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Yield and phosphorus-uptake by crops as influenced by chemical fertilizer and integrated use of industrial by-products

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Abstract

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To determine the best combination of P fertilizer for obtaining higher P fertilizer efficiency, industrial by-products i.e. filter cake (FC), poultry waste (PW) and di-calcium phosphates (DCP) were integrated in different proportions so as to supply 75 mg P kg^{-1} soil and evaluated against mineral P fertilizer i.e. single super phosphate (SSP) for growing maize and wheat in pots. The organic and inorganic fertilizers were thoroughly mixed with soil before sowing of maize and wheat while the effect of residual P on the yield and P-uptake on the following crop was assessed by growing rice in the same pots. Maize was harvested after 40 days of growth while wheat and rice were harvested at maturity. The results showed that irrespective to the source or combination, application of P increased the dry matter yield (DMY) of maize over control. Integration of PW and DCP in 2:1 P ratio gave maximum DMY and the highest P-uptake. Integrated use of FC, PW and DCP in 1:1:1 P ratio produced 95% of the maximum dry matter yield and 93% of the maximum P-uptake. Application of P through chemical source (SSP) produced 79 and 61% of maximum DMY and P-

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uptake, respectively and resulted in lowest P fertilizer efficiency (PFE) compared to all other combinations. For wheat integrated use of waste in all tested combinations except (FC+DCP) significantly increased total P-uptake and the grain yield of wheat over SSP. Highest grain yield as well as maximum P-uptake were recorded for DCP+PW combination. However, PW+DCP and FC+PW+DCP combinations also produced grain yields equivalent to DCP+PW combination. Integrated use of wastes increased wheat grain yield ranging from 15-42% and the PFE from 9-65% over SSP, respectively. Assessment of the residual P effect showed that integrated use of fertilizers resulted in 5-30% more grain yield than SSP alone. Thus for improved P fertilizer efficiency and sustainable crop yields, integrated use of PW and DCP in 2:1 P ratio was the best combination.

Key words : integrated use, organic, inorganic P-fertilizer, maize, wheat, rice

Pakistan's economy is based on agriculture. Cereals and cash crops cover the largest land area and remove substantial amount of nutrients from the soil depending on different rotations practiced (Ahmed, 1990; Ahmad *et al*., 1992). Growing high yielding crop varieties demand increased use of fertilizers in more balanced proportions for achieving higher production targets. The consumption of major nutrients (N, P, and K) in Pakistan though increased substantially but did not show a balance growth. Since introduction in early 1950, nitrogen consumption showed a consistant growth rate, which peaked at 2 million nutrient tonnes in 1998-99, whereas phosphorus and potassium showed a slow growth rate and thereby only 435 thousand tones of phosphate and 26 thousand tonnes of potash was consumed in 1998-99 (Ahmad, 2000). The nutrient balance sheet shows a negative balance for P, indicating more removal and less addition to the soil. Low P use was mainly due to increased price hike of phosphate compared to nitrogen fertilizers during the last two decades that deter the small or low-income farmers to apply fertilizers proportionately (Ahmad, 2000). The unbalanced use of fertilizers (wider N:P ratio) not only reduced yield but lowered the fertilizer use efficiency as well (Saleem, 1992). In such circumstances, sustainable agriculture can only be practiced through integrated use of organic, inorganic and bio-fertilizers. The agro-based industries such as sugar mills produce huge amount of filter cake (FC) and stillage as by-products and the gelatin industry produces di-calcium phosphate (DCP) and bone meal (BM) while the poultry industry produces poultry waste (PW) that contains good amount of nutrients (Table 1). These by-products are limited in quantity but are easily obtainable, and could be affordable by farmers due to nominal prices provided they could be applied in reasonably small quantity. Studies indicate that utilization of these sources as such or after composting may be profitable (Mian *et al*., 1990; Ibrahim *et al*., 1992, Nasir and Qureshi, 1999). Integrated use of these by-products with inorganic P sources showed the possibility of improving P-uptake and increasing crop yield (Alam and Shah, 2002; 2003). However, it will be desirable to know the correct proportion in which the nutrient sources should be integrated for maximizing P efficiency. This experiment was, therefore, conducted (1) to study the effect of integrated use of by-products in different proportions on the dry matter yield of maize and grain yield of wheat, (2) to select the best combination of fertilizers for improved P-fertilizer efficiency and (3) to monitor the effect of residual P on the yield and P-uptake by rice as compared to a standard chemical fertilizer i.e., SSP.

