FATE OF PHOSPHORUS ADDED WITH URBAN COMPOST TO A CALCAREOUS SOIL

KEY WORDS: Available-P, Calcareous soil, Organic-P, Soil-P fractionation, Total-P, Urban compost.

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ABSTRACT

The effect of successive applications of urban compost (up to 150 and 400 t ha⁻¹ during eight years) on the status of phosphorus in a calcareous soil (20%) was tested in a greenhouse experiment. An 8-15-15 complex fertiliser was also applied for comparison. Five years of ryegrass and three of horticultural plants (tomato and eggplant) were successively cropped during the experiment.

Increases of total- and available-P were observed with both organic and inorganic fertilisation. Total-P increased more in soils treated with the highest compost dose. Generally, available-P was similar for soils treated with the highest compost dose and inorganic fertiliser. Also a slight but significant increase of organic-P was found in soils treated with compost.

Phosphorus added to soil tends to increase soluble- plus exchangeable-P (more in inorganic fertiliser treatment), P in

calcium phosphates (more in highest compost treatment) and residual-P, the latter being greater in soils treated with compost.

INTRODUCTION

Land application of urban compost has become widespread during recent years because of the deficiency of organic manures and the rise in the price of conventional inorganic fertilisers. Moreover the agricultural use of compost contributes to the disposal of wastes.

Phosphorus is the most expensive of the plant nutrients and has a finite world supply. Therefore its recycling from compost may be important, although compost total phosphorus content is small and very variable, ranging from 0.08 to 0.40% P (d. w.) (Huret, 1985; Gallardo-Lara and Nogales, 1987).

There are few studies in the literature on the effects on soil phosphorus of using urban compost as manure. Huret(1985) and Gallardo-Lara and Nogales (1987), in two reviews on the effect of compost on the soil-plant system found contradictory results: some authors claimed that the addition of compost increases the soil availability of phosphorus and total phosphorus in plant tissue, while others reported decrease or blockage of the available-P and the corresponding decrease of plant phosphorus. In field experiments, Cabrera et al. (1989) reported that the addition of moderate amounts of urban compost (three doses of $14 \text{ t ha}^{-1} \text{ y}^{-1}$, a common agricultural dose) alone or together with mineral fertiliser, to a calcareous soil (9.8% CaCO_3), during four years, does not cause any statistically significant change in the initial level of available phosphorus.

The present paper studies the effect of the addition of high doses of urban compost ($150\text{--}400 \text{ t ha}^{-1}$ during eight years) to a calcareous, loam soil (ca. 20% CaCO_3) on the status of the soil

phosphorus in greenhouse experiments. Compost doses used in this study possibly exceed the recommended levels, but high accumulations of compost are possible on agricultural lands (Huret, 1985). It is possible that, as with farmyard manure (Mengel and Kirkby, 1982), much of the value of compost for soil fertility arises from the cumulative effects of successive applications, which could lead many farmers to apply excessive amounts of composts to soils. On that score, it is interesting to check whether high additions of compost sometimes produce decreases of the phosphorus content in crops, as suggested by some authors (Juste et al., 1980; Polo-Sanchez, 1989)

MATERIALS AND METHODS

The experiments were carried out in a greenhouse, in containers of ca. 0.42 m², 40 cm depth (ca. 250 kg soil), using as substrate a calcareous, loam soil typical of southern Spain, whose main characteristics are shown in Table 1.

Six randomized replications were set out for each of the following four treatments: 1) Treatment HDC (high dose of compost): annual loading of compost at a rate equivalent to 48 t ha⁻¹ y⁻¹ for four years, followed by a year without compost addition and then two subsequent additions of 100 t ha⁻¹ y⁻¹. The total dosage of this treatment was equivalent to ca. 400 t ha⁻¹. 2) Treatment LDC (low dose of compost): the pattern was the same as for treatment HDC, but with different compost loadings: 12 t ha⁻¹ y⁻¹ during the first four years, no addition during the following year, and additions of 50 t ha⁻¹ for the last two years. The total compost loading for this treatment was equivalent to ca. 150 t ha⁻¹. 3) Treatment IF (inorganic fertiliser) : annual fertilisation with an 8-15-15 complex NPK fertiliser at a rate

