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Integration of organic and inorganic P sources for improving P use efficiency in different soils

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Abstract

Efficiency of phosphorus in our soils is low. Present investigation was undertaken to assess the effect of organic (green manure (Sesbania), farmyard manure (FYM), poultry manure, press mud) and inorganic (DAP) amendments of P on three different soils. In a green house trial different efficiency fractions (agronomic efficiency (AE), physiological efficiency (PE) and recovery percentage (PR %)) of P were calculated. Farmyard manure was added @ 10 g kg^{-1} soil and other organic amendments of P were applied with respect to the carbon (C) contents of FYM. Chemical P as DAP was added to supply 35 mg P kg^{-1} soil. Treatments were equilibrated in triplicates. The dry matter production, P concentration and P uptake over control, were significantly increased in maize shoot by the integrated application of organic and inorganic P amendments. Regarding evaluation of various efficiency fractions of maize, agronomic efficiency and apparent P recovery rendered statistically more pronounced effects of integrating organic and inorganic P amendments over separate application of DAP. Similarly, agronomic efficiency, physiological efficiency and P recovery % of organic amendments of P, proved more efficient as compared to DAP. Results indicated that integration of organic amendments of P with inorganic source was significantly better over the separate use of DAP. Nevertheless, P application in all the soils, either separately or in integrated form, improved agronomic parameters of maize, and P uptake.

Keywords: Phosphorus, organic manure, maize, P efficiency, calcareous soils

Introduction

Phosphorus is one of the major plant nutrients. It contributes to plant biomass production as a macronutrient (Goldstein *et al.,* 1988). In the zone of alkaline calcareous soils, there is a two-pronged problem regarding the supply of plant available P. On one side, there is the problem of scarce supply of chemical P fertilizers (due to price hike and depletion of natural P reserves) and on the other side fixation of P in alkaline calcareous soils. Generally, the soluble P reacts with soil components to form relatively insoluble compounds (Sayin *et al.,* 1990). Therefore, in many cropping environments, its availability to plants is very low. Nevertheless, many soils have large reserves of total P, often hundred-time more than the P available to crops (Al-Abbas and Barber, 1964). About 80 to 90% soils from arid and semiarid regions of the world are deficient in available P (Memon *et al.*, 1992; NFDC, 2001). Attempts to alleviate nutrient deficiency by adding fertilizer is becoming an increasingly uneconomical and ecologically unsound practice, as the efficiency of the added P is as low as about 10 % (Werft and Dekkers, 1996). Our soils are alkaline (pH > 7.0) and mostly calcareous ($CaCO_3$ > 3.0 %) in nature. Calcareous soils fix added P due to reaction of P ions with $CaCO_3$. It is evident from the perusal of different studies, pertaining to recycling of organic wastes (Industrial or agricultural), that addition of these wastes to soils may increase the efficiency of applied and native nutrients required by plants. Therefore, the use of organic materials as fertilizers for crop production has received attention for sustainable crop productivity (Naeem *et al.,* 2009). Green manure crops may convert relatively unavailable native and residual P to chemical forms, which are more available after decomposition. This process produces CO_2, which forms H_2CO_3 in soil solution, resulting in the dissolution of primary P-containing minerals. Organic acids released during decomposition also help to dissolve soil mineral P. In soils with high P-fixing capacities, organic compounds released during decomposition processes may increase P availability by coating P adsorption sites or via anion exchange. Repeated incorporation of green manures can decrease soil bulk density and increase soil aggregation and moisture retention. All these factors may also help to increase P uptake by increasing root and mycorrhizal growth (Cavigelli and Thien, 2003).

Muhammad and Khattak (2009) mentioned that the yields of various crops including maize and millet showed substantial increases with press mud applications that were attributed to the improvement in soil physical, chemical and biological conditions. Therefore, judicious and efficient use of the existing land, nutrient fertilizers, financial resources

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and recycling of organic wastes is inevitable. In such circumstances, this study was designed to obtain knowledge regarding P uptake by maize plants from different organic and inorganic amendments of P, applied in different soils, separately or in integrated form.

Materials and Methods

Bulk surface (0-15 cm) samples were collected for the three soils from Chakwal and Gujranwala areas. The samples were air-dried and ground to pass through a 2 mm sieve. The soils were analyzed for texture, pH, ECe, extractable K, Olsen P, solution P, organic matter (OM), calcium carbonate and total iron contents (Table 1) following the standard procedures as described by US Salinity Lab. Staff (1954).

