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Effects of organic manure on solubility and mobility of different phosphate fertilizers in two paddy soils*

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Abstract

The solubility and mobility of three phosphate fertilizers [superphosphate (SP), Ca-Mg phosphate (Ca-Mg-P) and diammonium phosphate (DAP)] with or without combination of farmyard manure (FYM) and/or farmyard manure juice (FYMJ) in two paddy soils (Ultisol and Entisol) from the Zhejiang Province of China were determined. Incubation experiments were conducted under controlled greenhouse conditions in the Institute of Agricultural Chemistry, Bonn University, Germany. The results showed that water soluble P and Olsen P in both the application band and the adjacent zones (10 and 20 mm from the application band) was highest with DAP, and lowest with Ca-Mg-P. Both FYM and FYMJ increased water soluble P (100–300%) and Olsen P (80–300%) for the application band in both soils. Moreover, the combination of FYM significantly increased water soluble P and Olsen P for the adjacent zones (20 mm for the Ultisol and 10 mm for the Entisol), but such effects were not significant in combination with FYMJ. Consequently, the main effect of FYM is due to organic substances from decomposition rather than organic compounds in the FYMJ. Also, the combination of FYMJ with SP and DAP significantly increased the pH value in the application band. The pH in the adjacent zone (10 mm) was slightly increased by the combination of FYM with each of three P fertilizers. The solubility and mobility of phosphate in soils differed greatly among phosphate fertilizers. The combinations of organic manure with mineral phosphate fertilizers increased solubility and mobility of phosphate in both paddy soils, especially in the Ultisol.

Introduction

In China, more than 60 % of the arable soils are P deficient and need application of P fertilizers for optimum crop yields. In paddy soils, application of P fertilizers is necessary for crops growing in winter/spring season and also for the late rice plant. The utilization efficiency of P fertilizers is generally very low, especially in Ultisol, as acid soils are notorious for their ability to fix soluble P. To reduce P fixation, combination of mineral P fertilizer with organic manure is recommended (Ni et al., 1990). Confirming results of Formoli and Prasad (1979) and Pratt and Laag (1981) where in long-term field experiments available P in the soil increased after the application of organic manure. Thangudu et al. (1981) reported that available P in an acid soil significantly increased after amendments of organic matter. The utilization of mineral P fertilizer was shown to be higher when applied in combination with organic manure (Singh et al.,1983). In addition, the positive effect of organic matter, which produces organic acids during decomposition in soils, on the efficiency of mineral P fertilizers should be taken into consideration.

The objective of this study was to examine the influence of farmyard manure and juice of farmyard manure on the solubility and mobility of three main P fertilizers i.e. superphosphate (SP), calcium magnesium phosphate (Ca-Mg-P) and diammonium phosphate (DAP) in two paddy soils distributed widely in the southeast of China.

* This paper is dedicated to Professor Xi Sun.

Materials and methods

Incubation experiments were conducted with two types of paddy soils (Ultisol and Entisol) obtained from rice field of Zhejang province, P.R. China. Selected chemical properties of the two soils are shown in Table 1. Fresh pig manure was collected from a farm in Germany, immediately dried at 100°C and ground to pass through 2-mm sieve. Farm yard manure juices were obtained from fresh farmyard manure by using a machine which can squeeze juices out (pressed out). The mineral fertilizers of SP and DAP were bought from Germany, while that of Ca-Mg-P obtained from China. Water soluble P (fertilizer:water = 1:10) were 174.57 and 74.46 mg P g^{-1} fertilizer for DAP and SP, respectively; and 7.9, and 1.94 mg P g^{-1} manure for FYM and FYMJ (D.W.), respectively. P content extracted by 2% citric acid was 42.86 mg P g^{-1} fertilizer for Ca-Mg-P.

The treatments included three P fertilizers (SP, DAP and Ca-Mg-P) and the combinations of three mineral fertilizers with farmyard manure (FYM) and farmyard manure juice (FYMJ), respectively. Each treatment had four replications. Fertilizer application rates were 42 kg P ha^{-1}. Each treatment received the same quantity of water soluble P and/or citric acid extractable P in fertilizers and the manure except the treatment of mineral fertilizer (MF) plus FYM 2, in which manure P was not included in total P application rate in order to prove if the mobility of P in the soils is caused by P concentration gradient. The combination ratio of MF-P to FYM-P or FYMJ-P was 1:1 for the treatments of MF combined with FYM or FYMJ.

