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The effects of sulfur, cattle, and poultry manure addition on soil phosphorus

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Abstract: Use of organic manures for soil amendment has gained renewed attention with growing concerns about sustaining soil productivity. A greenhouse study was carried out to determine the influence of different soil amendments, namely poultry manure (PM), cattle manure (CM), and sulfur (S), on soil P status. The application rates were 0, 4, and 8 t ha^{-1} for PM; 0, 20, and 40 t ha^{-1} for CM; and 0, 0.75, and 1.5 t ha^{-1} for S treatments. Individual additions of PM and CM unlike S significantly affected phosphorus (P) concentrations in soils. The highest Olsen P and total P (TP) were with the highest PM (8 t ha^{-1}) and CM (40 t ha^{-1}) treatments. The addition of PM increased Olsen P to 59.2 mg kg^{-1} and TP to 761 mg kg^{-1}. For the CM treatments, the highest Olsen P (66.5 mg kg^{-1}) and TP (713 mg kg^{-1}) concentrations were with the highest CM treatments (40 t ha^{-1}). While PM additions decreased the bioavailability factor, CM increased it. Increasing S treatments decreased soil pH (8.0 to 7.8) but not statistically significantly. Application of S significantly increased EC (801.6 to 1163.4 µs cm^{-1}). While the applications of CM increased shoot P concentrations unlike root P concentrations, PM and S did not significantly influence plant shoot or root P concentrations. Plant shoot P concentration was higher compared to root P concentration as expected due to the transformation of P from root to shoot. Poultry manure had no effect on plant length or weight. However, they were significantly increased by increasing additions of CM and S. The study indicated that CM addition is more effective on soil Olsen P and plant P concentrations as well as plant growth compared to PM and S. There are controversial results in the literature depending on the nature of amendments, plant systems, and specific soil properties. Therefore, more research is needed on manure as a soil amendment.

Key words: Soil amendments, Olsen P, total P, bioavailability, plant P concentration

1. Introduction

Soil total phosphorus (TP) concentration ranges from 100 to 3000 mg P kg^{-1}. However, solution P content in agricultural soils is between 0.01 and 3.0 mg P L^{-1} (Frossard et al., 2000). When there is an insufficient soil solution P, application of inorganic and/or organic P fertilizers becomes necessary for optimal crop production. The efficiency of P fertilizer is low, and in the year of application, around 20% of the applied P is taken up by the crop and the remaining large amounts become insoluble and chemically bound (residual-P), unavailable to plants (Subba Rao et al., 1995). Excessive application of manures or fertilizer P to agricultural land can accelerate concentrations of soil P to levels above those needed for optimum crop production and can cause accumulations of P in soils (Ajiboye et al., 2004). Accelerated soil P results in high P losses from soils through leaching, runoff, and erosion, which in turn have adverse environmental effects such as eutrophication (Simard et al., 2001). Besides concern about water pollution, P is also a nonrenewable resource. Therefore, instead of continued application of high soluble fertilizer P to soils to meet plant requirements, P use efficiency should be maximized by increasing the desorption and availability of soil TP. Researchers studied different soil amendments such as biosolids and manure to increase soil P desorption and availability. Soil P sorption is influenced by soil organic matter through the process of soil organic matter/metal complexes, inhibition of polymerization and crystallization of metals, and competitive sorption (Hiradate and Uchida, 2004). Hosseinpur and Pashamokhtari (2013) studied the effects of biosolids on P desorption properties and P availability. They found that soil P availability was increased by biosolids addition, while P desorption was negatively influenced by soil organic matter. Sui and Thompson (2000) reported that biosolid amendments significantly increased desorption of P from soil and increased P availability. Leytem et al. (2005) reported that P retention in manure-

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amended calcareous soils was increased by organic C due to stable complexes with P. Reddy et al. (1980) reported that P desorption was increased by increasing the addition of swine lagoon effluent.

