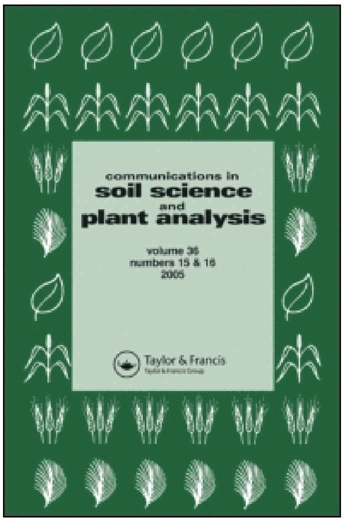

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Effect of composted sewage sludge amendment on soil nitrogen and phosphorus availability

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Effect of Composted Sewage Sludge Amendment on Soil Nitrogen and Phosphorus Availability

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ABSTRACT

Municipal sewage sludge previously composted with sawdust (CSS) was applied to an eutric sandy cambisol at rates of 7.5, 15.0, 22.5, and 30 g·kg^{-1}. Incubation and pot experiments were conducted to evaluate CSS effectiveness on nitrogen (N) and phosphorus (P) soil availability and on plant nutrition. The CSS rates did not increase soil mineral N and had little effect on organic P and on labile forms of P. Efficiency of total applied P was 17% for the soil labile forms and 4.8% for the resin extractable fraction. In contrast, CSS significantly increased hydroxide extractable inorganic P and nonextractable soil P fraction. The major portion of the increment on nonextractable forms was at the expense of HCl extractable P fraction [calcium (Ca)-bounded], dominant on the original CSS. Thus, chemical rather than biological reactions lead to the redistribution of CSS-borne P to more firmly held forms after its application to the soil. Ryegrass dry matter yield, N content, and N uptake did not increase in CSS-treated soils. Plant P content increased at the second harvest, but the effect was nil in the subsequent harvest. Total P uptake increased from 14.1 to 20.2 mg·pot^{-1}, but percentage P recovery by ryegrass was modest, averaging 2.5% of the CSS-borne P. Results suggest that moderate application of CSS to agricultural systems are inadequate for crop growth but may contribute to nutrient recycling without environmental risks related to N and P loss.

INTRODUCTION

Large amounts of urban sewage sludge are processed nowadays, and its quantity will increase in the near future since the number of waste water treatment plants are still increasing over the world. Landfill disposal or incineration plants are common addressees for these sludges. Notwithstanding, if no organic or mineral pollutants are present in detrimental concentrations, environmental concerns advise to consider the recycling of nutrients. Through its fertilizer potential, the interest in sewage sludge application is increasing to supply N, P, and other nutrients to agricultural and forestry soils. Accordingly, chemical fertilizer application can be reduced, depending on the rate of nutrient release from the sewage sludge. The knowledge of nutrient releasing rates is also important to prevent environmental risks for surface and groundwater quality through the loss of soluble nutrients in excess.

Nutrient availability of the sewage sludges depends on the nature of the sewage, on the technology of water purification, and on the subsequent treatment for sludge stabilization. Thus, it is to be expected that sludges from different waste water treatment plants may present distinct behavior concerning nutrient contents, N mineralization potential, and P bioavailability. Soil characteristics may also strongly affect sludge nutrient behavior (McLaughlin and Champion, 1987; Fine and Mingelgrin, 1996). On a dry weight basis, N content in sewage sludges ranges from 11 to 60 g·kg^{-1} (Mustin, 1987; Paccolat, 1979; Santos, 1995). Most of the N is in organic forms, and its mineralization and volatilization depends on pH, method of application and carbon (C)/N ratio of the sludge (Smith and Peterson, 1982). The P content ranges from 5.4 to 31.7 g·kg^{-1} (Morel, 1978; Santos, 1995) and tends to increase with the stringent standards placed for liquid effluents disposal. Usually, most of the P is in inorganic forms, and its bioavailability depends on the compounds used for sludge stabilization. Comparing the effectiveness of P in sewage sludges with that of P in monocalcium phosphate, de Haan (1980) found values from 20%, for sludges treated with iron (Fe) and aluminum (Al) salts, to almost 100% for sludges treated with lime.