Prior to addition of MF and FYM, soil samples were air dried and passed through a 2-mm sieve. One kg of soil per pot (13 × 7 × 7 cm) and band (10mm) application method were adopted. P fertilizer was dissolved in deionized water and then mixed thoroughly with the soils and/or FYM within the band. Nylon net (=0.5 μm) was used to seperate the application band from the adjacent zone. The soil moisture was maintained at 60% of field water-holding capacity by weighing the pots every day. Water was added to the bottom of pots through the plastic tubes (1.8 cm) which were inserted in the pots (two tubes per pot). The incubation experiment was undertaken in a temperature-controlled greenhouse at 25°C/19°C day/night. All pots were covered with a plastic sheet to prevent water evaporation from soils. After 30 and 60 days incubation, soil samples (0–10, 11–20, 21–25 mm distance from the application band to the adjacent zone) were taken, air dried, and passed through a 1-mm sieve before analysis.

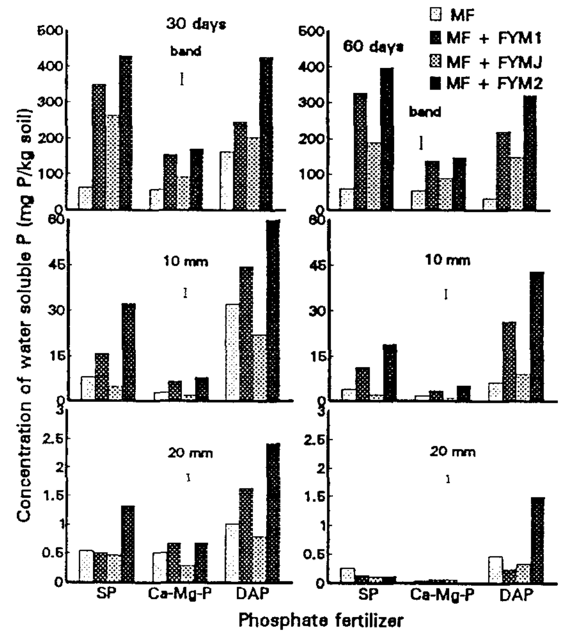

Fig. 1. Effects of farmyard manure and farmyard manure juice on water soluble P concentrations in application bands and adjacent zones (10 and 20 mm) after 30 and 60 days incubation in the Ultisol. The bars depict LSD ($\rho < 0.05$). MF = mineral fertilizer; MF + FYM1 = mineral fertilizer combined with farmyard manure; MF + FYMJ = mineral fertilizer combined with farmyard manure juice; MF + FYM2 = mineral fertilizer combined with farmyard manure in which P content in the FYM was not included in the total application rate; SP = superphosphate; Ca-Mg-P = calcium and magnesium phosphate; DAP = diammoniumphosphate.

Water soluble P was extracted by shaking the suspension for 2h using soil/water ratio of 1:2.5, and available P was extracted with 0.5 *M* $NaHCO_3$ (1:20, soil:extract) for half an hour. Phosphorus concentration in the extracts was analyzed by molybdate blue colorimetric method. Soil pH was measured using soil:water ratio 1:2.5. As it has been demonstrated that Olsen-P is better correlated with plant P uptake for paddy soils compared to Bray I and EDTA-P etc. (He et al., 1988), we used Olsen-P procedure for measuring soil available P in the present study.

Results

1. Water soluble P in different zones among the treatments:

Obvious differences in water soluble P for both the application band and adjacent zone were observed

Table 1. Agrochemical properties of the two paddy soils

soil type	pH (H_2O)	Clay content (%)	O.M. (%)	Total N (%)	Olsen-P (mg/kg soil)	Water solu.P (mg/kg soil)	Exch.K[a]
Ultisol	6.0	45.3	2.9	0.16	15.4	0.08	14.0
Entisol	6.5	46.3	5.1	0.21	23.7	0.25	21.7

[a]exchangeable K: extracted by 1.0 *N* NH_4Ac (pH 7.0).

