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Cumulative and Residual Effects of Organic Fertilizer Application on Selected Soil Properties, Water Soluble P, Olsen-p and P Sorption Index

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ABSTRACT

Long-term application of fertilizers containing P, especially organic fertilizers, usually increases the water soluble and available P of soil and at the same time may result in P accumulation in soil. Organic fertilizers may also increase movement of P in the soil profile that could result in surface and ground water pollution. An experiment was conducted on field plots that received three applications (25, 50 and 100 Mg ha^{-1}) of solid dairy manure, sewage sludge, or urban solid waste compost, and one application of chemical fertilizers (250 kg ha^{-1} urea plus 250 kg ha^{-1} mono-ammonium phosphate) for 1, 2, 3, 4 or 5 consecutive years in order to investigate the residual and cumulative effects of organic and chemical fertilizers on selected soil properties, water soluble and bioavailable P as well as the P sorption index of the soil. Average organic matter content in the soil increased as a result of organic fertilizer applications. The increase was proportional to the rate of application and was highest for dairy manure and lowest for urban solid compost. Both the water extractable and bioavailable P contents of soil increased with the rate of application, the nature of organic fertilizer and the number (years) of applications, with the rate being the most effective and the nature of fertilizer the least effective. Dairy manure had the largest and solid waste compost the smallest positive impact on both the water soluble and available P content of soil. Effect of sewage sludge application on available P content of the soil was greater than its effect on the water extractable P. The phosphorus sorption index was independent of the source of P (organic or chemical), the nature and the rate of organic fertilizers and was only significantly dependent on the number (years) of fertilizer applications.

Keywords: Bioavailable P, Cumulative effect, Organic fertilizers, Soluble P, Sorption index.

INTRODUCTION

Manure has been recognized as an excellent soil amendment that can improve soil quality and provide nutrients for crop production. Organic fertilizer has been a valuable source of nutrients for crop growth for many years and is usually applied based on the N crop Requirements (Qian *et al*., 2004). Phosphorus in the manure also plays an important role in crop P nutrient (Sims *et al*. 2000; Koopmans *et al*., 2004). When livestock manure is applied to soil for many years, the incorporation of manure P into the soil can lead to an increase in the amount of P available to the crop (Qian *et al*., 2004). Since manure N:P ratio is often smaller than the N:P uptake ratio of most crops and the rates of manure application are based on crop N requirements, P can accumulate in the soil from excess manure P added over several years (Grossal and Inskeep, 1991). This may increase the risk of P loss from the soil system before it is used by subsequent crops (Sims *et al*. 2000; Qian *et al*., 2004). The enrichment of surface water with P may lead to eutrophication and its associated

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adverse effects (Sharply *et al*., 1994). In addition to animal wastes, sewage sludge also provides a readily available alternative to organic N and P fertilizers in agriculture (Sims *et al*., 2000; Qian *et al*., 2004).

Although P in organic wastes is present in both organic and inorganic forms that display a complex continuum of solubility, several researche studies have suggested that the water-extractable inorganic P provides a simple indicator of the potential release of dissolved P into the agricultural run off system (Sharply *et al*., 1994). Increased availability of P following the addition of organic manure has been attributed to the production of organic acids during the decomposition of the manure. These acids can form stable complexes with Fe and Al and consequently block available P retention sites (Rowell, 1994).

A one-point P sorption index (PSI) as described by Bach and Williams (1971) is the amount of P sorbed from a single addition of 1.5 g P kg^{-1} soil and is positively correlated with P sorption capacity. Several studies have indicated that PSI is reduced by application of poultry litter and cattle feed lot waste (Mozaffari and Sims, 1994; Qian *et al*., 2004).

The objective of this study was to determine the cumulative and residual effects of a long-term (5-year) application of three different organic fertilizers and one rate of chemical fertilizer on *i*) water-extractable P, *ii)* bioavailable P, and *iii)* P sorption capacity (PSI) of a calcareous soil.