Elemental sulfur (S) as a soil amendment is generally used as a standard acidulant added to soil for pH reduction (Slaton et al., 1999). Upon the oxidation of S, sulfuric acid occurs and attacks insoluble calcium bounded P minerals and converts them into soluble and plant available P forms (Arai and Sparks, 2007). Jaggi et al. (2005) reported that the pH of alkaline soil was decreased by the addition of elemental S.

Long-term P management strategies should focus on residual-P availability to crops more than ever. Although many researchers have investigated the influence of soil amendments on P availability/extractability, there are controversial results in the literature depending on the nature of amendments, plant systems, and specific soil properties.

Our objective was to determine the influence of different soil amendments (poultry manure (PM), cattle manure (CM), and S) on soil P status.

2. Materials and methods

2.1. Soil and manure materials

To establish a greenhouse experiment, soil was collected from 0 to 20 cm depth of Ikizce series on Harran Plain at the Harran University research area in Eyyübiye Campus, Şanlıurfa, Turkey. The clay surface soil was air dried and crushed to pass a 2-mm stainless steel sieve for use in the pots. Original soil samples were kept in plastic bags at room temperature for analysis. Some physical and chemical properties of the soil are given in Table 1. The concentrations of Olsen P and TP are given in Table 2.

Pots were wrapped with a cellophane bag to prevent free drainage, and 1 kg of air-dried soil was weighed and mixed with treatments in the pots. The treatments were 0, 4, and 8 t ha^{-1} for PM; 0, 20, and 40 t ha^{-1} for CM; and 0, 0.75, and 1.5 t ha^{-1} for S. A total of 27 treatment combinations were assigned in the factorial experiment with a completely randomized design with three replications. The gravimetric moisture content of each pot was adjusted to 20% with deionized water. After a 7-day incubation period, samples of the soil were taken and retained for analysis. After the incubation period, 12 seeds of wheat (*Triticum durum*) per pot were planted. From emergence to harvest, with distilled water, each pot was watered daily and twice per week 100 mL of Hoagland's nutrient solution (Sonmez et al., 2009) was given to pots. Plant populations were lowered to 6 plants per pot 2 weeks after seeding.

After 50 days of growth under greenhouse conditions, the plants were harvested. To eliminate sticking soil particles, plant materials were washed with deionized water. Plant height and fresh and dry plant yield were determined.

Dried plant samples were ground to pass through a 2-mm sieve for further laboratory analysis and digested with a sulfuric acid/hydrogen peroxide digest in preparation for analyses of P (Linder and Harley, 1942). Analysis was done by using an inductively coupled plasma (ICP-OES) spectrometer.

Before seedling and after harvest, samples of soil were taken from the pots for analyses. The soils were analyzed for texture according to Bouyoucos (1951), for pH and electrical conductivity (EC) in 1:1 soil to water ratio with a combination of pH and EC electrodes, and for cation exchange capacity (CEC) and organic matter (OM) by the methods of Sumner and Miller (1996) and Walkley and Black (1934), respectively. Samples were extracted with 0.5 M $NaHCO_3$ (pH 8.5) and extractable inorganic P was measured calorimetrically in an aliquot of this extract (Olsen et al., 1954). The TP was digested with perchloric acid and determined calorimetrically by ascorbic acid blue

Table 1. Some physical and chemical properties of soil prior to treatment application (0–30 cm).

	pH	OM (%)	CEC (cmol kg^{-1})	Total P (mg kg^{-1})	Olsen P (mg kg^{-1})	$CaCO_3$ (%)	Sand (%)	Silt (%)	Clay (%)
Soil	7.85	0.9	49	627.9	37.9	11.5	24	26	50

Table 2. Phosphorus concentrations in poultry manure and cattle manure.

Manure	Total P (mg kg^{-1})	Water extractable P (mg kg^{-1})
Poultry	17850.4	2856.5
Cattle	3602.3	520.5

color method (Sommers and Nelson, 1972). Bioavailability factor (BAF) is calculated by the division of Olsen P by TP and multiplied by 100 (Bioavailability Factor ((Olsen P/Total P) × 100). Quality assurance-quality control (QA-QC) included 12% of samples run as blanks, and duplicates for each extraction.