Table 1: Physico-chemical properties of the experimental soils

Parameter	Soil-I	Soil-II	Soil-III
Soil colour	Dull yellowish brown	Brownish grey	Brownish grey
Sand (%)	74	52	68
Silt (%)	11	22	14
Clay (%)	15	26	18
Textural class	Sandy loam	Sandy clay loam	Sandy loam
pH	7.74	7.29	7.88
ECe (dS m^{-1})	0.63	1.17	0.59
Extractable K (mg kg^{-1})	60.0	100.0	130.0
Organic matter (%)	0.62	1.03	0.41
Olsen P (mg kg^{-1})	6.65	10.65	5.26
Solution P (mg L^{-1})	0.012	0.031	0.010
$CaCO_3$ (%)	4.06	2.12	5.5

Five kg prepared soil was filled in glazed pots. Soil in pots was moistened with excess amount of water. At field capacity, the pots were emptied and soil was remixed thoroughly. This process was repeated thrice to obtain equilibrium (Rahmatullah *et al.,* 1994). Then various treatments were imposed in triplicate using green manure (*Sesbania*), farmyard manure, poultry manure, press mud and inorganic (Diammonium phosphate) amendments of P (Table 2).

Table 2: Nitrogen, P and K status of amendments

Organic amendments	N	P	K
	%		
Poultry manure	2.13	0.98	1.11
Press mud	1.83	0.93	0.32
Farmyard manure	1.06	0.26	0.74
Green manure (*Sesbania*)	0.66	0.22	0.46

Diammonium phosphate was applied to supply 35 mg P kg^{-1} soil while organic sources of P were added @ 10 g kg^{-1} or equivalent to their carbon content basis. The experiment was conducted with factorial setup according to completely randomized design. Maize (cv. Pak Hybrid-7222) was sown and four uniform plants per pot were allowed to grow after germination. Moisture contents in pots were maintained with distilled water at about 60 % of the water-holding capacity throughout the growth period of plants.

Plant sample preparation and P analysis

Olsen's P determination

Blank and standards were prepared with 10 ml of 0.5 M $NaHCO_3$ solution and intensity of blue colour was measured as absorbance of light (λ (wavelength) = 882 *nm*) using method 54a of US Salinity Lab. Staff (1954) on spectrophotometer (Kuo, 1996).

Beneficial effects of integrated use of organic P amendments (Green manure, farmyard manure, poultry manure and press mud) and DAP on maize growth and P uptake were assessed by calculating following parameters according to Mengel and Kirkby (2001).

Agronomic Efficiency (g g^{-1}) =
(Yield F - Yield C) / Fertilizer P applied
Physiological Efficiency (g mg^{-1}) =
(Yield F - Yield C) / P uptake F - P uptake C
Apparent P Recovery =
((P uptake F - P uptake C) / Fertilizer P applied) x 100
Where, F = Fertilizer applied
C = Control (without fertilizer)

Statistical analysis

The data obtained were statistically analyzed using software MSTAT-C (Russel and Eisensmith, 1983) for analysis of variance (ANOVA). Duncan's Multiple Range (DMR) test was applied to separate the significant treatment means (Steel and Torrie, 1980).

Results

Texture of the soils I and III was sandy loam while soil- II was sandy clay loam. The three soils were alkaline in reaction (pH, 7.29 to 7.88), calcareous (2.12 - 5.5 % $CaCO_3$) and non-saline (EC_e, 0.59 to 1.17 dS m^{-1}). Soil I and soil III were deficient in organic matter contents but soil II had 1.31% organic matter. Extractable K ranged from 60 to 130 mg kg^{-1} and Olsen P varied from 5.26 to 16.65 mg kg^{-1} soil.

