auf dem stickstoffreichen Lehmboden sogar eine ausgeprägte Ertragsdepression zu beobachten. Die trotz gleicher oder gar sinkender Erträge mit zunehmender Gabe stark ansteigenden Stickstoffgehalte in der Erntemasse zeigen, daß diesen Pflanzen ganz offensichtlich ein Überschuß an Stickstoff zur Verfügung stand, der von der Erstfrucht nicht mehr in Ertrag umgesetzt wurde, sondern nur noch in den hohen Stickstoffgehalten von mehr als 3 % zum Ausdruck kam. Erst bei der Zweitfrucht Mais wirkten sich auch die höheren Klärschlamm- bzw. Kompostgaben auf die Pflanzenerträge eindeutig positiv aus, ohne daß hierdurch auch die Stickstoffgehalte in der Erntemasse wesentlich vermehrt worden sind.

Auffallend ist allerdings, vor allem auf dem sorptionsschwachen Sandboden, daß keine der Klärschlamm- bzw. Kompostgaben in ihrer Wirkung über das Ertragsäquivalent von 0,6 g mineralischem Stickstoff je Gefäß hinausgekommen ist, obwohl in der Mineraldüngerreihe durch 1,2 und 1,8 g Stickstoff noch erhebliche Ertragssteigerungen erzielt wurden. Eine analytische Überprüfung hat ergeben, daß die Zinkgehalte der Senfpflanzen auf diesem Boden bei den höheren Klärschlamm- bzw. Kompostgaben durchweg mehr als 350, in einigen Fällen sogar bis zu 800 ppm betrugen. Unter Berücksichtigung des in der Literatur genannten Grenzwertes für eine beginnende Toxizität von ungefähr 300 ppm Zink (3, 4) könnte daher der fehlende Ertragseffekt steigender Gaben auf dem leichten Sandboden auch auf den überhöhten Zinkgehalt des hier verwendeten Klärschlammes zurückzuführen sein. Auf dem tonreicheren Lehmboden war dieser Effekt dagegen weniger ausgeprägt.

Zusammenfassend wäre demnach festzustellen, daß die hier geschilderte Schnellkompostierung von Klärschlamm durch eine Kurzrotte bei Temperaturen bis zu 75° C zwar zu erheblichen Substanz- und insbesondere Stickstoffverlusten führt, aber ein für die praktische Verwendung als Düngemittel gut geeignetes Produkt erzeugt. Schwermetallbelastete Klärschlämme müssen allerdings auch hier von einer Verwendung ausgeschlossen werden.

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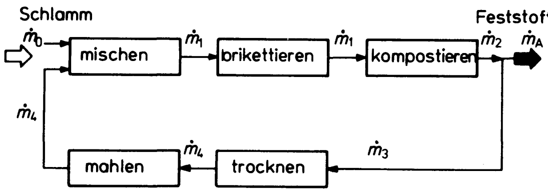
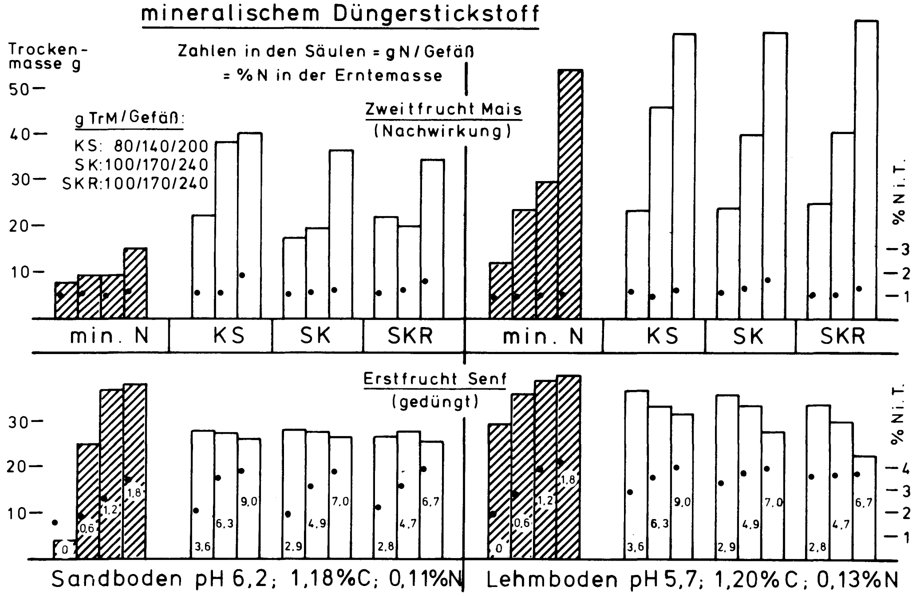


Abb. 1 Schnellkompostierung von teilentwässertem Klärschlamm

m_0 = Klärschlamm, 65 - 85 % Wasser
m_1 = Schlamm-Rückgut-Gemisch, krümelig bzw. gepreßt, 40 - 45 % Wasser
m_2 = Rotteprodukt, < 40 % Wasser
m_3 = Rottegut zur Trocknung
m_4 = rückgeführtes Rottegut, < 15 % Wasser
$m_\triangle$ = Nachrotte auf Mieten

Abb. 2 Ertragswirkung von Klärschlamm (KS), KS-Schnellkompost (SK) und nachgerottetem Schnellkompost (SKR) im Vergleich zu mineralischem Düngerstickstoff



Tab. I Einfluß der Schnellkompostierung und zusätzlichen Nachrotte auf die chemische Zusammensetzung von Klärschlämmen

Substrat	% Asche	% C	% N	% NH_4N	C/N	% Verluste org. Masse	% Verluste Stickstoff
Klärschlamm 1	43,3	32,9	4,5	0,09	7,2	-	-
Schnellkompost	55,3	27,2	2,9	0,61	9,5	38	51
2 Wochen Nachrotte	56,5	26,6	2,8	n.b.	9,5	41	53
6 Wochen Nachrotte	58,7	25,6	2,8	n.b.	9,1	46	55
Klärschlamm 2 (schwach kontam.)	29,4	46,0	3,9	0,12	11,7	-	-
Schnellkompost	38,2	41,5	3,0	0,35	13,7	33	40
Klärschlamm 3 (stark kontam.)	30,1	43,2	5,1	0,17	8,6	-	-
Schnellkompost	31,8	41,6	5,2	0,37	8,1	7	3

n.b. = nicht bestimmt

Tab. II Schwermetallgehalte von Klärschlämmen
(Angaben in mg/kg)

Bezeichnung	Zn	Cd	Pb	Cr
Schlamm Nr. 2	985	3	233	10
Schlamm Nr. 3*)	8213	74	67	389

*) Einfluß eines Galvanisierbetriebes

Tab. III Prozentuale Verteilung des in den Substraten enthaltenen C und N in verschiedenen Fraktionen - Klärschlamm Nr. 1 -

Substrat	NaOH-Extrakt		Rückstand hydrolysierbar		Rückstand nicht hydrolysierbar	
	C	N	C	N	C	N
Klärschlamm	72	78	17	20	11	2
Schnellkompost	54	56	25	41	21	3
2 Wochen Nachrotte	52	53	26	44	22	3
6 Wochen Nachrotte	52	53	23	45	25	2

LYSIMETRIC RESEARCH OF SEWAGE SLUDGE APPLICATION ON SOIL. NOTE I - NITROGEN BALANCE

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Summary

Experiments were carried out by lysimeters to evaluate the effects of aerobic and anaerobic sewage sludge applied to a wheat crop. Sewage sludges were compared with manure and chemical fertilizers. Each of these materials was tested at two doses. Analyses (to find different nitrogen forms) were made on the soil and on different parts of the plant at harvesting time, and monthly, on leached waters.

Data were worked out to evidentiate the different nitrogen balance according to the kind of sewage sludge and the application dose. Besides the effect on the yield and on its protein content, the nitrogen content of leached waters was evaluated in relation to the growth period of the plants and to the rainfall.

The data suggest that the risk of eutrofication does exist but it can be controlled by observing a few rules regarding dosage and time in the application of sewage sludge.

1. INTRODUCTION

The main characteristics of sewage sludge, when applied to the soil, regard its relative content of organic matter, nitrogen and heavy metals. These are, in fact, the caracteristics which, according to circumstances, most affect soil fertility and consequently yield, or, on the other hand, generate toxicity and pollution.

The fertilising properties of sludge depend chiefly on the nitrogen and phosphate relesed (1-2-4-5-6). The utilisation rate of nitrogen from sludge is around 15-30% of the total contained in it, in the case of barley and mustard (3) and 9% in the case of Cynodon dactylon (8).

It is also interesting to note that nitrogen present in sludge is originally mostly in the organic form but also as ammonium, and is quickly converted into nitrates in the soil. The transformation rate depends on the application dose (10-11-13). The fact that an increase in the nitrate nitrogen content of the water table has coincided with the use of sludge in agriculture is not casual (15).

Experiments were carried out using lysimeters, to evaluate the nitrogen balance in a wheat crop. Wheat is of pre-eminent importance, because of the large area devoted to this crop all over the world and the massive application of sewage sludge in its cultivation (9).

2. MATERIALS AND METHODS

Experiments were performed at the "Istituto di Agronomia" of the University of Pisa, using open sky lysimeter equipment, consisting in a set of sixteen growing tanks. Each of these was 0.47 m^2 in area (68.5 cm x 68.5 cm), soil depth 70 cm. Each tank was connected by pipes to a 20 l plastic container, where leached water was caught. The physical and chemical characteristics of the soil used in the experiment were the following: clay 11.8%; silt 15.5%; sand 71.1%; moisture 1.6%; organic matter 1.32%; total N 1.4‰; $CaCo_3$ 4.3%; total P_2O_5 0.7‰; pH 8.2.

Treatments tested, settled in a randomised block design with two replications, are presented in table I.

The only common factor in all treatment types was their organic carbon content. This was because of the necessity of respecting the conditions of general research underway in the field (9), where such criteria were followed. Nutrient content of sewage sludge, manure and fertilisers applied at

Figure I - Rainfall and temperature during the trial period .

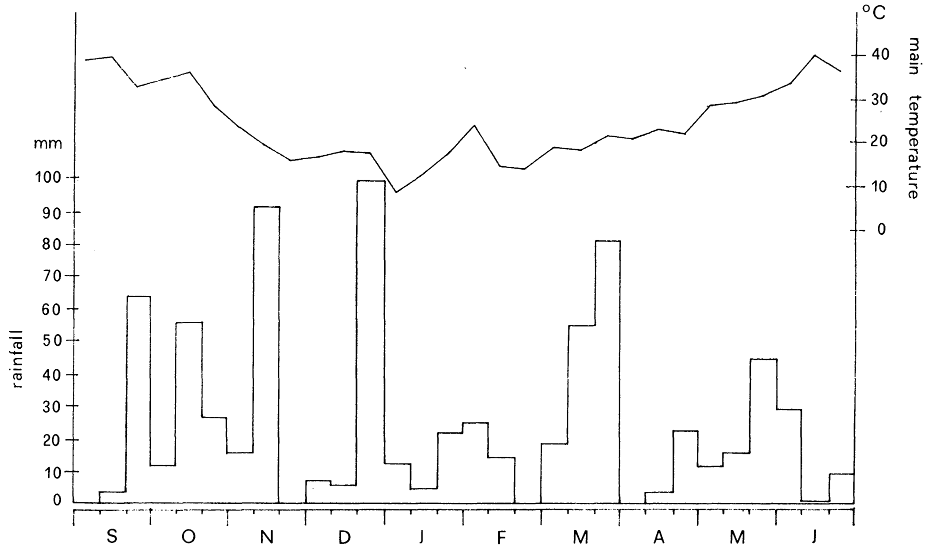

Table I - Nutrient content (kg/ha) of sewage sludge (s.s.), manure and chemical fertiliser applied at different rates

Treatment	Liquid material (m^3/ha)	Dry matter (m^3/ha)	Organic matter (m^3/ha)	Carbon	N				P_2O_5	K_2O
					NO_3	NH_4	Org.	Tot.		
Aerobic s.s.										
1 (dose 1)	760	12,2	6,7	3.891	0	23	484	507	507	98
2 (dose 2)	2.280	36,6	20,1	11.673	0	69	1.452	1.521	1.521	294
Anaerobic s.s.										
3 (dose 1)	300	10,5	6,9	4.000	0	108	259	367	409	82
4 (dose 2)	900	31,5	20,7	12.000	0	324	777	1.101	1.227	246
Manure										
5 (dose 1)	50	10,4	6,6	3.865	0	-	-	187	83	250
6 (dose 2)	150	31,2	19,8	11.595	0	-	-	561	249	750
Chem.fertiliser (x)										
7 (dose 1)					0	80		80	120	50
8 (dose 2)					0	240		240	360	150

(x) - Nitrogen from fertiliser was considered NH_4 - N on account of the transformation that urea undergoes when in the soil.

different rates is reported in table I. In the case of mineral fertilisation, phosphates and potassium were applied before seeding, nitrogen, as urea, 1/3 before seeding and 2/3 as top dressing.

Leached water, recorded monthly, was tested for nitrate and ammonium nitrogen by Orion Microprocessor Ion Analyser Mod. 901 with specific electrodes; nitrite nitrogen was determined by sulphanylamide and α-naphthylamine (14).

Grain and straw yield was measured, as well as their respective protein content (Kjeldahl).

Rainfall and temperature were recorded during the trials and are reported in figure I.

Applications were made on 9th Semtember 1979; before seeding (5th December 1979) the sludge and manure were incorporated into the soil to a depth of 10-15 cm.

The crop was harvested on 5th July 1980. Wheat variety used was "Orso".

3. DISCUSSION OF RESULTS

a) Yield and Protein Content - Production data are reported in table II. Highest values in grain production were obtained with the lower rate of aerobic sludge and the higher rate of chemical fertiliser, anaerobic sludge and manure.

The results considered as a whole also clearly show that when the rates of chemical fertiliser, manure and anaerobic sludge are tripled, grain production doubles, but if the rate of aerobic sludge is tripled grain production is halved.

These results confirm a theoretical evaluation of nitrogen availability (C:N ratio) for the plants in the different treatments (7-12).

The fact that the depressing effect of high rates of aerobic sludge is connected with an excessive organic nitrogen supply (or the product of its mineralisation) is shown by the straw/grain ratio, which shows a high production of the former, to the disadvantage of the latter. The excessive growth of the plants in this treatment was already evident at raising time (February-March) in which period lodging of the plants took also place.

As far as grain is concerned, yield was high using aerobic and anaerobic sludge as it was with high rates of chemical fertiliser. However, in the case of anaerobic sludge, this result is obtained at the higher rate

Table II - Wheat yield (g/tank) and protein content.

Treatment	Yield			Straw/Grain	Protein production			Protein % (dry matter basis)	
	Grain	Straw	Total		Grain	Straw	Total	Grain	Straw
Aerobic s.s.									
1 (dose 1)	319,1	502,1	821,2	1,57	29,8	18,3	48,1	10,57	3,97
2 (dose 2)	158,3	555,7	714,0	3,51	25,1	48,1	73,2	17,53	9,50
Anaerobic s.s.									
3 (dose 1)	152,6	345,1	497,7	2,26	13,7	10,4	24,1	9,94	3,25
4 (dose 2)	296,7	451,2	747,9	1,52	27,3	14,0	41,3	10,32	3,41
Manure									
5 (dose 1)	101,7	245,4	347,1	2,41	9,8	6,3	16,1	10,81	2,78
6 (dose 2)	265,0	568,0	833,0	2,14	23,2	14,1	37,3	9,75	2,72
Chem. fertiliser									
7 (dose 1)	151,9	368,2	520,1	2,42	12,7	9,7	22,4	9,26	2,88
8 (dose 2)	317,5	512,6	830,1	1,61	37,6	26,1	63,7	12,88	5,50

(900 m^3/ha), whereas in the case of aerobic sludge it is the lower rate (760 m^3/ha) which gives a better yield. This agrees with the respective supply of total nitrogen.

Highest protein yield per tank (73.2 g) was obtained from the highest rate of aerobic sludge. This was presumably due to the greater quantity (1521 Kg/ha) of total nitrogen supplied to the soil, which determined the higher protein content in the grain (17.53%) and in the straw (9.50%).

It is also worth noting the fact that in all treatments (except that with manure) a triple rate gave a higher protein content both in the grain and in the straw (table II). Where aerobic sludge was concerned, this percentage increase was particularly marked, reaching 66% in the grain and 139% in the straw.

Protein content of the product (grain and straw) in all of the treatments (except for manure) is in agreement with the quantity of nitrogen supplied to the soil in each case.

b) Leaching and Absorbtion of Nitrogen - Quantities of nitrogen expressed as g/tank as ammonium, nitrite and nitrate which were leached during the growth period are reported in table III, together with the amounts of percolated water.

An analysis of the results shows a considerable difference in the amounts. It is interesting to note that the highest values (from 7 to 15 g/tank) equal to 150 and 300 Kg/ha were obtained from manure, aerobic sludge and anaerobic sludge, in that order. Besides this, when the dose was tripled the total percolated nitrogen increased by only 1½. Greater quantities percolated in this treatment in comparison with that with only chemical fertilisers, is in the range of 4 to 12 g/tank (equal to 80 to 240 Kg/ha) according to which case.

In the different treatments the contribution of ammonium and nitrite nitrogen to total nitrogen leached was of small entity. Almost all (about 99%) of the total nitrogen leached in all of the treatments was nitrate nitrogen.

If the behaviour of leached nitrogen is considered over the whole period, it is seen that on an average over 90% it is leached in those months when heavy rainfall coincides with zero growth (December and January), or when the soil is bare (October and November) before seeding.

Nitrogen absorbtion by the crop is reported in table IV. Analagous

Table III - Leached nitrogen in different forms (g/tank) in the period from 9.9.1979 to 5.7.1980.

Treatment	Water Leached (kg)	Nitrogen			
		NH_4	NO_2	NO_3	Tot.
Aerobic s.s.					
1 (dose 1)	207,0	0,038	0,026	8,066	8,130
2 (dose 2)	204,4	0,033	0,078	12,204	12,315
Anaerobic s.s.					
3 (dose 1)	191,7	0,039	0,009	9,161	9,209
4 (dose 2)	219,2	0,038	0,051	15,297	15,386
Manure					
5 (dose 1)	207,6	0,041	0,034	6,978	7,053
6 (dose 2)	177,3	0,028	0,016	11,047	11,091
Chem. fertiliser					
7 (dose 1)	195,6	0,047	0,009	3,354	3,410
8 (dose 2)	182,0	0,023	0,006	2,902	2,931

Table IV - Nitrogen balance(g/tank) of sewage sludge (s.s.), manure and chemical fertiliser applied at different rates.

Treatment	N applied	N absorbed	N leached	Δ	Absorbed % applied	Leached % applied
Aerobic s.s.						
1 (dose 1)	23,83	7,70	8,13	+ 8,00	32,3	34,1
2 (dose 2)	71,49	11,71	12,31	+47,47	16,4	17,2
Anaerobic s.s.						
3 (dose 1)	17,25	3,86	9,21	+ 4,18	22,4	53,4
4 (dose 2)	51,75	6,61	15,39	+29,75	12,8	29,7
Manure						
5 (dose 1)	8,79	2,58	7,05	- 0,84	28,4	78,6
6 (dose 2)	26,37	5,97	11,09	+ 9,31	22,6	42,0
Chem. fertiliser						
7 (dose 1)	3,76	3,58	3,41	- 3,23	95,2	90,7
8 (dose 2)	11,28	10,19	2,93	- 1,84	90,3	26,0

Note: Percentage of negative figures must be considered according to the text.

observations may be made on this subject as for protein.

c) Nitrogen Balance - The balance drawn up here (table IV) is rather a particular one, since for experimental reasons it was not possible to carry out a control using soil only, and so neither the nitrogen in the soil nor that in the rain is taken into consideration.

It is therefore possible to establish by measurement of the nitrogen absorbed by the crop and that leached in comparison to that supplied by aerobic and anaerobic sludge at both the rates, that the balance is positive. This means that at the and of cultivation the soil was richer in nitrogen. This cannot be said for treatment with chemical fertilisers, or where low rates manure are concerned. In these cases, in order to compensate for losses through absorbtion and percolation, nitrogen is taken up from the soil. This obviously impoverishes it.

This hypothesis may be confirmed by an analysis which is already planned on the carry-over effect.

The data in table IV show that although the percentage of nitrogen utilised by the crop from sludge is quite high, it is even more so in the treatment with chemical fertilisers. This according to the different ways of applying them, that is in one dose (sludge) or fractionated (chemical fertiliserd).

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PHOSPHATVERFÜGBARKEIT VON KLÄRSCHLÄMMEN AUS DER DRITTEN REINIGUNGSSTUFE

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Zusammenfassung

Von den jährlich in die Oberflächengewässer der Bundesrepublik Deutschland eingetragenen etwa 100.000 t P entstammen rund 80 % aus Kläranlagenabläufen. In den mechanischen bzw. mechanisch-biologischen Kläranlagen wird nur eine durchschnittlich 25 %ige P-Eliminierung erreicht. Von den in den Klärschlämmen abgeschiedenen Phosphaten (ca. 25.000 t P pro Jahr) wird knapp die Hälfte auf landwirtschaftliche Nutzflächen ausgebracht. Durch die chemische P-Fällung in der sog. 3. Reinigungsstufe ist eine weitgehende P-Entfernung aus dem Abwasser möglich. Die Fällungsphosphate können in der Düngung verwandt werden. Die Klärschlämme aus den mechanisch-biologischen Reinigungsstufen zeigen in der Regel eine vergleichsweise geringere P-Verfügbarkeit und -wirksamkeit als die Mineraldüngerphosphate. Für die Nachfällungsphosphate konnte dagegen eine hohe Löslichkeit und in Gefäßdüngungsversuchen eine den Handelsdüngerphosphaten zumeist ebenbürtige Wirkung festgestellt werden. Insbesondere die Produkte aus der Kalk- und Dolomithydrat-Nachfällung zeigten eine gute Entwässerungsfähigkeit sowie hohe Löslichkeit und Pflanzenverfügbarkeit. In der 3. Reinigungsstufe der Abwasserklärung werdenAl-, Fe- und Kalkfällungsphosphate gewonnen, die für eine Verwertung in der Landwirtschaft geeignet sind.

Summary

Surface water becomes more and more eutrophicated by phosphorus from waste water and from the effluents of sewage plants. By mechanical and biological sewage treatment about 25 %, by chemical precipitation using aluminium or iron salts or lime more than 90 % of the phosphorus in the waste water can be removed. For evaluating the fertilizing effectivity of the precipitates the extractability of the phosphorus and the effect on plant yields and P-uptake have been investigated. Sewage sludge from the third purification stage shows high content of citric acid soluble phosphate. The highest fertilizing value is found from the application of the lime precipitated sludge. The experiments suggest that phosphorus in sewage sludge from the third purification stage has nearly the same value as phosphorus in fertilizers.

1. EINLEITUNG

Im Zuge des gestiegenen Umweltbewußtseins nimmt die Einsicht in die Notwendigkeit einer umfassenden Abwasserreinigung eine vorrangige Stellung ein. Nach der zunächst im Vordergrund stehenden möglichst vollständigen Erfassung (Kanalisierung) und Durchschleusung des Abwassers durch mechanisch-biologische Kläranlagen dürfte in Zukunft der Verbesserung der Reinigungsleistung der Anlagen größere Aufmerksamkeit geschenkt werden. Insbesondere eine stärkere P-Elimination scheint geboten, da mit den herkömmlichen Klärverfahren lediglich ein Viertel des im Abwasser vorhandenen P im Schlamm gebunden wird. Der Rest gelangt auch weiterhin in die Gewässer und ist als wesentliche Ursache für deren Eutrophierung anzusehen (Tab. I). Nach einer GDCH-Studie (1978) wird der abwasserbedingte P-Eintrag mit 82 % am Gesamteintrag in die Gewässer der Bundesrepublik Deutschland in Höhe von 103.500 t/a veranschlagt (Tab. II).

Darüber hinaus ist der Aspekt der Wiederverwendung der Phosphate in die Überlegungen über eine weitergehende P-Elimination aus den Abwässern mit einzubeziehen. In der Bundesrepublik werden lediglich 10 % des in die Kläranlagen eingeleiteten P über die Klärschlammanwendung in den landwirtschaftlichen Nährstoffkreislauf zurückgeführt (sh. Tab. I). Bei weltweit knapper werdenden Rohphosphatvorräten sollten die Möglichkeiten eines stärkeren Recyclings genutzt werden.

Eine weitgehende P-Elimination aus den Abwässern läßt sich durch die chemische Fällungsreinigung erzielen. Die für die P-Ausfällung durch Zugabe von Al- und(oder) Fe-Salzen bzw. Kalk in Betracht kommenden Verfahren der sog. 3. Reinigungsstufe sind in Abbildung 1 schematisch dargestellt. Bei den verschiedenen Verfahren fallen Schlämme unterschiedlicher Menge und Güte an. Die Direkt-(D), Vor-(V) und Simultanfällung (S) liefern Mischschlämme, in denen neben dem Material aus der mechanisch-biologischen Reinigung auch die Fällungsphosphate aus der chemischen Stufe enthalten sind. Die Nachfällung (N) ermöglicht dagegen die Gewinnung verhältnismäßig reiner Al-, Fe- oder Kalkfällungsphosphate, die sowohl vom P-Gehalt, der vergleichsweise geringeren Schwermetallkontamination und günstigeren hygienischen Beschaffenheit als auch leichteren Entwässerbarkeit (Kalkfällungsprodukte) am ehesten für eine düngemäßige Verwendung in der Landwirtschaft geeignet sind.

2. P-DÜNGEWIRKSAMKEIT VON KLÄRSCHLÄMMEN

Grundvoraussetzung für eine Klärschlammanwendung in der Landwirtschaft ist die hygienische Ungefährlichkeit und Schadstofffreiheit der Produkte. Die Bewertung der Klärschlämme sollte sich am Nährstoffgehalt und am Anteil an bodenfruchtbarkeitsfördernden organischen Substanzen orientieren. In den Versuchen über die Klärschlammwirkung auf Ertrag und Bodenfruchtbarkeit wurde zunächst die Komplexwirkung dieses Abfallstoffes erfaßt und eine Beziehung zur verabfolgten N-Menge herzustellen versucht (SCHMID et al. 1973; DE HAAN 1972; KRÄMER 1972). Bei ständig zunehmender P-Konzentration in den Klärschlämmen lassen sich derzeit jedoch schon bis zu 70 % des Düngewertes auf die P-Komponente zurückführen (FURRER u. BOLLIGER 1980), so daß für die nährstoffmäßige Bewertung das Element P stärker in den Vordergrund zu rücken ist.

Neuere Versuche bzw. gezieltere Versuchsauswertungen kommen hinsichtlich der Wirksamkeit und Verfügbarkeit der Klärschlammphosphate zu unterschiedlichen Einschätzungen. Bei Prüfung von Faulschlämmen aus vorwiegend mechanisch-biologischen Kläranlagen, die zumeist in hohen Aufwandmengen gegeben wurden, wurde ein relativ niedriger P-Wirkungsgrad gefunden (PLATZEN 1974; KELLING et al. 1977). Insbesondere bei Schlämmen mit hohen Schwermetallgehalten war die P-Verfügbarkeit beeinträchtigt (POMMEL 1979; DAMGAARD-LARSEN et al. 1979). Bei umfangreichen Analysen verschiedener schweizer Klärschlämme wurde eine gesicherte Beziehung zwischen dem citronensäurelöslichen P-Anteil des Schlammes und der P-Aufnahme von Weidelgras gefunden (HÄNI u. GUPTA 1978).

Zur Bewertung des düngewirksamen P-Anteils der Klärschlämme wird daher die Löslichkeit in 2 %iger Citronensäure vorgeschlagen. Hohe Citronensäure- und Ammoncitratlöslichkeiten sowie den handelsüblichen Mineraldüngerphosphaten vergleichbare P-Aufnahmeraten wurden bei Fällungsschlämmen aus der dritten Reinigungsstufe festgestellt (CERVENKA u. TIMMERMANN 1978; KOSKELA 1980). Die Ursachen für die unterschiedliche Verfügbarkeit der Klärschlammphosphate sind in Zusammenhang mit dem Trockensubstanzgehalt, den kationischen Begleitelementen (Schwermetalle, Fällmittel), der Schlammbehandlung und -aufbereitung (Hygienisierung, Entwässerung, Trocknung) sowie den Bodeneigenschaften (Bodenreaktion, P-Versorgungszustand) und dem P-Aneignungsvermögen der Anbaufrüchte zu bringen (GUPTA 1976).

3. KALK- UND DOLOMITHYDRAT-FÄLLUNGSPHOSPHATE AUS DER NACHFÄLLUNG

In der Klärpraxis werden zur P-Ausfällung überwiegend Al- und Fe-Salze eingesetzt; in einigen Fällen hat sich eine Kalkzugabe als vorteilhaft oder sogar notwendig erwiesen (z. B. Fällung mit Fe-II-Salzen). Unter dem Gesichtspunkt der düngemäßigen Verwertung ist den Kalk- bzw. Dolomithydrat-Fällungsphosphaten der Vorzug zu geben, da neben dem Nährelement P auch größere Mengen des insbesondere für die Böden des humiden Klimabereiches notwendigen Ca mit diesen Fällungsprodukten genutzt werden und einer zusätzlichen Mg-Zufuhr durchaus Bedeutung zukommt.

In Labor- und großtechnischen Fällungsversuchen in der Göttinger Kläranlage wurde der Einsatz von Kalk- und Dolomithydrat zur P-Eliminierung im Nachfällungsverfahren untersucht. Der P-Gehalt des zuvor mechanisch-biologisch geklärten Abwassers konnte durch Zusatz von 300 mg Kalk- bzw. Dolomithydrat/l Abwasser in der Nachfällung um mehr als 90 % auf weniger als 1 mg P/l gesenkt werden (Abb. 2 und 3). Dieser in Laborversuchen erzielte P-Eliminationsgrad konnte in den großtechnischen Versuchen bei Dolomitdosierungen von 215 bzw. 325 mg/l nicht erreicht werden (Tab. III und IV). Wie die Unterschiede in den Ortho- und Gesamtphosphatgehalten ausweisen, dürfte zwar die eigentliche Fällungsreaktion (Ca-P-Bindung) erfolgt sein, bei durchschnittlichen Aufenthaltszeiten im Absetzbecken von 3 (Versuch I) bzw. 4,5 Stunden (Versuch II) wurden jedoch nicht alle gefällten, zunächst kolloidal schwebenden Phosphate in absetzbare Flocken überführt. Die zusätzlich mit der Nachfällung verbundene Reduzierung der organischen Reststoffe ist aus der Verminderung der BSB_5- und CSB-Werte abzulesen.

Der bei Nachfällung mittels Kalk- oder Dolomithydrat gewonnene Schlamm zeigte eine gute Selbstentwässerung. Nach kurzem Aufenthalt im Absetzbecken wurden Trockensubstanzgehalte von 10 % erreicht. Auf dem anschließend beschickten Trockenbeet bildeten sich über die gesamte Schlammdecke verteilt große Schrumpfungsrisse, die eine gute Dränage gewährleisteten. Der TS-Gehalt stieg innerhalb von 2 Wochen auf 40 % an. Nach 5monatiger Lagerzeit waren 70 % TS erreicht und die Produkte konnten nach kurzer thermischer Nachtrocknung und Zerkleinerung als streufähiges Granulat für Düngungszwecke eingesetzt werden.

4. LÖSLICHKEIT UND DÜNGEWIRKSAMKEIT DER FÄLLUNGSPHOSPHATE

In Anlehnung an die in der Bewertung der Handelsdüngerphosphate gebräuchlichen Untersuchungsmethoden wurde die P-Löslichkeit der Fällungsprodukte bestimmt (Tab. V). Bei verhältnismäßig niedrigen Gesamt-P-Gehalten, die auf die für die angestrebte P-Eliminationsrate hohe Kalk- und Dolomithydrat-Dosierung zurückzuführen sind, weisen die Fällungsphosphate hohe Löslichkeiten in den angewandten Extraktionsmitteln auf. Das im großtechnischen Versuch gewonnene Fällungsprodukt wurde darüber hinaus einer Gesamtanalyse unterzogen und daraus die chemische Zusammensetzung kalkuliert (Tab. VI). Die hohen $CaCO_3$- und $Mg(OH)_2$-Anteile weisen die Produkte als Kalkphosphatdünger aus, in denen die Ca-Komponente als langsam wirkend, der Mg-Anteil als sofort wirksam einzustufen ist.

Für die Prüfung der pflanzenphysiologischen Wirksamkeit der Kalk- und Dolomit-Fällungsphosphate bietet sich ein Vergleich mit dem marktgängigen Thomasphosphat an. In Gefäßdüngungsversuchen mit Lolium perenne als Versuchspflanze konnten auf 2 vornehmlich im pH-Wert unterschiedlichen Böden bei 3 Grasschnitten keine signifikanten Unterschiede in der TS-Produktion und im P-Entzug zwischen dem Dolomitfällungsprodukt und Thomasphosphat festgestellt werden (Tab. VII).

Die vergleichende Prüfung mit Al- und Fe-Nachfällungsphosphaten aus 3 großtechnisch betriebenen Anlagen (Ahrensburg, Großhansdorf, Wittlage) weist auf einem P-armen Untergrund-Löß mit neutraler Bodenreaktion eine Überlegenheit der Kalk- und Dolomithydrat-Fällungsprodukte insbesondere gegenüber dem Fe-Fällungsphosphat aus (Tab. VIII). Es bleibt weiteren Untersuchungen vorbehalten, ob die in Gefäßversuchen nachzuweisenden Wirkungsunterschiede für die praktische Düngung im Feld von Bedeutung sind.

Insgesamt ist jedoch zu schlußfolgern, daß die in der dritten Reinigungsstufe bei der Abwasserklärung anfallenden Phosphate für die Düngung geeignet sind und von der Landwirtschaft gut nutzbar sind.

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Tab. I P-Austrag aus den Kläranlagen der Bundesrepublik Deutschland

(nach P-Studie der GDCH, 1978)

	t/a P	Anteil am Gesamtaustrag der Kläranlagen %
Ableitung in die Vorfluter	85.000	76,5
Schlammbeseitigung auf Deponien	15.500	14,0
Rückführung von Klärschlamm zu Düngungszwecken	10.600	9,5
Austrag aus Kläranlagen insgesamt	111.100	100

Tab. II P-Eintrag in die Oberflächengewässer der Bundesrepublik Deutschland

(nach P-Studie der GDCH, 1978)

	t/a P	Anteil am Gesamteintrag in die Oberflächengewässer %
Abwasser über Kanalisation und Kläranlagen	85.000	82,1
Abwassereinleitung nicht kanalisiert	2.200	2,1
Erosion	6.100	5,9
Tierische Ausscheidungen direkt ins Gewässer	4.100	4,0
Dränwasser	2.500	2,4
Oberflächlicher Abfluß von Regenwasser	2.000	1,9
Abschwemmung tierischer Ausscheidungen	600	0,6
Streu	500	0,5
Grundwasser	200	0,2
sonst. direkte Einträge	300	0,3
P-Eintrag insgesamt	103.500	100

Tab. III P-Elimination und Verminderung der organischen Belastung des Abwassers nach Dolomithydrat-Zugabe (Kläranlage Göttingen - Versuch I)

- durchschnittliche Dolomithydrat-Zugabe: 215 mg/l;
- durchschnittliche Aufenthaltsdauer im Absetzbecken: 3 Std.;
- Mittelwerte aus 22 Einzelmessungen

	Zulauf	Ablauf	Verminderung absolut	%
Ortho-P (mg/l)	9,2	1,8	7,4	80
Ges.-P (mg/l)	10,4	2,0	8,4	81
BSB_5 (mg/l)	12,6	8,6	4,0	32
CSB (mg/l)	53,5	46,0	7,5	24
pH	7,9	8,8		

Tab. IV P-Elimination und Verminderung der organischen Belastung des Abwassers nach Dolomithydrat-Zugabe (Kläranlage Göttingen - Versuch II)

- durchschnittliche Dolomithydrat-Zugabe: 325 mg/l;
- durchschnittliche Aufenthaltsdauer im Absetzbecken: 4,5 Std.;
- Mittelwerte aus 7 Einzelmessungen

	Zulauf	Ablauf	Verminderung absolut	%
Ortho-P (mg/l)	10,0	0,8	9,2	92
Ges.-P (mg/l)	10,0	2,1	7,9	79
BSB_5 (mg/l)	4,8	3,5	1,3	27
CSB (mg/l)	38,8	30,3	8,5	22
pH	7,7	9,2		

Tab. V Gesamt-P-Gehalte und P-Löslichkeiten der Kalk- und Dolomithydrat-Fällungsprodukte

P-Fällungsprodukte aus	Gesamt-P_2O_5 %	citronensäurelösl. P_2O_5 in v. H. d. Gesamt-P_2O_5	neutralcitratlösl. P_2O_5 (Fresenius-Neubauer) i. v. H. d. Gesamt-P_2O_5	alkalisch-ammoncitrat-lösl. P_2O_5 (Petermann) i. v. H. des Gesamt-P_2O_5
Kalkfällung (Laborversuch)	7,78	95	98	88
Kalkfällung + Flockungshilfsmittel (Laborversuch)	5,67	98	98	89
Dolomitfällung (Laborversuch)	5,86	95	83	84
Dolomitfällung + Flockungshilfsmittel (Laborversuch)	6,70	93	80	81
			ameisensäurelösl. P_2O_5 i. v. H. d. Gesamt-P_2O_5	
Dolomitfällung (großtechnisch) Versuch I - 215 mg/l Dolomithydrat	5,0	92	94	94
Dolomitfällung (großtechnisch) Versuch II - 325 mg/l Dolomithydrat	3,3	88	91	91

Tab. VI Gesamt-Analyse und kalkulierte mögliche chemische Zusammensetzung der Dolomithydrat-Fällungsprodukte (Kläranlage Göttingen - Versuch I)

Anteil	Gew. %	daraus errechnet	
P_2O_5	4,68	Hydroxylapatit	11,04 %
CaO	30,32	$CaCO_3$ (+ $SrCO_3$)	43,20 %
MgO	18,91	$MgCO_3$	1,75 %
SiO_2	7,55	$Mg(OH)_2$	26,16 %
Fe_2O_3	0,67	organischer Glühverlust	6,68 %
Al_2O_3	0,80		
K_2O	0,17		
Na_2O	0,17		
BaO	0,05		
SrO	0,11		
Mn_2O_3	0,05		
SO_3	0,31		
CO_2	19,91		
geb. H_2O + org. Substanz	14,96		

Tab. VII TS-Ertrag und P-Entzug von Deutschem Weidelgras bei gleicher P-Gabe in Form von Thomasphosphat bzw. Dolomithydrat-Fällungsprodukt

(Boden A: P-arme Braunerde, pH = 5,8; Boden B: P-armer Untergrund-Löß, pH = 7,1; P-Düngung: 0,75 g P_2O_5/Gefäß)

P-Düngung als	1. Schnitt Ertrag g	%	P_2O_5-Entzug mg	%	2. Schnitt Ertrag g	%	P_2O_5-Entzug mg	%	3. Schnitt Ertrag g	%	P_2O_5-Entzug mg	%	Gesamt Ertrag g	%	P_2O_5-Entzug mg	%
Boden A																
Thomasphosphat	20,47	100	84	100	22,77	100	98	100	28,05	100	70	100	71,30	100	252	100
Dolomithydrat-Fällungsprodukt		108		113		100		99		94		88		100		100
ohne		66		48		95		71		88		81		84		66
Boden B																
Thomasphosphat	21,30	100	86	100	20,67	100	115	100	25,72	100	80	100	67,70	100	281	100
Dolomithydrat-Fällungsprodukt		106		106		104		99		99		98		103		101
ohne		40		17		53		14		29		6		40		13

Tab. VIII TS-Ertrag von Deutschem Weidelgras bei gleicher P-Gabe in Form verschiedener Nachfällungsschlämme und Thomasphosphat

(Gefäßversuch; Boden: P-armer Untergrund-Löß, pH = 7,0)

P-Düngung als	rel. Citronensäurelöslichkeit der Produkte (%)	1. Schnitt g TS/Gef.	rel.	2. Schnitt g TS/Gef.	rel.	Gesamt g TS/Gef.	rel.
Thomasphosphat	92	14,11	100	16,22	100	30,33	100
Kalkhydrat-Fällungsprodukt	92		100		97		98
Dolomithydrat-Fällungsprodukt	88		101		97		99
Al-Fällungsprodukt (Ahrensburg)	68		87		93		90
Al-Fällungsprodukt (Großhansdorf)	56		86		90		88
Fe-Fällungsprodukt (Wittlage)	93		69		78		74
ohne	-		14		11		12

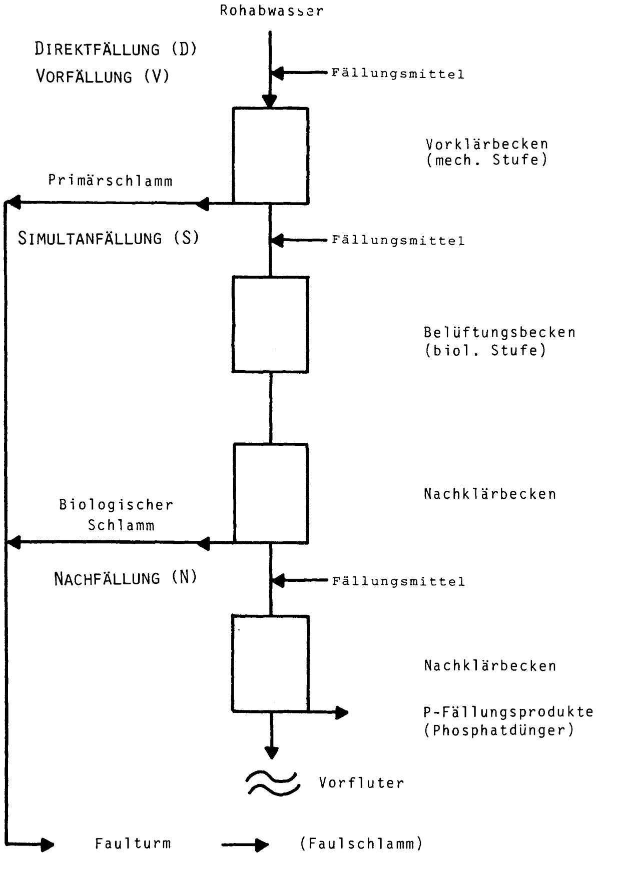

ABB. 1: VERFAHREN DER ABWASSERKLÄRUNG (SCHEMATISCH)

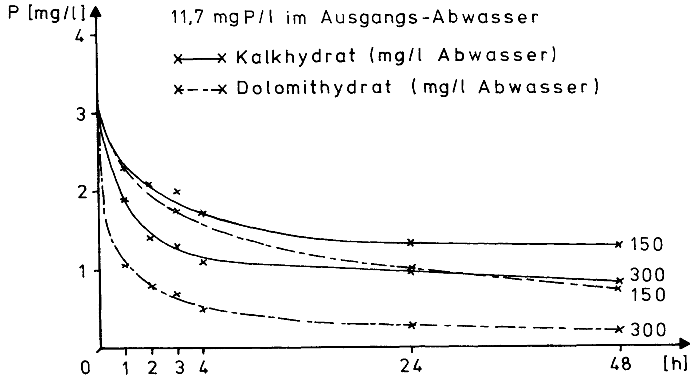

Abb.2: P-Eliminierung bei Kalk-und Dolomithydrat-Nachfällung in Abhängigkeit von der Absetzzeit

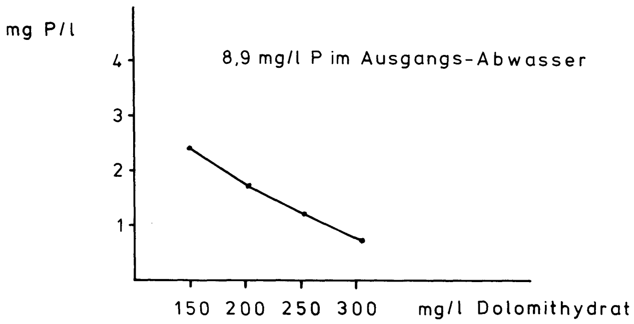

Abb.3: P-Elimination bei steigender Dolomithydrat-Zugabe

PREMIERES DONNEES SUR LA VALEUR AGRICOLE DES BOUES RESIDUAIRES D'UNE USINE DE TRAITEMENT PHYSICO-CHIMIQUE D'EAUX USEES.

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Abstract

First data about the agricultural value of sewage sludges resulting from a physicochemical sewage treatment plant.

In order to appraise the agricultural value of sewage sludges resulting from a physicochemical domestic sewage treatment plant, we have cultivated vegetables of different characters : lettuce, radish, bean, onion, rye-grass. These vegetables are grown in plant pots filled with a marked garden soil having been submited to different treatment :

- reference series without any dressing,
- series with a mineral fertilizer (125-111-150 units per hectar),
- series with sewage sludges incorporated (25 t of dry sludges per hectar and complementary mineral manure).

Two cultural groups have thus been made : at the beginning of the spring with simple settling sludges, and at the beginning of the summer with flocculated sludges.

The first observations we have been able to make, as well as the dry and wet weight measures, have shown a marked initial depressive effect of the sludges during the first series of crops, and a greatly less clear effect during the second. But, this depressive effect has progressively disappeared, and the buckets which had received sludges then had a greatest production than the pots which had received a mineral fertilization.

1. INTRODUCTION

Les expériences réalisées à l'étranger, et plus récemment en France ont largement prouvé qu'une utilisation rationnelle des boues secondaires en agriculture peut être intéressante tant sur le plan économique que sur le plan agronomique (1). Toutefois, certaines réserves sont encore formulées quant à l'utilisation de boues ayant subi un traitement chimique comme le conditionnement à la chaux ou la floculation par des sels de fer ou d'aluminium. Selon certains auteurs (2), les boues floculées par ces réactifs chimiques pourraient s'apparenter aux boues primaires non dégradées par les microorganismes. Ces dernières seraient moins riches en azote et en acide phosphorique que les boues secondaires et se minéraliseraient plus difficilement (3), tandis que l'adjonction de chaux et de sels de fer ou d'aluminium provoquerait la formation de phosphates insolubles (4) ou inhiberait la nitrification de NH_4^+ (5).

Afin d'apprécier la valeur agricole de ce type de boues, nous avons mis en place deux séries de cultures avec des végétaux présentant un certain intérêt économique mais de caractéristiques différentes.

2. MATERIEL ET METHODES

Les cultures ont été réalisées en vases de végétation soumis aux conditions climatiques naturelles et lorsque cela était nécessaire, arrosées avec l'eau du service de la ville, à doses équivalentes.

2.a. Conditions générales de culture

Les vases de végétation sont des seaux en plastique (H = 25 cm) dont le fond est percé et qui sont successivement remplis d'une couche de sable de Loire assurant le drainage, et de terre maraîchère (environ 13 kg) dont les principales caractéristiques sont décrites dans le tableau I.

Trois types de culture ont été réalisés :

- une série témoin sans aucun apport (t)
- une série avec apport d'engrais minéral (m)
- une série avec incorporation de boue (b)

2.b. Les boues

Les boues (tableau I) provenant de la station d'épuration de Livery (Guérande, France), qu'il s'agisse de boues de décantation simple (D.S.) ou de boues floculées (B.F.) au sulfate ferreux (120 ppm) et au sulfate d'alumine (175 ppm) sont traitées à la chaux (6 à 8 % des matières sèches) et à l'oxygène pur (environ 1 000 ppm). Un polyélectrolyte cationique

Tableau I : CARACTERISTIQUES PRINCIPALES DES TERRES ET DES BOUES UTILISEES (A : terre 1 ère culture ; B : terre 2ème culture ; D.S.:boue décantation simple ; B.F. : boue floculée).

	A	B	D.S.	B.F.
pH	6,5	5,8	6,6	6,5
matière organique %	20,8	19,2	665,2	637,6
C/N	15,5	11	12,71	13,42
P_2O_5 total g/kg	1,03	1,50	2,39	59,40
N total g/kg	0,78	0,93	30,4	27,6
K total g/kg	1,81	22,40	2,39	2,40
Ca total g/kg	1,56	7,50	84,35	35,30
Mg total g/kg	1,15	1,80	5,61	2,60
C.E.T. meq/100	7	6,4	46	17,60

BASF CL 400 est également utilisé à la dose de 3,3 à 4 kg par tonne de matière sèche.

Les boues D.S. utilisées pour des cultures de printemps et B.F. pour des cultures de début de l'été ont été homogénéisées avec la terre maraîchère à raison de 25 t (poids sec) à l'hectare.

2.c. La fertilisation minérale

Les boues étant très pauvres en potasse, nous avons apporté en couverture sur le mélange terre-boue une fertilisation minérale complémentaire équivalente à 35-75-150 unités à l'hectare.

La dose d'engrais, apportée en couverture, dans les séries de culture ne recevant qu'une fertilisation minérale a été estimée d'après les travaux de différents auteurs (2,6, 7, 8, 9) pour correspondre à l'apport de fertilisant des boues (tableau I). Nous avons ainsi apporté l'équivalent de 90 unités d'azote à l'hectare sous forme d'ammonitrate 34,5 % et 36 kg d'acide phosphorique sous forme de superphosphate 18 %. La même dose de sulfate de potasse 7-15-30 S a également été ajoutée.

2.d. Les végétaux

Plusieurs types de végétaux ont été cultivés sur les boues de décantation simple, présentant des types de morphologie variée : laitue (*Lactuca sativa* L.), radis (*Raphanus sativus* L. var. *radicula*), ray-grass

(Lolium perenne L.*)*, haricot (*Phaseolus vulgaris* L.), Oignon *(Allium Cepa* L.). Seuls ces trois premiers ont été utilisés pour les cultures sur les boues floculées.

3. RESULTATS

3.a. Les boues de décantation simple (D.S.)

La production végétale de chaque culture est estimée par l'intermédiaire du poids frais des organes présentant un intérêt alimentaire.

Nous observons un effet dépressif initial très net des cultures effectuées sur les sols amendés par les boues de décantation simple chaulées, que ce soit pour les plantes repiquées ou pour les plantes semées. Ce phénomène est illustré par les récoltes fractionnées des radis (semis A) où la production de la deuxième récolte provenant des boues est inférieure de moitié à celle effectuée sur le témoin (tableau II).

Cet effet tend à s'estomper après quelques dizaines de jours, les boues ont alors une production supérieure au témoin (tableaux II et III ; figure 1) mais présentent toutefois un retard vis-à-vis des cultures réalisées avec les engrais minéraux. Ainsi, la production des laitues cultivées sur les boues égale celle des laitues cultivées avec les engrais minéraux mais avec un retard d'une dizaine de jours (tableau III).

Par contre, pour les cultures à récolte plus tardive, les cultures sur boue ont une production supérieure à celle obtenue avec les engrais minéraux. C'est le cas des oignons, des haricots (tableau III) et du ray-grass (figure 1). Ainsi l'amendement en boues présente un effet bénéfique à long terme (70 jours environ) et ceci est particulièrement net pour le ray-grass pour lequel nous avons effectué cinq coupes successives (figure 1). En effet après une phase où la production sur les sols enrichis avec les engrais minéraux est nettement supérieure à celle des autres cultures, dans une seconde phase la production des terres amendées en boue augmente et dès la cinquième coupe présente la production cumulée la plus importante (figure 1), tandis que celle des autres séries régresse. De même, des semis de radis effectués 35 jours après l'incorporation des boues (semis B) ne subissent aucun effet dépressif et fournissent des plantules d'aspect normal avec une production toutefois inférieure à celle obtenue pour les cultures fertilisées par des engrais minéraux. Les boues ont un effet positif net sur la production du semis C effectué 80 jours après l'épandage (tableau II).

TABLEAU II : POIDS FRAIS TOTAL (g) DES DIFFERENTES RECOLTES DE RADIS (t : témoin ; m : minéral ; b : boue ; D.S. : boue de décantation simple ; B.F. : boue floculée).

Type de boue	Semis	Date de la récolte	t	m	b
D.S.	A	38e jour 43e jour 50e jour total	0 14,5 20,2 64,3	55,5 61,7 12,7 163,1	0 7,0 60,1 116,3
D.S.	B	77e jour	0,3	57,6	43,2
D.S.	C	106e jour	1,6	51,2	104,5
B.F.		42e jour	1,87*	2,16*	3,23*

* poids moyen (g) par individu

TABLEAU III : POIDS FRAIS TOTAL (g) DES RECOLTES DE DIFFERENTS VEGETAUX. (t : témoin ; m : minéral ; b : boue ; D.S. : boue de décantation simple ; B.F. : boue floculée).

Végétal	Boue	t	m	b
Oignon	D.S.	210	780	862
Haricot	D.S.	256	367	426
Laitue	D.S.	95*	356	383*
Laitue	B.F.	157	256	290

* récoltes en retard de 10 jours par rapport à m

3.b. Les boues floculées (B.F.)

Pour la série débutant en été, la production végétale est déterminée, comme pour la précédente série, à l'aide des valeurs de poids frais des organes comestibles.

L'effet dépressif observé lors de la première série de culture est très atténué pour cette seconde série : dès les premiers jours les plantules de radis paraissent vigoureuses sur la terre amendée avec les boues, tandis que les plants de laitue sont rapidement aussi vigoureux et verts sur les sols ayant reçu les boues que sur ceux ayant bénéficié de la fertilisation minérale. Seul le gazon paraît avoir eu des difficultés à croître au tout début de la végétation.

L'effet bénéfique des boues est sensible dès la première coupe de gazon ; la production est en effet presque double de celle obtenue avec les cultures témoins tout en restant inférieure à celle des cultures effectuées avec la fertilisation minérale (figure 1). Dès la seconde coupe, le rendement correspondant à l'amendement en boues est supérieur à celui dû aux seuls apports minéraux. Ce phénomène est général dès le 40ème jour pour l'ensemble des cultures : laitue, radis, gazon (tableaux II, III et figure 1).

4. Discussion et conclusions

Les boues de simple décantation (D.S.) et de floculation (B.F.) présentent des teneurs similaires en azote total et en matière organique, mais une forte disparité au niveau de l'acide phosphorique total, due notamment au traitement par les sels de fer et d'aluminium pour les secondes (tableau I). Ce sont, d'après Chaussod (8), des boues qui ne libéreraient l'azote que faiblement, ou du moins lentement.

Les boues de décantation simple fraîchement sorties de la station d'épuration ont provoqué un effet dépressif déjà constaté par plusieurs auteurs (10, 11) sur la croissance des plantules et des jeunes plants. Ces auteurs proposent plusieurs causes à cet effet : présence d'une substance inhibitrice labile ou lessivable, déficit en oxygène provoqué par une décomposition intense, ou plus vraisemblablement un dégagement d'ammoniac qui serait accru par le traitement à la chaux. Ce retard initial de la croissance pourrait également être dû à une immobilisation temporaire de l'azote malgré une stabilisation apparemment satisfaisante. Ceci pourrait expliquer la couleur jaunâtre des laitues, du gazon et des oignons en début de végétation.

Cet effet dépressif n'est pas apparu pour les cultures effectuées sur les boues floculées, or ces dernières subissaient une décomposition supérieure liée à des températures plus élevées, et dégageaient une odeur d'ammoniac plus intense. D'après nos premiers résultats, les boues floculées ne semblent pas provoquer de blocage des éléments nutritifs comme l'avaient suggérés certains auteurs (4, 5, 12) pensant que le fer et l'aluminium formeraient des précipités avec les phosphates sous des formes peu assimilables par les plantes. Ces résultats viennent confirmer les observations de Soon et col. (13). Ces derniers avaient, en effet, constaté un effet bénéfique pour certains végétaux (maïs et brome) cultivés sur des boues issues d'un traitement chimique.

Nos premières cultures mettent en évidence un effet bénéfique sur la production végétale à la fois des boues de décantation simple, et des boues floculées. Une libération des éléments nutritifs, sans doute plus progressive qu'avec une fertilisation minérale, et une correction des carences en oligo-éléments survenant d'une façon particulièrement rapide en vases de végétation (14) pourrait être à l'origine de ce bilan positif. Cet effet a été plus tardif dans le cas des cultures de printemps (boues D.S.), sans doute en raison des températures plus basses qui ont retardé la minéralisation et la nitrification.

Le fait que les cultures de végétaux réalisées sur des boues issues d'un traitement physico-chimique entraîne une production plus élevée que lors d'une fertilisation minérale classique ne doit pas nous faire oublier le risque potentiel que les polluants métalliques peuvent faire courir aux consommateurs ultérieurs et notamment à l'homme. Nous nous proposons donc, à partir des échantillons de végétaux que nous avons obtenus, d'effectuer des études pour quantifier le transfert des métaux des sols amendés par les boues aux plantes.

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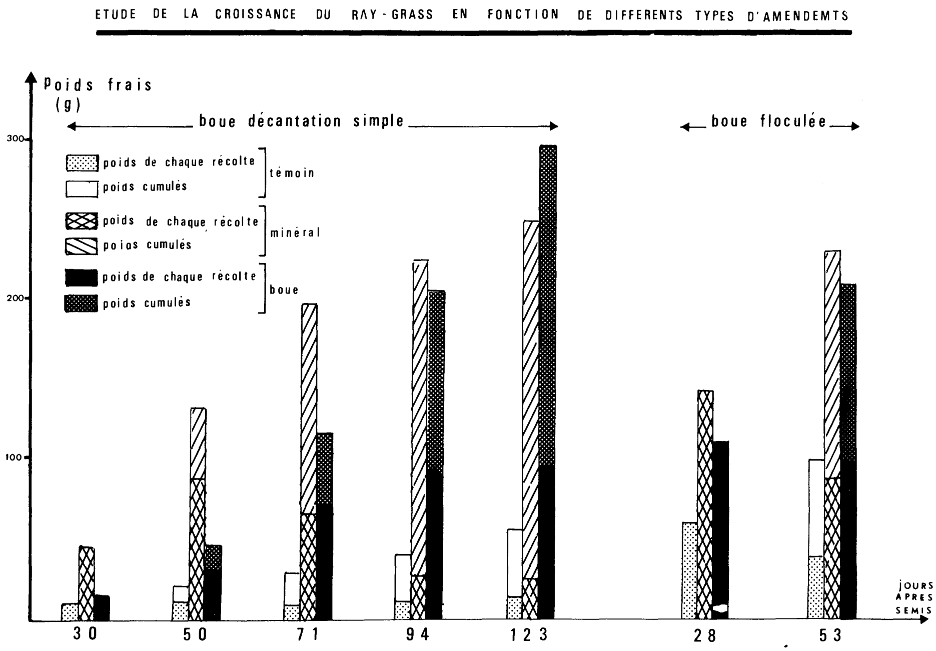

Figure 1

RELATIONSHIPS BETWEEN ORGANIC MATTER OF SEWAGE SLUDGE AND PHYSICO-CHEMICAL PROPERTIES OF SOIL*

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Summary

Application of sewage sludge to cultivated soils is currently being evaluated as one of the alternatives for utilization of a wasted resource.

Organic matter constitues approximately 50% of the solid fraction of sewage sludge. Therefore, at high rates of addiction beside macro and microelements also this constituent should be taken into account and its influence on the soil environment evaluated.

In this paper the importance of organic matter and the resulting modifications of some physico-chemical properties in sludge treated soils are discussed. Special emphasis is given to the influence of sludge organic matter on soil porosity and pore size distribution which are increasingly regarded as useful parameters to assess structural characteristics of soils.

The microbiological nature of most processes giving rise to improved soil physical properties is stressed. A brief mention is also given to those soil parameters able to influence the activity of soil microorganisms.

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1. INTRODUCTION

Close relationships existing between the level of organic matter in soil and good physico-chemical properties of soil itself are well known. However little has been done to quantify the effects of sludge organic matter on soil fertility and especially on the complex of properties responsible of physical fertility.

English farmers said recently to value sewage sludge mainly for its content of organic matter and its improving action on soil structure (6). In fact a consequence of modern agriculture is a lower apport of organic matter to soil. Therefore any practice leading to an increase of the amount of organic material added to soil should be favourably considered.

Soil can be imagined as a porous system in the voids of which an enormous number of organisms lives and chemico-physico-biological interactions, responsible of sludge organic matter transformations, take place.

2. ORGANIC MATTER OF SLUDGE AS AN INFLUENCING FACTOR ON SOIL PHYSICO-CHEMICAL PROPERTIES

In order to better understand the effect of sludge organic matter on the soil it is important to consider that sludge is produced by several different technological processes. At the end of each process organic matter can be associated with different kinds and amounts of inorganic compounds, such as water and mono and polivalent cations, which can modify soil properties in the same extent or even more than the organic matter alone.

Moreover, the nature itself of the chemical compounds present in the organic fraction of each type of sludge may influence interactions organic matter-soil. A thorough characterization of this fraction needs chemical analyses more sophisticated than a mere elemental analysis. A possible experimental approach could be the use of the proximate analysis which has been successfully employed to characterize various fractions of sludge organic matter, such as fats and waxes, resins, carbohydrates, hemicellulose, cellulose, proteins and lignine-humus (19). Further this method could be likely employed to relate the modifications of soil physical properties with the composition of the organic matter actually present in the soil.

Numerous aspects of soil fertility are affected by organic matter but despite the importance of some of them, for instance the influence on the fate of nitrogen, phosphorus and inorganic cations, the following discussion will be primarily concerned with those parameters which directly affect the relationships between gaseous, liquid and solid phase in the soil.

2.1 SOIL STRUCTURE

2.1.1 Porosity - Porosity and pore size distribution can be regarded as an useful way to define soil structure and besides that they can be better related to soil physical properties important for plant growth (9). It is in fact the pore space including its size distribution which affects many of the important phenomena directly related to crop yield, such as storage and movement of water and gases and ease of root penetration. If a more thorough understanding of these phenomena is required also a characterization of both shape and spatial arrangement of pores should be carried out, for instance by micromorphological techniques (27). A classification of pores in terms of their function in soil has been recently proposed (9) (Table 1).

From the agronomic point of view transmission and storage pores are the most important. The former allow the excess of water to drain and an easy exchange of gases between soil and atmosphere while the latter hold the water necessary for plant growth. Moreover a decrease of transmission and storage pores can be regarded as an index of damage to soil structure. This decrease can arise either from a lower total porosity or from a change in pore size distribution caused by an increase of residual pores.

Table 1 - A functional classification of soil pores (from Greenland, 1978) (10).

Equivalent cylindrical diameter um	pF	Name	Function
$>$ 50	$<$ 1.8	Transmission pores	Movement of air and water
0.5 - 50	1.8 - 3.8	Storage pores	Retention of water
$<$ 0.5	$>$ 3.8	Residual pores	Reservoir of nutrient ions
$<$0.005	$>$ 5.8	Bonding space	Interaction between soil particles

Addition rates of sludge and other waste materials ranging from 20 to 250 t/ha increased total soil porosity (26, 27, 31). Especially important was the finding that the proportion of large pores, i.e. those $>$50 um, was higher in the pore system of treated soils (18, 26, 27) thus indicating an improvement of soil physical conditions (9).

Large pore space increased over the growing season (18) and decreased over the winter (18, 26), according to the yearly variation of biological activity and physical stresses. Despite this decrease large pores were still more numerous in soil which had received organic dressings twelve months before (18, 26).

2.1.2 <u>Stability of soil aggregates</u> - The stability of soil structure has been affirmed to be of paramount importance in soil fertility provided neither the nutrient element status of soil nor disease is a limiting factor (20) and the major influence of the organic matter in this process is now well recognized (2, 14).

In a well structured soil aggregates are able to withstand stresses due to rainfall and agricultural machinery. For this reason the formation of surface crusts is unlikely while aeration and microbial activity are enhanced and water can penetrate the soil easily and deeply.

Among the agents responsible of the formation of water stable aggregates laboratory experiments pointed out the action of:

- filamentous microorganisms (1, 29);
- microbial polisaccharides (21, 28);
- phenolic compounds (11).

Addition of sludge to soil increases biomass (3) and enhances biological activity of microflora (30). Therefore the increased release in the soil environment of the products of microbial metabolism is probably the main factor of the improved aggregation in sludge treated soils (8, 18, 25). However the aggregating effect decays over time as the organic matter is mineralized, even though it has been observed that the number of stable aggregates in sludge treated soils remains higher than the control six (12, 25) or even twelve months (18) after treatments.

Periodic additions of organic residues are therefore required to maintain a good soil structure and this can be better understood considering that in favourable conditions up to 600 kg of C/ha/day can be mineralized in the soil (4).

Besides organic matter in some cases other components of sludge, such as calcium and polyelectrolytes, play an important role in soil aggregation (25).

2.1.3 <u>Bulk density</u> - Organic matter supplied with sludge or other kinds of wastes lowers the bulk density (13, 18, 32). Significant linear correlations between the increasing content of soil organic matter, from less than 1% to more than 6%, and the variations of bulk density, from about 1.5 g/cm^3 to about 1.0 g/cm^3, were found in a sand and loam soil (13, 32).

