AVAILABILITY OF N, P AND HEAVY METALS IN A LUVISOL DERIVED FROM LOESS AFTER LONG-TERM APPLICATION OF SEWAGE SLUDGE AND BIOCOMPOST

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Summary, keywords

In a long-term field experiment, established in 1962, the influence of the application of different amounts of sewage sludge and compost as compared with farmyard manure and mineral fertilizer on the dynamics of soil nitrogen and phosphorus as well as on the enrichment of heavy metals in the soil and on the heavy metal uptake of different crops in a cereal-root crop sequence was investigated.

Long-term field experiment, nitrogen, phosphorus, heavy metals, bio-availability

Introduction

Application to agricultural land is the principal way of deriving a beneficial use for the residual sewage sludge as well as for compost by recycling plant nutrients and organic matter to soil for crop production. Agricultural utilization also provides a cost-effective method for the deposal of sludge and other organic residues after composting. However, it is essential that sewage sludge and compost recycling in agriculture is controlled to minimize potential environmental problems. In Germany the application of sewage sludge is regulated by the German Sewage Sludge Ordinance and of compost by the Compost Ordinance. Much has already been done to reduce metal contamination of sewage sludge and compost and the levels have declined markedly and most sewage sludges being spread on agricultural land contain background concentrations of heavy metals that are unlikely to place the human food chain at risk.

In 1995 for Germany the quantities for sewage sludge are about 3 millions tons dry matter and for compost about 1,3 millions tons dry matter (Eurich-Menden et al., 1997) with a mean N content of 3,8 % N and 1,2 % P_2O_5, respectively.

Several researchers have shown, that applying biosolids following a N-based management plan will lead to an oversupply of P relative to crop requirements (Kelling et al., 1977; Kick, 1981). This over-application of P in turn can lead to an accumulation of P in soils (Peterson et al., 1994). Further the application of sewage sludge and compost results in an accumulation of the total N content of the soil, which is accompanied by a higher N mineralization potential (Werner, 1987).

Methods

At the experimental farm of the Institute of Agricultural Chemistry of the University Bonn (Germany) a long-term field experiment on a luvisol derived from loess (18 % clay; 67 % silt; 6 % sand) (randomized complete block design with four replications) was established in 1962, following a cereal-root crop sequence. The treatments are: mineral fertilizer (min), 5 and 10 t farmyard manure ha^{-1} (fym 1 and fym 2), 12,25, 24,50 and 49,00 t compost ha^{-1} (com 1, com 2, com 3) and 1,86, 3,72 and 7,44 t sewage sludge ha^{-1} (ss1, ss 2, ss 3). The amounts were given on dry weight basis and applied every second year until 1997. Afterwards the amounts were changed to 30, 60 and 120 t compost ha^{-1} and 5, 10 and 20 t sewage sludge ha^{-1} once in three years.

Results - discussion

The application of sewage sludge and compost to soil provides a useful source of plant nutrients, particularly N and P, and also organic matter, which improves soil physical properties (Metzger and Yaron, 1987).

In practice biosolids are usually applied according to crop N requirements. According to the literature the availability of sewage sludge N is ranging between 20 and 30 % of the total N, depending on different factors. A wide range of results has been obtained in relation to the efficiency of compost as a source of N for plants. N availability is closely related to the degree of compost maturity. According to Iglesias-Jimenez and Alvarez (1993) the bioavailable N is ranging between 16 and 21 %, while Scherer et al. (1996), who investigated in a pot experiment the N-mobilization and N-immobilization of composts from different input materials, degree of decomposition and C/N ratio found a maximum of N exploitation of 7 % of total N applied with compost. This suggests that only more labile organic N compounds were mineralized.

We investigated the influence of the application of increasing application rates of sewage sludge and compost in comparison to farmyard manure and mineral fertilizer on the total N content in our long-term field experiment.