MATERIALS AND METHODS

A five-year field experiment was conducted at Isfahan University of Technology Research Station located near Isfahan, Iran (32° 32' N; 51° 23' E). The average annual rainfall and temperature at the study site are 140 mm and 14.5°C, respectively. The soil is a fine-loamy, mixed, thermic, Typic Haplargid with clay loam texture, pH= 8.3, organic carbon (OC)= 4.6 g kg^{-1} and Olsen-P= 10 mg kg^{-1}. The experiment consisted of three organic fertilizers as solid dairy manure (DM), sewage sludge (SS) and urban solid waste compost (UC) each at 25, 50 and 100 Mg ha^{-1} (dry-weight basis), one rate of chemical fertilizers as 250 kg ha^{-1} urea plus 250 kg ha^{-1} mono-ammonium phosphate (CF) ($N= 232.5\ kg\ ha^{-1}+P= 42.5\ kg\ ha^{-1}$) and the control (no fertilizer). The fertilizers were spread evenly on each plot and were incorporated into surface (0-30 cm) soil by hand. The experimental plots were 3×15 m in the first year and were divided into two uneven plots (3 ×3 and 12× 3 m) in the second year; the larger plots were again divided into uneven plots (3×3 and 9×3 m) in the third, fourth (3×3 and 3×6 m) and fifth (3×3 and 3×3 m) years. Each year the smaller portion of the newly divided plots was left unfertilized so that after 5 years we had plots that had received the above treatments 1, 2, 3, 4 or 5 times. Each treatment was replicated three times.

After five years, surface (0-30 cm) composite soil samples were collected from all the plots, air-dried, gently crushed to pass a 2 mm sieve and stored for chemical analyses. Organic carbon in the soil samples and organic fertilizers was determined by the method described by Walkley and Black (1934), soil pH was determined both in water and 0.01 M $CaCl_2$ suspensions at a soil to solution ratio of 1: 2.5 (Rowell, 1994), electrical conductively (EC_e) in the soil saturated extraction (Allison and Modie, 1994) and calcium carbonate equivalent by titration with acid (Allison and Modie, 1994). Water extractable phosphorus (WEP) was extracted by shaking a 2 g sub-sample of soil with 20 mL of de-ionized water for one hour, the suspension was then centrifuged at 2,190 RCF for 15 minutes and passed through a Whatman No.42 filter paper (Murphy and Riley, 1962). Plant-available P was extracted by shaking a 1 g sub-sample of soil with 20 mL of 0.5 M $NaHCO_3$ (pH=8.5) for 30 minutes (Watanabe and Olsen, 1965). Phosphorus sorption index (PSI) was calculated from the quotient $x/\log c$ (x, the amount of P sorbed

Table 1. Selected properties of organic fertilizers.

	pH	EC (dS m^{-1})	OC (%)	N (%)	C/N	P (%)
DM [a]	8.60	17.00	25	1.20	20.58	0.75
UC [b]	7.80	14.70	15.69	1.30	11.77	0.30
SS [c]	6.40	9.40	18.02	1.90	9.41	2.10

[a] Dairy manure; [b] Urban compost, [c] Sewage sludge.

and *c*, the equilibrium P concentration) following the addition of 1.5 g P kg^{-1} (KH_2PO_4) (Bach and Williams, 1971). PSI was determined by shaking a 1 g sub-sample of soil with 40 mL of a solution containing 37.5 mg L^{-1} of P as KH_2PO_4 for 40 hours (Bach and Williams, 1971). The suspensions were centrifuged at 2,190 RCF and then filtered through a Whatman No.42 filter paper and P concentration was measured in the filtrate.

Water and bicarbonate extracts were analyzed for their P concentration spectrometrically by the molybdate-blue method of Murphy and Riley (1962). Selected properties of the organic fertilizers used in this experiment are given in Table 1. Experimental data were subjected to a standard analysis of variance according to a split-plot design. Statistical analyses were performed using SAS software (SAS Institute, 2001).

RESULTS AND DISCUSSION

Soil Properties

In this paper we refer to the residual effects for those plots that received fertilizers for 1, 2, 3 or 4 consecutive years and to the cumulative effects for the plots that received fertilizers for the entire five years of the experiment. Application of organic fertilizers had a significant effect on soil pH. Soil pH varied between 7.8 and 8.3 depending on the rate, the number of applications, and the treatment type (Table 2). Values of pH-H_2O were about 0.5-1.0 unit higher than those of pH-$CaCl_2$ indicating the effect of high Ca^{2+} activity on decreasing carbonate solubility. Whalen *et al*. (2000) reported that effects of manure on soil pH depend on the manure source and soil characteristics.

