Utilisation and effects of anaerobically digested sludge on a red sandy soil of Natal

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Abstract:

The benefits of well humified organic matter to soils in agriculture are well documented. This paper describes the effect of municipal anaerobically digested sludge cake on the growth of a common grass (*Eragrostis curvula*), grown on a red sandy Hutton type soil of Natal. The effects of the sludge on the wilting time of the plant and on the water holding capacity, bulk density, cation exchange capacity, organic carbon, pH and buffer capacity of the soil are measured. The sludge cake was generated by the Southern Waste Water Treatment Works near Durban which receives a high industrial waste load and contains relatively high concentrations of potentially toxic elements.

The uptake of potentially toxic elements by the growing plant, the concentrations of these elements in the soil leachates and the rate of pathogen decay in the soil are investigated.

Introduction

Urban development and population growth continue at an alarming pace, with a corresponding increase in the production of both domestic and industrial wastes. At the same time, more restrictions are being imposed on contamination of water, land and air. Consequently disposal of waste materials is becoming a greater problem now than in the past. Apart from the fact that more wastewater treatment works are being built to accommodate new and developing urbanisation, less and less land is available for treatment and disposal of sewage sludge. Specifically in the Durban area, existing wastewater treatment works are presently being expanded to meet increased inflows due to population growth and urban development. As a result, sludge production is increasing and available land for final disposal is decreasing. Alternative methods therefore have to be investigated for disposal of sludge, which are acceptable from the point of view of public health, environmental control and economics.

According to the Manual of British Practice in Water Pollution Control (IWPC, 1978), interest in the utilisation of sewage sludge, particularly digested sludges, was revived in the 1950's with the introduction of road tanker conveying of liquid sludge to farms. One of the contributary factors to this renewed interest was the efficient control of industrial wastewaters into public sewers and wastewater treatment works. A 1977 survey showed that 44% of the sludge produced in the United Kindom was utilised in agriculture. The Anglian Water Authority (AWA) consider agricultural utilisation to be the most cost effective option for sludge disposal (Matthews, 1982). Farmers pay for the service of applying it, rather than for the sludge as such.

The most effective method of sludge application is by ploughing into the soil, or by special mobile units which inject liquid sludge about 400 mm below the soil, leaving no trace of sludge on the land surface.

Soils benefit in many ways from the addition of well humified organic matter such as a good quality compost or anaerobically digested sludge. Apart from small amounts of the plants nutrients N,P,K, Ca, Mg, S, Si and micro-nutrients Zn, Cu, B, etc., present, the most important constituent of the sludge is its organic matter. The organic matter acts as a "soil conditioner" by improving the soil structure and permeability, making heavy clay soils more friable and manageable. This can reduce soil compaction caused by heavy farm implements. Soil water holding capacity (WHC) is increased by the organic matter, which means more efficient utilisation of rain or irrigation water, less surface water run-off and consequently less soil erosion. Organic matter increases the cation exchange capacity (CEC) of a soil. This is particularly important in sandy soils, which, due to a lack of clay colloid, have a very low CEC. This in turn means that nitrogenous fertilizers and cations such as potassium, are lost from the soil by leaching. South Africa's expenditure on fertilizers in 1979 was about R400 million (Easton and Buys, 1980). The figure soared to R650 million in 1981 (Plantfood, 1982), increasing by more than R100 million each year. A considerable portion of this could be lost due to leaching of soluble fertilizer constituents through the soil down to the groundwater system, creating a pollution problem.

Organic compounds in well humified organic material such as digester sludge, have amphoteric properties (small positive and negative charges, depending on the prevailing pH value, Bloomfield, 1964). When organic matter or sludge is mixed with a sandy soil these negative charges on the organic compounds increase the CEC of the soil which means that fertilizer elements are more effectively adsorbed by the soil and therefore more available to the growing plant. Epstein, *et al.* (1976) found that soil CEC was increased up to threefold by sludge organic matter.