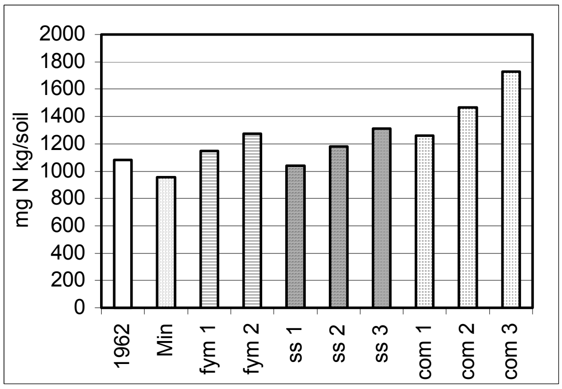

Fig. 1: Influence of long-term application of sewage sludge and compost as compared to farmyard manure and mineral fertilizer on the total N content of the soil

With exception of the lower dose of sewage sludge the application of the organic materials led to higher total N contents of the soil as compared to 1962 (Fig. 1). Scherer et al. (1985) even have shown that the accumulation of total N was not only restricted to the top soil, but also included the layer from 60 to 90 cm depth. This increase was caused by hydrolyzable as well as non-hydrolyzable organic N compounds.

To investigate the influence of the total N accumulation on the N delivery potential of the soil we conducted an incubation experiment.

Immobilized N becomes an integral component of the soil organic matter and is slowly mineralized to available N forms. The balance between ammonium release and immobilization is a function of the C/N ratio of the organic material. With exception of the treatment with the lower dose of sewage sludge the N enrichment of the soil, caused by the application of the different organic substances, resulted in a higher N delivery of the soils (Fig. 2). From the ecological point of view it should be mentioned that the potential for nitrate leaching may be increased especially during autumn and winter in soils, where N is accumulated.

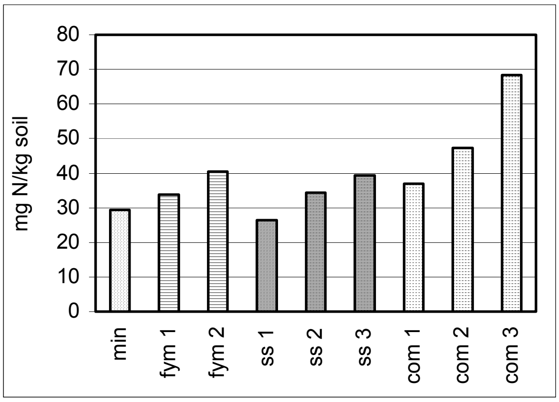

Fig. 2: Influence of long-term application of sewage sludge and compost as compared to farmyard manure and mineral fertilizer on the N delivery of the soil

On the other hand yield formation of the crop may be favored by a high N delivery potential of the soil. According results of Werner et al. (1988) from a long-term field experiment in the plots supplied with different organic materials the higher N uptake of the crop as compared to the mineral fertilizer treatment is the result of the mineralization of organic N compounds enriched in the soil by the application of organic fertilizers.

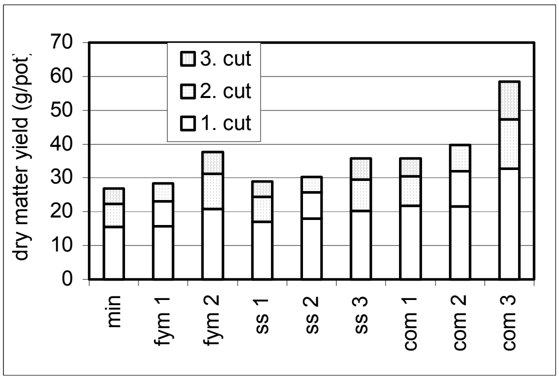

Fig. 3: Influence of long-term application of sewage sludge and compost as compared to farmyard manure and mineral fertilizer on dry matter yield of ryegrass

The higher N delivery of the treatments with organic fertilization, which could be shown in the incubation experiment is clearly reflected in the yield formation of ryegrass in a pot experiment (Fig. 3).

Sewage sludge has been used since many years as a P fertilizer (Kirkham, 1982) but still little information exists on the availability of P in these materials. De Haan (1981) compared the availability of P in 12 sewage sludges with that of MCP. According to his results the availability of sludge-borne P varied between 20 to 100 % of that in MCP. The P requirement of agricultural crops is only about 10 to 25 % of the quantity of N removed from soil (Cooke, 1982), whereas sewage sludge generally contains about half as much P as compared to nitrogen. For this reason, the current practice of applying sewage sludge according the N demand of the crops will supply P in excess of crop needs. The availability of P from compost is still matter of debate. The wastes of farm animals are also rich in P and may contain broadly similar amounts of P generally compared with sewage sludge.