Materials and Methods

Bulk soil sample (0-20 cm depth) collected from Nuclear Institute for Agriculture Biology experimental farm was air-dried, ground, passed through a 2 mm sieve and mixed thoroughly. The representative soil sample was analyzed for some physico-chemical properties employing standard methods. The soil was silt loam in texture; it was slightly alkaline (pH_s 7.8), non-saline (EC_e, 0.42 dS m^{-1}), moderately calcareous ($CaCO_3$ equivalent,

Table 1. Some properties of the by-products used in the study.

By-products	pH	P			Total N	Total C	C: N
	(1:10)	WS %	CS %	Total %	(%)	(%)	ratio
DCP	5.23	2.0	17.8	17.8	-	-	-
Filter cake	8.19	-	-	1.25	3.65	29.6	8.2
Poultry waste	8.03	-	-	1.59	2.85	33.8	11.6

WS- water soluble, CS- Citrate soluble

3.0%) and low in organic matter (0.75%), available P ($NaHCO_3$-extractable, 5.8 mg kg^{-1}) and zinc (DTPA-extractable 0.45 mg kg^{-1}). Five kg portion of the soil was filled in individual plastic pots lined with polyethylene. Phosphorus was applied @75 mg P kg^{-1} either as chemical fertilizer i.e., SSP (powdered form) alone or after integrating the by-products in 2:1 P ratio. The treatments were replicated 3 times and kept in a net-house following completely randomized design. The amount of N was equalized in all treatments by adding varying amounts of urea. Deionized water was added to bring the soil to 75% of maximum water holding (MWH) capacity. Six seeds of maize (*Zea mays* L. cv. C-20) were sown and after germination only 3 uniform seedlings were allowed to grow in eachh pot. Twenty-one days later, 100 mg N kg^{-1} as urea and 5 mg Zn kg^{-1} as zinc sulphate solution were applied to all pots. The plants were harvested at 40 days after sowing, separated into leaves and stem, dried in an oven for 3 days at 70ºC and weighed to record dry weights. After the harvest of maize, the soil was sieved to remove heavier roots. Phosphorus was applied @75 mg P kg^{-1} to the respective pots and 200 mg N kg^{-1} as urea was added in all pots. Ten seeds of wheat (*Triticum aestivum* L. cv. Punjab-96) were sown and after germination, 5 seedlings per pot were grown at 50% MWH capacity by method of weighing as and when required. Additional N as urea was applied @ 50 mg kg^{-1} after 21 and 47 days of sowing. At maturity, the data on plant height, the number of spikes per plant and thousand-grain weight (TGW) were collected. The harvested plants were dried at 70ºC in an oven and straw and grain weights were recorded. Harvest index (HI) was calculated by dividing the grain yield by the biological yield.

The soil was again sieved to remove heavier roots, and then de ionized water was added to flood the soil and kept as such for a week. Six 25 day old seedlings of rice (*Oryza sativa* L. cv. Super Basmati) were transplanted in each pot. After establishment, 3 uniform seedlings were allowed to grow and 50 mg N kg^{-1} as urea solution was applied. Another dose of 50 mg N kg^{-1} soil was applied when the plants were approaching panicle initiation stage. The plants were kept flooded throughout the growth period. At maturity, the plants were harvested to record grain and straw yields.

Chemical analysis. The samples of stems and leaves of maize and straw or grain of wheat and rice were ground to 40 mesh powder in the Wiley mill and digested in tri-acid mixture (Jackson, 1962). Phosphorus in the samples was determined by measuring the intensity of meta-vanadate yellow color at 470 nm on a spectrophotometer. Phosphorus fertilizer efficiency (PFE) was calculated using the formula:

$$PFE = [(Pf - Pc)/P]$$

where Pf and Pc are total P-uptake from the fertilized and control treatments, respectively and P is the quantity of P applied per pot in mg.