Whether sludge is disposed to land or utilised in agriculture, the question of heavy metals or potentially toxic elements (PTE) arises. In the case of continuous disposal of sludge to land, the possibility of contamination of the ground water due to leaching of PTE through the soil from the sludge exists, and has to be investigated. In the case of utilisation of sludge for growing crops, the problem of toxicity to the plant and possible transmission of PTE to the human and animal food chain (Wood,*et al.*, 1979) must be considered. The harmful effects of cadmium poisoning in humans was reported by Kobayashi (1970). Cadmium is an accumulative toxin in plants (Davis and Carlton-Smith, 1980) and in humans (Coker and Matthews, 1982; Naylor and Loehr, 1981), resulting in so-called itai-itai disease. However, metal elements in the sludge are not all necessarily in a form which is available to the plant. Davis and Coker (1980) reported a decline in the availability of sludge cadmium in soil with time. One of the best ways of checking this out is to grow a crop on soil, with and without sludge, and compare the uptake of PTE by analysis of the plant tissue in both cases.

Another matter which must be considered regarding the utilisation of sludge for agricultural purposes, is the public health aspect. Pathogenic organisms have and always will be a potential health hazard, and careful monitoring of any sludge utilisation programme is essential. In South Africa, two State Departments are involved in the legal control of the health aspects of sewage sludge, namely the Department of Environment Affairs (Water Act 54 of 1956) and the Department of Health and Welfare (Health Act 63 of 1977). The latter is presently involved with the Water Research Commission and the NIWR of the CSIR in a sludge utilisation programme, which involves the analysis of crops and soil leachates for heavy metals and includes pathogen tests (Water Research Commission, 1981). The Department of Health and Welfare (Oberholster, 1982) has set out guidelines for the utilisation of sludges of different hygienic quality. For example raw sludge (no agricultural use permitted), digester sludge (use permitted for crops not eaten raw by humans), and irradiated or heat treated sludge (use unrestricted). The Department of Health and Welfare further recommends that sludge users consult agricultural, horicultural and soil experts to advise on the possible detrimental effects of sludge on crops and soils, and the hazard of potentially toxic elements or chemicals.

The object of the work reported here was to investigate the advantages and disadvantages of utilisation of digester sludge from the Southern Waste Water Treatment Works (SWWTW) for agricultural purposes, as an alternative to sludge disposal. The results of this work will obviously be applicable to a specific type of sludge, namely a highly industrialised one, on a red sandy soil. The work was of a preliminary nature and the various experiments were designed for observational purposes and no replicas were included

Materials and Methods

The effects of sludge on the following were investigated:

- Plant growth.
- Heavy metal uptake by the plant.
- Wilting time of the plant.
- Soil physical and chemical properties:

  (a) moisture or water holding capacity (WHC);
  (b) bulk density (BD);
  (c) cation exchange capacity (CEC);
  (d) total organic carbon (TOC);
  (e) pH; and
  (f) buffer capacity (BC).

- Movement or leaching of heavy metals from the sludge through the soil.

A pathogen decay study was made to test the effects of soil, agricultural lime, and ageing on *Ascaris lumbricoides* and other pathogenic organisms in the sludge.

The soil

The soil used throughout this investigation is classified as the Clansthal soil series of the Hutton soil form (MacVicar *et al.*, 1977) and is widely distributed along the coastal regions of Natal and Zululand. It is a deep, red, well drained acid sandy soil of low nutrient status and low CEC. It has a fairly low WHC and for this reason requires frequent irrigation. Loss of fertilizer nitrogen and potasium can be a problem on this soil due to a low CEC. The red apedal B horizon, air dried and sieved < 5 mm, was used for the plant growth study. Plastic perforated type containers (for free drainage) were used to hold the soil (12 kg). Surface soil (topsoil) usually contains greater quantities of organic matter and nutrient elements than underlying subsurface or subsoil horizons. In order to avoid unnesessary variables, the infertile red subsoil was selected for the experiment. Any effects observed would then be due solely to the added sludge.

The indicator crop

Eragrostis curvula was used because of its ability to withstand the hot, humid climatic conditions of the region. The small seeds were weighed (1,5 g), spread evenly on the soil surface and pressed lightly onto the soil.

Sludge

Anaerobically digested, centrifuged sludge cake, air dried and sieved 5 mm was applied to the soil at rates equivalent to 0 (control), 20,50 and 100 t dry solids per hectare soil. In each case the sludge was thoroughly mixed with the entire mass of soil before placing in the plastic containers. A typical analysis of the Southern Works sludge cake is given in Table 1. The soil received no form of fertilization other than the sludge.