Application of SS had the greatest effect on soil pH, especially at the 100 Mg ha^{-1} application rate, when applied for 5 consecutive years, and CF the smallest effect. The higher cumulative effect of SS on soil pH was probably due to the lower initial pH of SS as compared to the UC and DM (Table 1) and, possibly, the release of a higher amount of organic and inorganic acids upon oxidation of SS. Other studies have also found a significant decrease in soil pH with organic fertilizer application (Tunney, 1981; Eghball, 1999; Clement, 2003). Chang *et al*. (1990) reported that soil pH in the top 15 cm of a calcareous soil (pH 7.8) amended with cattle manure annually for 11 consecutive years decreased by 0.3 to 0.7 units, and the decrease was greater in plots receiving three times the recommended rates for manure application. Decrease in soil pH may also be attributed to the production of carbonic acid and nitrification of NH_4^+ released from mineralization of organic fertilizers in the soil (Chang *et al*., 1991). They reported a 0.3 to 0.7 unit decline in the pH of a calcareous soil (pH 7.8) in the top soil following eleven years of cattle manure application. This decrease was attributed to the nitrification of NH_4^+ as well as the organic acid produced during the decomposition of the organic fraction of the manure. Differences in pH were not, however, significant for one- and two-year applications of the fertilizers as compared to the control, probably because of the high carbonate content and buffering capacity of the soil. Similar results have been reported by Tunney (1981).

The electrical conductivity (EC_e) of the plots amended with fertilizers increased significantly as compared to the control (Table 2) probably due to the soluble salt content of fertilizers and the release of organic and inorganic soluble species such as NO_3^-. The magnitude of the increase was proportional to the rate of applications and the number of years that fertilizers were applied, and was largest for DM and smallest for CF probably as a result of the differences in the initial EC of fertilizers (Table 1).

Cation exchange capacity (CEC) varied between 9.83 and 22.1 $cmol_c$ kg^{-1}. Application of both chemical and organic fertilizers significantly increased the CEC of soil as compared to the control (Table 2). The largest increase in CEC was observed in the plots receiving 100 Mg ha^{-1} SS for five consecutive years. Increase in the negative charge or CEC of soil, as the result of organic fertilizer application, has been reported by several researchers (Bergkvist *et al*., 2003; Qian *et al*., 2004). The cumulative effect of SS on CEC of the soil was larger than DM and DM was larger than UC at 100 Mg ha^{-1}. The effect of chemical fertilizer application on CEC was probably due to the higher yield of corn and wheat and, consequently, the higher plant residue that was returned to the soil.

Effects of treatments on the organic carbon (OC) content of the soil are shown in Figure1. Application of both chemical and organic fertilizers significantly increased the OC content of soil as compared to the control. The increase was much larger for organic fertilizers (especially at higher rates) and was mainly proportional to the rate and the number of applications. The type of fertilizer was only slightly effective on the OC content of soil at the higher rates. The difference between the residual and cumulative effects was much more pronounced at the higher rates, possibly indicating a limited potential of the soil microorganisms to mineralize added organic matter in a given time. The effect of chemical fertilizer was probably due to the higher yield of corn and wheat and a higher plant residue return to these plots.

At 25 Mg ha^{-1} rate, small differences were observed between the type of organic fertilizer and the number of applications with regard to the OC content of soil. At the higher rates, however, the differences between the treatments, particularly the cumulative effects, were greater. At a 100 Mg ha^{-1} rate, the residual effect of SS application was smaller and its cumulative effect was larger than DM and UC. It also seems that the cumulative effect of DM on soil OC content was somewhat larger than SS, and SS was larger than UC at the 25 and 50 Mg ha^{-1} rates. Cumulative and residual effects of treatments on OC content of the plots depended on the OC content and the nature of the organic matter in the organic fertilizers. Five year averages for OC content of DM, SS and UC treatments were 250, 180 and 157 g kg^{-1}, respectively (Table 1).

Water Extractable Phosphorus (WEP)

Residual and cumulative effects of organic fertilizers application on water extractable P (WEP) is shown in Figure 2. All the experimental factors affected WEP levels. Application of DM had a greater cumulative effect, especially at the 100 Mg ha^{-1} rate and a smaller residual effect, especially at the 25 Mg ha^{-1} rate on WEP as compared to UC treatment. The SS treatment indicated an intermediate effect in this respect. The larger effect of DM on WEP at the higher rate is likely due to the higher organic matter content of DM as compared to SS and UC (Table 1). Water soluble P increased from 2.5 mg kg^{-1} in the control to as high as 26 mg kg^{-1} in the plots receiving 100 Mg ha^{-1} DM for

Table2. Effect of treatments on some soil chemical properties.