The present study was undertaken to (i) evaluate the effect of one specific urban composted sewage sludge on N and P soil availability, through an incubation experiment and (ii) estimate its effectiveness as source of N and P to plant nutrition through a multiple cut pot experiment with ryegrass.

MATERIAL AND METHODS

The urban composted sewage sludge (CSS) was collected at Maia waste water plant, near Oporto. Activated sludge of mixed domestic and industrial sources is anaerobically digested, flocculated with an polyelectrolyte, and composted. Composting is conducted during 20 days with a ratio of 1:3 (v/v) of sludge and sawdust, respectively. Characteristics of CSS used are presented in Table 1.

Incubation and pot experiments were conducted using a sandy eutric cambisol developed over schist (Table 2) with a low N and P available status. Soil was sampled from the 20-cm top layer, air dried, and passed through a 2-mm sieve.

For the incubation experiment, samples of 1.5 kg of soil were mixed thoroughly with CSS dried and ground, and placed into polythene bags. Rates of CSS were nil (CSS0), 7.5 $g \cdot kg^{-1}$ (CSS1), 15 $g \cdot kg^{-1}$ (CSS2), 22.5 $g \cdot kg^{-1}$ (CSS3), and 30 $g \cdot kg^{-1}$ (CSS4) on a fresh weight basis, equivalent to CSS amendments up to 60 $Mg \cdot ha^{-1}$. The CSS was allowed to react with the soil at 70% field moisture capacity and room temperature (20°C). Each treatment was replicate three times. To assess short term N-mineralization potential, samples were collected at 30, 60, and 90 d. To evaluate P fractionation and availability, samples were collected at 240 d.

Simultaneously, a pot experiment was conducted in the greenhouse. Samples of 3 kg of soil were thoroughly mixed with similar rates of CSS (CSS0, 1, 2, 3,

TABLE 1. Selected properties of the composted sewage sludge.

parameter	value
moisture (%)	62.9
pH water	5.9
organic C (g kg^{-1})	477
carbonates (g kg^{-1})	1.7
total N (g kg^{-1})	15.7
ammonium (mg N kg^{-1})	161
nitrate (mg N kg^{-1})	413
total P (g kg^{-1})	7.5
organic P(g kg^{-1})	1.1
total K (g kg^{-1})	2.00
total Ca (g kg^{-1})	15.7
total Mg (g kg^{-1})	1.65
total S (g kg^{-1})	8.14
total Fe (mg kg^{-1})	7080
total Zn (mg kg^{-1})	980
total Cu (mg kg^{-1})	260
total Mn (mg kg^{-1})	19

TABLE 2. Selected properties of the soil.

parameter	value
organic matter (g kg^{-1})	4.4
pH water	6.6
pH 1M KCl	5.7
ammonium (mg N kg^{-1})	3
nitrate (mg N kg^{-1})	7
extractable P (mg kg^{-1})	6
exchangeable Ca ($cmol_c$ kg^{-1})	6.93
exchangeable Mg ($cmol_c$ kg^{-1})	0.18
exchangeable K ($cmol_c$ kg^{-1})	0.45
exchangeable Na ($cmol_c$ kg^{-1})	0.10
ECEC ($cmol_c$ kg^{-1})	7.66
oxalate extract Al (mg kg^{-1})	879
oxalate extract Fe (mg kg^{-1})	575

and 4). A nutrient solution containing 100 mg N, 50 mg P, and 100 mg potassium (K) was applied to each pot. Fifteen seedlings of ryegrass (*Lolium perenne* cv Karamba) were allowed to grow in each pot. Pots were weighed and watered daily, maintaining the soil at 70% of field moisture capacity. Plants were harvested to a 20-cm height every 30 d for 90 d. The harvested material was dried in the oven at 65°C, weighed, and ground prior to nutrient content analysis.