TABLE 1
TYPICAL ANALYSES OF DIGESTER SLUDGE CAKE (SWWTW)

		Heavy metals ($\mu g/g$)*		Pathogens	
Total solids	26%				
Moisture	74%				
Organic matter*	64%	Cr	384	*Ascaris L.*	220/g
Total-N*	2,5%	Ni	226	Viability	2%
NH_3-N*	0,3%	Cu	279	Others	nil
NO_3-N*	nil	Zn	1470		
P*	0,7%	Pb	356		
K*	0,1%	Cd	4		
N:P:K:	25:7:1				
Average production	5475 t/a (wet cake)				
	1423 t/a (dry solids)				

* dry solids basis

Irrigation

Distilled water was used to irrigate the soil each day and maintain the soil at approximately 70% of field moisture capacity. Occasionally this value was exceeded to moisten all the soil. The containers were rotated each day to avoid irregular growth, and received adequate sunlight.

Soil leachate tests

Special containers were prepared to obtain leachate samples from sludged soil for heavy metal (PTE) analysis. These containers had a single outlet at the bottom covered with a fine polyester filter material from the inside to prevent particles of soil and sludge being collected in the leachates. 20 kg of the soil was placed in the containers and sludge cake equivalent to 50 t sludge dry solids per hectare soil was mixed with the upper 50 mm layer of soil. This left a 200 mm layer of soil, free of sludge, in the lower portion of each container, through which sludge/soil leachate must pass. The sludge treated and untreated (control) soils were moistened to field capacity and allowed to stand for 12 weeks at just below field moisture capacity, to reach equilibrium. The soils were then irrigated to above field capacity, and leachate samples collected. This was repeated at about 4 week intervals, in order to monitor trends in heavy metal concentrations in the leachates. Sudden increases in metal concentrations would indicate saturation of exchange sites or cation desorption from the soil. Leachates were collected in clean glass bottles and analysed for the heavy metals chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), lead (Pb) and cadmium (Cd).

To test the capacity of this particular soil to accept large quantities of liquid digester sludge on a continuous basis, one container (L4) with soil was treated as follows: Liquid sludge (average 4,1% dry solids) was spread on the surface of the soil and allowed to dry completely before applying the next layer. Initially these layers were 45 mm deep, representing 450m< liquid sludge or 18,5 t dry solids per hectare soil. This was later increased to 60 mm layers, equivalent to 600m^3 liquid sludge or 24,6 t dry solids per hectare soil. Heavy metal (PT) concentrations in the leachates were monitored as described above. A sudden increase in PTE concentration in the soil leachate would indicate the acceptance limit of the soil for liquid digester sludge disposal. Further applications of sludge on this soil would then constitute a pollution hazard. These tests are in progress at the Southern Works laboratory. A description of the materials used in the soil leachate study is given in Table 2.

TABLE 2
MATERIALS USED FOR SOIL LEACHATE STUDY

Sample	Description
L1	Control (soil only)
L2	Soil with 50 t sludge* per ha in upper 50 mm soil
L4	Soil with continuous applications of liquid digested sludge

* dry solids

TABLE 3
MATERIALS USED FOR PATHOGEN DECAY TESTS

Sample	Description
MOH1	Control (soil only)
MOH2	Soil with 50 t* sludge per ha soil
MOH3	Soil with 50 t* sludge per ha, and 5 t lime/ha
MOH4	Sludge with lime (5: 1 m/m basis)
MOH6	Soil with 50 t* sludge** per ha

* dry solids
** filter press sludge cake from Northern WWTW

Pathogen decay tests

Red topsoil of the Clansthal soil was used for this test, since natural soil bacteria are believed to enhance the rate of decay of pathogenic organisms in sludge. The effect of lime ($CaCO_3$) on pathogen decay was also tested. The various soil, sludge and lime mixtures used for these tests are shown in Table 3.

The materials were thoroughly mixed and placed in large plastic containers. Samples for pathogen tests were taken by the City Health Department immediately and again every few months. The pathogen tests were carried out by the Government Pathologist. The materials in the containers were occasionally moistened, mixed and allowed to dry out again before the next test samples were taken. Since the ova of *Ascaris lumbricoides* appear to be highly resistant, their presence and viability are used as an indication of the hygienic quality of treated sewage sludge under South African conditions (Steer and Windt, 1978; Oberholster, 1982).

