

EXECUTIVE SUMMARY

1. BACKGROUND

Sewage sludge can be a valuable resource if used as a fertilizer and soil conditioner. South African farmers using sewage sludge as a fertilizer amendment reported a 20% increase in the yield of cultivated maize and 40% saving on inorganic fertilizer. The major benefits of sludge application are; increased supply of major plant nutrients; provision of some of the essential micronutrients (Zn, Cu, Mo, and Mn) and; improvement in the soil physical properties, i.e. better soil structure, increased water holding capacity, and improved soil water transmission characteristics.

Toxic compounds such as heavy metals and pathogens could compromise the beneficial use of sewage sludge. To minimise the risk of toxic effects and environmental contamination a "Guide: Permissible utilization and disposal of sewage sludge" was developed. It is therefore critical to establish the safe application rate of sewage sludge in different environmental conditions. Furthermore, with repeated sludge applications as soil conditioner, these heavy metals may accumulate in the soil to phytotoxic concentrations for crops, although at certain concentrations the metals may be deficient for crop growth.

At present, the sludge producers and legislators are hesitant to encourage the use of sewage sludge in agriculture due to lack of knowledge of the risks involved. The sludge legislation and guidelines were largely adapted from other countries and often based on theoretical risk assessments. The behaviour of sewage sludge applied to agricultural land has not been extensively researched under South African climate conditions. The quantification of the risk associated with the use of sewage sludge in agricultural practices will necessitate a long-term study under several field conditions. This research aimed to understand the behaviour of sewage sludge once applied to agricultural soil under South African conditions in the short-term.

2. OBJECTIVE OF THE STUDY

The main objectives of the study were to:

- Establish the extent of metal uptake in plants grown on sewage sludge-amended soils including winter and summer crops
- Establish the effect of soil properties on the mobility of nutrients and metals
- Establish a safe sludge load to prevent nitrogen leaching to groundwater
- Predict the persistence of sludge-borne pathogens during agricultural application
- Establish the perceptions of farmers, commercial markets and urban and rural communities for beneficial use of sewage sludge for edible crops.

3. SUMMARY OF THE MAJOR RESULTS AND CONCLUSIONS

3.1 Extent of metal uptake in plants grown on sewage sludge

Heavy metal fractions from sacrificial land disposal sites

This study did not aim to address the characteristics and behaviour of soils that have been subjected to high doses of sewage sludge for a long time. However, the short term agricultural applications used in this research indicated no toxic effects to soils or plants. Sites where sewage sludge had been applied at current guideline levels for a period of several years are extremely scarce. This is especially the case for high metal sludges. The three sites discussed were identified to determine the different metal fractions in un-limed and limed soil after long-term sludge application. The aim was to determine the influence of management practices (*regular liming versus no lime additions*) on the various metal fractions. In South Africa large volumes of sewage sludge with high metal levels are often disposed of on "sacrificial" lands, some of which have received prolonged regular applications of sewage in suspension form. In the Gauteng province around Pretoria three soils: a gravely sandy loam (Soil 1) on granitic parent material, a sandy clay loam (Soil 2) and a loam soil (Soil 3) on dolomitic parent material were collected for investigations into their accumulated heavy metal levels. Soils 1 and 3 had no additions of lime and were both very acid ($\text{pH}_{(\text{Water})}$ of 4.0). Soil 2 received regular additions of lime ($\text{pH}_{(\text{Water})}$ of 6.5) and was used as an agricultural soil. Four different extraction procedures were used namely: a saturated paste extract (water-soluble metals); BaCl_2 (exchangeable metals); NH_4 -EDTA (potentially plant available metals) and EPA 3050 digestion (total metal content). Appreciable quantities of different heavy metals and organic material have accumulated over time in

these soils. The EPA 3050 digestion indicated that Zn, Pb, Cu, Cd, Cr, Ni and V accumulated to levels above 100 mg kg^{-1} in the three soils. Cu, Pb and Zn levels in excess of 10 mg kg^{-1} were extracted with EDTA; Cu and Zn levels of more than 5 mg kg^{-1} with BaCl_2 and Zn and Ni levels above 0.5 mg kg^{-1} with water. In Soil 1 and 3 (pH 4) EDTA and BaCl_2 extracted similar levels of metals in most cases whereas EDTA extracted significantly more than BaCl_2 in Soil 2 (pH 6.5).