Seasonal variations of bulk density were observed in some cases and lower values found over the growing season were explained by the loosing effect exerted on the soil by root hairs and soil fauna (18).

2.2 SOIL-WATER INTERACTIONS

2.2.1 <u>Water retention</u> - One of the effects of the organic matter addiction to the soil is an increase of water retained by the soil. In a field situation this could be either a benefit or a detriment to crop growth depending on growing season, soil type and rainfall characteristics.

Factors affecting this process are probably (13):

- Increase of total porosity and decrease of bulk density (see 2.1.1 and 2.1.3);

- Modification of size distribution of both aggregates and pores (see 2.1.1);
- increase of soil adsorption capacity caused by the increase of both surface area and organic matter.

Results reported by different Authors are similar and indicate that application of sewage sludge increased soil water content (7, 8, 15) and soil water retention at specific water potential (7, 13, 18, 24). Most of the increase of soil water retention found in a sandy soil was attributed to the prevalent action of sludge organic matter (13) and the soil moisture regime was influenced for at least two years by application of liquid sludge (30 to 60 tons dry solids/ha) to a silt loam soil (15).

Contradictory results have been found for available soil water, defined as difference between the amount of water retained at field capacity and wilting point. However it is apparent that increases in available water have been found where high quantities of sludge had been used (Table 2).

Table 2 - Variation of available water in sludge treated soils.

Rate (t/ha)	Available water (%)		Reference
	Control	Treated	
30	20.5	19.7	Morel et al.(1978)
70	20.5	20.8	"
140	20.5	25.3	"
190	20.5	24.5	"
240	12.5	18.5	Epstein et al.(1976)
240	12.5	14.5	"

2.2.2 Water movement - Liquid sludge addictions to the soil surface may initially retard infiltration because sludge itself infiltrates very slowly regardless of soil type. However once the sludge has dried or is incorporated the infiltration rate fully recovers or improve. Because of this initial retardation of infiltration, surface runoff waters from sludge treated areas could contain relatively high quantity of N and P and therefore cause pollution hazards (15).

Field and laboratory experiments showed that saturated hydraulic conductivity increased in soil treated with sewage sludge provided that sufficient organic material had been used (7, 13, 24). In fact infiltration rates did not significantly change in an one year field experiment following the application of 56 t/ha of sewage sludge to three different soils (18).

Pot experiments with raw and digested sludges incorporated at a rate of 5% by weight into a silt loam soil showed that saturated hydraulic conductivity increased after the application time, reached a maximum and then dropped to that of the control (7).

This behaviour can be ascribed to a net increase of the number of pores in the soil system due to the enhanced biological activity. Polyvalent cations contained in sludge, such as calcium, and chemical compounds produced during the microbial growth are then able to make pore walls more resistant to water stresses (24). The stabilizing ability decreases as the mineralization of sludge organic matter proceeds, thus larger pores collapse and hydraulic conductivity decrease.

Digested sludge reached the maximum of hydraulic conductivity in fewer days than raw sludge. This is probably due to the higher rate of decomposition of the organic matter of raw sludge which can cause an initial clogging of pores with larger amount of gaseous or solid decomposition products.

2.3 OTHER PROPERTIES

2.3.1. pH - A side effect of the decomposition of organic matter is the production of acidic compounds and this mechanism explains the pH decreases found in some sludge treated soils (3, 8, 16, 25).

However when sludge contains high amounts of bases the overall effect is an increase of soil pH (5).

2.3.2 Cationic exchange capacity (C.E.C.) - CEC increases in sludge treated soils (8, 17, 18). The finding that high correlations have been found between the content of carbon in soil and CEC demonstrates that most of the additional CEC observed in sludge treated soils is due to the high exchange capacity (250 meq/100 g) of the sludge organic matter (18). Rates of sludge addictions up to about 90 t/ha doubled the content of organic carbon in the top soil (0-5 cm) and increased CEC from about 10 to about 20 meq/100 g (18).

Through the additional cation binding sites thus created many of the nutrients present in sludge can remain longer in the root zone and can be utilized more easily by plants.

2.3.3 Redox potential - In those soils where gaseous exchanges are limited, as in fine textured soils, the amount of oxigen necessary for an aerobic decomposition of organic matter is further severely limited as the content of soil moisture increases.

In fact additions of 240 t/ha of sewage sludge, 76% of water, to a silt loam soil had as consequence a sharp decrease of the soil redox potential which dropped to-200 mV after 40 days. The minimum value of redox potential observed after the addition of 240 t/ha of compost sludge, 35% of water, was on the contrary only about 0 mV (8).

At redox potentials lower than-150 mV anaerobic decomposition of organic matter may originate phytotoxic compounds such as hydrogen sulphide, methane and ethylene.

3. INFLUENCE OF PHYSICO CHEMICAL PROPERTIES OF SOIL ON ORGANIC MATTER DECOMPOSITION

It has been shown in the previous discussion that sludge organic matter is able to modify physico-chemical properties of soil. However complex relationships sludge-soil can be better understood bearing in mind that physico-chemical properties of soil microenvironments are recognized to influence microbial activity and that the microbial activity is responsible for the most part of the organic matter degradation in soil.

More important parameters influencing the activity of soil microorganisms are: clay, organic matter, aeration, moisture and pH (22).

3.1 Clay - Both type and amount of clay in the soil have been frequently cited as important factors in the breakdown of organic matter. In general the greater the percentage of expanding lattice clays, the slower will be the decomposition rate of organic matter.

3.2 Organic matter - Relationships between level of organic matter already present on the soil and decomposition of added organic matter are more complex even though the final effect seems to be a delay in biodegradation. This behaviour could be due to the presence in the humified organic matter of functional groups highly reactive, and thus able to exert a protective action towards fresh organic matter.

3.3 Temperature - Optimum temperature for the activity of most microorganisms ranges between 30 and 40°C. Relatively high temperatures increase decomposition while lower temperatures slow degradation.

Evidence of highly significant positive correlation between CO_2 evolved and degree days has been found for an anaerobically digested sewage sludge (23).

3.4 pH - Optimum pH range for most bacteria and actinomicetes is from 6 to 7 while fungi are more active in acidic soils. The highest total population of soil microorganisms is normally found at pH values near neutrality. Therefore these conditions are the best for a quick degradation of organic compounds while in acidic soils decomposition rates are lower.

3.5 Aeration and moisture - These two parameters are strictly related to each other. Because in the soil liquid and gaseous phases compete for the possession of the same pores they are particularly important as the content of clay increases.

In fact soil moisture content did not affect the decomposition of an anaerobic sludge in a sandy soil. But at saturated conditions decomposition was reduced moderately in a silt loam soil and stopped almost completely in a clay soil (23).

4. CONCLUSION

Though the literature relating to the influence of sludge organic matter on physico-chemical properties of soil is not abundant there is a clear evidence that structure, hydraulic characteristics and CEC have been improved in soils treated with sewage sludge. However these effects have been found in soils which have received high dressings of sludge and similar effects cannot be generally expected in soils where liquid sludge is added at a rate of about 100 t/ha, corresponding to about 2 t/ha of organic matter (5).

If we exclude the problem of heavy metals, whose level should be kept as low as possible in sludge, the application rates needed for a significant improvement of soil porperties have also the side effect to add high amounts of nitrogen and phosphorous to soil. For this reason problems of overfertilization and pollution of ground water may arise.

Despite the restrictions just mentioned the use of sludge as soil conditioning should be encouraged in all cases where the content of organic matter in soil is low and therefore more dramatic improvements of soil physical properties can be expected.

The more correct way to tackle this problem is with interdisciplinary studies so that all biological, chemical and physical aspects could be properly taken into account.

Future research needs can be summarized as follows:

i) Characterization of chemical constituents present in sludge organic matter and in sludge treated soils.

ii) Variation over time of soil physico-chemical properties according as decomposition of chemical constituents of sludge.

iii) Effect of sludge organic matter on soil biological activity with special regard to the production of aggregate stabilizing agents by microorganisms.

iv) Pore size distribution, shape and spatial arrangement of soil pores.

v) Pedogenetic processes affecting porosity.

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POROSITY AND PORE SIZE DISTRIBUTION IN A FIELD TEST FOLLOWING SLUDGE AND COMPOST APPLICATION *

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Summary

Soil porosity and pore size distribution have been studied in a field test. Aerobic and anaerobic sludges and their composted mixtures with the organic fraction of urban refuse were used and compared with manure. Addition rates were equivalent to 50 and 150 tons/ha of manure on the organic carbon basis. A control plot, was also present.

The residual effect on soil porosity and pore size distribution was also analyzed the year following that of treatments. Measurements were carried out on large thin sections of soil samples by means of electro-optical image analysis. All organic materials increased significantly the total porosity which remained significantly higher than the control the following year.

Pores ranging from 50 to 500 μm, which are considered the most important both in soil-water-plants relationships and in mantaining a good soil structure, also increased after all organic treatments. Therefore sludges and composts improved porosity and pore size distribution in a similar way to the manure.

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1.INTRODUCTION

The application of sludge to agricultural land may induce changes both on the physical condition and on the chemical composition of the soil. While a rich literature is available on chemical problems of fertility and pollution relate to the fate of macro and micronutrients in soils and plants, the knowledge of the effects of sludges on soil structure is limited (1).

Bearing in mind that soil structure is sometime considered the limiting factor of crop yield (2) and porosity is now believed to be the most suitable parameter to study soil structure (3,4), this study was undertaken to determine the effects of sludge application on soil porosity under natural field conditions. Measurements were carried out with micromorphological methods which, by the help of the electro-optical image analysis system, allow a thorough characterization of soil porosity (5,6,7).

2.MATERIALS AND METHODS

A field study was established in May 1978 on a sandy loam soil which contained 0.9 per cent organic carbon, 13.8 per cent clay, 18.0 per cent silt and 68.2 per cent sand. The pH in water was 5.5. Plots (500 m^2) were planted with corn followed by wheat as a tipic two-year crop rotation system in Italy.

The following treatments were compared:

1) Control (C)
2) Aerobic sludge (AS)
3) Anaerobic sludge (ANS)
4) Compost of aerobic sludge and organic fraction of urban refuse (40-60%) (CAS)
5) Compost of anaerobic sludge and organic fraction of

urban refuse (20-80%) (CANS)

6) Manure (M)

Organic materials were surface applied before the seedling of the corn and ploughed in. The addition rates were equivalent to 50 and 150 tons/ ha of manure on the organic carbon basis.

Three undisturbed soil samples were collected from the Ap horizon of each plots 4 and 12 months after treatments. Soil samples were dried by acetone replacement of the water and impregnated with polyester resin. Then thin sections 6 by 6 cm large and 20-25 μm thick were prepared according to the usual micromorphological procedure (8).

Thin sections were photographed (7) and each photograph analysed by an image analysing apparatus (Leitz Classimat). In this apparatus the image of a thin section under microscope or of a photograph under epidiascope is scanned by a plumbicon television camera and displayed on the screen of a monitor. An electronic signal processing unit analyses the video signals, and data digitally displayed are further elaborated by a connected desk computer. Pores are measured by setting the instrument to detect the corresponding grey level with the help of an electronic discriminating circuit which is able to group all features having the same grey level. Measurements include the area, number and size distribution of all pores in the field of view. Detailed information on the utilisation of the Leitz Classimat have been already reported (7,9). After the determination of total porosity, pore size distribution was obtained by dividing all pores in three size classes according to their diameter, i.e. $<$50 μm, 50-500 μm and $>$500 μm following Greenland's pore classification (3). The smallest pores included in the first class are those large 30 μm because of the thickness of the thin section.

3. RESULTS AND DISCUSSION

Values of total porosity reported in Table 1 are expressed as per cent of the total area of each thin section occupied by pores. Data reported in Table 1 are the mean of three replications.

Table 1 - Effect of treatments on total soil porosity. Addition rates correspond to 50 (low) and 150 tons/ha (high) of manure on the organic carbon basis.

Treatment		Total Porosity (%)* Months after treatments 4	12
C		16.0 a	9.4 a
AS	low	47.1 e	24.6 bc
	high	49.3 e	44.3 h
ANS	low	36.2 bc	27.9 cde
	high	38.3 bcd	31.8 fg
CAS	low	39.5 cd	22.9 b
	high	49.5 e	26.0 bcd
CANS	low	35.6 b	30.9 ef
	high	50.1 e	43.2 h
M	low	38.2 bcd	30.3 ef
	high	41.3 d	34.7 g

*Means in a column followed by the same letter are not significantly different at 0.05 level employing Duncan's Multiple Range Test.

Total porosity found in all treated plots was significantly higher than the control irrespective of the sampling dates. Obviously total porosity of samples taken twelve months after treatments, i.e. over the winter months, was in any case lower than that found in the set of samples collected after four months. This behaviour is the result of natural compactness of the soil mainly due to the freezing and the heavy winter rainfall. According to the micromorphological classification of soil porosity, the porosity of all treated plots could be considered still good even at the second sampling date. In fact by means of this classification, a soil is considered very dense with a total porosity less than 5%, dense with a total porosity of 5-10%, moderately porous 10-25%, highly porous 25-40% and extremely porous with a total porosity greater than 40%.

The two different rates of organic materials applied to soil did not show any clear effect on total porosity, especially for samples taken four months after the addition. However in this type of soil, which is not rich in clay, it is apparent that the improvement of soil porosity caused by lower doses makes the use of high doses not necessary.

Comparing the effect of sludges and composts with that of the manure it is possible to stress that all these materials behave in a similar way.

Besides total porosity also pore size distribution, which is an other parameter of soil pore system, must be considered because the agronomic function of pores depends on their size. According to Greenland (3) pores smaller than 50 µm in diameter are important as a reservoir for plants and microorganisms in the soil and pores ranging from 50 to 500 µm are important for transmission of air and water.

Data concerning pore size distribution according to

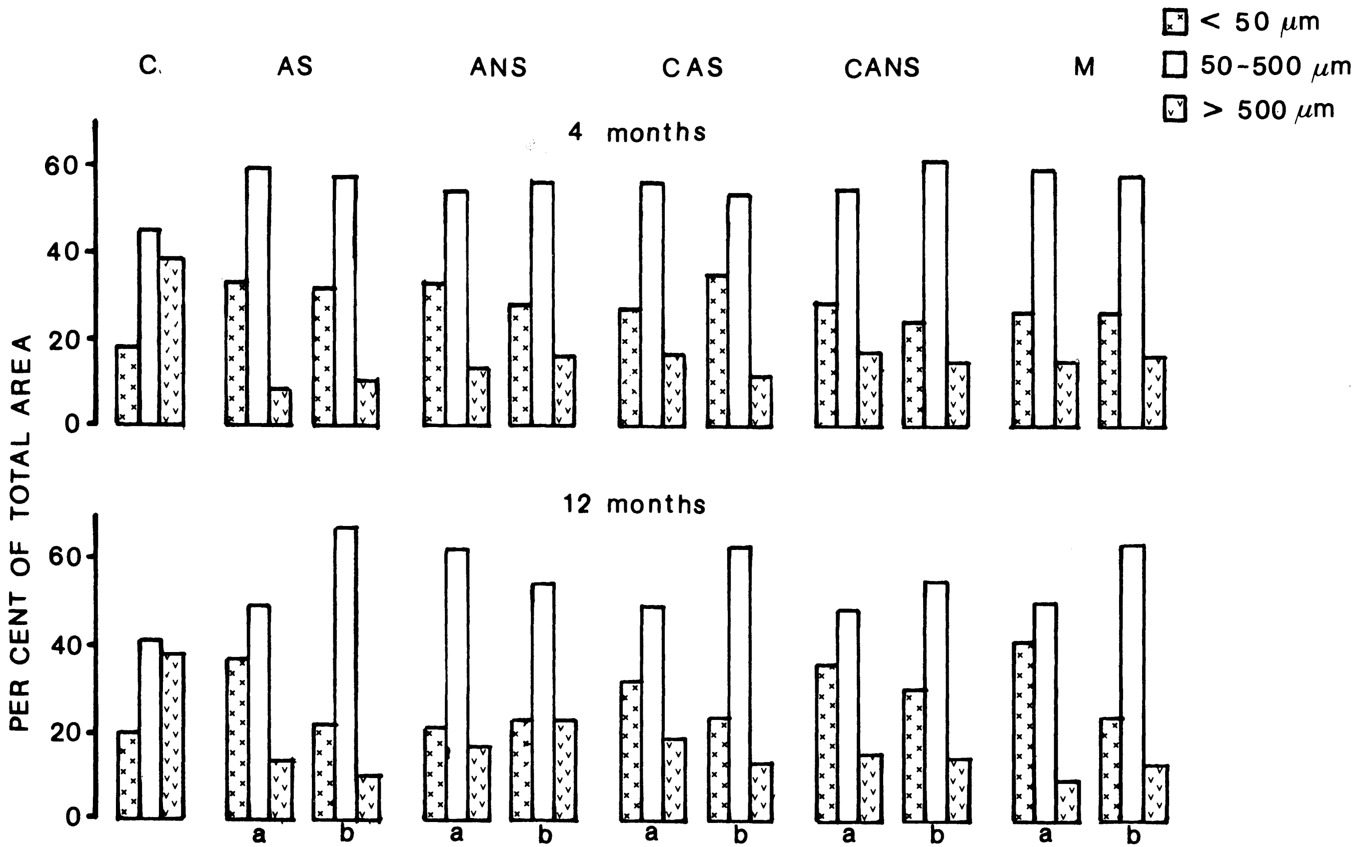

Fig. 1 - Frequency histograms of pore size distribution. a: low dose, b: high dose.

Greenland's classification are reported in fig. 1. At both sampling dates all treated samples contained less cracks (pores larger than 500 μm) and more transmission pores (50-500 μm) than the control. According to what previously found for total porosity also in this case very little differences were observed between samples treated with the two doses. Moreover findings confirmed that organic matter was able to reduce soil shrinkage (10). The increase of pores in the intermediate class (50-500 μm) was a clear symptom of a good soil structure, because it has been found that a damage to the soil structure can be recognized by the decrease in the proportion of pore space present in trasmission pores (3). Another positive result was that the frequency of storage pores (<50 μm) was higher in the treated samples. Very little difference could be noticed among the treatments, including manure.

In conclusion we found that sludges and composts were able to enhance both total soil porosity and pore size distribution which were significantly higher than the control also the following year. Moreover it should be stressed that the effect of manure were comparable to those of all other organic materials employed.

4. ACKNOWLEDGEMENTS

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BIOLOGICAL ACTIVITIES IN A SOIL-PLANT SYSTEM AFTER TREATMENT WITH DIFFERENT AMOUNTS OF DIGESTED SLUDGE. POT EXPERIMENTS

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Summary

Biological activities in the maize rhizosphere-plant system were assayed in order to ascertain the fertilizing value of different amounts of digested sludges from municipal treatment plant. Changes in oxygen uptake, protease and acid phosphatase activity, total microflora, nitrate and phosphate content were texted in the rhizosphere. Contemporarily, nitratereductase activity, nitrate and phosphate content were texted in the plant.

Results show that the different amounts of sludges play an important role on the microbial growth. Besides, a competitive action between microorganisms and plant regarding nitrate in evident.

1. INTRODUCTION

The quantities of sludge applied to agricultural lands will be limited in many respect by regional agronomic practices Guidelines proposed are based upon the fertilizer recomandation for nitrogen (1,2).Nitrogen is the fertilizer element applied in greatest amount to soil and it is found in sluge in substantial amount.However,it is important to note that fertilizing value of sludge is not only related to the nitrogen and phosphorus content,becouse of the high sludge content in organic matter,microelements,microrganism population,growth regulator substances and microbial metabolites.In consequence,sludge supply to croplands may cause considerable qualitative and quantitative alteration on soil properties and biological activities. Microflora may be considered as a "mediator" between nutrient sources of the soil and root system;as recent literature emphasyzes (3,4),it plays a definitive and considerable influence on the growth and development of the plants and,consequently, on the crop yield.The new equilibrium between soil microrganisms and plants,modifying root ability in nutrient absorption, determine the agronomic value of the sludge.

The sludge application rate should be determined so as to ensure that environmental requirement are met with;so special attention must be paid to good menagement of the soil.Useful information concerning the "health status" of soil could be obtained texting the soil-plant system ability in restoring biological equilibrium disturbed by sludge treatment.

Besides,the knowledge of nutrient uptake,especially nitrogen and phosphorus,and their fate both in soil or in plants, could furnish useful information in the determination of the best amount for sludge application.

We present here preliminar data about the effect of different amounts of digested sludge on soil microflora and some related biological activities.

Pot experiments were carried out in a controlled environment. Microflora, oxygen uptake, acid phosphatase and protease activity, nitrate and phosphate content in the rhizosphere; nitrate and phosphate content, nitratereductase activity in the plants were considered.

2. MATERIAL AND METHODS

Corn (Zea mays Saturno TV 34) was sown and raised in a controlled environment (temperature: 25°/18°C day/night; relative humidity: 60%; photoperiod: 14 h; irradiation intensity: 20.000 lux). The plants were grown in plastic pots containing 1 Kg of dry soil (clay:turf:silt:1:1:2). The soil pH was 6.5. Different amounts of domestic sludge (4 - 8 - 16 gd.w./Kg of soil) were mixed with the soil and conditioned for 15 days, without any mineral.

Sludge composition

H_2O	C_{tot}	C_{org}	C_{inor}	N	P
73.39	30.21	29.64	0.57	0.93	0.70

Soil rhizosphere and plant samples were texted after 7, 10, 16 , 27 days from the sowing.

Rhizosphere and plant analysis

a) Total microflora

Total microflora was determined by the agar plate method(5)

b) Endogenous respiration

Oxygen uptake was carried out on 3 ml samples of soil rhizosphere (300-400 mg d.w) in a Warburg apparatus at 25°C for 6 h.

c) Acid phosphatase

Acid phosphatase activity was texted by p-nitrophenol assay accordind to the Fishman 's method (6).

Plant analysis

Phosphate content both in roots or in leaves is dependent from the sludge amounts supplied to the soil and may be related to the sludge-$PO_4^{\equiv}$ available by the plants.

Concerning the relations between nitrate plant content and supplied sludge amuonts, a strong loss in nitrate content both in the roots or in leaves was evidentiated at the dose of 8 g sludge /Kg soil. This loss may be related to the minor nitrate content in the rhizosphere and may be explained as a result of competitive action between microrganisms and plants for for the nitrate However, in all cases, the good utilization of nitrate by plants is evidentiated by leaves nitratereductase actitity.

Results, as well those ones of our previous experiments (10,11,12) show that:

-the doses of sludge supplied are not harmful for the soil. Infact, no alteration on the tipical behaviour of the microbial development and rhizosphere activity are recorded;

-the different amounts of sludge play an important role on microbial growth and on biological activities ;

-a competitive action between microrganisms and plants regarging to the available nitrate.

d) Protease

Protease activity was carried out by following the degradation of a solution of casein (1% w/v) in a 0.1 M tris buffer pH 8.

e) Nitrate and phosphate content

Nitrate and phosphate content were determined both on rhizosphere soil or in plant tissues respectively by the Baker and Olsen 's methods (7,8).

f) Nitratereductase

Nitratereductase activity was assayed on roots and leaves samples according to the Hageman's method (9).

3. RESULTS AND DISCUSSION

Soil treatment was carried out with doses smaller than, equal to and greater than those usually applied in agriculture.

Microflora and rhizosphere activities

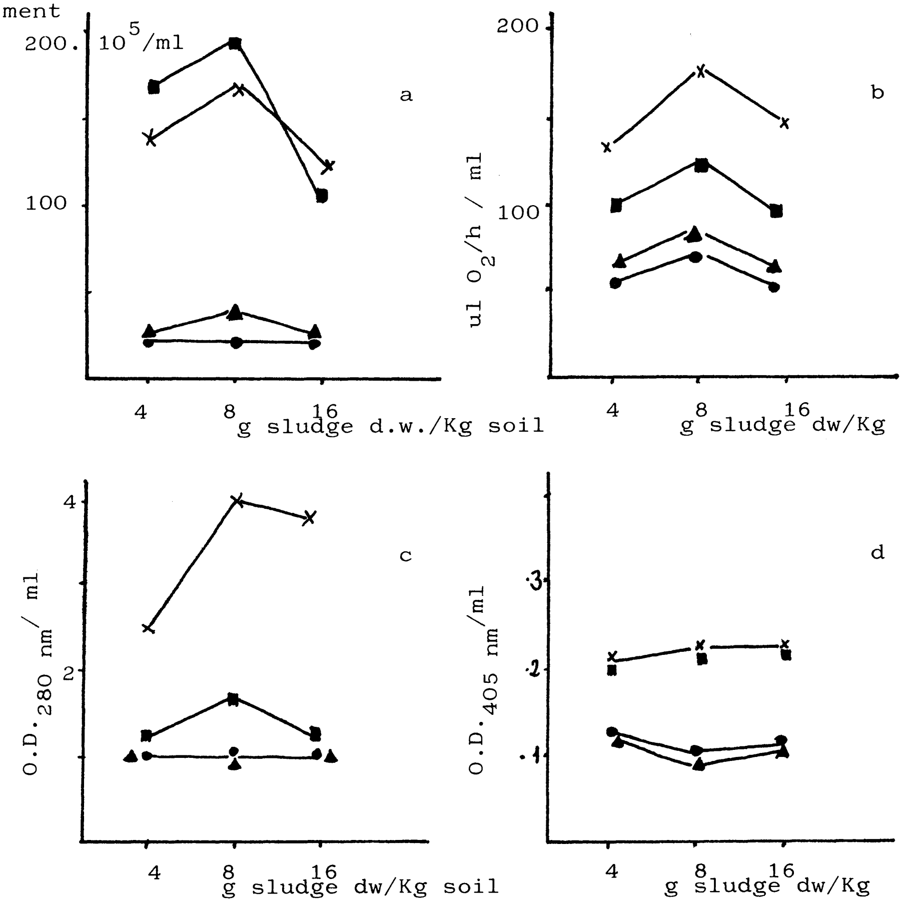
Results,summarized in table 1,show that the 8 g d.w.of sludge / Kg of soil was the most effective dose for microflora growth and biological activities on the maize rhizosphere as also comfirmed by oxygen uptake and protease activity.

As protease activity and oxygen uptake show,a good mineralization occourred,especially when doses of 8 or 16 g of sludge / kg of soil were supplied to the soil (table 1 b,c).

No differences were evidentiated for acid phosphatase activity (talle 1 d).In regard to the phosphate and nitrate rhizosphere content,no significant differences was assayed for phosphate (table 3 a),whereas a remarkable loss of nitrate for 8 g dose was recorded.(table 2 a).The active development of microflora,for which the optimal growth conditions were probably created,may explain this behaviour.

Table I

total microflora and rhizosphere activities after sludge treatment



a) total microflora
b) oxygen uptake
c) protease activity
d) acid phosphatase activity

● after 7 days
▲ " 10 "
■ " 16 "
× " 27 "

Table II

Nitrate content and nitratereductase activity (NRA)

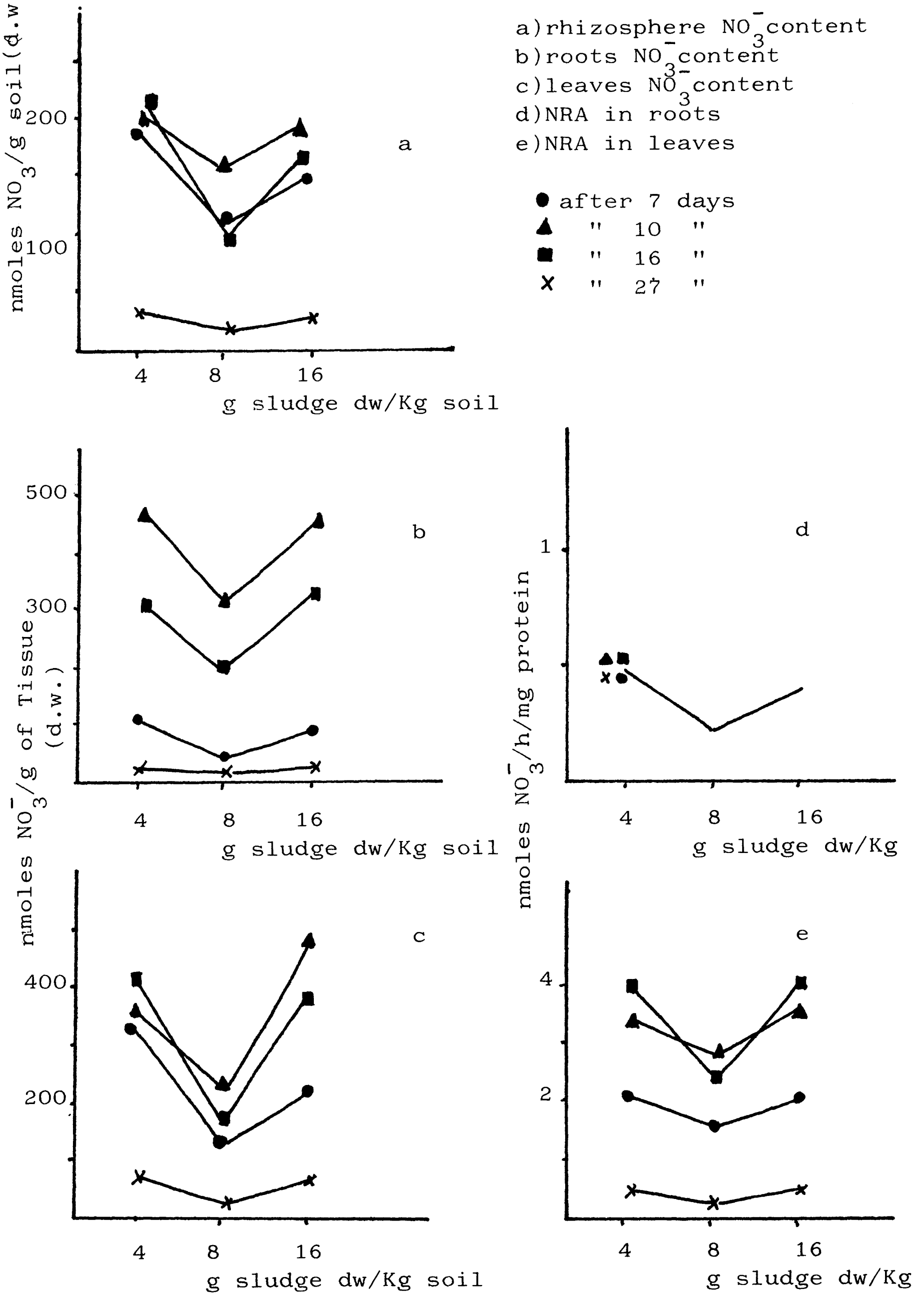
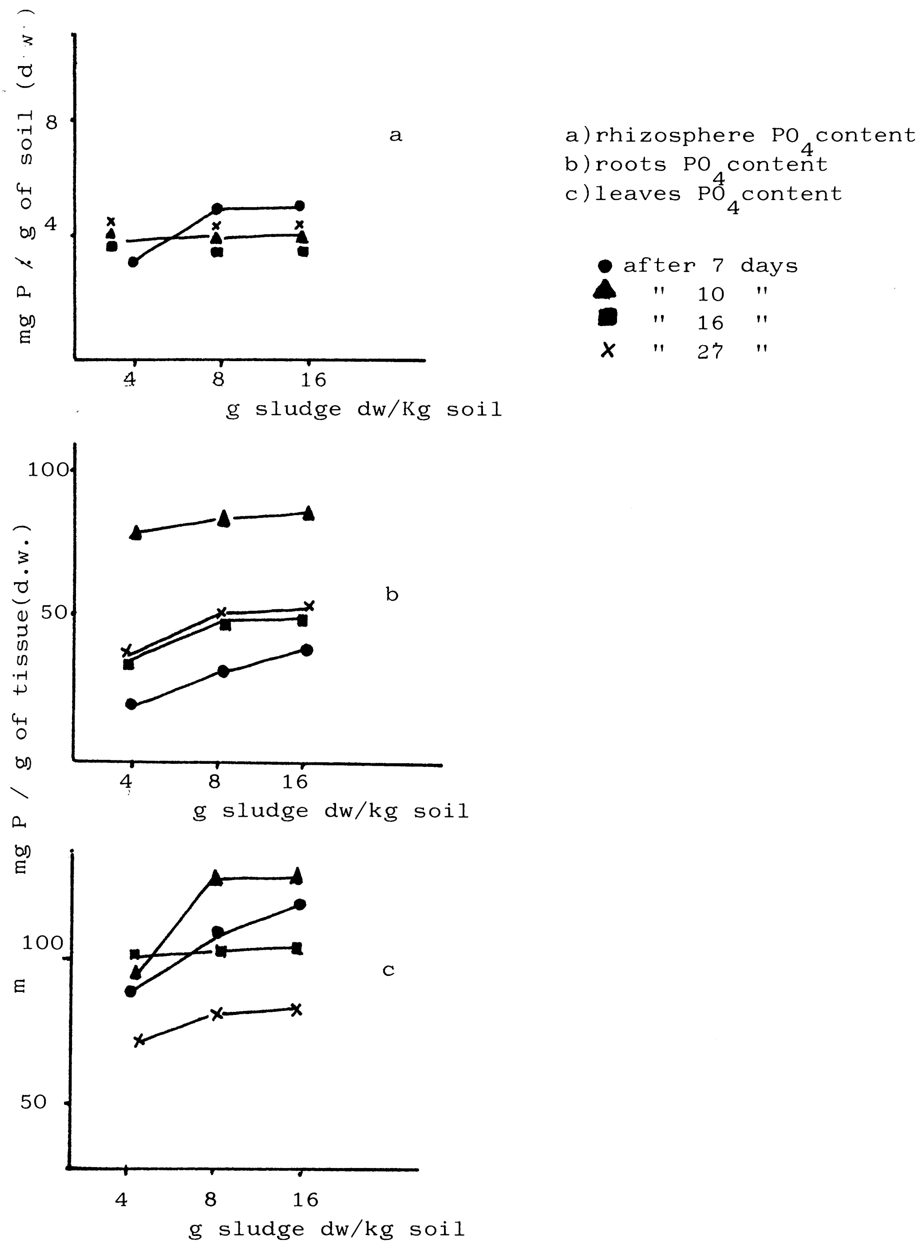


Table III
Phospate content in the rhizosphere and in plant



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EIN FELDVERSUCH ZUR PRÜFUNG DER STROH-KLÄRSCHLAMMDÜNGUNG UNTER DEN PRODUKTIONSBEDINGUNGEN DES ÖSTERREICHISCHEN MARCHFELDES

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Kurzfassung

Ein Feldversuch zur Prüfung der Stroh- und Klärschlammdüngung wird in Groß-Enzersdorf, Marchfeld, durchgeführt. Er umfaßt die Prüfglieder: Mineraldüngung, Kontrolle (ohne Stickstoff), Strohdüngung, bewässerte Strohdüngung, Stroh-Klärschlammdüngung, sowie Klärschlammdüngung. Die Versuchspflanzen sind Winterweizen, Winterroggen und Sommergerste. Über die Ergebnisse des 1. Versuchsjahres 1979 wird berichtet.

Während der Vegetationsperiode wurden im Abstand von 3 Wochen Proben aus den Bodenschichten o-25 cm, 25-6o cm und 6o-9o cm entnommen und auf den Gehalt an mineralischem Stickstoff untersucht. Die Proben aus der Schicht o-25 cm wurden zusätzlich einer Humuskomplexanalyse unterworfen.

Die Erträge an Weizen, Roggen und Gerste waren durch die Versuchsbehandlung nicht signifikant beeinflußt. Die im Bodenprofil festgestellten Mengen an pflanzenverfügbarem Stickstoff waren in der Klärschlamm- und Stroh-Klärschlammparzelle höher als in den mineralgedüngten Parzellen und in der Kontrollparzelle. Die organische Düngung, besonders die Stroh-Klärschlammdüngung, erhöhte deutlich den Gehalt an extrahierbaren Huminstoffen.

Summary

A field experiment on fertilization with sewage sludge and straw is conducted in Groß-Enzersdorf, Marchfeld. Treatments used are: Mineral fertilization, control (without nitrogen), application of straw, of straw + water, of straw + sludge and of sludge alone. Test crops used are winter wheat, winter rye and spring barley. The results of the first year (1979) are reported.

Soil samples were taken every three weeks from depths of o-25 cm, 25-6o cm and 6o-9o cm, respectively. These were analyzed for mineral nitrogen. Soil samples from o-25 cm were further analyzed for extractable humic substances.

Yields of wheat, rye and barley were not significantly influenced by the treatments. Plots treated with sludge and straw + sludge had, however, higher contents of mineral nitrogen and extractable humic substances.

1. EINLEITUNG

Der Ausbau der Abwasserreinigung führt allenthalben zu steigendem Anfall von Klärschlamm, der nutzbringend verwertet oder auch nur schadlos beseitigt werden muß. Die Verwendung im Landbau bedeutet eine Verwertung der im Klärschlamm enthaltenen, manchmal beträchtlichen Mengen an Pflanzennährstoffen, welche auf diese Weise in den natürlichen Kreislauf zurückgeführt werden. Klärschlämme enthalten vor allem Stickstoff und Phosphor, jedoch sehr wenig Kalium (1). Die weltweit stark angestiegenen Düngemittelpreise erhöhen das Interesse der Landwirtschaft an solchen, beträchtlich billigeren Nährstoffquellen (2, 3).

Die Kombination von Klärschlamm- und Strohdüngung bietet sich aus mehreren Gründen an: Klärschlamm bringt den zur Strohumsetzung nötigen Stickstoff, welcher dabei immobilisiert und so der winterlichen Auswaschung entzogen wird. In der nachfolgenden Mineralisierungsphase wird dieser Stickstoff wieder pflanzenverfügbar. Die mit dem Klärschlamm zugleich verabreichte Wassermenge reicht aus, um die Strohumsetzung, die sonst häufig durch Trockenheit gehemmt ist, in Gang zu bringen.

Die günstige Wirkung der Stroh-Klärschlammdüngung konnte in einer Serie von Gefäßversuchen gezeigt werden (4). Sie sollte nun auch im Feldversuch unter den Bedingungen eines der Hauptproduktionsgebiete Österreichs, des Marchfeldes, überprüft werden.

2. VERSUCHSANLAGE

Der Versuch wurde auf einer Fläche der Versuchswirtschaft Groß-Enzersdorf der Wiener Universität für Bodenkultur angelegt. Die Fläche hat die Ausmaße von 1oo mal 135 m. Folgende Behandlungen waren vorgesehen:

1.) Mineraldüngung (P-K mineralisch + 1oo % N mineralisch)
2.) Kontrolle (P-K mineralisch, ohne Stickstoff)
3.) Strohdüngung (P-K mineralisch + 16o % N mineralisch + Stroh)
4.) bewässerte Strohdüngung (P-K mineralisch + 16o % N mineralisch + Stroh + 2oo m^3/ha Wasser)
5.) Stroh-Klärschlammdüngung (P-K mineralisch + 5o % N mineralisch + Stroh + 2oo m^3/ha Klärschlamm)
6.) Klärschlammdüngung (P-K mineralisch + 5o % N mineralisch +

+ 2oo m^3/ha Klärschlamm).

Um die erwarteten Ungleichmäßigkeiten des Bodens auszugleichen, wurde der Versuch nach der Standard-Methode angelegt. Als Standard wurde die Behandlung 1 zwischen jede der anderen Behandlungen eingeschaltet. Es ergaben sich so insgesamt 11 Parzellen, die als Langparzellen von 8 m Breite, durch einen Streifen von o,4 m Breite von einander getrennt, angelegt wurden (5). Das Versuchsfeld wurde zu je einem Drittel mit Winterweizen, Winterroggen und Sommergerste bestellt. Diese Früchte sollen in einer dreigliedrigen Rotation aufeinanderfolgen, sodaß nach drei Jahren jeder Schlag einmal die gesamte Fruchtfolge durchlaufen hat.

Winterweizenstroh wurde in Mengen von 5.ooo kg/ha in gehäckseltem Zustand auf die Stoppeln der Vorfrucht Durumweizen ausgebracht. Phosphor und Kalium wurden als DC45 in Mengen von 7oo kg/ha gestreut. Klärschlamm wurde aus der nächstgelegenen Kläranlage Deutsch-Wagram bezogen und mit einem Güllewerfer möglichst gleichmäßig auf der Parzelle verteilt. Die Anwendungsmenge betrug 2oo m^3/ha entsprechend 2o mm Niederschlag. Auf die gleiche Weise wurde Wasser ausgebracht. Die Behandlungen 3 und 4 erhielten gleichzeitig 5o kg Reinstickstoff als N-Ausgleich zur Strohdüngung.

Alle Behandlungen außer der Behandlung 2 erhielten eine Mineralstickstoffgabe von 45 kg N im Frühjahr. Die Behandlungen 1, 3 und 4 erhielten zum Schossen eine zweite Stickstoffgabe in der gleichen Höhe.

Zur Ernte wurden aus jeder Langparzelle 8 Wiederholungen mit einem Parzellenmähdrescher von 1,25m Schnittbreite gewonnen. An getrennten Flächen wurde die Bestandesdichte und die Kornzahl pro Ähre ermittelt. Über die Ergebnisse des 1. Versuchsjahres 1979 wird berichtet.

3. ZUSÄTZLICHE UNTERSUCHUNGEN

Im Abstand von 3 Wochen wurden während der gesamten Vegetationszeit Bodenproben aus den Tiefen o-25, 25-6o und 6o-9o cm entnommen, unverzüglich ins Labor transportiert und dort sofort auf den Gehalt an Mineralstickstoff (6) untersucht. Die Bestimmung erfolgte durch Extraktion mit 2 N KCl und anschließende Wasserdampfdestillation mit MgO und Devarda'scher Legierung (7).

Der Rest der Bodenproben aus o-25 cm Tiefe wurde bei 5o° C getrocknet und im Kühlraum zur Humuskomplexanalyse aufbewahrt. Diese erfolgte nach der Methode von DANNEBERG u. SCHAFFER (8) durch erschöpfende Extraktion der Huminstoffe mit einem komplexbildenden Ionentauscher und Wasser, Trennung des Extraktes in die Fraktionen Fulvosäuren, Braunhuminsäuren und Grauhuminsäuren und Messung der Eigenfärbung dieser Fraktionen bei 4oo nm in gepufferter Lösung bei pH = 1o,o.

4. ERGEBNISSE UND DISKUSSION

Der Mineralstickstoff im durchwurzelbaren Teil des Bodenprofils war die ganze Vegetationszeit über in beträchtlichen Mengen vorhanden: Im Frühjahr wurde zwischen 9o und 15o kg N/ha festgestellt, am Ende der Vegetationszeit immerhin noch 6o-8o kg. Diese Stickstoffmengen stammten sowohl aus der mineralischen und organischen Düngung als auch aus der Nachlieferung durch den Boden selbst. Die Abnahme im Laufe der Vegetationszeit (Abb. 1) ist vor allem auf die N-Aufnahme durch die Kultur zurückzuführen. Sie ist bei Weizen und Gerste deutlich, bei Roggen jedoch wenig ausgeprägt. Möglicherweise ist dies auf die geringeren Stickstoffansprüche der verwendeten älteren Roggensorte (Tschermaks vom Marchfeld) zurückzuführen. Ebenso sind die Unterschiede der Behandlungen nur unter Gerste und Weizen, nicht jedoch unter Roggen statistisch zu sichern. Unter Weizen zeigt die Stroh-Klärschlammdüngung einen Gehalt an Mineralstickstoff, der den der Standardparzellen übersteigt. Bei Gerste ist dies nur am Beginn der Vegetationszeit der Fall, später verschwindet der Unterschied. Die hohe Eigenmineralisierung des Bodens zeigt die Kontrollparzelle: Sie ergibt nur unter Gerste signifikant niedrigere N-Gehalte als die mineralgedüngten Standardparzellen (Tabelle I).

Die Erträge ergaben bei allen drei Kulturen keine signifikanten Unterschiede. Desgleichen wiesen die Ertragsparameter, die Bestandesdichte, die Kornzahl pro Ähre und das Tausendkorngewicht, keine den Versuchsfehler übersteigenden Unterschiede auf.

Auch die Erträge der Kontrollparzelle lagen nicht signifikant niedriger. Daraus läßt sich folgern, daß nach einem Jahr ohne jede Stickstoffzufuhr die Eigenmineralisierung des Bodens noch ausreicht, um einen meßbaren Ertragsabfall zu verhindern. Dementsprechend konnten die anderen Behandlungen, die sich im wesentlichen in ihrem Stickstoffangebot unterscheiden, ebenfalls keinen meßbaren Einfluß auf den Ertrag haben. Es ist zu erwarten, daß Ertragsunterschiede erst nach mehreren Versuchsjahren meßbar werden.

Das Huminstoffsystem dieses Bodens, eines Tschernosems auf Feinsediment, besteht vorwiegend aus Grauhuminsäuren; sie machen zwischen 6o und 66 % des Huminstoffsystems aus (Tab. II). Der Anteil der Braunhuminsäuren liegt zwischen 24 und 29 %, der der Fulvosäuren bei etwa 1o %. Diese Zahlen entsprechen weitgehend früher gemessenen Werten eines ähnlichen Tschernosems (8). Deutlich ergibt sich ein Einfluß der Behandlungen: Wie Tabelle III zeigt, steigert vor allem die Klärschlamm- und die Stroh-Klärschlammdüngung die Menge der extrahierbaren Huminstoffe. Besonders die Grauhuminsäuren werden meßbar erhöht. Dies steht im Einklang mit früheren, in einem Gefäßversuch erzielten Ergebnissen(9).

Klärschlamm- und Stroh-Klärschlammdüngung vermochten also sowohl den wesentlichen Teil des Bodenhumus, die Huminstoffe, zu erhöhen als auch den pflanzenverfügbaren Stickstoff - trotz Einsparung der halben Mineralstickstoffgabe - zu steigern. Ein Einfluß auf den Ertrag jedoch zeigte sich nicht, da das Stickstoffangebot des Bodens allein schon ausreichte, um den Höchstertrag zu erzielen.

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6. DANKSAGUNG

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Tabelle I

Unterschiede des im Bodenprofil der Behandlungen im Mittel der Zeit enthaltenen Mineralstickstoffs zu jenen der mineralgedüngten Standardparzellen (in kg N/ha)

Behandlung	WW	WR	SG
1 (Mineraldüngung)	0,00	0,00	0,00
2 (Kontrolle)	- 7,33	-13,25	-10,50
3 (Strohdüngung)	3,75	- 3,58	5,83
4 (bewässerte Strohdüng.)	- 2,25	- 5,92	3,33
5 (Stroh-KS-Düngung)	11,25	0,50	5,33
6 (Klärschlammdüngung)	7,42	2,50	- 9,50
GD 5 %	11,69	13,53	10,41

Tabelle II

Die Zusammensetzung des Huminstoffsystems im Mittel aller Behandlungen und Zeitstufen (in OD/g Boden)

		WW		WR		SG	
Fulvosäuren	FS	7,43	10,2 %	7,08	10,2 %	6,97	10,0 %
Braunhuminsäuren	BHS	17,61	24,2 %	20,02	28,9 %	19,34	27,8 %
Grauhuminsäuren	GHS	47,59	65,5 %	42,27	60,9 %	43,30	62,2 %
Summe		72,93	99,9 %	69,37	100,0 %	69,61	100,0 %

Tabelle III

Unterschiede der Gehalte der Behandlungsparzellen an extrahierbaren Huminstoffen zum Gehalt der mineralgedüngten Standardparzellen (Angaben in OD/g Boden)

Sommergerste						Winterroggen					
Beh.	2	3	4	5	6	Beh.	2	3	4	5	6
FS	0,06	0,33	0,55	0,23	0,60	FS	0,33	-0,31	0,20	0,67	0,56
BHS	0,08	0,56	0,64	0,58	0,54	BHS	0,00	0,30	0,82	0,99	1,24
GHS	0,45	0,67	1,47	2,58	4,71	GHS	-0,05	-0,60	2,80	5,51	3,98
Summe	0,59	1,56	2,66	3,39	5,85	Summe	0,28	-0,61	3,82	7,17	5,78
GD 5 %			1,14			GD 5 %			1,53		

Winterweizen					
Beh.	2	3	4	5	6
FS	0,37	0,10	0,49	1,04	0,28
BHS	-0,12	0,61	1,17	1,32	1,24
GHS	-1,04	1,64	2,14	2,81	2,86
Summe	-0,79	2,35	3,80	5,17	4,38
GD 5 %			1,17		

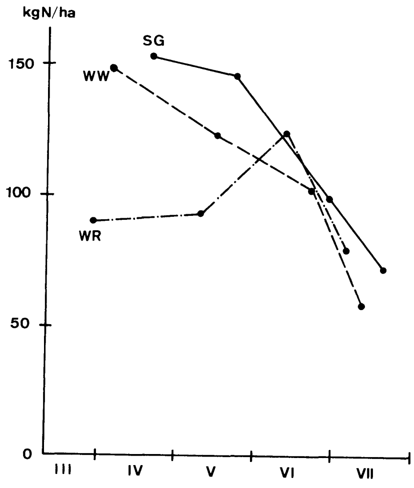

Abbildung 1 : Gehalt an Mineralstickstoff im Boden im Mittel aller Behandlungen (in kg N/ha)

THE USE OF SLUDGE IN HORTICULTURE AND AGRICULTURE

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Summary

Sludge from the waterpurification plants contains high quantities of organic matter so being worth to be investigated on it's value as horticultural substrate. Horticultural substrates mainly consist out of peat, pine litter or bark. These products becoming more and more expensive, it is likely to mix them with sludge in order to become a high quality product, which can be used as well as the classical horticultural substrates.

Before using sludge in substrates, it must be composted. This can be done together with bark as only composted bark can be used in substrates. The quantity of sludge which can be mixed up with bark is depending on the water - air relationship, therefore the physical properties of different mixtures will be investigated.

Those mixtures with good physical properties will then be tested out as horticultural substrates with different ornamental plants. The growth results will be discussed in comparison with these from the normal used substrates as peat, pine litter and bark.

1. INTRODUCTION

Surface waters are contaminated with more and more organic and inorganic waste from industries and sewage waters. Therefore in every town or place with industrial concentration, purification plants are or will be introduced. These plants are producing high quantities of sludge. That's the reason why we are looking for the valorization of this sludge in horticulture and agriculture.

The existing and planned capacity of the purification plants in Belgium is given in Tabel 1, expressed as inhabitant-equivalent (I.E.).

Table 1. Capacity of the waterpurification plants in Belgium in I.E. (situation in 1978).

Province	In use	In preparation
East-Flandern	144.500	1.010.000
West-Flandern	79.000	770.000
Antwerp	297.500	1.411.000
Limburg	255.500	697.000
Flemish Brabant	45.500	60.000
French Brabant	24.000	580.000
Hainaut	435.000	1.756.000
Namur	45.000	515.000
Liege	140.000	310.000
Luxembourg	14.000	143.000
Total	1.480.000	7.252.000
	8.732.000 I.E.	

From the results of table 1 and taking into account a mean production of 15 kg D.M./I.E./year of sludge, the total production of sludge (dry matter) can be calculated.
The excisting purification plants are producing about 22.000 tons of dry material which can increase to more than 100.000 tons in the near future.

2. CHEMICAL COMPOSITION

In our experiments 2 different sludges are used. The first one is coming from the water purification plant of a papermill and is containing practical no nitrogen. The second one is from a plant that is purifying the sewage water. This kind of sludge is very rich in organic nitrogen.
Table 2 gives the chemical composition.

3. COMPOSTING EXPERIMENTS

The composting experiments are carried out in a laboratory composting simulator. Cappaert et al. (1976) described this apparatus (foto 1).

Different mixtures of bark and sludge are composted with different amounts of mineral nitrogen (urea). The results are given in Table 3 and 4.

Table 2. Chemical composition of the 2 sludges in comparison with pine bark.

Chemical composition	Sludge rich in N	Sludge poor in N	Pine bark
pH_{H_2O}	7.31	7.61	6.37
Ec (µS 1/25)	900	470	240
% org. matter	62.0	66.7	93.2
% moisture content	70 - 75	65 - 75	60 - 70
% N	4.63	0.51	0.59
% C	34.4	33.7	51.8
C/N ratio	7.4	66.0	88.0
Elements in ppm			
Ca	40.000	1.650	12.500
Mg	3.376	753	958
P	16.000	1.517	587
K	1.025	1.650	2.000
Na	18.000	1.250	265
Fe	7.530	2.438	2.458
Mn	183	243	416
Zn	2.462	129	188
Cu	247	99	9
Pb	580	30	18
Ni	19	6	6
Cd	8	2	2
Co	4	<2	<2
Cr	22	12	5

These results indicate that both sludges can be used without danger in horticultural substrates and as organic soil conditioner.

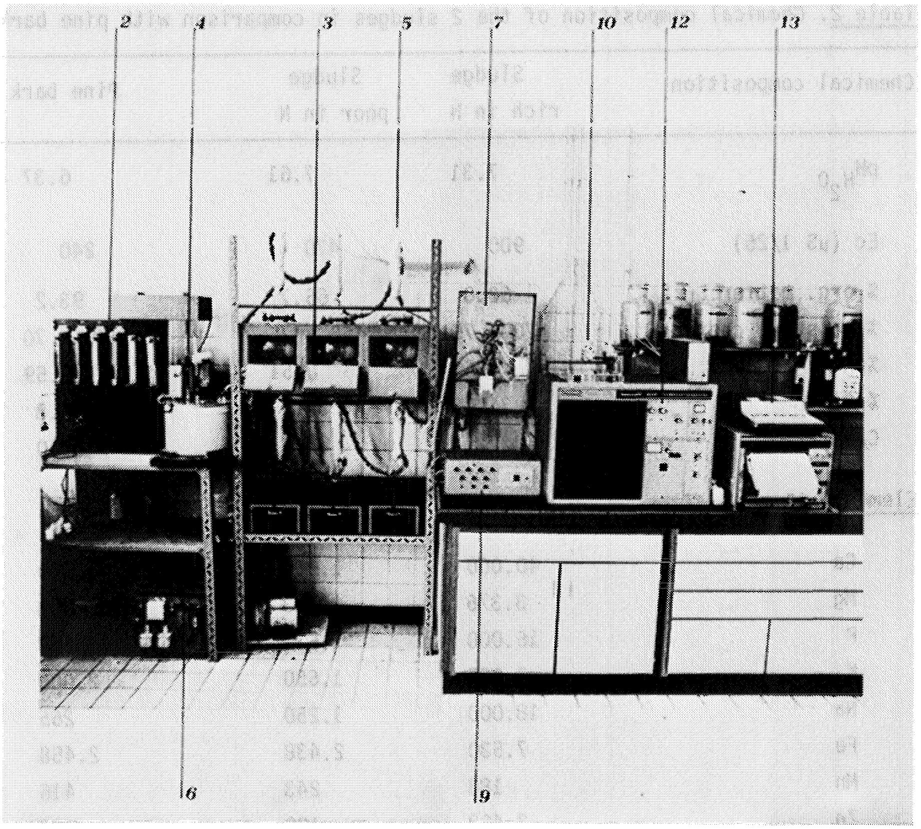

Photo 1. The composting simulator.

2. Flowmeters	7. Electromagnetic valves
3. Composting	9. Electronic regulator
4. Heating system	10. Sampling valve
5. Coolers	12. Gaschromatograph
6. Refrigerator	13. Recorder + Printer

Table 3. Oxygen consumption of the mixtures of N-rich sludge with bark.

N-addition in %	Mixtures bark/sludge					
	100/0	95/5	90/10	80/20	60/40	20/80
0	-	-	103	142	195	190
0.25	-	138	150	190	222	290
0.50	-	134	139	199	219	279
0.75	100	-	-	-	-	-

Table 4. Oxygen consumption of the mixtures of N-poor sludge with bark.

N-addition in %	Mixtures bark/sludge					
	100/0	95/5	90/10	80/20	60/40	20/80
0	-	44	50	59	76	91
0.25	-	83	85	89	85	77
0.50	-	95	98	104	96	87
0.75	100	97	103	106	95	87
1.00	-	109	108	112	105	87

From the results of table 3 and 4 the following can be concluded :

- When the sludge is containing high amounts of nitrogen the oxygen consumption is much more higher than the control (pine bark + 0.75% N) in all the mixtures.
- The ratio bark/sludge (rich N) 20/80 with addition of 0.25% N gives the best results.
- The sludge coming from the papermill gives practically no difference with the bark; all the mixtures give the same results when 0.50, 0.75 and 1.00 % N is added; only the ratio bark/sludge 20/80 gives slightly minor results.
- Following conclusions can be drawn :
  - for horticultural substrates sludge up to 40% can be added
  - for organic soil conditioners sludge up to 80% can be added
  - the addition of nitrogen for optimal composting is different for both sludges : 0.25% N has to be added when N-rich sludge is used, 0.75% N has to be added when N-poor sludge is used.

5. PHYSICAL PROPERTIES OF MIXTURES

It is very important to know if the water and air relationship in the different mixtures is changing when high amounts of sludge are added.
The results of the physical properties of different mixtures are given in table 5.

Figure 1 gives the water release curve of 4 mixtures. From the results of table 5 and figure 1, it can be said that :

- the bulk density is increased from 120 kg/m^3 to about 150 kg/m^3
- the water- and air economy is not changed by mixing sludge to bark. Only an increase of the vol % of water at the different tensions is obser-

ved but the easily available water is not changed, only the volume % of air is slightly decreased.

As conclusion, we can say that by mixing sludge with bark up to 50%, the physical properties don't change.

Table 5. Physical properties of different mixtures.

Mixtures	BD(*)	RD	TPS	Volume water at			Vol %	EAW	WBC
	9/cm^3	9/cm^3		10cm	50cm	100cm	air		
Bark	0.120	1.60	92.4	35.7	29.4	28.3	56.7	6.2	1.11
Bark +									
10% sludge	0.140	1.56	91.0	43.6	36.7	35.7	47.3	6.8	1.01
20% sludge	0.147	1.63	90.8	44.3	38.7	37.3	46.4	5.6	1.45
50% sludge	0.150	1.65	91.1	42.5	36.7	35.2	48.5	5.8	1.55

BD : bulk density
RD : real density
TPS : **total** pore space
EAW : easily available water
WBC : waterbuffering capacity

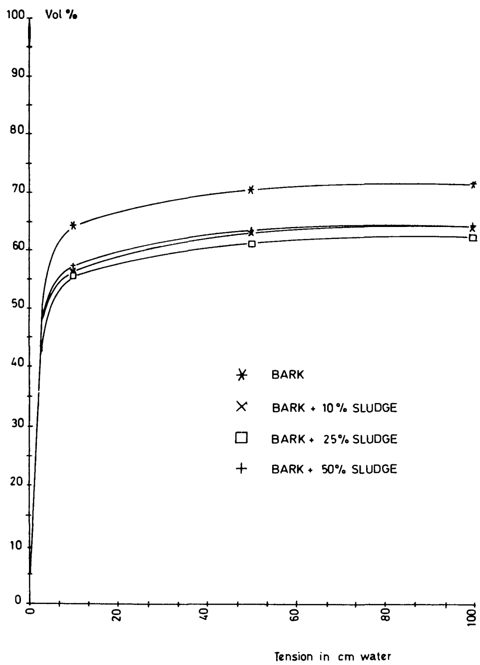

Figure 1. Waterrelease curve.

6. GROWING EXPERIMENTS

The mixtures of bark and sludge have been tested out during the last 4 years. The results are excellent when mixtures of bark with sludge (up to 50%) are used. Table 8 contains the results of some experiments.

Table 8. Growth results of plants in mixtures bark/sludge

Substrate	Kind of plant	Height in cm	Number of leafs	Width of the biggest leaf
Bark	Fatshedera	60.6	20.2	
Bark + 10% sludge		55.7	18.8	
Bark + 20% sludge		52.3	17.9	
Bark + 50% sludge		54.2	20.4	
Pine leaf mould	Aralia elegantissima	57.0	30.2	
Bark		59.4	31.8	
Bark + 10% sludge		58.5	29.5	
Bark + 20% sludge		54.5	29.3	
Bark + 50% sludge		58.7	30.5	
Pine leaf mould	Dieffenbachia exotica	62.3	15.3	
Peat		62.3	15.5	
Bark		63.3	16.4	
Bark + 10% sludge		62.4	13.9	
Bark + 20% sludge		61.6	14.4	
Pine leaf mould	Vriesea splendens	39.2	13.6	5.4
Peat		35.0	13.1	5.0
Bark		33.3	12.7	4.9
Bark + 10% sludge		36.3	13.3	5.1
Bark + 20% sludge		37.4	13.8	5.4
Pine leaf mould	Vriesea splendens	40.1	13.3	3.9
Peat	"De Meyers Favorite"	46.5	14.0	4.5
Bark		43.0	14.3	4.2
Bark + 10% sludge		44.3	13.9	4.4
Bark + 20% sludge		43.9	14.3	4.4
Bark	Monstera deliciosa	80.5	6.5	
Bark + 10% sludge		96.0	7.5	
Bark + 20% sludge		93.6	7.4	

In photo 2 Monstera plants grown in bark + 20% sludge are shown.

These results (Table 6) show that substrates made from bark and sludge can be used as horticultural substrates.

Photo 2. Monstera deliciosa grown in bark + 20% sludge

7. CONCLUSION

The analytical results of the two studied sludges give an idea about the possibilities of use and also if any element is present in high amounts Therefore it is necessary that sludge before using it, is analysed in order to prevent difficulties.

The composting experiments showed that there is a difference in adding mineral nitrogen. For sludge rich in N only 0.25% mineral nitrogen has to be added for optimal composting, this in contrast with the sludge coming from the papermill, where 0.75% N has to be added.

From the results of the growth experiments, we can see that sludge can be mixed up to 20% can in some cases up to 50%. These mixtures can be used as horticultural substrates.

Knowing that yearly about 250.000 - 300.000 m^3 of good substrates are used in Belgium we can say that a great deal of these waste products can be utilized in substrates so that the waste management problems can be solved in an environmently minded manner.

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DIE LANDWIRTSCHAFTLICHE VERWERTUNG VON KLÄRSCHLAMM IN ÖSTERREICH

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Summary

Until about 1970 there were scarcely any problems in connexion with sewage sludge in Austria. The extensive construction of sewage plants, however, lead to difficulties with the sewage sludge, especially in conurbations.

This development is reflected also by the range and state of the research. The first field tests were carried out according to the model of the Niersverband, Viersen,BRD, with the aim to find a solution of the sewage sludge problem of the main sewage plant of Vienna.

Subsequently it were the Landwirtschaftlich-chemische Bundesanstalt in Vienna and Linz, the Institut für Landwirtschaft of the Österr. Studiengesellschaft für Atomenergie in Seibersdorf and some other institutions beside the Institut für Wasserwirtschaft of the Universität für Bodenkultur in Vienna that dealt with the questions of the effects of nutrients, the straw- sewage sludge-fertilisation, the composting of sewage sludge etc. At all pot and field tests also the negative effects of sewage sludge were studied, including also the heavy metal problems.

According to our present state of knowledge the agricultural use of slightly contaminated sludges of mostly communal sewage plants proves rather successful during a limited period of time.

Future researches will not only have to deal with the effects of nutrients on different sites and catchment areas but also with ecological and hygienic effects of the contents and harmful substances within the sewage sludge on our environment.

1. EINLEITUNG

Um den Anforderungen des Umweltschutzes - insbesondere des Gewässerschutzes - Rechnung zu tragen, müssen die Abwässer vor ihrer Einleitung in die Gewässer so gut wie möglich gereinigt werden. Je weiter die klärtechnische Behandlung von Abwässern geht, umso größer ist dabei der Anfall von Klärschlamm.

Der Vielfalt unterschiedlicher Behandlungsverfahren von Klärschlämmen stehen zu deren endgültiger Beseitigung aber nur wenige wirtschaftlich und ökologisch vertretbare Alternativen gegenüber, nämlich die Deponie auf dem Land oder eingeschränkt im Meer und die Abgabe an die Land- und Forstwirtschaft.

2. LANDWIRTSCHAFTLICHE VERWERTUNG VON KLÄRSCHLAMM

Bis etwa 1970 gab es in Österreich kaum Probleme mit Klärschlamm. Die vorhandenen Kläranlagen konnten vorerst ihren Schlamm speichern oder größtenteils in der Landwirtschaft unterbringen. War die Speicherkapazität überschritten, hat man im einen oder anderen Fall den Klärschlamm kurzerhand in den Vorfluter abgelassen.

Die Entwicklung der Anzahl der kommunalen Kläranlagen für mehr als 1000 EGW in der Tab. I veranschaulicht diese Situation. Von 1960 bis 1970 haben sich zwar die Anzahl der Kläranlagen und die der angeschlossenen Einwohnergleichwerte verzehnfacht. Der Klärschlamm wurde aber erst infolge des raschen Ausbaues der Kläranlagen zwischen 1970 und 1980 zu einem gewissen Problem.

