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Evaluation of method and time of fertilizer application for yield and optimum P-efficiency in wheat

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Abstract

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Most of the Pakistani soils are alkaline and calcareous and the efficiency of P-uptake by wheat is low. To improve the efficiency, post emergence application of P in split dose was evaluated against the recommended broadcast and incorporation method of fertilizer application at seeding. Three field experiments were laid-out during 2001-2003 on wheat following randomized complete block design with four replications. The results showed that P applied through fertigation or top-dressing methods in split dose at first and second irrigation were equally effective for production of wheat grain and straw. However, application of full P dose at first irrigation and split application of N at first and second irrigation times by fertigation was superior to top-dressing. Fertigation applied N and P fertilizer increased wheat grain yield by 16%, P-uptake by 13%, P-fertilizer efficiency by 74%, and agronomic efficiency by 240% over top-dressed N and P at the same times.

Key words : application methods, fertigation, nitrogen, phosphorus, wheat

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Application of chemical fertilizers has played a pivotal role in increasing crop production all over the world. The alkaline and calcareous soils of Pakistan are low both in nitrogen (N) and in phosphorus (P), requiring the addition of nutrients in appropriate amounts for improving crop yields. Consequently, the use of N and P fertilizers increased many fold since their introduction in the late fifties (Ahmad, 2000). Nitrogen demand increased consistently and outstripped that of phosphate, thus leading to a serious imbalance in the use of these two nutrients. It is very well known that balanced fertilization helps efficient utilization of other agricultural inputs and increases crop yields (Rashid, 1994; Alam *et al*., 2000). Among other agronomic practices that influence the efficiency of applied fertilizer, time and method of application are also critically important. As fertilizer is a costly input and the fertilizer use efficiency under local soil and climatic conditions are low, maximum use efficiency should be the target for high economic returns.

The recommended method of application in Pakistan is to broadcast fertilizer on the surface of the soil, followed by incorporation, before seeding of the crops (Malik *et al*., 1992). This practice enhances the conversion of soluble phosphate to insoluble forms. Water-soluble P fertilizers triple super phosphate (TSP), di-ammonium phosphate (DAP) and mono-ammonium phosphate (MAP) when applied to soil react with soil components to form reaction products of low water solubility (Whitelaw, 1999). This process is known as P fixation or retention. The nature of the reaction products varies according to the soil pH; in acid soils, complex iron and aluminum phosphates predominates, while in calcareous soils such as those in Pakistan, di, tri, and octa-calcium phosphates are formed. In each case, the solubility of the reaction products is significantly lower than that of the applied water-soluble phosphate fertilizer. According to Orvis and Hellums (1993), the first crop takes up only about 10-20% of applied P during the first year after application, and the remainder goes to the building up of soil reserves. In an earlier study, Khan and Makhdum (1988) pointed out that a single application of NP to wheat could be made at sowing, but that better results were obtained if half of the N and all of the P were applied at sowing and another half of N was top-dressed at first irrigation. Ahmad *et al*. (1992) while reviewing the effect of method and time of P application concluded that under irrigated conditions, phosphatic fertilizer should be top-dressed at time of first irrigation rather than its incorporation in the soil at seeding. The results of some studies, however, suggest that split application of N and P by top-dressing or by fertigation methods could produce equivalent, or in some cases, higher grain yield and P-uptake compared to incorporation of P at sowing (Alam *et al*., 1999; 2002; Latif *et al*., 2001). The following experiments were conducted with the objectives to (a) compare the split application of P with the common method of a single P application and (b) determine the appropriate method and time of N and P application for improving the P-fertilizer efficiency in wheat.