To assess the behaviour of these sacrificial soils, two sacrificial soils were twice incubated with a total lime equivalent of 45 t ha^{-1} in pots but did not attain the desired pH of 6.5 due to a very high buffer capacity. Soil samples from the pots after the incubation were extracted with $\text{NH}_4\text{-EDTA}$ and BaCl_2 and the levels of Al, Fe, Mn, Cu, Zn, Pb and Cd determined by Atomic Absorption Spectrophotometry. The BaCl_2 extractable Mn, Pb, and Cd in Soil 1 and Mn and Cd in Soil 3 indicated increases or similar levels in extractability after liming and Al, Cu, Fe and Zn levels decreased after liming. The EDTA extractable Cu, Mn, Fe and Cd in both soils and Pb in Soil 3 increased after liming and Al, Zn and to a lesser extent Pb in Soil 1 decrease in extractability. The increased extractability of certain of these metals is contrary to what was expected from literature concerning the effect of liming and is the subject of further investigation. This aspect is a cause for concern in the short-term if liming is to be done on acidified sacrificial lands as a method of rehabilitation.

Extent of metal uptake in plants grown on sewage sludge-amended soils including winter and summer crops on three different soil types (Greenhouse trials)

The potential impact of the four main sludge-borne metals (Pb, Cd, Zn and Cu) was monitored in the research (glasshouse and field experiments) when sludge was applied to agricultural soils, taking into consideration the current S.A. guidelines.

Research was done in glasshouses on maize (*Zea mays* L.) (summer crop) and oats (*Avena sativa* L.) (winter crop), grown on different soil types (clay, loam, and sand) at a specific sewage sludge application rate (24 t ha^{-1}) using two different sludge types (low metal and high metal) over a period of 28 d. Poor sample homogenisation caused invariable results. Availability of sludge-borne metals differed between sludge types. The heavy metals were less available in the high metal industrial sludge compared to the low metal domestic sludge. The accumulation of sludge-borne metals in soil could not be proven to be in excess, even at a high application rate (24 t ha^{-1}). Furthermore, accumulation of heavy metals in seedlings did not reach phytotoxic levels. A significant increase in certain yield aspects was seen after sludge amendment to the different soil types, especially in the low metal sludge treatment.

Extent of metal uptake in plants grown on sewage sludge-amended soils including winter and summer crops (Field trials)

Field experiments on maize and oats using different total application rates (4 t ha^{-1} and 8 t ha^{-1} dry sludge for oats cultivation; and 12.5 t ha^{-1} and 25 t ha^{-1} for maize cultivation) of the low metal sludge were also completed. Difficulty in sampling was evident and possible errors in sample taking and/or analyses caused results that were difficult to interpret. No phytotoxic levels of metal accumulation were observed in the different plant parts of the crops. The sludge treatment plots compared well with plots where inorganic fertilizer (Positive Control) was added, when yield differences were calculated.

In the field experiments, no significant differences in yield were found between sludge-amended plots and the control treatments, although the number of ears per plant was significantly increased for maize plants after sludge amendment at 4 t ha^{-1} . The insignificant difference in yield between treatments was possibly due to the varying environmental conditions (e.g. hail during maize field experiment, and drought during oats field experiment) and change in soil conditions (e.g. soil pH controls availability of metals and nutrients). However, under more stable conditions in the glasshouse, a significant increase in yield (dry mass and shoot length) of crop seedlings was found. This was possibly due to the increased organic and nutrient status of the soil. A 50 and 20% increase in the yield of maize seedlings occurred when grown in the low metal and high metal sludge-amended soils, respectively, when compared to the Positive (soil amended with inorganic fertilizer) and Negative Controls (soil left unamended). However, when yield of oats seedlings was calculated on the sludge-amended soils, compared to the control treatments, the increase was 20 and 48% for the low metal sludge treatment compared to the Positive Control and Negative Control, respectively. No significant increase occurred in the yield of oats seedlings grown in the high metal sludge-amended soil compared to the controls. Insignificant differences occurred in the yield of seedlings between soil types, although the yield of seedlings in the loamy soil was higher.

The value of sludge as a soil conditioner and fertilizer was seen in the experiments although long-term experiments under field conditions still need to be done to assess possible accumulation of heavy metals in agricultural soils.