in the Ultisol among the three phosphate fertilizers after 30 days incubation, with the following sequence: DAP>SP>Ca-Mg-P (Fig. 1). The combination of each of the three mineral P fertilizers with FYM resulted in a significant increase in water soluble P for both the application band and adjacent zone (up to 20 mm) compared to the application of mineral fertilizers alone. This indicated that FYM increased both the solubility and mobility of all the three P fertilizers applied to the soil. However, the combination of FYMJ had less effects on water soluble P levels for adjacent zone although it had positive effects for the application band. Comparison of water soluble P among the treatments after 30 days incubation with that after 60 days incubation demonstrated that water soluble P levels were much lower for the latter than for the former, especially in the adjacent zone. Mobility of the phosphate applied to the soil occured mainly in first 30 days, and water soluble P had been immobilized during another 30 days incubation.

Results obtained from the Entisol showed similar tendency to those from the Ultisol (Fig. 2). The combinations of FYM with DAP or Ca-Mg-P significantly increased water soluble P for both the application band and the adjacent zone (up to 10 mm), whereas the combination of FYM with SP increased the water soluble P only for the application band with less effect on the adjacent zone. The combinations of FYMJ with each of the three P fertilizers increased water soluble P for the application band, but not for the adjacent zone. For this soil, the immobilization of water soluble P during another 30 days incubation was not so marked as was for the Ultisol, showing that the solubility and mobility of P in the Entisol could be maintained for longer period.

2. Available P in different zones among the treatments

In the Ultisol, available P levels were significantly higher in the treatments of mineral P fertilizers combined with FYM for both the band and adjacent zone (up to 10 mm) than those of mineral P fertilizers alone (Fig. 3). The combinations of mineral P fertilizers with FYMJ had no such obvious effects on the adjacent zone. Unlike water soluble P, available P levels of all treatments for the adjacent zone were slightly increased after 60 days incubation compared to those after 30 days incubation (Fig. 3). Significantly higher available P levels for the application band and adjacent zone (up to 10 mm) were also observed in the treatments of DAP + FYM and Ca-Mg-P + FYM for the Entisol (Fig. 4). However, the combinations of FYM with SP increased available P only for the application band. FYM had no effect on the mobility of SP in this soil. The combinations of FYMJ increased available P for the application band but not for the adjacent zone.

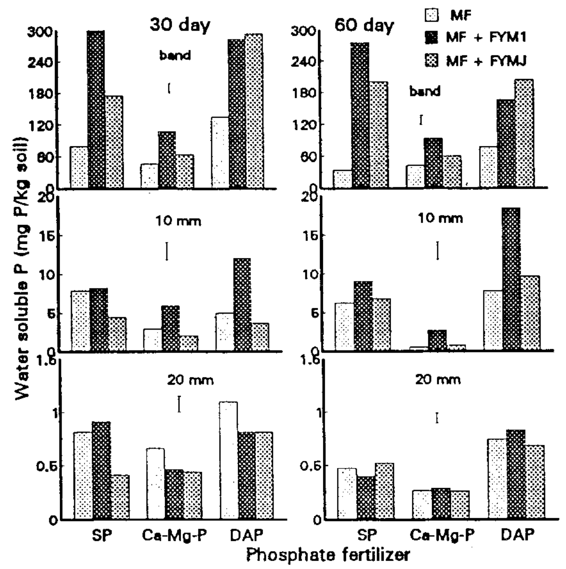

Fig. 2. Effects of farmyard manure and farmyard manure juice on water soluble P concentrations in application bands and adjacent zones (10 and 20 mm) after 30 and 60 days incubation in the Entisol. The bars depict LSD ($\rho < 0.05$). All other symbols are same as Figure 1.