TABLE 1

Some Characteristics of the Soil and the Different Batches of Urban Compost.

soil		urban compost	
		Max.	Min.
pH	7.8	7	8
Oxidisable O. M. (%)	1.05	20	30
CaCO ₃ (%)	20	-	-
Total-N (%)	0.06	1.5	2.0
Total-P (mg kg ⁻¹)	421	3500	5700
Avail.-P (mg kg ⁻¹)	17	86	1195
Organic-P (mg kg ⁻¹)	95	652	1195
Coarse sand (%)	33	-	-
Fine sand (%)	18	-	-
Silt (%)	22	-	-
Clay (%)	24	-	-

equivalent to 1.2 t ha⁻¹ y⁻¹. As in treatments HDC and LDC there was a year, the fifth, without any addition of mineral fertiliser.

4) Treatment C (control) without any fertilisation.

During the first period of five years ryegrass (Lolium multiflorum Lam. cv. Barwoltra) was cropped. Afterwards horticultural plants (tomato, Lycopersicum esculentum Mill. cv. Marmande and eggplant, Solanum Melogena L. cv. Long purple) were planted for a period of three years in which pots of treatments HDC, LDC and IF were fertilised only the two first years. Details of crops are described by Murillo et al., (1989ab).

Compost and fertiliser were always incorporated into the upper 5-6 cm of the soil. Periodical irrigation was used during plant cropping.

The urban compost was supplied by ABORGASE, obtained from composting municipal refuse of Sevilla. Table 1 shows some of the more relevant chemical properties of the compost batches used in this study.

Soil samples were collected at the end of the eighth year of cropping at three depths 0-10, 10-20 and 20-30 cm. Each soil sample was obtained by mixing two subsamples taken at two points in each pot. The samples were air-dried, ground to pass first through a 2-mm and then a 0.5-mm sieve, and analysed for the following parameters: total-P by the perchloric acid digestion method described by Hesse (1971), available-P by the method of Olsen et al. (1954), and organic-P by the ignition method recommended by Saunders and Williams (1955). Soil samples were also subjected to a sequential extraction procedure (Chang and Jackson, 1957) designed to partition the soil phosphorus into the following six fractions (Jackson, 1958): F1- soluble and exchangeable-P (1 N NH_4Cl); F2- P in aluminium phosphates (0.5 N NH_4F at pH 8.2); F3- P in iron phosphates (0.1 N NaOH); F4- P in calcium phosphates (0.5 N H_2SO_4); F5- P in occluded iron phosphates (0.3 M sodium citrate, 1 M NaHCO_3 and $\text{Na}_2\text{S}_2\text{O}_4$); F6- P in occluded aluminium phosphates (0.5 N NH_4F at pH 8.2). In addition, a seventh fraction F7- residual P, was calculated subtracting the sum of the former six fractions from the total-P.

Phosphorus in soil extracts was determined by the method of Murphy and Riley (1967).

Ryegrass shoots were cut four times per year. Tomato and eggplant fruits were collected at maturity. Plant material was washed with tap and deionised water, dried at 70 °C for 24 h and ground. Analysis of phosphorus was made by treating the samples with conc. HCl after calcination at 550 °C. Phosphorus in plant material extracts was determined by the spectrophotometric method of the phosphovanadomolibdic complex.

Statistical analysis of the results were carried out applying bifactorial ANOVAs, considering treatment and depth as independent variables. Monofactorial ANOVAs were also performed for each treatment or depth, taking depth or treatment respectively as independent variables. When null hypotheses were rejected, comparisons of means were performed by Student's t test

TABLE 2

Mean values of Total-, Organic- and Available-P, in mg kg^{-1} .

	depth (cm)	Treatments			
		C	IF	LDC	HCD
Total-P	0-10	377 a1	668 b2	656 b2	900 c2
	10-20	381 a1	504 a1	524 b1	615 c1
Organic-P	0-10	103 a1	97 a1	140 a1	139 a1
	10-20	112 ab1	88 a1	129 ab1	151 b1
Available-P	0-10	5.1 a2	40.5 c3	22.3 b3	36.7 c3
	10-20	4.1 a1	14.4 b2	13.1 b2	17.4 b2
	20-30	3.9 a1	5.4 b1	5.6 b1	8.0 c1

Values followed by the same letter (or number) in the same row (or column) do not differ significantly ($P < 0.05$).