Nach Schätzungen von W.v.d.EMDE liegen die Bruttoeinwohnergleichwerte der Industrie in Österreich bei rd. 17,0 Mio. (2). Einschließlich der Bevölkerung kann man daher mit rd. 25 Mio. EGW rechnen, wovon derzeit etwas mehr als die Hälfte an vollbiologische Kläranlagen angeschlossen sind.

Der Stand der Forschung im Bereich der landwirtschaftlichen Verwertung von Klärschlamm spiegelt die Situation in Österreich ebenfalls wider. In der Bestandsaufnahme der Ökosystemforschung in Österreich von CABELA,

Tab. I Anzahl der kommunalen Kläranlagen (> 1000 EGW) mit angeschlossenen projektierten EGW (einschl. Gewerbe und Industrie) im Endausbau oder in Betrieb (1)

Jahr	Art der biologischen Anlagen						Summe der biol. Anlagen		Mechanische Anlagen		Summe der biol. u. mech. Anlagen	
	1		2		3							
	Anz.	EGW	Anz.	EGW	Anz.	EGW	Anz.	EGW	Anz.	EGW	Anz.	EGW
1960	1	1.000	10	79.600	-	-	11	80.600	20	82.500	31	163.100
1965	7	80.000	17	100.000	-	-	24	180.000	63	349.800	87	529.800
1970	75	660.000	44	196.000	-	-	119	856.000	110	845.000	229	1.701.000
1975	95	780.400	51	218.200	18	128.200	164	1.126.800	141	952.500	305	2.079.300
1980	125	4.094.700	68	280.500	147	571.400	340	4.956.600	149	1.449.000	489	6.405.600

1 Belebungsanlage

2 Tropfkörperanlage

3 Biologische Anlage ohne nähere Angabe des Systems

Die Zahlen beruhen auf Erhebungen bei Wasserrechtsverhandlungen bzw. beim Wasserwirtschaftsfonds. Sie sind als Kapazität zu werten.

HORAK und LEUKER wurden vom Institut für Wasserwirtschaft, Abt. Landwirtschaftlicher Wasserbau, der Universität für Bodenkultur ein Forschungsvorhaben und von der Landwirtschaftlich-chemischen Bundesversuchsanstalt in Wien zwei Forschungsvorhaben genannt (3).

Im Forschungskonzept "Recyclingforschung von Österreich" wurden dagegen schon 17 Forschungsvorhaben angeführt, wobei im Arbeitskreis 2.5, Recycling in der Land- und Forstwirtschaft, 34 Fachleute aus drei Bundesministerien, zwölf Universitätsinstituten, vier Bundesanstalten, einer Landesregierung, anderen staatlichen und privaten Institutionen sowie aus der Industrie kamen (4). Von den 17 Forschungsvorhaben behandelten zehn die direkte Einbringung von flüssigen oder mechanisch entwässerten Klärschlämmen in den Boden. Die weiteren sieben beschäftigten sich mit Kompostierung von Klärschlämmen, meistens gemeinsam mit Hausmüll, zur Herstellung von Düngemitteln.

2.1 VERSUCHE UND UNTERSUCHUNGEN ZUR LANDWIRTSCHAFTLICHEN VERWERTUNG VON KLÄRSCHLÄMMEN

Die ersten Feldversuche mit Naßschlamm in Österreich wurden als Beitrag zu einer möglichen Lösung des Schlammproblemes der Hauptkläranlage in Wien zwischen 1968 und 1973 in Laxenburg auf einem schweren, trockengefallenen Auboden mit 60 bis 90 % Schluff- und Rohtongehalten in der Krume durchgeführt (5, 6). Verwendet wurde dabei ausgefaulter Schlamm der Kläranlage Baden, dessen wertbestimmenden Inhaltsstoffe in Tab. II zusammengestellt sind.

Die Feldversuche in Laxenburg sollten folgende Fragen klären:

Auswirkung von Klärschlammgaben auf Ertrag und Qualität von Feldfrüchten im Vergleich zur Mineraldüngung,
Auswirkungen auf den Bodenchemismus und die Bodenstruktur,
welcher Beschlammungsturnus und welche Beschlammungsfruchtfolge können im Hinblick auf eine kontinuierliche Schlammausbringung empfohlen werden.

In den Jahren 1971 und 1972 wurde zusätzlich ein mittelschwerer Boden in Leopoldsdorf im Marchfeld in das Versuchsprogramm mit einbezogen, wobei

Tab. II Wertbestimmende Inhaltsstoffe des ausgefaulten Schlammes der KA. Baden (1968 - 1972)

Inhaltsstoff	Max.	Mittel	Min.
Wassergehalt Gew.%	98,5	97,3	94,7
Trockensubstanz (TS) Gew.%	5,3	2,7	1,5
Org. Substanz % TS	63,5	51,2	36,6
Ges. - N % TS	8,5	6,3	3,4
Ges. - P_2O_5 % TS	3,3	3,0	2,6
K_2O % TS	0,5	0,5	0,4
CaO % TS	3,6	2,6	2,0
C/N - Verhältnis	6,6	4,9	3,1

vor allem die Stickstoffwirkung des Faulschlammes geprüft werden sollte. Als Versuchspflanzen in Laxenburg und Leopoldsdorf wurden Sommergerste, Winterweizen, Zuckerrübe, Körnermais, Erbsen und grüne Bohnen verwendet.

Parallel dazu wurde von KÖCHL auf den Versuchsflächen der Landwirtschaftlich-chemischen Bundesanstalt Wien in Fuchsenbigl mit Versuchen begonnen, die teilweise bis heute fortgeführt werden (7).

Am Institut für Pflanzenbau und Pflanzenzüchtung der Universität für Bodenkultur wurden unter der Leitung von STEINECK zur gleichen Zeit Gefäßversuche mit Zuckerrüben und Sommergerste angestellt, wobei der verwendete Klärschlamm ebenfalls aus Baden stammte.

Die Versuchsschwerpunkte lagen auch hier auf der Nährstoffwirkung des Klärschlammes hinsichtlich der Makronährstoffe N und P_2O_5 aber auch der Mikronährstoffe bzw. der Schwermetallproblematik.

Wegen einer geplanten möglichst kontinuierlichen Schlammabgabe nach dem Modell des Niersverbandes wurden bei den Laxenburger Versuchen Naßschlammgaben von 400 und 600 m^3/ha im jährlichen bis vierjährlichen Turnus mit Gülleregnern vor der Herbstackerung mit und ohne K_2O-Zusatzdüngung aufgebracht und eingearbeitet. Im Frühjahr wurden zu verschiedenen Terminen einmalige Schlammgaben von 300 oder 400 m^3/ha je nach Fruchtart als Kopfdüngung, ebenfalls mit und ohne K_2O, verregnet.

Aus pflanzenbaulicher Sicht stellte sich der N-Gehalt des Faulschlammes als begrenzender Faktor heraus. Zu hohe, zu häufige und zu späte Schlammgaben führten zu Ertragsdepressionen und Qualitätseinbußen.

Die Richtwerte für Stickstoff- und Phosphorsäureentzüge nach Schlammgaben im Herbst mit einer entsprechenden Kalizusatzdüngung sind in Tab. III zusammengestellt.

Tab. III Richtwerte für N- und P_2O_5-Entzüge mit K_2O-Zusatzdüngung im Herbst bei einem dreijährlichen Beschlammungsturnus.

		600 m^3/ha FS				400 m^3/ha FS			
Jahr	Fruchtart	Frucht		Erntegut		Frucht		Erntegut	
		kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
$N_{ges.}$	in der Schlammenge	1.020 kg/ha				680 kg/ha			
1969	Zuckerrüben	180	17,6	125	12,3	170	25,0	115	16,9
1970	Sommergerste	95	9,3	80	7,8	96	14,1	76	11,2
1971	Erbsen-Bohnen	56	5,5	30	2,9	79	11,6	41	6,0
	Summe	-	-	235	23,0	-	-	232	34,1
P_2O_5	in der Schlammenge	382 kg/ha				255 kg/ha			
1969	Zuckerrüben	67	17,5	48	12,6	65	25,5	47	18,4
1970	Sommergerste	45	11,8	40	10,5	45	17,6	38	14,9
1971	Erbsen-Bohnen	13	3,4	6,8	1,8	18	7,1	9,5	3,7
	Summe	-	-	94,8	24,9	-	-	94,5	37,0

KÖCHL fand in Fuchsenbigl eine ähnliche Verfügbarkeit der im Klärschlamm enthaltenen Pflanzennährstoffe, wenn im Anwendungsjahr eine Hackfrucht, z.B. Zuckerrübe, und im Folgejahr Getreide angebaut war. Etwas geringere Entzugswerte ergaben sich für die Fruchtfolge Getreide - Hackfrucht (7). Bei einem allfälligen Vergleich der angeführten Werte ist zu bedenken, daß in Tab. III die natürliche Nachlieferung des Bodens enthalten ist.

Die bodenphysikalischen Auswirkungen hingen von der Anzahl der Schlammgaben bzw. den Mengen an aufgebrachter Trockensubstanz (TS) ab.

Naßschlammgaben im Frühjahr erhöhten die Bodenfeuchte bis zu 6 Wochen. Die Herbstapplikation hatte keinen meßbaren Einfluß auf den Bodenfeuchteverlauf in der nächsten Vegetationsperiode. Die jährliche Beschlammung mit 600 m^3/ha mit zusammen 71,6 t/ha TS bzw. 40,0 t/ha org. Substanz führte zu keiner Veränderung der Kornverteilung, des spez.Gewichtes und der Konsistenzgrenzen nach ATTERBERG. Die Trockenraumdichte, das Porenvolumen und die Porenverteilung der bearbeiteten Bodenschichte wurden dagegen negativ beeinflußt (Zunahme der Feinporen, Abnahme von nK).

Die untersuchten bodenchemischen Parameter wurden durch zwei Schlammgaben wenig oder nur zeitweilig, durch fünf Schlammgaben deutlich verändert. Geringe Auswirkungen zeigten sich beim pH-Wert, zeitweilige bei der elektrischen Leitfähigkeit, deutliche Erhöhungen bei Na und den Pflanzennährstoffen N und P_2O_5.

Grundwasseruntersuchungen unter hochbeschlammten Flächen wiesen auf einen Anstieg der EL, der Na-, Cl- und NO_3-Gehalte sowie der Gesamthärte hin, während die Temperatur, die pH-Werte, die NH_4- und P_2O_5-Gehalte sich nicht änderten.

Alle Beobachtungsvarianten führten nach fünf Versuchsjahren zu einer unterschiedlichen Erhöhung des Humusgehaltes.

Schwermetalluntersuchungen in Pflanzen und im Boden zeigten keine wesentlichen Unterschiede. Vertretbare Schlammgaben können im drei- bis vierjährlichen Turnus je nach Frucht- und Bodenart sowie Applikationszeitpunkt zwischen 6 und 12 t/ha TS liegen.

Als günstige Fruchtfolgen sind Hackfrucht, Sommerung und Winterung oder Hackfrucht, Sommerung, Leguminosen und Winterung zu bezeichnen (6).

In der Landwirtschaftlich-chemischen Bundesanstalt Linz untersuchte GUSENLEITNER die Nährstoff- und Schwermetallgehalte verschiedener Klärschlämme aus Oberösterreich und Salzburg (8). Die Nährstoffgehalte wurden für die Jahre 1974 und 1975 für Orte, die in sechs Größenklassen von Großstadt bis zu ländlichen Gemeinden unterteilt waren, zusammengefaßt. Wegen der stark streuenden Ergebnisse wird hier nicht näher darauf eingegangen. Über die diesbezüglichen Schwermetalluntersuchungen und die weiteren Arbeiten der Bundesanstalt in Linz, die sich im wesentlichen mit Schwermetallfragen beschäftigen, wird HALBWACHS in seinem Bericht in Arbeitsgruppe 5 eingehen.

Umfangreiche Gefäßversuche wurden zwischen 1975 und 1977 vom Institut für Landwirtschaft der Österr. Studiengesellschaft für Atomenergie, Wien, im Auftrage des Bundesministeriums für Gesundheit und Umweltschutz zur Frage der Stroh-Klärschlammdüngung angestellt.

DANNEBERG und SISTANI untersuchten dabei die Wirkung der Stroh-, Klärschlamm- und Mineralstickstoffdüngung auf das Huminstoffsystem einer Braun- und einer Schwarzerde. Klärschlammdüngung erhöhte die extrahierbare Huminstoffmenge auf beiden Böden, die Strohdüngung nur auf Schwarzerde. Alle Düngungsvarianten führten zu einer Teilchenverkleinerung des Huminstoffsystems Die Kombination von Stroh- und Klärschlammdüngung bewirkte auf Schwarzerde jedoch eine Vergrößerung der Huminstoffteilchen (9).

HAUNOLD und ZVARA berichteten über die Ertragswirkung von Klärschlamm allein und in Kombination mit Stroh und einer mineralischen Stickstoffgabe. Mit zunehmenden Schlammgaben (40 bzw. 80 t/ha TS) stiegen die Erträge von Weizen und Gerste. Die besten Ergebnisse lieferte eine Kombination von Klärschlamm und mineralischem N. Strohzusatz hatte bei ausreichendem N-Gehalt keine Ertragsdepression zur Folge (10).

ZVARA prüfte die Nachwirkung von Klärschlamm im Gefäßversuch in Kombination mit Stroh- und mineralischen N-Gaben. Die Nachwirkung von Klärschlamm war bei Sommergerste und Sommerweizen auf beiden Böden positiv auf den Kornertrag und unterschiedlich auf den Strohertrag (11).

ZVARA und DANNEBERG befaßten sich auch mit der Wirkung sehr hoher Gaben von getrocknetem Klärschlamm auf die Trockensubstanzbildung von Gerste, Erbse und Spinat und auf die Gehalte an Makronährstoffen in diesen Pflanzen. Bei Gerste stieg der Ertrag bis zu Gaben von 320 t/ha TS. Erbsen und Spinat erreichten den Höchstertrag bei 160 t/ha TS. Höhere Gaben führten zu Ertragseinbußen, wobei Spinat am empfindlichsten reagierte. Die N- und Na-Gehalte aller Pflanzen stiegen mit den Klärschlammgaben. Die Gehalte an P, K, Ca und Mg variierten in den Versuchspflanzen (12).

DANNEBERG, HAUNOLD, HORAK und ZVARA faßten in "Möglichkeiten und Probleme der Stroh-Klärschlammdüngung" alle Versuchsergebnisse zusammen. Die Stroh-Klärschlammdüngung zeigt eine durchaus positive Wirkung auf die Erträge, auf die Humusgehalte des Bodens und auf dessen Fruchtbarkeit. Bei mehrjähriger Anwendung sind die Einzelgaben aber vorsichtig zu bemessen, damit es zu keiner N-Überdüngung kommt.

Klärschlämme von der Qualität des Badener Schlammes können durchaus über längere Zeit auf der gleichen Fläche angewendet werden, ohne daß pflanzentoxische oder humantoxische Anreicherungen von Schwermetallen im Erntegut zu befürchten sind. Pflanzentoxische Erscheinungen, etwa durch eine Zn-Überdüngung, sind eher wahrscheinlich als humantoxische.

Die Anreicherung von Schwermetallen im Boden ist wegen deren geringer Pflanzenverfügbarkeit so hoch, daß eine dauernde Klärschlammanwendung bedenklich erscheint. Wird eine Verwendung von Klärschlamm im Pflanzenbau als Dauerlösung angestrebt, muß durch technologische oder organisatorische Maßnahmen eine Verringerung der Schwermetallkontamination der Schlämme erreicht werden. Derzeit kann eine Schlammverwertung wegen ihrer Vorteile über eine begrenzte Zeit bei entsprechender Kontrolle verantwortet werden (13).

KURZWEIL setzte sich mit der Kompostierung von Klärschlamm auseinander, weil dabei ein weitgehend aufbereitetes, hygienisch einwandfreies Produkt erreichbar ist, welches die Verwertung von Klärschlämmen vor allem kleinerer Anlagen wesentlich erleichtern kann. Es werden die Grundlagen der Kompostierung von Klärschlämmen mit verschiedenen Beimischungen (Laub- bzw. Pflanzenabfall, Sägemehl, Torfmull und Stroh) behandelt und Angaben über die Inhaltsstoffe des kompostierten Materiales gemacht (14, 15).

Neben den laufenden Feldversuchen und Untersuchungen der Landwirtschaftlich-chemischen Bundesanstalten in Linz und Wien, wird vom Institut für

Wasserwirtschaft, Landwirtschaftlicher Wasserbau, in Groß-Enzersdorf seit 1977 im Rahmen eines Langzeitversuches (10 Jahre) mechanisch entwässerter bzw. kompostierter Klärschlamm mit jährlichen Gaben von 20 und 40 t/ha TS angewendet. Neben den Ertrags- und Qualitätsbestimmungen beim Erntegut und den Nährstoffuntersuchungen in Böden sollen nach Abschluß der Schlammapplikationen v.a. bodenphysikalische und bodenchemische Parameter untersucht werden.

DANNEBERG u. Mitarbeiter führen in Groß-Enzersdorf derzeit ebenfalls Feldversuche zur Ergänzung der Topfversuche zum Komplex Stroh-Klärschlammdüngung durch, über die im Rahmen dieses Symposions gesondert berichtet wird.

Im Zusammenhang mit der geplanten Verwertung von Klärschlamm des Abwasserverbandes Purgstall/Erlauf untersucht die Bundesanstalt für Kulturtechnik und Bodenwasserhaushalt in Petzenkirchen die Anwendung von Naßschlamm und von Schlammkuchen aus einer Kammerfilterpresse auf den Braunerden, Parabraunerden und Pseudogleyen in der Umgebung von Purgstall und Scheibbs. Neben Nährstoff- und Schwermetalluntersuchungen soll die Wirkung des Schlammkuchens zur eventuellen Bodenverbesserung dichter pseudovergleyter Böden geprüft werden.

2.2 BEISPIELE FÜR EINE LANDWIRTSCHAFTLICHE VERWERTUNG VON KLÄRSCHLAMM

Auf die Verwertung des Klärschlammes des Abwasserverbandes Pulkautal im Burgenland darf hier kurz hingewiesen werden. STALZER wird an anderer Stelle darüber ausführlich berichten.

Ein sehr interessanter Weg zur Bewältigung des Schlammproblemes wird im Bundesland Oberösterreich beschritten. MAYR vom Amt d.O.Ö.-Landesregierung, Abt. Wasserbau, berichtet über das sog. Modell Oberösterreich, das zur Erzielung einer vertrauensvollen Zusammenarbeit zwischen Landwirten und Gemeinden hinsichtlich einer Verwertung von Klärschlämmen von Fachleuten der O.Ö.-Landeslandwirtschaftskammer, der Landwirtschaftlich-chemischen Bundesversuchsanstalt Linz und dem Amt der O.Ö.Landesregierung 1976 entwickelt wurde. Es soll einen schadlosen, praxisgerechten Einsatz von Klärschlamm in der Landwirtschaft gewährleisten. Dazu hat sich das Modell, welches die folgenden Punkte umfaßt, bisher ausgezeichnet bewährt:

Erstellung von Ausbringungsrichtlinien mit Begrenzung der Schlammmenge und der Schwermetallgehalte (in Anlehnung an deutsche und schweizerische Richtlinien).
Einteilung der Klärschlämme auf Grund ihres Schwermetallgehaltes in geeignet, bedingt geeignet, nicht geeignet.
Erstellung eines zeitlich begrenzten Merkblattes über den "praxisgerechten Einsatz von Klärschlamm", in welches die zulässigen Ausbringungsmengen und die Nährstoffgehalte auf Grund der Analysenwerte eingetragen sind.

Die Klärschlammproben werden von Beamten der Anlagenbetreuungsstelle der O.Ö.-Landesregierung entnommen und von der Landwirtschaftlich-chemischen Bundesanstalt Linz untersucht. Die O.Ö.-Landeslandwirtschaftskammer führt mit dem Amt der O.Ö.-Landesregierung und der Landwirtschaftlich-chemischen Bundesversuchsanstalt Informations- und Beratungsveranstaltungen durch (16)

Das Merkblatt enthält neben den maximalen Schlammengen und den Gesamtgehalten an N, P_2O_5, K_2O und CaO auch Hinweise über die Vorteile und notwendigen Einschränkungen der Klärschlammverwertung. Analysenwerte hinsichtlich der Schadstoffgehalte der Klärschlämme liegen beim jeweiligen Gemeindeamt auf. Den Landwirten wird auch geraten, sich nach mehrmaliger Schlammanwendung an der Bodenuntersuchungsaktion der Landwirtschaftskammer zu beteiligen.

3. ZUKÜNFTIGES ARBEITSPROGRAMM

Für einige Standorte v.a. in den Ackerbaugebieten liegen in Österreich schon Versuchsergebnisse und praktische Erfahrungen vor. Im Hinblick auf die unterschiedlichen Standortsverhältnisse in den einzelnen Ländern bleibt jedoch noch einiges zu tun, wobei der Nährstoffwirkung der Klärschlämme etwas weniger Bedeutung zukommt als der Erforschung ökologisch tragbarer Grenzwerte bei ihrer Anwendung.

Im Forschungskonzept "Recyclingforschung in Österreich" wurden, von der Ist-Analyse ausgehend, folgende Themen zur Lösung der Recyclingprobleme in der Land- und Forstwirtschaft, bezogen auf Klärschlamm, als wichtig und vordringlich erachtet:

Untersuchungen über gefügeverbessernde Wirkungen und Veränderungen des Humushaushaltes sowie Qualitätsanforderungen an einen Schlamm hinsichtlich einer langjährigen Düngernutzung,
Untersuchungen über erforderliche Einsatzbeschränkungen von Klärschlamm in landwirtschaftlich genutzten Schongebieten, auf wasserwirtschaftlichen Vorbehaltsflächen für künftige Grundwassernutzungen sowie im Einzugsbereich stehender Gewässer mit besonderer Berücksichtigung des Komplexes Schwermetalle und bakteriologischer Fragen,
Untersuchungen hygienischer Parameter wie pathogener Keime, tierischer Schädlinge, chlorierter Kohlenwasserstoffe etc. (4).

Unter Berücksichtigung dieser Forschungsschwerpunkte und der ökologischen Aspekte im land- und forstwirtschaftlichen Bereich wurde der Klärschlammverwertung und allen damit zusammenhängenden Fragen die erste Prioritätsstufe zuerkannt.

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LANDWIRTSCHAFTLICHE KLAERSCHLAMMVERWERTUNG AM BEISPIEL DES ABWASSERVERBANDES WULKATAL IM BURGENLAND

W. STALZER
Amt der Bgld. Landesregierung, Abt. XIII/3-Gewässeraufsicht

Zusammenfassung

Die Kläranlage des Abwasserverbandes Wulkatal wurde 1972 für 50 000 EGW Kommunalanteil und 85.000 EGW Industrieanteil einer Konservenfabrik mit gleichzeitiger aerober Schlammstabilisierung ausgelegt. Durch Belastungsverschiebungen im Winterhalbjahr war auch der Anschluss einer Zuckerfabrik mit 150 000 EGW möglich. Während der Zuckerkampagne wird der nicht stabilisierte Ueberschussschlamm gemeinsam mit dem Erdschlamm der Zuckerfabrik auf Stapelteichen abgelagert. Zufolge der Lage im Einzugsgebiet des Neusiedlersees muss eine Phosphorelimination mittels Simultanfällung (Einsatz von $Fe^{II}SO_4 \times 7H_2O$) betrieben werden.
Der Schlammanfall lag 1979 bei 1.120 t ÜS, davon wurden während der Zuckerkampagne 530 t auf den Stapelteichen gelagert.
Der ausserhalb der Kampagne anfallende stabilisierte Ueberschussschlamm (590 t pro Jahr) wird grösstenteils als Flüssigschlamm (7 % TS) landwirtschaftlich verwertet. Der Schlamm, der bezogen auf Trockensubstanz im Mittel einen organischen Anteil von 46,4 %, Gesamt N-Anteil von 5,2 %, Gesamt P_2O_5-Anteil von 4,1 % und Gesamt K_2O-Anteil von 0,7 % aufweist, wird von den Landwirten in einer durchschnittlichen jährlichen Gabe von 80 m^3/ha aufgebracht. Beschlammt werden vor allem Zückerrüben, Mais, Getreide und Weingärten. Der Schadstoffgehalt (Schwermetalle) liegt weit unter den Toleranzgrenzen und dürte vor allem durch die Verunreinigung des Fällmittels bedingt sein.

Summary

The sewage plant of the association "Wulkatal"was built in 1972 for 50 000 PE as share of the community and for 85 000 PE as industrial share of a fruit and vegetable canning plant with an aerobic digestion of sludge at the same time. Because of shiftings in the loads during the winter-half-year it was possible also to connect a beet-sugar factory with 150 000 PE to the sewage plant. During the processing season of the sugar-beets the not digested waste sludge was deposited on storage ponds, together with the soil sludge of the beet sugar factory (waste sludge with about 2 % dry matter). Because of its location in the basin of the Neusiedler See, a phosphorus dissipation by simultaneous precipitation ($Fe^{II}SO_4$) is necessary. The annual sewage amount of 4,3 mio m^3 resulted in 1 382 tons of BSB_5. The amount of waste sludge was 1 120 tons; during the processing season of the sugar beets 530 tons of waste sludge were deposited on 2 storage ponds that were left to dry after 5 years application. The deposited soil is given to the agriculture.
The digested waste sludge (590 tons/a) that occurs out of the processing season, is mostly used as wet sludge (7% dry matter) by agriculture.
The sludge with contents of 46,4 % organic matter, 5,2 % total nitrogen, 4,1 % P_2O_5 and 0,7 % K_2O is used by the farmers by means of liquid manure tankers with an annual dose of 80 m^3/ha. They are spread on sugar-beets, maize, corn and vineyards that are treated with waste sludge; if the farmer uses his own transportation machines, he gets a compensation of 4.-AS/m^3 for the fuel.

1. Einführung

Der Abwasserverband Wulkatal umfaßt elf Gemeinden im Wulka-, Hirmerbach- und Nodbachtal sowie eine Konservenfabrik (28.000 t Jahresproduktion) und eine Zuckerfabrik (300.000 t Rübenverarbeitung). Die Verbandskläranlage wurde 1972 für künftig 50.000 EGW Kommunalanteil und 85.000 EGW Industrieanteil der Konservenfabrik mit gleichzeitiger aerober Schlammstabilisierung (Raumbelastung B_R = 0,3 kg/m³d) ausgelegt. Durch die Möglichkeit der externen Schlammbehandlung während der Zuckerkampagne und Kapazitätserweiterung durch Übergang auf Vollreinigung (Raumbelastung B_R = 1,0 kg/m³d) beträgt in der Zuckerkampagne die Bemessungsauslegung 250.000 EGW (Anteil Zuckerfabrik 150.000 EGW).

Zufolge der Lage im Einzugsgebiet des Neusiedler Sees muß eine Phosphorelimination mittels Simultanfällung (Einsatz von techn. reinem Eisensulfat als Fällmittel) betrieben werden. Die Kläranlage ging im Herbst 1977 in Betrieb. Der Anschluß der Zuckerfabrik erfolgte vor der Kampagne 79/80.

2. Schlammanfall

Im Betriebsjahr Mai 1979 bis April 1980 wurde die Anlage mit 4,3 Mio. m³ Abwasser und einer BSB_5-Fracht von 1.382 t belastet. Der Überschußschlammanfall betrug 1.120 t FS.

Davon entfielen 530 t auf nicht stabilisierten Überschußschlamm während der Zuckerkampagne. Dieser Schlamm wurde gemeinsam mit dem Erdschlamm der Zuckerfabrik auf deren Stapelteichen abgelagert. Der Klärschlammanteil betrug im Schlammgemenge 2 % bezogen auf Trockensubstanz. Die Zuckerfabrik verfügt über zwei Erdschlammstapelteiche, die intermittierend betrieben werden. Über die Dauer von 5 Jahren wird jeweils ein Teich beschickt und der andere abtrocknen gelassen und geräumt. Das abgelagerte Erdmaterial wird an die Landwirtschaft und den Gartenbau abgegeben.

Außerhalb der Zuckerkampagne fielen 1979/80 insgesamt 590 t stabilisierter Überschußschlamm an. Dieser wurde größtenteils als Flüssigschlamm landwirtschaftlich verwertet.

Lediglich etwa 10 % werden über Bandfilterpressen entwässert und anschließend im Gartenbau zur Bodenverbesserung eingesetzt.

3. Schlamminhaltstoffe

Um eine gesicherte landwirtschaftliche Verwertung auf Dauer zu ermöglichen, läßt der Verband den Schlamm regelmäßig hinsichtlich der enthaltenen Dünge- und Bodenverbesserungsstoffe sowie eventueller Schadstoffe untersuchen. In Tabelle 1 ist ein Auszug der Bodenverbesserungsstoffe wieder gegeben:

Tabelle 1: Dünge- und Bodenverbesserungsstoffe

Nr.	Datum	TS %	oTS %	Ges. N %	NH_3 N %	org. N %	Ges. P_2O_5 %	Ges. K_2O %	CaO %	MgO %
1.	20.01.78	5,5	45,5	6,4	1,3	5,1	3,8	0,6	4,6	1,5
2.	11.08.78	10,0	30,0	2,8	1,1	1,7	3,7	0,5	7,0	2,7
3.	02.03.79	7,0	51,4	4,0	0,9	3,1	4,1	1,0	6,0	2,9
4.	11.10.79	6,1	55,9	6,9	0,8	6,1	4,9	0,6	4,6	1,6
5.	06.03.80	7,2	45,6	6,8	0,7	6,1	4,2	0,9	5,8	2,4
	Mittel	7,2	45,7	5,4	0,9	4,5	4,1	0,7	5,6	2,2

Wird Probe 2, die durch größere Erdeinschwemmungen seitens der Konservenfabrik -hoher mineralischer Anteil- verfälscht war, außer Betracht gelassen, so zeigen die Analysenergebnisse keine größeren Schwankungen und auch über größere Zeiträume eine relativ gleichmäßige Zusammensetzung. Der organische Anteil des stabilisierten Schlammes liegt zwischen 46 und 56 %, der Stickstoffgehalt zumeist zwischen 6,4 und 6,9 % und der Phosphorgehalt (P_2O_5) zwischen 4 und 5 %.

Dem gegenüber sind in Tabelle 2 die Metallanalysen aufgegliedert.

Tabelle 2: Metallgehalt

Nr.	Datum	Cu ppm	Mn ppm	Fe ppm	Zn ppm	Co ppm	Mo ppm	Pb ppm	Cd ppm	Cr ppm	Ni ppm	AS ppm
1.	20.01.78	76	885	45455	945	236	2,5	62	1,6	71	35	4,7
2.	11.08.78	76	850	37800	980	18	1,6	95	2,0	90	90	4,4
3.	02.03.79	99	657	53943	1143	8	0,4	14	2,1	39	38	12,4
4.	11.10.79	104	757	64688	987	9	2,1	79	3,3	41	76	13,2
5.	06.03.80	74	806	25000	625	8	0,5	12	1,3	27	40	11,5

Zur Interpretation der Werte ist festzuhalten, daß Probe 1 hinsichtlich des Kobaltgehaltes durch die vor Inbetriebnahme (Sept.77) abgeführten Sauerstoffzufuhrversuche, bei denen Kobaltchlorid als Katalysator zugegeben wurde, beeinträchtigt ist. Probe 5 dagegen ist charakteristisch für den Metallgehalt ohne wesentliche Beeinflussung durch die Simultanfällung mittels Eisensulfat, da diese ab November 79 über die Dauer der Zuckerkampagne und die anschließende Restabarbeitung der Stapelteiche entfiel. Die Senkungen bei Zink, Blei und Chrom dürften somit auf Verunreinigungen des Eisensulfates zurückzuführen sein. Insgesamt kann jedoch festgestellt werden, daß die Analysenergebnisse weit unter den Toleranzgrenzen liegen und daß das durch die landwirtschaftliche Nutzung geprägte Einzugsgebiet nur geringe Schwermetallgehalte zur Folge hat.

4. Landwirtschaftliche Verwertung

Voraussetzungen

Die Bodennutzung im Einzugsgebiet erfolgt zu 37 % als Ackerland, 2,7 % als Weingärten und 7,8 % als Wiesen und Weiden. Bereits in der Planungsphase wurde daher primär eine lw. Verwertung angestrebt. Nach Inbetriebnahme der Kläranlage wurden gemeinsam mit Vertretern der Landwirtschaft Informationen beim NIERSVERBAND als klassisches Beispiel für die Flüssigschlammverwertung eingeholt. In abgewandelter und auf die kleineren Verhältnisse angepaßter Form übernahm der Wulkaverband in der Folge die Organisation zur Verwertung. Voraussetzungen bildeten:

Persönliche Information und Aufklärung der Landwirte
Bereitstellung von Transportgefäßen
Durchführung von Bodenuntersuchungen
bei Klärschlammabnahmeerklärung
Anlegung von Versuchsfeldern mit Langzeitkontrolle
Haftungsübernahme seitens des Verbandes
bei Flächen- und Beschlammungsregistrierung
Laufende Qualitätskontrollen durch entsprechende
Institute
Abgeltung des Investitionsaufwandes bei
Fremdtransportgeräten

Die potentielle ganzjährige Flüssigschlammausbringung war zudem durch die gegebene Fruchtfolge (Mais - Wintergerste od. Winterweizen - Sommergerste - Zuckerrübe - und seltener Hackfruchtanbau) sowie die Weingärten und Wiesenflächen gegeben.

Durchführung

Nach systematischer Anwendungserweiterung hat sich gegenwärtig folgender Ausbringungszyklus eingestellt:

Tabelle 3: Jahreszeitliche Ausbringung und Kulturgattung

	Jän.	Feb.	März	Apr.	Mai	Juni	Juli
Mais			xxxxxx	xxxxxxx	xxxxxx	xxxxxxxx	xxxxxxx
Getreide	xxxxxxx	xxxxxxx	xxxxxx				
Zuckerrübe	xxxxxxx	xxxxxxx	xxxxxx				
Wein				xxxxxxx	xxxxxx	xxxxxxxx	xxxx
Wiese						xxxxxxxx	xxxxxxx

	Aug.	Sept.	Okt.	Nov.	Dez.
Mais					
Getreide	xxxxxxxx	xxxxxxxx	xxxxxxx	xxxxxxx	xxxxxx
Zuckerrübe	xxxxxxxx	xxxxxxxx	xxxxxxx	xxxxxxx	xxxxxx
Wein					
Wiese					

Die Beschlammungsangaben schwanken je nach Bodenkennwerten und Kulturgattungen in nachstehenden Grenzen:

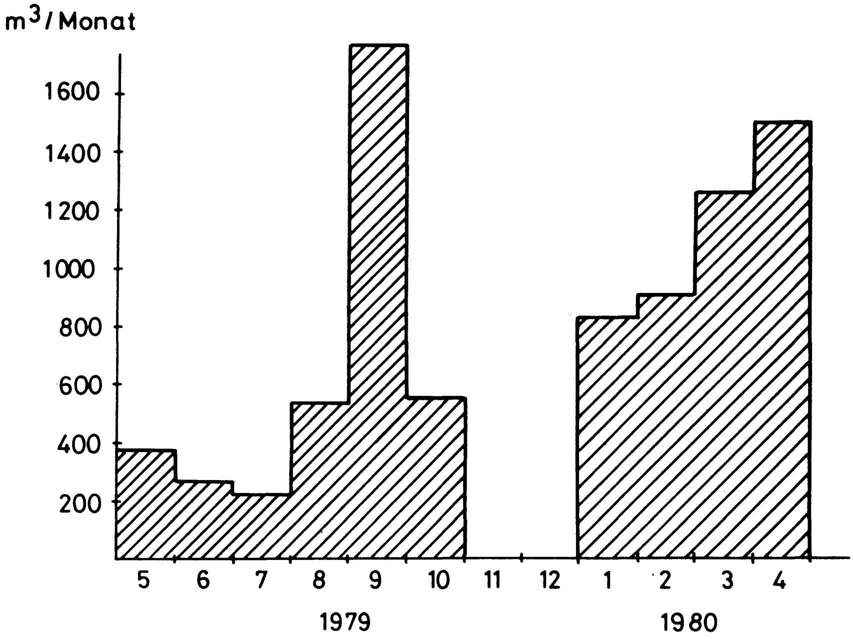
Mais	100 m^3 pro Jahr
Getreide	60 - 80 m^3 pro Jahr
Zuckerrübe	60 - 80 m^3 pro Jahr
Weinbau	bis 100 m^3 pro Jahr
Wiese	40 - 60 m^3 pro Jahr

Der Stickstoff- und Phosphorbedarf kann damit abgedeckt werden. Bei Kali sind Mineralzusatzdüngungen erforderlich. Die Abgabemengen sind auf Abb. 1 dargestellt.
Die Spitzenabgaben im September sind durch hohe Bedarfszahlen seitens des Getreideanbaues begründet. Im November und Dezember wurde der Schlamm zur Gänze in die Stapelteiche der Zuckerfabrik gefördert.
Transport und Ausbringung erfolgt mittels Gülle- und Jauchefässern. In Verwendung stehen 4 m^3, 6 m^3, 8 m^3 und eine 13 m^3 Einheit. Neben der Normalverteilung über Auslaufdüsen weist der 13 m^3 Behälter eine Weitwurfdüse mit 50 m Wurfweite auf. Der Einsatz dieser Weitwurfdüse erfolgt jedoch sehr selten, da eine exakte Flächenabgrenzung sowie gleichmäßige Beschlammung kaum möglich ist.
Die maximalen Transportentfernungen liegen bei 12 km, wirtschaftlich gut tragbar sind in Abstimmung auf die Transportbehälter Distanzen bis 10 km.
Bei Füllzeiten von fünf Minuten und Entleerungszeiten von 8 bis 15 Minuten (je nach Faßinhalt) konnten bisher 6 bis

10 Touren pro Arbeitstag (9 Stunden) registriert werden. Die Fahrgeschwindigkeiten betragen etwa 20 bis 30 km/h auf gut befestigten Zubringerstraßen und 8 bis 10 km/h bei der Aufbringung. Der Verband stellt ein 4 m^3 Jauchefaß zur unentgeltlichen Verfügung. Transport und Ausbringung erfolgen durch den Landwirt. Bei Verzicht auf das Leihfaß werden vom Verband S 4.--/m^3 als Investitionsentschädigung dem Abnehmer vergütet. Gegenwärtig ergibt sich für den Großabnehmer (13 m^3-Faß) etwa folgender Kostenaufwand:

Abschreibung Traktor + Faß	S 1.000.-- S/d
Reparaturen u. Betriebsmittel	S 1.400.-- S/d
Arbeitszeit	S 1.000.-- S/d
Gesamt	S 3,400.-- S/d

Dem steht ein Mineraldüngerwert von ca. S 70.-- pro m^3 Naßschlamm entgegen. Je nach Faßgröße und damit spezifischen Kostenaufwand müssen pro Arbeitstag 35 bis 50 m^3 Naßschlamm zur Kostendeckung ausgebracht werden.
Zufolge des Reinigungsverfahrens mit seinen großen Speicherkapazitäten im System sind bisher nur selten Engpässe aufgetreten. Die Ausbringungsart mittels Jauchefässern schränkt jedoch die Anwendbarkeit ein. Insbesondere in den Wechselperioden Frost - Warmwetter sowie nach stärkeren Niederschlägen ist ein Befahren der Äcker und Wiesen nicht möglich. Um hier künftig mehr Dispositionsraum zu erhalten sowie um eine Entlastung der Landwirtschaft bei gesteigerten Abgabekapazitäten zu erreichen wird eine Umstellung auf Großraumtransportfahrzeuge mit Ausbringung über Schnellkupplungsrohre und Güllewerfer in Erwägung gezogen. Die wirtschaftliche Grundlage hiefür könnte durch eine Zweckgemeinschaft mit den angrenzenden Abwasserverbänden (Neufelder-Seengebiet und Eisenstadt-Eisbachtal) erreicht werden.
Im bisherigen Beobachtungszeitraum wurden keine Schäden an den Kulturen registriert, die Ernteerträge waren zumindest in gleicher Größenordnung wie bei konventioneller guter Mineraldüngung.



LW - FLÜSSIGSCHLAMMABGABE

Abbildung 1

VALORISATION DES BOUES D'EPURATION SUR LE DEPARTEMENT DE VAUCLUSE

D. DAUDIN

Agence Nationale pour la Récupération et l'Elimination des Déchets
Chambre d'Agriculture de Vaucluse

Résumé :

L'Agence Nationale pour la Récupération et l'Elimination des Déchets a engagé plusieurs actions pilotes, avec les représentants du monde agricole, pour développer la valorisation en agriculture des déchets urbains industriels et agricoles. Monsieur Daudin qui a été chargé de cette action dans le département du Vaucluse présente son expérience. Après avoir souligné l'activité agricole orginale de ce département orienté vers la viticulture, l'arboriculture et le maraichage, il précise la qualité et les quantités de boues de station d'épuration produites par les industries et les communes. M. Daudin décrit alors les expérimentations qu'il a mises sur pied avec les utilisateurs de boues pour faire connaître le produit et développer sa valorisation en agriculture.

Summary :

The National Agency for Recovery and Disposal of Waste has undertaken, with the assistance of agricultural authorities, several experimental works on the urban industrial and agricultural wastes utilization in agriculture. In this paper, M. Daudin, in charge of an experiment in Vaucluse (southern France) presents his work. He describes the principal activities of this department : viticulture, arboriculture and market gardening, and gives data on the quantity and quality of urban and industrial sludges produced. Also presented are the methods used to encourage this process of waste treatment in agriculture.

L'A.N.R.E.D (Agence Nationale pour la Récupération et l'Elimination des Déchets) et la Chambre d'Agriculture de Vaucluse ont lancé conjointement une opération de valorisation des déchets urbains et industriels en agriculture sur le département.

L'utilisation agricole des boues issues du traitement des effluents d'origine urbaine et industrielle constitue l'un des "points clefs" de cette opération pour plusieurs raisons :

- Le milieu hydrogéologique départemental est particulièrement sensible aux risques de pollution que peut engendrer la mise en décharge de tels produits.
- Les cultures pratiquées dans la région exigent des sols bien pourvus en matière organique et des quantités importantes d'éléments fertilisants

I - LE CONTEXTE DEPARTEMENTAL

- L'épuration des eaux

L'équipement du département en matière d'épuration des effluents urbains est largement développé puisque l'on compte plus de 85 stations d'épuration, dont l'exploitation est souvent rendue difficile par l'étiage marqué des cours d'eau récepteurs.

La production annuelle des boues d'épuration urbaines est de l'ordre de 3.000 t de matière sèche, dont 40 % environ sont actuellement utilisées en agriculture.

Ces boues sont stabilisées par voie aérobie avant d'être déshydratées sur lits de séchage ou mécaniquement.

La plupart des stations importantes (capacité supérieure à 15.000 équivalents-habitant) traitent en fait essentiellement des effluents issus de l'activité agroalimentaire (conserveries de tomate, fabrication de plats cuisinés...).

- L'agriculture départementale

Le Vaucluse est l'un des départements les plus spécialisés dans les productions végétales : monocultures de longue durée (viticulture et arboriculture) ou cultures intensives (maraichage).

Ce type d'agriculture entraine une "fatigue du sol" l'utilisation des boues d'épuration en tant que source d'humus et d'éléments fertilisants constitue l'un des moyens d'y remédier.

II- LA DEMARCHE

Les différentes phases de la mise en oeuvre d'une telle opération de valorisation peuvent se résumer ainsi :

- un inventaire définissant les quantités disponibles, les lieux de production, les fluctuations saisonnières de cette production
- une phase d'analyse, qui en relation avec les résultats de la recherche, doit permettre de connaître la valeur agronomique des boues et les éléments indésirables pour une utilisation agricole qu'elles contiennent
- la mise en place d'essais dont les résultats doivent permettre de définir :
  - . les doses d'apport en fonction du type de sol et de culture
  - . les transformations préalables à faire subir éventuellement aux produits (compostage mixte par exemple)
  - . les modalités d'utilisation pour qu'au plan économique, le producteur de déchets et l'utilisateur trouvent leur intérêt (utilisation sous forme solide ou liquide ; prise en charge des frais de transport etc...).
- Une phase d'information auprès des producteurs de déchets et des utilisateurs potentiels et de leurs conseillers.
- La mise en place d'opérations de valorisation en "vrais grandeur" et un contrôle régulier de la qualité des boues.

III-QUELQUES RESULTATS

Les analyses des boues ont permis d'établir des choix:

- choix entre une utilisation sous forme solide ou liquide

- non utilisation de boues présentant par exemple des teneurs en métaux toxiques trop élevées

- choix du substrat carbone à incorporer aux boues pour effectuer un compostage mixte.

- Utilisation sous forme solide ou liquide

Sauf cas particulier, les agriculteurs ont tendance à opter pour une utilisation des boues solides pour plusieurs raisons :

- les conditions climatiques de la région permettent d'obtenir de très bons résultats de déshydratation des boues sur lits de séchage (teneur en matière sèche pouvant aller jusqu'à 80 % en période estivale).

Les teneurs en matière organique et éléments fertilisants sont donc beaucoup plus élevées dans les boues déshydratées que dans les boues liquides. Si une valorisation de boues solides est économiquement rentable dans un rayon de 50 km autour du lieu de production, cette distance se réduit à moins de 5 km pour l'utilisation de boues liquides.

- Nombreux sont les agriculteurs qui possèdent le matériel nécessaire à l'épandage de boues déshydratées (épandeurs à fumier).

- Les éléments indésirables :

Nous comprenons sous ce terme :

- les éléments non directement décelables pour l'utilisateur : germes pathogènes, métaux et éléments traces organiques.

- les éléments génants pour la mise en oeuvre de l'épandage pour la croissance des plantes (graisses, graines adventices, fortes teneurs en carbonates...).

- Les métaux

Le seul élément de référence dont on dispose actuellement est la norme AFNOR U 44-041. Les méthodes analytiques couramment utilisées déterminent les quantités totales de chaque élément sans différencier leur degrés ou liaison à la matière organique et ne permettent donc pas de connaître leur devenir après incorporation au sol.

De plus, la disponibilité des éléments métalliques pour les plantes dépend non seulement de facteurs relatifs à la boue (ph caractère complexant de la matière organique) mais également au sol (ph capacité d'échange, granulométrie...) et à la plante.

Cependant, si l'on compare les résultats d'analyse d'éléments métalliques effectués au niveau départemental avec ces résultats au niveau national, on constate que le problème n'est pas essentiel : les stations les plus importantes au département reçoivent surtout des eaux résiduaires d'industrie agroalimentaire donc peu susceptibles d'être contaminées par les métaux "lourds".

- Les germes pathogènes

Il est très difficile de quantifier les risques liés à la présence du germe pathogène en raison de la diversité des facteurs qui entrent en ligne de compte : filière de traitement des boues, types du sol et de culture.

Ces risques sont de plusieurs ordres :

- contamination des végétaux
- problèmes sanitaires liés à la manutention et au transport des boues
- contamination des eaux superficielles et souterraines. Les conditions d'utilisation doivent tenir compte de ces risques
- traitement d'hygiénisation. Le moyen le plus simple à mettre en oeuvre est un compostage préalable, en mélange avec des composts urbains frais, des marcs de raisins, des écorces broyées ou des pailles. Les essais entrepris dans ce sens donnent des résultats satisfaisants.
- enfouissement rapide après épandage
- interdiction d'épandre des boues sur des cultures de produits destinés à être consommés crus.

Cette dernière précaution limite considérablement les possibilités d'utilisation en culture maraichère, secteur d'activité prédominant sur le département de Vaucluse.

- Les autres éléments indésirables

Il s'agit essentiellement d'éléments dont la présence est liée au traitement d'effluents industriels, graisses, carbonates, graines diverses etc...

La solution à ces problèmes doit être trouvée au niveau de la fabrication : modifications des procédés, limitation des rejets, recyclage.

- Le compostage mixte

Le compostage des boues en mélange avec un substrat carboné présente les intérêts suivants :

- les besoins en matière organique des sols sont tels qu'il est impossible d'envisager un apport sous forme de boues uniquement sans risques de sur-fertilisation (azotée essentiellement)

- il est possible de rééquilibrer la carence généralisée des boues en potassium en pratiquant un compostage en mélange avec des marcs de raisin par exemple, produits bien pourvus en cet élément

- diminution des risques dus à la présence de germes pathogènes dans les boues.

Sur le département du Vaucluse, aucune installation de traitement des ordures ménagères par compostage n'est équipée pour recevoir des boues d'épuration en tête des traitements.

La solution adoptée pour les essais effectués a été dans tous les cas un compostage lent, à proximité des lieux d'épandage.

La mise en oeuvre en est simple :

- mise en place de couches successives de substrat carboné et des boues, dans des proportions préétablies en fonction des besoins particuliers des plantes et des sols

- suivis fréquents de quelques facteurs simples (T°, C/N, PH) permettent d'en suivre l'évolution.

- Les essais mis en place dans les divers secteurs d'activité agricole

Les effets recherchés par l'apport de boues d'épuration ainsi que les problèmes de mise en oeuvre sont différents selon les types de culture dans certains cas on recherche plutôt un apport de matière organique, dans d'autres cas, d'éléments fertilisants (azote et acide phosphorique).

Quelques questions fondamentales se posent au technicien sur le terrain :

- Quelle est la vitesse de minéralisation de l'azote organique des boues dans des conditions climatiques et édaphiques données

- Quelle quantité d'humus stable se formera dans le sol après un apport donné des boues d'épuration

- Dans un sol calcaire et en fonction des quantités des différentes formes du phosphore présentes dans les boues quelle proportion de cet élément risque de se trouver bloqué sous forme de phosphate tricalcique par exemple.

En l'absence de réponse précise à ces questions, l'utilisateur doit se contenter d'approximations, ce qui peut, dans certains cas, être à l'origine de résultats peu satisfaisants.

Dans le secteur des cultures pérennes (viticulture et arboriculture) l'apport de boues d'épuration à la plantation est intéressant pour l'azote organique, favorable à un bon départ des jeunes plants. L'appoint de matière organique et de potassium sera cependant insuffisant, c'est pourquoi un compostage mixte sera conseillé dans tous les cas.

L'effet d'un apport de boues sur une vigne ou un verger présente beaucoup moins d'intérêt si l'on compare les coûts de manutention et les résultats que l'on peut en attendre.

C'est certainement en culture maraichère de pleine terre que l'épandage de boues devrait présenter le plus d'intérêt : ces cultures sont très exigeantes en éléments fertilisants. Cependant, comme nous l'avons déjà signalé, la présence de germes pathogènes implique de grandes précautions d'utilisation.

D'autres essais ont été mis en place dans des secteurs plus particuliers : en pépinières ornementales, l'incorporation de boues dans des substrats de culture hors sol devrait permettre d'éviter les effets dépressifs liés à la présence de matériaux à rapport carbone/azote trop élevé (sciures ou écorces). Il semblerait qu'une proportion de 20 % de boues (en volume) donnerait les meilleurs résultats.

L'apport de boues peut également permettre de restituer leurs propriétés agronomiques à des sols pauvres ou remaniés (reboisement, réaménagement de carrières...).

CONCLUSION

Les 3000 tonnes de boues produites annuellement en Vaucluse représentent environ 80.000 unités d'azote, 110.000 unités d'acide phosphorique et 1.500 tonnes de matière organique, soit au coût actuel des unités fertilisantes, une valeur de 750.000 F qui sera doublée lorsque toutes les stations fonctionneront au maximum de leur charge.

Moyennant des faibles investissements, l'utilisation agricole des boues d'épuration constitue un moyen pour l'agriculteur de réduire sensiblement les charges croissantes liées à l'achat d'engrais.

Quelques questions fondamentales attendent cependant des réponses. Une collaboration entre les chercheurs et les techniciens de terrain devrait permettre d'y répondre et développer ainsi de telles actions.

RESEARCH AND QUALITY ASPECTS OF SLUDGE UTILISATION PRACTICES IN THE THAMES WATER AUTHORITY

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Summary

The size and scope of sludge disposal and utilisation practices in Thames Water are identified. The establishment and maintenance of a practical quality management policy for these activities is mentioned together with the elements which form the strategy for the determination of quality goals. Some recent research studies relating to metal uptake studies and potential pathogen problems, in relation to the agricultural utilisation of sludge, are described. The need to base environmental quality objectives on sound scientific information is stressed.

1. INTRODUCTION

Since 1974 Thames Water Authority has been responsible for providing water, river, sewerage and sewage disposal services to 12 million people living within a 5000 square mile area. The current total cost of discharging these functions is some £435 million. In an average year, Thames Water treats and disposes of some 300,000 tonnes of sewage sludge at an operating cost of around £18 million for the present financial year; when financing charges on capital are included, the total cost of sludge treatment and disposal exceed £22 million per annum. Although sludge constitutes only about 0.5% of the volume of sewage received at the Authority's 454 treatment works, its treatment and disposal accounts for some 25% of the total cost of sewage and sludge treatment and disposal operations.

2. SLUDGE TREATMENT AND DISPOSAL OPERATIONS

At present sludge is treated by a variety of methods and combinations of methods designed, in the main, to reduce its volume, render it relatively innocuous and to minimise its subsequent effects on public health and the environment. The diversity of sludge treatment methods are listed in Table I; the main methods of disposal in Thames are given in Table II.

3. THE QUALITY MANAGEMENT SYSTEM

The Authority maintains a quality management policy which provides that all sludge disposal and utilisation activities are carried out in accord with practices that minimise potential hazards to public health and the environment.

1. Sea Disposal

Disposal to sea is controlled by the Dumping at Sea Act, 1974. Under this arrangement the Ministry of Agriculture, Fisheries and Food (MAFF) issues an annual licence to the Authority defining the maximum quantity, maximum rate, dumping location and the composition of the sludge to be disposed. Continual monitoring of this operation is carried out and all data are reported annually to MAFF.

2. Utilisation on Agricultural Land

In the U.K. whilst there is general agreement that sludge should be utilised on agricultural land in accordance with good agricultural practice,

TABLE I. SLUDGE TREATMENT METHODS USED IN THAMES WATER LARGER WORKS 1977/78

Method	Quantity tonnes d.s. / annum
Anaerobic Digestion	213 200
Filter Press	25 800[1]
Vacuum Filter	8 900[2]
Raw to Land	4 400
Other	1 600
	242 900

1. Quantity includes 5 100 tonnes digested prior to pressing.
2. Quantity includes 5 900 tonnes digested prior to filtration.

TABLE II. SLUDGE DISPOSAL METHODS USED IN THAMES WATER 1977/78

Division	Population Equivalent Served	Final Disposal Method (tonnes d.s./annum			
		Agriculture	Sea	Incinerated	Tipped
Cotswold	260 000	4 700			3 100
Vales	520 000	11 000			1 000
Lambourn	1 240 000	18 200			2 400
Chiltern	1 140 000	23 800			
Southern	770 000	11 600		2 400	1 700
Lea	670 000	15 500			900
MPH	8 000 000	29 600	131 000		200
Total	12 600 000	114 400	131 000	2 400	8 300

a precise definition of such practice has yet to be agreed.

Guidance on the use of sewage sludges for agricultural purposes in the U.K. has been particularly influenced by two central government publications. In 1971 MAFF's Agricultural Development and Advisory Service published an information leaflet ADAS 10 (1). Limited experimental work provided guidance on the relative and additive phytotoxic effects of zinc, copper and nickel. Recommendations were given for the maximum permissible amounts of 'zinc equivalent' that could be added in sewage sludge to soils. ADAS 10 also recommended limits of addition for boron.

In 1977 additional recommendations were given for arsenic, cadmium, chromium, mercury, molybdenum, lead, selenium, nitrogen and pathogens in a Report by the Working Party on the Disposal of Sewage Sludge to Land (2).

At present few, if any, of the recommendations contained in these non-mandatory documents have been demonstrated to be fully justifiable by means of indisputable scientific evidence. Nevertheless, the Authority does pay regard to the spirit of these recommendations particularly in respect of metals causing human toxicity. Currently therefore Thames Water prefers to draw on its own experiences, and those of its predecessors, in regard to quality objectives for phytotoxic metals and nitrogen and for the determining the rate and periodicity of sludge applications. The development of realistic guidelines based on studies of metal levels in crops and associated sludge amended soils has been reported by Wood, King and Norris (3).

Recently the Authority introduced its own guidelines for minimising pathogen transmission in sludge to land operations. These are being used primarily to determine the process design of new sewage treatment works; where practicable they are also being introduced into existing works operations. A summary of these guidelines is given in Table III.

4. A STRATEGY FOR DETERMINING QUALITY OBJECTIVES

The continued disposal of sewage sludge to land and to sea must be largely dependent upon the containment of solution of potential problems associated with trace substances and potentially pathogenic micro-organisms. The Authority's approach to determining scientifically sound and operationally practical quality objectives can be summarised as follows:-

TABLE III SUITABILITY OF THAMES WATER SLUDGES FOR AGRICULTURAL USE.

Type of Sludge	Suitability
1. Digested Heat Dried	General use i.e. Amenity areas, pasture, crops for animal consumption, crops for human consumption uncooked, crops for human consumption cooked, seed potatoes and bulbs for export, forestry, gardens
2. Digested - lagooned for 2 years - dried and stacked for 12 months Raw - lime conditioned - lagooned for 2 years - dried and stacked for 12 months	General use but excluding seed potatoes and bulbs for export. Only dried sludge recommended for gardens
3. Digested Secondary - stabilised activated, humus	Similar to 2 but not recommended for gardens or for crops for human consumption uncooked unless 12 months interval before harvesting.
4. Raw Unstabilised activated	Similar to 3 but not for crops for human consumption uncooked.
5. Sludges containing substantial quantities of untreated wastes of animal origin e.g. abattoirs	Crops cooked before consumption or forestry only.
6. Sludges containing wastes from imported hides	Not suitable for use

Notes:

1. Where sludges are used on pasture up to 6 months depending on the type of sludge should elapse before grazing commences.

2. ALL sludges are considered unsuitable for playing field use.

1. <u>To support national and international research</u>

This area is becoming increasingly important particularly since so many of the problems relating to heavy metals persistent organic residues and pathogens have a common basis in many countries.

In Thames, close collaboration is maintained with the Water Research Centre, other regional water authorities and central government organisations when formulating the Authority's research programme; this helps to minimise unnecessary duplication of effort.

2. <u>To promote monitoring and control within operating divisions</u>

Of the nine operating divisions in Thames Water, seven have day-to-day responsibility for sludge treatment and disposal. A wealth of data and experience is therefore available to be drawn upon. The divisions deal with a wide range of sludge types and employ a variety of treatment processes and disposal operations. Currently whilst there is some variation in the degree of monitoring and control, all divisions are working to the same principles and control limits. Although it is not considered necessary at present to have a standard sludge monitoring system throughout the Authority, sampling and preparation of sludges and soils for analysis are being carried out in accordance with established procedures to ensure uniformity in the interpretation of results. It is such information that together with the results of research will provide the basis for verifying or modifying future quality goals.

The specification of operational practices to meet aesthetic quality objectives, like the prevention of odour nuisance, are often more forthcoming from those responsible for the daily practice of sludge treatment and disposal.

3. <u>To initiate in-house research</u>

Within Thames Water it has been clearly identified that the main objectives of research in this area can be confined to three main categories:-

(i) To defend and support existing operations i.e. to verify or modify existing/proposed quality objectives.

(ii) To reduce costs by introduction improvements into existing processes.

(iii) To examine and introduce new and more cost-effective processes.

Though all 3 categories of work have been contained within the Authority's programmes over the past few years, investigations have tended to concentrate on category (i) where studies have centred on yield response and metals uptake in crops and the potential problems related to the microbiological content of sludge. In more recent years the adoption of a more positive approach to sludge disposal by the Authority has been reflected in work associated with the extraction of potentially valuable constituents from sludge. The data generated will be used, together with that collected elsewhere, in assisting to establish a range of alternative disposal operations aimed at minimising net costs while maintaining security and flexibility of operation. Some of the more recent studies in regard to category (i) are described below.

5. RESEARCH IN THAMES WATER

1. Land utilisation of sludge - metals accumulation

Studies of various aspects of metals in sludges utilised for agricultural purposes have been carried out in collaboration with the Soil Science Department of Oxford University. The complex interactions between sludges, soils and crops have been examined by means of comprehensive field trials and laboratory experiments.

The field trials, consisting of 150, 6 m^2 plots were set up at a farm in Oxfordshire to examine the effect of sludge amendment of soil on crop production. Sludge application rates of up to 6 times those recommended in the MAFF ADAS-10 recommendations have been utilised and the study crops have included barley, lettuce and grass.

To enable the opposing effects of sludge mixed with soil, on crop yield, to be quantified, the field investigations have also included trials with:

(i) plots treated with inorganic nitrogen and phosphorus in concentrations equivalent to those contained in the sludges added to the main plots, and

(ii) plots treated with inorganic salts of the heavy metals in concentrations equivalent to the total corresponding metal contents of the sludges added to the main plots.

In supplementary studies several of the plots have been utilised to investigate the methodology involved in small plot trials. In particular the effects of cultivation on sludge movement between plots and on dispersion with plots have been studied; harvesting techniques have also been examined. The work has led to the tentative identification of design criteria for small scale plot investigations.

For the crops examined, tentative results from the main trials have indicated that sludge dressings up to 5.4 times the ADAS 10 recommended limit did not introduce any detectable heavy metal toxicity effects. However at this loading a direct yield reduction of barley and rye grass by the high nitrogen content was observed. Indirect yield reductions have also been shown to be due to the effects of "lodging" of crops. The effect of sludge dressing on the soil water holding capacity has been shown to be particularly beneficial for lettuce crops. So far no deleterious effects of germination of winter barley have been observed from the high sludge loadings. When the analysis of crop and soil samples has been completed the results should provide a suitable basis for modifying existing guideline recommendations.

Separate investigations have been concerned with a study of the decomposition of sludge in soil to determine whether trace metals contained in the sludge are liberated if complete decay of the sludge occurs. Tests with perfusion apparatus enabled the accelerated breakdown of sludge to be investigated. Studies carried out to date have indicated that it is unlikely that trace metals in sludge would be totally released into the soil solution and thus became available to plants. It would appear that the formation of new, biologically produced, organic matter is responsible partly at least for retention of metals. Other factors have been investigated using scanning electron microscopy; the results indicate that certain metals are concentrated in the iron oxide compounds in the sludge: whether this is accounted for by adsorption or by joint oxidation of metal sulphides originally present in the sludge has not yet been established.

A separate series of larger scale field trials, sponsored by the Department of the Environment, have also been set up on the same farm. The primary objective of this work has been to examine the effects of anaerobically digested sludge on crop yield and crop metal uptake, with particular reference to cadmium.

The investigations are being conducted on two sites in close proximity to each other but which have different soil characteristics. One site is covered with fine sandy loam deposits; the other is mainly clay. Soil type is an important factor in the regulation of crop metal uptake; studies on the two sites should therefore provide useful comparative information. On each site 180 rectangular plots, approximately 2 x 10 m^2 have been marked out. Following initial treatment of the plots with lime and fertilizers, randomly selected plots on each site were set aside to subsequently reflect the crop responses on unsludged soils. Sewage sludge was applied to the remaining plots to enable the effects of three sludge types at four different loadings to be investigated in duplicate crop trials.

To provide information on the distribution of the applied sludge in the soil following extensive cultivation of the plots, a comprehensive survey was undertaken to determine the resulting metal concentrations of the soils in differently dosed plots. The results of the survey have been compared with the calculated soil metal concentrations which would have been expected from the treatments, assuming uniform dispersion to have occurred.

In general the actual soil concentrations were found to be very close to the calculated values particularly in the case of the plots on the sandy loam site, indicating that the distribution of the sludge was fairly even. So far six crops have been sown and harvested on each site in duplicate trials; the crops were winter or spring wheat, rye grass, potatoes, lettuce, cabbage and red beet.

The yield of these crops has been determined and related to the quantites of sludge applied to the plots. Analysis of crops tissue has been undertaken to determine the concentrations of copper, nickel, zinc cadmium and lead present.

So far insufficient trials have been completed to comment in detail on the effects of sludge disposal. However, it appears that lettuce and beetroot tend to accumulate metals to a greater extent than does cabbage. In addition, the uptake of metals from the clay plots appears to be greater than that from the sandy loam and in general yields have improved with increasing sludge application.

A further study was recently initiated to examine practical and economical methods which might be used to return an Authority farm, which had a long history of sewage and sewage sludge applications, to a more acceptable condition. A soil profile survey carried out in conjunction with ADAS, confirmed the view that metals retention was largely restricted to the top-soil.

Four basic methods for rehabilitating the soil have been considered:-

(i) Physical removal of the contaminated layer. This was achieved by the use of a box grader of the type used in motorway construction. This method has the advantage that the contamination is permanently removed: the principal disadvantage would be cost, particularly where a suitable outlet for the removed material is not conveniently located.

(ii) Burying of the contaminated layer below root depth where it would not be subsequently brought to the surface by normal ploughing. Soil inversion does however require the use of specialised equipment. This method has yet to be evaluated.

