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IMPROVING PHOSPHORUS EFFICIENCY AND PRODUCTIVITY OF WHEAT BY APPLICATION OF MANURE AMENDED PHOSPHATE FERTILIZER

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Abstract

Phosphorus (P) efficiency from inorganic fertilizers is very low and major cause of lower crop productivity, thus proper remedy is required for maintaining optimum P supply from soil to ensure higher wheat productivity. Two-years (2015-16 & 2016-17) field trials have shown that application of phosphoric acid (PA) at 54 kg P ha^{-1} along with farm-yard manure (FYM) produced maximum wheat grain (5159 kg ha^{-1}), 23% higher over its sole application. Phosphorus uptake was increased with the increase in P rates (18, 36, 54 kg P ha^{-1}) which was usually associated to higher grain yield than P concentration in grain. The manure amended inorganic P fertilizers were found more effective in P uptake and grain yield than their sole application. In greenhouse, a similar trend as occurred in field condition was observed for P recovery and biomass production. The manure amended PA (followed by diammonium phosphate) exhibited maximum P derived from applied fertilizer (Pdff = 40.03%) by a 45-day old wheat plant, as determined by ^{32}P labeling technique. Phosphorus recovery efficiency (PRE) and phosphorus agronomic efficiency (PAE) were found lowest at highest P rate (54 kg P ha^{-1}). However, co-amended phosphate fertilizers showed higher PRE and PAE as compared to their sole application. Therefore, manure amended phosphate fertilizers application seemed appropriate to attain higher P availability from soil, improve efficiency of inorganic fertilizers and enhance wheat productivity grown in alkaline calcareous soils.

Key words: Phophoric acid, Diammonium phosphate, Farmyard manure, ^{32}P radioisotope labeling technique, Wheat yield, Phosphorus efficiency.

Introduction

Wheat (*Triticum aestivum*) ranks first among other cereals widely grown around the world while it is the major food crop in Pakistan with annual production of 24 million tons (Akhtar *et al.*, 2016). However, the average yield is very low both in irrigated areas (3.9 million ton) and under rain fed condition (1.3 million tons) (Ali *et al.*, 2013). Among several other limiting factors, the lower use of fertilizers and/or their use efficiencies, especially of phosphate fertilizers, are considered as the major impediments for decline in wheat productivity.

In phosphorus (P) deficit soil, crop production is highly contingent on the use of chemical fertilizer as it supports crop growth since the seedling emergence till the grain formation and hence proved a key driver for ensuring maximum possible yield (Klinglmair *et al.*, 2015). As 90% of arable soils in Pakistan encounter P deficiency having Olsen p <10 mg kg^{-1} in soil (Afif *et al.*, 1993), inorganic phosphate fertilizers are commonly applied to fulfill the crop requirement. In this regard, huge amount (170 million ton) of the phosphate rock out of total exaction (220 million ton) is consumed for the manufacture of phosphate fertilizers. This huge consumption of non-renewable resource poses a threat to current exploitable reserves (Cordell *et al.*, 2009; Gilbert, 2009).

Although, farmers of this region usually apply lower phosphate fertilizer than the recommended rate required for achieving optimum yield, yet a further drop due to recent hike in the fertilizer price will result in severe decreases in yield of field crops. In this situation, it is more convincible to devise certain technology that could enhance the efficiency of the applied fertilizers. Phosphate fertilizers are conventionally applied at the time of sowing through broadcast which encounter very low P use efficiency, especially as low as 20% under alkaline calcareous soils. The lower efficiency of the conventionally applied fertilizer is because of higher exposure of soluble fertilizers to soil colloids (Hopkins & Ellsworth, 2005). The Ca^{+2} ions in calcareous soil readily react with P ions and convert it into plant-unavailable form.

To decrease reactivity of applied fertilizer in soil and overcome the problem of fertilizer utilization, the use of mixture of animal manure and inorganic P fertilizer could be a better approach for increasing efficiency of P fertilizer in crop production. The use of manure amended phosphate fertilizers surrounds inorganic P and thus minimizes direct exposure for reaction with soil colloids. The farmyard manure provides a shield around fertilizer particles to avoid immediate reactions which ultimately results in lower P sorption and/or precipitation in soil. Furthermore, organic manure also serves as a source of plant nutrients and improves physicochemical properties of soil (Asghar *et al.*, 2006; Odlare *et al.*, 2008). In previous studies, the use of different P sources and their methods of application significantly affected P availability to field crops (Hashmi *et al.*, 2017). Co-application of inorganic and organic fertilizers is important in many aspects. It provides organic carbon to soil microbes which solubilize soil bound nutrients through the release of organic acids and therefore manures are someway slow but consistent with nutrients supply (Gopinath *et al.*, 2008; Sarwar *et al.*, 2008; Sharma *et al.*, 2013). The decomposition products like oxalate may produce plant-available organo-phosphates thus reducing further reactivity of P ions in soil (Rosling *et al.*, 2007).