Results and discussion

Crop growth study

The *Eragrostis* was planted in December, 1981, with an average daily temperature of about 24 °C. Germination took place in three days. After four weeks, distinct differences could be seen in the growth of the plants in the sludge treated soils. The higher growth rate was most noticeable in the soil with 100 t/ha sludge cake. Seed germination was comparatively poor in the soils which had received the least sludge (zero and 20 t/ha) and growth was weak and retarded in the control soil. By the end of the fifth week after planting, the grass was growing profusely in the soil with the 100 t/ha level of sludge, was dark green in colour, and showed no signs of nutrient deficiencies and no toxicity symptoms. The 50 and 20 t/ha sludge levels were progressively less spectacular.

The crop was harvested six weeks and again twelve weeks after planting. The plant material was dried and weighed, and increases in plant yield calculated for the different soil/sludge treatments.

The effect of the different levels of sludge on the wilting time (WT) of the plants was determined by irrigating the soils to 100% field capacity and then allowing the plants to wilt and die.

Soil physical and chemical properties were determined on the dry soils after termination of the crop growth experiment.

Soil water holding capacity (WHC) and bulk density (BD) were measured using 1 000 mℓ measuring cylinders. Unbuffered NH_4Cl at pH 7 was used for the cation exchange capacity (CEC) determination and a modified Walkley-Black method for organic carbon. Soil pH was measured in a 1:2,5 ratio with distilled water. The change in soil pH (ΔpH), measured after acidifying the soils with 1,2 me H^+/kg soil, was used as an (inverse) indication of the buffer capacity (BC) of the soil.

The results (Table 4) clearly illustrate the beneficial effects of digester sludge on an infertile sandy soil. The red Clansthal subsoil used in the experiment is extremely deficient in the major plant nutrients N,P and K. Sludge applied at the rate of 100 t dry solids per ha soil (sample C4) increased the crop yield on this soil by approximately 18 times in the first harvest and 34 times in the second harvest, compared with the control soil (sample C1) which received no sludge. Consequently, the entire nutrient requirement of the grass crop must have been derived from the applied sludge. The nutrient removal by 10 t (dry weight) of *Eragrostis curvula* is approximately 150 kg N, 50 kg P and 20 kg K. A

TABLE 4
THE EFFECT OF DIFFERENT LEVELS OF DIGESTER SLUDGE CAKE ON THE GROWTH OF *ERAGROSTIS CURVULA* GROWING ON AN INFERTILE RED SANDY SUBSOIL OF THE CLANSTHAL SOIL SERIES

Sample No.	Treatment t sludge/ha	First Harvest Yield* kg/ha	First Harvest Increase** %	First Harvest Times	Second Harvest Yield* kg/ha	Second Harvest Increase** %	Second Harvest Times
C1	0	11,5	–	–	18,3	–	–
C2	20	18,5	61	1,6	–	–	–
C3	50	44,3	285	3,9	124,0	578	6,8
C4	100	204,1	1675	17,7	625,1	3316	34,1

*dry weight basis
**increase in yield with respect to control, expressed as percentage of, and times greater than, the control

TABLE 5
NUTRIENT BALANCE SHEET FOR SUCCESSIVE HARVESTS OF *ERAGROSTIS CURVULA* WITH ONE APPLICATION OF 100 t SLUDGE DRY SOLIDS PER HECTARE SOIL

Nutrients Supplied by 100 t sludge per ha			Nutrients removed (kg) by 10 t dry grass per ha per year					
Nutrient	%	kg	1st yr	2nd yr	3rd yr	4th yr	5th yr	remainder
Total-N*	2,5	2 500	–	–	150	150	150	1 750
NH_3-N**	0,3	300	150	(150)	–	–	–	–
P	0,7	700	50	50	50	50	50	450
K	0,1	100	20	20	20	20	20	0

* slow release N (2,2% N) (estimate by author)
** portion of total N immediately available to the plant

TABLE 6
HEAVY METAL (PTE) CONCENTRATION IN *ERAGROSTIS CURVULA* GROWING ON A RED SANDY SOIL WITH DIFFERENT LEVELS OF APPLIED SLUDGE

