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Phosphorus availability to maize plants from sewage sludge treated with Fe compounds

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Abstract

Five loamy and four sandy soils were incubated with either $CaHPO_4$ or two sewage sludges with the P:Fe ratios 1:1.5 (sludge Sh) and 1:5.4 (sludge Gö) for 1 and 6 months. P sorption and $_{inorganic}$ P (P_i) concentration of the soil solution were measured. In a pot experiment P uptake of maize was examined. The application of sludge Sh did not modify P sorption compared to soils without sludge. However, after application of sludge Gö the P sorption increased to 116 % in loamy and 112 % in sandy soils. After application of sludge Sh the mean P_i concentration increased in loamy soils to 124 % and in sandy soils to 113 %. On the other hand the P_i concentration decreased after applying sludge Gö to 82 % (loamy soils) and 62 % (sandy soils) as compared to the controls of the respective soils. One month after the application of increasing amounts of sludge Gö (5, 10, 15 t DM ha^{-1}) both the concentration of oxalate-soluble Fe in the soil and the P sorption were increased. The relationships between these two parameters were highly significant ($r^2 = 0.87 - 0.97$). Plant uptake of P was lower after application of sludge Gö than after application of sludge Sh and much less than P uptake from $CaHPO_4$. Sewage sludges with a P : Fe ratio of 1 : 5 should not be recommended for agricultural use, as the P availability is significantly reduced. Iron salts should not be used for conditioning of sludges.

Introduction

In Germany 500 000 t of iron salts are used every year in waste water purification plants to precipitate P. 38% of the $2.4*10^6$ t DM of sewage sludge are used in agriculture. The aim of this investigation was to study the P availability of soils treated with sludges containing different iron contents. Five loamy and four sandy soils were incubated with two sludges (separately) for periods of 1 and 6 months. Following these treatments, P sorption, the soil content of oxalate soluble Fe and the P_i concentration of soil solution were measured. The P uptake of maize plants from one soil treated with two sludges was determined in a separate experiment.

Materials and methods

Table 1. Characteristics of the sludges

sludge	DM cont. g kg^{-1}	pH	Ca	P kg t^{-1}DM	Fe	P : Fe
S Gö	320	11,5	197*	12	65*	1:5.4
S Sh	40	7,0	21	25	39**	1:1.5

* Application of $FeSO_4$ at aerobic basin and $FeCl_3$ and $Ca(OH)_2$ for conditioning process.

** Application of $FeCl_3$ at aerobic basin.

Incubation experiment 1

Five loamy soils and four sandy soils were each mixed with S Gö , S Sh or $CaHPO_4$ (30 mg P kg^{-1} soil = 60 kg P ha^{-1}) and incubated at 20°C and 50% of maximum water holding capacity in pots (6.5 kg) for 1 and 6 months. Soil solution for P_i determination were collected (Adams, 1974). P sorption ability was determined according to Fritsch and Werner (1988): extraction of 10 g soil with 100 ml of a 10 mg P L^{-1} solution for 2 hours.

Incubation experiment 2

Experiment 1 was repeated but sludge equivalent to 30, 60, 90 mg P kg^{-1} soil was added. P sorption was determined as in experiment 1. The amorphous Fe of soil was extracted with NH_4 oxalate (Fe_{ox}) and determined according to Schwertmann (1964).

Pot experiment with maize

Four maize plants were grown in pots filled with 6.5 kg of a loamy soil (sand 5%, silt 75%, clay 20%, C_{org} 13 g kg^{-1} , pH 7.2 ($CaCl_2$) , two P levels: lactate soluble P: 46 or 110 mg kg^{-1}) for 90 days. 30 mg P kg^{-1} soil were applied as $CaHPO_4$ or sludge. P content of above ground biomass was measured.

More details are given by Römer and Samie (2001).

Results

One month after application of S Gö the P_i concentration was reduced to 82% in the 5 loamy and 62% in the 4 sandy soils compared with the controls without P (Tab.2), whereas the P sorption was increased to 116% and 112%, respectively (Tab.3). For S Sh P_i concentration increased to 113 and 124 %, respectively, but the P sorption ability remained similar in all soils (95 to 103 %). 6 months later results were quite similar date not shown.