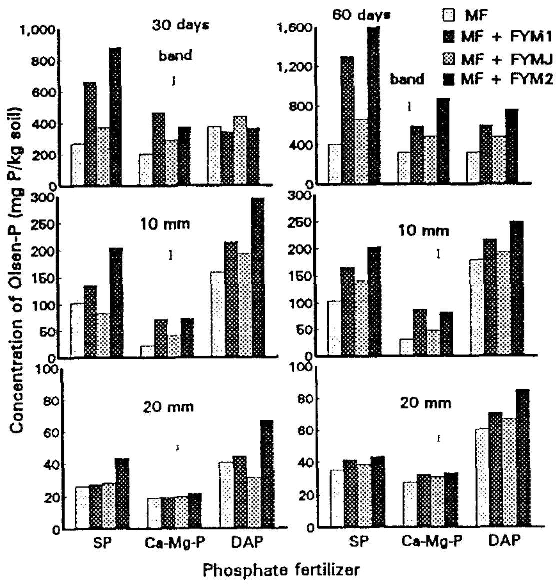

Fig. 3. Effects of farmyard manure and farmyard manure juice on Olsen-P concentrations in the application bands and adjacent zones (10 and 20 mm) after 30 and 60 days incubation in the Ultisol. The bars depict LSD ($\rho < 0.05$). All other symbols are same as Figure 1.

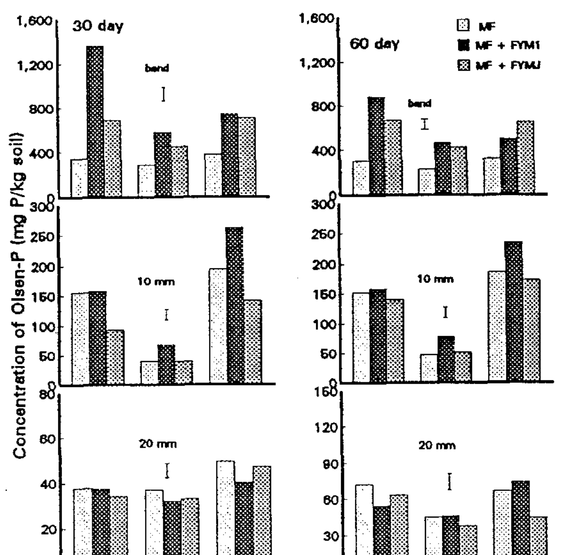

Fig. 4. Effects of farmyard manure and farmyard manure juice on Olsen-P concentrations in the application bands and adjacent zones (10 and 20 mm) after 30 and 60 days incubation in the Entisol. The bars LSD ($\rho < 0.05$). All other symbols are same as Figure 1.

3. Soil pH in different zone among the treatments

pH values of the application band were higher than those of the adjacent zone among all the three P fertilizers, especially for Ca-Mg-P (Table 2). The combinations of FYM with SP and DAP increased pH values of the application band in both soils. However, pH changes in the adjacent zone in the combination of FYM were not statistically significant. As for Ca-Mg-P, the combinations of FYM tended to decrease pH of the application band and increased pH of the adjacent zone (10 mm). However, the combinations of FYMJ had no such effects.

Discussion

Because of the strong adsorption of phosphate by amorphous iron and aluminium oxides, the efficiency of P fertilizers is generally very low in acid soils (Scherer and Werner, 1992). However, long-term field experiments have showed that combinations of FYM with mineral P fertilizers increased available P levels in soils (Singh et al., 1983) and crop yields (Ni et al., 1990) compared to the application of mineral P fertilizer alone. Numerous reports indicated that an important reason for the increase in available P by organic manure incorporation may be due to the decrease in P adsorption and fixing capacity of soils by organic manure (Amberger and Amann, 1984; Frossard et al., 1986; Meek et al., 1979; Reddy et al., 1980; Werner, 1990). A study of P sorption by Scherer and Werner (1992) showed that the concentration of water soluble P was higher in the treatment of triplesuperphosphate (TSP) combined with FYM than that of TSP application alone. According to these authors, larger amounts of dissolved organic carbon in the application band of TSP/FYM treatment as well as in the adjacent zone from the band decreased P adsorption capacity in soils. Similarly, the combination of mineral P fertilizer with FYM significantly increased water soluble P and available P in the adjacent zone in the present investigation (Figs. 1–4). However, FYMJ had little effect, showing that the organic substances produced during decomposition of FYM were responsible for the decrease in P sorption by either forming stable complexes with Al and Fe, thus, eliminating retention sites for P (Sah and Mikkelsen, 1989) or by blocking sorption sites for P through sorption of the organic anions. Citrate and oxalate may decrease P adsorption (Earl et al., 1979; He et al., 1990; Kafkafi et al., 1988). Similar effects have also been observed by other researchers(Sah and Mikkelsen, 1986; 1989; Singh and Jones, 1976). In addition, the recovery rate of applied ^{32}P fertilizer in the soil solution was remarkably increased by the appli-