The ^{32}P labeling technique is extensively used to assess P uptake by plant and differentiate the accumulated P ions either as derived from native soil (Pdfs) or from applied fertilizer (Pdff). This isotopic labeling is also capable of quantifying actual amount of plant available phosphorus by calculating L-value (isotopically available P ions). In this respect, indirect labeling is usually employed to avoid physicochemical nature of applied fertilizer sources (Nanzer *et al.*, 2014). This technique irradiate P ions present in soil with ^{32}P radioactive isotopes (half-life= 14.3 days) to determine the P fraction either coming from different applied fertilizer sources or native soil (Hashmi *et al.*, 2017).

The present studies were conducted both in greenhouse and under field conditions to evaluate the mixing of commercially available inorganic P fertilizer (i.e. DAP and Phosphoric acid) with farmyard manure and to explore their effectiveness on phosphorus recovery and agronomic efficiency for higher wheat productivity. In general, the purpose of present study was to develop a feasible and simple technique for sustaining better utilization of phosphate fertilizer and higher productivity of wheat through efficient fertilizer technique.

Materials and Methods

Site description: Field experiments were conducted for two years (2015-16 & 2016-17) at experimental farm area of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad located at 31°23' 54.8" N and 73°02' 02.1" E with an altitude of 184 m. Mean rainfall in the area lies between 300-350 mm annually (Hashmi, 2016), whereas June is the hottest month in this region with an average temperature of 48°C while January is the coolest one with an average temperature of 4.8°C. According to World Reference Base (WRB) soil system, the studied soil is classified as Calcisol with protocalcic nature. The soil is also considered as Aridisol pertaining to ecological phenomenon of the region having low rainfall and extreme temperature.

Experimental treatments and procedure: The field study comprised of 13 different treatments i.e. Control (zero P & zero FYM), di-ammonium phosphate (DAP) and phosphoric acid (PA) applied at 18, 36 and 54 kg P ha^{-1} as alone and after pre-mixing with farm yard manure (at a ratio of two portions of FYM with one portion of P fertilizer). The triplicated treatments were arranged in RCBD in plots each having an area of 54 m^2 (9×6 m^2). Although, FYM was applied at very low rate as it contributed a little amount (only 0.04%) of organic matter and it couldn't significantly affect soil composition. However, the FYM was also applied to sole fertilizer treatment plots in the same order to keep similar concentration of organic matter and nutrients as contributed by FYM.

The mixing of inorganic P fertilizers (i.e. PA & DAP) with FYM was done by using a blender usually used for soil mixing. During mixing of FYM with inorganic fertilizer, water (10% w/w) was sprayed using a garden sprayer to moisten the content for avoiding dust and to have better reactivity of the components. The mixture was stored for about a month, before application, for complete impregnation of the materials. The recommended basal doses of potassium, nitrogen and zinc were applied at sowing time in order to evade deficiencies of other major nutrients. Nitrogen was applied as urea fertilizer in split doses (1st dose at sowing and 2nd at first irrigation) to all treatments apart from DAP treated plots. In DAP treated plots, nitrogen was applied after adjusting nitrogen provided from DAP. Wheat variety of Galaxy-2013 was grown at recommended seed rate of 125 kg ha^{-1} and sowing was done using tractor mounted seed drill. Recommended agronomic practices were adopted during crop growth. The data on growth and yield parameters were collected at maturity.

Analysis of plant samples: Plant samples were kept in oven for drying at 70°C. The samples were then ground and took 1 g of ground sample for digestion using H_2SO_4–H_2O_2 method to asses P concentration by metavanadate yellow colour method as followed by Chapman & Pratt (1961). Furthermore, P uptake by plant (PU), efficiency of phosphorus i.e. PAE (P agronomic efficiency) and PRE (P recovery efficiency) was calculated using formulae as followed by Hussein (2009); Akhtar *et al.,* (2016).

$$\mathrm{PU\ (kg/ha.)} = \frac{\mathrm{Wheat\ Yield\ (kg/ha.)} \times \mathrm{Plant\ P\ (\%)}}{100} \quad (1)$$

$$\mathrm{PRE} = \frac{\mathrm{P}\,(fert) - \mathrm{P}\,(control)}{\mathrm{P}\,(applied)} \times 100 \quad (2)$$

where P *(fert)* is phosphorus uptake by the plant, P *(control)* is phosphorus taken up by control treatment and P *(applied)* is fertilizer applied at specific rate (kg P ha^{-1}), whereas:

$$\mathrm{PAE} = \frac{\mathrm{Y}\,(fert) - \mathrm{Y}\,(control)}{\mathrm{P}\,(applied)} \quad (3)$$

where Y *(fert)* is yield obtained by fertilized treatments, Y *(control)* is yield obtained by control and P *(applied)* is fertilizer applied at specific rate (kg P ha^{-1}).