Sewage sludge and plant nutrient composition were determined after mineralization with H_2SO_4+H_2O_2 (Novozamsky et al., 1983). Ryegrass N and P accumulation were computed as the product of nutrient content and dry matter yield. Total, inorganic, and organic P in the sewage sludge were assessed according to Saunders and Williams (1955). Soil mineral N was computed as the sum of ammonium (NH_4^+) and nitrate (NO_3^-) contents. Both were measured by molecular absorption spectroscopy in a 1M KCl extract with a segmented-flow analysis system. Ammonium was determined by the Berthelot reaction, and NO_3^- was determined by the Griess-Ilosvay reagent after reduction in a cadmium column (Houba et al., 1994). The P fractionation was performed according to Hedley et al. (1982). Soil available P was determined by the Egnér-Riehm method (Balbino, 1968). Phosphorus content in the different extracts was analyzed in a segmented-flow system by the molybdate-ascorbic acid blue method (Murphy and Riley, 1962). All the analysis were conducted in duplicate.

The results were statistically analyzed by an ANOVA procedure to evaluate the significance of the treatments (CSS rate and time). Mean separation was performed using Fisher-LSD test at a $P \leq 0.05$ level of significance.

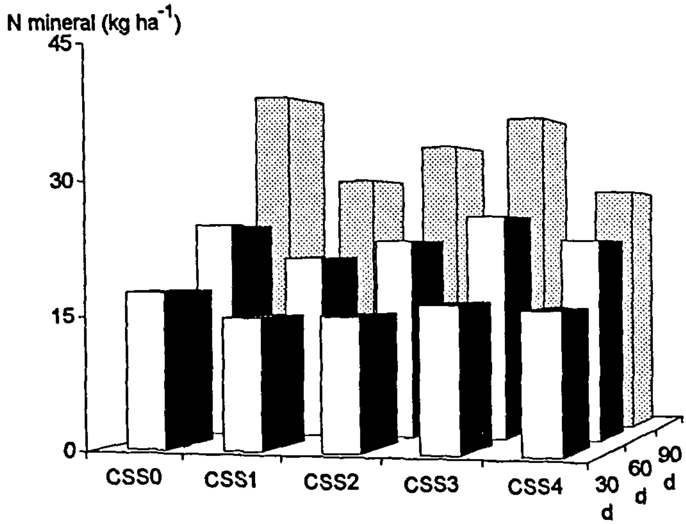

FIGURE 1. Effect of composted sewage sludge (CSS) rates and time of incubation on the mineral N content of the soil.

RESULTS AND DISCUSSION

Incubation Experiment

Concerning N mineralization, time had a highly significant effect on the NH_4^+ and NO_3^- *contents. Reflecting* the favorable conditions in temperature and moisture for microbial activity during the incubation, average values increased progressively from 10 mg·kg^{-1} in the original soil to 16, 25, and 36 mg·kg^{-1}, after 30, 60, and 90 d, respectively. However, CSS has a general negative effect on net N mineralization, as can be observed in Figure 1. Trends on N mineral contents among sludge doses were consistent during all the incubation, but the depressive effect was negligible after 30 and 60 d. Nevertheless, the lack of differences may represent an actual immobilization of the mineral N carried by the sludge itself, near 4 mg·kg^{-1} of soil for CSS1. The C/N ratio of 30.4 in the CSS suggests a low availability of organic N for microbial activity, and therefore no important N release would be expected. Furthermore, the high proportion of sawdust in the mixture for composting leads to a cellulose enriched final CSS, which is a very slow decomposing organic pool.