Results and Discussion

Effect of integrated use of fertilizers on P uptake and yield of maize

Phosphorus applied as chemical fertilizer,

Table 2. Effect of integrated use of industrial by-products on the dry matter yield of maize

Treatment		Dry matter yield		
Source	**Rate ($mg\ kg^{-1}$)**	**Stems ($g\ pot^{-1}$)**	**Leaves ($g\ pot^{-1}$)**	**Total ($g\ pot^{-1}$)**
Control	-	1.23 b	3.53 c	4.76 b
SSP	75	8.59 a	17.66 b	26.25 a
FC+DCP	50+25	8.31 a	17.61 b	25.91 a
DCP+FC	50+25	9.63 a	20.26 ab	29.90 a
PW+DCP	50+25	8.42 a	24.89 a	33.31 a
DCP+PW	50+25	9.77 a	23.32 a	33.09 a
FC+PW+DCP	25+25+25	9.30 a	22.53 a	31.84 a

Figures with similar letters within each column do not differ significantly at $P<0.05$ as determined by DMR test.

SSP alone or combination of industrial by-products in 2:1 P ratio significantly increased the dry matter yield (DMY) of 40-days old maize plants over control (Table 2). The differences in the total DMY caused by integrated use of industrial by-products and the chemical fertilizer SSP were not significant. However, integrated use of fertilizers produced 14 to 27% more DMY compared to the chemical fertilizer alone. This increase in DMY was due to the significant difference in dry matter production of leaves compared to stems. It appears that the plants acquiring P from integrated fertilizers (particularly, PW and DCP combination) started to develop leaves more vigorously by the time they were harvested, because the leaves: stems ratio were higher by 16 to 44% over SSP alone at this time of growth. In the present study the fertilizers were mixed with the soil and maize was sown immediately and little time was given for attaining equilibrium. The short duration between P application and plant harvest might have affected P mineralization and its utilization by maize plants for dry matter production. Ghosal (1975) pointed out that farmyard manure retains or immobilizes added P, sub-sequently mineralizes it and makes it available to plants for an extended period of time. Reddy *et al*. (1996) reported that with manure application, P fixation increased only during the first 6 weeks and thereafter decreased continuously. Thus, the presence of farmyard manure shortened the period of P fixation and promoted its availability in later stage.

Analysis of the stems for P concentration showed little difference among treatments and thereby resulted in almost similar P-uptake (Table 3). On the other hand, P concentration and P-uptake in leaves varied significantly over SSP due to integrated use of the by-products. Highest P concentration and P-uptake were recorded in PW+DCP combination. Integrated use of FC and DCP in tested ratio did not increase total P-uptake significantly over SSP. Integration of PW and DCP in 2:1 P ratio and *vice versa* or FC, PW and DCP in 1:1:1 P ratio, however, increased total P-uptake significantly over SSP alone. This increased P-uptake from various combinations of by-products resulted in 30 to 66% higher P fertilizer efficiency over SSP alone (Table 3). This indicates that integrated use of PW and DCP in 2:1 P ratio, compared to SSP alone, could be more effective for better utilization of applied P by maize plants.

Effect of residual and applied P fertilizers on wheat following maize

Residual plus applied P fertilizers affected the yield of wheat following maize positively (Table 4). It is evident that lack of adequate P in the medium, restricted wheat growth and the

Table 3. Effect of integrated use of industrial by-products on concentration and uptake of P by maize and P fertilizer efficiency

Treatment	P concentration		P uptake			PFE (%)
	Stems (%)	Leaves (%)	Stems	Leaves (mg pot^{-1})	Total	
Control	0.12 b	0.12 e	1.41 b	4.35 d	5.8 c	-
SSP	0.21 a	0.22 d	18.23 a	39.61 c	57.8 b	13.9 b
FC+DCP	0.22 a	0.31 a	18.31 a	55.33 b	73.6 ab	18.1 ab
DCP+FC	0.21 a	0.28 bc	20.86 a	56.99 b	77.8 ab	19.2 ab
PW+DCP	0.21 a	0.31 a	17.74 a	74.63 a	92.4 a	23.1 a
DCP+PW	0.23 a	0.27 c	22.96 a	63.82 ab	86.8 a	21.6 a
FC+PW+DCP	0.22 a	0.30 ab	20.21 a	67.47 ab	87.7 a	21.9 a

Figures with similar letters within each column do not differ significantly at P<0.05 as determined by DMR test.