Assessing P uptake by wheat using radioisotope (^{32}P) labeling technique: The pot experiment was conducted in the greenhouse of NIAB for 45 days due to shorter half-life (14.25 days) of ^{32}P radio-isotope. The study consisted of the same treatments as were applied in field experiments, however, only one P rate (54 kg P ha^{-1}) was used in the pot studies to elaborate the effect of sole and pre-mixed fertilizer on P uptake by plant during vegetative growth.

In this experiment, indirect labeling technique was employed which involved tagging native P in soil with ^{32}P radioisotope to distinguish the fraction of P uptake by wheat derived from soil (Pdfs) and/or fertilizer (Pdff). In this method, phosphate ions present at soil-solid were labeled despite of fertilizer.

Procedure: Two kg of soil was filled in each pot on oven dry weight basis. To label the native P before fertilizer application, carrier-free ^{32}P was applied to each soil and mixed thoroughly in a plastic tray to ensure homogenous labeling of P present in soil. After that, all P amended fertilizer treatments were mixed thoroughly in soil while control treatment received zero P fertilizer. Each pot consisted of four wheat plants, grown to get enough biomass for fractionation of P ions. Plants were harvested after 45 days, then dried for 48 hours at 65ºC while fresh and dry weights were noted accordingly. Sulphuric acid and H_2O_2 methods were used to digest plant biomass. The radioactivity in the digested samples were analyzed by Liquid Scintillation Counter (LSC) (Rackbeta II. Wallac), while the same sample was used to determine P content following Barton's reagent method.

The L-value (P actually taken up by plant) was calculated using ^{32}P labeling and total P uptake by the plant (*Pt*) as determined from the digest. These calculations of radioactivity introduced (*R*) were based on the assumption that the applied radioactivity is diluted homogeneously in plant available pool and all the P fractions have same isotopic composition. After harvesting, the remaining radioactivity (*r*) in the plant digest and that initially introduced (*R*) were measured using liquid scintillation counter.

$$\frac{R}{L} = \frac{r}{Pt} \quad (4)$$

$$L\ value = Pt \times \frac{R}{r} \quad (5)$$

To determine P uptake from native soil (*Ps*), P taken up from fertilized treatments (*Pf*) and total P uptake (*Pt*) that is derived from P fertilizer applied (*Pdff*, in %) and derived from native soil (*Pdfs* in %) were calculated as follows (Achat *et al.*, 2014).

$$Ps = \frac{Pt\ (control) \times r(fertilized)}{r(control)} \quad (6)$$

$$Pf = Pt - Ps \quad (7)$$

The Pdff and Pdfs was calculated by the formula as given below:

$$Pdff = \frac{Pf}{Pt} \times 100 \quad (8)$$

$$Pdfs = 100 - Pdff \quad (9)$$

Statistical analysis

The data pertaining to field experiments were subjected to ANOVA and were statistically analyzed using Statistix 8.1 software (Analytical Software, Tallahassee, FL, USA). Mean differences among treatments were identified using Tukey's HSD test at 5% level of probability. The Pearson's correlation coefficients were employed to analyse the nature of relationships between labile P (L-value) and the grain yield of wheat obtained from field experiment.

Results and Discussion

The soil is slightly calcareous (6.1 % $CaCO_3$), low in plant available phosphorus and mineral nitrogen. This type of soil commonly prevails on a range of cultivated area in Pakistan. The physicochemical properties of soil are presented as Table 1. The P sources used in the experiment had different chemical composition i.e. Phosphoric acid (PA) contained 54% P_2O_5 and diammonium phosphate (DAP) contained 46% P_2O_5 and 18% N, however, farmyard manure (FYM) used in the experiment contained N (0.64%), P_2O_5 (0.21%) and K_2O (0.59%) on dry weight basis.

Table 1. Basic analysis of experimental soil.