Materials and Methods

Experiment 1

Field experiments were conducted at the Nuclear Institute for Agriculture and Biology farm, Faisalabad, on a Hafizabad loam soil (Typic Calciargid) during the years 2001-2002 and 2002-2003; the soil is slightly alkaline (pH (1:1) -7.5) and calcareous ($CaCO_3$ equivalent-1.65%), low in organic matter (0.75%) but moderately deficient in P content (Olsen P-9.3 mg kg^{-1}). During first year, urea was applied uniformly at the rate of 75 kg N ha^{-1} at the time of field preparation and the field was divided into 16 plots, each measuring 10x6 m. P treatments were imposed to randomly selected plots in blocks that were replicated four times. The total amount of P (100 kg P_2O_5 ha^{-1} applied as SSP) was either incorporated into the soil at sowing, or applied as a split dose, half at first irrigation (28 days after sowing, DAS) and another half at second irrigation (52 DAS). Seeds of wheat (cv. Inqelab-91) were sown at 120 kg ha^{-1} by a tractor drill. A second dose of urea applied

at 75 kg N ha^{-1} was top-dressed at first irrigation to all plots. Two more irrigations were given at one-month interval and other agronomic practices were uniformly followed. At maturity, wheat from a 2 m^2 area was harvested from five different places in each plot and was left for sun drying. Biological yield was obtained by weighing, and the grain weight was determined after threshing the samples.

Experiment 2

Two field experiments were laid out during the year 2002-2003 to study the effect of N application by fertigation and top-dressing at first and second irrigations. Phosphorus was applied either at sowing or at first irrigation by fertigation. Seeds of wheat, variety Inqelab-91, were sown at 120 kg ha^{-1} with a tractor drill on plots measuring 15x7.5 m. After seed germination, fertilizer treatments were imposed as detailed below:

T_1 - Control, no N or P applied
T_2 - Urea @ 75 kg N ha^{-1} half top-dressed at first irrigation (21 DAS) and half at second irrigation (82 DAS)
T_3 - Urea @ 75 kg N ha^{-1} half applied through fertigation at first and half at second irrigation.
T_4 - SSP @ 33 kg P ha^{-1} broadcast and incorporated into the soil at sowing; urea applied as in T_2
T_5 - SSP @ 33 kg P ha^{-1} applied through fertigation at first irrigation; urea as in T_2

The crop was given two more irrigations at 21 and 25 days intervals, and other recommended agronomic practices were applied uniformly to all plots. At maturity, plants from 3.5 m^2 areas were randomly harvested from four places in each plot and were bulked. Grain and straw yields were recorded after drying and threshing.

Experiment 3

The objective of this experiment was to compare top-dressing and fertigation methods of N and P fertilizer application simultaneously on their efficiency of uptake by wheat. Seeds of wheat, cv. Inqelab-91, were sown at 120 kg ha^{-1} with a tractor drill. After germination, the following treatments were imposed on 10x6 m plots, laid out in a randomized complete block design with four replications.

T_1 - Control, no N or P applied
T_2 - Urea @75 kg N ha^{-1}, top-dressed at first and second irrigation
T_3 - SSP @ 33 kg P ha^{-1}, top-dressed at first irrigation and urea as in T_2
T_4 - SSP @ 33 kg P ha^{-1}, by fertigation at first irrigation and urea as in T_2
T_5 - SSP @ 33 kg P ha^{-1}, by fertigation at first irrigation and urea @75 kg N ha^{-1} by fertigation at first and second irrigations

First irrigation was given at 25 days after sowing while second irrigation was given 63 days later. Three more irrigations were given and other agronomic practices were applied uniformly. At maturity, plants from 2 m^2 area were harvested randomly from five places in a plot. After drying and threshing, grain and straw yields were recorded.

Chemical analysis:

The grain and straw samples were ground in a Wiley mill and sub- samples were digested in tri-acid mixture (Jackson, 1962). The concentration of P was determined by developing metavanadate-yellow color and measuring the intensity on a spectrophotometer. The data were analyzed statistically using MSTAT-C software. Agronomic efficiency (AE) and P-fertilizer efficiency (PFE) were calculated by the following formulas:

AE = {Grain yield (fertilized) - Grain yield (control)} / amount of P applied

PFE = {P-uptake (fertilized) - P-uptake (control)} /amount of P applied

Results

Comparison of recommended and split methods of P application:

Application of P, by all three methods

significantly increased the straw and grain yield of wheat as compared to the control (Table 1). The method of P application did not differ significantly in producing the grain yield except that split application of P by fertigation resulted in significantly lower straw yield than full dose of P applied at sowing. P application methods had no significant effect on P-uptake in straw or grain (data not shown) but total P-uptake was significantly lower in fertigation compared to incorporation of P at sowing. Similarly, the agronomic efficiency and the P-fertilizer efficiency of the applied P fertilizer by either method were statistically similar. This indicates that P could be applied as a split dose by top-dressing or by fertigation methods to obtain grain yield equivalent to the recommended broadcast and incorporation method of P at sowing. Thus, in case of shortages or non-availability of P fertilizers, a problem that the majority of small farmers have to face at sowing of wheat, could be overcome by applying the P fertilizer in a split dose either top-dressed or by fertigation at 1st and 2nd irrigations.