Sample Number	Treatment t sludge/ha	Cr	Ni	Cu	Zn	Pb	Cd
		mg/kg					
C1	0	3,8	0	22	81	–	0,3
C3	50	7,3	21	22	375	0	0,8
C4	100	5,5	24	17	341	0	0,5
Barley*	–	–	(1/26)	(10/20)	(10/290)	(2/35)	(<1/15)
Field plants*	–	–	(2/11)	(8/20)	(40/200)	(3/35)	(<0,5/8)

*Values in brackets denote normal/upper critical limites of PTE in young barley (Davis *et al.* 1978), and mean in various field plants (Davis and Carlton-Smith, 1980).

farmer applying 100 t of sludge (dry solids) per ha would therefore reap an excellent grass crop for a number of years. The theoretical nutrient balance sheet is shown in Table 5.

The immediately available nitrogen (300 kg NH_3-N) would satisfy the N-requirement of the crop for up to two years if 10 t dry grass were reaped per year, assuming minimal loss of N by leaching. This loss of N could be small as a result of adsorption of NH_4^+ ions by sludge organic matter (Bloomfield, 1964). As the sludge organic matter decomposes in the soil, more available N is slowly released. 100 t of sludge could theoretically supply the entire N, P and K nutrient requirement of *Eragrostis curvula* for up to 5 years. In practice however, occasional supplementation by small amounts of inorganic fertilizers may be necessary to allow optimum utilisation of the sludge. The remaining 450 kg P (Table 5) builds up the phosphate status of the soil, so that the need for inorganic phosphate fertilizer would be reduced. It is also possible that fixation or immobilisation of costly inorganic fertilizer phosphate (Easton and de Villiers, 1980) may be reduced by sludge organic compounds, but this aspect will be investigated at a later date.

The dried plant material from each individual soil was analysed for heavy metals (Table 6) in order to test for uptake of PTE by the growing plants.

The results (Table 6) indicate that, apart from Ni and Zn, there was very little uptake of metals by the plant, relative to the control soil (sample C1) which received no sludge. Comparing the results with available data on the normal and upper critical limits of PTE for young barley (Davis, *et al.*, 1978), and various othe field plants (Davis and Carlton-Smith, 1980) it appears that the concentrations of Ni and Cu are very near to or exceed the upper critical limit. The concentration of Zn in the *Eragrostis* grass was considerably greater than the upper critical limit on the soils with 50 and 100 t sludge per ha. Uptake of Pb and Cd by the grass was minimal. The relatively high uptake of Cu in the control soil is not easily explained, and is of the same order of magnitude as Cu uptake in ryegrass grown on sludge amended soils (Davis and Carlton-Smith, 1980). Although the uptake of Ni , Cu and Zn by the *Eragrostis* exceeded the accepted upper critical limits for these metals, no toxicity symptoms were observed in the growing plants, and growth was by no means stunted or retarded.

The Southern Waste Water Treatment Works (SWWTW) receives a very high proportion of industrial effluent. Consequently the concentrations of heavy metals (PTE) in the sludge cake are relatively high (Table 1). However, the rate of addition of these metals to the soil by 5 t sludge dry solids applied per hectare soil every year for 30 years (Table 7) does not exeeded the limits for addition of heavy metals to acid soils recommended by the Department of the Environment (DOE) of the U.K. (Matthews, 1982).

The levels of PTE in SWWTW sludge, compared with maximum levels of PTE in sludge according to German (Möller, 1982) and American (Gerardi, 1981) standards, are shown in Table 8. The data indicate that, apart from Ni, all the PTE concentrations in the SWWTW sludge are within the acceptable limits. Of particular significance is the relatively low level of cadmium in the sludge (4 mg Cd/kg sludge dry solids). Cadmium is an accumulative toxin in plants and animals, causing itai-itai disease in humans, and for this reason is under the spotlight internationally

TABLE 7
ADDITION OF PTE TO THE SOIL BY 5 t SWWTW SLUDGE DRY SOLIDS PER HECTARE SOIL PER YEAR FOR 30 YEARS, COMPARED WITH DOE RECOMMENDED LIMITS OF ADDITION OVER THE SAME PERIOD OF TIME

		Cr	Ni	Cu	Zn	Pb	Cd	Zinc eqv.
					kg/ha			
SWWTW Sludge 5 t/ha/a for 30 yrs	:	58	34	42	221	54	0,6	577
Limits of addition over 30 years	:	1 000	70	280	560	1 000	5	560*

* 1120 kg/ha permitted for permanent pasture on non-calcareous soil.