Significant differences among rates were observed at 90 d. However, the effect on mineral N content is not proportional to CSS doses. Between CSS0 and CSS1 a significantly decrease, from 42 to 31 mg·kg^{-1}, in mineral N occurred. Mineral N

TABLE 3. Effect of composted sewage sludge (CSS) rates on the soil P extracted by Egnér-Riehm method.

	CSS0	CSS1	CSS2	CSS3	CSS4	LSD
P (mg kg^{-1})	6.6	7.6	9.9	13.2	17.0	0.3

content increased for CSS2 and CSS3, to 35 and 39 mg·kg^{-1}, respectively, and no difference was observed between CSS0 and CSS2. Therefore, it appears that the lag phase for N mineralization decreases from CSS1 to CSS3. This effect may be due to the mineral N supply coming from the sludge, since if N availability is a limiting factor for microbial growth, N mineral additions increase and accelerate N mineralization (Brito and Santos, 1996).

However, a significant decrease on mineral N content was observed on CSS4, and the value dropped to 29 mg·kg^{-1}. A less pronounced trend was also observed at 60 d. Based on these results, it appears that the level of 30 mg of sludge per kg of soil may affect N microbial growth and, therefore, N mineralization.

Regarding the effect of CSS application on the soil P content, Table 3 presents the values of Egnér-Riehm extractable P at 240 d. As expected, the overall effect of the sludge was highly significant, and the differences among all CSS rates were also significant. Average efficiency of P extracted by this method is about 12.4% in relation to the amount of P added in the sludge, and efficiency rises with the increase of CSS rate. For the first increment, efficiency is 4.9%, and for the

TABLE 4. Effect of composted sewage sludge (CSS) rates on the soil P fractionation (mg P kg^{-1}).

P fraction	CSS0	CSS1	CSS2	CSS3	CSS4	LSD
labile forms						
resin Pi	4.1	5.3	6.1	8.0	8.0	0.5
bicarbonate Pi	4.9	6.7	8.1	9.3	11.4	0.6
bicarbonate Po	1.6	2.1	2.9	2.6	2.8	0.4
hydroxide Po	9.9	11.3	12.4	12.4	12.7	0.6
slow release forms						
hydroxide Pi	37.7	44.1	50.2	55.1	62.2	2.3
sonic Pi	7.4	8.8	9.2	9.4	10.1	0.9
sonic Po	1.0	1.3	1.8	2.0	1.9	0.2
acid Pi	15.1	15.9	17.8	23.2	24.7	1.5
nonextractable	305.4	313.4	320.3	326.2	337.9	3.8

Pi=inorganic P; Po=organic P.

last increment efficiency is 20.2%, although these values may not have a biological or biological meaning. The amount of P extracted by the common routine soil tests are the sum of the Intensity factor and a restrict and unknown proportion of the Quantity factor. Therefore, it is not possible to assess if the nutrient remains in the less available native P species of the sludge or if it became solubilized, adsorbed, or precipitated with various cations, leading to the formation of new secondary phosphates. Consequently, the dynamics of P supplied by the sludge, mostly in inorganic forms, can not be studied with those routine methods.

The method of Hedley et al. (1982) allows the fractionation of soil P into organic and inorganic forms with chemical and biological meanings, as proposed by Tiessen et al. (1984). Results of soil P fractionation as a function of applied CSS are presented in Table 4. Recovery percentage of the added P by the CSS is 98%. As it can be observed, the general pattern of P distribution did not change dramatically with the treatments. In the CSS0 treatment, labile forms of P represented 5.3% of total P, and organic P represented 3.2% of total P. In CSS4 treatment, the distribution changes to 7.4 and 3.7%, respectively.

The increments on the extractable organic fractions are negligible, namely on the more labile form (bicarbonate-extractable), as the result of the low proportion of organic P in the sludge and its unavailability. Mineralization of organic P was expected to be negligible from the CSS under study. The C/P ratio in the organic fraction of the CSS under study was about 433, much higher than the critical ratio pointed out by White (1981).