(iii) Overtipping with uncontaminated top-soil.

(iv) Dispersion by deep ploughing. This method might be of use for reinstating soils which have metal concentrations marginally in excess of acceptable levels.

When all treatments have been successfully completed it is planned to carry out extensive crop trials to assess the relative merits of each method.

2. Land utilisation of sludge - potential microbiological hazards

The risk of directly or indirectly causing infectious disease in man and cattle by the utilisation of sludge on land has been the subject of a number of investigations carried out in the U.K. From these studies it has been generally concluded that the health risk to humans and animals alike from bacterial pathogens, is very low.

Work carried out by the Authority, in collaboration with the Agricultural Research Council's Institute for Research on Animal Diseases, has provided sufficient data to enable relationships to be established between the occurence of bacterial pathogens in sludges subject to different treatment processes and the relative risks to grazing animals.

The extent to which such organisms, particularly Salmonella, occur in sludges was examined, both qualitatively and quantitatively for ranges of sludge types.

All treatment methods used produced a marked reduction in salmonella numbers. Lime treatment of raw sludge and lagoon storage of digested sludge for periods in excess of two years resulted in the virtual elimination of salmonella.

From these data and other studies on the infectivity of animals, it was concluded that infection risks to grazing animals were unlikely where pasture is not grazed for a sensible period after sludge has been spread. Details of this work have been reported by Jones et al (4).

Investigation into the type and numbers of potentially harmful viruses in sludges is currently being carried out by Thames Water in collaboration with the University of Surrey. The objectives of this work are to study the distribution and fate of viruses in sewage and sludge treatment processes to develop methods for their enumeration and to assess their significance in relation to health risk. Work so far has been confined to a major literature review and the development of appropriate techniques for the isolation, enumeration and identification of viruses.

Recently a suitable method was tentatively identified. It involves concentration of the virus particles by elution with beef extract followed by removal of suspended matter by centrifugation. The protein-virus isolate is separated by acid precipitation and subsequently taken up into solution. Viruses have been cultured from the solution on the Buffaloe Green Monkey kidney cell line, using a suspended cell plaque technique. Viruses have subsequently been identified by neutralisation with specific antisera.

So far insufficient numbers of samples of different sludges have been examined to draw any firm conclusions on the effects that different types of sludge treatment processes have on viral populations. However, tentative results have indicated that the ranges of virus concentrations in different sludges can be large. The greatest numbers of viruses have been found in raw sludge where a range of 0-60,000 pfu/l has been observed. Identification of viruses present in sludge has been restricted to the polio strains and Coxsackie B groups. Viruses have been shown to be absent from large numbers of samples and therefore a study of the factors affecting virus survival has been undertaken.

Further details of progress on these studies together with information on other projects contained within the Authority's research and development programme, such as the extraction of potentially useful materials from sewage sludges, are regularly reported (5).

6. CONCLUSIONS

The primary function of an organisation like Thames Water, in relation to sludge treatment and disposal, is to provide a service which protects public health and the environment. It would however be unrealistic in this day and age to suppose that this service can be provided for all time regardless of cost. It will therefore become increasingly important to pay closer attention to the mechanisms by which environmental constraints are defined. In Thames only the most conclusive information arising from research and operating experiences will be used to introduce changes in existing operating practices. Only with such information will it be possible to strike a balance between the provision of low cost, reliable and robust methods of disposal and utilisation and the occasional illogical demands for extreme environmental protection.

7. ACKNOWLEDGEMENTS

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HERSTELLUNG VON KLÄRSCHLAMM-SCHWARZTORF-GRANULATEN UND PRÜFUNG IHRER EIGNUNG ALS DÜNGEMITTEL

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Kurzfassung

Streufähige Trockengranulate aus Kalk-konditioniertem Klärschlamm und Mischgranulate aus Klärschlamm + Schwarztorf im Verhältnis 1:1 und 3:1 wurden im Labormaßstab hergestellt, auf ihre physikalischen Eigenschaften, in Gefäßversuchen mit Gerste, Raps und Gras auf ihre Düngewirkung sowie durch Impfung mit Salmonellen vor der Trocknung auf ihren hygienischen Zustand untersucht. Die Gefäßversuche ergaben, daß mit nicht-granuliertem Klärschlamm bessere Erträge erzielt werden konnten als mit granuliertem und mit Mischgranulaten. Die Mischgranulate waren bei Erhitzung auf 65° C nach 6 min frei von Salmonellen.
Die Anwendung von Klärschlamm-Schwarztorf-Granulaten als Düngemittel bringt keine ersichtlichen Vorteile gegenüber der landwirtschaftlichen Nutzung von ungranulierten reinen Klärschlämmen.

Summary

Dry granules that can be easily spread in the field were produced at laboratory scale from sewage sludge conditioned with lime and from 1:1 and 3:1 mixtures of sewage sludge and dark peat. Their physical properties were investigated and pot tests were made to investigate the fertilizer effect using barley, rape and grass. Before drying the granules, their hygienic condition was tested by inoculation with Salmonella. The pot tests yielded the result that non-granular sewage sludge gave higher yields than granular sewage sludge and mixed granular material. The Salmonella contained in the granules of sewage sludge were killed after heating 6 min at 65° C.
The use of granules of sewage sludge and dark peat as fertilizer offers no visible advantage in comparison with the use of non-granular sewage sludge.

Zur Entwicklung eines lager-, transport- und streufähigen, aber auch hygienisch unbedenklichen Trockengranulats für Bodenverbesserungs- und Düngezwecke sind die Möglichkeiten der Granulierung und Trocknung eines mit $Ca(OH)_2$ und $FeCl_3$ gefällten, mit der Filterbandpresse abgepressten Rohschlamms und eines ebenso behandelten Faulschlamms sowie Polymer-konditionierter, mit Siebbandpresse entwässerter Klärschlamm untersucht worden.

Bei der Granulierung des Kalk-konditionierten Klärschlammkuchens wurden nach anschließender Trocknung auf 30 % Wassergehalt feste, streufähige und geruchsfreie Granulate erhalten, die allerdings durch die hohen pH-Werte (11) infolge des hohen $Ca(OH)_2$-Gehaltes den Einsatz als Düngemittel nur bedingt gestatten. Der pH-Wert des Trockengranulats konnte herabgesetzt werden, indem die genannten Presskuchen zusammen mit Schwarztorf zerkleinert, vermischt, granuliert und getrocknet wurden. Beim Mischungsverhältnis Klärschlamm : Schwarztorf = 3 : 1 (jeweils Trockenmasse) wurden pH-Werte um 9,5, beim Mischungsverhältnis 1 : 1 für Düngezwecke annehmbare pH-Werte von 7-8 für das Trockengranulat erhalten.

Die Granulierung selbst erfolgte mit Humintorf mit 51 % Wassergehalt, wobei während des Granuliervorgangs geringe Wassermengen zugesprüht werden mußten. Dabei resultierten Rohgranulate mit 60 bis 63 % Wassergehalt, die bei 120° C unter beachtlicher Schrumpfung auf 30 % Wassergehalt getrocknet wurden. Bei Übertragung auf großtechnische Verhältnisse werden für die Trocknung pro kg Mischgranulat (mit 30 % Wassergehalt) 700 kcal Wärmeenergie benötigt. Sowohl die reinen Klärschlamm- als auch die Mischgranulate besitzen eine hohe Festigkeit, die allen Anforderungen in der Praxis entsprechen dürfte.

Polymer-konditionierte, mit Siebbandpresse oder Zentrifuge entwässerte Klärschlämme, die den Nachteil des hohen pH-Wertes nicht besitzen (pH um 7), ließen sich trotz höheren Wassergehaltes 80 bis 86 %) bei Zusatz von trockenem Schwarztorf-Pulver im Verhältnis 1 : 1 gut granulieren.

Bei Versuchen in einer Pilotanlage (Trockentrommel vom Eisenwerk Alfeld) entmischten sich die aus Schwarztorf und Kalk-konditioniertem Klärschlamm hergestellten Granulate während der Trocknung in der Trommel. Dagegen ließen sich aus Kalk-konditioniertem Klärschlamm ohne Zusatz und Polymer-konditioniertem Klärschlamm mit Torfzusatz feste Granulate herstellen.

Mit den genannten Granulatarten und ungranulierten Klärschlämmen wurden vom Bodentechnologischen Institut des NLfB in Bremen Gefäßversuche in Aufwandmengen, die 20 und 100 t TM/ha entsprechen unter Verwendung unterschiedlicher Bodenarten durchgeführt. Zur Prüfung der Nährstoffwirkung wurden durch Zusatz von Salzen die Düngungsvarianten "Volldüngung" und "Teildüngung" eingefügt.

In der ersten Vegetationsperiode zeigten die Gerstepflanzen bei allen Gefäßversuchen ein gesundes Wuchsbild. Nur unwesentliche Wachstumsunterschiede zeigte die Gerste, die mit granulierten und ungranulierten, Kalk-konditionierten Klärschlämmen behandelt worden ist. Deutlich blieb das Wachstum der Gerste besonders bei niedrigen Düngegaben zurück, die mit ungranuliertem Polymerfaulschlamm behandelt worden ist.

Im Gegensatz zum Wachstum sind die Erträge sowohl bei Gerste als auch bei Grünraps durch die Klärschlammgaben deutlich differenzierter. Alle Granulate führten bei der Gerste und noch deutlicher bei Grünraps zu niedrigeren Erträgen, als bei der Anwendung von nicht granulierten Klärschlämmen. Mit zunehmender Torfzugabe vermindern sich die Erträge an Gerstekorn und besonders an Grünraps sowie an Gras auch in der dritten Kulturfolge. Eine Langzeitwirkung der verschiedenen Granulate hinsichtlich der Nährstoffabgabe gegenüber nicht granuliertem Klärschlamm konnte nicht nachgewiesen werden.

Hygienische Untersuchungen wurden am Institut für Tiermedizin und Tierhygiene mit Tierklinik der Universität Hohenheim durchgeführt. Als Testkeim wurde Salmonelle senftenberg bei Versuchen mit flüssigen und abgepreßten Klärschlämmen verwendet. Bei flüssigem Klärschlamm wurde festgestellt, daß die Abtötung der Salmonelle bei 60 bis 70° C etwa 6 min dauert.

Die Hygieneversuche sind weiter an Granulaten mit Kalk-konditioniertem reinen Klärschlamm sowie an Granulaten mit Torfzusatz 1:1 und 3:1 während der Herstellung der Granulate im Labor durchgeführt worden. Die Impfung mit Salmonellen erfolgte während des Mischvorganges. In dem Klärschlammgranulat ohne Torfzusatz waren 5-6 Std.

nach der Impfung auch ohne Temperatureinwirkung keine Salmonellen mehr nachzuweisen. Das im Klärschlamm enthaltene $Ca(OH)_2$ wirkte also entseuchend.

Die geimpften nicht erhitzten Mischgranulate 1:1 und 3:1 enthielten eine hohe Anzahl von Salmonellen, die aber nach 6 min Erhitzung bei 65^{o} C Granulattemperatur entseucht waren.

Die in der Pilotanlage hergestellten Mischgranulate aus Polymerkonditioniertem Klärschlamm und Schwarztorf erwiesen sich nach dem ersten Versuch als hygienisch nicht einwandfrei.

Zusammenfassend kann festgestellt werden, daß nach den bisher vorliegenden Untersuchungsergebnissen die Anwendung von Schwarztorf-Klärschlamm-Granulaten als Bodenverbesserungs- und Düngemittel keine eindeutigen Vorteile gegenüber der landwirtschaftlichen Nutzung von reinen Klärschlämmen erkennen läßt.

SESSION V - ENVIRONMENTAL EFFECTS OF SLUDGE

ACTIVITIES OF WORKING PARTY 5 "ENVIRONMENTAL EFFECTS OF SLUDGE"

INTRODUCTORY REMARKS

by

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Summary

The definition of environmental effects against our working party in the symposium announcement is based on that in the original formation of the concerted action project and our work has been slightly modified. We have not looked at constraints on pathogens because it has been generally agreed that it is more appropriate for Working Party 3 which has the expertise to consider that aspect.

Although it has been pointed out to us that we are not to make recommendations on guidelines we realise that the end product of our work will be the drafting and inclusion of criteria in codes of practice by others. We have therefore limited our work on the subject of standards in our list of activities to up-dating the comparison of guidelines presented at Cadarache and include a copy as an appendix to this paper.

We have concentrated on the harmful effects of heavy metals and the pollution of ground water. In considering these we have considered not just the direct and more immediate effects on agriculture but to the best of our ability the indirect effects on animals and on man.

1. INTRODUCTION

This paper summarises the work carried out by Working Party No 5 on the wide topic of environmental effects of sewage sludge. I should like to take this opportunity to thank all members of the working party for their valuable help and support.

2. MEETINGS

Since our last report at Cadarache in February 1979 we have held meetings in Bremen, Ghent and Haren (Netherlands). Opportunity has been taken to visit the laboratories and field trials at each location as an understanding of the work being carried out, facilities available and particular interests of each country is such an important part of our work. The meeting at Haren was coupled with a joint meeting with Working Party 4 (Valorization of Sludge in Agriculture) and a Seminar on Phosphorus in Sewage Sludge and Animal Waste Slurries. The first joint meeting of two Working Parties provided a unique opportunity to discuss matters of common interest.

At the time of writing it is proposed to hold a meeting prior to the Effluents from Livestocks Research Programmes Workshop on problems encountered with copper in Bordeaux in October 1980 so that we can make a contribution and benefit from the expertise available.

3. DETERMINATION OF EFFECTS OF SEWAGE SLUDGE

Applications of sewage sludge usually continue over a period of many years with rising soil concentrations. Research has the difficult task of predicting effects realistically so that appropriate variations can be made to the applications. Research can be based on field trials and/or pot trials. The difficulty is how to accelerate effects without deviating from practice so that the application of the results has to be qualified. It is usual to increase the application rates but the longer the time available and the greater the similarity to field conditions the closer and more accurate the predictions. Field trials however need considerable planning, are costly, and take a long time to produce conclusive results. Pot trials on the other hand are relatively quick and cheap but they are more remote from the practical situation and their results have to be carefully considered before they can be applied. Both have a role to play and many projects involve both types of investigation.

4. CROP TRIALS

We have reviewed over 50 crop trials and found that 45% of these were examining the uptake of heavy metals in soils and sludge. Some 48% involved field trials, 23% pot experiments and 24% laboratory studies. Many projects were examining both the beneficial and the harmful effects.

The size of plots used varied from $6m^2$ to $1,000m^2$ and included a wide range of soil types. The sludges used were mainly from municipal sewage works with a very wide variation in sludge composition. Studies included land with a history of sewage sludge treatment over many years, land with a single application of sludge and land with annual applications of sludge.

Most projects determine the heavy metal and nutrient value of sludge and soils, the range of metals studied varying considerably.

The crop species studied also varied widely, some examined a single crop whilst others examined many crops. Cereal crops feature strongly in Central Europe and beet, potatoes and lettuce are included in many projects.

We have prepared a check list of steps to be taken in the design of field trials and hope this will help others to avoid the many pitfalls.

5. DETERMINING THE UPTAKE OF CROPS

There is considerable information on the heavy metal content of soils and crops but forecasting the uptake that will follow from a particular sludge application is a different matter. Since availability to plants is largely dependent on solubility in the soil-sludge mixture this has been determined by using one or more of many extractants. The availability does, of course, vary widely with pH and most extractants forecast this. Unfortunately the results vary very widely depending on the extractant selected.

The relation between application of sludge to soil and the consequent effect on crops as a result of their uptake of heavy metals is not simple. Some parts of each metal become locked up in the soil and less readily available to plants. The solubility or availability of most metals increases with acidity; selenium and molybdenum are notable exceptions as their availability decreases with acidity.

The amount of each element that is immediately available is indicated by that that is soluble in an extractant but, as previously noted, there are variations in the amounts extracted with commonly used extractants and these cannot be related mathematically to each other. It was therefore proposed that a series of pot trials should be held in as many countries as possible so that the extractant that gave the best results ie those nearest to plant uptake in the widest range of soils should be determined and recommended for general use.

For some time we had been aware of the Food and Agriculture Organisation's European Co-operative Network on Trace Elements and we held a meeting with the leaders of the two networks relevant to our work, Professors Kick and Cottenie, to exchange information to our mutual benefit. As a result it is very pleasing to see that the sludge pot trials are being carried out on a joint basis at 13 sites this year and we are hopeful that the trials will be extended next year. The FAO had planned similar work and as a result of the liaison with Professor Kick we have a more effective joint project.

Raising the pH generally has the intial advantage that it locks the metals up in the soil but some of the metals that are locked up in the soil can be released as a result of changes in pH. Some metals such as cadmium and nickel vary far more with pH than others such as copper and lead. Organic matter increases fixation. "Total" metals indicate long term effects but warning of some short term effects is best determined from "available" metals. "Available" metals vary with time and "total" metals have a wider application and acceptance in the present state of knowledge. It is therefore advisable to consider both.

6. DETERMINATION OF MOBILITY OF HEAVY METALS IN SLUDGES BY PROGRESSIVE ACIDIFICATION

A proposal by Professor Cottenie and Dr Dhaese that the mobility of heavy metals should be determined by progressive acidification was considered. We thought that the proposal would be useful provided there was a means of determining the link between metals in soil and metals in plants. Since that could be determined by pot trials we agreed that the method merited detailed consideration and referred it back to Working Group 2 so that they could carry out ring tests. This proposal would determine a direct link between acidity of soil, sludge application and availability of metals and enable adjustments to be calculated.

7. GROUNDWATER STUDY

Dr Huylebroeck (Co-pilot, Belgium) has carried out a review of the groundwater studies being carried out by 21 laboratories.

Column percolation, lysimeters and field experiments are widely used in varying combinations. The parameters examined in soil, sludge and groundwater vary considerably as do the analytical methods. Consideration should be given to standardising soil analytical methods so that results can be compared with each other.

The review concludes with the following general conclusions:-

a. Column, lysimeter and field experiments conducted by the same laboratory give similar results.

b. Nitrate concentration in groundwater is increased by sludge application. The increase is comparable to that of a high dose of inorganic fertilizer.

c. Groundwater contamination by heavy metals has been found to a minor extent and depends on the metal, soil type and pH.

d. No bacteriological pollution of groundwater has been observed in these studies.

e. Phosphorus movement could lead under certain conditions to an increased phosphorus concentration in groundwater.

8. CADMIUM

Cadmium production has increased considerably during the 20th Century and it has been blamed for many human ailments. It has been argued that the input of cadmium from the application of sewage sludge to land can be an important factor in man's intake and that in exceptional circumstances the input can exceed that recommended by the World Health Organisation.

At the request of the Concerted Action Committee we prepared a paper setting out the uses of cadmium, its occurrence in sewage sludge, the input to land and the consequent uptake by crops for submission to the EEC Ecotoxicological Committee.

Obviously there is no problem with domestic sludges but there is some risk of high uptake where sludge with high cadmium content is applied to soil used for vegetable production. The problem is a long term one involving forecasting effects over the future normal life of man. It is, mainly, limited to sludge disposed from large cities to arable land but cadmium also has phytotoxic properties and it is probably this that limits growth and uptake. Possible interaction with other metals is an important aspect of uptake.

9. OTHER METALS

Probably the most important other metals are the phytotoxic group zinc, copper and nickel. Whilst zinc is the most important from the sludge disposal point of view since it is likely to be present in quantities that limit disposal, copper demands special attention.

Copper is essential in animal diets and a deficiency is likely to result in malnutrition. Deficiency may be aggravated by the presence of molybdenum which may lock up copper and sulphur is also a relevant factor. The problem is confined to a limited number of countries and then to limited areas. Copper deficiency can be rectified by injections. On the other hand excess copper can be toxic to sheep giving rise to a condition known as teart. Sheep may die with more than 10mg/kg copper in their diets.

Boron is both an essential micro-nutrient and phytotoxic; where it is present in excessive quantities plants sometimes grow but fail to mature. It is however soluble and can be applied from waste water if land is flooded as well as from sludge.

Chromium can affect growth of crops such as sugar beet. Discharges from tanneries may result in high concentrations. The soluble hexavalent form is unlikely to be present in significant quantities.

Lead, fluorine, arsenic, mercury and selenium have well known toxic effects and a sludge concentration limit seems more relevant than an application limit where there is a risk of ingestion.

The effects of metals are complicated by interaction and combined effects, the presence of one often affecting the action of another.

10. NUTRIENTS - NITROGEN, PHOSPHORUS AND POTASSIUM

The effects of nutrients is the responsibility of Working Party 4. It is however relevant to our work that a healthy plant receiving adequate nutrients is able to withstand toxic metals better than an under-nourished plant. This is a further example of interaction. Excessive applications of nitrogen and phosphorus can themselves, however, be harmful.

11. ORGANICS

There is increasing interest in the effects of organics and efforts are being made to curtail their input to the environment. Analytical methods are sometimes very difficult.

12. TYPES OF SLUDGE

Environmental effects vary with types of sludge. Apart from variations depending on input to a sewage treatment works the form and availability of metals depends on the treatment given to the sludge. Smell and appearance likewise depend on treatment. Treatment should be sufficient to produce a sludge that is satisfactory for the particular purpose.

13. ECONOMIC ASPECTS OF DISPOSAL

Following on from the last paragraph there is no point in spending more on sludge treatment than is necessary for a particular application. One of the main costs of disposal is the costs of transport. High rates of application are therefore more economic than low rates. Analyses are expensive when carried out on a large scale. Sludge application criteria should only be specified when they are genuinely required to protect man or some part of the environment. Such criteria should not be unduly restrictive yet be sufficient to provide an acceptable standard of protection. Complete removal of a particular metal is not only virtually impossible but it is extremely expensive. In some circumstances the applications limits should be based on longer intervals than a year as frequent small doses, apart from being uneconomic disrupt farming operations.

14. GUIDELINES

An updated version of the comparison of guidelines is attached as an appendix. The earlier edition issued at Cadarache in 1979 has been amended and should be destroyed. The wide variations in criteria confirm the need for our work to continue so that there is an agreed scientific basis for sludge disposal. Guidelines themselves will of course vary depending on the local priorities and land availability.

COMPARISON OF GUIDELINES FOR SEWAGE SLUDGE APPLICATION TO AGRICULTURAL LAND

		UNITED STATES (ENVIRONMENTAL PROTECTION AGENCY)			UNITED STATES (WISCONSIN)
Type of sludge acceptable for agricultural use.		Sludges must undergo processes to reduce pathogens (chemical, physical, biological or thermal treatment). Sludges with hospital wastes should be pasteurised, irradiated, composted, stored long-term, or pH raised to 12. Further treatment required if human food to be grown in 18 months. PCBs > 10 mg/kg for animal feed.			Raw should not be used. Root crops or crops to be consumed raw not to be grown within 1y. of application. Milk cows should not be grazed until 2 months after application, other animals 2 weeks.
Application recommendations		Avoid highly porous soils, direct contamination of crops, ingestion by animals and humans, and public nuisance.			At least 2 feet soil above impermeable layer or water table. At least: 1000 feet from public supply well; 500 feet from private supply well; 500 feet from nearest residence.
Maximum application		Crop demand and N in sludge limits Cd. addition 2 kg/ha. year (up to 1984). Cd. addition 1.25 kg/ha. year (1984-1986). Cd. addition 0.5 kg/ha. year (from 1987) and on land used to produce tobacco, leafy veg. and root crops for humans.			Crop N demand. Metal addition limited to 10% of soil CEC and Cd. 2.4 kg/ha. year
Metal additions		Cumulative addition kg/ha.			Cumulative addition kg/ha.
		Soil CEC (cationic exchange capacity) 0-5	5-15	15-	
	As				
	Cd	5*	10	20	24
	Co				
	Cr				
	Cu	125	250	500	364
To crops	Hg				
	Mn				
	Mo				
	Ni	50	100	200	182
	Pb	500	1000	2000	
	Se				
	Zn	250	500	1000	728
	B				
To pasture		above levels may be exceeded *also applies where soil pH is < 6.5			no differentiation
Application period		Not specified			Not specified
Soil pH		> 6.5 except where Cd concentrations are 2 mg/kg or less			> 6.5
Zinc Equivalent concept Zn: Cu: Ni.		Not used			1: 2: 4. ZnE additional limited to 10% of CEC Cd limit.

COMPARISON OF GUIDELINES FOR SEWAGE SLUDGE APPLICATION TO AGRICULTURAL LAND

		CANADA (ONTARIO)		UNITED KINGDOM (1980)		
Type of sludge acceptable for agricultural use.		Only digested or stabilised sludges acceptable. Land not to be used for fruit, vegetables or grazing within 6 months of application by sheep and swine and within 2 months by horses and dairy and beef cattle.		Raw sludge may only be used for animal feed and crops to be cooked. On pasture, delay required between application and grazing: 6 months for untreated and 3 weeks for treated sludges. Salad crops not sown within 12 months of application.		
Application recommendations		No application to soils with organic content > 17% or available p > 60 ppm		Avoid water contamination, odour and raingun drift. Phase out supplies general public.		
Maximum application		Crop N. demand max. 135 kg/ha ammoniacal N over 5 years or 4 years on turf. $130 m^3$/ha liquid per application.		Up to 1/5 of total 30 year metal addition in any one year and no more until running average falls to 30 year average adjusted where soil metal levels are high or low.		
Metal additions		Cumulative kg/ha	Min ratio ammoniacal N: metal	Cumulative kg/ha. 30 years	Annual g/ha. year	Concentration Limit mg/kg
	As	15	100	10	333	
	Cd	1.6	500	5	167	
	Co	30	50			
	Cr	220	6	1000	33,000	
	Cu	168	10	280	9,300	
To crops	Hg	0.9	1500	2	67	
	Mn					
	Mo	3.8	180	4	133	
	Ni	36	40	70	2,300	
	Pb	94	15	1000	33,000	2,000
	Se	2.7	500	5	167	
	Zn	363	4	560	18,600	
	B				3,500	(4,500-1st yr)
	Fl			600		3,500
To pasture		no differentiation		as above, except:		
				Cu 560	18,600	
				Ni 140	4,600	
				Zn 1,120	37,200	
Application period		5 applications at 5 year, intervals suggested		30 years		
Soil pH		>6.0		Arable >6.5 Pasture >6.0		
Zinc Equivalent concept Zn: Cu: Ni		Not used		1: 2: 8		

COMPARISON OF GUIDELINES FOR SEWAGE SLUDGE APPLICATION TO AGRICULTURAL LAND

		NETHERLANDS	GERMANY		
Type of sludge acceptable for agricultural use.		Only treated sludges to be used on pasture land and a no-grazing period of 6 weeks.			
Application recommendations.		Limited to arable and grassland.	Precautions to be taken against disease infections in agricultural use.		
Maximum application.		2t dm/ha. year on arable land 1t dm/ha. year on grassland or metal addition limit.	5t dm/ha. year or metal addition limit.		
Metal additions		Concentration limit mg/kg	Concentration limit in	air dry SOIL mg/kg	SLUDGE mg/kg
	As	10	Figures in	(20)	
	Cd	10	brackets are	3	30
	Co		Prof Kloke's		
	Cr	500	values for	100	1,200
	Cu	600	tolerable	100	1,200
To arable crops	Hg	10	amounts.	2	25
	Mn		Remainder are in		
	Mo		a draft pro-	(5)	
	Ni	100	posal for a FRG	50	200
	Pb	500	ordinance.	100	1,200
	Se			(10)	
	Zn	2000		300	3,000
	B			(25)	
To horticultural crops		as above			
To pasture		as above			
Application period		80/100 years	60 years		
Soil pH		Not specified	Not specified		
Zinc Equivalent concept Zn:Cu:Ni		Not used	Not used		

COMPARISON OF GUIDELINES FOR SEWAGE SLUDGE APPLICATION TO AGRICULTURAL LAND

		FRANCE	SWITZERLAND	
Type of sludge acceptable for agricultural use.		At least 70% domestic origin. At least 25% dry matter (dm)	Only stabilized (digested or aerated) sludge; on grassland during vegetation period only pasteurised sludge.	
Application recommendations.			Dosage based on N and P content.	
Maximum application.		Not specified	100 kg plant available N/ha per year (about 5 kg/ha of dry matter)	
Metal additions		Concentration limit mg/kg	Concentration limit mg/kg (ppm) in dry matter in sludge	
	As			As
	Cd	15	30	Cd
	Co	20	100	Co
	Cr	200	1000 (3000 for	Cr
	Cu	1,500	1000 tanneries)	Cu
To arable crops	Hg	8	10	Hg
	Mn	500		Mn
	Mo		20	Mo
	Ni		200	Ni
	Pb	300	1000	Pb
	Se			Se
	Zn	3,000	3000	Zn
	B			B
To horticultural crops				
To pasture				
Application period		Not specified	Vegetation period: only pasteurised sludges on grassland.	
Soil pH		Not specified	Not specified	
Zinc Equivalent concept Zn:Cu:Ni		Not used	Not used	

COMPARISON OF GUIDELINES FOR SEWAGE SLUDGE APPLICATION TO AGRICULTURAL LAND

		DENMARK		FINLAND	
Type of sludge acceptable for agricultural use.		Raw sludge not acceptable. Stabilised sludges only allowed for parks, arable and industrial crops, and pasture. Sludges containing abattoir waste to be disinfected for pasture and crops for raw consumption.		Raw sludge not acceptable. Biological or lime stabilised or composted acceptable for parks, arable and industrial crops, but not recommended for pasture or crops for consumption raw.	
Application recommendations.		Avoid surface and groundwater pollution, public nuisance and health hazards.		Avoid surface and groundwater pollution, public nuisance and health hazards.	
Maximum application.		Crop demand and release inorg. N or metal addition limit.		20t dm/ha. 5 years or 4t dm/ha. years.	
		Metal addition g/ha. year	Concentration limit mg/kg	metal addition g/ha. year	Concentration limit mg/kg
Crops for animal or human consumption	As				
	Cd	15	30	20	30
	Co			400	100
	Cr		500	4,000	1000
	Cu		700	12,000	3000
	Hg			100	25
	Mn			12,000	3000
	Mo				
	Ni			2,000	500
	Pb	600	1200	4,800	1200
	Se				
	Zn		6000	20,000	5000
	B				
Recreation, forestry, flowers		As above, except:		Not specified	
	Cd	30	30		
	Pb	1200	1200		
Application period		Not "long term" for consumable crops		Not "long term" for consumable crops	
Soil pH		Not specified		Not specified	
Zinc Equivalent concept Zn:Cu:Ni.		Not used.		Not used.	

COMPARISON OF GUIDELINES FOR SEWAGE SLUDGE APPLICATION TO AGRICULTURAL LAND

		NORWAY		SWEDEN	
Type of sludge acceptable for agricultural use.		Raw sludge not recommended. Biological or lime stabilised acceptable for parks, arable and industrial crops, but to be left 2 years before grazing pasture or growing crops for consumption raw. Composted or heat-treated sludges generally acceptable.		Raw sludge acceptable for corn cultivation or oil-yielding plants, but not for parks, pasture or crops for consumption raw. Stabilised sludge not acceptable for pasture or crops for consumption raw. Disinfected sludges acceptable for all uses.	
Application recommendations.		Avoid surface and groundwater pollution, public nuisance and health hazards.		Avoid surface and groundwater pollution, public nuisance and health hazards. Spray irrigation not recommended. Sludge to be worked into soil within 1 day.	
Maximum application.		50 t dm/ha once only 20 t dm/ha. 10 years repeated 10 t dm/ha. 5 years " 2 t dm/ha. years "		5 t dm/ha. 5 years 1 t dm/ha. year	
		Metal addition g/ha. year	Concentration limit mg/kg	Metal addition g/ha. year	Concentration limit mg/kg
Crops for animal or human consumption	As				
	Cd	30	15	15	15
	Co			50	50
	Cr			1000	1000
	Cu			3000	3000
	Hg	14	7	8	8
	Mn				
	Mo				
	Ni			500	500
	Pb	600	300	300	300
	Se				
	Zn			10000	10000
	B				
Recreation, forestry, flowers		According to case		According to case	
Application period		Not "long term" for consumable crops.		5 years but repeated application discouraged.	
Soil pH		Not specified		Not specified	
Zinc Equivalent concept Zn:Cu:Ni.		Not used.		Not used.	

KLÄRSCHLAMMAUSWIRKUNGEN AUF DIE UMWELT: EIN ÜBERBLICK ÜBER EINSCHLÄGIGE FORSCHUNGSARBEITEN IN ÖSTERREICH

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Kurzfassung

Über einige aktuelle Forschungsarbeiten in Österreich, die sich mit negativen Begleiterscheinungen der Klärschlammanwendung in der Land- und Forstwirtschaft befassen, wird überblicksartig berichtet.

Die strenge Trennung von positiven und negativen Wirkungen erscheint nicht einfach, weil die Zusammensetzung der Klärschlämme, vor allem was ihren Gehalt an Salzen und Schwermetallen betrifft, stark variiert. Außerdem bestehen auch große Unterschiede in den Bodentypen, auf denen Klärschlämme zur Anwendung gelangen, und auch bezüglich der Aufwandsmengen und Ausbringungszeitpunkte.

Vor allem die möglichen und tatsächlichen negativen Auswirkungen auf das System Boden-Pflanze werden aufgezeigt und durch Ergebnisse von Gefäß- und Freilandversuchen belegt.

Summary

A broad survey is given on recent Austrian research dealing with negative side effects of the application of sewage sludge in agriculture and forestry.

A clear separation of positive and negative effects seems not to be an easy task, since the composition of sewage sludges is extremely variable especially regarding the content of salts and heavy metals. In addition there are great differences in the types of soil to which sewage sludge is applied as well as in the amounts applied and the times of application.

Emphasis is given to possible and proven negative effects on the soil - plant system, which are demonstrated by the results of pot and field trials.

1. EINLEITUNG

Die starken Variationen in der qualitativen Zusammensetzung von Klärschlämmen, die unterschiedlichen Bodenarten, auf denen sie zur Anwendung gelangen, und die Tatsache, daß neben für die Pflanzenernährung essentiellen Elementen und Spurenelementen praktisch auch immer ein gewisser Anteil an unerwünschten Beimengungen, wie z.B. Schwermetallen und nicht essentiellen Elementen, in Klärschlämmen enthalten ist, deuten die Schwierigkeiten an, eine klare Trennung von positiven und negativen Wirkungen vorzunehmen. Auch die Konsistenz des Klärschlammes, die Ausbringungsmenge und der Applikationszeitpunkt sowie die Dauer der regelmäßigen längerfristigen Anwendung sind von wesentlichem Einfluß auf das Überwiegen der positiven oder negativen Erscheinungen.

Die in Österreich mit der landwirtschaftlichen Verwertung von Klärschlamm befaßten Institutionen (1) sind demnach größtenteils ident mit jenen Forschungsstellen, die über tatsächliche und mögliche negative Begleiterscheinungen unter verschiedenen Bedingungen berichten können. Auch über die von forstlicher Seite in Österreich vorliegenden Erfahrungen zur Anwendung von Müllklärschlammkompost wird kurz berichtet.

2. NEGATIVE BEEINFLUSSUNGEN DES SYSTEMS BODEN - PFLANZE

Die im Zuge der landwirtschaftlichen Verwertung von Klärschlamm auftretenden negativen Umweltbeeinflussungen betreffen in erster Linie das System Boden - Pflanze. Beim Substrat Boden stehen neben hygienischen Belangen, die in einem anderen Arbeitskreis behandelt werden, vor allem klärschlammbedingte physikalische und chemische Veränderungen bzw. deren Einfluß auf die bodenbiologischen Verhältnisse zur Diskussion. In engem Zusammenhang mit der Bodenbeeinflussung stehen diverse negative Auswirkungen auf Pflanzen. Diese äußern sich z.B. häufig in einer Störung der Stoffaufnahme bzw. in Veränderungen der Pflanzenverfügbarkeit verschiedener im Boden vorhandener Ionen, was von Keimhemmung über Ertragsminderungen und Schadstoffanreicherungen in Pflanzengeweben z.B. bei landwirtschaftlichen Kulturpflanzen bis zu diversen sekundären Auswirkungen auf die in der Nahrungsmittelkette folgenden Glieder führen kann.

2.1 AUSWIRKUNGEN AUF DEN BODEN

Die b o d e n p h y s i k a l i s c h e n Auswirkungen hängen stark vom Bodentyp und von der Art der Ausbringung (Naßschlammgaben z.B. durch Berieselung oder durch Tankwagen; luftgetrockneter Klärschlamm z.B. durch Miststreuer) sowie von der Anzahl der Schlammgaben bzw. von der Menge der aufgebrachten Trockensubstanz ab. Naßschlammgaben im Frühjahr können zu einer Erhöhung der Bodenfeuchte bis zu 6 Wochen nach der Applizierung führen (2). Eine jährliche Beschlammung mit 6oo m^3/ha (rd. 14.5oo kg TS/ha) durch 5 Jahre führte bei leichteren Böden zu positiven, bei relativ schweren Böden jedoch zu negativen Auswirkungen, die sich in einer Verdichtung und damit Verringerung des Porenvolumens bzw. in der Porenverteilung (Zunahme der Feinporen) äußerten. Dabei wurden vor allem die Luftkapazität (Porendurchmesser lo μm) und die pflanzennutzbare Wasserkapazität (Porendurchmesser 2 - lo μm) eingeschränkt (2). Die Gefahren der oberflächlichen Bodenverdichtung, oft verbunden mit stärkerer Durchfeuchtung und daraus resultierendem Sauerstoffabschluß, sind vor allem auf Waldstandorten nicht zu unterschätzen, da dort keinerlei Bodenbearbeitung stattfindet. Bei hohen Naßschlammgaben zu landwirtschaftlichen Kulturpflanzen kann es durch starke Überwässerung des Bodens aber auch zeitweilig zu anaeroben Verhältnissen und dadurch bedingten starken Wachstumsminderungen kommen (3). Die durch den Sauerstoffabschluß eingeleitete reduktive Phase wirkt sich vor allem in bodendiologischer Hinsicht ungünstig aus.

Die negativen Auswirkungen von Klärschlämmen auf den B o d e n c h e m i s m u s sind kaum in der funktionellen Richtung, wie Einfluß auf den Kationenaustausch oder Bildung von Sorptionskomplexen u.ä., begründet, sondern werden meist durch die in den Klärschlämmen enthaltenen Elemente verursacht. Unter diesen beanspruchen die Schwermetalle sowie Natrium und Chlor die größte Beachtung. Da die Schwermetalle bei höheren pH-Werten nur in sehr geringem Maße pflanzenverfüglich sind, kann es bei Daueranwendung zu bedenklichen Anreicherungen im Boden kommen (4). Dies wurde in 4 verschiedenen landwirtschaftlichen Betrieben Oberösterreichs, die in verschiedenen Klimabereichen angesiedelt waren und 3 verschiedene Bodentypen repräsentierten, für Zink, Kupfer, Kobalt, Blei, Nickel, Chrom und Cadmium nach Klärschlammgaben mit z.T. stark schwermetallbelasteten Schlämmen beobachtet (5). Geringe Metallkonzentrationen im Schlamm beeinflußten die Bodenwerte kaum, sehr stark belastete Schlämme jedoch erhöhten den Gehalt des Bodens an den betreffenden Schwermetallen auf das Mehrfache des Ausgangswertes. Besonders kritisch waren die Elemente Zink und Chrom. Bei Chrom wurde die Konzentration von loo ppm im Boden in zwei Fällen überschritten (5). Aus diesen Versuchen wurden folgende Empfehlungen für die Praxis abgeleitet (6):

a) Zur Düngung sollen nur Klärschlämme verwendet werden, deren chemische Zusammensetzung bekannt ist, da sich die Aufwandsmenge nach den Inhaltsstoffen zu richten hat.
b) Da die Böden einen unterschiedlichen Schwermetallgehalt aufweisen, wären sie vor und periodisch nach Klärschlammdüngungen zu untersuchen, um mögliche Schwermetallanreicherungen durch diese Kontrollanalysen sofort feststellen zu können.

Die Gefahr, die natürlichen Gehaltsverhältnisse im Boden durch Klärschlammgaben zu verändern, besteht vor allem bei den Schwermetallen, weil deren Konzentration im Klärschlamm die Normalgehalte im Boden um das loo- bis looo-fache übertreffen kann und keine nennenswerte Reduktion durch Entzug oder Auswaschung besteht. Daher sind unerwünschte Anreicherungen im Boden möglich (7).

Die folgende Tabelle gibt einen Begriff von den Größenordnungen, mit denen wir in Österreich bei den Schwermetallgehalten in Klärschlämmen rechnen müssen. Die Zusammenstellung enthält einerseits Analysenergebnisse von 25 Proben aus 18 Kläranlagen, verteilt über die Bundesländer Niederösterreich, Steiermark und Kärnten. Die Stichproben beinhalten auch Städte mit größerer Einwohnerzahl und Industrie (7). Andererseits stammen die Analysen von 6 Klärschlämmen aus Anlagen des Raumes Oberösterreich und Salzburg, die in 2 aufeinanderfolgenden Jahren untersucht worden waren, und folgende Herkünfte repräsentierten: Großstadt mit Industrie, Kleinstadt mit Industrie, Markt mit Mittelbetrieben, Markt mit Molkerei (2x) und ländliche Gemeinde (8).

TABELLE: Schwermetallgehalte in Klärschlämmen verschiedener österreichischer Herkünfte

Element	Schwankungsbereich in ppm TS nach (7)	Schwankungsbereich in ppm TS nach (8)
Kupfer	86 - 1.222	2o - 7oo
Mangan	114 - 3.117	163 - 1.5oo
Eisen	4.973 - 31.25o	3.361 - 166.667
Zink	25o - 5.89o	67 - 5.1oo
Kobalt	3 - 67	Spuren - 4.ooo
Molybdän	1 - 14	Spuren - 1o
Blei	8 - 557	2o - 27.568
Cadmium	1 - 94	Spuren - 73
Chrom	5 - 1.o89	6 - 5.742
Nickel	18 - 2o9	2o - 1.547

Die bodenchemischen Parameter pH-Wert und elektrische Leitfähigkeit der oberen Bodenschichten zeigten durch zwei verschieden hohe Schlammgaben (2x6o mm Faulschlamm im Abstand von 3 Jahren und 5x6o mm jährlich durch 5 Jahre) gar keine oder nur zeitweilig eine geringe Beeinflussung (2). Deutliche, beschlammungsbedingte Unterschiede zu den Kontrollen zeigten sich in Feldversuchen nur beim Na-Gehalt und dem Gehalt an Pflanzennährstoffen bei fünfmaliger jährlicher Naßschlammapplikation von je 6o mm. Die Strukturverschlechterung im Boden war z.T. auf den erhöhten Na-Gehalt zurückzuführen, der zu Beginn der zweiten Vegetationsperiode nach der Beschlammung Maximalwerte erreichte. Die Natriumionen sind nicht nur für die Pflanzen, sondern auch für den Boden selbst von Nachteil. Der Anteil der Natriumionen am Sorptionsbelag des Bodens kann nämlich immer mehr zunehmen und eine Verschlechterung der Bodenstruktur nach sich ziehen, wie Quellung der Ton- und Kolloidsubstanzen, Lösung der Humusverbindungen und Dichtschlämmung des Bodens (9). Ungünstige Verschiebungen des Nährstoffhaushaltes infolge höherer Na-Gehalte konnten aber nicht festgestellt werden (2). Die Stickstoffgehalte lagen bei den jährlich beschlammten Flächen klar über den Werten der Kontrollflächen (mit Mineraldüngung), während bei Phosphor trotz der erheblichen Phosphatzufuhr durch die Schlammgaben nur eine geringfügige Erhöhung zu registrieren war. Dies hing offenbar mit der beachtlichen Phosphatfixierung in Form von Ca-, Al- und Fe-phosphaten bei jährlichen Schlammgaben zusammen, da diese Elemente reichlich im Schlamm vorhanden waren (2). Die klärschlammbedingten bodenphysikalischen und bodenchemischen Veränderungen entfalten eine entsprechende Wirkung auf die im Boden vorhandenen Mikroorganismen. Diese sind zwar z.B. in der Lage, organische Verbindungen zumindest teilweise abzubauen, nicht jedoch Elemente, die in größerer Konzentration anfallen. Langfristige Ausbringung von Klärschlamm birgt daher neben physikalisch-chemischen Beeinflussungen auch die Gefahr einer bodendiologischen Wirkung durch Veränderung der Mikroorganismenpopulation. Im allgemeinen wirken aus Siedlungsabwässern stammende Klärschlämme positiv auf die Vermehrung der meisten Bodenmikroben ein. Allerdings sind kurz nach der Schlammaufbringung die Gesamtkeimzahlen schwach reduziert. Nach kurzer Anlaufzeit stimuliert die Schlammdüngung vor allem die Massenentwicklung der Bakterien (besonders der Kokken und Stäbchen). Die Actinomyceten reagieren später. Das Pilzwachstum wird durch Klärschlamm nur in geringem Maße angeregt; ähnlich verhalten sich die mikroskopischen Algen, die jedoch starke Veränderungen in der Artenzusammensetzung erkennen lassen. Die Bodenfauna kann durch frischen Klärschlamm, der die Bodendurchlüftung unterbricht bzw. unterbindet, vernichtet werden, was vor allem die Mesofauna, die Milben und die Collembolen betrifft.

Klärschlämme industrieller Herkunft mit größeren Mengen von Spurenelementen und verschiedenen giftigen organischen Verbindungen wirken sich von vornherein nachteilig auf das Bodenleben aus. Auch die Änderung des pH-Wertes und des Salzgehaltes kann die Entwicklung des Bodenlebens hemmen. Viele Bodenmikroben, besonders unter den mikroskopischen Pilzen, reagieren z. B. äußerst empfindlich auf Erhöhungen des Salzgehaltes (9).

2.2 AUSWIRKUNGEN AUF PFLANZEN

Aus pflanzenbaulicher Sicht spielen aber nicht nur die Schwermetalle sowie Na und Cl eine negative Rolle, sondern auch der Stickstoffgehalt der Klärschlämme kann als begrenzender Faktor auftreten. Zu hohe, zu häufige (zu kurze Beschlammungsabstände) und zu späte Schlammgaben in der Vegetationsperiode können zu Ertragsdepressionen und Qualitätseinbußen führen. Bei Getreide (Winterweizen und Sommergerste) wurde z.B. frühzeitige Lagerung und eine Verminderung des 1ooo-Korn-Gewichtes, bei Bohnen ein Anstieg des Nitratgehaltes und bei Zuckerrübe Qualitätsverminderung und Ertragseinbußen festgestellt (2). Hohe Klärschlammgaben können durch ihren hohen Stickstoffgehalt, der von den Pflanzen nicht mehr verwertet werden kann, sowie durch ihren Überschuß an Natrium schädigend auf Böden und Pflanzen wirken, da es zu unerwünschten Anreicherungen von Nähr- und Schadstoffen kommt (1o).

Eine Beeinträchtigung des Pflanzenwachstums durch höhere Gehalte des Klärschlamms an Mineralölen, Teerprodukten und Detergentien ist nur zeitweilig zu erwarten, da diese Substanzen im Boden durch Mikroorganismen relativ rasch abgebaut werden (11). Umstritten im Hinblick auf die Aufnahme durch Pflanzen ist die Bedeutung der in den Klärschlämmen enthaltenen cancerogenen polyzyklischen Aromate (12).

Einen breiten Raum in den österreichischen Forschungsaktivitäten nehmen Untersuchungen ein, die sich mit der Belastung von Nutzpflanzen durch die mit dem Klärschlamm zugeführten Elemente befassen. Natürlich stehen auch dabei wieder die Schwermetalle im Mittelpunkt des Interesses. Auf zwei unterschiedlichen Böden, einem lehmigen Sandboden mit pH 4,9 und einem sandigen Lehmboden mit pH 7,3, wurde die Wirkung von leicht löslichen Gaben der Schwermetalle Chrom, Nickel und Cadmium einzeln und in Kombination auf Italienisches Raygras geprüft. Bei dem lehmigen Sandboden wirkte sich Nickel, bei dem sandigen Lehmboden dagegen besonders Chrom und z.T. auch Cadmium ertragsmindernd aus. Die aufgewendeten Schwermetallmengen entsprachen bei Nickel und Chrom einem Bodengehalt von loo ppm, bei Cadmium von 5 ppm (13). Da es sich um derzeit laufende Untersuchungen handelt, kann zum jetzigen Zeitpunkt noch nichts über die Pflanzengehalte ausgesagt werden.

Die Auswirkung verschieden hoher Mengen luftgetrockneten Klärschlammes auf Weizen, Gerste, Mais und Raps wurde in Gefäßversuchen mit 2 unterschiedlichen Bodentypen und Aufwandsmengen entsprechend 4o t/ha bzw. 8o t/ha untersucht (14). Erst bei der höheren Aufwandsmenge zeigten sich bei den Getreidearten Weizen und Gerste Veränderungen im Gehalt einiger Schwermetalle, z.B. Zunahmen von Zink und Kupfer. Bei den Kulturpflanzen Raps und Mais verursachten nur stark erhöhte Gaben (32o t/ha bzw. 64o t/ha) eine Zunahme von Zink, Kupfer, Mangan und Molybdän. Diese Gehaltsänderungen bei den Spurennährstoffen können für das Pflanzenwachstum von Bedeutung sein. Vor allem der Zink-Anreicherung im Boden wird die größte phytotoxische Bedeutung zugemessen.

Bei Pflanzen, die für die menschliche Ernährung eine Rolle spielen wie z.B. Getreidearten, erhebt sich die Frage, ob nach Zufuhr von Schwermetallen zum Boden durch Klärschlamm, die gesetzlich zulässigen Höchstmengen in den zur Verwendung gelangenden Pflanzenteilen noch eingehalten werden können. Für Cadmium und den Mehlkörper des Weizenkornes konnten die Verhältnisse durch Verwendung markierten Cadmiums geklärt werden (15). Die Einwanderung in die Sprosse war auf 2 verschiedenen Böden (A: vorzüglicher Weizenboden, kalk- und humusreiche, stark ionenfixierende Schwarzerde, pH 7,4; B: wenig geeigneter Boden für Weizen, kalk- und humusarme, schwach ionenfixierende

Braunerde, pH 5,4) sehr unterschiedlich. Auf dem wenig für Weizen geeigneten Boden B gelangte rund zehnmal mehr Cadmium in die Sprosse als auf dem Boden A. Im Mehl selbst war das Verhältnis ähnlich, nämlich o,o66 ppm (Boden A) zu o,55 ppm (Boden B). Bei gleichem Zusatz von Cadmium zu den Böden war also die in der BRD vorgeschlagene Höchstmenge in Getreideprodukten in einem Fall klar unterschritten, im anderen Fall klar überschritten. Die Problematik nicht toxikologisch begründeter, relativ niedriger Grenzwerte wird im Zusammenhang mit Klärschlammdüngungsmaßnahmen aufgezeigt (15). Auf den gleichen Böden A und B wurde ferner die Wirkung von Cadmium- und Zinkbeigaben (als Sulfat) einzeln und in Kombination auf den Ertrag von Weizenpflanzen geprüft (16). Während auf der Schwarzerde kaum eine Wirkung eintrat, betrug das Ertragsdefizit auf der Braunerde maximal 89 %, wobei bei gemeinsamem Zusatz der Metalle zum Boden deutliche synergistische Effekte auftraten. Derzeit laufen Versuche mit den Metallpaaren Cadmium - Kupfer und Kupfer - Zink. Eine Interpretation der synergistischen Phänomene erscheint erst nach Abschluß dieser Untersuchungen sinnvoll.

Neben den beiden bereits genannten Untersuchungen laufen weitere Forschungsarbeiten in der Landwirtschaftlich-chemischen Bundesversuchsanstalt Wien mit dem Ziel, die Folgen einer Belastung von Böden und Pflanzen durch toxische Schwermetalle, wie sie im Gefolge einer Klärschlammanwendung von 3oo m^3/ha (TS 2 %) auftreten, aufzudecken (17). Zum sicheren Nachweis der von den Pflanzen in den Modellversuchen aus dem Boden aufgenommenen sehr kleinen Metallmengen wurden die zugesetzten Schwermetalle radioaktiv markiert. Es zeigte sich, daß die chemisch nahe verwandten Metalle Cadmium und Zink von der Schwarzerde (A) stärker festgehalten wurden als von der Braunerde (B), was auch mit den drastischen Unterschieden in der Aufnahme durch die Pflanzen (Weizen und Roggen) in den Gefäßversuchen übereinstimmte.

Untersuchungen über die Verteilung von Cadmium und Quecksilber in Getreideprodukten nach Zufuhr dieser Metalle zum Boden ergaben, daß Quecksilber in wesentlich geringerem Maße als Cadmium von den Pflanzen aufgenommen wird. Die Ursache lag in der festen Bindung des Hg im Boden, das im Gegensatz zu Cd kaum löslich ist. Hg ist zwar giftiger als Cd, bedeutet aber keine unmittelbare Gefährdung von Mensch und Tier. Dagegen erfordert Cd wegen seiner großen Pflanzenverfügbarkeit erhöhte Wachsamkeit bei der Klärschlammanwendung. Besonders aus der schwach adsorbierenden Braunerde (B) wurde Cd stets in wesentlich größeren Mengen als aus der stark adsorbierenden Schwarzerde (A) aufgenommen. Die geringe Hg-Aufnahme bedeutete, daß die Toleranzgrenze in keinem Pflanzenteil überschritten wurde. Die Cd-Anreicherung übertraf dagegen - außer im Weizenmehl der von Boden A stammenden Körner - in allen Pflanzenteilen die Toleranzgrenze (17).

Die Möglichkeiten der Verringerung der Cd-Aufnahme wurden überprüft, indem neben der Düngung mit Kalk, Phosphat und elementarem Schwefel auch Ionenaustauscher (Lewatit) als "Schwermetallfänger" im Boden zum Einsatz kamen. Der Austauscher setzte die Cd-Aufnahme von Weizen beträchtlich, je nach Austauscherform (Ca- oder Mg-Form) und Bodenart auf ein bis zwei Drittel des Kontrollwertes herab (17).

Neben der Hg-Aufnahme war auch die Chrom-Aufnahme durch Getreidepflanzen Gegenstand von Untersuchungen (17). Die Cr-Aufnahme betrug z.T. nur ein Tausendstel der Cd-Aufnahme. Aufgrund dieses Befundes erscheint eine Einschleppung von Cr in den Boden durch Klärschlammgaben daher weniger bedenklich als die des Cadmiums. Auch ließ sich die Cr-Aufnahme durch pflanzenbauliche Maßnahmen verringern: im Gefäßversuch mit Sommerweizen wurde sie durch Phosphatdüngung halbiert und durch Kalkung je nach Bodenart auf 6o% bis 8o% der Kontrolle herabgesetzt. Dagegen war der Ionenaustauscher Lewatit, der sich bei Zusatz zum Boden zur Bindung von Cd und Zn bewährt hatte, im Falle des Chroms wirkungslos.

Dem Cd kommt daher wegen seiner häufigen Verbreitung als Begleiter von Zn und Pb, wegen der Leichtigkeit seiner Anreicherung in Pflanzen und wegen seiner hohen Giftwirkung auf Mensch und Tier besondere Beachtung zu. Die Cd-Aufnahme von Getreide konnte durch die Anwesenheit anderer Schwermetalle z.B. im

Klärschlamm beeinflußt werden, und zwar förderten geringe Cu-Zusätze die Cd-Aufnahme, Zn-Zusätze dagegen hemmten sie stets. In ausreichend mit Zn versorgten Böden ist daher die Gefahr einer hohen Cd-Anreicherung in den Pflanzen gering. Die Wirkung der Cu- und Zn-Zusätze war auf der kalkreichen Schwarzerde durchwegs größer als auf der kalkarmen vergleyten Braunerde. Diese Ergebnisse weisen auf die ausgeprägte Standortsabhängigkeit von Schwermetallinteraktionen hin (17).

3. AUSWIRKUNGEN AUF DAS GRUNDWASSER

Bei der landwirtschaftlichen Schlammverwertung stellt sich auch die Frage nach deren Auswirkungen auf das Grundwasser. Grundwasseruntersuchungen (Probenahme mittels Sonden in 14-tägigen Intervallen) unter hochbeschlammten Flächen (5 Schlammgaben von 4o mm bzw. 6o mm im jährlichen Turnus) wiesen auf einen Anstieg der Leitfähigkeit, der Na-, Chlorid- und Nitratgehalte sowie der Gesamthärte hin (2,18). Schlammgaben von 4o mm bzw. 6o mm im dreijährlichen Turnus zeigten keine derartigen negativen Auswirkungen auf die Grundwasserqualität. Der pH-Wert des Grundwassers, der $KMnO_4$-Verbrauch und der Phosphatgehalt blieben bei allen Beschlammungsvarianten unbeeinflußt.

4. PROBLEME BEI DER MÜLLKLÄRSCHLAMMKOMPOST (MKK)-ANWENDUNG IN DER FORSTWIRTSCHAFT

MKK unterscheiden sich wegen der in ihnen ablaufenden aeroben Umsetzungen, die auf dem mikrobiellen Sektor zu gravierenden Veränderungen im Artenspektrum führen können, von den bisher besprochenen Klärschlämmen deutlich. Auf die Umweltwirkungen von MKK wird dennoch kurz eingegangen, da in Österreich einige Erfahrungen über den Einsatz von MKK in der Forstwirtschaft vorliegen. Am Institut für Forstökologie der Universität für Bodenkultur wird seit mehreren Jahren die Problematik der MKK-Anwendung auf Forstgewächse in Gefäß- und Freilandversuchen untersucht (19,2o,21). Die bisher vorliegenden Ergebnisse weisen klar darauf hin, daß nur MKK mit möglichst geringen Gehalten an Natrium, Chlorid und Schwermetallen für die Verwendung in Forstgärten oder als Substrat für Ballenpflanzen zu empfehlen ist.

Als besonders salzempfindlich unter den Forstgehölzen erwiesen sich Koniferen. Obwohl der in einem Gefäßversuch (19) angewendete MKK relativ geringe Gehalte an Na und Cl aufwies, traten bei 2-jährigen Schwarzkiefern- und Fichtensämlingen auf Silikatboden + 2o Vol.% MKK, Karbonatboden + 2o Vol.% MKK und reinem MKK schon im ersten Abschnitt der Vegetationsperiode Nadelschäden (Salzschäden) auf. Aussagen über die Wirkungen der relativ hohen Cu-, Zn-, Pb- und Cd-Gehalte auf den Boden, die Bodenorganismen und auf die Pflanzen konnten nicht gemacht werden; auf diesem Sektor wären dringend Versuche notwendig, da bisher noch zu wenig Informationen über Langzeitwirkungen von Schwermetallen auf Waldbäume vorliegen (19).

Die Beseitigung bzw. Herabsetzung der besonders nachteiligen Na- und Cl-Gehalte wurde bei einem MKK österreichischer Herkunft durch bis zu viermalige Auswaschung versucht (21). Obwohl der Na-Gehalt durch diese Behandlung fast auf die Hälfte reduziert wurde, lag er noch immer weit über dem Wert von 2o - 25 mg/loo g TS, ab dem mit Schäden an Koniferen zu rechnen ist. Der Wirkungsgrad der Auswaschung nahm mit jeder Wiederholung rasch (logarithmisch) ab. Welchen Einfluß die unterschiedlichen Auslaugungsgrade des MKK auf Wuchs und Vitalität von Kiefer und Fichte ausüben, wurde in Gefäßversuchen getestet. Das Ergebnis war insofern negativ, als mit einem noch vertretbaren Aufwand für die Auswaschung kein für Fichte und Kiefer unmittelbar brauchbares Substrat erzeugt werden konnte. Hohe Mortalität (Kiefer 52%, Fichte 29%) und geringe Vitalität unterstrichen dies deutlich.
Ein besonderer Nebeneffekt konnte an den Wurzeln der vitalsten Fichten beobachtet werden: korkartige Wucherungen, die aufgrund mikroskopischer Untersuchungen nicht als Lentizellen anzusprechen waren und offenbar eine Reaktion auf das Substrat darstellten. Korreliert war dieses Phänomen mit dem Na-Gehalt des aus den Töpfen austretenden Sickerwassers. Dies deutete bei der am stärksten ausgewaschenen MKK-Variante auf einen

Rücktausch von Na^+-Ionen aus den Sorptionsträgern in die Bodenlösung über H^+-Ionen aus der H_2O-Dissoziation nach Absinken des Gehaltes an freien Salzen im MKK. Das Auftreten der Korkwucherungen wurde als mögliche Abwehrreaktion der Pflanzen gedeutet (21).

Unter Berücksichtigung der bisherigen Erfahrungen werden die Möglichkeiten des MKK-Einsatzes in der Forstwirtschaft im Vergleich zur Landwirtschaft auch in Zukunft eher als bescheiden zu bewerten sein (2o). Besonders problematisch dürfte ein Einsatz in bereits bestehenden Kulturen, Stangen- und Baumhölzern wegen des damit verbundenen Eingriffes in das Waldökosystem, besonders in die Mikroorganismenpopulation (z.B. Mykorrhizen), und die daraus folgenden Auswirkungen auf die stockenden Baumarten sein (2o).

5. SCHLUSSBETRACHTUNG

Der hier unternommene Versuch, die aktuellen österreichischen Forschungsaktivitäten zur Thematik "Negative Aspekte der Klärschlammanwendung" vorzustellen, verfolgt nicht zuletzt auch das Ziel, die Komplexität der gesamten Klärschlammproblematik zu vermitteln. Die manchmal geübte Praxis, aus den Gehalten an einzelnen Schadstoffen in Klärschlämmen mittels Hochrechnung abzuleiten, durch wie viele Jahre oder Jahrzehnte noch Klärschlammapplikationen in der Land- und Forstwirtschaft bis zur endgültigen Bodenzerstörung erfolgen können, zeugt von einem tiefen Mißverstehen ökologischer Zusammenhänge. Die landwirtschaftliche Verwertung von Klärschlämmen wäre nämlich an sich eine wünschenswerte Recycling-Strategie, die aber gleichzeitig sehr viel an umwelttoxikologischer Umsicht erfordert.

Die schon im Titel geäußerte Absicht, nur die einschlägigen österreichischen Arbeiten zu referieren, wobei kein Anspruch auf Vollständigkeit erhoben wird, spiegelt sich natürlich auch im folgenden Literaturverzeichnis wider, in das bewußt nur österreichische Autoren aufgenommen wurden.

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PREDICTION OF CADMIUM CONCENTRATIONS IN DANISH SOILS

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Summary

Detailed studies on the effects of sludge utilization in agriculture have been conducted in Denmark since 1973.

The paper presented is the English version of the compilation of results and conclusions drawn from numerous experiments at several research institutions.

The main subjects reported on include the behaviour of selected trace pollutants in the soil-plant system and the inactivation of contagions in the sludge-soil system. The consequences for the future strategy on agricultural use of sludge is discussed in view of the toxic and contagious risks to sections of the population.

1. INTRODUCTION

Cadmium is a potentially dangerous inorganic pollutant, which reaches agricultural land by different routes. Being a relatively plant available metal ionic species in soils, changes of Cadmium concentrations in agricultural soils have direct consequence for the human food intake of the metal.

Prediction of increases in cadmium concentrations in agricultural soils due to realistic and high inflows by atmospheric precipitation, phosphatic fertilizer and sludge application, combined with low outflows by leaching and crop removal, is thus important in assessing future cadmium load to the populations.

There have been several attempts to simulate the attenuation of cadmium in soils PATTERSON /1/, YOST /2/, VAN ENK /3/, POELSTRA /4/. The common feature of these investigations is a predicted average retention time for cadmium in soils in the range 5-50 year. Such results would imply that cadmium accumulation in soils be low, and that a steady state be nearly manifest.

The validity of these suggestions seems questioable. Recent Danish investigations as to the Cadmium balance on normal agricultural soils indicate a much longer retention time than normally anticipated. In view of the serious consequenses of an increased human intake, investigations are varranted to properly assess the Cadmium attenuation, and hence the necessary controls on inflows to the soil system.

2. INFLOW OF CADMIUM TO AGRICULTURAL LAND

Based on actual measurements and calculations the present average flows of Cadmium to and from Danish agricultural soils (0-25 cm = ploughing layer) are visualized in Fig. 1, after HOVMAND /5/.