Table 2. Mean values of P_i concentration of the soil solutions 1 month after P application (µg P L^{-1})

Soils	Without P	$CaHPO_4$	S Gö	S Sh
5 loamy	222 (100)	438 (198)	182 (82)	275 (124)
4 sandy	118 (100)	275 (232)	73 (62)	133 (113)

Table 3. Mean values of P sorption 1 month after P application (mg P kg^{-1})

Soils	Without P	$CaHPO_4$	S-Gö	S-Sh
5 loamy	43 (100)	35 (81)	50 (116)	41 (95)
4 sandy	58 (100)	53 (91)	65 (112)	60 (103)

With increasing rates of sludge applications a linear relationship was found between Fe_{ox} and P- sorption for one loamy soil well as for sandy soils (Fig. 1a, b).

At low soil P level plants apparently took up P from all three P sources, but the lowest amount from S Gö. At high soil P level plants variable to utilize P from $CaHPO_4$ and S Sh only but not from S Gö (Tab. 4).

Table 4. P uptake of maize plants grown on a loamy soil at two P levels

Treatment		Low P[1] 46 mg kg^{-1}	High P[1] 110 mg kg^{-1}
Without P	mg P pot^{-1}	160	231
Without P	rel.	100 c	100 c
$CaHPO_4$	rel.	160 a	131 a
S Gö	rel.	131 b	98 c
S Sh	rel.	167 a	115 b

[1] Ca acetate lactate soluble P
Different letters in one columne show significant differences at p =5% (Tukey test)

Discussion

The P uptake by the plants was significantly lower after the application of S Gö as compared to P uptake after the application of $CaHPO_4$ or S Sh (Table 4). This lower P uptake is related to the low P_i concentration in the soil solution after the application of S Gö (Table 2). The low P_i concentration is a result of the significantly higher P sorption in the soil (Table 3). Obviously application of S Gö results in an increase of sorption sites for phosphate ions, due to its wide P:Fe ratio (1 : 5). Figure 1 shows that the P sorption capacity in soil increases with the increasing rate of applied Fe. This process has a negative impact on plant growth since it decreased the P availability. The sludge Sh has a P:Fe ratio of 1 : 1.5.and did not cause a significant increase in P sorption. As a result plants were able to take up P from the soil treated with sludge Sh nearly as good as from the soil where $CaHPO_4$ had been applied (Table 4).

Conclusions

Maize plants took up the lowest P amounts from the soil treated with S Gö with a P:Fe ratio (1 : 5.4). It has to be assumed that this is due to the increased P sorption ability of the soil and the decreased P_i concentration of soil solution. Such sewage sludges are not suitable for use as fertilisers on arable land.

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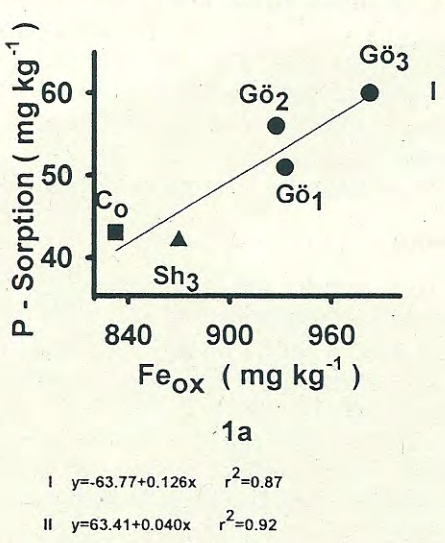

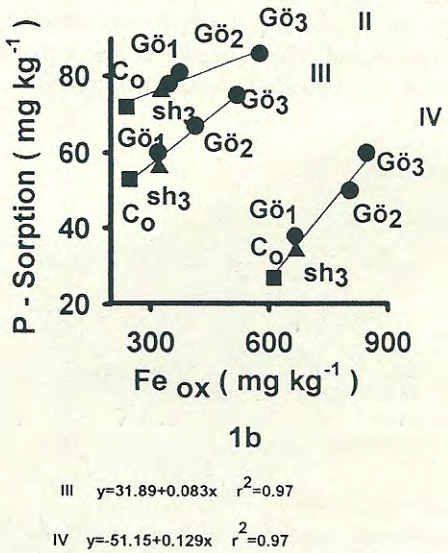

Figure 1. Relationship between Fe_{OX} content of soil and P sorption (1a: loamy soil " Börry"; 1b: 3 sandy soils)
C_0 = control (without P), $Gö_1$ = 157, $Gö_2$ = 214, $Gö_3$ = 471, Sh_3 = 132 mg Fe kg^{-1} as sludge.