Table 3: Effect of various organic and inorganic amendments on agronomic parameter and P Uptake by maize in calcareous soils

Treatment	Shoot Dry Matter (g pot^{-1})				P Concentration (%)				P Uptake (mg pot^{-1})			
	Soil-I	Soil-II	Soil-III	Mean	Soil-I	Soil-II	Soil-III	Mean	Soil-I	Soil-II	Soil-III	Mean
Control	14.38	16.44	11.03	13.95	0.113	0.125	0.095	0.111	16.25	20.55	10.48	15.76
GM	17.38	18.63	13.22	16.41	0.121	0.129	0.111	0.120	21.03	24.03	14.67	19.91
FYM	17.64	18.86	13.67	16.72	0.127	0.136	0.125	0.129	22.40	25.65	17.09	21.71
PM	20.50	21.52	14.93	18.98	0.128	0.140	0.127	0.132	26.24	30.13	18.96	25.11
P mud	18.08	18.72	13.01	16.60	0.124	0.131	0.124	0.126	22.42	24.52	16.13	21.02
DAP	20.83	21.89	15.73	19.48	0.136	0.145	0.135	0.139	28.33	31.74	21.24	27.10
GM + DAP	23.13	24.69	17.49	21.77	0.140	0.153	0.138	0.144	32.38	37.78	24.14	31.43
FYM+DAP	23.68	24.91	18.16	22.25	0.145	0.166	0.150	0.154	34.34	41.35	27.24	34.31
PM+DAP	26.16	29.79	23.36	26.44	0.175	0.205	0.261	0.214	45.78	61.07	60.97	55.94
Pmud+DAP	21.37	24.49	18.13	21.33	0.167	0.140	0.154	0.154	35.69	34.29	27.92	32.63
Mean	20.32	21.99	15.87		0.138	0.147	0.142		28.49	33.11	23.88	
LSD Soil	0.3090				0.0183				0.6140			
LSD Tr	0.5642				0.0334				1.1209			
LSD Soil x Tr	0.9773				0.0579				1.9415			

Shoot growth

There were significant *(P < 0.05)* main and interactive effects of application of various amendments and soils on shoot dry matter (SDM) production (Table 3). All the amendments produced significantly more SDM over control. Application of DAP produced significantly higher SDM. On an average, it increased the SDM by about 40 % as compared to control. Among organic amendments, poultry manure proved to be the best. The relative increase in SDM by the application of poultry manure was 36 % as compared to control. Combined application of DAP with various organic amendments produced significantly (P < 0.05) more SDM. Maximum SDM (26.44 g pot^{-1}) was obtained by the combined application of DAP and poultry manure. This was 90 % more than control, 36 % more than DAP and 39 % more than separate use of poultry manure. The tested soils also differed significantly *(P < 0.05)* with respect to SDM production. Soil-II produced maximum (21.99 g pot^{-1}) SDM followed by Soil-I (20.32 g pot^{-1}) and Soil-III (15.87 g pot^{-1}) in descending order. Interactive effect of various amendments and soils also increased SDM production with integrated use of organic and inorganic amendments. Maximum (111 %) increase in SDM over control was observed in Soil-III when poultry manure and DAP were applied in integrated form.

Phosphorus concentration

There were significant *(P < 0.05)* main and interactive effects of various soils and organic amendments on P concentration of maize plants (Table 3). Application of all amendments significantly increased the P concentration when compared to control. Application of DAP alone, significantly *(P < 0.05)* increased P concentration in maize shoot. This increase was about 25 % over control. However, poultry manure performed better than other organic amendments. The relative increase in P concentration by the application of poultry manure was 19 % as compared to control. Integration of organic amendments with DAP resulted in significantly *(P < 0.05)* more P concentration in maize shoots. Maximum (0.214 %) P concentration was recorded with the integrated application of DAP and poultry manure. This was 93 % more than control, 54 % more than DAP and 62 % more than separate application of poultry manure. Significant *(P < 0.05)* difference with respect to P contents of various soils was recorded. Soil II yielded maximum (0.147 %) P concentration followed by Soil-I (0.142 %) and Soil-III (0.138 %) in descending order. Interactive effects of soils and amendments resulted in increased P concentration with integrated use of organic and inorganic amendments. Maximum (174 %) increase in P concentration over control was observed in Soil-III when poultry manure and DAP were applied together.

Phosphorus uptake

There was significant main and interactive effect of various amendments and soils on P uptake by maize (Table

3). Application of all the organic amendments significantly increased the P uptake by maize as compared to control. Combined application of all the organic amendments with DAP produced significantly *($P < 0.05$)* more P uptake. Maximum P uptake (55.94 mg pot^{-1}) was obtained by the combined application of DAP and poultry manure. This was 254 % more than control, 106 % more than DAP and 123 % more than separate use of poultry manure. Application of DAP alone resulted in significantly *($P < 0.05$)* higher P uptake by maize shoot. On an average, it enhanced 72 % more P uptake as compared to control. Among organic amendments, poultry manure proved best. The relative increase in P uptake by the application of poultry manure was about 59 % as compared to control. Interactive effect of various amendments and soils also resulted in increased P uptake with integrated use of organic and inorganic amendments. Maximum (482 %) increase in P uptake over control was observed in Soil-III when poultry manure and DAP were applied together. The tested soils also differed significantly *($P < 0.05$)* with respect to P uptake by maize shoot. Soil-II produced maximum (33.11 mg pot^{-1}) uptake followed by Soil-I (28.49 mg pot^{-1}) and Soil-III (23.88 mg pot^{-1}) in descending order.