Table 2. Changes of pH values in different zones among the treatments in the Ultisol and Entisol after 30 and 60 days incubation

Treatment	Ultisol				Entisol			
	30 days		60 days		30 days		60 days	
	Band	10 mm	Band	10 mm	Band	10 mm	Band	10 mm
SP	5.14	5.09	5.69	5.11	5.41	5.44	5.69	5.43
SP + FYM1	6.30	5.58	6.34	5.29	6.44	5.91	6.16	5.30
SP + FYMJ	5.88	4.94	5.82	4.82	5.87	5.29	5.35	5.55
SP + FYM2	6.18	5.43	6.17	4.98				
Ca-Mg-P	8.23	5.05	7.98	4.98	7.67	5.56	7.89	5.56
CaMg-P+FYM1	7.78	5.43	7.35	5.41	7.63	5.70	7.37	5.69
CaMg-P+FYMJ	8.05	5.54	7.97	5.24	7.87	5.48	7.76	5.67
CaMg-P+FYM2	8.00	5.74	7.70	5.46				
DAP	5.72	5.21	4.68	4.60	5.50	5.08	5.14	4.88
DAP + FYM1	6.37	5.41	6.82	4.85	6.63	5.24	6.20	5.30
DAP + FYMJ	5.99	5.15	5.12	4.85	6.24	5.15	5.58	4.87
DAP + FYM2	6.50	5.37	6.00	4.73				
$LSD_{5\%}$	0.18	0.64	1.07	0.43	0.31	0.30	0.77	0.23

* All the values are the means of 4 replications; LSD = least significant difference ($\rho < 0.05$). SP = superphosphate, Ca-Mg-P = calcium and magnesium phosphate, DAP = diammoniumphosphate, FYM1 = farmyard manure in which P content included in the total application rate, FYMJ = farmyard manure juice in which P content included in the total application rate, FYM2 = farmyard manure in which P content did not included in the total rate.

cation of aliphatic acids (Amann and Amberger, 1988). The results of Hue (1991) indicated that carbohydrates or cellulose could be adsorbed by clay minerals, thus masking sorption sites for P. Consequently, the efficiency of P fertilizers could be increased if they are applied together with organic manure like FYM or green manure.

In the present study, it was shown that the combinations of FYM with mineral P fertilizer not only increased the solubility of P fertilizers but also increased the mobility of P in soils, especially for the Ultisol (Figs 1,2), which may result from increased P desorption and P concentration gradient in soils due to the amendament of farmyard manure. Organic acids such as citric acid were found to be effective in desorbing P from surfaces of clay minerals and soils by ligand exchange (He et al., 1992). The activity of soil enzymes as well as the number of microorgansims decomposing organic-bound P were increased by organic manure amendments (Lou, 1992; Martens et al., 1992) thus stimulating the transformation of non-available to soluble P. The difference between the two soils may be attributed to their differences in organic matter and sesquioxide content and clay mineral composition (Kuo and Mikkelsen, 1979; Zhang et al., 1993a; 1993b).

As P adsorption and desorption by soil clays depend much on pH (He et al., 1989; 1990; Nanzyo and Watanabe, 1981; Strasser and Werner, 1991), enhanced effects of FYM on solubility and mobility of phosphate fertilizer may be also related, to some extent, to pH changes in the application band and adjacent zone. Reaction products of water-soluble P fertilizers in noncalcareous soils can only be found in the fraction of adsorbed P (Werner, 1970), where the intensity of adsorption depends mainly on soil pH (Barrow, 1985). This could be demonstrated in the present investigation that the concentrations of water soluble P in the application band and adjacent zone of DAP was higher than those of SP (Figs. 1, 2) with lower pH (Table 2). Similar results were observed by Werner and Strasser (1992), in which DAP and triplesuperphosphate were compared.

In conclusion, the combinations of organic manure with mineral phosphate fertilizers could significantly enhance the solubility and mobility of P in soil, thus increasing pant-availability of both fertilizer and indigenous P, particularly in the high P fixation capacity soils.

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