Effect of method of N and P fertilizer application on wheat:

The various tested methods of N and P application significantly improved the grain and straw yields as well as uptake of N and P over the control (Table 2). Application of N by fertigation increased wheat grain yield by only 4% and the straw yield by 5% over top-dressed N, and the yields were not significantly different. Incorporation of P fertilizer at sowing and top-dressing N fertilizer in split dose also increased yield over control, but not significantly over N alone applied by either method. However, application of P at first irrigation through fertigation increased grain and straw yields significantly over top-dressed N alone. Fertigated-P at first irrigation produced about 9% more grain and 16% more straw over broadcast and incorporated P at sowing. Phosphorus applied through fertigation also resulted in significantly improved P-uptake (19%), agronomic efficiency (152%) and P-fertilizer efficiency (157%) as compared to broadcast and incorporated-P at sowing (Table 2).

Comparison of simultaneous application of N and P fertilizers by top-dressing and fertigation methods:

Table 3 shows that the application of P by either method increased the grain and straw yields of wheat and the P-uptake by grain over the control. Application of N fertilizer in split dose by fertigation together with P performed comparatively better than top-dressing. Split application of N at first and second irrigations by top-dressing and P application by fertigation or top-dressing at first irrigation could not improve the grain yield or P-uptake significantly over N alone. However, when both N and P were applied through fertigation, the grain yield and P-uptake increased significantly over N alone. This indicates that on soil

Table 1. Effect of method and time of phosphorus application on wheat yield, P-uptake, agronomic efficiency and P-fertilizer efficiency

Fertilizer treatment		Grain yield	Straw yield	Total P uptake	AE[1]	PFE[2]
Method	Time	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg kg^{-1})	(%)
Control	Control	4055 b	6040 c	11.81 c	-	-
Broadcast-incorporation	Sowing	4732 a	7602 a	17.88 a	15.40 a	13.77 a
Top-dressing	1st + 2nd irrigation	4802 a	7385 ab	17.26 ab	16.99 a	12.38 a
Fertigation	1st + 2nd irrigation	4830 a	7042 b	16.31 b	17.61 a	10.21 a

[1] AE- Agronomic efficiency [2] PFE - P fertilizer efficiency

Figures sharing common letter in a column do not differ significantly at P<0.05 as determined DMR test

Table 2. Effect of method of N and P fertilizer application on wheat yield, N and P-uptake and P-use efficiency

Fertilizer treatment N	P	Method	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	P uptake (Grain) (kg ha^{-1})	N-uptake (Grain) (kg ha^{-1})	AE[1] (kg kg^{-1})	PFE[2] (%)
Control		Control	2719 c	4206 c	8.86 c	45.27 b	-	-
150	-	Topdressing	4043 b	5762 b	13.03 b	92.05 a	-	-
150	-	Fertigation	4205 ab	6043 b	14.83 b	95.62 a	-	-
150	33	Broadcast	4305 ab	6160 b	14.88 b	98.15 a	7.9	5.6
150	33	Fertigation	4700 a	7160 a	17.78 a	104.40 a	19.9	14.4

[1] AE- Agronomic efficiency [2] PFE-P fertilizer efficiency
Figures sharing common letter in a column do not differ significantly at P<0.05 as determined DMR test

Table 3. Effect of method of N and P fertilizer application on wheat yield, P-uptake and P-use efficiency