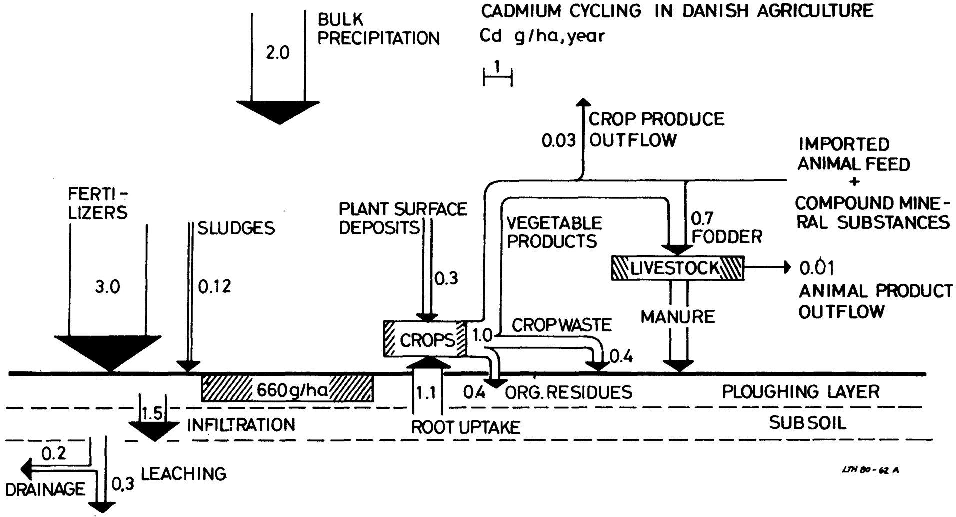


Figure 1. Present average flows of Cadmium to and from agricultural land (0-25 cm) in Denmark. From HOVMAND /5/.

The main feature of this study is that inflows are much greater than outflows. The inflows from the atmosphere and fertilizer are of the same magnitude, while sludge in average is a minor source. Locally sludge may of course be very important, especially around major cities, efficiently disseminating large quantities of contaminated sludge to farming. Such a situation may be aggravated by cropping of vegetables from sludged fields, thus raising the amount of Cadmium recycled directly to man through food.

The outflows by leaching, drainage and net plant removal constitutes only minor amounts compared to inflows. The annual accumulation of Cadmium in soil is thus determined to be around 4 g/ha,y which at present should increase the soil concentrations in average by approximately 0,6 %/y.

Of the examined flows the input from atmosphere and fertilizers seem to be in close agreement with results obtained by other authors in Europe cf. for example, VERMEULEN /6/ and SIMA /7/. The low figures for outflows by leaching and crop removal are however controversial and require a more thorough validation before general acceptance.

3. CADMIUM OUTFLOW FROM SOIL BY LEACHING AND DRAINAGE

Drainage water constitutes part of the water infiltrating soils. The total infiltration in Denmark vary between 170 mm/y (east Denmark) and 350 mm/y (West Denmark).

Drainage water from 1-1.2 m depth has been analyzed for content of Cadmium at 15 locations in Denmark, JENSEN /8/. The average soil outflow from this depth by drainage is assessed to be approximately 0.2 g/ha,y carried in 1150 m^3/ha,y of water (0.2 ppb). Assuming an infiltration of 2500 m^3/ha,y the total outflow of Cadmium in 1 m depth will be around 0.5 g/ha,y.

The translocation by percolation from the ploughing layer proper will probably be somewhat higher. I order to assess this loss, the results obtained by CHRISTENSEN /9/, see Fig. 2, may give an indication. The average Cadmium concentration in Danish agricultural soils is estimated to be 220 ppb, a typical sandy soil around 100 ppb and a sandy loam ~300 ppb, cf. TJELL /10/.

Relevant figures for pH ($CaCl_2$) in Danish soils have been obtained from OLESEN /11/. (Sandy soils: pH ~5.2, loamy sands: pH ~6.2, sandy loams: pH ~7.0). Average Calcium concentrations in soil solutions seem to be around 2 mmole/ℓ, JAKOBSEN /12/. Looking at the curves in Fig. 2, the average Cadmium concentrations in the soil solution then seem to vary between 0.2 ppb and 1.0 ppb with a likely average around 0.6 ppb. Assuming again 2500 t/ha,y of total infiltration, this means that Cadmium losses from the ploughing layer vary between 0.5 g/ha,y and 2.5 g/ha,y and in average approximately 1.5 g/ha,y. Extreme values

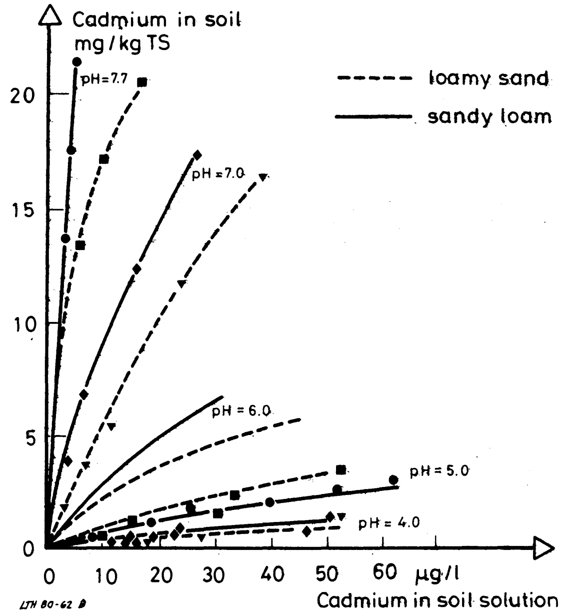
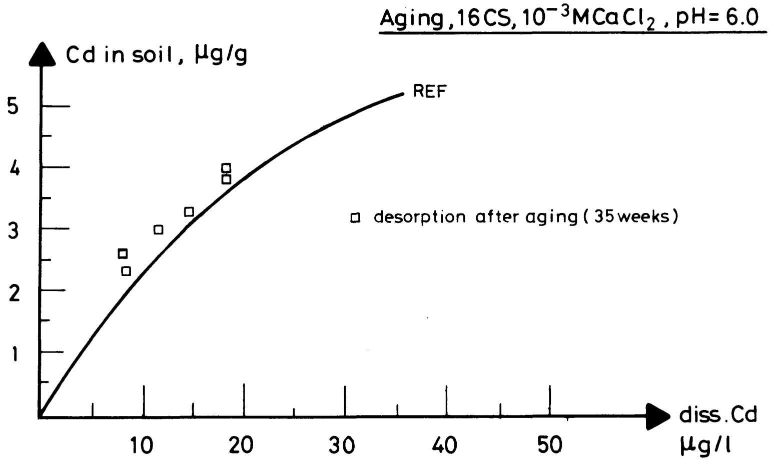


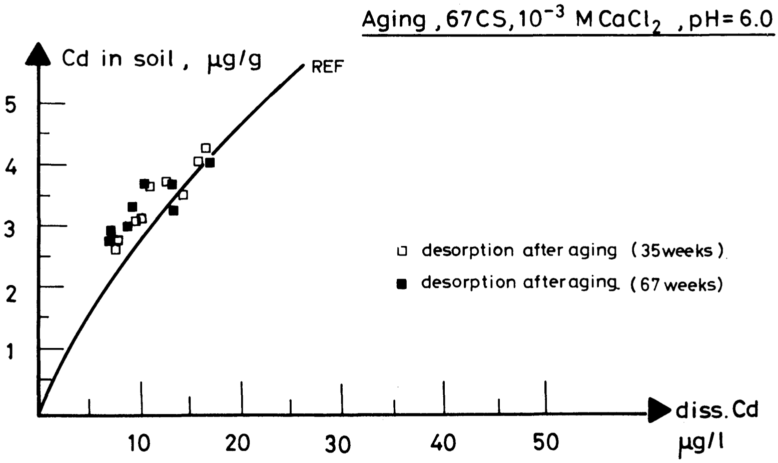
Figure 2. Relations between the concentrations of Cadmium in soil solution in two Danish subsoils, at $[Ca^{2+}]=10^{-3}M$ and varying pH. (-) Sandy loam. (---) Loamy sand. From CHRISTENSEN /9/.

of ~10 g/ha,y may be encountered in western Denmark, (acid ligth soil, with an infiltration of 3500 t/ha,y).

An important question to ask is whether the Cadmium in soil is transformed into less soluble compounds with time. This applies both to naturally occurring Cadmium and to Cadmium reaching soil from the atmosphere, fertilizers and sludges. The ageing process is not yet fully investigated. However, changes in the desorption of Cadmium in two subsoils under wet storage over a period of 67 weeks have been studied by CHRISTENSEN /9/ cf. Fig. 3. The conclusion from this experiment is that the adsorption of Cadmium to soils is almost fully reversible and that apparently no appreciable fixation takes place during ageing. Although the period of investigation is relatively short this finding conforms well with experiences from sludge application in the field, where the plant availability of Cadmium appears to be constant after the first few years of a transient state, cf. CHANEY /13, 14/.



Cadmium Desorption from Soil 16 CS in 10^{-3}M $CaCl_2$ at pH = 6.00 after Aging in 35 Weeks. (Cadmium Added before Aging.)



Cadmium Desorption from Soil 67 CS in 10^{-3}M $CaCl_2$ at pH = 6.00 after Aging in 35 and 67 Weeks. (Cadmium Added before Aging.)

Figure 3. Cadmium desorption from two Danish subsoils after ageing for 35 and 67 weeks. The full line indicate the adsorption isotherm. pH = 6.0 and $[Ca^{2+}]$ = 10^{-3}M. From CHRISTENSEN /9/.

4. CADMIUM UPTAKE IN PLANTS

The amounts of Cadmium taken up by crops are assessed in Fig. 1 to be 1.1 g/ha,y. This is a weighed average based on actual determinations of Cadmium concentrations in crops, and crop yield data. In practice plant uptake may vary with a factor of ~10 from a grain crop to a vegetable crop (spinach).

The two most important factors governing Cadmium uptake by crops seem to be soil pH and Cadmium concentrations in the soil. In Fig. 4 is shown as an example the Cadmium uptake in Italian ryegrass from sandy loam, a typical soil type in Denmark. Controlled parameters in this pot experiment were the pH, (adjusted by $Ca(OH)_2$ or H_2SO_4), and Cadmium concentrations altered by sludge additions. It is rare to find such a clear picture, especially in field experiments, where both Calcium contrations and pH in soil solution may vary considerably, cf. CHANEY /14/. Similar relationships have been found by other authors, WILLIAMS /16/ is a good example.

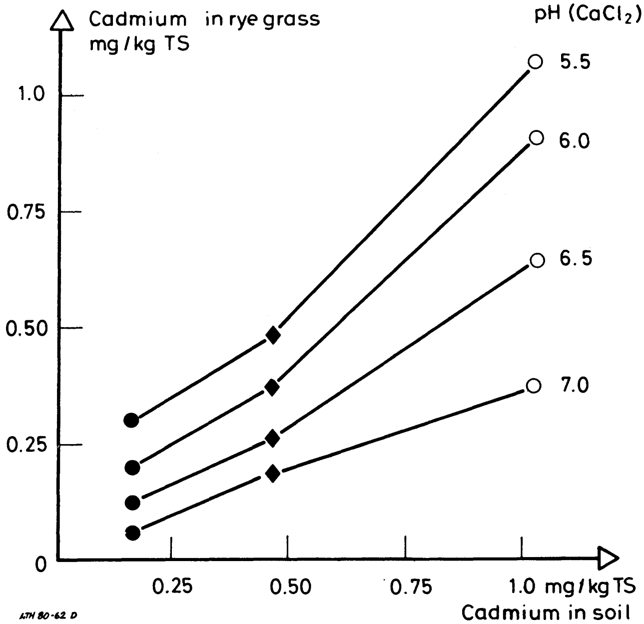


Figure 4. Cadmium uptake in Italian ryegrass, as influenced by pH and Cadmium concentrations in sandy loam (Askov). Pot experiment. From TJELL /15/.

The plant uptake as shown in Fig. 4 resembles the qualitative picture in Fig. 2, indicating that plants take up Cadmium mostly in proportionality with the soil solution concentration, although as shown by BINGHAM /17/ the individual selectivity variation between plant species is considerable.

The plant uptake of Cadmium from the atmosphere is rarely thought of as important compared to root uptake from soil. Using an isotope dilution technique is was however found that ~30% of the Cadmium in a grass crop in a normal background area in Denmark originate directly from the atmosphere, TJELL /18/. Most of the Cadmium deposited on the vegetation is probably washed off by rain, thus raising the cadmium inflow to soil. Although undoubtedly important, it is not yet possible to give a correct figure for this inflow. ZÖTTL /19/, working on a pine plantation has given an estimate of more than a doubling of the atmospheric inflow as determined only by funnel. The flow of 0.3 g/ha,y given in Fig. 1 is thus on the conservative side. Further details from a more thorough investigation on the atmospheric deposition on vegetation will follow later.

The crop uptake of Cadmium from soil may then be assessed to be in the order of 1.1 g/ha,y, HOVMAND /5/, assuming a dry matter production of approximately 10 t DM/ha,y, cf. LUND /20/ (excluding root and stubble). The variation in crop uptake of Cadmium is significant, from ~5 g/ha,y for a beet crop to ~0.7 g/ha,y for a barley crop, cf. HOVMAND /5/, and DAM KOFOED /21/.

The overall crop removal of Cadmium from agriculture is however much lower, as most crops produced are utilized for raising cattle and hogs, and manure recycled to land. Abattoir waste is also processed and used for stock feeding and thus an even larger fraction of the total crop uptake of Cadmium is recycled to land. Total recycling of Cadmium is assessed by HOVMAND /5/ to be more than 95%. Thus less than 0.05 g/ha,y in average is effectively removed from agriculture in produce consumed by the human population at large.

5. PREDICTION OF CADMIUM CONCENTRATIONS IN DANISH SOILS

Employing the Cadmium flows for agricultural areas as presented above, it is now possible to predict the future

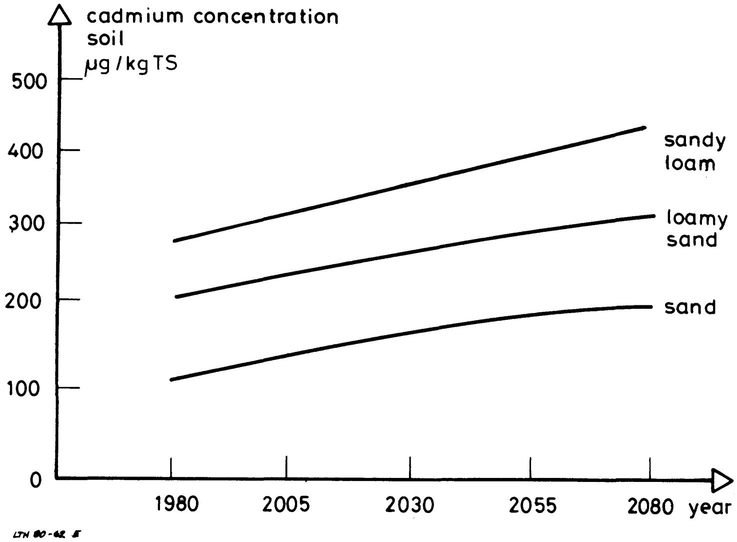


Figure 5. Prediction of Cadmium concentrations in typical Danish soils, assuming continued inflow of Cadmium to the agricultural area.

development in Cadmium concentrations in Danish soils. For illustrative purposes it is attempted to calculate the average situation, and further to assess the situation both for a ligth sandy soil and a heavy clayish soil. It is sufficient to apply a simple linear model for the average situation, and the heavy soil, due to the high inflows compared to low outflows. The sandy soil requires a dynamic model.

For the average situation, the predictions covering the period 1980-2080, are given in Fig. 5. In the same Figure is shown the situation for the loamy soil, and the results for the ligth sandy soil. It is obvious that the heavy soils with high pH will retain nearly all Cadmium received, while a light soil with low pH fairly quickly will reach equilibrium where outflows outbalance inflows.

A preliminary attempt has been made to verify this hypothesis. A sandy soil was sampled underneath and nearby two 80 year old buildings in Jutland. The protected soil contained 85 ppb, while the open air cultivated soil, sampled in the vicinity contained 160 ppb. Thus an average increase appears to be ~1 ppb/year or approximately 0,6 %/year of the present level.

These results are to be published later, together with results of samplings now in preparation for other sites and periods of protection from open air exposure.

6. CONSEQUENSES FOR CROPS AND CONSUMERS

The consequenses of slow increases in soil concentrations with time, for the average Cadmium concentration in agricultural produce is naturally of a speculative nature.

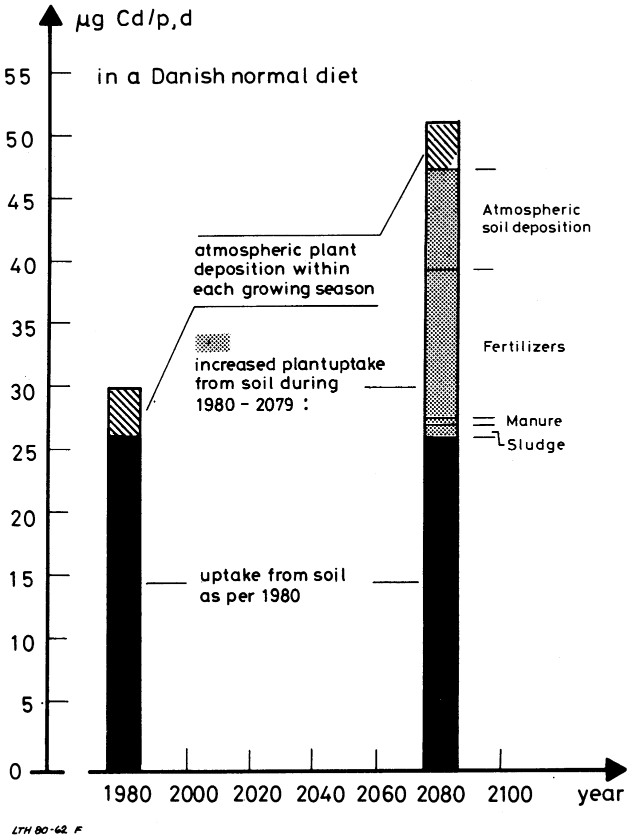


Figure 6. Prediction of the future Cadmium content in the average Danish diet, assuming continued inflow of Cadmium to agricultural soils at present level. From HANSEN /22/.

Let us assume an increase of 0.6 %/y in the average Cadmium concentration in Danish soils to be correct, that Cadmium in soil is not fixed in time, and further that plants behave as shown in Fig. 4. With these assumptions in mind it is possible to predict the likely human food intake of Cadmium in Denmark in the year 2080. The result is shown in Fig. 6. The present food intake, ~30 µg/p,d, is determined both in a basket survey, ANDERSEN /23/ and as an excretion study, HANSEN /24/. The predicted increase to ~50 µg/p,d is largely due to inflows to soils by fertilizer and atmospheric precipitation. Agricultural utilization of sewage sludge is only a minor source in average, but may locally be rather important.

It is interesting to note that KJELLSTRÖM /25/ in their retrospective study on wheat in Sweden found an increase rate in the average concentration of Cadmium in the grain over the last century of approximately 0.6 %/y (of the present level). This Figure from a neighbouring country is in close agreement with the predicted future value based on soil balance studies.

7. CONCLUSIONS

Danish soils presently contain app. 0.2 ppm Cadmium. If no safeguards or controls be introduced, domestically and abroad, an increase may be envisaged which would amount to app. 0.6 %/y, using 1980 as reference.

This figure is based on a simple Cadmium balance established from actual in- and outflows to the soil system, and the result would hold for normal, arable land and loamy to clayish soils. For sandy soils the annual increase may be lower due to increased leaching, but further investigations are required to validate this speculation.

The impact of an annual 0.6 % increase of Cadmium in soil would be a proportionally equal increase of human Cadmium intake. In view of the present Danish weekly intake of app. 200 µg per person, ANDERSEN /23/, HANSEN /24/, as compared with a maximum tolerable weekly intake of 400-500 µg/p as recommended by WHO /26/, such increase in not acceptable. And for several other countries the situation is much more critical.

Therefore, efforts must be made to decrease inflows of Cadmium to agricultural land. In order of priority Cadmium controls should be imposed on emissions to the atmosphere, concentrations in phosphatic fertilizers, and sludges applied to land. For sludges such controls imply lowering of Cadmium in sludge (and sewage); and designated land should be preferred to general agricultural utilization.

It is hoped that investigators in other countries would assess similarly their situation regarding Cadmium soil balances. Ideally the assessment should be based on concentrations and flows such as those identified in the present paper. Particular emphasis should be placed on soil and soil water concentrations of Cadmium in different depths together with a soil characterization comprising a.o. texture, pH, and Calcium.

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EASILY EXTRACTABLE CD-CONTENT OF A SOIL - ITS EXTRACTION, ITS RELATIONSHIP WITH THE GROWTH AND ROOT CHARACTERISTICS OF TEST PLANTS, AND ITS EFFECT ON SOME OF THE SOIL MICROBIOLOGICAL PARAMETERS

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Summary

A laboratory Cd-adsorption experiment with six different soils was conducted to find out the soil parameters which are important in regulating 0.1 M $NaNO_3$ extractable soil Cd. The difference in Cd-adsorption behaviour of soils is explained by the difference in cation exchange capacities and pH of soils.

A growth experiment using five different plants in a sandy loam soil, which was also taken in the Cd-adsorption experiment, was carried out in the green house. Graded doses of Cd in form of nitrate salt were applied. The Cd-doses ranged between 3.6 to 58.1 µg Cd/g soil. There exists a statistically significant relationship between 0.1 M $NaNO_3$ extractable soil Cd, dry matter yield and Cd-uptake for all five plants. In the case of corn the soil samples were also investigated for their microbiological properties and were analysed for NH_4OAc and NH_4OAc + EDTA extractable soil Cd. Both extractants were found to extract in the range of 70 to 90 % of the added Cd which weems to be quite high compared to Cd removal by corn (3-4% of totally added Cd). In contrast, $NaNO_3$ removes only 8-11% of the totally added Cd and is comparable to the Cd-uptake values.

There is a straight-line relationship between $NaNO_3$ extractable soil Cd and tolerance indices (TI) at all Cd-doses and also for all five test plants. From individual equations for each test plant, 0.1 M $NaNO_3$ extractable soil Cd is calculated for a fixed value of tolerance index of 0.8 (at this value 20 % yield reduction occurred). These calculated values for monocot plants i.e. rye grass and corn are 2.71 and 2.53 respectively. In contrast, these calculated values are significantly lower for dicot plants i.e. red clover, turnip and dandelion and found to be 0.54, 0.34 and 0.34 respectively. Further, the calculated extractable soil Cd values are significantly correlated with the cation exchange capacities of roots (r^2 = 0.7). These results substantiate the fact that dicot plants which have low root exchange capacities would tolerate higher amounts of extractable soil Cd than monocot plant roots.

Microbiological studies (counts and biochemical processes) in soil samples suggest that bacteria and yeasts counts were adversely affected at 2.79 µg of extractable soil Cd. Similarly, the NH_4-N accumulation which is an indicator of the inhibition in the nitrification process was found to be directly correlated with the extractable Cd and there is a significant increase at 2.79 µg of extractable Cd.

1. Introduction

Considering the polluting action of a metal which may reach the soil from different sources i.e. air, wastes, water etc. we have to pay special attention to the mobile fraction which includes the free metal ions, soluble complexes present in soil solution and part of the slightly bound metal. This fraction is available to the plant roots and of immediate concern to the optimum growth of plants and soil microorganisms. This makes it clear that the limiting values for soils should not only be based on the total metal content alone, but also include the easily extractable (exchangeable) fraction (5).

In this paper the results of a laboratory and growth experiment are presented and discussed keeping the following objectives in mind:

- to find the effect of soil properties on Cd-adsorption
- to find the relationship between easily extractable Cd, Cd-uptake and dry matter yield of 5 different test plants.
- to find the relationship between easily extractable soil Cd and the cation exchange capacities of plant roots.
- to find the relationship between easily extractable soil Cd and some of the important soil microbiological parameters.

2. Materials and Methods

A laboratory adsorption experiment was initiated to find the effect of soil properties on the magnitude of Cd-adsorption (4). All six bulk soil samples were analysed for selected soil properties which are presented in table 1.

Table 1

Chemical composition of six soils used for the adsorption experiment

Soil Number	Local Name	Clay %	Humus %	Fe_2O_3 %	pH	CEC meq/100g soil
1.	La Châtagne	41.4	18.1	5.03	5.9	57.4
2.	La Châtagne	38.0	17.6	4.33	7.2	54.4
3.	Gänsemoos	14.5	6.0	0.78	5.7	13.6
4.	Gasel	9.4	5.3	0.64	7.2	17.4
5.	Steinhof	13.1	2.1	0.63	5.6	8.0
6.	Erlach	15,6	1,9	0.90	7.3	13.0

All soil samples were supplied with predetermined amounts of total Cd in form of its nitrate salt ranging from 0 to 170 μg Cd/g soil. Increasing amounts of cadmium nitrate solution were added separately to a mixture of 10 g soil + 50ml 0.2 M $NaNO_3$ solution. The final volume of the solution phase was made up to 100 ml with the help of 0.2 M $NaNO_3$. The final ratio between soil: solution was 1:10. These samples were shaken for 90 minutes and filtered. The Cd ion concentration of the clear filtrate was determined through ion specific electrode (4).

A growth experiment in Wagner type pots using 5 different test plants in a sandy loam soil (Steinhof) was conducted. Each pot was filled with 6.6 kg dry soil and received separately 1.5g N, 0.436g P and 1.66g K. The salts used were ammonium nitrate, superphosphate and potassium magnesium sulfate. The amounts of nitrogen added to the pots which received Cd-doses ad cadmium nitrate were respectively corrected. The chemical and physical characterstics of the soil (sandy loam) are shown below:

pH	Clay	Loam	Sand	Humus	total N	P	K	Mg	B	Cation ex change capacity of soil (CEC)meq/100g
	%					μg/g soil				
5.8	16.2	14.6	69.2	2.5	0.15	0.47	0.58	51.3	0.25	4.8

In order to supply 3.6, 14.6, 29.1 and 58.2 μg Cd/g soil, increasing volumes of standard cadmium solution were added to the pots and mixed well. The experiment involves the growth of corn (maize), rye grass, red clover, turnip and dandelion. Each of the treatment was repeated for three times. The dry matter yield was recorded and dried plant materials were analysed for Cd concentration. After the harvest of the test plants, representative soil samples from each pot were collected for the determination of 0.1 M $NaNO_3$ extractable soil Cd. In case of soil samples from corn (maize) pots, the samples were analysed for NH_4OAc + EDTA extractable Cd (4) and for some of the microbiological parameters (6). The cation exchange capacties of roots are taken from the literature (2) and given in table(6).

3. Results and Discussion

A. Cd-adsorption on six test soils varying in physical and chemical properties:

The cadmium adsorption data for six test soils are presented graphically in Fig. 1. A close observation of Fig.1 indicates that with the increase in added total Cd, there is a corresponding increase in the Cd concentration of soil solution, although they differ in their order of magnitude. The following facts can be very clearly illustrated by Fig. 1.

- the difference in the free Cd ion concentration in case of soil 3 and 5 could be attributed to their humus content.
- the difference in free Cd ion concentration in case of soil 1 and 2 is mainly due to the difference in their pH values.
- the difference in free Cd ion concentration in case of soil 4 and 6 could be explained by the difference in their clay and humus content.

It seems that Cd ion concentration of soil solution is closely related to the soil properties such as clay, humus and iron oxides. The statistical analysis of the data (4) show that cation exchange capacities of soils are significantly correlated with the clay, humus and iron oxide content (multiple regression $r^2 = 0.99$). This relationship suggests that cation exchange capacities (CEC_S) of soils represent the other three important soil properties. Further statistical analyses show that there is a significant relationship between $NaNO_3$ extractable soil Cd, CEC_s, total Cd added and pH (multiple regression analysis $r^2 = 0.63$).

Plant roots usually absorb metal from soil solution in ionic form. The $NaNO_3$ extractable soil Cd is easily exchageable and thus could be effective in regulating the uptake of Cd by plants and microorganisms. The amount of Cd ions present in $NaNO_3$ solution at different amounts of total Cd additions, if found correlated with the growth of plants and microorganisms, could provide an estimate for plant available portion of soil Cd content.

B. Comparision between extractable Cd (% of totally added) content removed by three different extractants and Cd-uptake (% of totally added) through corn (maize):

The growth experiment is used to compare the extraction efficiency of $NaNO_3$ with that of other two commonly used extractants i.e. NH_4OAc + EDTA. In table 2 the percentage of extractable soil Cd (% of the totally added) by three different extractants at a ratio of soil to extractant 1:2.5 is presented as a function of totally added Cd. The data indicate that all three extractants dissolve an increasing % of the extractable Cd to the same extent as the amount of added Cd increases. NH_4OAc and NH_4OAc + EDTA extract between 60-85% of the totally added Cd in the soil. Both extractants dissolve such a large amount of added Cd that could be due either to low pH in the first case or low pH and chelate action in the latter (1). On the contrary, the uptake (% of the totally added) of corn ranges between 3.0 to 4.0%. The fact that there exists a large difference in the Cd-uptake (% of total) and extracted soil Cd (% of totally added) indicates that the extracted amount of Cd by both extractants is not a real measure for the soil Cd which is of immediate concern for the growth of corn. It is reasonable to accept the view of Andersson (1) that these extractants determine a part of the potentially available Cd content of soil and are thus a better indicator of the "Quantity Factor". In contrast to both extractants, 0.1 M $NaNO_3$ extracts around 11% of the totally added Cd which is close to the % Cd-uptake i.e. 3-4%. Thus this extractant provides the "Intensity Factor" of soil.

Table 2

Comparision between different values of extractable Cd (% of totally added) and Cd-uptake (% of totally added) through corn (maize)

(Average of three replications)

Cd-doses mg/pot	Cd-uptake (% of the totally added Cd/pot)	Extractable Cd (% of the totally Cd added/pot)		
		NH_4OAc	NH_4OAc+EDTA	0.1 M $NaNO_3$
23.3	4.0	69	75	8
47.0	3	71	78	8
95	3	71	80	9
190.1	3	76	85	10
380.2	3	77	88	11

Relationship between Cd-uptake, dry matter yield and $NaNO_3$ extractable soil Cd:

The soil samples were collected from the pots where all different five plants were grown. The samples were analysed for 0.1 M $NaNO_3$ extractable soil Cd (μg/g soil or 2.5 ml extractant). The plant materials were analysed for Cd content. The results are presented in table 3.

Table 3

Effect of 0.1 $NaNO_3$ extractable soil Cd on the dry matter yield and Cd-uptake of different crop plants. (Average of three replications)

Cd-doses	Soil Parameter	Plant Parameters		
µg/g soil	0.1 M $NaNO_3$ extractable Cd (µg/g soil)	Dry matter	Cd Concentration µg/g	Cd Uptake µg/pot
		Corn (maize)		
0.0	0.05	250.3	0.261	65.2
3.6	0.29	235.4	4.14	975.1
7.3	0.61	230.4	7.31	1683.7
14.6	1.31	213.3	14.48	3087.7
29.1	2.79	194.3	32.57	6327.7
58.2	6.36	149.4	71.18	10634.1
		RYE GRASS		
0.0	0.05	92.2	0.14	13.2
3.6	0.17	91.3	3.32	303.2
7.3	0.36	91.3	6.61	603.8
14.6	0.67	87.6	10.88	953.0
29.1	1.45	81.6	17.78	1450.2
58.2	2.71	74.5	32.45	2420.4
		RED CLOVER		
0.0	0.05	72.3	0.30	21.5
3.6	0.25	68.9	10.36	713.8
7.3	0.43	46.0	22.48	1043.3
14.6	1.03	0.0	-	-
29.1	2.36	0.0	-	-
		TURNIP		
0.0	0.05	96.1	1.54	148.3
3.6	0.13	93.7	38.1	3565.2
7.3	0.33	96.8	65.48	6338.6
14.6	0.81	77.3	107.74	8328.5
29.1	1.46	-	-	-
		DANDELION		
0.0	0.05	26.1	-	-
3.6	0.24	22.5	-	-
7.3	0.50	18.0	-	-
14.6	0.97	7.4	-	-
29.1		0.0	-	-

The statistical analysis which is presented in table 4 shows that there is a significant relationship between the Cd-uptake, dry matter yield and $NaNO_3$ extractable soil Cd. This is true for all five crop plants used in the experiment.

Table 4

Relationship between Cd-uptake by different plants, dry matter yield and $NaNO_3$ extractable soil Cd (soil to extractant ratio: 1:2.5)

Crop plants	Correlation Coefficients (r^2)	
	Dry matter yield	Cd-uptake
Corn (maize)	0.969	0.975
Rye grass	0.984	0.974
Red clover	0.976	0.960
Turnip	0.804	0.958
Dandelion	0.997	

D. Effect of $NaNO_3$ extractable soil Cd at graded Cd-doses on the tolerance indices calculated for different crops:

The tolerance index is calculated in the following way:

$$\text{Tolerance Index (TI)} = \frac{\text{Growth in contaminated soil}}{\text{Growth in normal soil}}$$

The values of tolerance indices and the respective $NaNO_3$ extractable soil Cd are presented in table 5. Out of this table the following valuable information can be drawn:

- The tolerance index for a particular crop decreases as the extractable Cd soil concentration increases. These tendencies are true for all five crops investigated in this experiment.
- In case of monocot plants i.e. rye grass and corn a high level of extractable soil Cd is tolerated (2.8 and 6.4 ppm) compared to dicot plants such as red clover, turnip and dandelion where the values range between 0.43 and 0.97 ppm. However, at these concentrations the calculated tolerance indices (TI) are quite different.

Table 5 - Effect of graded doses of Cd on the 0.1 M $NaNO_3$ extractable soil Cd (µg/g soil) and tolerance indices (TI) of five plants (Monocots and Dicots). (Average of three replications)

Cd-doses µg/g Soil	PLANTS									
	MONOCOT				DICOT					
	CORN		RYEGRASS		RED CLOVER		TURNIP		DANDELION	
	Extr. Cd	T I	Extr. Cd	T I	Extr. Cd	T I	Extr. Cd	T I	Extr. Cd	T I
3.6	0.29	0.94	0.18	0.99	0.25	0.95	0.13	0.98	0.24	0.86
7.3	0.61	0.92	0.36	0.99	0.43	0.64	0.33	1.0	0.5	0.69
14.6	1.31	0.85	0.65	0.95	1.0	-	0.80	0.80	0.97	0.30
29.1	2.79	0.77	1.45	0.89		-	1.46	-		-
58.7	6.36	0.60	2.71	0.81		-		-		-

Table 6 - Relationship between 0.1 M $NaNO_3$ extractable soil Cd and the tolerance indices (TI) (Calculated $NaNO_3$ extractable soil Cd at 0.8 tolerance index).

Plants	CEC_R * meq./100g roots	r^2	T I = a + b. extractable Cd	Calculated extractable soil Cd at 0.8 tolerance index (TI) or 20% yield reduction
Corn	17	0.99	T I = 0.94 - $5.52 . 10^{-2}$. extractable Cd	2.53
Rye Grass	22.5	0.99	T I = 1.0 - $7.54\ 10^{-2}$. extractable Cd	2.71
Turnip	47.5	0.89	T I = 1.21 - 0.76 . extractable Cd	0.54
Red Clover	47.5	0.99	T I = 1.20 - 1.18 . extractable Cd	0.34
Dandelion	65.0	0.99	T I = 1.06 - 0.77 . extractable Cd	0.34

* CEC_R = Roots cation exchange capacity (meq./100 g roots)

The above discussion shows that there is some sort of relationship between extractable soil Cd at various Cd-doses and tolerance indices

As a first step we tried to find the relationship between the tolerance indices and extractable soil Cd at various Cd-doses. The equations are presented in table 6.

The straight-line relationship between extractable soil Cd and tolerance indices are statistically significant. From these equations the amount of extractable soil Cd for different plants at which one would expect a tolerance index of 0.8 (this means a 20% yield reduction) is calculated and also shown in table 6.

The essential and non-essential metals are taken up by different plants by the help of their roots from the soil. Roots of different plants as is known differ in their capacities to absorb nutrients from soil. Thus the cation exchange capacity of root is one of the most important factor which must determine the uptake behaviour of plants. This can be seen out of Fig. 2 which shows a clear relationship between extractable soil Cd at 0.8 tolerance index and the root cation exchange capacity of the five plants tested.

The study of the literature (2) has shown that most of the monocot plant roots have exchange capacities of less than 30 meq. In contrast the cation exchange capacities of dicot plant roots are higher than 30 meq. This means that the dicot plants are quite efficient in absorbing the metals from soil even at a very low concentration of metals in soil solution. Thus 20% of yield reduction (TI = 0.8) is observed between 0.34 and 0.54 µg Cd/g soil for dicot plants, whereas the limit ranges between 2.53 and 2.71 for monocots (s.table 6).

E. Effect of $NaNO_3$ extractable soil Cd on the soil microbiological parameters:

The soil samples where corn was grown are used to study the influence of $NaNO_3$ extractable soil Cd on the soil microbiological properties. These were investigated by Walter and Stadelmann (6) and are presented in table 7.

Table 7

Relationship between 0.1 M $NaNO_3$ extractable soil Cd and some of the plant and soil microbiological parameters. (Average of three replications)

Cd-doses /ug/g soil	Soil Parameters		Plant Parameters			Microbiological Parameters**			
	Ectractable Cd 0.1 M $NaNO_3$ /ug/g soil	pH	Dry matter *	Cd-uptake	N-uptake*	Microbial counts		Biological Activities	
			g/pot	/ug/pot	g/pot	Bacteria	Yeasts	CO_2-Evolution	NH_4-N
						10^7	10^5	/ug/g soil	/ug/g soil
0	0.12	5.1	250.3	65.2	3.5	5.82	1.65	69.3	5.12
3.6	0.29	5.1	235.4	975.1	2.3	4.35	0.82	59.6	4.55
7.3	0.61	5.1	230.4	1683.7	2.3	5.77	1.03	66.1	4.77
14.6	1.31	5.1	213.3	3087.7	2.3	5.17	1.24	78.2	6.25
29.1	2.79	5.1	194.3	6327.7	2.4	0.86	0.24	44.4	6.75
58.2	6.36	5.2	149.4	10634.1	2.7	1.22	0.24	42.6	12.46

** Walter und Stadelmann (7)

* Besson, Daniel and Contat (3)

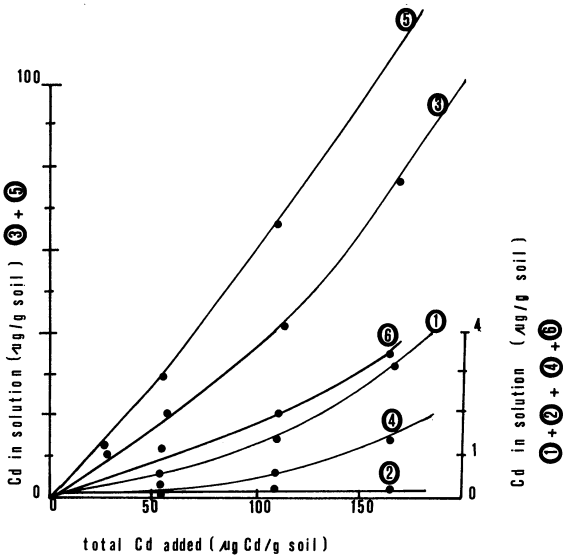

Fig. 1 - Effect of soil properties on Cd concentration at grades doses of Cd

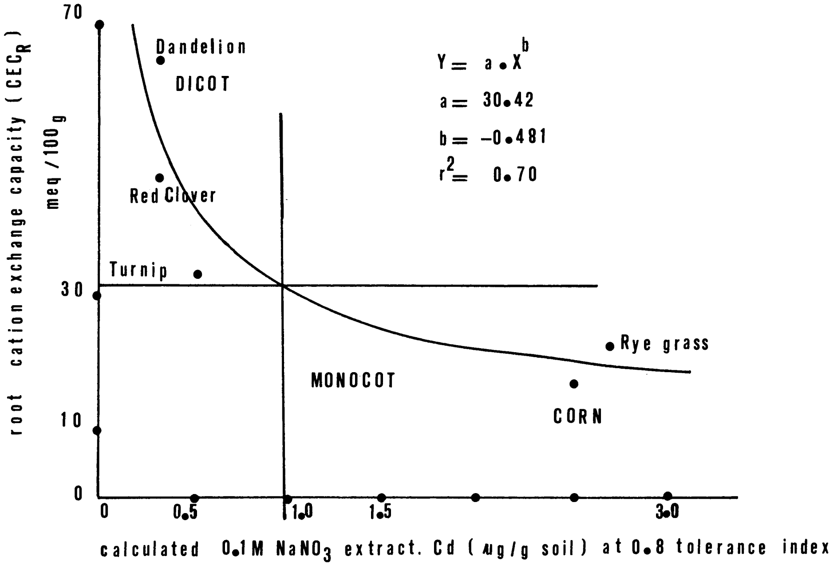

Fig. 2 - Relationship between calculated 0.1 M Na NO_3 extractable soil Cd at 0.8 tolerance index (Tl) of five test plants and cation exchange capacities of their roots

The results presented indicate the following facts:

- There is a linear positive relationship between 0.1 M $NaNO_3$ extractable soil Cd at different Cd-doses and NH_4-N concentration in soil ($r^2 = 0.96$). This means that the increase in Cd-ion concentration in soil solution causes a proportionate increase in NH_4-N content of soil. This accumulation is due to the decrease in nitrifying bacteria inhibited by the increase in soil Cd-ion concentration. In order to support this hypothesis the authors stated that N-uptake by corn at different Cd-doses was about the same. Tough a slight increase in N-uptake is observed at a dose of 58.2 µg Cd/g soil. This observation suggests that NH_4 ion accumulation was not due to different nitrogen uptake but was only due to increase in Cd ion concentration of soil.

- After 2.79 µg $NaNO_3$ extractable soil Cd, a significant reduction in Co_2-evolution, bacterial counts and yeasts were observed. (For camparison: according to table 6 2.53 µg of extractable Cd caused a 20% yield reduction of corn).

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MODELLVERSUCHE ZUR CADMIUMWIRKUNG IN BÖDEN UND PFLANZEN NACH KLÄRSCHLAMMDÜNGUNG

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Kurzfassung

Es werden Ergebnisse aus einem Schwermetallbelastungsversuch mit unterschiedlichen Bodeneigenschaften vorgestellt.

Ergebnisse

Die Aufnahme von Cadmium durch die Pflanze ist stark von der Pflanzenart und den untersuchten Pflanzenteilen abhängig.

Niedrige pH-Werte im Boden verstärken die Aufnahme von Cadmium durch die Pflanze.

Der Einfluß des Tongehaltes im Boden auf die Cadmiumaufnahme der Pflanze ist geringer als der des pH-Wertes.

Die Verfügbarkeit des Cadmiums für die Pflanze ist noch von weiteren Bodenparametern wie Redox - Potential und dem Anteil an org. Substanz abhängig.

Summary

Results of a heavy metal - load trial at different soil parameters are presented.

Results:

The uptake of Cadmium by agriculture plants depends on flora species and the examined parts of the plants.

Low pH-values in soils increase the uptake of Cadmium by plants.

The influence of clay contents in soils on the uptake of Cadmium by plants is lower than it is the pH-value.

The availability of Cadmium for plants depends as well on other soil parameters like oxidation - reduction potential and content of organic matter.

1. EINFÜHRUNG

In der Bundesrepublik Deutschland fallen jährlich etwa 2 Mio. t Klärschlamm-Trockenmasse an. Diese Menge wird sich nach Schätzung des Umweltbundesamtes nach Endausbau der Abwasserreinigung auf ca. 4 Mio. t erhöhen (8).
Zur Zeit werden von dem anfallenden Klärschlamm nur ca. $^1/_3$ landwirtschaftlich verwertet.
Oftmals stehen hohe Gehalte an Schwermetallen einer landw. Verwertung entgegen. Hierbei spielt das Cadmium mit seiner hohenpflanzenphysiologischen Aktivität eine besondere Rolle. Feige u. Grunwaldt haben 1977 erste Richtwerte für Schwermetallgehalte in Klärschlämmen hinsichtlich ihrer landbaulichen Verwertung aufgestellt (1). So gelten Schlämme, die Cadmiumgehalte von 10 - 30ppm Cd in der TS enthalten, als bedingt geeignet. Die Richtwerte für Klärschlämme der Schweiz, Schwedens und der Niederlande liegen in der gleichen Größenordnung. In den USA sind teilweise (Pennsylvania) bis zu 50ppm Cadmium erlaubt.
Nach einer Erhebung in der Bundesrepublik von von Rincke u. Riegler werden 30ppm Cadmium nur in 4,2% der untersuchten Klärschlämme (n=728) überschritten (7).
Für Cadmiumgehalte im Boden gibt es zur Zeit keine gesetzlichen Grenzwerte. Kloke stellte 1977 Orientierungsdaten für tolerierbare Gesamtgehalte von einigen umweltrelevanten Schwermetallen im Boden auf (4). Für Cadmium lag dieser Wert bei 5ppm im luftrockenen Boden. Kloke geht dabei von dem mit Königswasser extrahierbaren Anteil aus; da nicht nur mit der aktuellen Gefährdung durch Schwermetalle gerechnet werden darf, sondern ausgehend vom ungünstigsten Fall, der potentiellen Gefährdung. In England z.B. beträgt dieser Grenzwert für Cadmium im Boden bei 2ppm.

2. VERSUCHSANSTELLUNG

Zur Überprüfung des Einflusses bodenkundlicher Parameter auf die physiologische Aktivität (Aufnahme durch die Pflanze) der Schwermetalle Cd, Cu, Zn, Pb, Cr und Ni wurde 1977 ein Gefäßversuch angelegt.

Im Folgenden soll hier nur auf die Problematik des Cadmiums eingegangen werden.
Die Böden wurden aus einer Mischung aus Klärschlamm und $CdSO_4$ auf Gehalte von 2 5,und 10ppm Cadmium im Boden eingestellt. Der Wert von 5ppm entsprach dem von Kloke für toleriebar gehaltenen Orientierungswert. Daneben läuft noch ein Prüfglied ohne zusätzliche Belastung von Schwermetallen mit einem Basisgehalt von 0,4ppm Cadmium.
Die pH-Werte der Böden wurden auf 4,7; 5,7; 6,7 und 7,0 mit 2% freiem Kalk gebracht.
Der Tongehalt der Versuchsböden (Brackmarsch, uT) wurde mit Hilfe von Quarzsand auf drei Stufen von 10%, 20% und 40% Ton eingestellt. Somit sind einheitliche Tonmineralgemische in den drei Versuchsböden gewährleistet.
Die Vegetationsversuche wurden in 5-l-Mitscherlich-Gefäßen durchgeführt und mit dest. Wasser gegossen.
Alle Versuchsfrüchte wurden mit einer Ausgleichsdüngung von N,P und K nach Bodenuntersuchung versehen.
Als Versuchsfrüchte wurden 1977 und 1980 Oldenburger Weidelgras (Lolium multiflorum) und 1978 Sommergerste (Hordeum vulgare) und Raps (Brassica napus) ausgewählt.
Zur Untersuchung des Reaktionsverhaltens von Cadmium an org. Substanz wurden Schüttelversuche mit Torfen durchgeführt, welche unterschiedlich stark mit Eisen und Calcium belegt waren(3).

3. UNTERSUCHUNGSMETHODEN

3.1. Pflanzenvorbereitung

Nach der Ernte wurde das Pflanzenmaterial bei 105°C über 24h getrocknet und danach der Trockensubstanzgehalt bestimmt.
Anschließend wurde das Pflanzenmaterial mit einer Schlagkreuzmühle der Fa. Retsch staubfein gemahlen.
2,5g der Trockensubstanz wurden in Quarzschalen eingewogen und im Muffelofen bei 450°C verascht. Die Asche wird mit 12,5ml 8N HCl aufgenommen und in einen 250ml Kolben überspült und mit dest. Wasser aufgefüllt.

3.2. Bestimmung des Cadmium durch AAS

Zur Bestimmung von Schwermetallen steht ein AAS-Gerät der Fa. Zeiss, Typ FMD 3 mit Untergrundkompensator, zur Verfügung. Gemessen wird in einer C_2H_2/Luft - Flamme, Wellenlänge 228,8nm, Spaltbreite 0,4mm, Lampenstrom der Hohlkathodenlampe 5mA.
Die höchste Eichlösung wird mit 2µg Cd ml^{-1} in 0,4N HCl angesetzt.

4. ERGEBNISSE

4.1. Weidelgras

Das Weidelgras wurde im Versuchsjahr 1977 besonders durch die hohen Schwermetallgehalte im Boden während der Vegetationszeit geschädigt; was sich später in den geringen TM-Erträgen bemerkbar machte. Hohe pH-Werte und Tongehalte im Boden verminderten die Aufwuchsstörungen merklich.
Die Cadmiumgehalte im Weidelgras (siehe Tabelle I) zeigen eine deutliche Zunahme in Abhängigkeit von den Belastungsstufen. In der unbelasteten Variante (0,4ppm Cd) wird durch das Gras nicht mehr als 1,0ppm Cadmium in der TS aufgenommen. Schon in der unbelasteten Variante zeigt sich aber eine Abhängigkeit der Cd-Aufnahme vom pH-Wert und Tongehalt. Diese Tendenz verstärkt sich in den mit Cadmium belasteten Stufen noch deutlicher.
Das Gras der Belastungsstufe III(10ppm Cd im Boden) nimmt im 1. Versuchsjahr Cadmium bis zu einem Gehalt von 35ppm auf. Trotzdem ist auch in der III. Belastungsstufe eine Abnahme der Cadmiumgehalte in Abhängigkeit des pH-Wertes zu erkennen. In den Varianten pH 4,7 und der höchsten Belastungs stufe finden sich geringere Cadmiumgehalte als in der pH 5,7 Variante. Dieses ist wahrscheinlich darauf zurückzuführen, daß die Erträge in diesen Gefäßen nur sehr niedrig lagen.

Nicht so ausgeprägt wie die pH-Wirkung auf die Cadmiumaufnahme durch das Gras ist der Einfluß des Tongehaltes im Boden. Hier lassen sich keine gesicherten Unterschiede, sondern zunächst nur Tendenzen erkennen. Während bei den Böden mit 10% bzw. 20% Tongehalt die Abhängigkeit der Cd-

TABELLE I

Ton-gehalt	pH-Wert	Belastungs-stufe(ppm Cd)		So-Gerste Stroh	So-Gerste Korn	Raps	Gras
10 %	4,7	0	0,4	1,4	0,2	5,1	1,0
		I	2,0	1,9	0,4	6,5	1,1
		II	5,0	27,0	-	-	6,0
		III	10,0	-	-	-	-
	5,7	0		1,5	0,3	2,0	1,0
		I		1,3	0,4	1,3	1,0
		II		7,0	0,4	8,0	4,8
		III		5,7	-	-	22,0
	6,7	0		0,6	0,2	0,9	0,4
		I		0,6	0,4	1,1	1,0
		II		3,9	0,5	5,6	4,5
		III		22,0	2,0	18,0	18,0
	7,0+ 2% $CaCO_3$	0		0,4	0,3	0,6	0,7
		I		0,6	0,4	0,7	0,8
		II		2,6	0,6	4,5	2,8
		III		56,0	0,6	10,0	4,5
20 %	4,7	0		0,3	0,4	3,6	0,5
		I		2,2	0,4	6,0	1,2
		II		10,0	0,6	-	5,8
		III		22,0	2,8	-	10,0
	5,7	0		0,4	0,4	0,6	0,5
		I		1,1	0,5	1,2	1,1
		II		5,5	1,2	6,5	6,6
		III		32,0	2,3	-	35,0
	6,7	0		0,4	0,3	0,5	0,6
		I		0,6	0,6	1,0	1,0
		II		3,3	0,6	5,3	5,3
		III		8,4	1,3	10,0	12,0

TABELLE Ia

Ton-gehalt	pH-Wert	Belastungs-stufe (ppm Cd)		So-Gerste		Raps	Gras
				Stroh	Korn		
20 %	7,0 + 2% $CaCO_3$	0	0,4	0,3	0,2	0,4	0,5
		I	2,0	0,5	0,3	0,6	0,5
		II	5,0	2,2	0,6	4,7	2,7
		III	10,0	4,3	0,7	10,0	4,7
40 %	4,7	0		0,5	0,3	2,3	0,4
		I		2,5	0,6	3,3	1,3
		II		12,0	1,5	-	5,9
		III		16,0	2,7	-	11,4
	5,7	0		0,4	0,2	1,7	0,6
		I		1,7	0,5	2,6	1,6
		II		12,0	1,8	-	6,7
		III		17,0	3,1	-	15,8
	6,7	0		0,4	0,3	0,7	0,8
		I		1,3	0,5	1,7	1,0
		II		10,5	1,6	10,0	4,4
		III		23,0	4,1	-	10,7
	7,0 + 2% $CaCO_3$	0		0,3	0,4	0,5	0,5
		I		0,6	0,7	0,6	0,5
		II		1,7	0,6	5,5	2,7
		III		4,1	1,1	13,0	5,4

Tabelle I und Ia: Cadmiumgehalte von Pflanzen in Abhängigkeit verschiedener Cadmiumbodengehalte, Boden-pH und Tongehalt.

-Aufnahme vom pH-Wert des Bodens durch größere Unterschiede im Cadmiumgehalt zu erkennen ist, sind bei allen Belastungsstufen im schweren Boden (40% Ton) die Cadmiumgehalte auf ein relativ niedriges Niveau gesunken.
Obwohl in einigen Varianten kein Aufwuchs festzustellen war, läßt sich der Ertragsausfall nicht allein auf die hohe

Cadmiumbelastung des Bodens zurückführen. Die Böden waren wie o.a. mit weiteren Schwermetallen (Cu, Zn, Pb, Ni und Cr) sehr hoch belastet worden, so daß die toxische Wirkung auf die Gesamtheit der im Boden vorhandenen Schwermetalle zurückgeführt werden muß.

4.2. Sommergerste

Die Gerste reagierte sowohl mit dem Stroh als auch mit dem Kornertrag empfindlich auf hohe Schwermetallgehalte im Boden. Auch die Schädigung der Gerste wurde durch hohe pH-Werte und Tongehalte im Boden merklich verringert.
Die Aufnahme von Cadmium durch die Sommergerste im 2. Versuchsjahr (siehe Tabelle I) gestaltet sich ähnlich wie beim Gras. Die Cadmiumgehalte im Stroh der Gerste liegen in etwa in der gleichen Größenordnung. Ebenso deutlich ist der Einfluß des pH-Wertes zu bemerken.
Die Cadmiumgehalte im Korn liegen dagegen wesentlich niedriger als im Stroh. Bei einigen extremen Varianten (niedriger pH-Wert und hohe Cadmiumbelastung) findet man mehr als 1ppm Cadmium im Korn der Gerste. Doch in der Regel liegen die Cadmiumgehalte im Gerstenkorn unter 0,6ppm.
Auch bei der Gerste ist die Tonwirkung nicht so deutlich ausgeprägt wie die des pH-Wertes. Abgesehen von der Tatsache, daß es in den tonarmen, sauren Böden bei Belastungsstufe II und III nicht mehr zur Kornausbildung kommt.

4.3. Grünraps

Aus den Gehaltsangaben von Cadmium im Raps(siehe Tab. I) läßt sich erkennen, daß Raps als Blattfrucht Cadmium stärker anreichert als Gerste. Selbst bei den Böden mit 0,4ppm Cd (Belastungsstufe 0) finden sich bei niedrigen pH-Werten bis zu 5,1ppm Cadmium in der Pflanze. Doch scheint das Aufnahmevermögen des Rapses für Cadmium begrenzt zu sein, da auch unter extrem hohen Belastungsbedingungen maximal "nur" 18ppm Cadmium wiedergefunden werden.
Auch beim Raps ist wiederum eine ausgeprägte pH-Wirkung festzustellen. Gerade bei dieser Pflanze bewirkt eine pH-Erhöhung im Boden stark sinkende Cadmiumgehalte.

Eine Tonwirkung läßt sich in den sauren Varianten erkennen. sie ist aber nicht sehr ausgeprägt.

4.4. Schüttelversuche zum Sorptionsverhalten von Cadmium

Die Gleichgewichtsversuche von Cadmiumlösung mit Torfen unterschiedlichen pH-Wertes ergaben eine deutliche Abhängigkeit des Sorptionsverhaltens vom pH-Wert. Mit steigendem pH-Wert (bis pH 7,0) wurde der Anteil des gelösten Cadmiums von der zugegebenen Menge (940 µval) von 60 auf durchschnittlich 10% gesenkt. Die Wirkung unterschiedlicher Eisengehalte in den Torfen auf das Sorptionsvermögen von Cadmium an der org. Substanz ist nicht so ausgeprägt wie der Einfluß des pH-Wertes.

5. DISKUSSION

Die vorliegenden Ergebnisse basieren auf Versuchen, welche mit einer Vielzahl von Schwermetallen durchgeführt wurden. Dieser Versuch sollte die komplexen Vorgänge eines mit hohen Schwermetallgehalten versehenen Klärschlamm - Boden - Gemisch wiederspiegeln. Hierbei spielen sicherlich auch Antagonismen oder Synergismen der einzelnen Elemente eine wichtige Rolle, welche aber im Einzelnen nicht geprüft werden konnte. Trotzdem lassen sich die Anreicherungen von Cadmium in den Pflanzen recht gut zu den Gehalten im Boden in Beziehung setzen. Allerdings kann bei den aufgetretenen Ertragsdepressionen gerade wegen der komplexen Wirkung vieler Schwermetalle nicht von einer reinen Cadmiumwirkung gesprochen werden.
Die Frage nach der Wirkung der org. Substanz auf das Verhalten des Cadmiums im Boden ist in diesen Versuchen nur im Modell bearbeitet worden (3). Die Ergebnisse decken sich weitgehend mit den von Leeper(6) beschriebenen Reaktionen. Inwieweit die Mineralisation der org. Substanz Auswirkungen auf die Mobilität des Cadmiums hat muß in weiteren Untersuchungen überprüft werden.
Unberücksichtigt bei unseren Untersuchungen blieb auch der Einfluß des Red-Ox-Potentials auf die Pflanzenverfügbarkeit des Cadmiums. Herms u. Brümmer (2) haben festgestellt, daß

Cadmium gerade unter oxidierenden Bedingungen bei niedrigem pH-Wert eine hohe Löslichkeit besitzt. Dieses würde die deutliche pH-Wirkung in den vorliegenden Versuchen erklären.
Aus den bisherigen Untersuchungen kann der große Einfluß der Bodenreaktion vor dem Tongehalt auf die Cadmiumaufnahme der drei Versuchspflanzen deutlich gemacht werden. Die von Kloke insgesamt herausgestellten mittleren Toleranzstufen (II) haben sich bei unseren Versuchen als in ihrer Größenordnung richtig herausgestellt.
In tonarmen Böden (10%) ermöglichen steigende pH-Werte zwar noch ein Pflanzenwachstum, jedoch ist mit hohen Cadmiumgehalten in den Versuchspflanzen zu rechnen.
Aus diesem Grunde hat Kloke 1980 die Orientierungswerte für Cadmium im Boden von 5 auf 3ppm herabgesetzt. Nach den dargestellten Ergebnissen scheint dieser Schritt durchaus richtig zu sein. Denn letzlich geht nicht nur darum die Pflanze vor Schädigungen durch Schwermetalle zu bewahren, sondern auch Anreicherungen von Schwermetallen in den Pflanzen zu vermeiden. Der Sprung zwischen den Belastungsstufen II (5ppm) und I (2ppm) in den Pflanzengehalten an Cadmium zeigt, daß hier die Grenze der toleriebaren Gehalte von Cadmium im Boden zu suchen sind. In sauren Böden (pH4,7 und 5,7) wird Cadmium bei 5ppm im Boden schon relativ stark in den Pflanzen angereichert.
Der Unterschied bei der Aufnahme von Schwermetallen zwischen Monokotyledonen und Dikotyledonen ist in der Literatur mehrfach beschrieben worden.

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EFFECTS OF SEWAGE SLUDGE ON THE HEAVY METAL CONTENT OF SOILS AND CROPS : FIELD TRIALS AT CASSINGTON AND ROYSTON

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Summary

In order to assess the impact of the agricultural utilisation of sewage sludge on the heavy metal content of soils and crops the UK Department of the Environment has commissioned three comprehensive field trials. These trials are concerned principally with Cd, but Pb, Cu, Ni and Zn are also being monitored. One trial, managed by the Water Research Centre, is taking place at Royston on a calcareous loam soil and the two remaining trials at Cassington, managed by the Thames Water Authority, are on sandy loam and clay soils. The design of the three, 180 plot experiments is described; the highest rate of application of sludge added 21 kg Cd/ha to the soil. A rotation of crops including wheat, potatoes, ryegrass, cabbage, lettuce and beetroot will be grown throughout the duration of the experiment. The first year's results confirmed the importance of crop genotype as well as soil properties in determining the availability of metals in soil. Assessment of potential hazard where sludge is used on land should take account of both soil concentrations of metals which indicate the extent of contamination, and metal concentrations in crops which indicate the significance of contamination in terms of phytotoxicity and entry into the foodchain.

1. INTRODUCTION

The population of the UK has probably the highest proportion in the world served by sewerage systems, and sewage-treatment produces 30 million wet tonnes (1.25 million dry tonnes) of sludge annually. Approximately 50 per cent of this sludge is disposed of by utilisation on agricultural land as a fertiliser. It is obviously desirable to recycle the plant nutrients and organic matter in the sludge. At the same time, it is well known that sludge contains higher concentrations of various elements than do most soils so that uncontrolled applications of sludge to land could conceivably build up soil concentrations of these elements to levels toxic to plants or the animals which eat them. Awareness of this problem has led to stricter controls on industrial discharges to sewers with the result that metal concentrations in sludges from sewage-treatment works with industrial catchments have been reduced by up to tenfold over the last decade. A recent survey found that the median concentration of cadmium in UK sludges was 17 mg/kg dry solids (d.s.) and the mean was 29 mg/kg d.s.; less occurs in sludges derived from predominantly domestic sewage (about 8 mg/kg d.s.) and more in sludges from works receiving industrial effluents. For instance, the concentration of Cd in sludge from one large works near London was about 65 mg/kg d.s. in 1979 despite limitations on Cd discharges in industrial effluents chosen as being the most stringent realistically attainable by industry, requiring advanced pretreatment techniques in some cases (1). In contrast to sludge, the concentration of Cd in uncontaminated soil is less than 1 mg/kg.

Whilst Cd and other metals continue to occur in higher concentrations in sludge than in soil a potential contamination problem will exist where the sludge is disposed of as a fertiliser of agricultural land. The significance or hazard associated with the accumulation of sludge-borne metals in soil depends on their availability for plant uptake and for leaching into groundwater. Where sludge is used only on soils with a pH value of at least 6, which is the usual practice in the UK, leaching of metals is likely to be minimal. Instead, the elements added in sludge accumulate in the top soil and any hazard relates to their availability for crop uptake on which phytotoxicity and entry into the foodchain depend.

In order to assess the impact of the agricultural utilisation of sewage sludge on the heavy metal content of soils and crops the UK Department of the Environment has commissioned three comprehensive field trials.

The trials are concerned principally with Cd, but Pb, Cu, Ni and Zn are also being monitored. One trial, managed by the Water Research Centre, is taking place at Royston on a calcareous loam soil and the two remaining trials at Cassington, managed by the Thames Water Authority, are on sandy loam and clay soils. A major purpose of the trials is to assess the hazard of using sludge in agriculture by quantifying the extent to which metals pass from sludge-treated soil into crops. This paper briefly describes the design of the trials and discusses some of the first year's results from crops harvested in 1979.

2. DESIGN AND ESTABLISHMENT OF THE TRIALS

Soils at the three sites are described in Table I. The design of the trial at each site was identical, consisting of 6 randomised blocks of 30 plots of 10 m x 2 m, making 180 plots in all. There were 15 treatments within each block, comprising 5 rates of application (including a nil) of 3 sludges, all treatments being replicated. Metal concentrations in the sludges are shown in Table II. Apart from their metal content, sludges S_1 and S_2 were very similar in nature, both being digested and lagoon-matured. The third sludge (S_3) was obtained by mixing sludges S_1 and S_2 in the ratio 1:2 on a dry solids basis. Sludge was applied to the plots during the winter of 1978/79 following the installation of dividers between the plots which were required to prevent lateral movement of the sludge. In 1979 it was decided to incorporate 2 further treatments into each block using dried, digested sludge (S_4) which permitted very high rates of application of sludge dry solids to be made. Table III describes the treatments in terms of metal additions at the Royston site and has been adjusted to take account of small variations found amongst batches of sludge received on-site. Rates of application of metals at the Cassington site were very similar. Sludge was cultivated into the soil to a depth of 15 cm. A rotation of crops will be grown on each of the 6 blocks over the duration of the experiment. The crops selected were winter wheat (*Triticum aestivum* L. cv. Maris Huntsman) although spring wheat (cv. Timmo) had to be grown in 1979; potatoes (*Solanum tuberosum* L. cv. Pentland Crown); ryegrass (*Lolium perenne* L. cv. Melle); Cabbage (*Brassica oleracea* L. cv. Stonehead); red beet (*Beta vulgaris* L. cv. Crimson globe) and Lettuce (*Lactuca sativa* L. cv. Mildura). Management of the sites including such aspects as crop husbandry and harvesting, treatment with inorganic fertilisers, herbicides and pesticides, protection from birds, and irrigation, is conducted

Table I Details of the soils

Location	Royston	Cassington	
Texture	Calcareous loam	Sandy loam	Clay
Series	Swaffham Prior	Sutton	Carswell
Cation exchange capacity, CEC (meq/100g)	20	13	29
pH value	8.0	6.5*	6.5*
Nitric acid extractable metals (mg/kg)			
Cd	0.5	0.2	0.7
Pb	49	29	33
Cu	12	21	26
Ni	9	38	43
Zn	60	123	143

* after liming

Table II Concentrations of metals in the sludges (mg/kg d.s.)