(only two means) or by Tukey's test (for more than two mean values). A significance level of $P < 0.05$ was considered throughout the study.

RESULTS AND DISCUSSION

Total-, Organic- and Available-Phosphorus

Table 2 shows mean values of total-, organic- and available-P in soils of the four treatments.

Mean values of total-P are highest in the treatment HDC and lowest in C in both surface (0-10 cm) and subsurface soil samples (10-20 cm). For treatments IF and LDC mean values of total-P are similar and intermediate between those for treatments C and HDC.

In all the treatments except in C, highest mean values of total-P are found in the surface.

These results imply that there is an expected increase of total-P in those soils receiving P as inorganic or organic fertilisation. The trend of these increases is in accordance with the amounts of P supplied to the soils, which are 4.5 and 1.7 times greater for treatments HDC and LDC respectively than for IF. Since P was added to the surface (5-6 cm), a migration of P can also be observed from the surface inwards. On the other hand, soil of treatment C suffers an impoverishment of total P during cropping (see Tables 1 and 2).

From Table 2 it can be seen that mean values of organic-P in both surface and subsurface soils treated with compost (treatments LDC and HDC) are higher than those for treatments IF and C. However, due to the large dispersion of the replicate values, this was not substantiated by ANOVA, except for HDC and IF in subsurface soil.

For all the treatments except for C, mean values of organic-P in surface soil are higher than those in the subsurface soil. However, ANOVA showed no significant differences between surface and subsurface organic-P mean values of each treatment.

Nevertheless, comparing mean values of organic-P of the soil used for the experiment before the treatments (Table 1) with the results at the end of the treatments (Table 2), it can be observed that there are slight but noticeable (statistically significant) increases of the mean values of organic-P in soils treated with compost.

For available-P three depths were studied (Table 2). In the surface, mean values of available-P follow the trend IF>HDC>LDC>C, although differences between IF and HDC are not significant. In the subsurface there are no significant differences between mean values for treatments IF, LDC and HDC; furthermore they are significantly higher than the corresponding mean value for the Control. Deeper soil samples (20-30 cm) show a different behaviour: treatments C and HDC show the lowest and highest mean

values respectively, while treatments IF and LDC have similar intermediate mean values.

For all treatments, a decrease in available-P mean values was found with depth, this behaviour being generally substantiated by the ANOVA. It is interesting that mean values of available-P of the Control are lower than that of the initial soil (Tables 1 and 2), possibly due to uptake of P by the crops and the redistribution of part of the more soluble forms of soil phosphorous into less available fractions on account of soil management (e.g., soil homogenization, filling of the pots, watering, etc.) during the experiment. This hypothesis will be expanded on later when discussing fractionation of the soil phosphorus.

From these results it can be deduced that addition of compost to the upper 6 cm of soil causes an increase of available-P throughout the profile compared with the control. At the surface, treatment HDC produces similar effects on availability of P to mineral fertilisation (IF). At the subsurface, the treatments IF, LDC and HDC give similar mean values for available-P, whereas at greater deep it is treatment HDC which gives rise to the highest availability of P. It can be observed that both mineral and organic treatments increase or maintain the initial level of available-P up to 20 cm depth (Tables 1 and 2). Also it is interesting to note that in both mineral and compost treatments, mean values of available-P in soil up to 20 cm, correspond to the level considered 'high' by Thomas and Peaslee (1973), whereas at deeper (20-30 cm), these values are 'low' for treatments IF and LDC, but 'medium' for HDC.

Phosphorus Fractionation

Table 3 shows mean values of the fractionation of P from surface and subsurface soils.