Fertilizer treatment N	P	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	No. of tillers (m^{-2})	P-uptake (Grain) (kg ha^{-1})	AE[1] (kg kg^{-1})	PFE[2] (%)
Control	Control	1340 c	2243 b	306 c	5.47 b	-	-
150 (TD)[3]	-	3793 b	6073 a	346 b	12.00 a	-	-
150 (TD)	33(TD)	4070 ab	6197 a	356 b	14.56 a	8.4	7.76
150 (TD)	33 (F)[4]	4230 ab	6887 a	398 a	15.55 a	13.2	10.76
150 (F)	33 (F)	4733 a	7150 a	433 a	16.46 a	28.5	13.52

[1] AE- Agronomic efficiency [2] PFE-P fertilizer efficiency
[3] Top-dressing of N at first and second irrigation [4] Fertigation of P at first irrigation
Figures sharing common letter in a column do not differ significantly at P<0.05 as determined DMR test

where top-dressing N and applying P by fertigation at first irrigation did not improve the yield, applying both N and P through fertigation increased the grain yield significantly over top-dressed N alone. Fertigation and top-dressing methods of both N and P application were equally effective, but the former may be considered superior than the later due to its effect on increasing the number of tillers m^{-2}. Similarly, applying both N and P by fertigation resulted in a 13% increase in P-uptake, 74% increase in PFE and 240% increase in AE over top-dressed N and P fertilizers.

Discussion

Fertilizer use is imperative for achieving higher yield on N and P deficient soils of Pakistan. Recommended amounts of fertilizer should be applied in balanced proportion, at appropriate times and using the best method, so that the plants can absorb these nutrients efficiently and produce maximum yield. In Pakistan, many small farmers fail to meet the above requirements and therefore, harvest low yields. Researchers have shown their concern for marginal increase or the stagnation of yield of cereal in general and of wheat in particular, during the last two decades (Twyford, 1994; Ali, 2000). Unbalanced use of fertilizer (wider N:P ratio) may be one of the important factors. However, inappropriate time and method of fertilizer application might have played a role in lowering the yield through reduction in fertilizer use efficiency (Saleem, 1992). Another important factor that might have contributed to low yield of wheat is the sowing time (Aslam *et al*., 1993). Wheat in Pakistan is generally sown during winter. The

wheat crop, following summer crops such as cotton, rice and sugarcane, is often planted late. The optimum time of planting cannot be substituted by any cultural practices, such as enhanced seed rate, closer row spacing, input use change or even the use of a late planted variety (Chaudhry *et al*., 1995, Khan *et al*., 2002).

Yields are significantly reduced as planting is delayed after 15 November. The reduction is almost linear. A ten-year study on comparison of wheat planted fortnightly from 25th October till 10th January showed that the quantum of loss after 10th November could be as high as 42 kg ha^{-1} day^{-1} if planting is delayed until 10th January. There were 8, 16, 32, and 50% reduction respectively for each fortnight after 10th November (Khan, 2003). The results of our study indicate that the delay in wheat sowing due to non-availability or shortage of fertilizer at planting time may be avoided by split application of fertilizer. Application of N and P fertilizers may be delayed to about three weeks after sowing (Table 1).

Fertilizer use optimization, next to timely planting, is the major contributor to wheat crop yield. High prices of fertilizer, their non-availability at the right time, and non-availability of credit, smallholdings and poor economic conditions of the farmers mostly account for low fertilizer usage. At present, average fertilizer use is less than half that recommended and some farmers do not apply P at all (Khan, 2003). Incorporation of lower P dose at sowing gave significantly lower yield than the recommended rate, whether it is applied full at sowing or applied as a split dose (Latif *et al*., 1997; Shah *et al*., 2001). Even if only half of the P dose is applied at sowing, the second half may be applied at 1st or 2nd irrigation by fertigation without loss in grain weight (Latif *et al*., 1994, 1997). However, if farmers can afford only half of the recommended P dose, this should be applied through fertigation at 1st irrigation instead of its incorporation at sowing. In an earlier study, the lower P rate applied by fertigation at 1st irrigation resulted in equivalent wheat yield and 25-30% higher PFE compared to higher P rate applied broadcast and incorporated at seeding (Alam *et al*., 1999, 2002). Thus, we conclude that if fertilizers are not available at sowing, post emergence application of N and P fertilizers through fertigation is feasible up to about three weeks after planting; this would prevent late planting and the resulting loss in wheat grain yield.

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