Element	Sludge Type		
	S_1	S_2	S_3
Cd	68	12	31
Pb	500	420	447
Cu	1160	400	650
Ni	240	60	120
Zn	2050	1100	1420

Table III Metals added to soil by the sludge treatments

Sludge type	Treatment	Dry solids addition (t/ha)	Metal additions (kg/ha)				
			Cd	Pb	Cu	Ni	Zn
S_1	R_1	19	1.3	9.5	22	4.5	39
	R_2	38	2.6	19	44	9	78
	R_3	76	5.2	38	88	18	156
	R_4	152	10.4	76	176	36	312
S_2	R_1	19	0.24	8	7.5	1.2	21
	R_2	38	0.48	16	15	2.4	42
	R_3	76	0.95	32	30	4.7	83
	R_4	152	1.90	65	60	9.3	166
S_3	R_1	18	0.6	8.5	12	2.3	27
	R_2	35	1.2	17	24	4.5	53
	R_3	71	2.3	33	48	9	105
	R_4	141	4.6	66	96	18	210
S_4	R_4	250	10.5	105	190	58	333
	R_5	500	21	209	380	116	666

according to normal farming practices. Detailed records of crop growth are kept throughout each season so that anomalous effects, on yield for instance, are detected.

3. RESULTS

Various parameters will be measured for the duration of the trials; the main factors being crop yields and contents of heavy metals, and total (strong acid-extractable) and extractable metal concentrations in the soil. Secondary factors include the effect of sludge on soil physical and chemical properties (density, water-holding capacity, pH value, CEC), and the movement of metals down soil profiles. At this time, it is possible to present only a brief summary of the results and this is based on Cd and the effects of the two most contaminated sludges, S_1 and S_3 (Table II) at rates R_1-R_4 (Table III). Each point on the graphs shown in the figures is a mean of 2 replicates.

Figure 1 shows that increases in soil concentrations of Cd were a linear function of Cd added in sludge; correlation coefficients (r values) for soils from the three sites were highly significant ($P = <0.001$). Increases in soil concentrations of Cd on the sandy loam soil agreed quite closely with expected concentrations assuming even mixing of sludge throughout 15 cm of top soil. Increases in concentrations on the calcareous loam and clay soils were similar (up to about 9 mg/kg of Cd at the highest application rate of sludge) but were greater than the expected values.

Figure 2 shows Cd concentrations in crops grown on the Royston site in 1979, the first growing season after application of sludge. Wheat grain, ryegrass and potato tubers showed little increase in tissue concentration of Cd as a result of Cd additions in sludge. Concentrations of Cd in these crops increased from about 0.1 mg/kg dry matter (d.m.) in samples from the control plots which had received no sludge, to about 0.25 mg/kg d.m. on plots which had received 10.4 kg Cd/ha added as sludge. Cabbage and the roots of red beet showed slightly greater increases in Cd concentrations as a result of sludge treatment and at the highest rate of application of Cd (10.4 kg/ha) cabbages contained 0.57 mg Cd/kg d.m. and roots of red beet 0.69 mg/kg d.m. Much higher concentrations of Cd occurred in lettuce and in the leaves of red beet. Concentrations of Cd in these crops were higher than those in the other crops even on the control plots and they increased markedly as a result of sludge treatment. At the highest application rate,

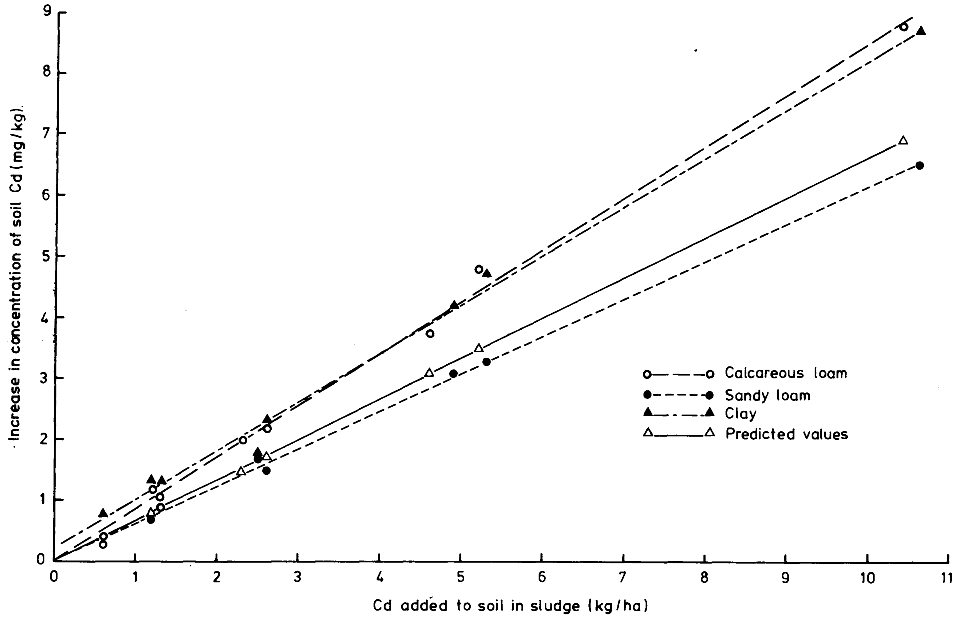

Fig. 1 - Increases in soil concentrations of Cd resulting from Cd added in sludge

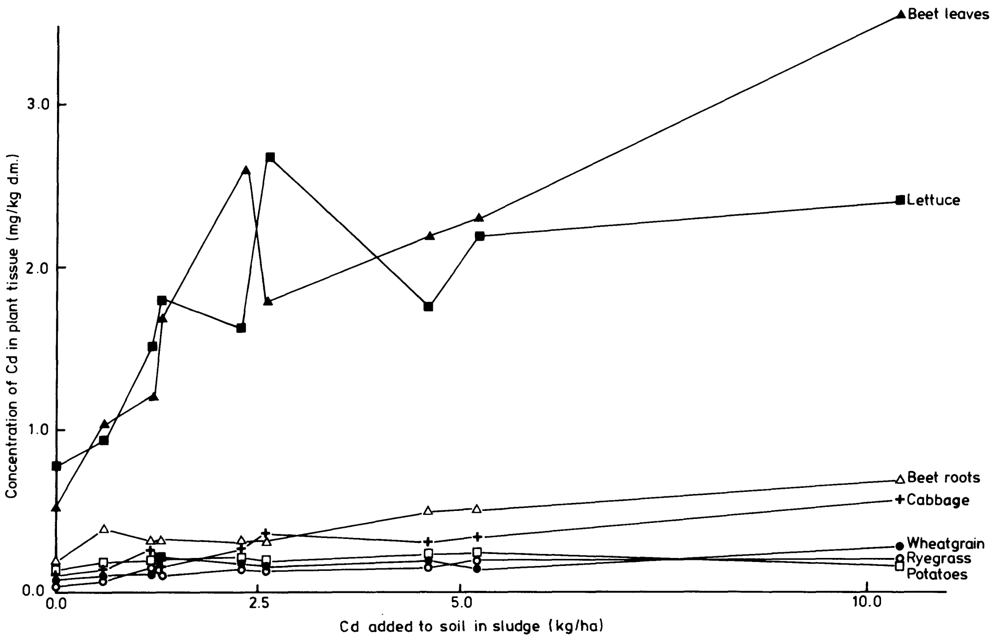

Fig. 2 - Cd concentrations in crops from the Royston site

the concentration of Cd in lettuce leaves was 2.39 mg/kg d.m., and in red beet leaves 3.56 mg/kg, compared with 0.78 mg/kg and 0.52 mg/kg respectively on the control plots. Concentrations of Cd in the crops from Royston decreased in the order: red beet leaves > lettuce >>> red beet roots = cabbage >> ryegrass = wheat grain = potatoes. A similar trend was observed amongst crops grown on the Cassington sites.

Figure 3 shows how soil type influenced Cd concentrations in two crops, wheat grain and ryegrass. These results relate to crops grown on plots treated with the most contaminated sludge, S_1 (Table III). For both crops, highest concentrations occurred on the clay soil followed by the sandy loam, with lowest concentrations on the calcareous loam.

Figure 4 shows uptake of Cd by wheat from the calcareous loam at Royston; wheat gave the highest yield of dry matter per hectare in 1979. There was greater uptake into wheat straw than into grain. At sludge treatment S_1R_3, which added 5.2 kg Cd/ha to the soil, 0.33 g Cd was recovered in wheat grain and 1.38 g in wheat straw making a total recovery of 1.71 g or 0.033 per cent of the Cd added in sludge. If allowance is made for the 0.57 g of Cd taken up by wheat grown on the control plots, then 1.14 g or 0.022 per cent of the Cd added to soil in the sludge was recovered in the standing crop.

Cadmium apart, there were modest increases in crop concentrations of Ni and Zn with increasing additions of sludge to soil, smaller increases in Cu concentrations in crops but no noticeable response to Pb added to soil in sludge. Highest concentrations of Ni, Zn and Cu occurred in the leaves of the crops compared with non foliar edible parts such as the roots of red beet, potato tubers and wheat grain. Zinc concentrations in ryegrass from the three sites are shown in Figure 5. Concentrations of Zn in this crop increased most on the sandy loam and clay soils with smaller increases on the calcareous loam. There was a steady increase according to sludge treatment from about 30 mg Zn/kg d.m. on the control plots to about 85 mg/kg d.m. on plots which had received 312 kg/ha of Zn as sludge in the case of the sandy loam and clay soils, and to about 65 mg/kg d.m. for the calcareous loam.

4. DISCUSSION

A problem encountered in experiments with sludge occurs in the separation of the beneficial effects of the plant nutrients and organic matter it

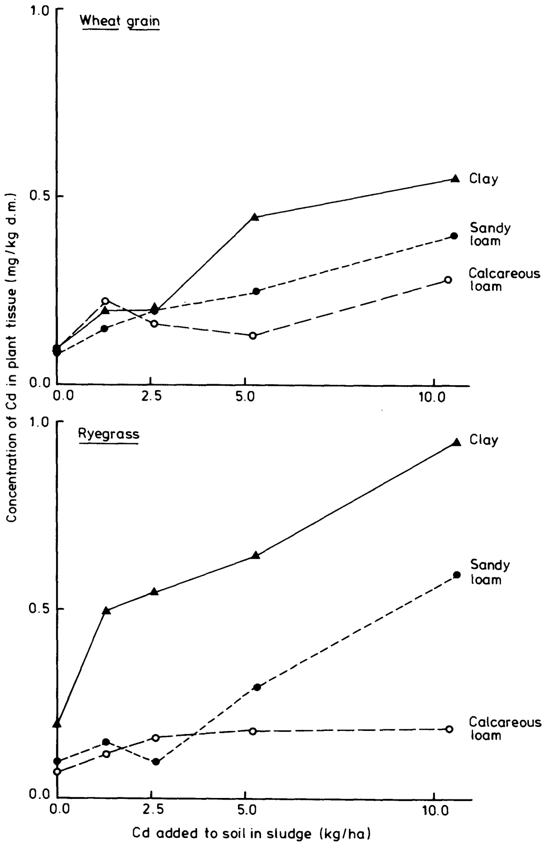

Fig. 3 - The effect of soil type on crop concentrations of Cd

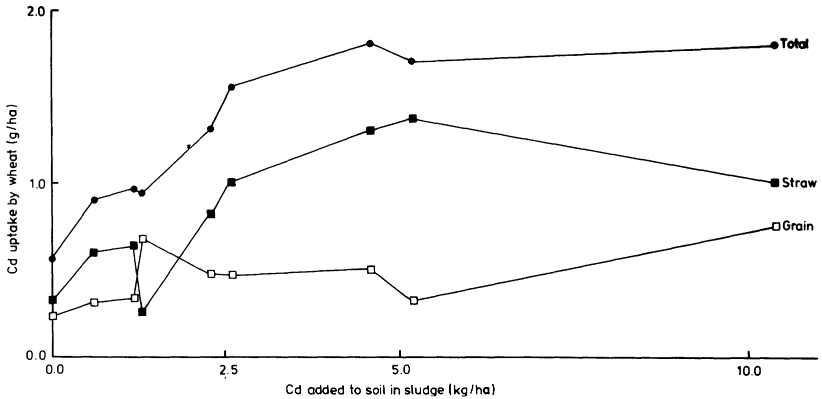

Fig. 4 - Cd uptake by wheat from the Royston site

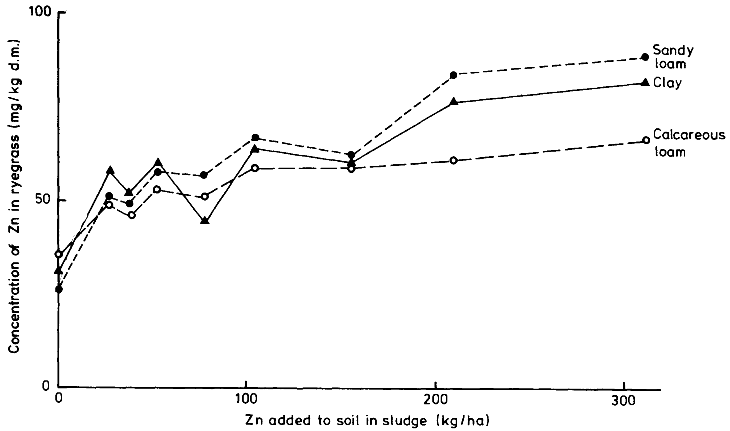

Fig. 5 - Zn concentrations in ryegrass from the three sites

contains from the harmful effects of metals; this applies particularly to the interpretation of yield data. The design of the trials at Cassington and Royston has the advantage that corresponding rates of application (R_1-R_4) of the three different sludges (S_1-S_3) involved approximately the same quantity of sludge dry solids (Table III). Since the sludges were all of the same type and differed only in their metal contents, any variations in yield according to sludge-type at the same rate of application should be attributable to metal effects. For instance, application rate R_4 of sludge S_1 added to the soil considerably more metals than rates R_4 of sludges S_2 and S_3 yet all R_4 plots for these sludges received comparable amounts of sludge organic matter and plant nutrients. In the first year, yields were affected by the very large quantities of nitrogen added in sludge at the high rates of application. Thus application rate R_4 for sludges S_1-S_3 added to the soil approximately 6 t/ha of nitrogen. As this nitrogen is dissipated during successive years of cropping it is expected that any yield effects due to metals in the sludge will become apparent. In the first year, there was no evidence of depressed yields at the high rates of application of sludge. Indeed, yields were higher on plots which had received sludge compared with unsludged control plots. This was probably connected partly with nutrients, although control plots received inorganic fertiliser, and partly with improvements in soil water-holding-capacity on plots which had received sludge.

Figure 1 shows that additions of sludge to soil increase soil concentrations of Cd in proportion to the quantity of Cd added in the sludge. It is of interest that Cd concentrations observed in two of the soils (the clay and calcareous loam) differed considerably from predicted values based on the assumption that sludge was evenly incorporated into 15 cm of top soil. It seems that a simple relationship between Cd added to soil in sludge and the resulting concentration of soil Cd cannot be assumed even for experimental plots where every care is taken to incorporate the sludge evenly. This relationship is likely to be more uncertain in operational practice especially where sludge is applied to the soil surface and not ploughed in.

Figure 2 illustrates the importance of crop genotype with respect to availability of Cd in soil. The results confirm that certain crops, such as lettuce and red beet, are capable of achieving concentrations of Cd in their leaves which may sometimes exceed the concentration of Cd in the soil in which they grow. In this respect they are much more efficient in assimilating Cd from soil than the other crops tested (cabbage, ryegrass, wheat, potatoes) and may be regarded as Cd-accumulators. In the UK, less than 2 per cent of sludge is used on horticultural land where these accumulator crops are grown and they contribute only 0.5 per cent (fresh-weight basis) to the food intake of the average consumer. Figure 2 shows that wheat grain and potatoes, which are the major plant components of the human diet, are relatively insensitive to increased concentrations of Cd in soil. It is frequently said that Cd in soil is readily available for plant uptake but this statement requires qualification. In general terms, the results suggest that Cd is more available than Pb, as equally available as Zn and perhaps Cu, and less available than Ni. All the metals tested (Cd, Pb, Cu, Ni and Zn) are tightly held in soil which is why they accumulate in top soil and are not readily leached. In comparison with the major plant nutrients for instance, they are by no means readily taken up by crops. Thus Figure 4 shows that <0.1 per cent of Cd added to soil in sludge was recovered in a standing crop of wheat even in the first year after application of sludge to soil when availability is thought to be maximal (2).

Figure 3 shows that soil conditions represent another factor affecting availability of metals. The results confirm that soil pH value is of primary importance since higher concentrations of Cd occurred in wheat grain and ryegrass from the two soils of pH 6.5 compared with crops from the calcareous loam of pH 8. Crops grown on the clay soil with the higher cation exchange capacity were expected to show lower concentrations than those from the sandy loam of similar pH value. This was not the case for reasons still under investigation.

In assessing the significance of the results for Zn shown in Figure 5, it is of interest to note that the phytotoxic threshold for Zn in ryegrass leaves is about 200 mg/kg d.m. but the concentration of Zn required in the diet of grazing animals is 50 mg/kg. Thus sludge treatment raised Zn concentrations in herbage from a deficiency level to an adequacy level with respect to the nutrition of grazing animals. Moderate applications of sludge can supply useful quantities of trace elements to deficient soils.

Crop trials such as those at Cassington and Royston will contribute towards the knowledge which provides a basis for guidelines for the use of sewage sludge on agricultural land. In view of this, it is important to realise the limitations of different experimental approaches. Pot trials are convenient and subject to small experimental errors but tend to overestimate heavy metal uptake by crops, particularly when conducted in glasshouses. Experiments with inorganic salts or with sludges directly enriched with inorganic salts are subject to the same criticism; they tend to overestimate the metal uptake which would occur in conventional sludge utilisation practice. For instance Dijkshoorn and Lampe found that plant tissue concentrations of Cd were twice as high in ryegrass grown on soil treated with cadmium sulphate compared with soil supplied with an equivalent amount of Cd in sludge (3). Results from this kind of experiment must be interpreted with caution. The most informative results are likely to come from field trials with unenriched sludge. In such trials the intention is usually to define the extent of metal problems by determining the maximum rate of addition of sludge-borne metals which is compatible with acceptable crop quality and yield. To achieve this, it is necessary to exceed conventional rates of application of sludge to agricultural land by a wide margin. For instance, in the present trials the maximum rate of application of sludge to soil was 152 t/ha of a sludge containing 68 mg/kg d.s. of Cd, and has since been extended to 500 t/ha (Table III). In the interpretation of results it must be borne in mind that conventional dressings of sludge to agricultural land in Europe usually involve modest amounts of relatively uncontaminated sludges. For instance, in the UK the average annual dressing is 2 or 4 t/ha, to grassland or arable land respectively, of a sludge containing about 20 mg/kg d.s. of Cd. It cannot be assumed that the availability to crops of metals added in repeated light dressings of this type will be the same as in field trials where large amounts of metals have been added in single heavy applications of sludge. Thus, there is evidence that the availability for crop uptake of metals added to soil in sludge declines with time (2,4). In consequence, the concentration of metals observed in crops may depend much more on the amount of metal in the most recent application of sludge than on the cumulative amount of metal built up by previous applications. The half-life of availability of metals in soil has important implications for the long-term utilisation of sludge on land as an acceptable disposal option. Information on this aspect will be obtained from the trials at Cassington and Royston as concentrations of metals in the crops are monitored in successive years following the addition of sludge to soil in 1978/79. Current knowledge of this and other questions has been recently reviewed with respect to Cd in sludges used in agriculture (4).

The results obtained so far from the Cassington and Royston trials suggest that the availability, and hence potential hazard, associated with metal accumulations in soil resulting from the use of sludge on land cannot be predicted simply from the quantities of metals added to soil in sludge. Soil analyses are required to assess the extent of contamination by metals and crop analyses are required to assess its significance in terms of phytotoxicity and entry into the foodchain. Satisfactory regulation of sludge additions to agricultural land may need to take account of environmental quality criteria based on concentrations of contaminants in soils and crops, in addition to their concentrations in sludge.

ACKNOWLEDGEMENT

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STABILITE BIOLOGIQUE D'ACIDES HUMIQUES ASSOCIES A DU CADMIUM*

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Résumé

On a enrichi des acides humiques extraits de l'horizon de surface d'un podzol humique sableux avec du cadmium à pH 4. La stabilité biologique des composés humiques enrichis ou non en cadmium a été mesurée à l'aide d'une méthode respirométrique. L'addition de cadmium bloque la décomposition de l'acide humique auquel il est associé, vraisemblablement en rendant inaccessible aux micro-organismes les fonctions réactives de ce dernier. En présence de glucose, on constate une stimulation de la décomposition du composé humique, que ce dernier soit associé ou non au cadmium. Cette déstabilisation de l'humate de cadmium pourrait s'expliquer par la libération et l'inactivation du métal par les produits du métabolisme du glucose.

Summary

Humic acids were extracted from the surface layer of a sandy humic podzol and were enriched at pH 4 with Cd. The biological stability of the humic compounds (with or without Cd) was studied with a respirometric method. Cd addition hindered the humate decomposition, likely by protecting the functional groups of the organic compound against the micro-organism action. Glucose addition enhanced the decomposition of the humic compounds (with or without Cd). This effect could be explained by the solubilization and further complexation of the metal by the metabolism products of glucose.

1/ INTRODUCTION.

Un certain nombre de travaux ont été consacrés à l'étude de la stabilisation de la matière organique des sols par les métaux polyvalents préexistants (Ca, Mg, Fe, Al) ou intentionnellement ajoutés (Cu, Zn).

Souvent, ces études ont été conduites en utilisant comme modèle de la fraction stable de la matière organique du sol les acides humiques extraits de ces derniers (1, 2, 3, 4).

Il existe par contre très peu de travaux relatifs à l'étude de l'action stabilisante des métaux lourds pour lesquels l'intérêt manifesté par les agronomes est plus récent.

Le but de cette communication est d'exposer les résultats d'une recherche conduite en vue de préciser les modifications de stabilité biologique d'un acide humique lorsqu'on enrichit celui-ci avec du cadmium.

2/ MATERIEL ET METHODE.

a) Obtention des composés humiques.

Les acides humiques sont extraits de l'horizon de surface d'un podzol humique développé sur sable des Landes, par une solution de soude 0,5 N, précipités par $H\,NO_3$ à pH 1, puis lavés à l'eau permutée par centrifugation suivie de dialyse.

Les humates de cadmium sont obtenus par mélange de la suspension d'acides humiques et d'une solution normale de nitrate de cadmium dont le pH est ajusté à 4. L'acide humique témoin est constitué par le composé humique de départ, dont le pH est ajusté à 4.

Les deux produits sont isolés par centrifugation, lavés à l'eau permutée puis séchés à 45°C en étuve ventilée.

Après broyage, on détermine l'humidité résiduelle, la teneur en carbone (four à induction Leco) et en azote (Kjeldahl). Après minéralisation par voie sèche, le fer, le sodium, le cadmium sont dosés par spectrophotométrie d'absorption atomique, et l'aluminium par colorimétrie du complexe ériochrome-cyanine Al.

La capacité d'échange des acides humiques est mesurée à pH 4 par saturation par une solution normale de chlorure de baryum.

b) Mesure de la stabilité biologique.

Elle a été réalisé par la mise en oeuvre d'une méthode respirométrique, la consommation d'oxygène par unité de temps pouvant être considérée comme un critère inverse de cette propriété.

On a utilisé un respiromètre Gilson fonctionnant à pression constante, le bain thermostaté étant réglé à 30°C. Les échantillons testés ont été introduits dans des fioles de 30 ml, dont le puits central contient de la potasse concentrée et une mèche de papier filtre. On mesure chaque soir la quantité d'oxygène consommée, qui est ramenée à une moyenne horaire journalière (désignée par IRH, ou indice respirométrique horaire, exprimée en µl de O_2 consommés à l'heure). La mesure effectuée, le circuit est réouvert de manière à permettre une réoxygénation du milieu. L'expérience conduite de cette manière dure 5 jours, au terme desquels les fioles sont retirées de l'appareil et exposées à l'air, à la température du laboratoire, pendant 2 jours. L'expérience peut être reconduite pendant 5 jours supplémentaires.

Deux types d'expériences ont été réalisés.

Expérience I -

1 g d'un sol témoin très pauvre en matière organique, utilisé comme source de microflore, est mélangé ou non à une quantité de composé humique correspondant à 20 mg de carbone. L'ensemble est humidifié avec 1 ml d'eau bipermutée. Chaque traitement comporte 3 répétitions, le témoin étant constitué par le sol de référence.

Les résultats de cette expérience (qui a duré 2 fois 5 jours pour chaque type d'humate) sont donnés sous forme de graphique, où figurent en ordonnées les différences entre les IRH enregistrées pour les composés testés et l'IRH du sol témoin.

Expérience II -

Elle s'inspire de la méthode utilisée par JUSTE, DELAS et LANGON (3). Elle a pour but de préciser si la stabilisation des différents humates, éventuellement mise en évidence lors de l'expérience précédente, est due à un blocage des sites réactifs de la matière organique par les métaux qui protège ainsi celle-ci de l'attaque de micro-organismes ou à une action toxique de ces métaux sur la microflore du milieu. Pour cela, on a comparé pendant 5 jours consécutifs la consommation d'oxygène par des mélanges de sol et d'humates humidifiés, soit avec de l'eau bipermutée, soit par une solution de glucose à 1 ‰. Pour un même composé, les différences d'IRH obtenues doivent être imputées à la dégradation du glucose ; on pourra considérer que la toxicité du métal sera inversement proportionnelle à cette différence.

3/ RESULTATS ET DISCUSSION.

La composition de l'acide humique témoin et de l'humate de cadmium est indiquée dans le tableau. Les résultats montrent que la quantité de cadmium fixée par les acides humiques correspond sensiblement à la capacité d'échange du composé témoin mesurée à pH 4 (250 mé/100 g). Cette saturation est confirmée par l'examen du spectre infra-rouge de l'humate de cadmium qui est totalement salifié.

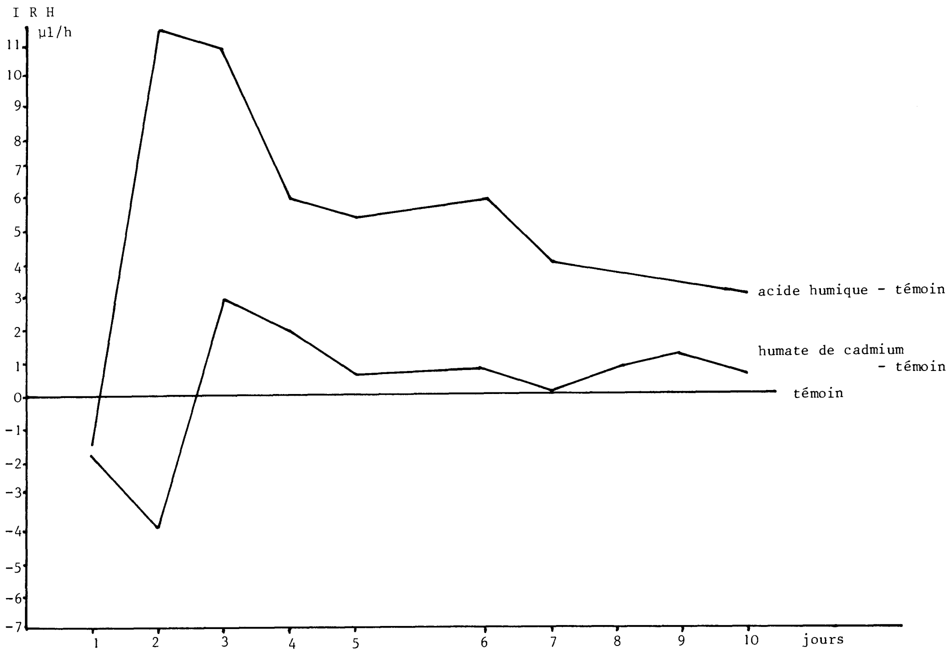
L'étude cinétique du phénomène (graphique I) montre qu'en l'absence de métal le maximum de l'activité respirométrique se situe les 2e et 3e jours de l'expérience. En présence de cadmium, on assiste à une diminution de la biodégradation de la matière organique originelle du sol de référence (témoin), effet dépressif qui disparaît à partir du 3e jour.

L'effet du cadmium est mieux mis en évidence dans le graphique II, où l'on a représenté en ordonnée l'intégrale des différentes courbes respirométriques : le métal a à peu près complètement bloqué la dégradation du composé humique auquel il est associé.

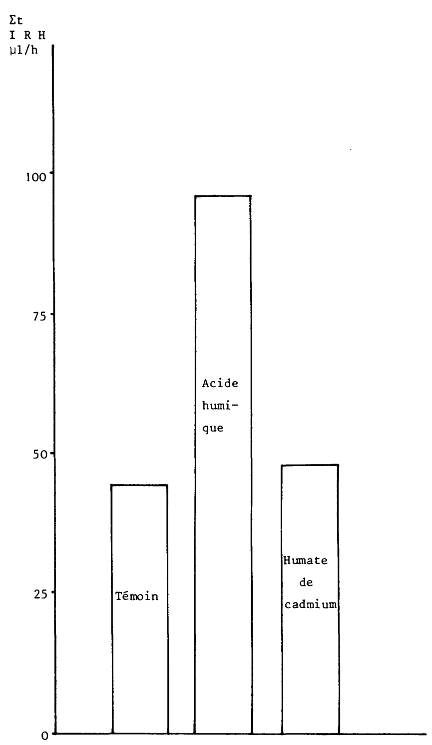
Les graphiques III et IV qui représentent la différence entre les indices respirométriques horaires relevés en présence ou en l'absence de solution glucosée, et qui donnent une image des indices respirométriques horaires relatifs au glucose dans les différents milieux, montrent que l'addition des composés humiques déprime initialement l'activité respirométrique liée à la présence de glucose. Cet effet disparaît le 2e jour pour l'acide humique et le 3e jour pour l'humate de cadmium. On constate alors une forte stimulation de l'activité respirométrique en présence de glucose pour les deux composés : l'addition de cette substance très labile favorise la biodégradation des deux composés humiques, le supplément d'oxygène consommé (partie hachurée sur le graphique V, dans lequel on a schématisé l'intégrale des différentes courbes d'indices respirométriques relatives au glucose) ne pouvant s'expliquer que par une stimulation de la décomposition de l'acide humique et de l'humate de cadmium, induite par l'addition de glucose.

Tableau

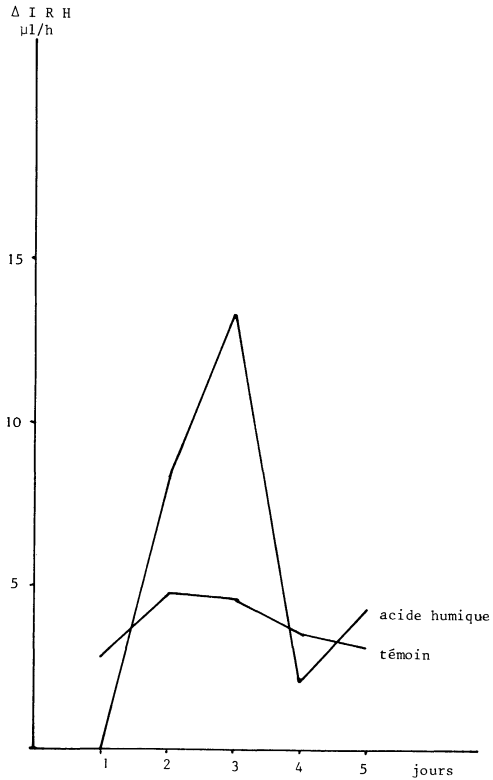
	Humid. % du prod. brut	Teneur en cendres	en p.cent de matière sèche						
			Fe	Na	Al	Cd	C	N	C/N
Acide humique témoin	8.5	11.4	1.70	1.33	2.4	0	50.4	2.91	17.3
Humate de cadmium	6.5	22.1	1.42	0.04	2.0	14.19	42.4	2.52	16.8



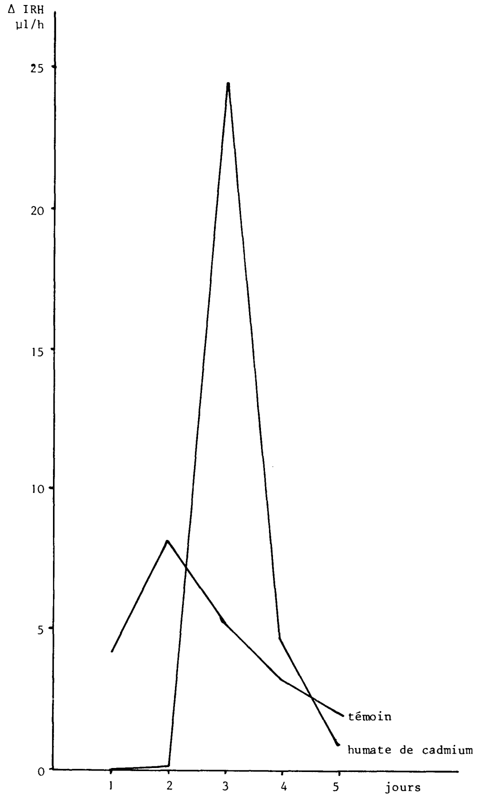
Graphique I - Evolution, au cours du temps, de la consommation en oxygène des mélanges de sol avec les différents composés humiques



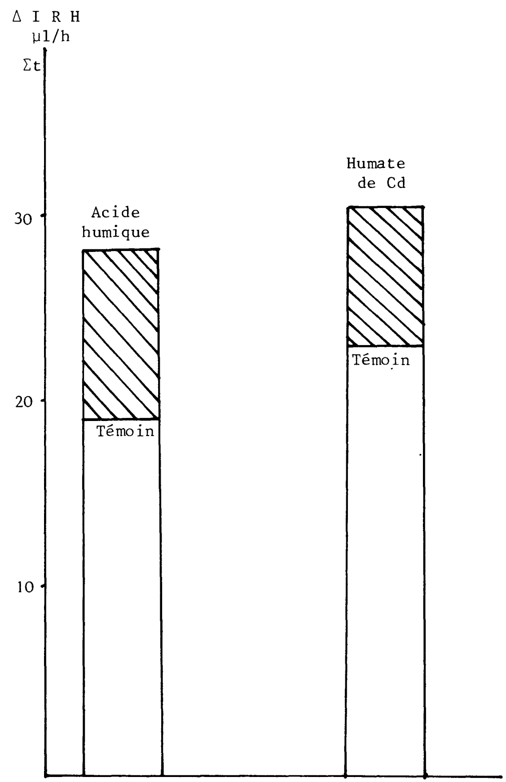
<u>Graphique II</u> - Sommation des indices respirométriques horaires des différents composés humiques



<u>Graphique III</u> - Evolution, au cours du temps, des différences entre I R H mesurées en l'absence ou en présence de solution glucosée



<u>Graphique IV</u> - Evolution, au cours du temps, des différences entre IRH mesurées en l'absence ou en présence de solution glucosée



<u>Graphique V</u> - Sommation des différences entre les IRH mesurées en l'absence ou en présence de solution glucosée

4/ CONCLUSION.

L'addition de cadmium, dans les conditions décrites, conduit à un composé humique de plus grande stabilité biologique que les acides humiques correspondants.

Cette stabilisation s'explique plus par un blocage des fonctions réactives du composé humique par le cadmium (fonctions sur lesquelles s'exerce peut-être préférentiellement l'action des micro-organismes) que par un effet toxique du métal qui ne peut être mis en évidence qu'en début d'expérience. La stimulation de la décomposition de l'acide humique lié au cadmium par l'introduction du glucose laisse supposer que les produits du métabolisme de ce dernier libèrent le métal et l'inactivent, permettant ainsi aux micro-organismes d'exercer leur action sur la fraction humique libérée.

Contrairement à ce qui a pu être observé pour d'autres métaux lourds (5), la rétention du cadmium par la fraction organique du sol ne constitue donc pas un facteur susceptible de restreindre la dissémination de ce métal dans l'environnement, cette rétention risquant d'être remise en cause par l'incorporation au sol de substances très biodégradables (engrais verts, vinasses, lisier, etc.).

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SCHWERMETALLAUFNAHME VERSCHIEDENER GETREIDEARTEN AUS HOCHBELASTETEN BÖDEN UNTER FELDBEDINGUNGEN

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Zusammenfassung

Den Untersuchungsgegenstand bilden 75 Standorte, die mehr oder weniger lang, zum Teil über Jahrzehnte, mit Klärschlamm beaufschlagt wurden. Von diesen Standorten wurden die Schwermetallgehalte der Böden (Krume, Bodenart sL - t'L, pH 6,5 - 7,2) und der darauf angebauten Feldfrüchte untersucht. Die Untersuchung erstreckte sich auf die Elemente Cd, Zn, Cu, Pb, Cr und Ni und die Feldfrüchte Winterweizen, Wintergerste, Winterroggen, Sommergerste, Hafer und Mais. Die Schwermetallanreicherung in den Böden erreicht zum Teil Werte, die um ein Vielfaches über den Richtwerten liegen. Mit steigenden Konzentrationen im Boden steigen auch die Schwermetallgehalte in den Pflanzen, - für die einzelnen Elemente, Pflanzenarten, vegetative und generative Pflanzenorgane allerdings unterschiedlich. Während sich für Zn und Cd relativ hohe Anreicherungskoeffizienten errechnen lassen - in den vegetativen Organen durchwegs stärker als in den generativen -, verändern sich die Cu-, Pb-, Cr- und Ni-Gehalte der Pflanzen auch bei stark steigender Bodenbelastung nur relativ wenig oder überhaupt nicht. Aufgrund eines artspezifisch starken Aufnahme- und/oder Anreicherungsvermögens werden bedenklich hohe Cd-Gehalte im Korn von Weizen und Hafer sowie in Blättern und Stengeln von Mais erreicht.

Summary

Object of investigation were 75 sites treated with sewage sludge for a more or less long period some for several decades. The heavy metal contents of the soils (top soil, texture sL - t'L, pH 6,5 - 7,2) and the plants of these sites were determined. Investigations included the elements Cd, Zn, Cu, Pb, Cr and Ni, and the field crops winter wheat, winter barley, rye, spring barley, oats and corn. The heavy metal accumulation in the soils reaches values that are many times above the standard values. Increasing concentrations in the soil are followed by increasing heavy metal contents in the plants. The degree of concentration, however, varies both for the elements and for plants. While the accumulation-coefficient for Zn and Cd is relativly high - in straw always higher than in grains - the contents of Cu, Pb, Cr and Ni in plants are hardly influenced by rising contents in the soil. Due to a specifically strong uptake and/or accumulation ability high contents of Cd in grains of wheat and oates as well as in leaves and stalks of corn are reached.

1. EINLEITUNG

Über die Schwermetallaufnahme von Pflanzen aus belasteten Böden ist in den letzten Jahren eine umfangreiche Literatur erschienen. Meist handelt es sich dabei um Modellversuche, in denen Böden unter kontrollierten Bedingungen unterschiedliche Mengen von löslichen Schwermetallsalzen zugegeben wurden (4, 5, 6, 12 u. a.). Die Ergebnisse solcher Untersuchungen sind auf Klärschlamm-gedüngte Böden nur mit Einschränkung anzuwenden, da die Schwermetalle hier zumindest teilweise in organischer Bindung vorliegen und antagonistische Wirkungen wahrscheinlich sind (8).

Die vorliegende Arbeit befaßt sich mit der Schwermetallaufnahme landwirtschaftlicher Kulturpflanzen aus Böden, die mehr oder weniger lang und mehr oder weniger intensiv mit stark belasteten Klärschlämmen gedüngt wurden und dementsprechend eine mehr oder weniger starke Schwermetallanreicherung aufwiesen.

2. MATERIAL UND METHODEN

Untersucht wurden 75 mit Klärschlamm beaufschlagte Böden, einschließlich 3 unbeschlammter Vergleichsböden und die darauf angebauten Feldfrüchte Winterweizen, Wintergerste, Winterroggen, Sommergerste, Mais und Hafer. Sämtliche Untersuchungsproben stammen aus dem Erntejahr 1979 und wurden als Mischproben aus normal bewirtschafteten landwirtschaftlichen Betriebsschlägen gezogen. Bei den Böden handelt es sich um normal humose, durch die Klärschlammdüngung zum Teil stark humose, sandige bis schwach tonige Lehme aus Kalkschotterverwitterung mit pH-Werten zwischen 6,5 und 7,2, im Niederschlagsbereich von ca. 900 mm/Jahr.

Die Bestimmung der untersuchten Elemente im Boden erfolgte nach dessen Aufschluß mit Königswasser mittels Atomabsorptions-Spektralphotometrie in der Flamme. Die Pflanzenproben wurden mit einer Säuremischung aus Salpeter- und Perchlorsäure (Verhältnis 10 : 1) verascht. Die Bestimmung der Elemente wurde genauso wie im Boden durchgeführt.

3. ERGEBNISSE

In den Tabellen I und II sind die ermittelten Cd-, Zn-, Cu-, Pb-, Cr- und Ni-Gehalte der Böden und der darauf gewachsenen Getreidefrüchte dargestellt.

Daraus ist ersichtlich,

daß sich die Bodengehalte über einen weiten Bereich erstrecken und teilweise extrem hohe Werte erreichen,

daß die verschiedenen Getreidearten ein unterschiedliches Aufnahmevermögen für die einzelnen Schwermetalle besitzen und

daß Schwermetalle in generativen (Korn) und vegetativen Pflanzenorganen (Stroh) unterschiedlich stark angereichert werden.

Tabelle I: Schwankungsbreite der Cadmium-, Zink- und Kupfergehalte in Böden und Pflanzen (mg/kg TS)

Gegenstand		Cadmium	Zink	Kupfer
Winterweizen	Boden	<0,5 - 52	28 - 1440	14 - 294
	Korn	0,04 - 1,16	20 - 89	2,7 - 7,9
	Stroh	0,10 - 4,27	12 - 170	9,4 - 15,9
Wintergerste	Boden	8,6 - 38	226 - 1360	40 - 256
	Korn	0,3 - 0,82	66 - 109	13 - 25
	Stroh	0,48 - 1,85	54 - 196	6,2 - 9,6
Winterroggen	Boden	<0,5 - 33	26 - 1200	18 - 224
	Korn	0,06 - 0,3	32 - 80	4,6 - 8,6
	Stroh	0,07 - 0,56	18 - 156	5,8 - 9,6
Sommergerste	Boden	<0,5 - 55	72 - 1480	19 - 302
	Korn	0,01 - 0,37	24 - 86	3,6 - 18,7
	Stroh	0,01 - 1,2	16 - 155	6,5 - 10
Mais	Boden	1 - 44	52 - 880	2,5 - 9,8
	Korn	0,05 - 0,7	18 - 96	5,5 - 13,4
	Stroh	0,07 - 22	11 - 365	6,3 - 16,5
Hafer	Boden	3 - 49	148 - 1350	33 - 260
	Korn	0,14 - 1,74	24 - 93	2,3 - 8,9
	Stroh	0,35 - 2,93	18 - 163	6,5 - 9,6

Die Pflanzenaufnahme der Elemente Pb und Cr ist auch bei hoher Bodenbelastung sehr gering, eine Korrelation zwischen Boden- und Pflanzengehalten somit nicht gegeben (sh. Tab. II). Dies gilt mit Einschränkungen auch für das Element Ni. Bei wesentlich geringeren Bodengehaltsschwankungen ist hier immerhin die Tendenz einer positiven Korrelation zwischen Boden- und Pflanzengehalten erkennbar.

Tabelle II: Schwankungsbreite der Blei-, Chrom- und Nickelgehalte in Böden und Pflanzen (mg/kg TS)

Gegenstand		Blei	Chrom	Nickel
Winterweizen	Boden	25 - 1300	18 - 259	25 - 76
	Korn	0,1 - 0,3	<0,1	<0,1
	Stroh	0,5 - 2,2	0,5 - 0,8	0,5 - 0,8
Wintergerste	Boden	220 - 1420	36 - 150	32 - 60
	Korn	0,5 - 1,7	<0,1	<0,2 - 0,4
	Stroh	1,9 - 4,4	<0,5 - 0,8	<0,5
Winterroggen	Boden	60 - 1320	13 - 142	23 - 64
	Korn	0,5 - 0,9	<0,1	0,3 - 0,4
	Stroh	2,6 - 4,6	<0,5	<0,5
Sommergerste	Boden	26 - 1600	32 - 204	29 - 74
	Korn	0,2 - 1,0	<0,1 - 0,5	0,1 - 0,5
	Stroh	0,9 - 4,0	<0,5 - 0,6	<0,5 - 0,5
Mais	Boden	24 - 1600	22 - 194	26 - 69
	Korn	<0,1	<0,5	<0,5 - 1,0
	Stroh	2,7 - 4,3	<0,5 - 1,0	<0,5 - 0,8
Hafer	Boden	110 - 1300	40 - 216	33 - 59
	Korn	0,2 - 0,4	0,3 - 0,5	1,0 - 8,1
	Stroh	1,0 - 2,3	<0,5	0,6 - 1,9

Bessere Korrelationen ergeben sich für die Elemente Cd, Zn und Cu. Sie sind in den Abbildungen 1 - 3 als lineare Regressionen dargestellt. Die Steigung der Regressionsgeraden kennzeichnet das Anreicherungsvermögen einer Pflanzenart für ein bestimmtes Schwermetall. Anreicherungskoeffizient und relative Aufnahmemenge bei niedriger Bodenbelastung gehen aus den Gleichungen für die Regressionsgeraden hervor (sh. Tab. III).

Tabelle III: Regressionsgerade und Relationskoeffizienten für die Beziehungen zwischen Boden- und Pflanzengehalten (n = Zahl der Standorte, r = Relationskoeffizient, y = Gehalte in der Pflanze, x = Gehalte im Boden)

Getreideart		n	Cadmium Regressionsgerade	r	Zink Regressionsgerade	r	Kupfer Regressionsgerade	r
Weizen	Korn	21	y = 0,016x + 0,24	0,64	y = 0,039x + 38,9	0,68	y = 0,014x + 4,07	0,65
	Stroh	21	y = 0,049x + 0,48	0,58	y = 0,072x + 39,6	0,64	y = -0,008x + 12,50	-0,34
Wintergerste	Korn	8	y = 0,016x + 0,18	0,79	y = 0,039x + 65,7	0,85	y = 0,006x + 19,60	0,07
	Stroh	6	y = 0,045x - 0,10	0,80	y = 0,123x + 9,39	0,87	y = 0,014x + 6,0	0,76
Roggen	Korn	5	y = 0,005x + 0,12	0,84	y = 0,039x + 35,5	0,98	y = 0,002x + 6,58	0,13
	Stroh	5	y = 0,011x + 0,14	0,90	y = 0,093x + 15,5	0,88	y = 0,015x + 5,65	0,91
Sommergerste	Korn	23	y = 0,006x + 0,03	0,79	y = 0,031x + 34,4	0,79	y = 0,011x + 5,40	0,21
	Stroh	23	y = 0,014x + 0,15	0,70	y = 0,075x + 19,5	0,79	y = 0,006x + 7,36	0,54
Mais	Korn	12	y = 0,015x + 0,04	0,93	y = 0,039x + 27,6	0,85	y = 0,017x + 5,58	0,63
	Stroh	12	y = 0,500x - 0,11	0,94	y = 0,183x + 46,2	0,76	y = 0,020x + 8,8	0,64
Hafer	Korn	6	y = 0,030x + 0,12	0,92	y = 0,052x + 22,3	0,96	y = 0,026x + 2,42	0,94
	Stroh	6	y = 0,045x + 0,24	0,90	y = 0,101x + 16,9	0,93	y = 0,012x + 6,36	0,92

3.1 CADMIUM

Betrachtet man nur die generativen Organe (Korn), so zeigt das stärkste Anreicherungsvermögen der Hafer. Der in einer Probe gemessene Cd-Gehalt von 1,74 mg/kg TS ist mit Abstand der höchste ermittelte Wert.

Weizen, Wintergerste und Mais reagieren auf steigende Bodenbelastung mit etwa gleichen Anreicherungskoeffizienten, doch liegt der Cd-Gehalt von Weizen und Wintergerste von Haus aus höher als der des Maises (sh. Abb.1).

Bei Roggen und Sommergerste bleiben die Gehalte und Anreicherungskoeffizienten weit hinter denen des Weizens und der Wintergerste zurück. Die gleiche Tendenz ist auch bei den Cd-Gehalten des Strohs zu beobachten. Das Stroh zeigt bei allen Früchten höhere Gehalte und ein stärkeres Anreicherungsvermögen als das Korn. Besonders kraß ist das Cd-Anreicherungsvermögen des Maisstrohs - eine Beobachtung, die auch schon in anderen Jahren gemacht wurde (1, 2).

3.2 ZINK

Zink wird nach Menge und Anreicherungsvermögen von fast allen Früchten stärker aufgenommen als die anderen Schwermetalle. Nur das Maisstroh zeigt für Cd einen stärkeren Anreicherungskoeffizienten als für Zn (0,5 gegenüber 0,183).

Das stärkste Anreicherungsvermögen im Korn besitzt der Hafer, das geringste die Sommergerste. Weizen, Wintergerste, Roggen und Mais verhalten sich gleich, wobei die absolute Zinkaufnahme der Wintergerste erheblich über der der anderen Getreidearten liegt.

Die Zn-Anreicherung im Stroh fällt in der Reihenfolge der Früchte Mais, Wintergerste, Hafer, Roggen, Sommergerste, Weizen. Wie bei Cd, so ist auch bei Zn der Anreicherungskoeffizient für Stroh größer als für Korn. Bei Wintergerste, Sommergerste und Roggen liegen die Zn-Gehalte des Strohs zunächst unter denen des Korns und übersteigen diese erst bei höheren Bodenbelastungen (Abb. 2).

3.3 KUPFER

Die Cu-Gehalte der Pflanzen werden durch steigende Bodenbelastung weit weniger beeinflußt als die Cd- und Zn-Gehalte. Die stärkste Anreicherung im Korn zeigt wieder der Hafer, gefolgt von Mais, Weizen, Sommergerste,

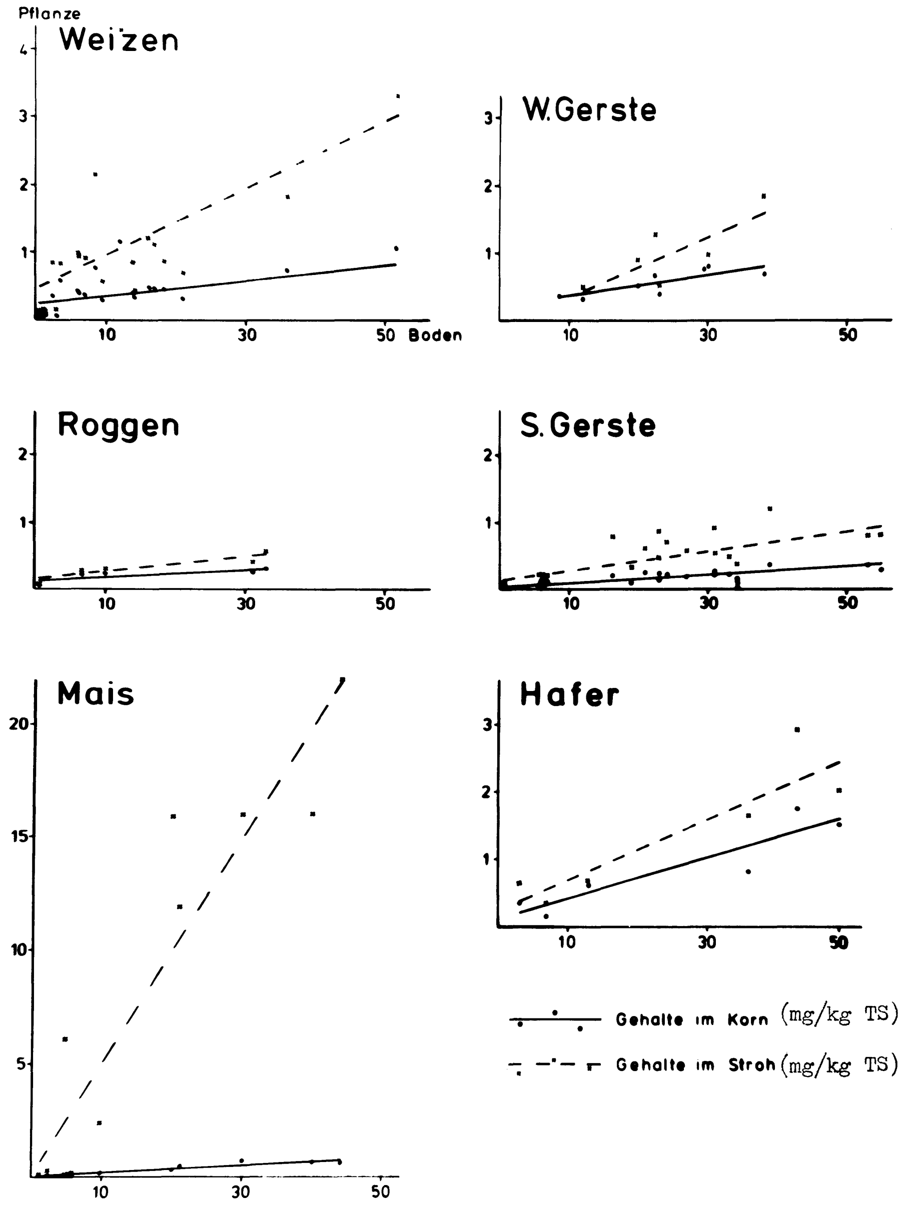

Abbildung 1: Cadmium-Aufnahme verschiedener Getreidearten in Abhängigkeit vom Cadmium-Gehalt des Bodens

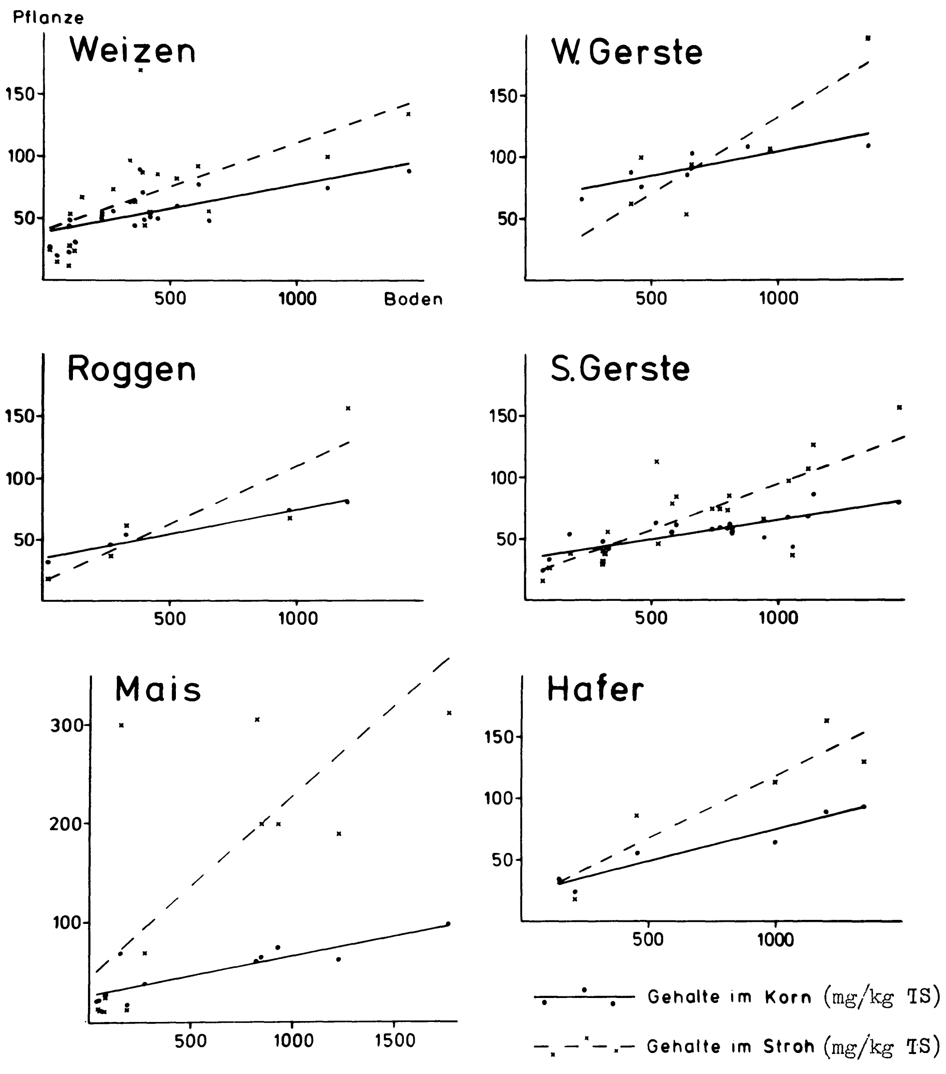

Abbildung 2: Zink-Aufnahme verschiedener Getreidearten in Abhängigkeit vom Zink-Gehalt des Bodens

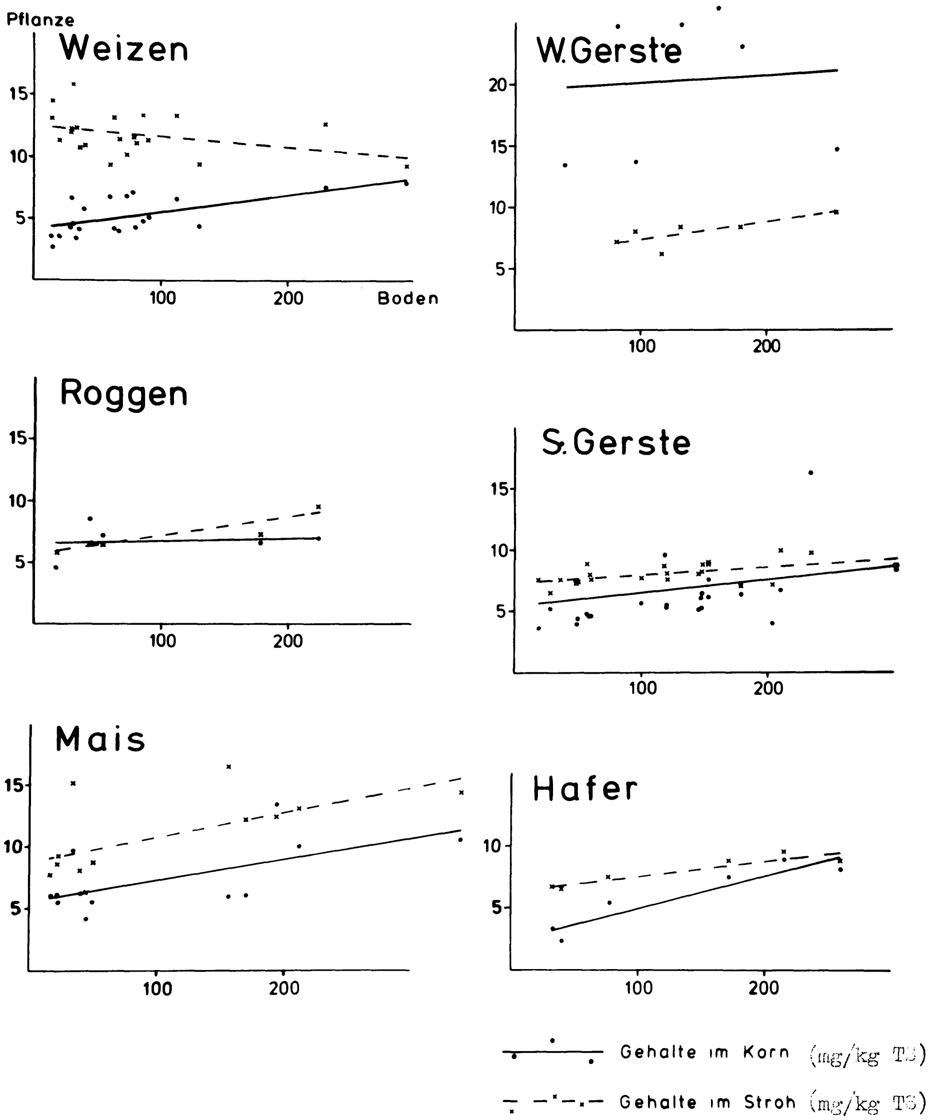

Abbildung 3: Kupfer-Aufnahme verschiedener Getreidearten in Abhängigkeit vom Kupfer-Gehalt des Bodens

Wintergerste und Roggen. Für Roggen, Wintergerste und Sommergerste sind die Korrelationskoeffizienten allerdings so niedrig, daß die Regressionen nur als Tendenzen gewertet werden können.

Die Cu-Gehalte und Anreicherungskoeffizienten des Strohs liegen teils über, teils unter denen des Korns. Weizen mit den absolut höchsten Cu-Gehalten im Stroh bei niedriger Bodenbelastung zeigt als einzige Frucht eine negative Korrelation zwischen Kupfergehalten des Bodens und des Strohs (sh. Abb. 3).

4. WERTUNG DER ERGEBNISSE

Die vorliegenden Untersuchungen sind als Beitrag zur Frage der Gefährlichkeit hoher Schwermetallanreicherungen in Böden bei langjähriger, intensiver Klärschlammdüngung zu verstehen. Obwohl die Richtwerte für Böden von allen untersuchten Schwermetallen meist um ein Vielfaches überschritten werden (9), konnten noch nie Wachstumsstörungen beobachtet werden, die auf eine erhöhte Schwermetallbelastung zurückführbar gewesen wären.

Die festgestellten hohen Aufnahmeraten für Cd und Zn sowie die niedrigen für Pb, Cr und Ni werden auch von anderen Autoren unter anderen Standortbedingungen bestätigt (3, 8, 10, 11, 12). Die in einer früheren Arbeit beschriebenen hohen "carry-over-Werte" für Cr und Ni (1) haben sich nicht mehr bestätigen lassen. Wahrscheinlich waren die hohen Pflanzengehalte an diesen Elementen auf Metallabrieb im Zug der Probenaufbereitung zurückzuführen.

Eine Beeinträchtigung der Nahrungsqualität durch Schwermetallanreicherung scheint nur bei Cadmium befürchtet werden zu müssen. Bedenklich sind vor allem die um ein Mehrfaches über den Richtwerten (7) liegenden hohen Cd-Gehalte im Hafer- und Weizenkorn, da diese Getreidearten unmittelbar der menschlichen Ernährung dienen. Bedenklich erscheint auch das außerordentlich starke Cd-Anreicherungsvermögen in den vegetativen Organen des Maises, soweit diese als Grundfutter (Maissilage) in der Rinderfütterung Verwendung finden.

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EFFETS DE L'APPLICATION MASSIVE DE BOUE A TRES FORTE CHARGE EN CADMIUM ET EN NICKEL SUR DES CULTURES DE MAÏS ET DE LAITUE.

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Résumé

Un sol sableux acide a été enrichi pendant quatre années consécutives avec des boues polluées par Cd et Ni, du fumier ou une fertilisation minérale. Les quantités de Cd et Ni incorporées dans le sol par les boues ont varié respectivement de 86 à 512 kg/ha et de 171 à 946 kg/ha. Le champ a été cultivé avec du maïs pendant 3 ans et, en 1979, avec de la laitue suivie à nouveau d'un maïs. Les résultats de 1979 montrent qu'il n'y a pas d'effet des boues sur la production des laitues mais qu'elles entraînent une baisse de rendement du maïs (-20 %). L'application des boues diminue fortement le contenu en phosphore du maïs, élève la concentration en Zn, Cd et Ni des feuilles de maïs et de la laitue, celle de Ni et de Cu de la graine mais abaisse la concentration en manganèse dans les deux espèces. La plus haute accumulation de cadmium a lieu dans les feuilles de maïs et celle de Ni dans la laitue. Les deux niveaux de boue (30 ou 40 t/ha et 200 t/ha) produisent des effets voisins.

Summary

An acid, sandy soil was enriched for 4 years in succession with Cd and Ni polluted sewage sludge, manure or mineral fertilizers. The amount of Cd and Ni incorporated in the soil through the sludge varied respectively from 86 to 512 kg/ha and 177 to 946 kg/ha. The field was cultivated for 3 years with continuous maize and in 1979 with a lettuce crop and then by maize. The 1979 data showed no effect of the sludge on the lettuce yield but a deleterious effect on maize production (-20 %). Sewage sludge application decreased drastically the P content of the maize (leaf and grain), increased the Zn, Ni and Cd content of the maize and lettuce leaves and the Ni and Cu content of the grain, but decreased sharply the Mn concentration in both species. The highest Cd accumulation was observed in the maize leaves and the highest Ni accumulation in the lettuce. The two levels of sewage sludge (30 or 40 t/ha and 200 t/ha) produced almost similar effects.