TABLE 8
LEVELS OF PTE IN SWWTW SLUDGE (mg/kg DRY SOLIDS) COMPARED WITH GERMAN AND AMERICAN RECOMMENDED MAXIMA

		Cr	Ni	Cu	Zn	Pb	Cd
SWWTW Sludge	:	384	226	279	1 470	356	4
German Standard	:	1 200	200	1 200	3 000	1 200	20
USA Standard	:	1 000	200	1 000	2 000	1 000	50

TABLE 9

THE EFFECT OF DIGESTER SLUDGE ON THE WILTING TIME (WT) OF *ERAGROSTIS CURVULA* AND ON THE WATER HOLDING CAPACITY (WHC), BULK DENSITY (BD), CATION EXCHANGE CAPACITY (CEC), TOTAL ORGANIC CARBON (TOC), pH AND BUFFER CAPACITY (BD) OF A CLANSTHAL RED SANDY SOIL.

Sample No.	Treatment t sludge per ha	WT days	WHC %	BD g/cm^3	CEC me/100g	TOC %	pH (H_2O)	BC ΔpH*
C1	0	22	16,0	1,43	1,4	0,20	6,10	0,90
C2	20	–	19,8	1,40	1,8	0,32	6,35	0,35
C3	50	30	22,8	1,30	2,6	0,80	6,65	0,25
C4	100	66	25,0	1,20	3,0	2,00	6,80	0,10

*ΔpH is the change in soil pH due to addition of 1,2 me acidity (H^+ /kg soil and is inversely related to the buffer capacity of the soil

TABLE 10

HEAVY METAL CONCENTRATIONS (mg/ℓ°) IN SOIL LEACHATES FROM A RED SANDY SOIL TREATED WITH DIGESTER SLUDGE

Sample No.	Time weeks	Cr	Ni	Cu	Zn	Pb	Cd
L1	12	*	*	*	*	*	**
L1	20	*	*	*	0,26	*	**
L1	27	*	*	*	0,18	*	**
L2	12	*	*	*	0,10	*	**
L2	20	*	*	*	0,16	*	**
L2	27	*	*	*	0,10	*	**
L4	12	*	*	*	0,42	*	**
L4	16	*	*	*	0,10	*	**
L4	20	*	*	*	1,20	*	**
L4	27	*	0,10	*	3,50	0,10	0,01

*Less than 0,1 mg/ℓ
**Less than 0,01 mg/ℓ

TABLE 11

THE EFFECT OF THE CLANSTHAL RED SANDY TOPSOIL AND AGRICULTURAL LIME ON THE DECAY RATE OF PATHOGENS IN DIGESTER SLUDGE CAKE

Sample No.	Pathogens found initially		Pathogens after 5 months	
	*Ascaris**	Viability	*Ascaris**	Viability
MOH 1	nil	nil	nil	nil
MOH 2	50	nil	nil	nil
MOH 3	nil	nil	nil	nil
MOH 4	200	nil	nil	nil
MOH 6	1 000	2%	nil	nil

**Ascaris Lumbricoides* count per gram

The results of the physical and chemical test on the sludge treated soil are presented in Table 9.

The results obtained (Table 9) illustrate some of the important beneficial effects of digested sludge organic matter on an infertile sandy oil. Wilting time was increased threefold, water holding capacity by more than 50%, organic carbon from 0,2% to 2,0% while soil bulk density was reduced from 1,43 to 1,20 g/cm³. The increase in CFC was less than expected but the method used (unbuffered NH_4Cl) does not reflect the highest CEC possible for the amphoteric nature of the sludge organic matter. This would be achieved by using the ammonium acetate method (buffered at pH 8,5). Similar improvements in soil properties due to addition of sludge have been reported by Epstein *et al.* (1976), Khaleel *et al.*, (1981) and others. The soil pH was increased from 6,1 to 6,80 which is very nearly the pH value for optimum uptake of most plant nutrients and micronutrients. More important however, is the greatly improved buffer capacity of the soil due to the sludge organic matter. This is shown by the small change in pH value (Δ pH) when 1,2 me of acidity (H^+)/kg is added to the sludge treated soil (Table 9). A well buffered soil is important in agriculture where arable soils become acid due to the continual use of inorganic fertilizers and require frequent applications of agricultural lime (Barnard and Fölscher, 1980; Easton and Buys, 1980; Easton, 1980).