Determinants	Unit	Values
Sand	%	27
Silt	%	44
Clay	%	29
Textural class		Clay Loam
Field Capacity	%	16.83
pHs		7.36
EC	dS m^{-1}	1.54
Organic matter	%	1.27
Total mineral N	mg kg^{-1} soil	8.21
Available P	mg kg^{-1} soil	13.24
Extractable K	mg kg^{-1} soil	136
$CaCO_3$	%	6.1
Soluble Ca^{2+} + Mg^{2+}	meq L^{-1}	6.2

Wheat yield response to different P amendments: Phosphorus application from both sources either applied alone (DAP & PA) or as pre-mix with farmyard manure (DAP+FYM & PA+FYM) significantly increased grain yield as compared to control. The increase in grain yield (% over control) were found significantly higher in co-applied treatments (i.e. DAP+FYM & PA+FYM) than that occurred in sole PA and DAP application (Fig. 1). However, the variation in both years' experiment could be attributed to different environmental and experimental conditions.

Biological and grain yields of wheat were increased as P application rate was increased (18 to 54 kg P ha^{-1}) for both sources (DAP & PA) either applied alone or applied after mixing with FYM. Among fertilized treatments, the maximum biological yield (13263 kg ha^{-1}) and grain yield (5159 kg ha^{-1}) were obtained by PA+FYM at 54 kg P ha^{-1} while minimum biological yield (9934 kg ha^{-1}) and grain yield (3426 kg ha^{-1}) were obtained by sole DAP application at lowest rate (18 kg P ha^{-1}). Among sole P application, the maximum biological yield (11224 kg ha^{-1}) and grain yield (4307 kg ha^{-1}) was obtained by PA application at highest rate (54 kg P ha^{-1}) (Table 2).

During the field experiment 2015-16, FYM amended fertilizer produced higher yield as compared to sole fertilizer treatments. The co-application of PA with FYM at 54 kg P ha^{-1} produced 23% higher yield than sole PA application followed by co-applied DAP+FYM which produced 15% higher grain yield than sole DAP application at similar P rate (Fig. 2). Furthermore, P sources and mode of their application also significantly increased thousand grain weight when compared with control. Maximum thousand grain weight (52.9 g) was observed in PA+FYM applied at highest P rate followed by DAP+FYM (51.8 g) at similar rate (Fig. 3). A similar trend was observed in both the years of experimentation.