2.2. Data analyses

The data were analyzed by using the Statistical Analysis System (SAS for Windows version 8.2, SAS Inc., Cary, NC, USA). The general linear model was used for mean separations when significant interactions were present. The main effects were compared using least significant difference (LSD) values at probabilities of 0.05 or less.

3. Results and discussion

There was no significant interaction among PM, CM, and S treatments on Olsen P or TP. However, individual additions of PM and CM, unlike S, significantly affected P concentrations in soils (Table 3). The addition of 8 t ha^{-1} PM increased Olsen P to 59.2 mg kg^{-1} and TP to 761 mg kg^{-1}, which were significantly higher than other PM treatments (Table 3). Nonzero CM treatments had a significantly higher Olsen P in soil compared to the control. The highest Olsen P (66.5 mg kg^{-1}) and TP (713 mg kg^{-1}) concentrations were with the highest CM treatments (40 t ha^{-1}). However, soil TP concentration was not significantly influenced by CM additions (Table 3). While PM additions decreased BAF, CM increased it. This means the portion of Olsen P in TP increased with increasing CM additions.

Elgala et al. (1998) and Brashi et al. (2003) reported that the addition of CM increased soil Olsen P. Sharpley et al. (1984) observed that inorganic and organic fractions of P were increased in soils receiving feedlot manure. Iyamuremye et al. (1996) found that P availability was increased by the application of organic residues because of a decrease in P sorption by soils. This might be due to a complexation of fixation sites by P originating from organic residues. Opala et al. (2012) also reported an increase in the availability of P with time was because of microbially mediated mineralization of soil organic P to form inorganic P.

The reason for increasing soil available P could be the high inorganic P concentrations of PM and CM used in our study. However, this elevation of soil available P was not so great compared to contents of PM and CM. That might be attributed to the adsorption process to soil clay complex or precipitation as calcium phosphate since the soil used in our study was an alkaline soil. Prior to treatment applications, water-soluble and TP concentrations of PM and CM were determined (Table 2). PM had a higher water-soluble P compared to CM; however, soil that received CM treatments had higher values of soil P availability than PM. This could be because of higher phytate content of PM compared to CM since there is a strong negative correlation between manure phytate content and bicarbonate extractable P (Leytem et al., 2006)

Increasing S treatments decreased soil pH. The pH was lowered from 8.0 to 7.8 with the addition of 1.5 t ha^{-1} S, but it was not statistically significant. However, EC was significantly increased by the application of S (Table 4). Soil EC was elevated from 801.6 to 1163.4 µs cm^{-1} with the highest S treatment (1.5 t ha^{-1}). El-Fayoumy and El-Gamal (1998) found that soil pH was decreased by the addition of S. However, Tang (1999) reported that upon organic amendment increase in soil pH was due to the rapid proton (H^+) exchange between the soil and the organic amendments. Soaud et al. (2011) reported that the EC of two out of three tested soils was increased by S applications.

Upon additions of S, a decrease in soil pH is an expected result in the soil environment because of the formation of sulfuric acid (Arai and Sparks, 2007). Additions of PM and CM did not change soil pH or EC. This could be due to increasing soil buffering capacity by PM and CM additions. Dikinya and Mufwanzala (2010) reported that

Table 3. Treatment effects on soil extractable P (Olsen P) and total P.

Poultry manure (t ha^{-1})	Olsen P	Total P	BAF (%)	Cattle manure (t ha^{-1})	Olsen P	Total P	BAF (%)	Sulfur (t ha^{-1})	Olsen P	Total P	BAF (%)
	------(mg kg^{-1})----				------(mg kg^{-1})----				------(mg kg^{-1})----		
0	54.6b	677.9b	8	0	46.8c	696.2a	6	0	50.7a	715.7a	7
4	54.6b	678.2b	8	20	54.9b	708.8a	7	0.75	50.6a	700.2a	7
8	59.2a	761.9a	7	40	66.5a	713.0a	9	1.5	51.8a	702.1a	7
F-test	**	**		F-test	**	NS		F-test	NS	NS	

*, **, NS show statistical significance 0.05, 0.01, nonsignificant, respectively.
BAF: Bioavailability factor ((Olsen P/Total P) × 100).