Concerning the effect of CSS rates on the labile pools in soils (Figure 2), the average increment on extractable P was about 470 mg per kg of CSS (fresh weight), reflecting an apparent efficiency of 17% in relation to total P applied. Resin extractable P, which is considered to be related with P availability to plants (Sibbensen, 1978), showed an efficiency of 4.8%.

Based on these results, the contribution of CSS for readily available P is very moderate, probably due to the nature of CSS. Presumably, most of the P is coming from the sludge fraction rather than from sawdust, and the subsequent composting process will further reduce P available content. Results of Handreck (1996) suggest that composting material with wood wastes decreases P availability in the final media as the result of microbial activity, which immobilize the more labile forms of P.

In regard to the slow release forms, increases in P content are more pronounced in hydroxide extractable and residual fractions (Figure 3). On average, both forms account for about 82% of the total increase in these pools. Relatively to the initial forms of P in the CSS, it can be observed an important evolution on P fractionation. The original material presented an hydroxide extractable Pi content of 2.0 $g \cdot kg^{-1}$ and an acid extractable Pi content of 3.6 $g \cdot kg^{-1}$. These values suggest that major part of inorganic P in the CSS may be either sorbed onto Al and Fe amorphous hydrous oxides or precipitated as secondary phosphates, mainly calcium

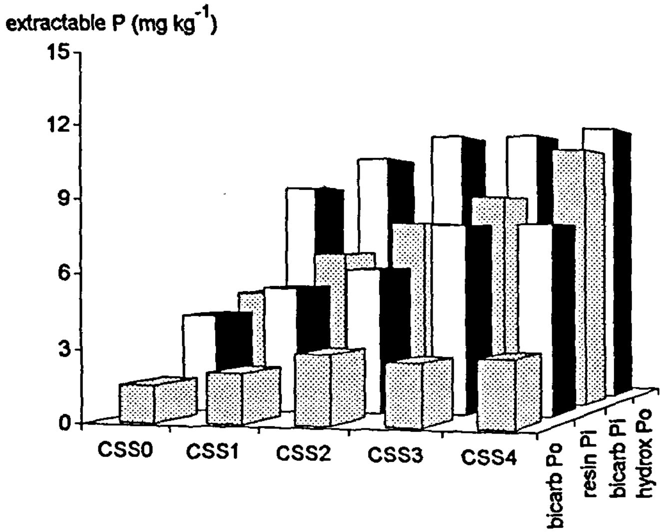

FIGURE 2. Effect of composted sewage sludge (CSS) rates on the distribution of P in labile forms.

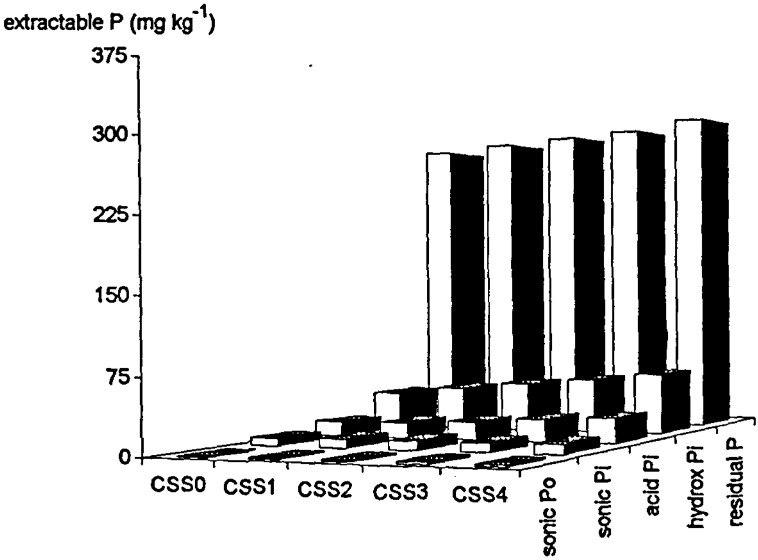

FIGURE 3. Effect of composted sewage sludge (CSS) rates on the distribution of P in slow release forms.