Treatment rate (T ha^{-1})	Application no.	pH (water)	pH ($CaCl_2$)	ECe (dS m^{-1})	$CaCO_3$ (%)	CEC ($cmol_c$ kg^{-1})
Control		8.1	7.4	2.1	37.7	9.8
		Urban compost				
25	1	8.3	7.4	2.7	35.2	10.9
	2	8.2	7.4	3.1	35.1	11.3
	3	8.2	7.3	3.1	34.6	11.9
	4	8.1	7.3	3.2	34.1	12.3
	5	8.1	7.3	3.5	33.9	14.6
50	1	8.3	7.5	2.9	36.8	11.2
	2	8.3	7.5	2.8	35.8	11.5
	3	8.2	7.4	3.3	35.4	11.9
	4	8.2	7.4	3.5	36.5	12.5
	5	8.2	7.3	3.8	36.4	14.6
100	1	8.1	7.5	2.9	37.3	11.7
	2	8.2	7.5	2.9	36.2	11.9
	3	8.1	7.4	3.1	35.8	12.2
	4	8.1	7.3	3.5	33.5	17.9
	5	7.9	7.3	4.2	34.2	17.8
		Sewage sludge				
25	1	8.1	7.4	2.2	35.3	10.5
	2	8.1	7.3	2.8	33.2	10.9
	3	8.1	7.3	3.1	33.5	11.2
	4	7.9	7.2	3.8	32.4	13.5
	5	7.9	7.2	4.3	30.2	16.8
50	1	8.1	7.4	2.9	37.2	11.4
	2	8.1	7.4	3.1	35.5	12.5
	3	7.9	7.3	3.5	34.5	12.8
	4	7.7	7.3	3.8	34.3	16.5
	5	7.8	7.2	4.1	34.1	18.4
100	1	8.1	7.5	3.8	36.2	12.5
	2	8.1	7.4	3.5	35.8	13.5
	3	8.1	7.3	3.3	35.5	16.5
	4	7.9	7.2	4.5	33.5	17.5
	5	7.8	7.1	4.7	30.2	22.1
		Dairy manure				
25	1	8.2	7.4	2.9	35.5	11.2
	2	8.2	7.4	3.1	35.2	12.3
	3	8.1	7.3	3.3	34.5	12.9
	4	8.1	7.3	3.3	33.5	14.5
	5	7.9	7.2	3.8	32.1	16.2
50	1	8.3	7.5	3.2	37.7	11.9
	2	8.3	7.5	3.3	37.9	12.5
	3	8.2	7.4	3.5	37.9	13.9
	4	8.1	7.3	3.8	36.5	14.5
	5	8.1	7.3	4.4	35.6	16.1
100	1	8.3	7.5	3.8	37.5	12.7
	2	8.2	7.5	4.1	37.2	13.5
	3	8.2	7.4	3.9	36.8	15.5
	4	8.1	7.3	4.5	36.2	16.8
	5	7.9	7.2	5.3	34.5	18.5
		Chemical fertilizer				
	1	8.3	7.5	2.5	37.5	11.2
	2	8.2	7.4	2.8	37.4	11.3
	3	8.1	7.3	3.1	37.5	12.5
	4	8.2	7.3	3.2	37.2	11.6
	5	8.1	7.4	4.2	36.2	12.8
LSD*		0.1	0.1	0.1	0.1	0.1

[*] $P< 0.05$ (LSD test).

five consecutive years. The high WEP in plots treated with 100 Mg ha^{-1} DM for 5 consecutive years show possible P movement to the ground water. The water soluble P is affected by the solubility of P minerals in the soil. Manure application may alter the composition of soluble and exchange ions in the soil and, possibly, the nature and formation of minerals in the solid phase that control P solubility in soil solution (Paul *et al*., 2003). Grossl and Inskeep (1991) reported that dicalcium phosphate dehydrate (DCPD) precipitation is inhibited by the presence of organic acids such as humic, fulvic, citric, and tannic acids. They postulated that organic acid molecules are adsorbed onto the DCPD surface blocking the sites for crystal growth. Harris *et al*. (1994) studied surface horizons in areas with intensive dairy operations and suggested that manure components, specifically organic acids, Mg, and Si, can inhibit crystallization of stable Ca-P minerals, resulting in high P solubility in these soils. Kalbasi and Karthikeyan (2004) incubated soil samples with untreated and Ca-treated liquid dairy manure for up to two years and reported relatively large increases in both the WEP and Bray-1 P of soils. The increase was proportional to both the rate of application and the background P content of the soils. Application of organic material to soil may also increase the P solubility of soluble carbon compounds competing with P for sorption sites (Paul *et al*., 2003). Mineralization of organic P may also release P into the soil solution, contributing to the observed high water soluble P content with a high P manured soil.