Soil leachate tests.

The results to date of the soil leachate tests (Table 10) indicate no release of sludge heavy metals by the soil (L2) containing 50 t sludge dry solids per ha in the upper 50 mm layer, compared with the control soil (L1) with no sludge. In the case of the soil (L4) receiving continuous applications of liquid sludge however, a steady increase in the concentration of Zn was observed with each sludge application. After 27 weeks and four applications of liquid digester sludge, slight increases in the levels of Ni, Pb and Cd were detected in the soil leachate of L4. It would appear, therefore, that continuous disposal of liquid digester sludge to land where the soil texture is sandy, could create a pollution problem as far as the groundwater system is concerned.

Pathogen decay tests.

The results (Table 11) show that after a period of 5 months, the *Ascaris L* originally present in samples MOH2, MOH4 and MOH6, had been reduced to below detectable levels. Most important was the Northern WWTW sludge (MOH 6), which had a relatively high *Ascaris* count originally, with a 2% viability, both of which were nil after 5 months. These preliminary results are encouraging, and further tests in conjunction with City and State Health Departments would be well worth while.

Conclusions

The results of this investigation have brought the problems and benefits of utilisation of anaerobically digested sewage sludge for agricultural purpose into clearer perspective. With municipal and state control on the quality of the sludge generated by a wastewater treatment works, utilisation and recycling of this valuable material can be a profitable alternative to sludge disposal to land, sea or by incineration, where transportation is not prohibitive.

There is no doubt that the use of digested sludge improves the quality of a sandy, infertile soil. This is illustrated by the marked increase in growth of *Eragrostis curvula* on a red sandy soil treated with different levels of sludge. The relatively high metal content of the sludge used does not appear to adversely affect the growth of the grass. The following physical and chemical properties of the soil were improved by the sludge organic matter: water holding capacity; bulk density; cation exchange capacity; organic carbon; soil acidity; buffer capacity; and plant wilting was increased due to the greater water holding capacity of the soil.

Apart from the observed effects of sludge organic matter as a soil conditioner, there is a small but significant inorganic fertilizer value of the sludge. This is illustrated by the higher growth rate of the grass on the soil with 100 t sludge per ha. This amount of sludge contains sufficient N, P, K and other elements to satisfy the entire nutrient requirement of the grass for a number of years. This would reduce expenditure on inorganic fertilizers, the greatest single cost item in modern farming.

However, the use of a highly industrialised sludge such as this on agricultural land would require very strict control and careful management of the soil. A single application of 100 t/ha of this sludge would be potentially hazardous regarding PTE under UK DOE/NWC guidelines. This would supply over 380 kg/ha zinc equivalents, while the maximum permissible would be 112 kg/ha for a single application on non-calcareous arable soils and 224 kg/ha zinc equivalents on permanent pasture land. The maximum single application of SWWTW sludge according to the DOE/NWC guidelines would be about 30 t dry solids per ha to non-calcareous soils ($pH \leqslant 7$).

Infertile sandy soils, which are fairly widesdpread in South Africa, could be converted into fertile soils of high productive potential by an adequate application of treated sludge. This would apply also to old mine dumps, beach sands or disturbed soils on building sites, sports fields, and road cuttings, provided transport and irrigation do not present a problem.

As far as the public health aspect is concerned, pathogens in the sludge decay within 5 months after application, to below detectable limits for *Ascaris*.

Continuous dumping or disposal of a contaminated sludge to land however, especially on sandy soils, can lead to pollution of the groundwater system by metals such as zinc. In other cases, the soil or underlying rock formations may be impervious and unsuitable for continuous disposal or spreading of liquid sludge to land. This, together with the problem of restricted land area, makes sludge utilisation an important and attractive alternative now and for the future.

It is suggested that with adequate control, digester sludge could be distributed, as a non profit making service.

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