In the year of mineral fertilizer P application, P exploitation of the crop seldom exceeds 20 to 25 % of applied P (Sharma et al., 2002). After the application of sewage sludge and compost, respectively, P uptake of plants may even be lower. Therefore, large amounts of insoluble and stable P may be accumulated in soils with regular P application. According to Scherer and Sharma (2002) long-term application of different organic materials resulted in an increase of total P in the soil as compared with the year of the start of the experiment.

Compared with the soil sampled at the beginning of the experiment, in our experiment bioavailable P (H_2O-P) increased in all treatments (Fig. 4). The increase was highest in the treatment with the high fym application, even the total P content of the soil was higher in the treatment with the high compost application rate and all the sewage sludge treatments. The positive effect of fym on the P availability is probably due to organic anions, which are formed during the decomposition of the organic matter supplied with fym, competing with inorganic PO_4^{3-} and therefore reduce fixation (Werner and Scherer, 1995).

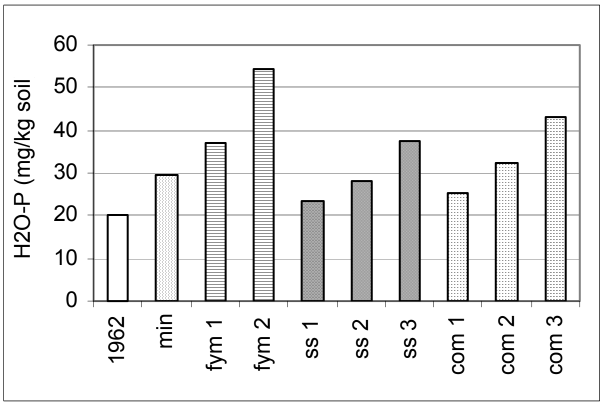

Fig. 4: Influence of long-term application of sewage sludge and compost as compared to farmyard manure and mineral fertilizer on the bioavailable P (H_2O-P).

The bioavailability of P in sewage sludge and compost is less than that of fym. The low availability of sewage sludge can be attributed to Fe salts added at the wastewater treatment plant to bind P.

In Germany the CAL extraction is commonly used to determine plant available P, on which P fertilizer recommendations are based. The continous addition of P as mineral fertilizer or organic sources increased the CAL extractable P from its original status of 43,1 mg P kg^{-1} soil up to 175,9 mg P kg^{-1} soil after 38 years in the treatment with the high P application rate. The increase was lowest in the treatment with mineral P application and with low and medium application rates of sewage sludge. This confirms results of Sharma et al. (1997) who reported a large build up in the plant available P pool with long-term manuring and cropping in acid soils of the western Himalaya. From an ecological point of view the origin of sewage sludge and soil available P content must be taken into account when advising sludge application to crops to adjust P inputs to plant need (Frossard et al., 1996).

A major concern associated with the use of sewage sludge and compost remains the presence of heavy metals, that can be toxic to plants, enter the food chain and affect human health. The occurrence of heavy metals in sewage sludge and compost arises principally through domestic and industrial input as well as through road run-off. In the last years there has been a dramatic reduction in the inputs of heavy metals to the sewers resulting in a remarkable reduction of heavy metal concentration in German sewage sludges (Fig. 6). The same holds true for sewage sludges in Great Britain (Rowlands, 1992)

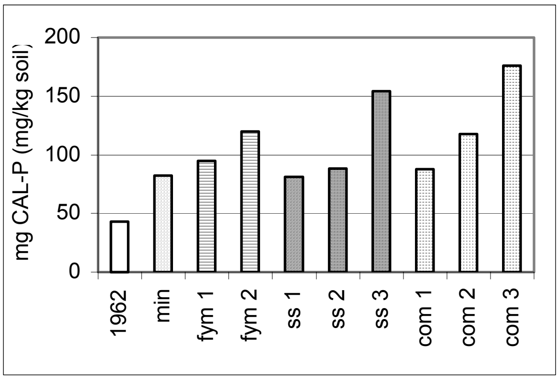

Fig. 5: Influence of long-term application of sewage sludge and compost as compared to farmyard manure and mineral fertilizer on CAL extractable P