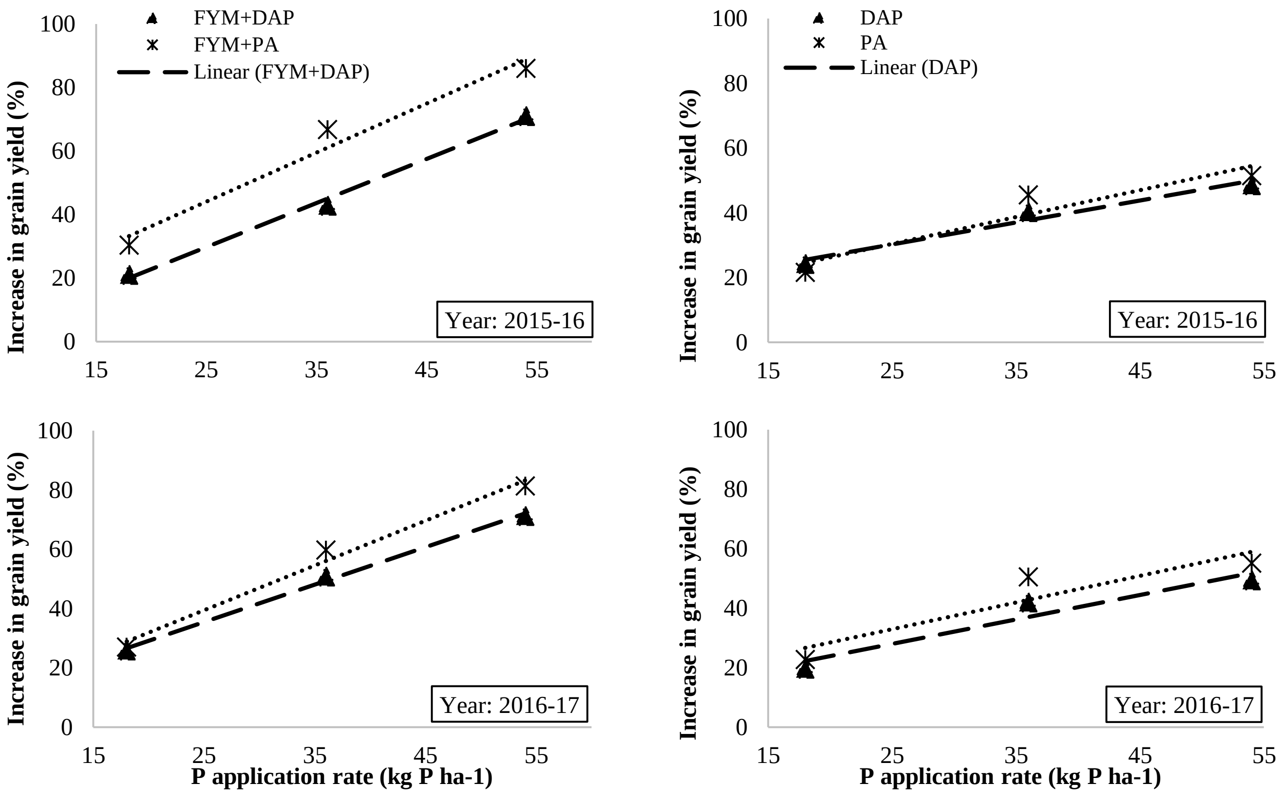

Fig. 1. Impact of P sources applied alone and as premixed with FYM on % increase in grain yield over that of control (zero P).

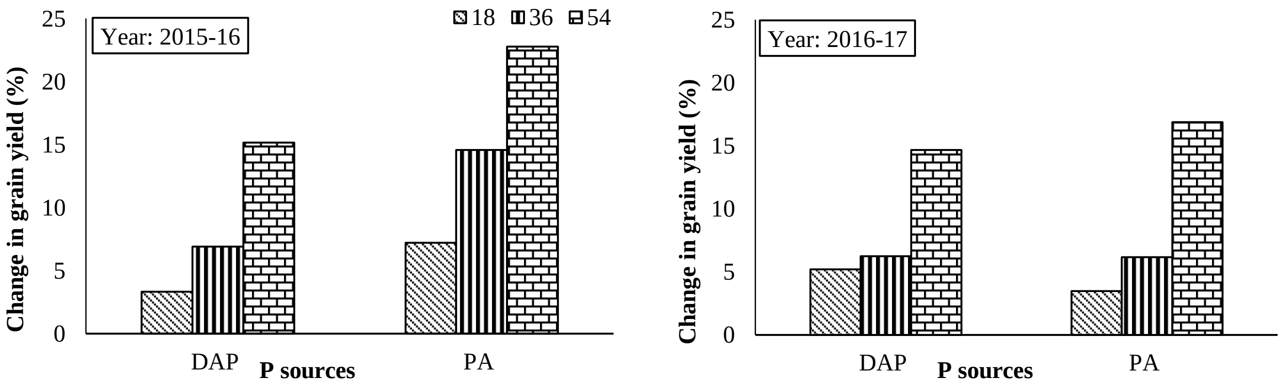

Fig. 2. Percent increase in grain yield by premixed diammonium phosphate and phosphoric acid (with FYM) over their sole application at different P rates, i.e. 18, 36 and 54 kg P ha^{-1}.

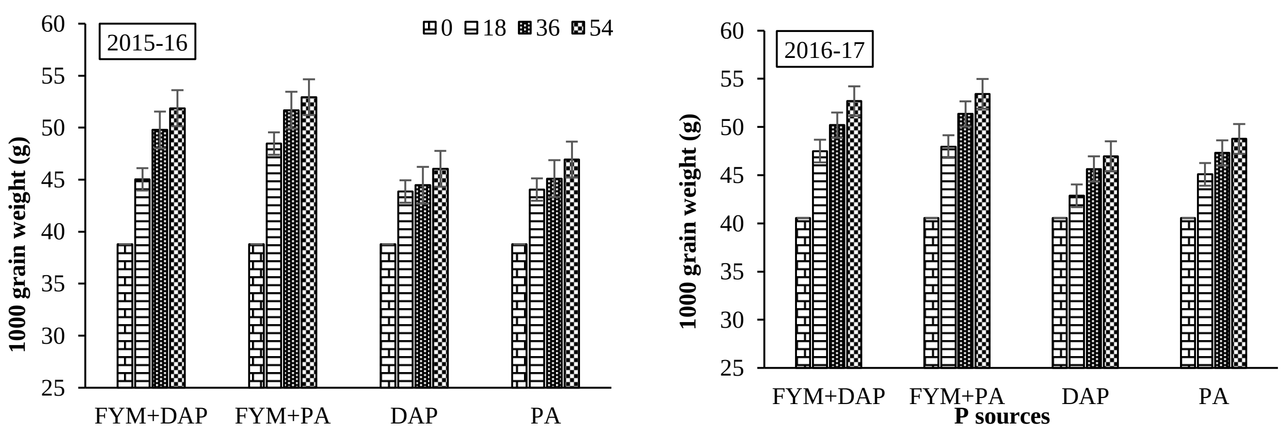

Fig. 3. 1000 grain weight of wheat as affected by applied P fertilizer treatments at different rates (0 – 54 kg P ha^{-1}) for two years field experiment.