Table 4. Treatment effects on pH and EC.

Sulfur (t ha^{-1})	pH	EC (µs cm^{-1})
0	8.0a	801.6c
0.75	7.9a	992.1b
1.5	7.8a	1163.4a
F.test	NS	**

*, **, NS show statistical significance 0.05, 0.01, nonsignificant, respectively.

applications of PM (5%, 10%, 20%, and 40%) did not have any effect on soil pH or EC.

CM was the only amendment having a significant effect on plant shoot P concentrations (Table 5). Increasing the addition of CM increased shoot P concentrations from 2985 mg kg^{-1} to 3452 mg kg^{-1}. The highest shoot P concentration was with the highest CM treatment, while it had no effect on plant root P concentrations (Table 5). The applications of PM and S were not significantly effective on plant shoot P and root P concentrations. The plant shoot P concentration was higher compared to the root P concentration as expected due to the transformation of P from root to shoot.

PM had no effect on plant length or weight. However, they were significantly increased by increasing additions of CM and S (data not shown). Manure is not only a source of nutrients but also an effective mobilizing agent due to the complexation of soil Fe and Al and blockage of P adsorption sites by organic acids (Kelling, 2004). Reddy et al. (2000) found that the application of manure increased P uptakes and yields of wheat and soybean due to improved soil physical, chemical, and biological properties as well as provision of plant nutrients by the addition of manure that enhanced plant growth.

4. Conclusions

Individual additions of PM and CM, unlike S, significantly affected P concentrations in soils. The highest Olsen P and TP were with the highest PM (8 t ha^{-1}) and CM (40 t ha^{-1}) treatments. The application of PM increased Olsen P to 59.2 mg kg^{-1} and TP to 761 mg kg^{-1}. The highest CM treatments (40 t ha^{-1}) had the highest Olsen P (66.5 mg kg^{-1}) and TP (713 mg kg^{-1}) concentrations. While PM additions decreased BAF from 8% to 7%, CM increased it from 6% to 9%. This means the portion of soil Olsen P in TP increased with increasing CM additions. Although increasing S treatments decreased soil pH (8.0 to 7.8), this decrease was not statistically significant. The addition of S increased EC (801.6 to 1163.4 µs cm^{-1}), while plant shoot P concentrations were only influenced by applications of CM. The highest CM treatment had the highest shoot (3452 mg kg^{-1}) and root P (2016 mg kg^{-1}) concentrations. PM and S treatments did not have any effects on shoot or root P concentrations. Plant shoot P concentration was higher compared to root P concentration as expected due to the transformation of P from root to shoot. PM had no effect on plant length or weight. However, they were significantly increased by increasing additions of CM and S.

Table 5. Treatment effects on shoot and root P concentrations.

Poultry manure (t ha^{-1})	Shoot P	Root P	Cattle manure (t ha^{-1})	Shoot P	Root P	Sulfur (t ha^{-1})	Shoot P	Root P
	-------(mg kg^{-1})-----			-------(mg kg^{-1})-----			-------(mg kg^{-1})-----	
0	3280a	1897a	0	2985b	1797a	0	3041a	1860a
4	3268a	1928a	20	3330ab	1849a	0.75	3323a	1904a
8	3227a	1836a	40	3452a	2016a	1.50	3403a	1899a
F-test	NS	NS	F-test	**	NS	F-test	NS	NS

*, **, NS show statistical significance 0.05, 0.01, nonsignificant, respectively.

Our study indicated that CM addition is more effective on soil Olsen P and plant shoot P concentrations as well as plant growth compared to PM and S. There are controversial results in the literature depending on the nature of amendments, plant systems, and specific soil properties. Therefore, more research is needed on manure as a soil amendment.

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