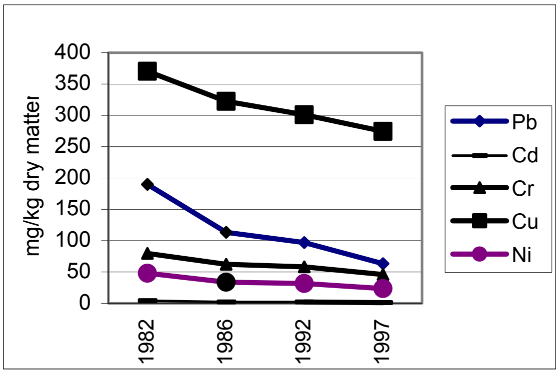

Fig. 6: Development of heavy metal concentrations in Germany

In Germany recycling of sewage and compost is controlled by the general Fertilizer Legislation as far as nutrients are concerned (Kluge and Embert, 1996) and the German Sewage Sludge Ordinance (for sewage sludge) and the German Compost Ordinance (compost) as far as environmental contaminants are concerned. The ultimate endpoint of the precautionary principle is the balancing of heavy metal inputs with their offtakes in crops thereby maintaining a status quo and avoiding the long-term accumulation of heavy metals in soil (Smith, 1996). However, this goal is probably not to achieve in practice due to the diverse range of heavy metal inputs to soil from different sources like other fertilizers as well as from atmospheric depositions

In the first years of our long-term field experiment the objective was focused on the availability of plant nutrients supplied with the different organic materials. However, later also the heavy metals gained interest and their concentrations in soils as well as in plant material were investigated.

Our results (Fig. 7) show, that the application of compost resulted in an increase of the Zn concentration of the soil as compared with the treatment with mineral fertilizer (control). In the treatment with the highest compost application rate the Zn concentration is above the treshold value of the German Sewage Sludge Ordinance. Also in the treatments with sewage sludge application the Zn concentration is higher as compared to the control. However, it should be mentioned that in the treatment with the lowest sewage sludge application rate – this rate is almost on the same level, which is allowed according to the German Sewage Sludge Ordinance – the Zn concentration of the soil is in the same order of magnitude as the control.

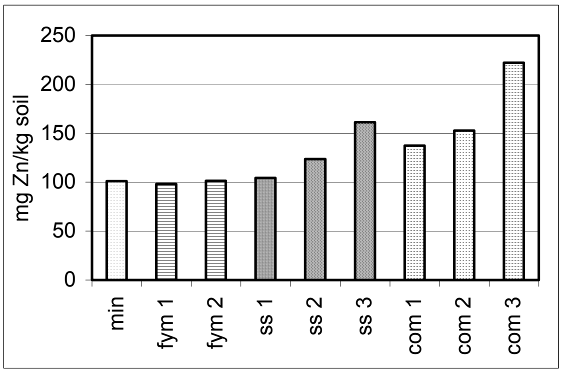

Fig. 7: Influence of long-term application of sewage sludge and compost as compared to farmyard manure and mineral fertilizer on the Zn concentration of the soil

In addition to sewage sludge and compost other inputs of heavy metals to agricultural land are from livestock waste. However, according to our results the Zn concentration of the soil in the treatments with long-term farmyard application was in the same order of magnitude as in the mineral fertilizer treatment and the treatment with the low sewage sludge application rate.

Cadmium is the main heavy metal in sewage sludge treated land, which circumvents the soil-plant barrier potentially impacting the human food chain (Smith, 1996). Its concentration in sewage sludge and composted refuse varies widely and may be high. In our investigations the Cd concentration of the soil increased with each increment of sewage sludge and compost, but the treshold value of the German Sewage Sludge Ordinance was never reached, even high amounts of both organic materials were applied over a long period of time. The highest Cd concentration was found in the treatment with the highest compost application rate.

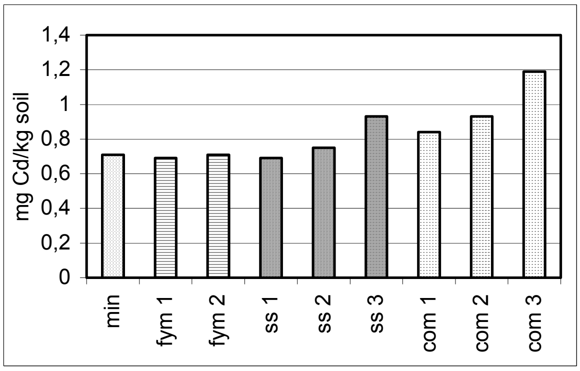

Fig. 7: Influence of long-term application of sewage sludge and compost as compared to farmyard manure and mineral fertilizer on the Cd concentration of the soil

As far as the most mobile heavy metals Cd and Zn are concerned Werner and Warnusz (1997) investigated the vertical movement into the subsoil in our long-term field experiment. According to their results the Zn content in the subsoil is about 50 % for all treatments of that in the topsoil and the Cd content is only in the range of 20 to 25 %.