TABLE 3
Fractionation of Soil Phosphorus. Mean Values in mg kg⁻¹.

	depth (cm)	Treatments			
		C	IF	LDC	HDC
F1. Soluble and Exchangeable-P	0-10	5.77 a2	41.3 c2	15.2 a2	24.5 b2
	10-20	3.99 a1	12.2 b1	8.2 ab1	10.0 b1
F2. Aluminium Phosphate-P	0-10	13.3 a1	38.3 b2	33.3 b2	39.1 b2
	10-20	11.9 a1	18.9 bc1	14.4 ab1	21.4 c1
F3. Iron Phosphate-P	0-10	-	-	-	-
	10-20	-	-	-	-
F4. Calcium Phosphate-P	0-10	218 a1	421 c2	315 b2	553 d2
	10-20	188 a1	278 b1	189 a1	290 b1
F5. Occluded Iron Phosphate-P	0-10	7.56 a1	13.2 ab1	53.3 c1	24.6 b1
	10-20	22.5 a2	34.3 ab1	48.0 b1	27.6 a1
F6. Occluded Aluminium Phosphate-P	0-10	3.61 a1	2.80 a1	3.32 a1	3.49 a1
	10-20	3.05	3.30 a1	2.47 a1	3.17 a1
F7. Residual-P	0-10	127 a1	151 ab1	236 ab1	262 b1
	10-20	155 a1	157 a1	262 b1	265 b1

Values followed by the same letter (or number) in the same row (or column) do not differ significantly ($P < 0.05$).

Soluble and exchangeable-P (F1) mean values at the surface follow the trend IF>HDC>LDC>C. In the subsurface, these values decrease and are not significantly different for treatments IF, LDC and HDC, which are higher than that corresponding to the Control.

Mean values for aluminium phosphates (F2) in the surface are not significantly different for IF, HDC and LDC, and these are higher than for C. In the subsurface, aluminium phosphate mean values are lower than in the surface, and follow the trend HDC>IF>LDC>C.

Iron phosphates (F3) are negligible for both surface and subsurface soils of all the treatments.

For calcium phosphates (F4) the following trend is observed in surface soils: $HDC > IF > LDC > C$. In the subsurface, mean values for IF and HDC are similar and higher than for C and LDC, which in turn are also not significantly different.

Occluded iron phosphates (F5) in surface soils follow the trend $LDC > HDC > IF > C$, and in the subsurface $LDC > IF > HDC > C$.

For occluded aluminium phosphates (F6) no significant differences are found between treatments or depths.

Residual- P (F7) in the surface follows the trend $HDC > LDC > IF > C$. In the subsurface, LDC and HDC have similar mean values, which are higher than those for C and IF, which in turn are also not significantly different. Differences between residual- P mean values in surface and subsurface soils for each treatment are not significant.

The Chang and Jackson (1957) fractionation method has been criticised mainly because of the formation of CaF_2 during NH_4F extractions, which frequently leads to the underestimation of fractions F2, F3, F5 and F6, and overestimation of F4 (Syers et al., 1972). This is more pronounced in soils containing iron oxides (Khin and Leeper, 1960; Fite, 1962). In spite of this problem, the method is one of the best known and most used of the fractionation methods. Furthermore, fractionation method reagents generally extract phosphate from chemical linkages other than those specified, and results must therefore be treated with caution (Wild, 1988).

The soil used in the present work has ca. 1.5% iron oxides, as is characteristic of this kind of andalusian calcareous substrate (De la Rosa, 1984), which minimizes the problem pointed out by Syers et al. (1972). Therefore, from the fractionation of P it seems that in general, P added to soil tends to increase all the inorganic fractions of P in the soil, except that bound to iron phosphate (F3) (which is negligible in this calcareous soil) and the occluded aluminium phosphates (F6) (which remain unchanged). This increase is more important in the calcium phosphate fraction (F4), as expected for a soil with 20% of

calcium carbonate. On the other hand, it is worth knowing that fractionation of the soil phosphorus before treatment showed that the mean value of P bound to calcium (160 mg kg^{-1}) is lower than those found later for the Control (218 and 188 mg kg^{-1} at surface and subsurface respectively) (Table 3). However, the value of fraction F1 for the initial soil (14.8 mg kg^{-1}) is higher than those for the Control (5.77 and 3.99 mg kg^{-1} at surface and subsurface respectively) (Table 3). Therefore it seems that part of the more soluble forms of P in the soil shifts to less soluble forms during the experiment.