1/ INTRODUCTION

La présence dans la ville de Bordeaux d'une station d'épuration qui traite des effluents provenant, entre autres, d'une fabrique d'accumulateurs, nous a conduits à mettre en place une expérimentation de longue durée destinée à préciser les effets sur une monoculture intensive de maïs et sur les sols d'applications massives de boue issue de cette station. Les premiers résultats fournis par cette expérimentation ont donné lieu à deux publications (1 et 2), dont l'une a été présentée lors du 1er Symposium européen sur la Caractérisation et l'Utilisation des Boues à Cadarache en février 1979. L'objet de la présente communication est de rendre compte des effets comparés de ces mêmes déchets urbains sur une culture de laitue mise en place dans le dispositif au printemps 1979 et sur la culture de maïs qui lui a immédiatement succédé.

2/ MATERIEL ET METHODES

a) Dispositif et protocole expérimentaux.

Ces derniers ont été décrits en détail dans une précédente publication (2).

Nous rappellerons que le dispositif a été mis en place en 1976 sur un sol sableux à réaction initialement très acide et très moyennement pourvu en matière organique.

Les 4 traitements expérimentés sont les suivants :

T = témoin ne recevant qu'une fertilisation strictement minérale ;

F = application de 10 t/ha/an de fumier de ferme (matière sèche) ; quantité totale épandue depuis le début de l'essai : 40 t/ha (avant le maïs 1979) ;

B_1 = application de 10 t/ha/an de boue de station d'épuration (matière sèche) ; quantité totale épandue depuis le début de l'essai : 40 t/ha (avant le maïs 1979) ;

B_2 = application de 100 t/ha de boue tous les 2 ans (matière sèche) ; quantité totale épandue depuis le début de l'essai : 200 t/ha (avant la culture de laitue 1979).

Pour des raisons climatiques, le fumier et la dose la plus faible de boue (B_1) n'ont pu être épandus qu'après la culture de laitue ; les traitements F et B1 correspondent donc à 30 t/ha de matière sèche de boue ou de fumier pour la culture de laitue et à 40 t/ha de matière sèche pour la culture de maïs : bien que ces différences de doses correspondent en fait à des variations relatives assez faibles de la quantité totale d'éléments incorporés, il est possible que l'écart séparant l'incorporation des boues ou du fumier de l'implantation de la culture ait pu avoir une influence notable sur l'assimilabilité des éléments contenus dans ces amendements organiques.

Les quantités totales de fertilisants et de métaux lourds introduits dans le sol par les boues sont indiquées dans le tableau I. Ce tableau fait ressortir que les apports cumulés de boue ont enrichi le sol de 77 à 86 kg/ha (faible dose) et de 512 kg/ha (forte dose) en cadmium, et de 142 à 171 kg/ha (faible dose) et 946 kg/ha (forte dose) en nickel. On peut considérer dans ces conditions que la totalité du cadmium et du nickel ainsi introduits dans le sol représente 32 % de la capacité d'échange cationique de l'horizon 0-30 cm pour la plus forte dose de boue et 6 % de cette capacité pour la dose la plus faible.

La culture de laitue (variété Aurélia - plants issus de semis en serre) a été mise en place au mois de mars ; les résidus de la culture précédente de maïs ont été enfouis à 15-20 cm par un labour de fin d'hiver ; les laitues ont été repiquées à raison de 140 pieds par parcelle de 18 m2 sur 7 rangs espacés de 40 cm. Une fumure minérale standard de 150 unités/ha d'azote, phosphore et potasse a été appliquée juste avant le repiquage des laitues.

Immédiatement après la récolte des salades (début juin), on a procédé à l'épandage annuel de la faible dose d'amendement organique, qui a été enfoui à 8-10 cm par une façon superficielle. Le semis du maïs (variété INRA 260) a été précédé de l'apport des éléments fertilisants minéraux, ce dernier étant réalisé de manière à ce que la totalité de la fertilisation N-P-K (organique et minérale) de chacun des traitements T, F et B_1, soit la même, l'azote des amendements organiques étant considéré comme disponible pour moitié l'année de leur enfouissement.

b) Déterminations réalisées.

Le poids moyen en frais des laitues a été mesuré par pesée séparée de chaque pied des 3 rangs centraux de chaque parcelle (60 plantes).

Tableau I

QUANTITES TOTALES D'ELEMENTS MAJEURS ET MINEURS INCORPORES PAR 4 ANNEES D'APPORTS DE BOUES (en kg/ha)

Elément	Traitement		
	B_1		B_2
	Laitue	Maïs	
N	360	449	2 410
P_2O_5	1 320	1 636	8 800
Ca	3 740	4 457	24 900
Mg	140	176	950
K	30	45	195
Fe	1 245	1 521	8 299
Cu	16	18	104
Mn	29	34	193
Zn	105	130	702
Cd	77	86	512
Cr	2	4	14
Ni	142	171	946
Pb	23	29	156

Tableau II

INFLUENCE DES DIFFERENTS TRAITEMENTS SUR LA PRODUCTION DES LAITUES

Traitement	Poids moyen d'une laitue (g de matière fraîche)	Indice de comparaison
T	321	100
F	292	126
B_1	260	113
B_2	205	89
Degré de signification	1 %	1 %
ppds 5 % (en g)	60	
ppds 1 % "	84	

T = témoin;
F = fumier, 10 t/ha/an = 30 t ;
B_1 = boue, 10 t/ha/an = 30 t ;
B_2 = boue, 100 t/ha en 1976 + 100 t/ha en 1978 = 200 t.

Dans le cas du maïs, la pesée de la récolte a été effectuée pour la totalité de la parcelle.

Les concentrations en éléments majeurs (N, P, K, Ca, Mg) et mineurs (Cu, Fe, Mn, Zn, Cd, Cr, Ni, Pb) de la laitue ont été mesurées à partir d'échantillons de feuilles entières prélevées au 3e niveau d'insertion ; on a également dosé l'azote nitrique dans la nervure centrale des feuilles prélevées également au 3e niveau d'insertion.

Dans le cas du maïs, les concentrations ont été mesurées aux trois stades de végétation suivants (analyse d'un échantillon moyen issu de chaque parcelle) :

stade I - stade 10-12 feuilles, analyse de la 6e feuille ;

stade II - stade 50 % de la floraison mâle, analyse de la feuille de l'épi (1/3 médian, débarrassé de la nervure centrale) ;

graine - analyse d'un échantillon moyen issu de chaque parcelle

L'azote a été dosé par la méthode Kjeldahl et l'azote nitrique, extrait de la nervure centrale par une solution de sulfate de cuivre, par électrode spécifique. Les métaux ont été déterminés par absorption atomique après minéralisation par voie sèche et le phosphore par colorimétrie du complexe phospho-molybdique réduit par l'acide ascorbique.

3/ RESULTATS

a) Rendements.

L'addition de boue au sol, même à très forte dose, n'a pas provoqué d'effet dépressif significatif sur le rendement des laitues (tableau II) ;on n'a pas observé par ailleurs de symptôme de phytotoxicité. Par contre, la végétation spontanée du terrain d'expérience, assez mal contrôlée par des binages à la main, avait envahi au moment de la récolte les parcelles correspondant aux traitements témoin et fumier mais était quasiment absente des parcelles correspondant aux traitements "boue".

En ce qui concerne le maïs, quelques symptômes très passagers de jaunissement ou de rougissement des feuilles les plus âgées ont affecté en début de végétation les plantes des parcelles correspondant à la forte dose de boue. L'application de cette dernière a abaissé le rendement de 16 et 20 % (tableau 5) sans qu'il soit possible cependant de faire apparaître une différence significative entre les deux doses de boue. On peut remarquer par ailleurs que, si 3 années consécutives d'incorporation de fumier ont élevé de 26 % la production de la laitue, ce même amendement dont le dernier apport a précédé de peu le semis du maïs a fait chuter sensiblement le rendement de cette plante.

b) Composition des plantes.

α - Laitue. En ce qui concerne les éléments majeurs, on constate seulement une légère baisse de la teneur en azote total des laitues, provoquée par l'application de la forte dose de boue (tableau III). Les teneurs en zinc, cadmium et surtout nickel ont été notablement accrues par les boues et la teneur en manganèse non moins significativement abaissée (tableau IV).

β - Maïs. Les deux amendements organiques ont provoqué une chute importante de la teneur en azote total des feuilles prélevées au stade 10-12 feuilles mais, au stade 50 % floraison mâle, seul le fumier a continué à déprimer la nutrition azotée de la plante. Contrairement à ce que l'on a pu observer dans le cas de la laitue, l'application des boues provoque une chute spectaculaire de la teneur en phosphore du maïs, notamment au stade juvénile où cette teneur est réduite de moitié ; l'intensité de cet effet s'atténue progressivement lors du développement de la plante mais on l'observe encore de manière très nette au niveau de la graine (tableau VI).

Comme pour la laitue, seuls le zinc, le nickel et le cadmium pénètrent de manière notable dans les parties végétatives de la plante mais seule une accumulation de nickel dans la graine est observée pour la plus forte dose de boue. On constate aussi une augmentation de la teneur en cuivre des graines provenant des traitements "boues", alors qu'aucune accumulation de ce métal n'a pu être mise en évidence dans les parties végétatives. Comme dans le cas des laitues, l'application de boue a considérablement déprimé l'absorption et la translocation du manganèse dans la totalité du plant de maïs (tableau VII).

4/ DISCUSSION ET CONCLUSION

Bien que la comparaison des effets exercés par les boues sur maïs et sur laitue ne soit pas totalement satisfaisante (pour la raison principale que les cultures ont été conduites durant des périodes climatiques différentes), cet essai démontre que les deux espèces réagissent de

Tableau III

INFLUENCE DES DIFFERENTS TRAITEMENTS
SUR LA TENEUR EN ELEMENTS MAJEURS DE LA LAITUE

Traitement	% de la matière sèche					
	N total	P_2O_5	Ca	K	Mg	N nitrique
T	3.96	1.48	0.17	0.58	0.03	0.54
F	4.06	1.56	0.18	0.67	0.04	0.77
B_1	4.19	1.36	0.16	0.61	0.03	0.73
B_2	3.61	1.31	0.19	0.53	0.03	0.51
Degré de significat.	5 %	N.S.*	N.S.	N.S.	N.S.	N.S.
ppds 5 %	0.34					
ppds 1 %	-					

* : non significatif

T = témoin ;
F = fumier, 10 t/ha/an = 30 t ;
B_1 = boue, 10 t/ha/an = 30 t ;
B_2 = boue, 100 t/ha en 1976 + 100 t/ha en 1978 = 200 t.

Tableau IV

INFLUENCE DES DIFFERENTS TRAITEMENTS
SUR LA TENEUR EN ELEMENTS MINEURS DE LA LAITUE (ppm M.S.)

Traitement	Cu	Fe	Mn	Zn	Cd	Cr	Ni	Pb
T	4.4	122	91	48	5.9	1	1.7	1
F	3.9	109	71	50	4.3	1	1.4	1
B_1	5.4	99	37	68	27.2	1	15.4	1
B_2	5.2	105	22	64	42.6	1	46.4	1
Degré de signific.	N.S.	N.S.	1 %	1 %	1 %	N.S.	1 %	
ppds 5 %			32	9	11.3		3.5	
ppds 1 %			44	12	15.8		4.9	

T = témoin ;
F = fumier, 10 t/ha/an = 30 t ;
B_1 = boue, 10 t/ha/an = 30 t ;
B_2 = boue, 100 t/ha en 1976 + 100 t/ha en 1978 = 200 t.

Tableau V

INFLUENCE DES DIFFERENTS TRAITEMENTS SUR LA PRODUCTION DU MAÏS

(en q/ha de grain à 0 % d'humidité)

Traitement	Rendement	Indice de comparaison
T	83.7	100
F	74.7	89
B_1	70.5	84
B_2	67.1	80
Degré de signification	1 %	1 %
ppds 5 % (q/ha)	6.2	
ppds 1 %	8.6	

T = témoin ;
F = fumier, 10 t/ha/an = 40 t ;
B_1 = boue, 10 t/ha/an = 40 t ;
B_2 = boue, 100 t/ha en 1976 + 100 t/ha en 1978 = 200 t.

Tableau VI

CONCENTRATION EN AZOTE ET PHOSPHORE DU MAIS A DIFFERENTS STADES VEGETATIFS

Elément	Traitement	Feuilles Stade I	Feuilles Stade II	Graine
N total % M.S.	T	4.77	4.60	1.64
	F	4.43	4.39	1.60
	B_1	4.39	4.50	1.66
	B_2	4.29	4.57	1.64
	ppds 5 %	N.S.	0.14	N.S.
	ppds 1 %	N.S.	N.S.	N.S.
P_2O_5 % M.S.	T	1.91	1.46	0.89
	F	1.70	1.26	0.90
	B_1	0.79	0.89	0.74
	B_2	0.70	0.87	0.68
	ppds 5 %	0.21	0.17	0.14
	ppds 1 %	0.29	0.24	0.20

T = témoin ;
F = fumier, 10 t/ha/an = 40 t ;
B_1 = boue, 10 t/ha/an = 40 t ;
B_2 = boue, 100 t/ha en 1976
+100 t/ha en 1978 = 200 t.

Tableau VII

TENEUR EN ELEMENTS MINEURS DU MAIS A DIFFERENTS STADES VEGETATIFS (en ppm de M.S.)

Elément	Feuilles								Graine			
	Stade I				Stade II							
	T	F	B1	B2	T	F	B1	B2	T	F	B1	B2
Cu	12	11	10	14	12	12	13	14	traces	traces	1.7	1.0
ppds 5%	N.S.				N.S.				0.5			
ppds 1%	N.S.				N.S.				0.7			
Fe	167	158	143	134	154	142	131	125	25	22	24	22
ppds 5%	N.S.				N.S.				N.S.			
ppds 1%	N.S.				N.S.				N.S.			
Mn	120	48	45	40	124	66	44	34	5.8	5.1	2.5	1.4
ppds 5%	19				26				0.8			
ppds 1%	26				37				1.1			
Zn	24	21	54	62	27	26	50	47	21	21	26	26
ppds 5%	8				6				3			
ppds 1%	11				9				4			
Cd	4.7	1.8	47.4	70.8	2.2	0.8	22.8	31.4	traces	traces	traces	traces
ppds 5%	9.6				3.5				N.S.			
ppds 1%	13.4				4.9				N.S.			
Cr	traces	traces	traces	traces	traces	traces	traces	traces	traces	traces	traces	traces
ppds 5%	N.S.				N.S.				N.S.			
ppds 1%	N.S.				N.S.				N.S.			
Ni	2.1	1.9	3.6	8.5	1.4	1.1	2.0	3.8	traces	traces	traces	1.9
ppds 5%	1.3				1.1				0.3			
ppds 1%	1.8				1.5				0.5			
Pb	4.1	4.2	4.9	4.6	4.4	4.4	4.4	4.9	traces	traces	traces	traces
ppds 5%	N.S.				N.S.				N.S.			
ppds 1%	N.S.				N.S.				N.S.			

T = témoin ;
F = fumier, 10 t/ha/an = 40 t ;
B_1 = boue, 10 t/ha/an = 40 t ;
B_2 = boue, 100 t/ha en 1976 + 100 t/ha en 1978 = 200 è.

manière très différente. Au niveau des rendements, l'effet dépressif qu'exerce le fumier sur la culture de maïs est sans doute à relier à l'utilisation de matériau trop pailleux, incorporé au sol peu de temps avant le semis et qui a donc perturbé la nutrition azotée de la plante. L'effet dépressif des boues (identique pour les deux niveaux expérimentés) sur les rendements n'apparaît que pour le maïs ; cet effet demeure relativement modeste (-20 % au maximum) si l'on tient compte des quantités caricaturales de cadmium et de nickel (plus de 500 kg/ha et près de 1 t/ha respectivement) qui ont été apportées au sol par les plus fortes doses de boues.

Au niveau composition minérale de la plante, la différence principale porte sur la teneur en phosphore, qui est très fortement abaissée dans tous les organes du maïs, alors qu'elle ne l'est pas dans la laitue. Cette observation pourrait indiquer que la mobilité physico-chimique du phosphore des boues n'est pas en cause mais qu'il s'agit plutôt, dans le cas du maïs, d'un trouble d'absorption de cet élément lié à la forte activité de certains métaux lourds au niveau des racines (2).

Bien que le zinc, le cadmium et le nickel soient les seuls métaux qui donnent lieu à une absorption notable par les deux plantes en présence de boue, des différences relatives à l'accumulation de chacun d'entre eux apparaissent : c'est ainsi que le maïs, contrairement aux nombreuses données de la littérature rappelées par GIORDANO, MAYS et BEHEL (3), concentre dans les conditions de cette expérience beaucoup mieux le cadmium que ne le fait la laitue, l'inverse étant vrai pour le nickel. Les deux espèces ont par contre un comportement assez voisin en ce qui concerne le manganèse, dont l'absorption et la translocation sont particulièrement déprimées par l'application des boues, phénomène qui peut sans doute s'expliquer par l'existence d'une compétition au niveau de l'absorption des différents métaux. Maïs et laitue réagissent aussi de manière comparable à l'accroissement des doses de boue appliquées, les effets observés pour les doses 30 à 40 t/ha étant somme toute assez voisins de ceux observés pour 200 t/ha, ce qui tendrait à confirmer les résultats de HINESLY et al. (4), montrant que la teneur en métaux lourds des plantes qui se développent sur un sol enrichi avec des boues atteint rapidement un maximum sur lequel des apports supplémentaires de boue n'ont que peu d'influence.

Ces résultats indiquent donc clairement qu'il est difficile de prévoir avec beaucoup de précision le comportement des plantes lorsqu'on enrichit un sol avec des boues de station d'épuration : l'abondance relative des différents métaux dans le déchet organique paraît revêtir une importance tout aussi décisive que la nature de l'espèce végétale, ce qui rend difficilement utilisables pour cette prévision les résultats d'expériences dans lesquelles plusieurs espèces sont soumises à l'action d'un seul métal ou à celle d'un ensemble de métaux intervenant simultanément mais dans un seul rapport.

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HEAVY METALS EXTRACTABILITY FROM SOIL TREATED WITH HIGH RATES OF SEWAGE SLUDGES AND COMPOSTS

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Summary

Results of field experiments (1978-1979) to evaluate the accumulation in soil of heavy metals are described in terms of their extractability with H_2O (readily soluble), KNO_3 (exchangeable), and DTPA (available). High application rates, equivalent to 150 tons/ha/yr of manure, on the organic carbon basis, were applied to an acidic sandy loam soil planted with corn. Treatments included aerobic and anaerobic sludges and their composted mixtures with the organic fraction of urban refuse. After two years of applications negligible quantities of heavy metals were found in the aqueous extracts of soil. Generally the maximum amounts of DTPA extractable metals were found after treatment with aerobic sludge and aerobic sludge compost. The greatest extractability was found for copper. For this metal the sequential extraction with KNO_3 and DTPA solubilized more than 70 % of total soil copper in the case of composted aerobic sludge.

At harvest time heavy metals extractability tended to decrease with the exception of KNO_3 extractable lead which generally increased.

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1. INTRODUCTION

The use of soil as a disposal medium for sewage sludge has been increasingly emphasized in recent years but its utilisation on agricultural land may be limited by the content of heavy metals. In fact, once applied to the soil, heavy metals contained in the sludge may persist, and build up from repeated sludge applications producing long terms problems. Excessive contamination of soils with these metals may produce phytotoxic conditions. Even at subphytotoxic levels serious metal contamination of food may result. Therefore more information is needed on the fate of applied metals in soils in order to ascertain their availability to plants. The objective of this research was to evaluate in a field experiment the possible increase in the soil of the most mobile forms of heavy metals after application of high rates of sewage sludge and composts, by assessing their extractibility with H_2O, KNO_3 and DTPA.

2. MATERIALS AND METHODS

An acidic sandy loam soil was treated in 1978 and 1979 with sewage sludges and compost at a rate equivalent to 150 tons/ha/yr of manure on the organic carbon basis and planted with corn. Treatments included aerobic (AS), and anaerobic sludge (ANS) and their composted mixtures with the organic fraction of urban refuse (CAS and CANS respectively). The content of heavy metals in the organic materials have been previously reported (1,2). The soil contained, on a dry weight basis, 0.81% organic matter, 10.6% clay, 16.7% silt, and 72.7% sand, pH 5.6, $CaCO_3$ absent, and cation exchange capacity 14.4 meq. $100g^{-1}$.

Soil samples were collected to a 20 cm depth at the beginning of the experiment (t_0) and for two years both 30 days after sludge application (t_1 and t_3) and at the harvest time (t_2 and t_4). Extractability of Zn, Cd, Pb, Ni, Cu was tested following a sequential extraction with H_2O, 1M KNO_3 and DTPA (diethylene-triaminepentaacetic acid) (3). Zn, Cu, Pb, Ni and Cd were analyzed in all extracts by atomic adsorption spectrophotometry (Perkin Elmer mod 403).

3. RESULTS AND DISCUSSION

Amounts of water soluble metals were always negligible, and are not reported. Patterns of extractability in KNO_3 and DTPA over time are reported hereafter for each single metal.

As known, extraction by KNO_3 removes metals linked to the negatively charged exchange sites and those adsorbed through weak non-Coulombic forces: "exchangeable fraction". DTPA extractability was used as "availability index" and was preferred to a dilute acid extraction since the latter may remove occluded metals which are thought to be unavailable to plants (4,5).

ZINC - Figures of DTPA extractable Zn are presented in table I. At t_1, 30 days after sludge addition, extractable Zn increased, particularly for AS and CAS treatments. Soil sampled at harvest 1978 (t_2) showed that DTPA extractable Zn decreased compared to t_1 for all treatments, particularly for CAS.30 days after the second treatment (t_3) the change in the Zn extractability was generally not as great as after the first addition but an increase with respect to t_2 was found everywhere. After harvest 1979 (t_4) DTPA extractability decreased particularly for AS and ANS.

KNO_3 extracted less applied Zn than DTPA. The greatest extractability was found at t_1, particularly for ANS treatment. A sharp decrease was always present at t_2 (harvest 1978). The second addition of organic materials produced only a slight increase in the extractability at t_3 and further small changes at t_4 (harvest 1979).

COPPER - Extractable Cu is reported in table I. Also in this case 30 days after the first addition of organic materials (t_1) there was an increase in the DTPA extractable Cu with a maximum for AS and ANS. Extractable Cu at harvest 1978 (t_2), decreased for all treatments. The second addition of organic materials produced a certain increase at t_3 nevertheless the extractability values were always less than those at t_1. In any case decreases of DTPA extractable Cu were observed at t_4 (harvest 1979).

The KNO_3 extractable Cu followed the typical solubility pattern previously found, i.e. higher values at t_1, particularly remarkable for ANS treatment, and a decrease at t_2 (harvest 1978). Similar trends were observed also after the second addition of the organic materials, with the maximum of extractability for ANS treatment.

NICKEL - As shown in table I applied Ni remained at relatively low DTPA extractable levels after all treatments, being more than 5 ppm only for AS treatment. Trends over time were similar to those found for Zn and Cu but all differences were flattened.

The KNO_3 extractability for this metal over time followed the pattern already showed for DTPA with a maximum of the extracted metal for AS and CAS treatments after the second addition of organic materials. Decreases were always noticed at both harvest sampling times and the KNO_3 extractability was always higher than DTPA extractability.

LEAD - Data of DTPA extractable Pb over time are presented

TABLE I - Heavy metals extractability by KNO_3 and DTPA*.

Time	AS		ANS		CAS		CANS	
	KNO_3	DTPA	KNO_3	DTPA	KNO_3	DTPA	KNO_3	DTPA
				ZINC				
t_0	2.6	2.0	2.5	1.9	2.6	2.0	2.4	1.9
t_1	7.1	20.4	8.3	8.4	5.2	10.2	5.2	4.8
t_2	5.5	10.3	4.1	5.0	3.2	2.2	3.8	1.5
t_3	5.8	15.9	4.5	5.9	5.7	3.9	4.5	2.6
t_4	5.1	10.5	4.4	3.6	3.9	3.4	3.8	2.4
				COPPER				
t_0	3.1	16.6	3.2	16.8	3.2	16.4	3.1	16.6
t_1	6.6	31.0	14.3	22.4	7.0	21.8	6.7	21.2
t_2	3.2	23.3	3.2	8.9	3.6	17.4	4.0	13.3
t_3	4.4	27.4	6.9	11.3	4.9	20.7	4.5	14.1
t_4	5.6	17.2	2.5	10.8	3.1	17.6	3.1	11.8
				NICKEL				
t_0	8.0	3.1	8.0	3.2	8.1	3.1	8.0	3.0
t_1	10.0	5.9	9.5	4.2	11.6	4.9	8.8	4.8
t_2	8.0	5.3	8.0	3.7	10.6	3.7	8.0	2.5
t_3	15.3	5.8	10.2	4.1	15.3	4.2	10.2	3.1
t_4	8.3	4.8	7.6	3.7	12.8	3.3	9.3	2.1
				LEAD				
t_0	3.0	6.7	3.0	6.6	3.1	6.7	3.0	6.7
t_1	4.0	8.6	5.6	9.0	4.0	11.5	2.8	7.5
t_2	9.3	10.0	12.0	3.8	12.1	9.0	11.8	5.3
t_3	9.3	17.5	4.6	11.7	3.7	19.1	3.2	10.2
t_4	13.4	14.6	2.2	7.3	6.9	16.1	7.0	8.7

* Data are expressed as ug/g soil.

in table I. In this case the effect of the first addition of organic material (t_1) was generally less pronounced with the respect to the second addition (t_3). Decreasing levels of the extractable metal were noticed at t_2 (harvest 1978) and t_4 (harvest 1979). The greatest quantities of DTPA extractable Pb were found for CAS and AS treatments after the second addition of organic materials, 19.1ppm and 17.5ppm respectively.

Particularly remarkable were the patterns of Pb extracted by KNO_3, which exhibited contrasting results with those of the other heavy metals. Apart the ANS treatment where the extractability pattern followed an anomalous trend, for the other treatments the KNO_3 extractable Pb showed an increase at both harvest times (t_2 and t_4), while a decrease was noticed at t_3 both for CAS and CANS. At this point of the experiment we are not able to find a fully satisfying explanation of the described trends. Probably the chemical forms of lead in soil might change over time or this metal could be present in a chemical form different from the others in the organic materials.

CADMIUM - Despite the high affinity of DTPA for Cd the quantities found at different sampling times were negligible, therefore they are not reported. Probably Cd was present in a chemical form characterized by weak linkages so that 1M KNO_3 was sufficient to solubilize all extractable metal.

Data of KNO_3 extractable Cd over time are reported in table II. After the first addition of organic materials there was an increase for all treatments, while at t_2 (harvest 1978) the values dropped almost to the original. A sharp increase was noticed at t_3 with the highest value of KNO_3 extractability for the CAS.

In any case it should be noted that values of Cd extractability were always rather high, ranging from 25% to 65% of the total content of cadmium in soil.

TABLE II - KNO_3 extractable Cd. Data are expressed as ug/g soil.

Time	AS	ANS	CAS	CANS
t_0	0.8	0.8	0.7	0.8
t_1	1.8	2.1	1.8	1.8
t_2	0.9	0.5	0.8	0.8
t_3	1.9	2.2	2.6	2.1
t_4	1.8	1.6	2.3	1.4

4. CONCLUSIONS

A comparison of data for DTPA and KNO_3 extractable metals over time, displayed certain features common to almost all investigated metals. Data from t_0 to t_1 showed the tendency of the extractibility to increase for all metals both in KNO_3 and DTPA. Soil sampled at both harvest times showed decreased extractable levels of all metals in DTPA, while different trends are showed by Pb for KNO_3 extraction.

Considering the extractability as percent of total metals content of soil at each sampling time (data not reported here), the adopted sequential extraction procedure solubilized notheworthy quantities of metals. The highest values of extractability were observed for Cu, more than 70% for CAS and more than 50% for ANS and CANS treatments;and the lowest values for Ni which were always less than 10%.

Differences in the extractability between Pb and the other metals may imply a difference in the chemical form of the metals in the organic materials. To account for the decrease at the harvest times it should be also considered the possible effect of plants. They remove in fact a certain amount of metals, particularly with the root system which is able to link the metals in forms unextractable by KNO_3 and DTPA. At the end of the first two year period we may remark that dangerous levels of mobile heavy metals were not observed in this field experiment, even though levels of extractable metals were always higher when organic materials have been added.

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ZUM RÜCKGANG DER SCHWERMETALLBELASTUNG VON BÖDEN NACH DER BEENDIGUNG EINER STÄDTISCHEN ABWASSERVERRIESELUNG

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Summary

Decrease of heavy metal contamination of soils after the termination of a municipal sewage infiltration

The reduction of a long term heavy metal contamination of a braunerde created by a 60 year sewage infiltration has been studied in the area of a sewage farm.

It has been possible to show that during 18 years after termination of the sewage infiltration which lasted approx. 60 years, a significant regeneration and decontamination of the soil and the underlaying aquifer took place.

Results will be shown of a detail investigation of analogous areas which have been polluted till 1962, till recent years and those which are unpolluted.

The results can be used to estimate the future reduction of the heavy metal content in soils after the agricultural application of sewage sludge.

1. EINLEITUNG

Wegen der begrenzten Belastbarkeit der Böden mit Schwermetallen entstehen Schwierigkeiten, städtische Klärschlämme umfassend landwirtschaftlich zu nutzen.

Daher wird die Frage bedeutsam, in welchem Umfang bei welchen Böden ein Rückgang der Schwermetallbelastung, eine Dekontamination, mit der Zeit auftritt.

Zur Teilbeantwortung dieser Frage können auch Studien über den Rückgang der Schwermetallgehalte von Rieselfeldböden herangezogen werden, die eigentlich einer Beurteilung von Veränderungen des Reinigungsvermögens dieser Böden dienen (1).

2. UNTERSUCHUNGSOBJEKT - UNTERSUCHUNGSUMFANG

Es wurden Braunerden im Bereich des Rieselfeldes Berlin-Karolinenhöhe bearbeitet, die aus pleistozänen Hochflächensanden hervorgingen (Bild 1). Durch eingehende bodenkundliche und geologische Untersuchungen konnten analoge Standorte festgelegt werden für Gebiete

- von 1900 bis zur Gegenwart berieselt
- von 1900 bis 1962 berieselt
- unberieselt (Bild 2).

Ein Vergleich von Schwermetallgehalten dieser drei Standorte erlaubt Rückschlüsse auf den Rückgang der Belastung eines seit ca. 18 Jahren nicht mehr durch Berieselung beanspruchten Bodens und den Grad der Annäherung an den unberieselten.

Die Rieselfelder werden mit nur mechanisch gereinigtem Abwasser aus städtisch-industrieller Mischbesiedlung beaufschlagt.

Im Maximum wurden im Jahr 20,6 · 10^6 m^3 verrieselt (1961). Eine Menge, die einer durchschnittlichen Rieselwassergabe von mehr als 7000 mm entspricht. Seit 1961 sind die Verrieselungsgaben stark gefallen und liegen heute bei ca. 1000 mm (2 - 4 10^6 m^3) (Bild 2).

Die Schwermetallbelastung des verrieselten Abwassers zeigt heute die in Bild 3 dargestellten Werte. Werte der Schwermetallkonzentration im Abwasser von 1962 liegen nicht vor. Grundsätz-

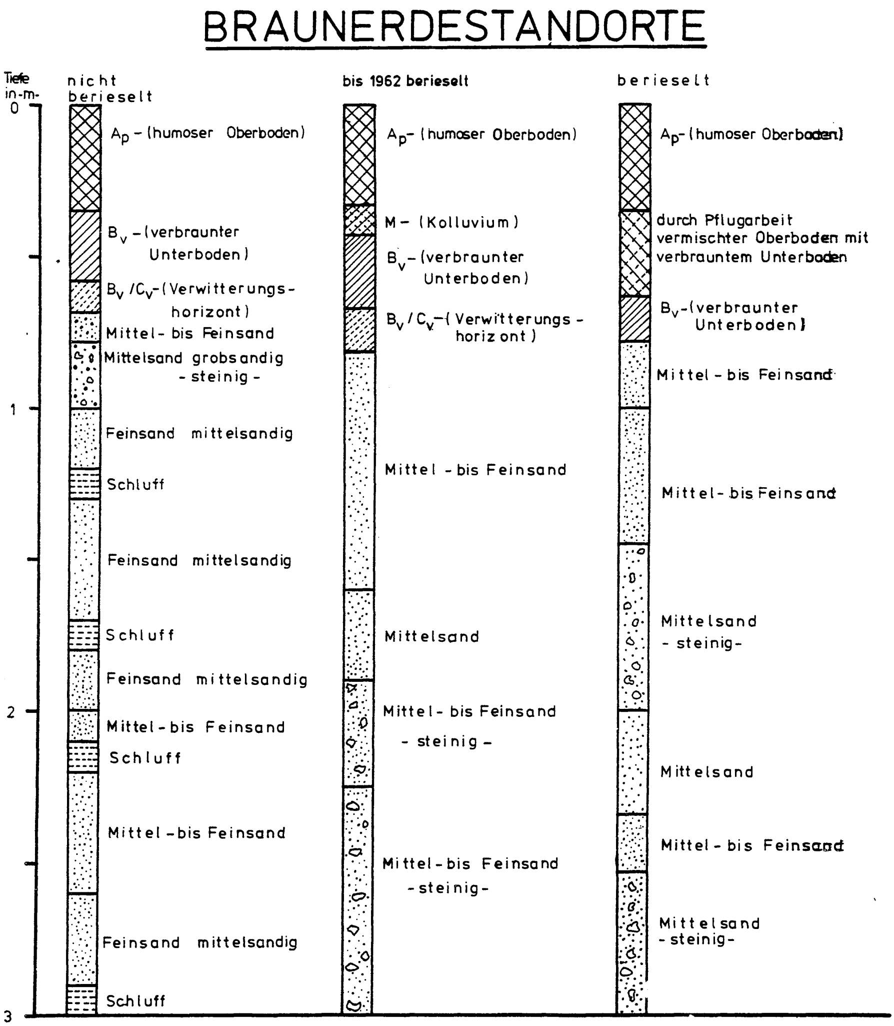


Bild 1 – Bodenkundlich-lithologische Charakterisierung der Braunerdestandorte

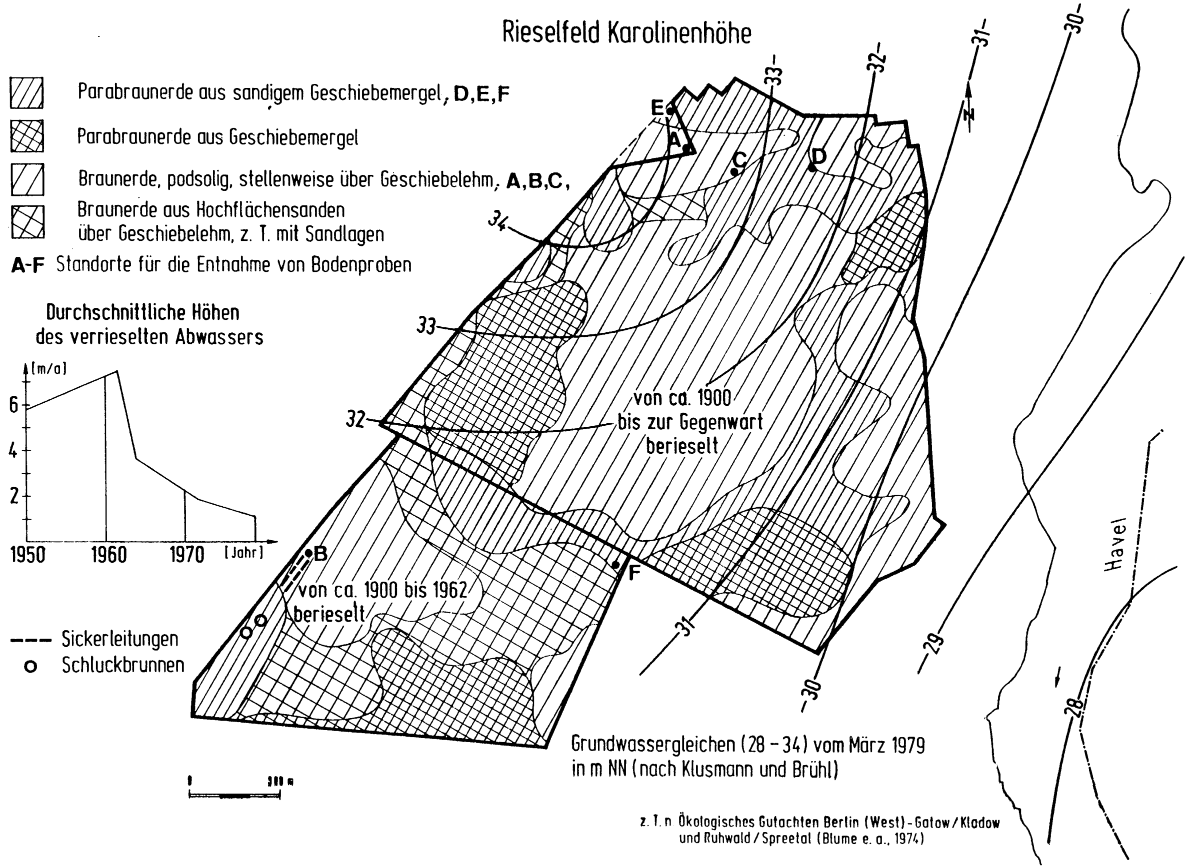


Bild 2 - Rieselfeld Karolinenhöhe (z.T. nach (2) und (3))

Chemische Gehalte der Rieselfeldaufgabewässer (1980)
und Vergleichswerte "Sickerwasser aus Böden u. Klärschlämmen (de Haan)"

	Cd	Pb	Cr	Zn
Rieselfeld-Aufgabewasser				
Filtrat d.Aufgabewassers /ug/l	2,1...6,2	125...198	44...68	210...1870
Aufgabewasser (Gesamt) /ug/l	6...16,6	241...326	71...86	610...2193
Filterrückstand (0,129...270 g/l) mg/kg	30...46	434...994	85...112	850...1520
Klärschlamm-Sickerwasser /ug/l	1...250	<5...47	10...1720	40...5600
sandige Böden - Sickerwasser /ug/l	<1	< 5	10	42
tonige Böden - Sickerwasser /ug/l	<1	< 5	20	20
Rieselfeld				
Quadratmeterbelastung $mg.m^{-2}.a^{-1}$ bei 1000 mm **Rieselung**	6...16,6	241...326	71...86	610...2193
Quadratmeterbelastung $mg.m^{-2}.a^{-1}$ bei 7000 mm **Rieselung**	42...116	1687...2282	497...602	4270...15351

Bild 3 - Schwermetallgehalte im Abwasser lich kann aber davon ausgegangen werden, daß damals die Gehaltswerte von Schwermetallen erster "Priorität" (Cd, Cr, Hg, Se) (4) im Abwasser nicht unter den heutigen lagen. Zersplittertere industrielle Produktion und noch wenig entwickeltes "Abwasserbewußtsein" lassen im Gegensatz sogar höhere Werte vermuten. Die charakteristischen Anionen zeigen in der zeitlichen Entwicklung (1962 - 1977) eine wechselnde Tendenz (Phosphat: 20...70 mg/l; Chlorid: 120...170 mg/l; Sulfat: 120...90 mg/l; Ges.Stickstoff: 45...65 mg/l (6)).

Bei Niederschlägen zwischen 750 und 400 mm gehen dem Grundwasser um 100 mm an Neubildung zu (7). Unter Berücksichtigung der im wesentlichen aus der Bodenzone gespeisten Transpiration unterliegt ein nicht mehr berieselter Boden einer "Durchwaschung" mit 100...700 mm/a.

Mineralogisch können die Hochflächensande und die aus ihnen hervorgegangenen Braunerden als Quarzsande (50 - 60 % im humosen Oberboden, 70 - 75 % in den Fein- Mittel-Sanden) mit einem Feldspatgehalt um 10 % und Glimmergehalten zwischen 3 und 5 % (Schluffe > 10%) charakterisiert werden. Signifikant hohe Gehalte an organischer Substanz sind nur bis knapp 1 m unter Gelände zu finden (Bild 4). Der berieselte Boden ragt dabei mit Gehalten zwischen 10 und 12 % im Oberboden hervor. Selbst im Bv-Horizont bis 80 cm Tiefe konnten noch organische Gehalte bis zu 5 % festgestellt werden. Die organischen Gehalte nicht berieselter Braunerde-Oberböden liegen bei 4 - 5 % und sind im Unterboden kaum nachweisbar. Die 18 Jahre nicht berieselte Braunerde weist zwar eine deutliche Abnahme der organischen Gehalte im Oberboden auf, jedoch fällt der Gehalt von noch 4 % im Unterboden auf.

Der geringe Anteil der Tonmineralfraktion ($< 2\ \mu$) weist besonders in den Verbraunungshorizonten ein einheitliches Verteilungsbild auf (Illite 63 - 65 %, Smectite 9 - 11 %, Vermiculite 13 - 15 %, Chlorit 7 - 9 %, Kaolinit bis 2 %). Einen Überblick über Austauschkapazität und pH-Wertverteilung gibt Bild 5. Dabei ist der Rückgang der Austauschkapazität gleichlaufend mit der Abnahme der organischen Substanz charakteristisch.

BRAUNERDESTANDORTE

MINERALGEHALTE

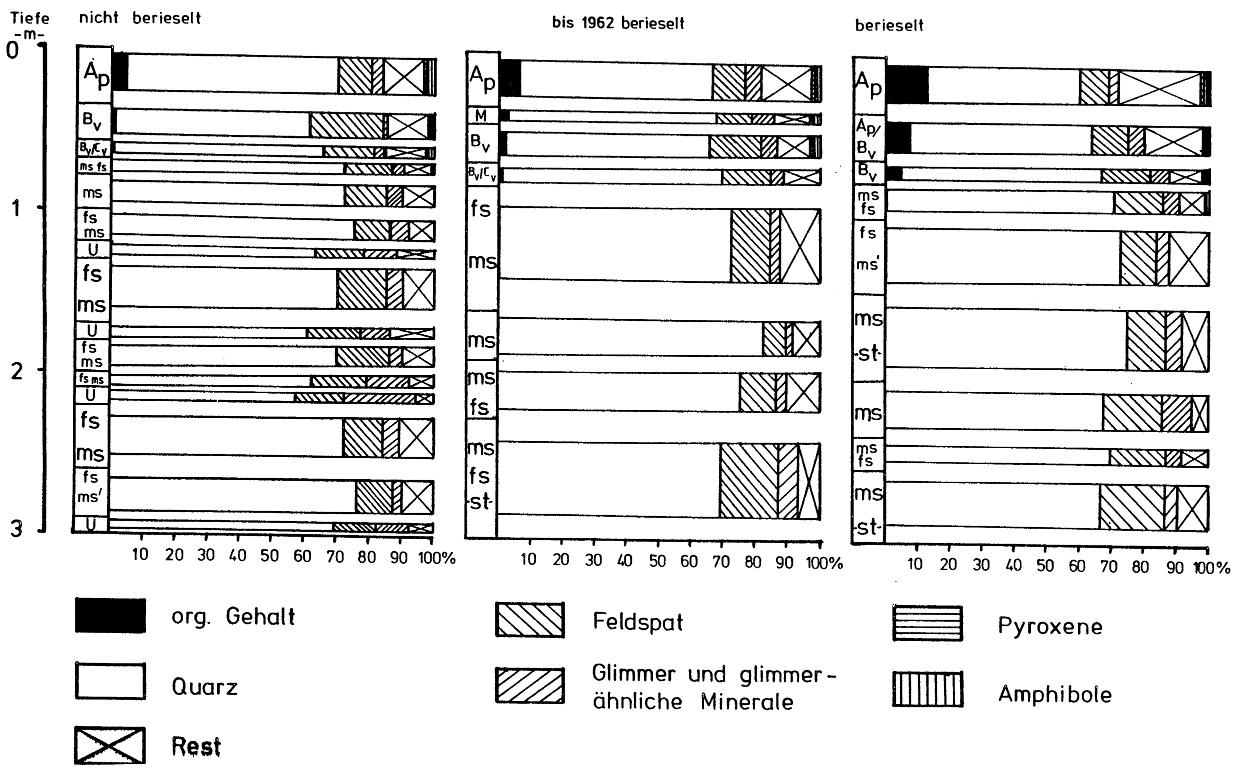


Bild 4

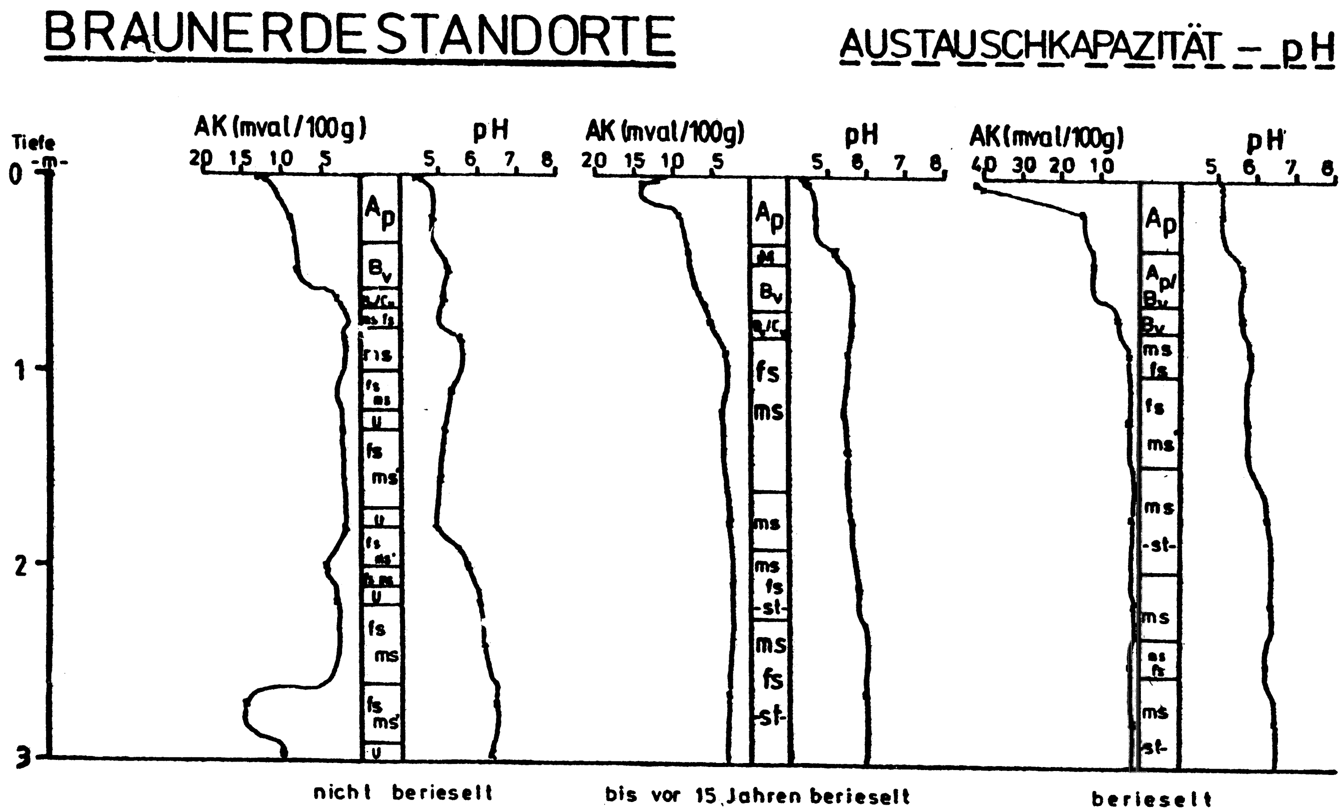

BRAUNERDESTANDORTE
AUSTAUSCHKAPAZITÄT -- pH
Tiefe -m-
AK (mval/100g)
pH
nicht berieselt
bis vor 15 Jahren berieselt
berieselt
Ap
Bv
fs
ms
-st-

Bild 5

Die pH-Wertbestimmung zeigt stärker sauere Verhältnisse in den Oberböden der nicht und der seit 18 Jahren unberieselten Böden. Der berieselte Standort weist nur mäßig bis schwach sauere Reaktionen auf, ein Unterschied zu den beiden anderen Typen, der auf die merkliche Regeneration des 18 Jahre nicht berieselten Standorts hindeutet.

3. SPEZIFISCHE UNTERSUCHUNGSERGEBNISSE

Entsprechend der Stufe 1 der "Prioritätenliste" (Erfassung von Umweltchemikalien und anderen Schadstoffen) (4) und den Untersuchungsmöglichkeiten wurden die Böden auf ihre Cd-, Pb- und Cr-Gehalte untersucht, sowie die Zn-Gehalte festgestellt.

Nach KLOKE (5) sind Gesamtgehalte dieser Elemente bis zu folgenden Werten tolerierbar (bzw. häufig anzutreffen) (mg/kg):

- Cd 3 (0,1....1)
- Pb 100 (0,1...20)
- Cr 100 (10.....50)
- Zn 300 (10.....50)

Das Verrieselungswasser weist Gesamtgehalte auf bis zu folgenden Konzentrationen (µg/l) (Bild 3):

Cd 17 , Pb 326 , Cr 86 , Zn 2193

Über die Gesamtelementgehalte der Böden liegen zwei Untersuchungsreihen vor (79 und 80) (Bilder 6 und 7).

Das wesentliche Untersuchungsergebnis besteht in dem Befund, daß im ständig berieselten Boden bis zu Tiefen von 0,5 m die Toleranzgrenze (4) deutlich überschreitende Werte (z. T. außer Zn) zu finden sind.

Nach einer Rieselruhe von 18 Jahren gehen diese Metallgehalte deutlich in Bereiche des unberieselten Bodens zurück und liegen mit Ausnahme des Pb-Befunds 1980 auch deutlich unter der Toleranzgrenze. Die Pb-Befunde 1980 belegen sowohl für den 18 Jahre unberieselten wie ebenso auch für den generell unberieselten Boden Werte oberhalb der Toleranzgrenze, hervorgerufen durch die allgemeine Umweltbelastung im Raum Berlin. Die Annäherung an den Tongesteinsstandard nach TUREKIAN und WEDEPOHL

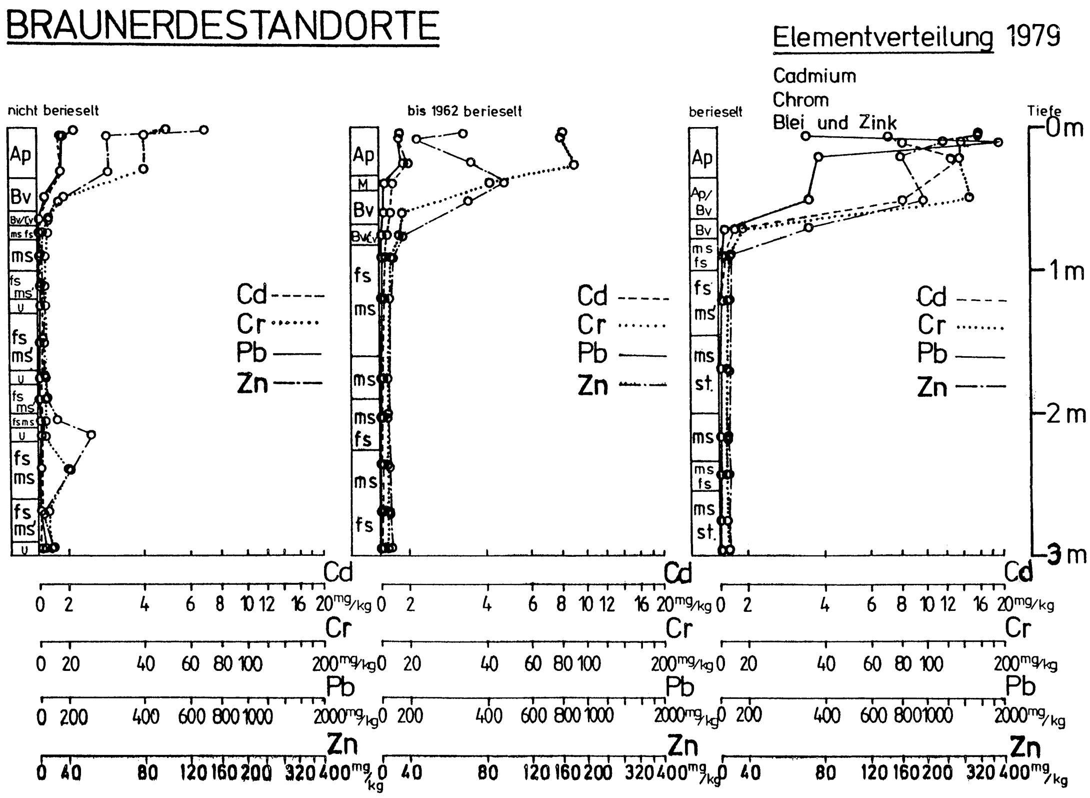


Bild 6 - Gesamtelementgehalte der Braunerdeböden (Unters.reihe 1979)

Gesamt-Elementgehalte - Braunerde berieselt - 1980

Nr.	T (cm)	A	Zn MW (mg/kg)	s (mg/kg)	Cd MW (mg/kg)	s (mg/kg)	Cr MW (mg/kg)	s (mg/kg)	Pb MW (mg/kg)	s (mg/kg)
1	o - 3	7	51o	± 12o	9,1	± 2,o	19o	± 33	49o	± 15o
2	o - 5	1o	365	± 78	8,5	± 2,1	16o	± 29	396	± 12o
3	o - 1o	1o	238	± 51	8,1	± 1,9	145	± 28	1712	± 31o
4	o - 25	1o	198	± 33	13,2	± 3,1	138	± 23	41o	± 11o
5	25 - 45	9	21o	± 31	8,5	± 2,o	1o8	± 18	358	± 1oo
6	25 - 63	9	196	± 22	2,1	± o,8	77	± 12	364	± 98
7	63 - 78	9	51	± 5	1,o	± o,6	13	± 3	32	± 5
8	85 - 95	9	19	± 3	o,7	± o,5	1o	± 2	11	± 2,o
9	95 - 11o	7	18	± 3	o,4	± o,2	7,5	± 1,5	9,5	± 2,3
1o	11o - 13o	7	17	± 3	o,2	± o,1	7,o	± 1,6	6,8	± 2,1
11	13o - 145	9	15	± 2	o,2	± o,1	6,2	± 1,o	4,9	± 1,2
12	17o - 18o	9	15	± 2	o,1	± o,o5	5,9	± 1,o	4,2	± 1,o
13	2oo - 234	7	17	± 3	o,1	± o,o2	5,4	± o,9	4,o	± 1,o
14	234 - 253	7	12	± 2	o,2	± o,o5	5,2	± o,8	4,8	± 1,1
15	253 - 285	7	12	± 2	o,2	± o,o5	5,2	± o,7	4,6	± 1,o
16	29o - 3oo	7	11	± 1	o,2	± o,o5	5,o	± o,7	2,9	± o,7
17	25o - 35o	3	1o	± 1	o,2	± o,o5	5,o	± o,7	2,7	± o,7
18	35o - 4oo	3	67	± 5	1,5	± o,2	1o,2	± 1,2	2o	± 3,5
19	5oo	3	22	± 3	o,5	± o,1	5,o	± o,5	4,9	± o,5
2o	5oo - 6oo	5	8,6	± o,8	o,2	± o,o5	2,6	± o,5	1o	± 1,8
21	6oo - 7oo	5	12,2	± o,7	o,2	± o,o5	3,8	± o,6	38	± 1o,o

Bild 7.1

Gesamt-Elementgehalte Braunerde, seit 18 Jahren nicht berieselt - 1980

Nr.	T (cm)	A	Zn MW (mg/kg)	s (mg/kg)	Cd MW (mg/kg)	s (mg/kg)	Cr MW (mg/kg)	s (mg/kg)	Pb MW (mg/kg)	s (mg/kg)
1	0 - 3	3	110	± 11	2,3	± 0,3	89	± 8	199	± 25
2	0 - 5	5	91	± 8	1,7	± 0,3	82	± 7	189	± 18
3	0 - 7	3	72	± 7	1,4	± 0,2	79	± 8	177	± 16
4	0 - 25	9	71	± 8	1,7	± 0,3	81	± 4	185	± 19
5	0 - 30	3	78	± 9	1,9	± 0,4	89	± 7	196	± 21
6	7 - 33	7	75	± 8	2,0	± 0,3	91	± 5	203	± 11
7	33 - 43	5	90	± 10	0,9	± 0,2	19	± 3	35	± 7
8	43 - 67	7	75	± 5	0,9	± 0,2	15	± 2	21	± 5
9	67 - 81	9	32	± 3	0,5	± 0,1	6,4	± 1	11	± 2
10	81 - 100	9	18	± 2	0,3	± 0,05	5,8	± 0,8	7,3	± 0,4
11	100 - 125	7	13	± 2	0,3	± 0,05	5,6	± 0,4	7,0	± 0,5
12	100 - 140	7	12	± 2	0,2	± 0,05	5,1	± 0,6	6,7	± 0,8
13	160 - 190	5	11	± 1	0,1	± 0,05	5,0	± 0,6	4,5	± 0,3
14	190 - 225	7	9	± 1	0,1	± 0,05	5,0	± 0,4	4,1	± 0,7
15	230 - 245	9	7	± 2	0,1	± 0,05	4,9	± 0,3	3,9	± 0,2
16	270 - 280	9	10	± 2	0,08	± 0,02	4,7	± 0,3	3,2	± 0,3
17	290 - 300	9	12	± 2	0,08	± 0,02	4,7	± 0,4	3,0	± 0,4
18	300 - 330	3	10	± 1,2	0,08	± 0,01	5,1	± 0,3	3,0	± 0,8
19	330 - 360	5	9,6	± 1,0	0,07	± 0,02	6,1	± 0,4	3,1	± 0,6
20	360 - 390	3	7,3	± 0,8	0,06	± 0,01	6,2	± 0,3	3,8	± 0,6
21	390 - 420	3	8,1	± 0,8	0,07	± 0,01	5,9	± 0,2	3,2	± 0,5
22	420 - 450	3	5,9	± 0,5	0,05	± 0,01	5,8	± 0,2	2,9	± 0,4
23	450 - 480	5	6,2	± 0,6	0,05	± 0,01	6,0	± 0,3	2,8	± 0,4
24	480 - 540	5	7,1	± 0,8	0,05	± 0,01	6,2	± 0,1	3,0	± 0,3
25	540 - 630	3	8,2	± 0,9	0,03	± 0,01	5,9	± 0,2	3,2	± 0,3
26	635	1	8,1	(± 0,7)	0,03	(± 0,01)	6,1	(± 0,3)	3,4	± 0,3
27	660 - 720	3	13,7	± 1,6	0,09	± 0,02	6,4	± 0,2	3,5	± 0,3

Bild 7.2

Gesamt-Elementgehalte - Braunerde, nicht berieselt - 198o

Nr.	T (cm)	A	Zn MW (mg/kg)	s (mg/kg)	Cd MW (mg/kg)	s (mg/kg)	Cr MW (mg/kg)	s (mg/kg)	Pb MW (mg/kg)	s (mg/kg)
1	o - 3	3	16o	± 2o	7,5	± o,8	54	± 5	23o	± 11
2	o - 5	5	13o	± 3o	2,1	± o,2	42	± 5	19o	± 1o
3	o - 25	9	7o	± 1o	1,8	± o,2	35	± 5	185	± 9
4	5 - 3o	3	65	± 5	1,7	± o,2	31	± 4	18o	± 9
5	5 - 4o	1	58	(± 4)	1,6,	(± o,2)	3o	(± 4)	175	(± 8)
6	3o - 55	9	39	± 3	o,5	± o,1	18	± 3	16o	± 8
7	4o - 58	5	37	± 3	o,4	± o,o5	16	± 2	4o	± 5
8	6o - 7o	9	19	± 2	o,2	± o,o5	7,o	± 1	4,o	± 1
9	7o - 8o	9	1o	± 1	o,2	± o,o5	6,5	± 1	3,8	± o,8
1o	85 - 95	7	7	± 1	o,15	± o,o2	6,o	± 1	2,6	± o,5
11	1oo - 12o	7	8	± 1	o,15	± o,o2	5,5	± 1	3,1	± o,4
12	12o - 13o	5	7	± 1	o,15	± o,o2	5,4	± 1	2,4	± o,4
13	14o - 16o	7	7	± 1	o,15	± o,o2	5,6	± 1	2,8	± o,5
14	17o - 18o	7	7	± 1	o,1	± o,o1	5,2	± 1	2,4	± o,4
15	19o - 2oo	9	21	± 3	o,1	± o,o1	5,8	± 1	3,8	± 1,o
16	2oo - 21o	9	52	± 9	o,1	± o,o1	6,4	± 1	4,2	± 1,1
17	21o - 225	9	6o	± 11	o,1	± o,o1	19	± 4	8,5	± 2,1
18	2oo - 25o	7	16	± 2	o,o5	± o,o1	6,4	± o,2	4,9	(± o,8)
19	25o - 29o	9	5,8	± 1	o,o4	± o,o1	6,2	± o,2	2,4	(± o,5)
2o	25o - 3oo	7	5,6	± o,9	o,o3	± o,o1	6,1	± o,3	2,5	(± o,4)

Bild 7.3

(9) und die Ähnlichkeit der Gehalte am nicht berieselten und am 18 Jahre lang nicht berieselten Standort belegen die Regenerationsfähigkeit des Braunerdestandorts (Bild 8).

Ohne auf Details weiterer Untersuchungsstandorte einzugehen, ist hier noch zu erwähnen, daß bei Untersuchungen von Parabraunerden im gleichen Untersuchungsgebiet (Untersuchungsorte D, E, F - Bild 2) grundsätzlich ähnliche Regenerierungsverhältnisse nach 18 Jahren berieselungsfreier Zeit festzustellen sind (Bild 9).

Für Betrachtungen über die Mobilisierbarkeit, die Abgrenzung anthropogen bedingter Metallgehalte u. dgl. ist es sinnvoll, die Böden einer Stufenreihe von Extraktionsverfahren wachsender Stärke zu unterziehen (0,1 m Bariumchlorid, 0,1 n Natronlauge, CO_2-Behandlung, 0,1 n Salzsäure, 30 % H_2O_2 und 1 n Ammoniumacetat, 1 m Hydroxylaminhydrochlorid und 25 % Essigsäure).

Die jeweiligen Extrakte lassen sich vereinfacht bestimmten Elementbindungsformen zuordnen (adsorptive Phase, organisch gebundene Phase, carbonatisch gebundene Phase, oxidische Phase, oxidierbare Phase, Hydroxid- und Oxidhydratphase, mineralische Phase (Differenz zwischen Gesamtgehalten und dem extrahierbaren Gehalt)).

Bei den Elementbindungsformen des Cadmiums (Bild 10) fällt der hohe Anteil der organisch gebundenen Phase auf - im berieselten Boden bis in ein Tiefenniveau von 2 m bemerkbar. Wie auch beim Zink zu zeigen ist, kommt es im "Dauerrieselboden" zu carbonatischen Ausfällungen, die in sehr schwachen Relikten auch noch in Teilen des 18 Jahre nicht mehr berieselten Bodens auftreten. Auch das Blei (Bild 11) tritt im berieselten Standort mit einer bis auf 30 % erhöhten organisch gebundenen Phase auf, wodurch auch eine höhere Mobilität des Blei gekennzeichnet wird (Bild 11). Besonders beim Zink (Bild 12) zeigt sich auch im Oberboden des berieselten Standorts ein Hervortreten carbonatischer Phasen, oxidierbarer Phasen vornehmlich organischer Substanzen sowie organisch gebundener Phasen. Auch durch die Elementbindungsformen wird die Regenerationstendenz des 18 Jahre nicht berieselten Bodens deutlich.