TABLE 5. Effect of composted sewage sludge (CSS) rates on ryegrass dry matter yield and N and P uptake.

parameter	CSS0	CSS1	CSS2	CSS3	CSS4	LSD
total DM yield (g/pot)	4.2	4.3	4.5	4.6	4.4	n s
total N uptake (mg/pot)	101	103	108	110	105	n s
total P uptake (mg/pot)	14.1	15.9	17.4	18.9	20.2	0.8

phosphates (Sommers and Sutton, 1980; Fine and Mingelgrin, 1996). Therefore, when sludge P is added to the soil, the existing equilibrium is disturbed, and it seems that P is converted to the more firmly held forms, just as Barrows (1980) refers for mineral P fertilizers.

The results suggest that after 240 d, precipitation and occlusion phenomena occurred with soil components and the nonextractable P fraction increases at the expense of the more soluble acid extractable Pi fraction. Thus, P availability from sludges appears to depend on the nature of the soil, since P-borne sludge follows the same type of redistribution of the soil native P.

Pot Experiment

Total dry matter yield (Table 5) was not significantly affected by doses, although a slight trend of increasing was observed between CSS0 and CSS3.

Regarding yield comparisons among individual harvests, the first and third harvests gave lower yields for all treatments, 1.0 and 1.3 g·pot^{-1}, respectively. The higher dry matter yield at the second harvest, 2.2 g·pot^{-1}, was due to a considerable tilllering and development of the crop after the first stimulating cut. The decrease in yield for the subsequent harvest seems to be the result of an extreme shortage of available N to the grass. This suggestion is further supported by the visual signs of N deficiency and the N content of the plants. Moreover, grass did not regrow for a fourth harvest. To ensure that other nutrients were not limiting ryegrass growth, levels of K, Ca, magnesium (Mg), sulfur (S), Fe, zinc (Zn), manganese (Mn), and copper (Cu) were monitored in plants (data not shown). At no time were observed analytical values or visual symptoms of nutrient deficiency or toxicity, except for N. Furthermore, an additional treatment supplying 100 mg of mineral N per pot was conducted and ryegrass dry matter yield at the third harvest was significantly higher, 6.4 g·pot^{-1}.

Ryegrass N content also did not show significant differences among treatments within each harvest (Figure 4). As expected, first harvest presented an average value significantly higher, 49.9 mg·kg^{-1}, than the second and third harvest, 17.1 and 14.6 mg·kg^{-1}, respectively. Accordingly with dry matter yield and N tissue content results, total uptake of N by ryegrass was not significantly different with increasing rates of CSS (Table 5).

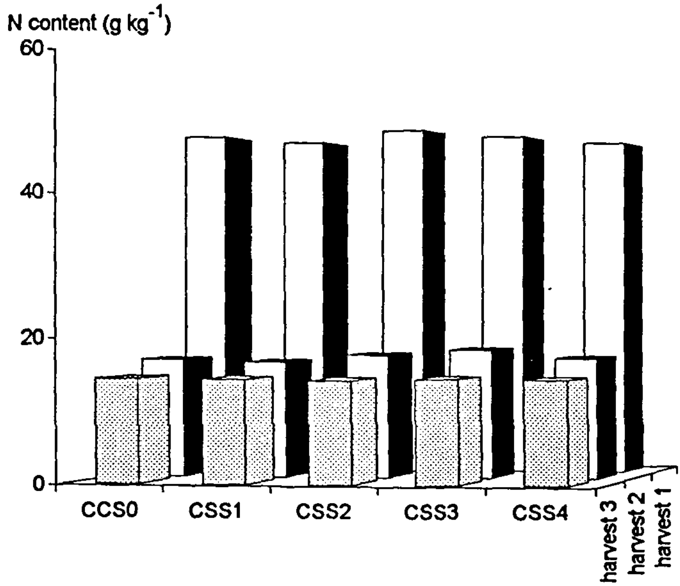

FIGURE 4. Effect of composted sewage sludge (CSS) rates on the N content of ryegrass.