Agronomic efficiency (AE) of P

Application of all the organic and inorganic amendments significantly *($P < 0.05$)* increased the agronomic efficiency of P applied to the soils (Table 4). Application of DAP alone gave high (31.72 g g^{-1}) AE. Among organic amendments, poultry manure proved best with higher (28.87 g g^{-1}) AE of applied P. Integration of organic amendments and DAP showed significantly ($P<0.05$) more AE of applied P. Maximum AE (71.61 g g^{-1}) was obtained by the combined application of DAP and poultry manure. This was 92 % more than DAP and 113 % more than separate use of poultry manure. Interactive effect of various amendments and soils also resulted in increased P uptake by maize. Maximum (76.54 g g^{-1}) AE of applied P was observed in Soil-II when poultry manure and DAP were applied in integrated form. The three soils also differed significantly *($P < 0.05$)* with respect to AE of applied P in maize. Soil-I depicted maximum (34.03 g g^{-1}) AE followed by Soil-II (31.86 g g^{-1}) and Soil-III (27.78 g g^{-1}) in descending order.

Physiological P efficiency (PPE)

Significant *($P < 0.05$)* main and interactive effects of various soils and amendments were recorded (Table 4) regarding physiological efficiency of maize to the applied P on calcareous soils. Separate application of organic amendments depicted statistically *($P < 0.05$)* pronounced increase in PPE when compared to DAP. Maximum PPE (0.591 g mg^{-1}) was computed for the separate application of green manure. This was 22 % more than DAP. The tested soils also differed significantly ($P<0.05$) with respect to PPE of applied P to maize. Soil-I depicted maximum (0.471 g mg^{-1}) PPE followed by Soil-II (0.435 g mg^{-1}) and Soil-III (0.399 g mg^{-1}). Interactive effects of organic amendments and soils also resulted in significant differences with respect to PPE of applied P. Separate application of green manure significantly increased PPE over DAP and integrated use of DAP with green manure. Maximum (0.648 g mg^{-1}) PPE of applied P was observed in Soil-II when green manure was applied separately. This was 34 % more than DAP and 35 % more than integrated application of DAP + green manure. Nevertheless, integration of organic amendments and DAP showed poor PPE as compared with the PPE obtained by their separate use. On an average maximum (0.648 g mg^{-1}) PPE was achieved by separate application of green manure. This was 34% more than that of DAP and 30 % more than integrated application of green manure + DAP.

Phosphorus Recovery Percentage

Main and interactive effects of various soils and amendments on P recovery percentage of maize plants (Table 4) were significant *($P < 0.05$)*. Application of organic amendments with or without DAP, increased the recovery percentage of applied P. Combined application of all the organic amendments with DAP showed significantly *($P < 0.05$)* more P recovery percentage of applied P in the soils. On an average maximum (18.57 %) P recovery of applied P was obtained with the combined application of DAP and poultry manure. This was 186 % more than DAP and 246 % more than separate use of poultry manure. Results revealed that DAP application resulted into 6.51 % recovery of applied P which was significantly higher as compared to separate application of organic amendments. However, among organic amendments, poultry manure proved better with 5.37 % recovery of P. The three soils also differed significantly *($P < 0.05$)* with respect to P recovery % of applied P by maize. Soil-II depicted maximum (7.56 %) recovery of applied P, followed by Soil-I (6.90 %) and Soil-III (6.21 %) in descending order. Interactive effect of amendments and soils also resulted in increased P recovery % of applied P with integrated use of organic amendments and inorganic source of P. Maximum (23.2 %) recovery of P was observed in Soil-II when poultry manure and DAP were applied in integrated form.