3.2 Nitrogen

To quantify the nitrogen added to soil through sludge application, it is necessary to quantify the total nitrogen applied through the sludge and the nitrogen release rate. Nitrogen losses in agricultural soils result through crop removal, leaching, surface run-off, gaseous losses through NH_3 volatilisation, denitrification and erosion (Jarvis *et al.*, 1996). The loss of nitrogen from agricultural soils is of concern due to the possible NO_3^- leaching from cultivated soils that is responsible for increasing concentrations of NO_3^- in surface and groundwaters (Cheshire *et al.*, 1999).

In this study, the nitrogen-mineralisation rate of sewage sludge, at different application rates, was quantified under South African conditions and compared to the release of inorganic nitrogen from commercial fertilizer such as limestone ammonium nitrate (LAN).

The results indicated that the addition of sludge stimulates microbial activity and the subsequent release of NH_4^+ -N. The maximum extractable NH_4^+ -N content was observed after 7 d when it started to decline and after day 28, the total NH_4^+ -N in the soil was depleted. Autotrophic microorganisms' activity increased from day 7 as indicated by the extractable NO_3^- -N. This process happens concurrently with the NH_4^+ -N production. After 28 d the extractable NO_3^- -N content reached a maximum, indicating that most of the readily mineralisable N was depleted. Treatments that received commercial fertilizer, showed an immediate increase in NO_3^- -N content, and from there a gradual increase in NO_3^- -N content. After the 63 incubation days, 32.5% of the total N content of the 10 t ha^{-1} sludge treatment were mineralised. The higher application rate gave higher values, while the lower application rate gave lower values, indicating that higher additions of sludge lead to higher microbial activity. The maximum extractable NO_3^- -N content obtained on both sludge and commercial fertilizer indicated that under ideal conditions it will take up the 28 d to mineralise and nitrify approximately 30% of the organic N in sludge and the total N in commercial fertilizer. Applied NO_3^- -N from fertilizer is immediately available, while organically applied N become s available over a 28 d period equivalent to a slow release fertilizer. NO_3^- -N production from the sludge does not immediately take place, it is slowly released over time. More NO_3^- -N can be produced from sludge during the incubation period than from fertilizer, but being slowly released, it has a lower leaching risk and has more advantages in terms of crop production.

N from sewage sludge only became available after some time, through mineralisation. This fraction of NO_3^- can be utilised much more efficiently by crops, compared to commercial fertilizer, which is an inorganic fertilizer, and immediately available.

From an agricultural point of view, the slow release of N can hold numerous advantages. When the efficiency of commercial N fertilization is limited by factors such as high NO_3^- leaching losses, or NH_4^+ volatilisation, the use of sludge as a slow release N material may decrease the N losses and increase N availability.

Different values in terms of sludge mineralisation have been obtained, due to the large number of factors that may influence the microbial activity, such as soil type, climatic factors, and sludge type.

Possible losses due to denitrification still needs to be investigated. Accurate N balances cannot be made, due to unmeasured N loss in the gas form, during the process of nitrification. It is advisable to carry out more studies on this topic, especially on the long-term. Use of lysimeters can be beneficial to study the whole N cycle including factors such as N uptake by plants, N lost due to volatilisation and leaching.

3.3 Pathogens

In South Africa, most sewage treatment plants produce a type B sludge (WRC, 1997). A type B sludge contains pathogenic organisms. It is therefore important to understand the risk of infection due to the use of sludge on agricultural soils and for a variety of crops. For this research, a comprehensive literature survey and preliminary investigations were done as well as preliminary experiments to assess the survival of sludge-borne pathogens.

The preliminary study was done on potato (*Solanum tuberosum*) as it represents a high risk crop for the use of sewage sludge and is one of the staple foods in South Africa. It has been shown that *Ascaris* and microorganisms studied, namely faecal coliforms, *E. coli* and *Salmonella* will thrive in soil for a prolonged period of time. The presence of these microorganisms on the potato peel indicates their potential hazard to public health. Due to the limitations of the techniques used, the presence or absence of microorganisms within the core of the potato could not be established conclusively. Further analysis of potatoes using PCR will be carried out, to establish whether or not these microorganisms are capable of migrating to the core of the potato. It appears that doubling the application rate from 8 t ha^{-1} to 16 t ha^{-1} does not affect the growth of microorganisms.