Table 4. Effect of residual plus applied P fertilizers on yield and some yield components of wheat

Treatment	Yield		Plant height	Number of spikes	1000- grain weight	Harvest index
	Grain (g pot^{-1})	Straw (g pot^{-1})	(cm)	(plant^{-1})	(g)	(%)
Control	8.47 d	19.37 d	70.3 c	1.53 c	31.21 c	29.41 c
SSP	32.65 c	63.98 a	85.8 b	4.31 a	35.52 c	33.82 bc
FC+DCP	37.64 bc	51.76 c	94.9 a	3.27 b	41.40 ab	42.10 a
DCP+FC	39.59 b	60.64 ab	92.2 a	4.13 a	37.95 b	39.54 ab
PW+DCP	42.89 ab	62.97 a	95.2 a	4.20 a	39.61 ab	40.50 a
DCP+PW	46.22 a	64.28 a	84.9 b	4.00 a	39.88 ab	41.81 a
FC+PW+DCP	43.37 ab	56.78 bc	95.0 a	3.53 ab	43.03 a	43.32 a

Figures with similar letters in a column do not differ significantly at P<0.05 as determined by DMR test.

application of P through chemical source alone, or through combination of by-products, increased straw and the grain yield significantly over control. Integrated use of FC and DCP was relatively less effective while integrated use of DCP and PW in 2:1 P ratio or *vice versa* and FC, PW, DCP in 1:1:1 P ratio increased wheat grain yield significantly over SSP alone. Akhtar *et al.* (2000) and Khanam *et al.* (2001) reported similar effects of combined application of organic and chemical fertilizers on the yield of wheat and rice, respectively. The increase in yield due to integrated use of fertilizers was related to the improvement in some of the yield contributing factors (Table 4). Integrated use of by-products improved plant height over SSP, but the number of spikes per plant remained the same. The increase in grain yield may therefore be attributed to the improved harvest index and thousand-grain weight. Akhtar *et al.* (2000) reported that combined application of farmyard manure and chemical fertilizer improved yield-contributing factor in wheat significantly more than the chemical fertilizer alone. In an earlier study we reported similar effects of integrated use of fertilizers on the yield-contributing factors of wheat (Alam and Shah, 2003).

Analysis of grain and straw for P content showed that, compared to all other treatments

Table 5. Residual plus applied fertilizer effect on P uptake by wheat and P fertilizer efficiency

Treatment	P uptake (mg pot^{-1})			PFE (%)
	Grain	Straw	Total	
Control	25.8 c	2.2 d	27.9 d	-
SSP	140.0 b	13.4 a	153.4 c	33.46 c
FC+DCP	150.6 b	6.3 c	156.9 c	34.39 c
DCP+FC	200.0 a	10.2 b	210.2 ab	48.61 b
PW+DCP	189.1 a	10.6 b	199.7 b	45.80 b
DCP+PW	214.7 a	13.6 a	228.4 a	53.45 a
FC+PW+DCP	188.7 a	7.0 c	195.7 b	44.75 b

Figures with similar letters in a column do not differ significantly at P<0.05 as determined by DMR test.

except DCP+PW combination, P-uptake in straw was significantly higher in SSP alone while P-uptake in grain was significantly lower in SSP alone than all other treatments except FC+DCP combination. This indicates that transportation of assimilates from source to sink was relatively higher and they were better utilized for grain production where the fertilizers were applied as integrated treatment. Total P-uptake by wheat was also higher for integrated treatment than SSP alone, except FC+DCP combination. Because of increased P-uptake, P-fertilizer efficiency improved ranging from 2.8 to 59.7% over SSP alone (Table 5). The DCP and PW combination when applied in 2:1 P ratio resulted in highest PFE, indicating the possibility of higher efficiency if the ratio between inorganic and organic sources are narrowed.