Bioavailable P (Olsen-P)

Residual and cumulative effects of organic fertilizer application on bioavailable P (Olsen-P) are shown in Figure 3. Both chemical and organic fertilizers increased bioavailable P in the soil. The increase was proportional to the rate of application and was much larger for the SS and DM treatments compared with the UC treatment. The effect of chemical fertilizer was similar to UC treatment; the residual and cumulative effects of SS and DM treatments were also similar especially for 50 and 100 Mg ha^{-1} rates. Olsen-P reached 200 mg kg^{-1} for the highest rate of DM or SS after five consecutive applications indicating a very high potential for environmental concern. Heckrath *et al*. (1995) believe that Olsen-P above 60 mg kg^{-1} raises a high level of environmental concern. The higher effect of SS and DM on Olsen-P of soil was probably due to the higher OM and/or P contents of these two fertilizers compared to the UC treatment (Table 1) as well as to the differences in the nature of organic matter resulting from differences in their production procedures. UC undergoes composting process during which most of easily oxidizable organic compounds is removed from compost. DM and SS, on the other hand, were not composted and probably contained organic materials that could release organic acids upon oxidation after addition to the soil. Organic acids and other soluble organic compounds are capable of competing with P for adsorption sites and may even coat adsorption and precipitation sites. Paul *et al*. (2003) suggested that organic fertilizer may increase P solubility by the production of organic acid or humic substances that compete with adsorption P sites and result in a higher concentration of P in the soil solution, mixed with manure, compost or sewage sludge (Olsen *et al*., 1954; Tran and Yegamiye, 1995). The effect of SS application on Olsen-P content of soil was greater than its effect on the water extractable P (Figures 2 and 3). Adding organic fertilizers to the soil can increase water extractable and bioavailable soil P by direct addition, dissolution, displacing sorbed P, or reducing sorption capacity for P (Paul *et al*., 2003). The effect of liquid DM on bioavailable P was also reported by Kalbasi and Karthikeyan (2004). They found