Element	Tongest. Stand. mg/kg	ständig berieselt mg/kg	Anreicherung	18. J. nicht berieselt mg/kg	Anreicherung	nicht berieselt mg/kg	Anreicherung
B R A U N E R D E N							
Zink	95	610	6,4fach	193	2,0fach	161	1,7fach
Cadmium	0,3	18,1	60,0fach	3,1	10,0fach	2,1	7,0fach
Chrom	90	185	2,0fach	142	1,6fach	96	1,1fach
Blei	20	2840	142,0fach	330	16,5fach	310	15,5fach
P A R A B R A U N E R D E N							
Zink	95	512	5,4fach	138	1,5fach	101	1.1fach
Cadmium	0,3	11,9	40,0fach	1,9	6,3fach	2,3	7,7fach
Chrom	90	138	1,5fach	115	1,3fach	120	1,3fach
Blei	20	590	29,5fach	286	14,3fach	266	13,3fach

Bem.: Die Ergebnisse beziehen sich je Standort auf Mittelwerte aus 10 Proben

Bild 8 – Elementgehaltsanreicherungen in Oberböden der Braunerden und der Parabraunerden im Vergleich zum Tongesteinsstandard n. TUREKIAN und WEDEPOHL (9)

Gesamt-Elementgehalte - Parabraunerde, berieselt - 198o

Nr.	T (cm)	A	Zn MW (mg/kg)	s (mg/kg)	Cd MW (mg/kg)	s (mg/kg)	Cr MW (mg/kg)	s (mg/kg)	Pb MW (mg/kg)	s (mg/kg)
1	o - 3	5	378	± 98	3,1	± 1	11o	± 13	335	± 35
2	o - 5	5	312	± 1o6	2,9	± o,8	78	± 1o	228	± 31
3	o - 3o	7	151	± 58	1,o	± o,4	42	± 8	139	± 13
4	3o - 6o	5	35	± 7	o,7	± o,2	9,2	± 2,3	7,4	± 1,2
5	6o - 9o	5	3,4	± o,4	o,4	± o,1	5,8	± 1,5	5,2	± 2,1
6	9o - 12o	5	7,4	± 1,8	o,3	± o,o5	14,6	± 2,1	13,3	± 4,2
7	12o - 15o	5	1,6	± o,3	o,3	± o,o5	16,6	± 2,8	1o,o	± 3,1
8	15o - 18o	5	27,4	± 4	o,5	± o,1	14,2	± 2,3	13,o	± 4,1
9	18o - 21o	5	1,6	± o,3	o,3	± o,o5	14,3	± 2,9	9,2	± 2,8
1o	21o - 24o	5	1,4	± o,2	o,3	± o,o5	12,7	± 2,o	9,6	± 2,9
11	24o - 27o	5	37,6	± 7,5	o,3	± o,o5	12,2	± 2,8	22,o	± 5,4
12	27o - 285	5	34,8	± 8,2	o,4	± o,1	12,o	± 2,o	1o,2	± 1,8
13	31o - 33o	5	4o,4	± 9,o	o,3	± o,o5	1o,2	± 1,8	8,5	± 1,6
14	33o - 36o	5	23,8	± 4,2	o,4	± o,12	12,1	± 1,6	11,1	± 1,8
15	36o - 39o	5	21,2	± 3,9	o,4	± o,14	8,o	± 1,4	5,2	± o,8
16	39o - 5oo	5	21,4	± 3,8	o,3	± o,o5	9,o	± 1,5	8,9	± o,9
17	5oo - 6oo	5	23,o	± 4,5	o,2	± o,o2	1o,1	± 1,6	11,1	± 1,2
18	65o - 72o	5	1o,2	± 1,2	o,4	± o,1	4,8	± o,3	3,3	± o,8
19	75o	3	7,4	± o,9	o,3	± o,1	3,9	± o,8	4,o	± o,9
2o	72o - 81o	5	7,4	± o,9	o,3	± o,o5	4,8	± o,9	6,1	± 1,2

Bild 9.1

Gesamt-Elementgehalte - Parabraunerde, seit 1962 nicht berieselt - 1980

Nr.	T (cm)	A	Zn MW (mg/kg)	s (mg/kg)	Cd MW (mg/kg)	s (mg/kg)	Cr MW (mg/kg)	s (mg/kg)	Pb MW (mg/kg)	s (mg/kg)
1	0 - 3	3	111	± 10	0,9	± 0,1	99	± 9	83	± 7
2	0 - 5	3	85	± 8	0,6	± 0,1	67	± 6	31	± 5
3	0 - 25	5	70	± 8	0,4	± 0,05	30	± 4	17	± 3
4	25 - 50	5	56	± 5	0,3	± 0,05	22	± 2	15	± 3
5	50 - 75	5	62	± 6	0,3	± 0,05	23	± 2	16	± 3
6	75 - 100	5	64	± 7	0,5	± 0,1	24	± 2	16	± 3
7	100 - 125	5	46	± 5	0,5	± 0,1	16	± 2	19	± 4
8	125 - 150	5	48	± 4	0,5	± 0,05	16	± 2	17	± 3
9	150 - 175	5	54	± 4	0,5	± 0,05	17	± 2	22	± 2
10	175 - 200	5	58	± 4	0,5	± 0,1	17	± 2	19	± 3
11	200 - 225	5	44	± 4	0,5	± 0,05	14	± 1,5	14	± 2
12	225 - 250	5	23	± 2	0,5	± 0,05	15	± 1,5	20	± 3
13	275 - 300	5	39	± 3	0,5	± 0,05	20	± 2	28	± 4
14	300 - 400	5	21	± 2	0,5	± 0,1	20	± 2	20	± 2
15	400 - 425	5	21	± 2	0,6	± 0,1	21	± 2	15	± 2
16	425 - 450	5	19	± 2	0,3	± 0,05	10	± 1	15	± 3
17	450 - 475	5	9	± 1	0,3	± 0,05	9	± 1	6	± 1
18	475 - 500	5	9,0	± 1,2	0,3	± 0,05	8,4	± 0,9	5,7	± 0,9
19	500 - 550	5	5,6	± 0,9	0,3	± 0,05	5,8	± 0,8	5,7	± 1,1
20	550 - 600	5	7,1	± 1,1	0,3	± 0,05	4,9	± 0,7	11,3	± 2,0
21	600 - 650	5	5,2	± 0,9	0,2	± 0,02	4,4	± 0,6	6,3	± 1,2
22	650 - 700	5	6,1	± 0,8	0,2	± 0,02	4,4	± 0,6	13,5	± 2,1
23	700 - 750	5	14,3	± 1,6	0,2	± 0,02	6,6	± 0,6	39,2	± 8,9
24	750 - 800	5	9,9	± 1,2	0,4	± 0,03	6,8	± 0,5	8,4	± 2,0
25	800 - 850	5	5,2	± 0,8	0,3	± 0,02	5,4	± 0,5	3,6	± 0,9
26	850 -1000	5	3,3	± 0,6	0,2	± 0,02	5,4	± 0,5	4,2	± 0,6

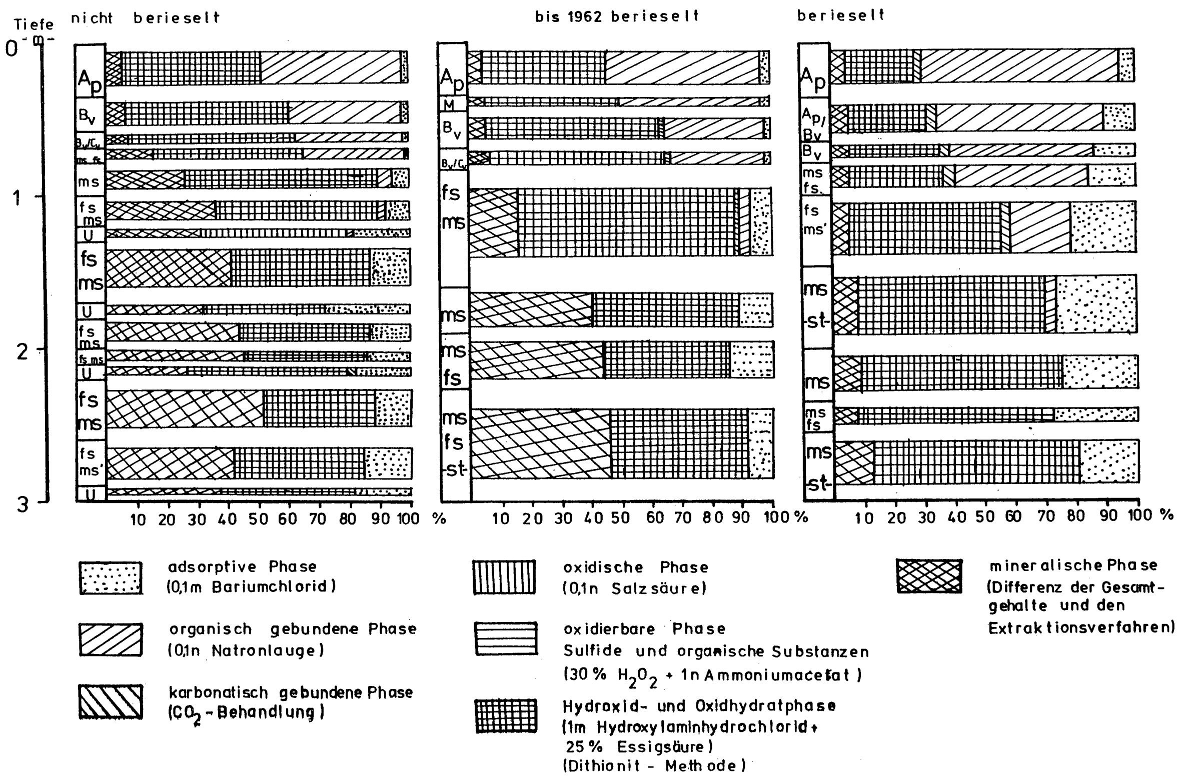
Bild 9.2

Gesamt-Elementgehalte - Parabraunerde, nicht berieselt - 1980

Nr.	T (cm)	A	Zn MW (mg/kg)	s (mg/kg)	Cd MW (mg/kg)	s (mg/kg)	Cr MW (mg/kg)	s (mg/kg)	Pb MW (mg/kg)	s (mg/kg)
1	0 - 3	3	71	± 5	1,1	± 0,05	119	± 18	71	± 7
2	0 - 5	5	65	± 6	0,8	± 0,05	23	± 5	53	± 6
3	5 - 10	5	70	± 5	0,9	± 0,05	22	± 5	56	± 7
4	10 - 15	5	71	± 4	0,8	± 0,02	20	± 3	51	± 5
5	15 - 25	5	83	± 6	0,9	± 0,02	24	± 3	61	± 6
6	25 - 35	5	111	± 10	1,3	± 0,08	27	± 2	120	± 13
7	35 - 40	5	108	± 7	1,2	± 0,08	32	± 2	103	± 11
8	44 - 55	5	45	± 4	0,4	± 0,05	26	± 2	70	± 7
9	55 - 80	5	37	± 3	0,5	± 0,02	14	± 1	31	± 3
10	75 - 83	5	34	± 3	0,4	± 0,02	12	± 1	18	± 2
11	83 - 88	5	50	± 4	0,5	± 0,05	18	± 2	20	± 2
12	88 - 110	5	22	± 2	0,3	± 0,02	17	± 2	10	± 1,8
13	110 - 149	5	25	± 3	0,3	± 0,02	20	± 3	11	± 1,6
14	150 - 160	5	7,6	± 1,6	0,2	± 0,02	8	± 1	5	± 1,2
15	180 - 190	5	13	± 2	0,2	± 0,02	12	± 2	7	± 0,8
16	220 - 260	5	5,2	± 1,2	0,2	± 0,02	5	± 0,5	5	± 0,8
17	270 - 290	5	5,0	± 1,0	0,4	± 0,02	4,6	± 0,4	5	± 0,7
18	300 - 350	5	12,4	± 1,2	0,3	± 0,05	6,6	± 1,1	14,7	± 1,7
19	350 - 400	5	9,0	± 1,0	0,2	± 0,05	5,4	± 1,0	13,2	± 1,8
20	400 - 450	5	6,6	± 0,8	0,2	± 0,02	4,0	± 0,8	9,6	± 1,2
21	450 - 500	5	7,1	± 0,8	0,2	± 0,02	4,4	± 0,8	12,9	± 1,9
22	500 - 550	5	9,5	± 0,9	0,3	± 0,02	4,8	± 0,8	9,0	± 1,7
23	550 - 600	5	6,1	± 0,7	0,2	± 0,02	3,6	± 0,7	11,4	± 1,2
24	600 - 650	5	10,9	± 0,8	0,3	± 0,02	4,9	± 0,8	7,5	± 0,8
25	650 - 700	5	6,6	± 0,7	0,3	± 0,02	4,4	± 0,9	9,3	± 0,9
26	700 - 750	5	8,5	± 0,8	0,3	± 0,04	4,8	± 0,9	12,9	± 1,0

Bild 9.3

BRAUNERDESTANDORTE ELEMENTBINDUNGSFORMEN CADMIUM



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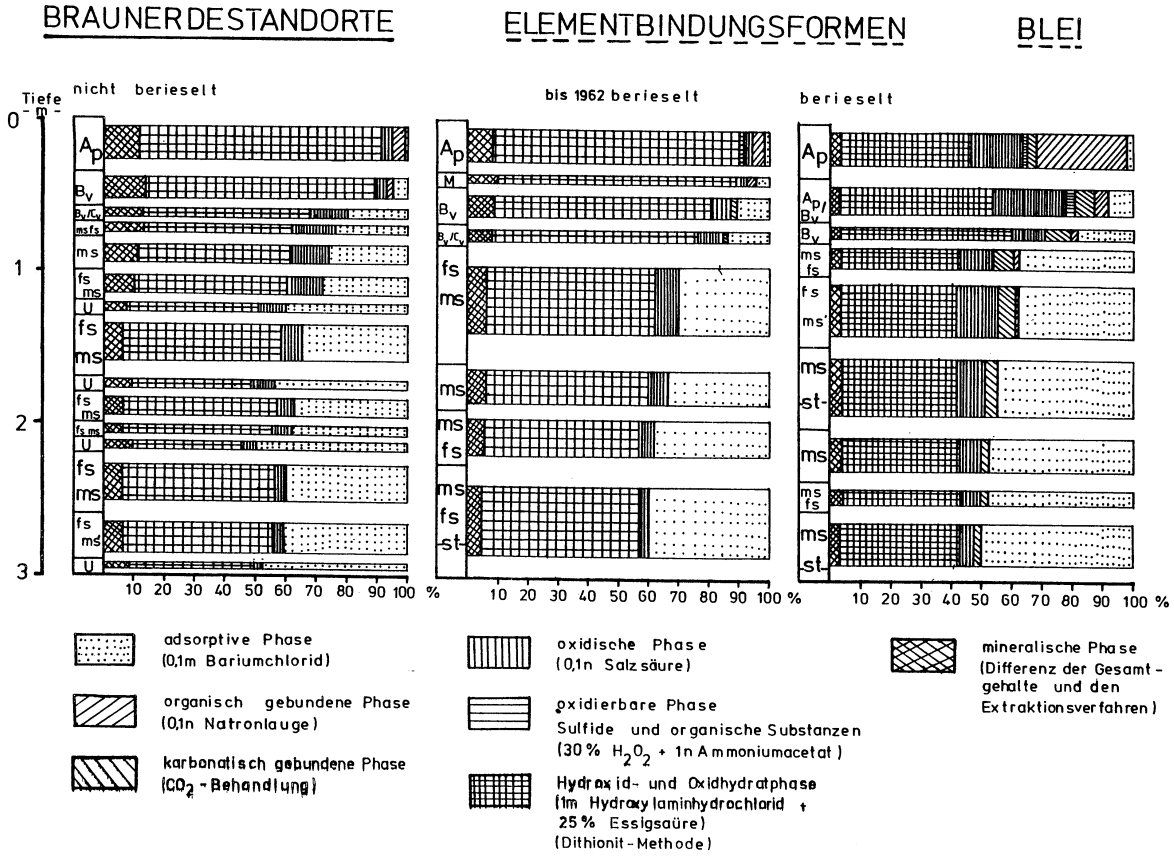
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(0,1m Bariumchlorid)
organisch gebundene Phase
(0,1n Natronlauge)
karbonatisch gebundene Phase
(CO2 - Behandlung)
oxidische Phase
(0,1n Salzsäure)
oxidierbare Phase
Sulfide und organische Substanzen
(30% H2O2 + 1n Ammoniumacetat)
Hydroxid- und Oxidhydratphase
(1m Hydroxylaminhydrochlorid +
25% Essigsaüre)
(Dithionit-Methode)
mineralische Phase
(Differenz der Gesamt-
gehalte und den
Extraktionsverfahren)

Bild 11

BRAUNERDESTANDORTE ELEMENTBINDUNGSFORMEN ZINK

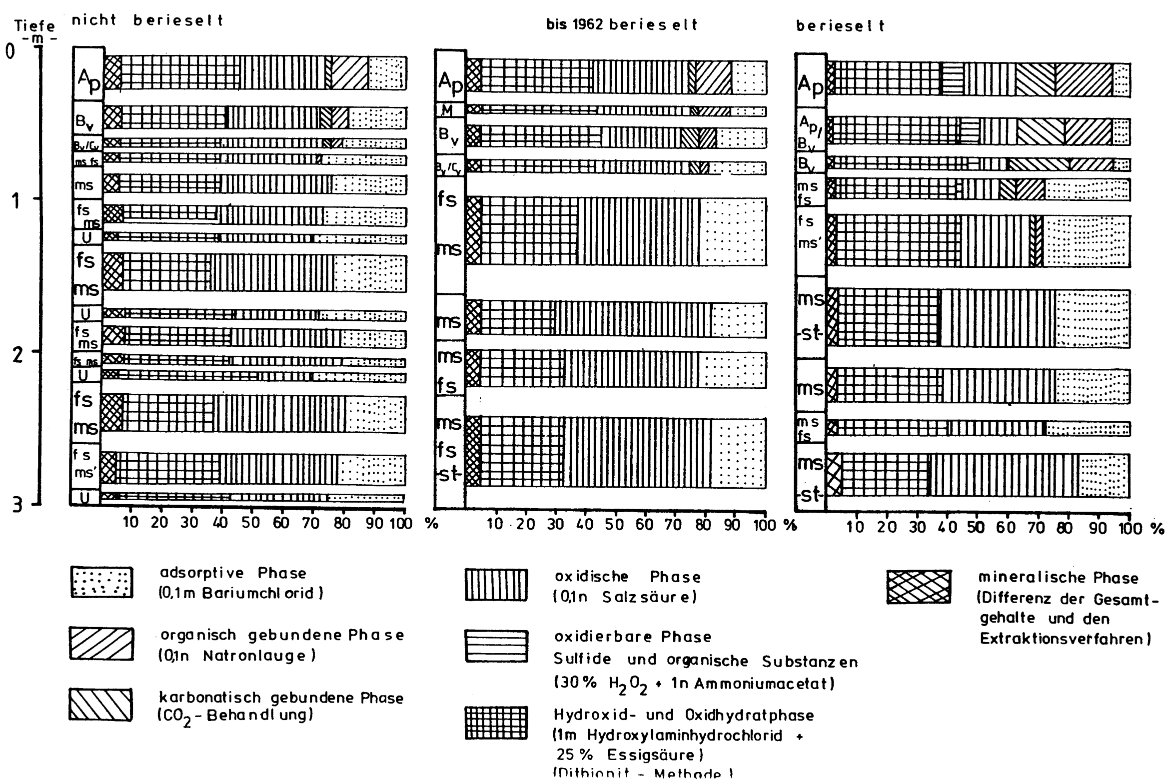

Bild 12

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TEST BIOLOGIQUE POUR LA SURVEILLANCE DE L'ABSORPTION ET DU TRANSFERT, DANS LES VEGETAUX, DE METAUX LOURDS CONTENUS DANS LES BOUES

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BELGIQUE

Résumé

Les boues d'épuration et les composts d'ordures ménagères contiennent souvent des teneurs élevées en métaux lourds. L'analyse chimique ne permet pas de préjuger du transfert de ces éléments dans le sol et les végétaux.

Il s'avère indispensable de disposer d'un test biologique rapide pour estimer la disponibilité et la mobilité de ces éléments dans le système boue-sol-plante-chaîne alimentaire.

A l'aide d'essais en vases de végétation, nous avons comparé les transferts du Cd, du Zn, du Cr et du Ni chez des végétaux réputés sensibles : la laitue, l'épinard, l'escourgeon et le ray-gras.

Ces végétaux sont cultivés en présence de concentrations croissantes de boues d'épuration. Nous mesurons les effets de ces traitements sur le rendement, l'absorption et l'accumulation des métaux dans les organes consommables des végétaux.

Nous établissons des relations entre les teneurs en Cd et en Zn des tissus végétaux et les concentrations de ces métaux dans les boues.

Dans nos essais, la laitue est la meilleure indicatrice et le ray-gras, le meilleur accumulateur.

Summary

A biological test to survey the uptake and the transfer to crops of heavy metals present in sludge.

High contents of heavy metals may be frequently present in sludge or comparable waste products. With only analytical data, we are unable to predict the final levels of metallic contamination of crops and vegetables grown on treated soil. Because there are great variations among the sludges, from sewage plant to sewage plant, and for a same sludge from time to time, there is a need for a quick method to etablish these differences, and to find out whether heavy metals in the sludge are available for plants and may be harmful.

Different "sensitive" vegetables, lettuce, spinach or Italian ray-grass and barley were compared in pot trials (soil added with increased quantitie of sludge) for their uptake of heavy metals, and the transfer of these elements to edible parts.

We find a very good relation between Cd and Zn contents in crops tissues and the addition of contamined sludges to soil.

Lettuce seems to be the most suitable bioindicator plant in our trials.

1. INTRODUCTION

Les boues d'épuration sont utilisables en agriculture, leur valorisation présente des avantages économiques certains. Elles fournissent aux cultures, de l'azote et du phosphore et amènent au sol de grandes quantités de matières organiques, qui autrement seraient perdues.

Un des obstacles majeurs à l'extension de leur emploi en agriculture et en horticulture est leur teneur souvent élevée en métaux lourds. Quelquefois ces éléments métalliques (Cd, Zn, Ni, Cu, Cr, Co, Pb etc) sont présents à des concentrations qui peuvent affecter négativement la croissance ou la qualité des végétaux croissant sur des sols amendés et fertilisés par les boues (1, 2, 3).

Cet apport de métaux lourds par les boues entraîne un risque important d'accumulation de ces éléments dans le sol. Absorbés par voie racinaire, ils sont transférés dans les tissus végétaux. Ils peuvent exercer une phytotoxicité ou présenter des risques pour l'affouragement du bétail et la consommation par l'homme.

L'analyse chimique des boues permet d'y mesurer, avec une grande précision, les teneurs de chaque élément considéré comme indésirable (encore que la concentration même de l'élément soit seule responsable d'éventuels effets toxiques). Les résultats analytiques ne permettent pas de préjuger du taux de transfert d'un métal lourd vers les plantes, ni de pronostiquer la concentration en cet élément dans les fourrages, les fruits ou les légumes produits. Il s'avère dès lors intéressant de disposer d'un test biologique rapide qui permette de mesurer pratiquement la disponibilité d'un ou de plusieurs élément(s) métallique(s) présent(s) dans les boues et d'estimer valablement les risques de transfert du sol vers la plante.

Compte tenu des variations importantes des teneurs en Cd, Zn, Ni et Cr de certaines boues d'épuration produites en Belgique, nous nous sommes particulièrement intéressés à ces 4 éléments.

D'autre part, depuis plusieurs années, nous nous sommes attachés à définir les transferts air-plante et sol-plante du Cd. L'intérêt porté à ce métal résulte de ses propriétés :

- sa présence dans la plupart des boues provenant de stations urbaines,

- son absorption, son transfert et son accumulation dans les fourrages et aliments d'origine végétale,
- son potentiel de risque sanitaire élevé tant pour l'homme que pour l'animal,
- la faible marge existant entre les concentrations réputées normales et celles induisant des effets toxiques décelables.

Pour l'ensemble de ces raison, nos essais portant sur la mise au point de tests biologiques ont considéré le Cd comme élément privilégié.

2. TECHNIQUES

2.1. Analyse chimique

Le Cd, le Zn, le Ni et le Cr sont dosés après minéralisation par voie humide (HNO_3-$HClO_4$), soit pas polarographie impulsionnelle différentielle avec redissolution anodique, à l'aide d'un polarographe PAR, modèle 174, couplé à une cellule PAR, modèle 303 ; soit par spectrométrie d'absorption atomique à double faisceau Perkin Elmer (modèle 372) couplé à un four modèle HGA 500 : tous les résultats sont exprimés en p.p.m./ M.S. (mg par kg de matière sèche).

2.2. Méthode de culture

Les cultures se déroulent en vases de végétation (d'une capacité de deux litres), contenant un sol artificiel. Celui-ci est constitué de 70% de sable blanc, 25% de limon et 5% de terreau. On y ajoute, selon l'essai, des volumes croissants de boue liquide.

Nous avons repris une méthodologie proposée par le dr. S. DE HAAN de l'Institut pour la Fertilité du Sol à Haren (Pays-Bas). Cette méthode consiste à ajouter des quantités croissantes de boues à ce sol, de manière à déterminer si la boue est apte à servir d'engrais d'amendement ou de substrat. DE HAAN préconise de cultiver la plante indicatrice trois fois de suite sur le même substrat et de suivre, au cours de ces trois cultures, l'absorption des métaux lourds par la plante.

Les doses de boue ajoutées au sol sont en progression logarithmique : 0, 1, 2, 5, 10, 20, 50 et 100% (doses établies en volume). Les boues mises à la disposition des agriculteurs belges sont toutes des boues liquides, dont l'hydratation varie de 93 à 95% ; aussi avons-nous, pour les deux derniers traitements, modifié le protocole initial. La dose de 50% est dédoublée en un apport de boue séchée à l'air et un apport de boue liquide, tandis que la dose 100% est constituée uniquement de boue déshydratée.

Le dispositif expérimental comporte cinq répétitions par lot (blocs aléatoires complets). La durée de végétation varie selon l'espèce cultivée entre 6 et 8 semaines. On mesure le rendement des différents traitements par pesée de la matière sèche produite et on analyse les métaux lourds présents dans les tissus récoltés.

2.3. Choix des plantes

Une revue récente de la littérature décrit de nombreux essais de transfert des métaux lourds chez les céréales et chez d'autres plantes de grande culture (betterave, pomme de terre, soja, etc) ou des plantes fourragères (3).

Parmi les légumes, les choux et la bette poirée (Swiss chard) ont été retenus comme accumulateurs de métaux lourds (1, 4).

Pour notre part, d'après nos expériences de transfert du Cd, nous préconisons des légumes foliacés tels l'épinard et la laitue (5).

Des cultures d'épinard et de laitue sur sols traités avec des boues d'épuration ont déjà été faites par divers auteurs (6, 7, 8). Pour nos essais en vases de végétation, nous avons eu, également, recours à des légumes racines comme la carotte et le radis.

Parmi les graminées de prairie, le Lolium multiflorum ou ray-gras Italien, s'est révélé comme une espèce intéressante par son haut potentiel d'accumulation de métaux lourds.

3. ESSAIS REALISES

En plus des essais menés en champs, et dont les résultats sont décrits dans d'autres rapports, nous avons mené un certain nombre d'essais en vases de végétation.

3.1. Comparaison de la disponibilité d'éléments métalliques pour deux plantes : la laitue et le céleri

Deux échantillons différents de boue provenant d'une même station d'épuration, et dont les teneurs en Pb, Cu, Cd, Ni et Zn sont du même ordre de grandeur, ont été utilisés (à raison de 50% en volume) dans 2 essais de culture de laitue (Lactuca *sativa*, var. Hilde) et de céleri (*Apium graveolens*, var. tardif d'Anvers). Les essais ont duré 42 jours (tableau n°I).

Nous exprimons un taux de transfert égal au rapport entre la teneur en un élément dans les tissus végétaux et la concentration de ce même élément dans la boue. Ce taux de transfert est différent de celui défini comme étant le rapport de concentrations de l'élément dans les tissus végétaux et des concentrations de cet élément disponible dans le sol (9).

Nos résultats font apparaître une forte accumulation de Cd chez la laitue, plante qui, dans notre essai, absorbe proportionnellement plus de métaux que le céleri.

3.2. Comparaison du transfert du Cd présent ou ajouté aux boues

Des cultures de laitue (*Lactuca sativa*, var. Hilde) et d'épinard (*Spinacia oleracea*, var. Géant d'hiver) ont été faites en des bacs de culture de 20 litres de capacité recevant 18 litres de sol et 2 litres d'une boue contenant 3,62 mg Cd/litre.

Certains lots ont reçu un complément de 30 mg Cd/litre de boue sous forme de $CdCl_2$.

Le rendement en matière sèche des lots traités a été supérieur à celui des lots témoins. L'effet fertilisant de l'apport de boue est bien marqué, sans apparition d'une phytotoxicité due à l'addition de Cd.

Le transfert du Cd dans les deux plantes choisies est prononcé, ce qui confirme les données de la littérature (8, 10), (tableau n°II).

La laitue mobilise davantage le Cd au niveau des parties épigées que l'épinard. Cette observation est l'inverse de celle faite par BINGHAM (10).

Le rapport entre la teneur en Cd des organes épigés et celle du sol est égal :

- pour l'épinard : 0,84 (boue sans apport de Cd),
  et 0,73 (boue avec apport de Cd),
- pour la laitue : 1,01 (boue sans apport de Cd),
  et 0,96 (boue avec apport de Cd).

3.3. Essai standard sur l'escourgeon (*Hordeum vulgare* L.)

Nous suivons le protocole d'essai défini par DE HAAN. la boue utilisée (6,8% de matière sèche) provient de la station d'épuration de Bastogne. Elle est caractérisée par ses teneurs élevées en métaux lourds (Zn : 2.620 ; Cd : 8,1 ; Ni : 1.590 ; Cr : 1.479 mg/kg sur la matière sèche).

Le rendement en matière sèche, 42 jours après la germination des graines, est fortement accru dans les lots recevant 20% de volume de boue, et ce au cours des 3 cultures successives.

Le transfert des métaux lourds a varié selon l'élément et selon la culture. Il est impossible de citer tous les résultats acquis. Nous donnons les résultats pour les 4 métaux étudiés, en fin de la première culture (tableau n°III) et les résultats de l'absorption et du transfert du Zn (tableau n°IV).

Le cadmium

Au cours de la première culture, les teneurs en cadmium du mélange feuilles et racines s'écartent peu des teneurs dans les témoins. Seul le lot 100% sec fait exception.

Par contre, lors de la deuxième culture, on constate une forte pénétration de métal dans les racines, avec un transfert réduit vers les feuilles et les tiges. Il y aurait donc un certain blocage de l'élément au niveau des racines. Lors de la troisième culture, cette tendance se précise avec une diminution relative des teneurs en Cd dans les parties épigées et des teneurs élevées dans les racines.

Le zinc

Cet élément est parmi les 4 métaux étudiés, le plus abondant dans les tissus végétaux. L'absorption du Zn par les racines d'orge est relativement faible, pour des apports de boue inférieurs à 20% volume. Quand on dépasse cette dose, il y a une forte accumulation, tant dans les tiges que dans les racines.

Le chrome

Le type de transfert du Cr est proche de celui du Cd ; avec un blocage très net au niveau des racines. Cette absence de translocation est manifeste lors de la deuxième culture, avec des concentrations dans les feuilles inférieures, au seuil de détection, tandis que dans les racines, on atteint des teneurs de 20 à 30 p.p.m. de Cr.
A la fin de la troisième culture, on retrouve, dans les tiges et les feuilles, 10% environ du Cr présent dans les racines.

Le nickel

L'aspect le plus étonnant dans l'absorption et la translocation de cet élément est la formidable augmentation des concentrations en Ni pour les traitements à base de boue déshydratée.

Ce phénomène est particulièrement évident chez les racines, où l'on observe un rapport de 1 à 20 (de 16,3 à 331 p.p.m., culture n°2 et de 83,4 à 1.123 culture n°3) entre les traitements 50% de boues liquides et 100% de boues séchées.

Bien que ces deux traitements mettent en jeu des quantités de matière sèche différentes, on peut se demander si le Ni ne se trouve pas dans les boues déshydratées, sous une forme plus accessible aux racines d'orge que dans les boues liquides.

4. DISCUSSION

Nous avons tenté de présenter brièvement certains types d'essais destinés à suivre les risques potentiels de passage des métaux lourds, amenés par les boues, dans les sols et les végétaux.

L'addition de métaux lourds aux boues, est un procédé artificiel qui ne permet que de suivre le mécanisme d'absorption et d'accumulation par la plante, sans qu'il soit vraiment représentatif de la disponibilité des métaux amenés par les boues.

Il s'avère indispensable de standardiser les essais biologiques prévus pour prévenir et étudier les risques d'accumulation des éléments métalliques dans les sols cultivés et les récoltes. Une proposition en ce sens a déjà été faite au sein du groupe de travail 5 de l'action COST de la C.E.E. (11). Le choix des plantes préconisé : plantes sensibles : épinard, haricot et radis et plante accumulatrice : le ray-gras, convient très bien à l'expérimentation. La nécessité de recourir à des légumes foliacés, à croissance rapide, s'impose pour obtenir le plus rapidement possible les informations sur le transfert, que l'analyse chimique de la boue ne peut seule fournir.

Dans nos conditions expérimentales, la laitue s'est montrée très satisfaisante pour des essais de routine que l'on pourrait mener également avec l'épinard et le radis. Le pouvoir accumulateur du ray-gras est bien connu et exploité dans d'autres recherches : notamment la surveillance des retombées atmosphériques de métaux lourds.

Tableau 1

Comparaison des transferts de métaux lourds chez la laitue et le céleri cultivés sur deux boues de stations d'épuration

	Pb	Cu	Cd	Ni	Zn
Boue A analysée	210,00	428,00	4,80	81,50	2.167,00
Laitue A'	7,20	25,20	3,40	7,10	192,00
Rapport $\frac{A'}{A}$ en %	3,42	5,88	70,50	8,71	8,86
Boue B analysée	247,00	481,00	4,90	112,00	1.787,00
Céleri B'	2,43	6,83	0,37	4,83	166,60
Rapport $\frac{B'}{B}$ en %	0,98	1,42	7,55	4,31	9,33

Résultats exprimés en p.p.m. (mg/kg M.S.).

Tableau 2

Teneur en cadmium dans le sol et dans la partie aérienne des plantes d'épinard et de laitue à la récolte

Traitement	Teneur en Cd (mg/kg M.S.) Sol	Epinard	Laitue
Sol	0,18	0,38	0,22
Sol + boue	0,33	0,28	0,30
Sol + boue + Cd	1,80	1,44	1,55

Légende : Sol : teneur initiale 0,18 mg Cd/kg M.S.
Boue de Fleurus: 3,62 mg Cd/kg M.S.
Cd : apport de 30 mg Cd/litre de boue.

Tableau 3

Teneurs en métaux lourds chez Hordeum vulgare L.
cultivées en présence de doses croissantes de boues d'épuration
(Première culture)

Traitement	Feuilles et racines Cd	Cr	Ni	Zn
Témoin	0,41	1,8	3,2	50
1%	0,25	3,9	3,4	50
2%	0,19	4,8	3,2	65
5%	0,33	2,3	2,1	50
10 %	0,22	2,1	1,9	70
20 %	0,44	2,1	3,6	115
50 %	0,05	1,8	9,5	87
50%*	0,30	6,8	25,4	235
100 %*	0,79	11,8	124,0	825

Tableau 4

Evolution des teneurs en Zn de tiges et racines
d'Hordeum vulgare en présence de concentrations croissantes
de boue d'épuration, au cours de 3 cultures successives

Zinc Traitement Apport de boue	Culture n°1 Tiges + racines	Culture n°2 Tiges	Racines	Culture n°3 Tiges	Racines
0% liq	50	90	150	100	115
1% liq	50	85	250	86	115
2% liq	65	80	250	104	103
5% liq	50	83	150	86	110
10% liq	70	93	175	120	110
20% liq	115	110	400	196	267
50% liq	87	250	275	327	516
50% sec	235	500	700	500	856
100% sec	825	1.075	1.340	1.042	1.698

Légende : résultats exprimés en p.p.m./M.S. (mg/kg M.S.),
liq : boue liquide, 93% d'hydratation,
sec : boue déshydratée, 60% d'hydratation.

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CONCLUSIONS OF THE SYMPOSIUM

prepared by the

COORDINATORS OF THE WORKING PARTY

SLUDGE PROCESSING

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This Session of 17 papers highlighted once again the very wide range of technical topics covered by Working Party n° 1 but is is possible and convenient to divide the topics into 4 broad subject areas-Sludge Production and Characterization, Dewatering, Stabilization and Economics. It is notable that 3 of the Review papers on these main areas were each written jointly by authors from different countries. This reflects the very good co-operation which exists between those involved in sewage sludge research in Europe and which has been largely the result of the formation of the COST 68 Working Parties.

Working Party n° 1 has previously defined the basic objective of sludge processing as'to render sludge suitable for disposal at minimum cost'. All the research described in the various papers is seen to be directed in some way or other at that aim. Much of the research is related to process engineering and evaluation and to developing improved methods of sludge processing and handling. The subject matter is much less controversial than that which is covered by the other Working Parties dealing with 'environmental impact' aspects of sludge disposal.

Sludge Production and Characterization

For planning and plant design purposes, there is a need for reliable data on the rates of sludge production per capita and for quantitative information on the factors which affect production rates. It is generally assumed that the rates may range from about 60 to 260 g dry solids/ person day according to the method of treatment of the sewage (Haugan and Mininni). However, the detailed survey of sludge production in the Netherlands (Duvoort-van Engers) showed a much lower daily rate of about 36 g/population equivalent; similarly low figures have been reported from the F.R.Germany. The explanation for the low rate may lie in the type and proportion of trade waste present in the sewages. Working Party N° 1 intends to investigate the reasons for the apparent differences between countries. The aim will be to produce a standard protocol for assessing sludge production.

Sludges can vary enormously in their characteristics but, fortunately, there are now many useful laboratory tests for characterizing the physical properties and behaviour of sludges in relation to the various processing methods. Such tests may be important as design aids as well as for monitoring and control purposes at sewage works. There is still a need, however, for a simple test of centrifugability and also for a reasonably simple and widely applicable test for determining the degree of stability of aerobically or anaerobically digested sludges (Haugan and Mininni). At present, there is no common definition of a stabilized sludge.

The use of Differential Thermal Analysis (Balmer and Kaffehr) is a novel approach to the problem of measuring stability but it is still too early in this study to draw conclusions about its potential application for this purpose. Leschber lists some 32 currently recognized parameters for sludge characterization and this list will no doubt lengthen in time as new parameters and methods are proposed. A strong case is made for international standardization and harmonization of methods of characterization. It is the intention of Working Party n° 1 to do as much as possible to promote such harmonization and a start has already been made in this direction by a survey of national methods and the preparation of a compedium.

Sludge Dewatering

Dewatering of sludge, including thickening, is an important means of reducing the cost of handling and transportation and research and development in this area is still very active. A state of the art review of dewatering methods is in preparation by Working Party n° 1. In a preliminary survey, it has been shown that the proportion of total sludge production which is dewatered, and the methods of dewatering that are employed, vary considerably from country to country (Spinosa and Eikum). Thus, 75 per cent of all sludge dewatered in Norway is dewatered by centrifuge while the figure for the United Kingdom is only 3 per cent. There are no drying beds in Norway whereas in Ireland all sludge which is dewatered is dewatered on drying beds. The reasons for these sorts of differences in methods may relate to differences in climate etc. but there is also undoubtedly an element of local fashion. This is an area for further study. One common trend in all countries is the increasing use of polyelectrolytes for sludge conditioning and this is related to some extent to an increased use of belt presses for dewatering.

To improve our understanding of the mechanisms of dewatering, there is a need for further study of the physical phenomena involved and for the development of improved mathematical models of the processes. Activated sludge is particularly difficult to dewater mechanically and it has now been shown (Casey and Daly) that the normal model for cake filtration under elevated pressures does not apply to activated sludges owing to compressibility effects. It has also been shown (Englmann) that the normal methods for characterizing sludges for dewaterability do not always give good prediction of full-scale performance of dewatering machines. Sludges from chemical-precipitation plants may also be difficult to dewater and the detailed description of the dewatering behaviour of these sludges (Gleisberg) using various devices is a useful advance in knowledge.

It is of interest to learn that Finland is intending to ban the disposal of liquid sludge within a few years while in the United Kingdom and in some other countries the disposal of liquid sludge is on the increase. For small works in cold climates the method of natural freeze-thawing for conditioning sludge followed by drainage on a peat medium seems attractively simple and economic (Puolanne). But clearly this method is restricted to areas where natural freezing can be relied upon.

Sludge Stabilization

Stabilization of sewage sludge is important for reducing the environmental impact of sewage sludge particularly that of odour. Indeed, the primary objective of all methods of stabilization is odour reduction (Bruce and Loll) but other benefits may also be obtained. Anaerobic digestion at 30-35 $^{\circ}$ C is by far the most popular method in all countries surveyed by Working Party n^{o} 1 and is likely to remain so far the foreseeable future, particularly in view of the fact that it is a net energy-producer.
Aerobic digestion at ambient temperatures is too energy-demanding and inefficient to be widely popular, but thermophilic aerobic digestion using air may prove of more importance. Composting seems to be of very localized significance only. Chemical stabilization will continue to be attractive in certain situations in view of the minimal investment costs and the rapidity with which the process can be put into operation.

One major disadvantage of mesophilic anaerobic digestion is its high capital cost where conventional concrete tanks are employed. This factor has been a disincentive to the use of the process at small rural works. The successful installation of a low-cost prefabricated system (Noone and Boyd) based on farm equipment is therefore a very significant development.
There is always an attraction in the possibility of producing a saleable product as a result of the stabilization of sewage sludge. The new method of producing a stable material with good handling properties by treating sludge with quicklime (Thormann) appears very promising but the economics are uncertain and it remains to be seen if it will be successful. As with dewatering methods, there appears to be a strong element of fashion in the methods of stabilization favoured in different areas.

Economics of Sludge Processing

There is a great need to assess the relative costs of alternative sludge treatment and disposal 'routes' so that the planner can make appropriate decisions about what systems to select in particular circumstances. The cost comparisons obtained by Colin are in broad agreement with those obtained for some other countries but it would be unwise to assume that they are of absolutely general application. The data given do bear out the assumption that the less treatment given to a sludge the less the cost and this might be usefully linked with the other truism that there is no point in providing more treatment for sludge than is actually required for its safe disposal.

General

The contribution by Busby was a most useful reminder to all those involved in research in sludge of the practical problems faced by operators in having to deal day-in and day-out with the relentless flow of the material on behalf of us all.

CHEMICAL POLLUTION OF SLUDGES

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As on previous occasions, contributions to the symposium on the subject of "Chemical Pollution of Sludge" concentrated on the heavy metals problem. The papers dealt with analytical studies conducted within the programme established by Working Party 2 (WP 2) of Concerted Action 68 bis, by members of WP 2 and a number of other laboratories from the partner countries.
The results have shown that these papers meant essential contributions on the problem of heavy metals in sludges, their determination and their forms of binding. These results are expected to meet with considerable attention on the national and international levels with a view to the preparation of legislation on the agricultural use of sludges. It has again been possible to present to the public information on the activities of WP 2 which is being continued (1,2).

The method of digestion as a step of the determination of heavy metals in sludge has been the subject of detailed studies in this context. Aqua regia proved to be well suitable as a digesting agent if some elementary procedures were observed and it was seen that even less experienced analysts could obtain results that permitted an evaluation of sewage sludges. This statement does not exclude the alternative use of other methods by experienced workers (1).

The damaging action proper of heavy metals present on or in the soil to crops is essentially influenced by the various types of binding and of the mobility of these metals.
Efforts are made at present to provide a basis for invariably suitable criteria of evaluation by means of joint studies (2).

Furthermore, a report on special studies of the determination of heavy metals in Belgium was presented (3). New data on the sources on heavy metals contamination and the content of such metals in sewage sludges from defined regions were also communicated (4,5). Like similar results determined elsewhere, such knowledge is of particular importance because it will serve as a basis for specific measures of their reduction and avoidance in wastewater. Such measures are necessary to obtain a reduction of the heavy metals loads of the respective sludges and thus to make an essential contribution to the solution of problems arising in the agricultural utilization of sludges.

The true extent of the hazards for humans and animals resulting from this type of waste disposal is at present known only in some sectors. For this reason regional requirements in respect of the maximum permissible concentrations of hazardous substances in sewage sludges have remained rather stringent in part. This might be furthermore elucidated by future detailed studies of transfer mechanisms and of the content and distribution of heavy metals in plant material. Thus, the programme of WP 2 has envisaged long-term work on these problems.

Unlike heavy metals, other anthropogenic sewage sludge contaminants which may cause health risks have not been studied much. Reasons for this may have been the variety of chemical compounds involved and the difficulty of or the unjustified expenditure necessary for their analysis. Nevertheless, there has been detailed research into certain classes of compounds as e.g. polychlorinated biphenyls in various countries including Switzerland. From results presented in respect of the region of lake Geneva, it is concluded that such organohalogenide compounds may well cause problems in defined areas and thus raise increased attention in the future (6).

It became evident from an Italian contribution (7) that in addition to special analysis of trace substances, a general analysis of sewage sludges, i.e. the determination of type and quantity of inorganic and organic fractions might be an aid in the treatment and utilization of sludges. This might also link the work of WP 1 where recently activities have concentrated on problems of sludge characterization.

Discussions on the fields described and on the subject of topic 5 (Environmental Effects) when a number of the above problems were raised, with particular reference to practical aspects, resulted in the following main features of future work :

1. Despite the identical usefulness of a number of methods to determine the heavy metals content of sludges, it is recommended to adopt one single method for purposes of comparison, particularly so if reference materials are involved. Such approach will contribute to a better understanding of the subject also by those who are preparing corresponding legislation but do not have a detailed knowledge of analytical procedures. This would also permit an impartial quality control of the performance of laboratories which might be attributed greater importance in the future.

2. There should be an improved knowledge of the mobility of heavy metals in the soil together with more detailed studies of the transfer of these elements within the chain, sludge-soil-plant-animal and/or man. Objective criteria might result in an improved assesment of the presently existing and not only presumtive hazard for man and provide an approach for specific pollution control measures.

3. The same effect might be obtained by studies resulting in an improved knowledge of the sources of heavy metals contamination and the behaviour of heavy metals when passing through the different processes of wastewater treatment.

4. The problems presently existing in the field of organic micropollutants of sludge seem to be of a regionally limited type, a broad programme of research towards further elucidation in this field is subject to certain constraints because of the complicated and costly analytical procedures involved. Nevertheless developments are followed with interest.

5. In the view of WP 2, essential points include an improvement and standardization of methods of sludge characterization closely associated with the treatment of sludges which are increasingly considered by WP 1 in its activities. In case such methods concern adjoining fields of physics and chemistry it might be desirable to establish joint programmes for both groups.

BIOLOGICAL POLLUTION OF SLUDGE

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In accordance with the terms of reference defined by the Concerted Action Committee, Working Parties were established where the objectives among others were "the quality of sludge and derived products for agricultural use" and to contribute scientific results to the harmonization of rules or recommendations with regard to sludge application on soil concerning the content of pollutants and pathogens. Working Party 3 should deal with the "Characterization of bacteria, viruses, parasites and all aspects of disinfection".

The work has resulted in a report the summary of which will be in the Symposium proceedings. A number of the conclusions and suggestions were mentioned during our session and only a few points will be repeated : we conclude that economically and practically a no-risk level cannot be obtained although the potential technological possibilities are there. There are no fail-safe procedures. Risk assessments are difficult from many points of view because even if a careful examination of the types and number of pathogens present at any time were carried out, all the other factors remain that make an absolute assessment impossible. The importance of local factors of cultural, geographical, economic, political etc. nature cannot be stressed too much.

We have reached agreement on some suggestions for required treatment for various applications.

These are essentially divided into 3 groups :

1. "No treatment" with limited and very restricted application by special permission
2. "Stabilized sludges" with a number of restrictions suggested
3. "Sanitized sludge" where there would be no restriction from an hygienic point of view.

These suggestions are described in our summary report and are supposed to be minimal requirements, which could be augmented locally.

In our group we have been concerned about the various pathogens that may be present in sludge and their importance from a public health point of view.
We have tried to understand the efficiency of the various treament processes in rendering the pathogens harmless.
We have even defined what we mean by various terms in connection with treatment. The resistance of residual pathogens in the soil and the difficult indicator problems have been discussed. We have identified a number of controversial issues and we have made it a point to focus on some of them in the invited papers. The proferred papers also touch various important and to some degree controversial questions.
I shall now try to summarize some of this work.

ALDERSLADE's paper and the presentation by CROMWELL stresses that the potential possibilities for pathogens being in waste waters and consequently in sludges seem considerable, but if proper treatment practices are adhered to, the actual risk of transmission is minimized.
In addition, good hygienic practice will reduce the risk of transmission.
A discussion arose as to what was meant by "good hygienic practice".

On the question of indicators much needs to be done before agreement within the group can be reached. The various pathogens are not present all the time in feacally polluted waste waters. The amount present varies considerably. For some pathogens, we do not have proper methods for their detection. Consequently we need indicators, that are

1. regularly and abundantly present in the intestinal tract
2. are easy to cultivate quantitatively and
3. to a suitable degree use more resistant than the pathogens that they are supposed to be indicators for. HAVELAAR talked on this subject and it is obvious that indicators for the presence of pathogens in sludges are not necessarily the same as the ones that might be useful for estimations of efficiency of various treatment processes.

Another area, of, at least apparent, considerable disagreement is the importance of the presence of salmonellae in sludges. There is agreement on their presence all in Europe, but the actual amount in sludges and on pastures varies.

PIKE reviewed the situation and HESS gave specific examples of desease caused by the spread of salmonellae through land application of sludges. It seems that the reasons for the apparent variations in importance partly may be connected with variations in the actual load. Variations in methodology is also suggested.

STRAUCH presented work on the survival of salmonellas and ascaris eggs in forest applied sludge. The survival of the bacteria for at least one year and the ascaris eggs for at least 60 days prompted the conclusions that special measures to prevent spread of infections to man and animal were indicated.

In the report presented by BERRON faecal coliforms and streptococci have been followed under field conditions.
It is concluded that the 3-4 months survival time must be remembered when possible health hazards are evaluated.
ANSELME presented work on sulphate reducing clostridia. As these very resistant, spore forming anaerobs are present anyway in the soil, they are essentially disregarded in sludge. The paper questions this attitude because the load is considerably increased through sludge application.
LACROIX reported that the resistance of clostridia towards gamma-irradiation could be somewhat decreased by simultaneous oxidation with CaO.

HANNAN reviewed the various parasites that might be present in European sludges. He pointed out the high resistance of a number of these, e.g. the ascaris eggs, but concluded that Taenia Saginata probably was the most important. Toxoplasma Gondii and Toxocaxa Canis, which both can reach the sludge from stormwater have perhaps more importance by this route of transmission than hitherto recognized.

The group has had correspondence with US E.P.A. and has received some information. The USA "Interim final" guidelines on sludge application is made with special reference to Ascaris and Taenia and to protozoan cysts. The concern about viruses would probably then be covered also as they are not as hardy as the parasites. They admit that different climatic and environmental conditions would affect the time required to destroy the pathogens and also that various comments have been received to this effect. The EPA welcomes contact with our work.

BEYTOUT presented a report on the virological problems, especially connected with the difficulties in obtaining quantitatively relevant results. The background problems associated with the nature of the virus particles and their adherance to various materials was explained.

RINALDI presented work on virus inactivation during anaerobic digestion where it was confirmed that the process works somewhat faster than could be expected from a simple temperature time relationship.

The subject of the pre-pasteurization was treated by BREER and STRAUCH. If the two reports are considered together both field studies, pilot plant experiments are included and some important conclusions may be reached. The pre-pasteurization as studied bacteriologically is at least not inferior to conventional pasteurization. It seems that from a treatment plant point of view important advantages may be obtained. If proper heat exchange is established the pasteurization would cost little extra energy and may even be a technological improvement.
The pre-pasteurization should be studied further both from a general hygienic point of view as well as from a technological point of view.

The Working Group has identified a number of research needs and recommends that funds should be made available to promote research in these areas, in particular :

1. the indicator problems
2. low level technology and energy saving stabilization and sanitation methods and their efficiency
3. various lime treatment problems
4. the importance of spread of infection by protozoan cysts from sludge
5. virological studies (on detection methods and the resistance of various types of viruses etc.)
6. the importance of animal vectors in the spread of pathogens.

VALORISATION AGRICOLE DES BOUES

CONCLUSIONS GENERALES

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Le Groupe de Travail 4 - valorisation agronomique des boues - effets bénéfiques, occupe une place bien particulière dans l'action Cost 68 bis, puisque seuls ses résultats peuvent justifier l'utilisation en agriculture des boues dont on sait qu'elle présente des effets nocifs ou à tous le moins des risques pour l'Environnement.

Le travail du groupe s'est concrétisé lors des communications présentées au Symposium de Vienne mais les conclusions et les réflexions que je vais présenter par la suite couvrent l'ensemble de l'action.

Les objectifs de travail du groupe : valorisation agricole - effets bénéfiques nous ont fait considérer les boues selon trois aspects :

- les boues comme engrais azotés
- les boues comme engrais phosphatés
- les boues comme amendement organique.

Il faut rajouter à cela un intérêt évident pour les éventuels effets nocifs dûs aux éléments majeurs apportés par les boues : azote, phosphore, qui, s'ils sont actuellement du ressort du Groupe de Travail 5, n'en ont pas moins été considérés simultanément et dévraient dans l'avenir être pris en compte par le Groupe 4.

Le Groupe 4 s'est par ailleurs engagé à fournir pour 1981 deux rapports sur l'azote et le phosphore qui résumeront, à l'attention des décideurs et des services conseils ce qui est <u>connu</u> et ce que l'on peut <u>recommander</u>.

Quelles sont actuellement les connaissances acquises et quels sont les besoins de recherche ?

En ce qui concerne l'azote, il faut tout d'abord rappeler que l'effet azote est l'effet principal recherché par l'agriculture, on peut dire que :

- L'effet à court terme commence à être connu et sera bien connu dans un proche avenir.
  Il reste que les boues ne seront jamais un engrais azoté très facile d'emploi qui exigera toujours une bonne technicité de l'agriculteur et/ou un bon encadrement.

- les arrières-effets et les effets à plus long terme ne sont pas assez connus

- les pertes soit par voie gazeuse et je pense principalement à la dénitrification soit par lessivage ne sont pas connues.

Ces points sont essentiels à connaître si l'on veut correctement conseiller et légiférer en prenant l'azote en compte.

Il convient à ce stade, d'insister sur l'utilisation du raisonnement par bilan que l'on est souvent enclin à employer. Encore faudrait-il l'employer correctement !
Lorsque l'on base la détermination de la dose de boues applicable sur l'azote en exigeant que les boues n'apportent pas plus d'azote que les cultures n'en exportent, cela n'a aucun sens au plan agronomique si l'on ne précise pas azote minéralisable et si l'on ne tient pas compte des pertes par voie gazeuse, volatilisation d'ammoniac et/ou dénitrification. Ou bien nous aurons des rendements diminués ce que l'agriculture n'acceptera pas sans compensation.

En ce qui concerne le phosphore, les problèmes sont assez différents dans la mesure ou un excès de phosphore dans le sol (la notion d'excès restant assez floue) ne gène pas la production végétale.

En général, l'utilisation des boues, si elle est basée sur l'apport d'azote, conduit à apporter trop de phosphore qui s'accumule pour la quasi-totalité et migre très peu ou en quantités très faibles. Il n'y en a pas moins augmentation des risques pour les eaux notamment par ruissellement mais là encore, il faut faire remarquer que le problème de l'eutrophisation est loin d'avoir la même importance pour tous les pays participants à cette action.

En effet, les risques d'eutrophisation sont très différents, selon que l'on a obligation ou non de protéger lacs et canaux. Surtout, le niveau moyen de richesse en phosphore des sols varie certainement beaucoup entre pays.

- Concernant l'efficacité du phosphore des boues et les risques de migration, le point vient d'être fait récemment à Haren lors d'un séminaire CEE dont les comptes rendus sont prêts à être imprimés.

- Il restera à préciser certains points notamment pour les boues physio-cochimiques et les boues de déphosphatation.

- De même il semble intéressant d'approfondir l'étude des relations Phosphore - métaux lourds en connection avec les plantes.

Enfin pour la matière organique des boues, il faut reconnaître que nous manquons globalement de données pratiques utilisables notamment pour :

- la capacité des boues à produire de l'humus
- les effets des boues sur les propriétés physiques des sols. La question est en effet la suivante : peut-on avoir un effet économiquement intéressant pour l'agriculture, notamment à faible dose par exemple à dose n'apportant pas d'azote en excès?

Finalement, il y a très peu de données sur l'influence des boues sur la Biologie des sols notamment mauvaises herbes, faune et microflore du sol, particulièrement les agents pathogènes des plantes.

Ce premier bilan étant fait, et compte-tenu des connaissances acquises dans le domaine des métaux lourds et des agents pathogènes, il convient de se reposer la question fondamentale : Compte-tenu des risques que cela représente, doit-on utiliser les boues en agriculture ?

Qu'il soit permis au pilote du Groupe 4 de proposer quelques remarques personnelles à la réflexion du lecteur.

La première remarque est que les boues représentent un faible pourcentage des fertilisants utilisés en agriculture : si les engrais minéraux et les effluents d'élevage sont les deux apports principaux - du même ordre de grandeur - les boues représentent au plus de 2 à 5% des engrais minéraux azotés et phosphatés utilisés.

On peut en tirer deux conclusions contradictoires :

- L'agriculture a la capacité d'utiliser les éléments majeurs apportés par les boues,
- mais elle est déjà confrontée à ses propres problèmes de déchets d'un autre ordre de grandeur.

La deuxième remarque est que l'agriculture n'a pas besoin des boues. Il est d'ailleurs fort peu probable qu'une augmentation même dramatique du coût de l'énergie, donc du coût des engrais, entraîne une forte augmentation de la demande de boues car l'énergie entre pour un faible pourcentage dans la formation du produit brut de l'agriculture.

Dans ces conditions, l'agriculture ne prendra les boues que si elle y trouve des avantages suffisant pour contrebalancer les contraintes.

Ces contraintes sont essentiellement les agents pathogènes et les métaux lourds.

Pour les agents pathogènes qui sont des éléments disparaissant dans le temps on peut considérer qu'il y a des solutions pratiques possibles. Par contre les métaux s'accumulent et les exemples donnés lors du symposium étaient particulièrement démonstratifs à ce sujet.

On en viendra évidemment à diminuer l'apport de boues en se basant sur les métaux lourds. Mais je crains beaucoup que l'on ne finisse par épandre les boues avec une petite cuillère.

Si la dose de boues que l'on peut péconiser n'apporte plus assez d'azote et de phosphore, ceci pour respecter un apport minimal de métaux lourds, alors pourquoi les agriculteurs utiliseraient-ils les boues.

Quelles conclusions peut-on tirer actuellement ?

Il est de notre devoir de ne pas accepter und dégradation irréversible de nos sols, ce qui serait le cas avec les métaux lourds, et ceci même à l'échéance du siècle.

Or actuellement, si l'utilisation agricole des boues est une opération bénéfique globalement, il apparaît que c'est plus la collectivité que l'agriculture qui tire les marrons du feu.

Si dans un avenir proche, les métaux lourds conduisent à diminuer les doses de boues utilisables en dessous d'un certain seuil, l'agriculture ne pourra pas les accepter sans compensation.

Je suis personnellement convaincu que si dans l'avenir, nous ne réussissons pas à diminuer fortement la teneur des boues en métaux lourds et à les enrichir simultanément en éléments fertilisants, alors l'utilisation agricole des boues n'a qu'un avenir très limité pour ne pas dire pas d'avenir du tout.

ENVIRONMENTAL EFFECTS OF SLUDGE

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1. The Working Party 5's task has been to consider research into the effects of heavy metals and organics on the soil, effects of sludge on groundwater and on the environment. It has taken into account the effects on man and animals since their protection and well being must be the ultimate objective. The Working Party has noted the criteria being used in guidelines and prepared a comparison of known guidelines with the object of seeing that research and criteria are related as far as possible and our work should be very important in providing scientific evidence for criteria.

2. The Working Party has considered interaction not just between one metal and another but also the effects of nutrients on phytotoxicity (Halbwachs). They attended seminars on phosphorus and copper in order to appreciate both the adverse and beneficial effects of these elements. With these and other elements it is important to note that any difficulties result from man's aim to cut the cost of disposal and dispose on limited areas. There would be no problem if the copper in sludge was disposed on the many areas of copper soil deficiency and the phosphorus used appropriately as a fertilizer. Even the problem of cadmium would disappear if sludge is utilised over a much larger area of land.

3. The object of research in our area is to seek information on what application rates are acceptable for the most sensitive land use that may occur as land use may change. The rates must take into account the need to prevent yield depression and to prevent high uptake of toxic contents.

Heavy metals

4. These can be broadly divided into those that are toxic such as lead, cadmium, fluorine, arsenic and selenium and those that are phytotoxic such as zinc, copper, nickel, boron and also cadmium. For the former a concentration limit seems appropriate and for the latter an application limit.

5. Phytotoxic effects depend on the presence of the element in the soils, uptake and toxic effects. Uptake is a very complex matter depending on many factors and is a small fraction of that available in the soil. It varies with the elements and plants. The accumulation co-efficient for zinc and cadmium is relatively high - always higher in straw than in grain - whilst the content of copper, lead, chromium and nickel in plants is hardly influenced by rising contents in the soil (Diez). Heavy metal effects are likely to appear when nitrogen release declines.

6. Applications of sludge containing high contents of cadmium and nickel, up to 512 kg/ha and 946 kg/ha respectively, reduced maize production by 20%. It also decreased considerably the P content of maize in both leaf and grain and increased the zinc, nickel and cadmium content of the maize and lettuces and the nickel and copper content of the grain. It decreased the manganese concentration in both species (Juste).

7. Availability of metals to plants depends largely on their solubility in the sludge soil mixture. Whilst this can be determined by the use of an extractant their performance varies and depends on the type of sludge. Aerobic sludge usually gave higher extractability, that for copper being the greatest, being more than 70% of the total for composted aerobic sludge. Extractability tended to decrease at harvest time.

8. The heavy metal contamination of soils has been shown to decrease after a long period of contamination with sewage infiltration and those results could be used to estimate the reduction after the application of sludge (Milde).

9. A series of pot trials has been set up with the United Nations Food and Agricultural Organisation to determine the extractant which will indicate the availability of metals to plants in a wide range of conditions most accurately. In the present limited state of knowledge it seems preferable to base applications on "total" metals rather than "available" metals.

10. The solubility of metals is pH dependent but raising the pH is not always the right solution because the availability of some metals increases with pH and with others a subsequent fall in pH can release metals.

11. The use of soil concentrations as a limiting objective in sludge disposal is theoretically sound but results to date have been too variable to recommend this as a sound basis.

12. Many trace elements such as selenium, and boron have to be used within fine limits. They are required for growth but in excess can be harmful.

13. It is fortunate that the staple food for animals (grass) and for man (grain) are poor assimilators and the input of toxic metals limited.

14. It was suggested that the uptake and transfer to edible parts of crops of heavy metals could be predicted by means of a biological test (Impens).

Cadmium

15. Cadmium is particularly important because of its possible effect on man's health and phytotoxicity. Cadmium is mobile and translocated by plants particularly to the leafy parts of vegetables. It is present in most sludges and the concentration rises where there are trade discharges to the sewers. The metal could have toxic effects on man as it accumulates in the body with age. At the same time it is right to note that atmospheric precipitation and phosphatic fertilizers as well as sludge have an input to agriculture. Furthermore man's input is greatly influenced by his smoking habits.

16. Nationally sludge is a minor input but locally the position is likely to be quite different. The outflow is much less than the inflow so that effects are likely to increase (Tjell).

17. Cadmium solubility increases considerably as soil pH falls. There is a linear positive relationship between extractable cadmium and NH_4 - N concentration in soil. Increase in cadmium concentration in the soil causes a proportionate increase in NH_4 - N due to the inhibition of nitrifying bacteria (Hani).

18. The uptake of cadmium depends on the species and the various parts of the plant. Particularly high concentrations of cadmium have been found in grain of wheat and oats and in leaves and stalks of corn (Diez). The clay content of the soil has less influence than the pH. Availability of cadmium also depends on oxidiation - reduction potential and organic matter content (Pluquet).

19. Assessment of the potential hazard where sludge is used on land should take account of the sludge application, the concentration in the crops which could result in phytotoxicity and the effect on the food chain (Davis).

20. Cadmium hinders humate decomposition although that is enhanced by the presence of glucose through metabolisation (Gomez).

Organics

21. There is increasing interest in organics but analytical methods are sometimes very difficult.

Environmental Aspects

22. There is little research on acceptability of sludge and these are subjective matters difficult to quantify.

Groundwater Pollution

23. The results of research on groundwater pollution do not give any cause for concern.

Forestry

24. Applications to forestry are likely to be limited by the physical difficulties of spreading sludge.

Conclusions

25. There is a need for research to continue or commence on

a. input of cadmium to the food chain
b. other toxic effects
c. phytotoxic effects
d. selection of the most suitable extractant
e. long term fate of heavy metals
f. effects of organics

It is of prime importance to protect the environment and the task of scientists to devise means by which this can be done effectively and economically.

Although the great majority of sludge disposal is carried out in an acceptable manner research is required to show that the criteria being used are an acceptable compromise between safety and minimum cost.

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