Table 2. Effect of P sources applied as sole and premixed with FYM on wheat yield and harvest index.

Treatments	P rates (kg P ha^{-1})	Biological Yield (kg ha^{-1})			Grain Yield (kg ha^{-1})			Harvest Index (%)		
		2015-16	2016-17	Average	2015-16	2016-17	Average	2015-16	2016-17	Average
	Control[a]	6862 h[b]	7454 h	7158 i	2789 i	2829 i	2809 i	40.6 ab	38.0 a	39.3 a
DAP+FYM	18	9875 fg	11148 ef	10511 g	3377 h	3563 g	3470 h	34.2 e	32.0 d	33.1 d
	36	10625 d	11885 c	11255 d	3983 ef	4267 e	4125 e	37.5 cd	35.9 bc	36.7 c
	54	12031 b	13003 b	12517 b	4772 b	4847 b	4809 b	39.7 a-c	37.2 ab	38.5 ab
PA+FYM	18	10500 de	11200 ef	10850 ef	3635 g	3593 g	3614 g	34.6 e	32.0 d	33.4 d
	36	11094 c	12716 b	11905 c	4651 b	4520 c	4585 c	41.9 a	35.5 c	38.7 ab
	54	12813 a	13714 a	13263 a	5188 a	5130 a	5159 a	40.5 ab	37.4 ab	39.0 ab
Sole DAP	18	9531 g	10336 g	9934 h	3465 h	3387 h	3426 h	36.3 de	32.8 d	34.6 d
	36	10104 ef	11141 ef	10622 fg	3913 f	4017 f	3965 f	38.7 b-d	36.0 bc	37.4 ab
	54	10625 d	11552 cd	11089 de	4144 cd	4226 e	4185 e	39.0 bc	36.6 a-c	37.8 a-c
Sole PA	18	9833 fg	10767 fg	10300 g	3391 h	3472 gh	3431 h	34.5 e	32.2 d	33.4 d
	36	10563 d	11397 de	10980 de	4059 de	4258 e	4158 e	38.4 b-d	37.3 ab	37.9 a-c
	54	10625 d	11823 cd	11224 d	4225 c	4389 d	4307 d	39.8 a-c	37.1 a-c	38.4 ab
HSD ($\leq$ 0.05)		457	483	337	139	121	102	2.56	1.66	1.61

[a]Control = Zero phosphorus applied, FYM = Farm Yard Manure, DAP = Di-ammonium phosphate, PA = Phosphoric acid, HSD = Honest Significant Difference
[b]Numbers in columns sharing the same letter(s) do not differ significantly at p<0.05

In previous study, the positive response in increasing grain yield of wheat was observed by applying of liquid P fertilizer (PA) alone on different calcareous soils (Akhtar *et al.*, 2016). The same study showed that liquid P fertilizer (i.e. polyphosphate and phosphoric acid) produced significantly higher wheat grain as compared to commercial granular P fertilizer applied to alkaline calcareous soils. In another study, Holloway *et al.,* (2001) found dominance of PA over commercial granular P fertilizers. The integrated use of organic source with inorganic P fertilizer was evaluated in an earlier research endeavor and found higher P availability to crop grown on alkaline calcareous soil and consequently obtained higher wheat yield and other yield parameters (Ali *et al*., 2019; Nziguheba *et al*., 1998). Aye *et al.,* (2009) revealed that application of farmyard manure with half dose of inorganic P fertilizer (TSP) produced same grain yield as obtained by full dose of sole inorganic P fertilizer.

Phosphorus uptake and efficiency in wheat: Generally, an increase in P accumulation by wheat grain was observed on increasing rate of P application regardless of application method and source of P fertilizer (Table 3). The results of both the trials showed that maximum P uptake (15.7 kg ha^{-1}) occurred at highest PA+FYM application while minimum P uptake (6.0 kg ha^{-1}) was observed in control (zero P application) (Table 3). In general, the P accumulation in grain was higher significantly in co-applied treatments as compared to sole P application. However, among sole P application, PA produced higher concentration of P in grain as compared to sole DAP application. The higher P uptake might be associated with higher grain yield in manure amended fertilizer as compared to sole fertilizer application.