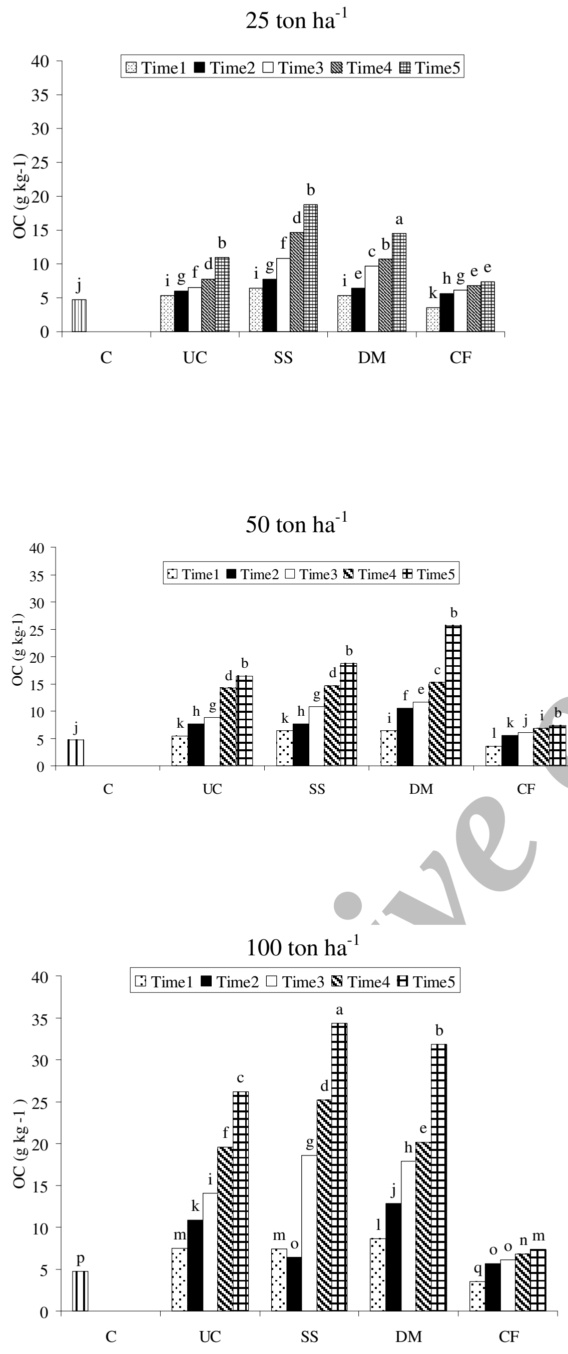

Figure 1. Residual and cumulative effects of organic fertilizers on soil organic carbon. Treatments with different letters are significantly different at 5% level.

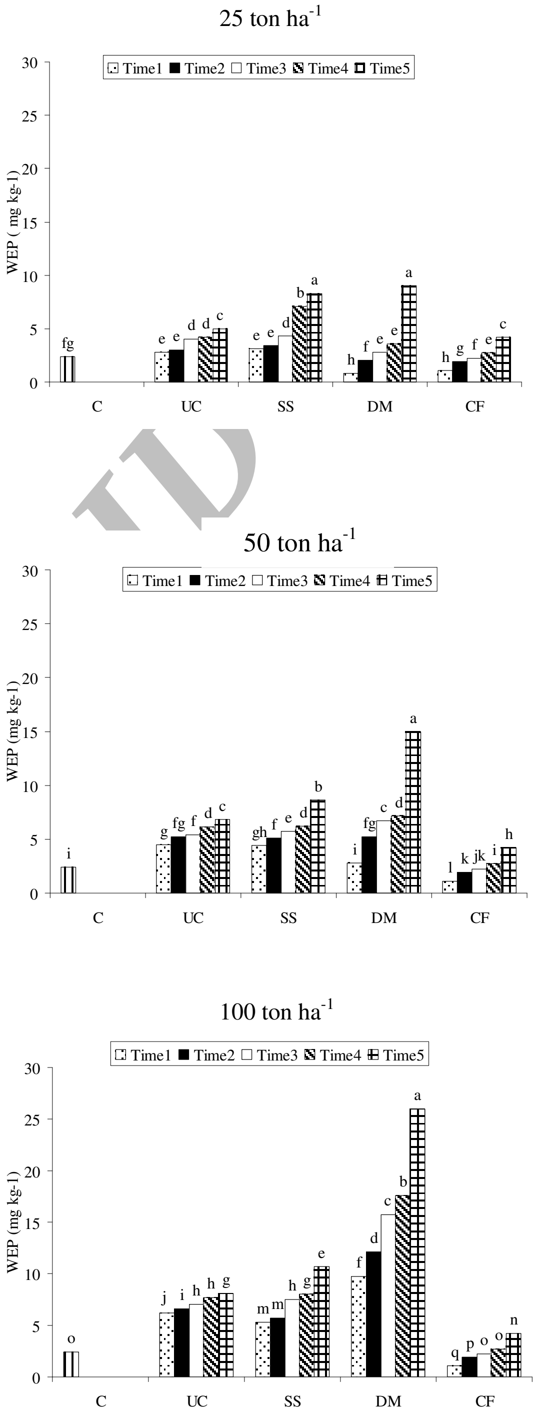

Figure 2. Residual and cumulative effects of organic fertilizers on water extractable P. Treatments with different letters are significantly different at 5% level.