Discussion

Shoot dry matter, P concentration and P uptake were significantly increased with application of P. It might be due to the beneficial effects of OM and effects of organic and inorganic P applied to crop. Several researchers have

Table 4: Effect of various organic and inorganic amendments on various efficiency fractions of maize in calcareous soils

Treatment	Agronomic Efficiency (g g^{-1})				Physiological Efficiency (g mg^{-1})				P Recovery (%)			
	Soil-I	Soil-II	Soil-III	Mean	Soil-I	Soil-II	Soil-III	Mean	Soil-I	Soil-II	Soil-III	Mean
Control	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GM	17.22	12.59	12.57	14.13	0.607	0.648	0.520	0.591	2.81	1.94	2.43	2.39
FYM	18.69	13.87	15.13	15.90	0.522	0.475	0.400	0.466	3.56	2.93	3.79	3.43
PM	35.09	29.14	22.38	28.87	0.608	0.537	0.455	0.533	5.77	5.43	4.92	5.37
P mud	21.20	13.11	11.37	15.22	0.587	0.590	0.351	0.509	3.61	2.28	3.24	3.04
DAP	36.96	31.25	26.96	31.72	0.533	0.484	0.436	0.484	6.92	6.44	6.16	6.51
GM + DAP	50.15	47.34	37.04	44.84	0.536	0.481	0.473	0.497	9.32	9.86	7.82	9.00
FYM+DAP	53.34	48.58	40.88	47.60	0.512	0.408	0.425	0.448	10.40	11.9	9.63	10.64
PM+DAP	67.56	76.54	70.73	71.61	0.399	0.331	0.453	0.394	16.90	23.2	15.60	18.57
Pmud+DAP	40.10	46.15	40.73	42.33	0.412	0.395	0.475	0.427	9.70	11.6	8.57	9.96
Mean	34.03	31.86	27.78		0.471	0.435	0.399		6.90	7.56	6.21	
LSD Soil	1.8748				0.0256				0.3489			
LSD Tr	3.4229				0.0468				0.6369			
LSD Soil x Tr	5.9287				0.0810				1.1032			

also reported similar benefits of organic manures. Fernandez and Sanchez (1990) and Dusberg *et al.* (1989) reported that OM was the main source of several mineral nutrients and increased P availability with the addition of OM. Dorado *et al.* (2003) found that soil organic matter affected the physical soil parameters relevant to P availability like water retention, bulk density and aggregate stability. Application of chemical fertilizers combined with the on farm available organic sources help to increase the bioavailability of residual soil P (Beri *et al.,* 2002).

Phosphorus fixation is a serious problem in alkaline and calcareous soils (Sharif *et al.,* 2000). Therefore, response of calcareous soils to P application from either source was inevitable. Tandon (1987) also found that despite increased total P contents of fertilized soils, two-third of world soils give a universal response to P application. Khanna *et al.* (1984) incubated P fertilizers with organic matter before applying to soil and studied the efficiency of the water insoluble phosphates. They found that P uptake increased manifold by this treatment over control. They reported that it was due to the improved efficiency of the P fertilizers. The increase in P use efficiency by pre-incubation with cattle dung was owing to the solublization of insoluble P fraction during the humification. Phosphorus fixation in soil was also decreased due to the protective action of manures. Concentration of solution P in soil increased with increase in organic matter and lime. Several mechanisms have been proposed to explain decrease in P adsorption capacity (Iyamuremye and Dick, 1996) including (i) competition with the phosphate anions for adsorption sites by organic anions produced from the decomposition of plant materials and (ii) saturation of the adsorption sites by P added to the soil.

Under our in vogue cropping systems, cost of inputs including fertilizers is compared to the income received; therefore, there is vivid trend of fertilizer application below recommended levels. In this perspective, the present study also assessed the various efficiency fractions affected by diversified sources of P applied in combinations or as a single source of P. Different indicators of applied P efficiency, including agronomic efficiency, nutrient recovery and physiological efficiency were used.

Papadopoulos (1994) observed that application of fertilizer P in soil increased P use efficiency. Effectiveness of inorganic P fertilizers was increased and P recovery was improved with the addition of organic manure (Whalen and Chang, 2001). It was also inferred that lower rates of fertilizers resulted in increased efficiency than the higher rates of fertilizers. Results of the present study regarding increased efficiency fractions due to low P availability from organic sources of P are in accordance with the previous experiences. Cassman *et al.* (2002) concluded that nutrient efficiency was greatly affected by the amount of nutrient used and by the synchronization between demand and supply of the nutrients. They observed increased nutrient efficiency where the fertilizer use was relatively low and crop demand was high.

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