Phosphorus efficiencies (PRE & PAE) of both P sources (DAP & PA) applied at increasing rates (18 to 54 kg P ha^{-1}) were calculated for two consecutive years. The manure amended P fertilizers (DAP & PA) resulted in higher PRE and PAE as compared to their sole application. The higher range of PRE (3.65% – 9.29%) was found in manure amended treatments while sole application of DAP produced lower range of PRE (2.55% - 5.74%) at increasing P rates. In general, the maximum P recovery efficiency was found at medium P rate (36 kg P ha^{-1}). Similarly, higher agronomic efficiency of applied P was observed in co-applied treatments as compared to sole P application. The agronomic efficiency of P for both sources usually decreased due to increase in P rates. However, the maximum PAE of 25.85 kg kg^{-1} (mean of two years data) was found in co-applied PA+FYM at lowest rate (18 kg P ha^{-1}) while the minimum PAE (13.38 kg kg^{-1}) was found in sole DAP application at highest rate of 54 kg P ha^{-1}). Increase in P application rate decreased P efficiencies in wheat, this might be due to less utilization of applied P by plant at higher application rates as defined by law of minimum and limiting factors (Blackman, 1905). The lower P efficiencies of sole P application from both the sources was witnessed when compared with manure amended treatments. This might be due to less availability of P to plants by conventional (broadcast sole fertilizer) method of P application in alkaline calcareous soils (Hussein, 2009).

In previous investigations, the co-application of inorganic P fertilizer with manure increased plant-available pool in alkaline calcareous soils (Haq *et al.*, 2014). In another study Sarwar *et al.,* (2008) recorded that the integrated use of mineral fertilizer along with manure improved productivity of crop due to higher availability and lower P sorption in calcareous soils. The earlier studies in this context also reported that manure enriched inorganic P fertilizer enhanced P availability in soil for plant uptake and resultantly showed higher fertilizer use efficiency (Soumaré *et al.*, 2002; Soumare *et al.*, 2003). Similarly, Haq *et al.,* (2014) also observed that mixing of FYM with P fertilizers improved their efficiency, P uptake and yield of crop.

Proportion of P uptake from native soil and fertilizer in wheat: Plant can uptake P ions indiscriminately whether comes from soil P pool or applied as fertilizer. The green-house study was conducted to assess the impact of fertilizer treatments on P accumulation and biomass production at vegetative growth of wheat, and also differentiate the proportion of P uptake by wheat either derived from fertilizer (Pdff) and/or derived from soil (Pdfs) during vegetative stage (up to 45 days) of wheat.

The results tracer technique using ^{32}P labeling approach exhibited significant effect of treatment induced P recovery and resultant biomass production of wheat. The lowest biomass production (0.94 g pot^{-1}) was obtained in control treatment. However, among fertilized treatments, the maximum biomass (2.25 g pot^{-1}) was produced by PA+FYM treatment followed by DAP+FYM (2.05 g pot^{-1}) whereas the lowest biomass (1.81 g pot^{-1}) was obtained on sole DAP application (Table 4). Similarly, the maximum P uptake (3.40 mg) was obtained in PA+FYM treatment. The increase in P concentration taken up by plant could be attributed to either increase biomass production and/or by an increase in P accumulation from the applied fertilizer (Akhtar *et al.*, 2016). The significant contribution of P derived from different P fertilizer treatments (Pdff) was also obtained in co-applied treatments. The highest Pdff (40.03%) was obtained in PA+FYM treatment while the lowest one (14.05%) was recorded in sole DAP application (Table 4). In one of the previous studies, the efficiency of acidic P source (i.e. PA) was found higher than that of alkaline one (i.e. DAP) in order to improve P uptake and productivity of wheat in calcareous soil (Lu *et al.*, 1987). Furthermore, the co-application of manure along with P fertilizer enhanced yield of wheat and P uptake as compared to sole fertilizer application.

The L-value (i.e. labile P pool) indicates the actual amount of P taken up by plant during crop growth (Achat *et al.*, 2014). The L- value was calculated by isotopic labeling techniques under greenhouse study and it has strong co-relation with the crop yield obtained in the field experiment. Among all treatments, the increase in L-value (plant available P) was strongly correlated (R=0.97) with the yield of wheat crop (Fig. 4). This positive relationship showed that the results obtained from short term (45 days) greenhouse experiment are reliable and consistent with the results obtained from field experiments for evaluating the efficacy of applied fertilizer and thereby crop productivity.