Other studies have shown an increase in yield, N tissue content and N uptake when sludges were applied to soil (Smith and Peterson, 1982). However, the experiments were conducted with activated-sludges presenting different mineralization potentials than the composted sewage sludge under study. The present data for biomass yield and N nutrition seem to imply a limited amount of available N, which agrees with the results of the incubation experiment.

Regarding P content in ryegrass, only at the second harvest increasing CSS rates showed a positive and significant effect (Figure 5). Comparison among individual harvests shows the highest P content for all treatments but CSS0 at the second harvest.

Other studies have shown also an increase of P availability with time in soils receiving sludge amendments (Pommel, 1981; McLaughlin and Champion, 1987). The lower P content at the third harvest probable reflects a depletion on P availability, since yield also decreased and no mass concentration effect was observed in dry matter.

Total P uptake (Table 5) increased significantly with increasing rates of CSS. However, this effect was observed only at the expense of second harvest. Moreover, P recovery by ryegrass was modest. The percentage recovery of applied P by the sludge averaged 2.5%, equivalent to 80 mg P per kg of CSS (fresh weight).

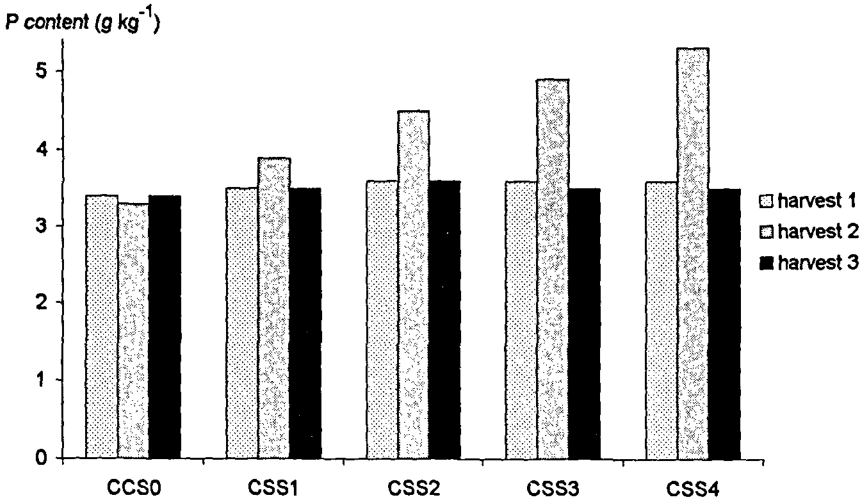

FIGURE 5. Effect of composted sewage sludge (CSS) rates on the P content of ryegrass.

Willett and Bond (1994) observed an apparent recovery of P from sludge treatments of 16% for a perennial pasture in field conditions. However, those authors used a lime-treated sewage sludge, which presents a P availability equivalent to superphosphate fertilizers, as reported by de Haan (1980). In the present study, the low P bioavailability from CSS agrees with its modest contribution to the more labile P forms in soil referred for the incubation experiment.

CONCLUSIONS

Regarding the composted sewage sludge under study and its application on the present soil, the following conclusions can be drawn:

1) Nitrogen mineralization is inadequate for normal growth rate of ryegrass.
2) Chemical rather than biological reactions lead to the redistribution of CSS-borne P after its application on soil.
3) Ryegrass has shown a low recovery of added P, result of the negligible contribution of CSS to the more P labile fractions in soil.
4) Moderate application of CSS to agricultural systems may contribute to nutrient recycling without environmental risks related to N and P loss.

ACKNOWLEDGMENTS

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