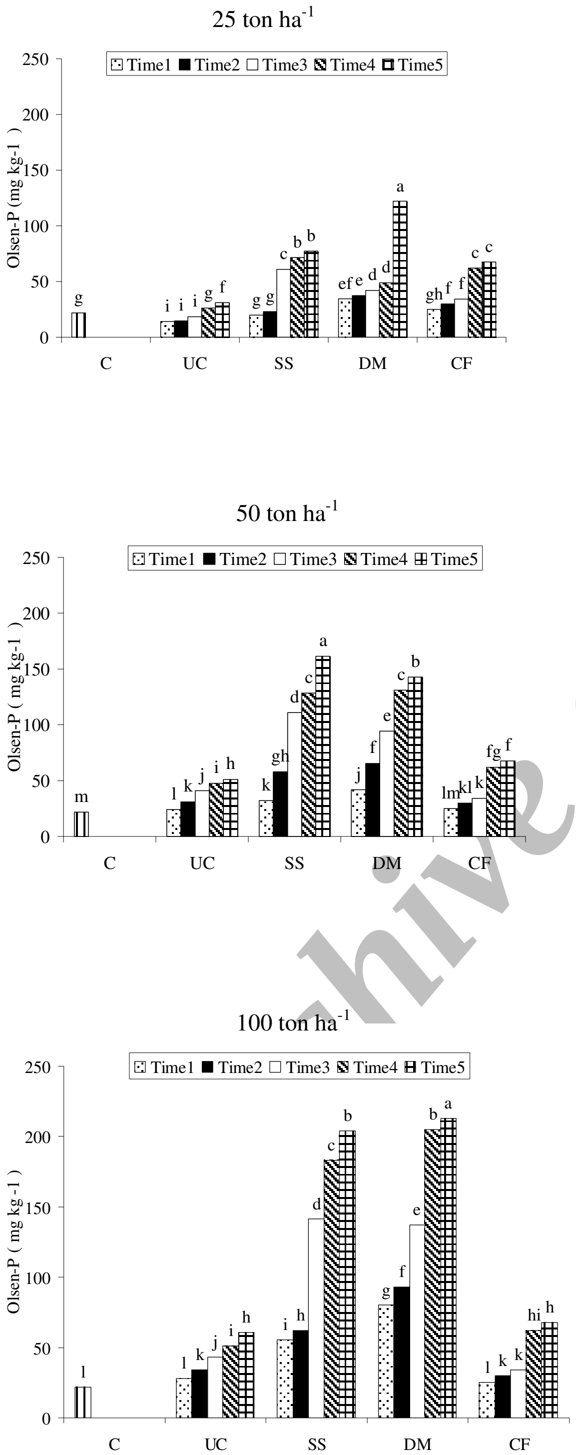

Figure 3. Residual and cumulative effects of organic fertilizers on Olsen-P. Treatments with different letters are significantly different at 5% level.

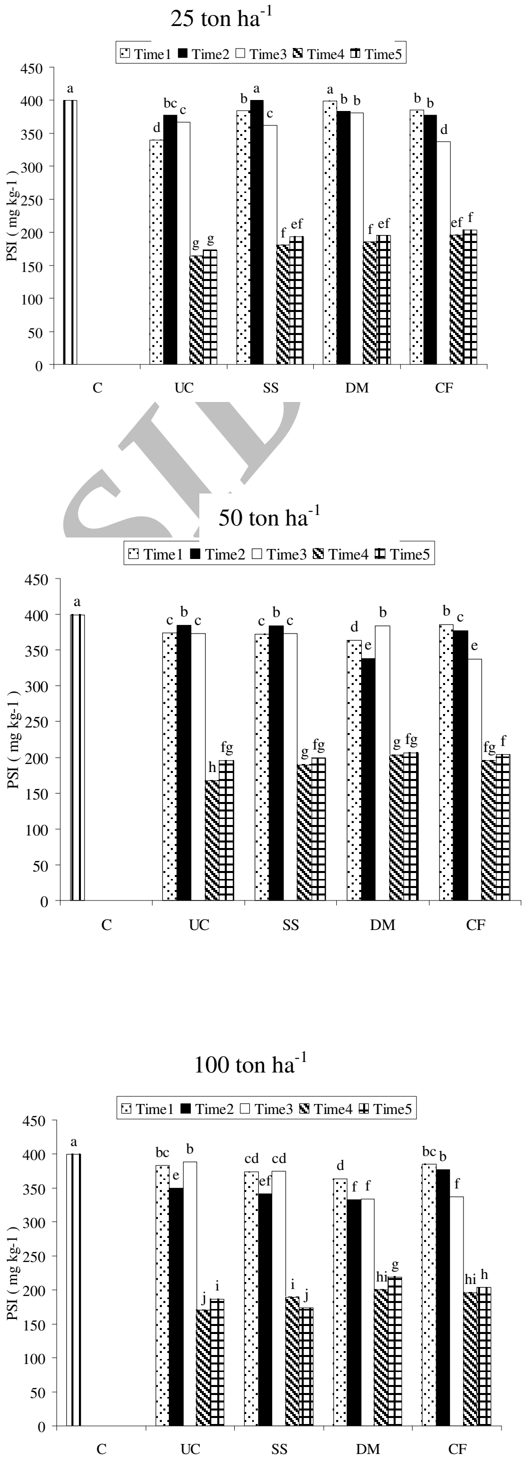

Figure 4. Residual and cumulative effects of organic fertilizers on PSI. Treatments with different letters are significantly different at 5% level.

that Bray-1 P increased when soils were amended with both untreated and Ca-treated manure and decreased when amended with Al- and Fe-treated manure.