A large number of studies have examined the fate of heavy metals in agricultural soils after the application of sewage sludge and compost and their uptake of plants. Much evidence indicates that metal inputs via organic materials accumulate in topsoils and, even over a longer term, measured in years, do not become bioavailable for crop uptake. McGrath (1987) for example, estimated that only a few percent of the sewage-applied heavy metals were taken up by crops over a 20 years period from a field receiving annual sludge treatments. However, it should be mentioned, that in mineral soils, the main factors influencing heavy metal adsorption or mobility are pH, organic matter content, content of Fe and Mn oxides and percentage clay content.

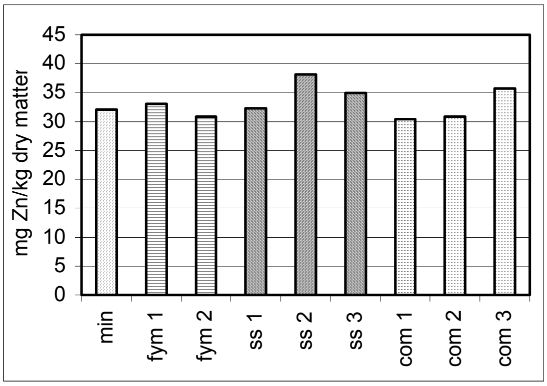

Fig. 8: Influence of long-term application of sewage sludge and compost as compared to farmyard manure and mineral fertilizer on the Zn concentration of wheat grains

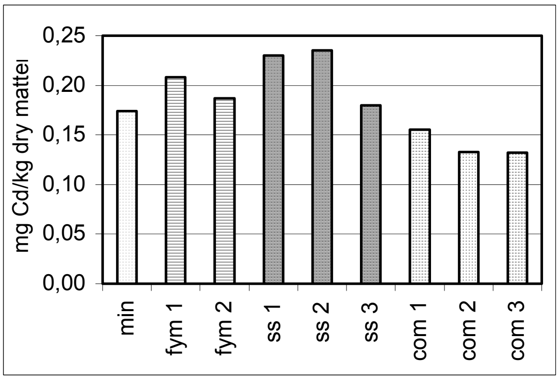

Fig. 9: Influence of long-term application of sewage sludge and compost as compared to farmyard manure and mineral fertilizer on the Cd concentration of wheat grains.

The influence of long-term application of organic materials on the bio-transfer of Zn is shown in figure 8. Confirming results of Delschen and Werner (1989) there was no relationship between the total Zn content of the soil and the Zn concentration of the plant material. Even the Zn content in the soil of the treatment with the highest compost application rate was more than twice as high as in the control, the Zn concentration of wheat grains was almost the same in both treatments. One main reason for these results is the pH of the soil which was higher in the compost treatments as compared with the mineral fertilizer treatment and the pH is one parameter controlling the Zn availability Herms and Brümmer (1984).

Cadmium represents the human dietary poison of principal concern in relation to the utilization of sewage sludge on agricultural land (Smith, 1996). In our experiments the Cd concentration of wheat grains decreased with increasing compost and sewage sludge application rates, while the Cd content of the soil increased (Fig. 9). The availability of this element is also governed by the pH of the soil, which increased with increasing amounts of compost applied. According to Brümmer and Herms (1983) Cd is much more soluble at pH 4-5 than in the range 5-7.

Our results prove evidence that long-term application of sewage sludge and compost not only supply nutrients but also increase the heavy metal content of soil. Further, these organic materials modify soil properties like the cation exchange capacity of the soil and heavy metals can be adsorbed in high amounts. In addition in the case of the application of compost the pH of the soil is raised and Zn and Cd become less available. However, also the mobilizing effect on heavy metals of the recycled organic matter should be mentioned, which is due to the fact that the production of dissolved organic compounds, which have a mobilizing effect on heavy metals and the microbial activity are favored. In total as far as compost and sewage sludge are concerned our long-term field experiments demonstrate, that there is no danger, if both organic materials are applied in agreement with the legislative permissions.

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