Comparing the effects of the addition of compost and of inorganic fertiliser to soil, it can be observed that at the end of the experiment the amounts of soluble- and exchangeable- P (F1) in surface soils of treatments LDC and HDC are less than in the surface soil of IF. In the subsurface, mean values are similar for these three treatments. These results show that compost seems to be less effective than the inorganic fertiliser in maintaining high levels of readily available-P in the surface. However, examining Tables 2 and 3 it can be observed that for treatments IF and C. mean values of available-P and fraction 1 (F1: soluble- and exchangeable-P) are statistically equal, but not for LDC and HDC in which available- is higher than soluble- plus exchangeable-P. Also, for the initial soil, similar levels for available-P (17.0 mg kg^{-1}) and fraction 1 (14.8 mg kg^{-1}) were observed. Results of other P fractions cannot explain the above differences between available-P and F1, for treatments LCD and HCD. Therefore fraction F1 seems to account for all the available-P only in those treatments in which organic-P was not added, but not in those treated with compost.

For the calcium phosphate fraction (F4), treatment HDC gives higher mean values in the surface than IF; in the subsurface both treatments give similar results.

Residual- P (F7) increases more in treatments LDC and HDC than in IF both in surface and subsurface soils, indicating that compost introduces a fraction of P which is slowly available.

TABLE 4
Mean Values of Total P in Fruits of Tomato and Eggplant.

	Treatments			
	C	IF	LDC	HDC
	Total P per plant (mg).			
	Tomato			
1st crop	228 a	318 b	375 c	516 d
2nd crop	198 a	320 b	532 c	1119 d
3rd crop	103 a	267 b	326 c	616 d
	Eggplant			
1st crop	113 a	548 c	209 b	547 c
2nd crop	117 a	261 b	316 c	525 d
3rd crop	99 a	114 a	599 b	766 c

Values followed by the same letter in the same row do not differ significantly. (P<0.05).

Plant Phosphorus Uptake

In general, values of phosphorus uptake by plants for the different treatments show similar trends to that found for the available-P of the soils. In fact, Fig. 1 shows that from the first year of treatment, the mean values for total phosphorus content of the aerial part of ryegrass are the highest for treatment HDC and lowest for treatment C, being intermediate for IF and LDC.

Results for horticultural plants (tomato and eggplant), showed a similar pattern. Table 4 shows mean values of total phosphorus content per plant in the fruits, where phosphorus tends to accumulate. In general, total P in fruit follows the same pattern described above for ryegrass and available-P, i.e. HDC>LDC>IF>C, this trend being substantiated by ANOVA.

FIGURE 1. Mean Values of Total P in the Aerial Part of Ryegrass: Δ High Dose of Compost (HDC); $\circ$ Low Dose of Compost (LDC); $\square$ Inorganic Fertiliser (IF); $\diamond$ Control (C) (see text). NSD, Non-Significant Difference ($P < 0.05$).

CONCLUSIONS

The results described in this paper suggest that continuous use of urban compost in a calcareous substrate increases the levels of organic- and available-P of soil, and produces a consequent increase in the uptake of P by plants. Therefore massive compost application can in some cases be an important source of phosphorus for plants. However, this fact cannot justify the agricultural use of compost if at the same time it causes a marked accumulation of undesirable substances (e. g. heavy metals, polynuclear aromatic compounds, lipidic substances) in soils (Cabrera et al., 1989, Murillo et al., 1989b, Gonzalez-Vila et al., 1985, 1988) and plants (Purves, 1972; Purves and Mackenzie, 1973; Giordano et al., 1975, Murillo et al., 1989a).

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