Phosphorus Sorption Index (PSI)

The effects of the organic and chemical fertilizers application on the P sorption index (PSI) of the soils are shown in Figure 4. PSI was almost independent of the source of P (organic or chemical), the nature and the rate of organic fertilizers and was only significantly dependent on the number of years (times) the fertilizers were applied. PSI was significantly lower in the plots receiving fertilizer applications for longer periods of time (over 4 and 5 consecutive years) compared to those receiving them for shorter periods (over1, 2, and 3 years). This may be due to the saturation of the adsorption and fixation sites with P as suggested by McKenzie *et al*., (1992).

Since chemical fertilizer decreased PSI in a similar manner to organic fertilizers, it may be concluded that organic matter did not affect PSI directly but that the P released from these fertilizers decreased PSI. Another conclusion that may be drawn is that the effect of P fertilizers on PSI is time-related and lasts for a certain period of time (two years in this experiment). This may be due to the uptake of the sorbed P by plants or precipitation of the sorbed P as an independent mineral during the 2-year period that had passed since the last fertilizer application.

CONCLUSIONS

Application of organic fertilizers increased organic carbon, and the water extractable and bioavailable P content of soil. The residual and cumulative effects of organic fertilizer applications depended on the rate, the number of years, and the type of organic fertilizers applied. Consecutive applications of high rates of organic fertilizers, specifically dairy manure or sewage sludge, can increase the risk of surface and ground water pollution. The phosphorus sorption index (PSI) was independent of the source, the nature and the rate of P fertilizers and was only significantly dependent on the number of years (times) the fertilizers were applied.

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اثرات تجمعی و باقیمانده کاربرد کودهای آلی بر برخی ویژگی های خاک، فسفر محلول، فسفر قابل دسترس و شاخص جذب فسفر

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چکیده

کاربرد طولانی مدت کودهای فسفره بویژه کودهای آلی حاوی فسفر معمولاً باعث افزایش فسفر محلول و فسفر قابل دسترس خاک شده و ممکن است منجر به انباشت فسفر در خاک شود. کودهای آلی همچنین ممکن است حرکت فسفر در نیمرخ خاک را تسهیل نموده و باعث آلودگی منابع آب زیرزمینی شود. یک آزمایش مزرعه ای بر روی کرتهایی که سه سطح (۲۵، ۵۰ و ۱۰۰ مگاگرم بر هکتار) کود گاوی، لجن فاضلاب یا کمپوست زباله شهری و یک سطح کود شیمیایی (۲۵۰ کیلوگرم اوره به اضافه ۲۵۰ کیلوگرم فسفات آمونیوم در هکتار) را برای ۱، ۲، ۳، ۴ یا ۵ سال متوالی دریافت نموده بودند به منظور مطالعه اثرات تجمعی و باقیمانده کودهای مذکور بر بعضی خصوصیات خاک، فسفر محلول در آب، فسفر قابل دسترس گیاه و شاخص جذب فسفر، انجام شد. میانگین مقدار ماده آلی خاک با کاربرد کودهای آلی افزایش یافت و مقدار افزایش برای کود گاوی بیشترین و برای کمپوست زباله کمترین و با سطح کاربرد کود متناسب بود. مقدار فسفر محلول در آب و فسفر قابل دسترس گیاه با سطح کاربرد کود و سالهای کاربرد افزایش یافت و به نوع کود کاربردی نیز وابسته بود. بیشترین اثر بر فسفر محلول و فسفر قابل دسترس مربوط به سطح کاربرد و کمترین اثر مربوط به نوع کود بود. کود گاوی بیشترین و کمپوست زباله کمترین اثر مثبت را بر فسفر محلول و فسفر قابل دسترس داشتند. اثر کاربرد لجن فاضلاب بر فسفر قابل دسترس بیشتر از اثر آن بر فسفر محلول بود. شاخص جذب فسفر مستقل از منبع کود (شیمیایی یا آلی)، نوع کود آلی و سطح کاربرد کود آلی و تنها به تعداد سالهای کاربرد کود وابسته بود.