Post harvest Soil P: After the harvest of maize and wheat crops the soil was extracted with $NaHCO_3$ (Olsen-method, Jackson, 1962) to measure the amount of available P in soil. It was observed (Figure 1) that available P in soil in P treatments after each crop harvest, was higher than the control due to applied P from either source. Extractable P in soil after maize harvest was generally higher in treatments where fertilizers were applied after integration compared to the treatment of chemical source alone. Similarly,

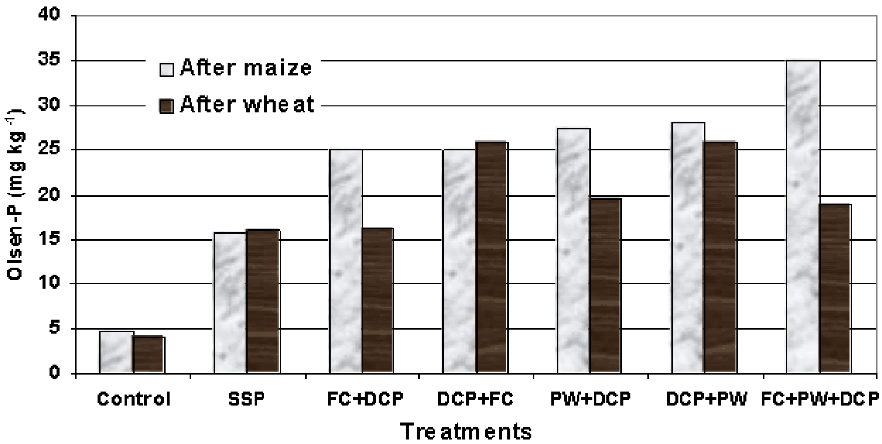

Figure 1. Post harvest available P as measured by Olsen method.

Table 6. Effect of residual fertilizer on the yield and P-uptake by rice

Treatment	Yield (g pot^{-1})		P-uptake (mg pot^{-1})		
	Grain	Straw	Grain	Straw	Total
Control	10.93 b	25.38 a	16.09 e	11.34 d	27.43 b
SSP	21.27 a	30.74 a	67.69 c	13.62 cd	81.31 a
FC+DCP	27.95 a	37.94 a	77.54 ab	20.91 abc	98.45 a
DCP+FC	22.97 a	38.15 a	72.69 bc	18.47 bcd	91.16 a
PW+DCP	27.49 a	34.95 a	83.65 a	19.57 abc	103.21 a
DCP+PW	22.45 a	38.08 a	66.73 c	27.02 a	93.75 a
FC+PW+DCP	20.95 a	34.91 a	55.15 d	23.92 ab	79.07 a

Figures with similar letters in a column do not differ significantly at $P<0.05$ as determined by DMR test.

available P in soil measured after wheat harvest was also higher where fertilizers were applied after integration except in the FC+DCP combination. The organic and inorganic fertilizers when applied in 2:1 P ratio had lower available P compared to those in which they were applied otherwise. Other workers have also reported increase in available P in soil where P was either applied alone from different sources or after pre-incubation with FYM (Ibrahim *et al*., 1992; Saeed *et al*., 1998; Khalid and Sultan, 2001).

Effect of residual phosphorus on the yield and P-uptake by rice

The information on the effect of residual P on yield and P-uptake by rice is given in Table 6. It is evident that residual P had little effect on the straw yield but markedly ($P<0.05$) improved the grain yield over control. The difference in grain yield due to integrated use of by-products and the chemical fertilizer (SSP) was not significant. However, different combinations of by-products improved grain yield ranging from 5 to 31% over SSP alone. Similarly residual P increased total P-uptake over control although the differences among P treatments were not significant. Thus, integrated use of organic source (PW or FC) and inorganic source (DCP) in 2:1 P ratio produced about 30% more grains than in which only SSP was applied to previous crops. Increased grain yield was attributed to the improved P nutrition caused by submergence (Nadeem and Ibrahim, 2002) and also due to decomposition of the added organic by-products by the microbes. The presence of organic matter in the form of PW or FC would be expected to increase the microbial activity manifold under the submerged soil conditions that would contribute to improve the nutritional status of rice. Higher microbial biomass C and N contents were observed under integrated usage of organic manure (Santhy *et al*., 1999). Similarly, Kumar *et al*. (2000) found that the organic materials applied alone or in combination with the inorganic fertilizers greatly enhanced the residual soil fertility in terms of increase in organic carbon content and available N, P and K in the 2-year cropping cycle.

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