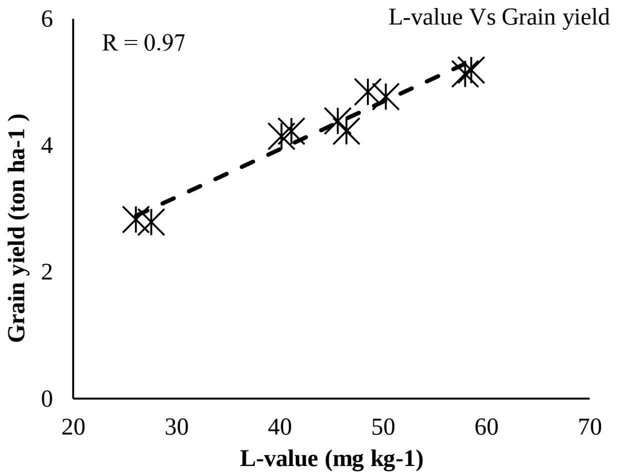

Fig. 4. Impact of L-value (plant available P) on grain yield (ton ha^{-1}) of wheat described by Pearson correlation.

Table 3. Effect of P sources applied as sole and premixed with FYM on P uptake by grain, phosphorus recovery efficiency (PRE) and phosphorus agronomic efficiency (PAE) in wheat.

Treatments	P rates (kg P ha^{-1})	P uptake by grain (kg ha^{-1})			PRE (%)		PAE (kg kg^{-1})	
		2015-16	2016-17	Average	2015-16	2016-17	2015-16	2016-17
	Control[a]	**5.8 i**	**6.2 h**	**6.0 i[b]**	-	-	-	-
DAP+FYM	18	8.8 f	9.4 f	9.1 f	7.52	8.28	21.39	23.16
	36	12.5 cd	13.6 bc	13.0 cd	8.35	9.29	18.27	20.39
	54	13.9 b	14.3 b	14.1 b	6.77	6.80	18.76	18.42
PA+FYM	18	7.5 g	7.6 g	7.6 g	4.31	3.65	27.85	23.91
	36	12.6 cd	12.5 d	12.5 d	8.54	7.93	26.62	23.54
	54	15.7 a	15.8 a	15.7 a	8.24	8.02	22.22	20.78
Sole DAP	18	7.2 gh	7.2 g	7.2 gh	3.42	2.55	23.58	18.76
	36	10.3 e	10.7 e	10.5 e	5.64	5.72	17.40	17.26
	54	12.4 cd	12.9 cd	12.6 d	5.52	5.61	13.52	13.25
Sole PA	18	6.5 hi	6.9 gh	6.7 hi	1.79	1.84	21.73	20.91
	36	12.2 d	13.0 cd	12.6 d	8.03	8.53	19.21	20.27
	54	13.2 bc	14.0 b	13.6 bc	6.20	6.52	14.19	14.61
HSD ($\leq$ 0.05)		0.82	0.86	0.81				

[a]Control = Zero phosphorus applied, FYM = Farm Yard Manure, DAP = Di-ammonium phosphate, PA = Phosphoric acid, HSD = Honest Significant Difference

[b]Numbers in columns sharing the same letter(s) do not differ significantly at p<0.05

Table 4. Phosphorous uptake by wheat partition either by native soil or different fertilizer sources.

Treatment	Shoot Weight (g)	P Conc. (mg g^{-1})	P Uptake (mg)	Plant Specific Activity (kBq mg^{-1})	L value (mg kg^{-1})	Pdff (%)	Pdfs (%)
Control**	0.94 d	1.13 c	1.06 e	0.037	26.81 d	---	100
DAP+FYM	2.05 b	1.38 ab	2.83 b	0.020	49.39 b	29.25 b	60.59
PA+FYM	2.25 a	1.51 a	3.40 a	0.017	58.25 a	40.03 a	46.67
DAP	1.81 c	1.22 bc	2.20 d	0.025	40.65 c	14.05 d	84.19
PA	1.99 b	1.32 a-c	2.62 c	0.022	46.04 b	24.12 c	73.20
HSD (<0.05)	0.123	0.204	0.169	--	3.39	4.48	

*Numbers in columns sharing the same letter(s) do not differ significantly at $p<0.05$

**Control = zero P applied, PA = Phosphoric acid, DAP = Di-ammonium phosphate, Pdff = P derived from fertilizer, Pdfs = P derived from soil, and HSD = Honest Significant Difference

Conclusion

The field studies clearly suggest mixing of inorganic P fertilizer along with FYM before soil application as an appropriate technique for enhancing P utilization and thereby productivity of wheat grown in alkaline calcareous soil. Therefore, efficiency of P (i.e. PRE and PAE) would be greater for manure amended P fertilizers as compared to their sole application.

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