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DIRECT AND RESIDUAL EFFECT OF HAZARA ROCK PHOSPHATE (HRP) ON WHEAT AND SUCCEEDING MAIZE IN ALKALINE CALCAREOUS SOILS

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Abstract

The potential of Hazara rock phosphate (HRP) containing 18 % acid soluble P_2O_5 as cheaper substitute for costly commercial fertilizer for crop production, was evaluated. Field experiments were conducted on silty clay loam, calcareous (16 % $CaCO_3$), high pH (8.6) soil where 0, 250, 500, 1000 and 1500 kg HRP ha^{-1} was added to wheat (*Triticum aestivum* L.), cv "Serin" with three replications in RCB arrangement. Recommended doses of N and K were applied to all plots. Maize (*Zea mays* L.) cv "Babar" was grown as a succeeding crop for evaluating the residual effect of HRP as a source of P. Addition of HRP produced significant increase in wheat grain and biomass yield over control. HRP demonstrated a significant residual effect on grain and biomass yield over control. Similar increases were registered in the number of grains, grains $spike^{-1}$ of wheat and cobs weight and grain weight cob^{-1} of maize. The variations induced by levels of HRP were mostly similar while the residual levels showed better results for higher doses compared to lower for maize yield and yield components. The soil analysis performed for the growth stages revealed significant water soluble P concentrations with HRP treatments over control suggesting sustained supply of P into the soil solution for crop growth and development. The total P uptake by both wheat and maize closely followed the pattern of WSP, which corroborated the yield data. It was concluded that HRP offer promise as alternate source of P, however, to ensure optimum crop production on high pH calcareous soil, some acidification after careful standardization will be advisable.

Key words: Hazara rock phosphate (HRP), Alkaline calcareous soil, Residual effect, Water soluble P, Rhizosphere.

Introduction

Majority of Pakistani soils, being alkaline and calcareous (Anon., 2007) lose a greater portion of available P from applied WSP fertilizers due to adsorption, precipitation or conversion to immobilized organic form. The alarming increase in population has been putting a great pressure on our soils in terms of nutrients mining leading to degradation of soil and environment. Phosphorus being one of the main limiting nutrients with much lower bioavailability indices needs more attention than any other nutrient for an ever increasing demand of agricultural production. It needs to be supplemented on regular basis for maintaining soil P status at a level that can withstand the crop requirements especially in areas with low inherent soil P. According to the findings of Holford (1997), more than 80 % of the readily available P of the applied chemical fertilizers is converted to immobile and insoluble compounds and become unavailable to plant roots. Though a low P concentration (0.2 mg L^{-1}) in soil solution may be adequate for normal plants growth, it must be continuously replenished in the soil solution for optimum yields in the vicinity of roots during their growth cycle (Kamprath, 1970; Barber, 1995). Mineralization of organic P returns P back to the soils but in the present scenario of intensive agricultural practices, aiming larger optimum yields, one cannot rely solely on mineralization of organic P (Chater & Mattingly, 1980; Mattingly *et al*., 1975) and thus the application of water soluble phosphorus (WSP) fertilizers from different sources becomes crucial.

The deficiency of P in Pakistani soils ranges from 70 to 80 % (Memon, 2005) and P supplementation is needed for conserving these soils from degradation. The P availability in soil promotes the growth of crop plants (Khan *et al*., 2012; 2013). However, practically the phosphatic fertilizer application track record is much lower than the minimum required level. The lower consumption could mainly be associated with their unaffordable higher market prices besides many other constraints. The higher prices of these fertilizers have led to imbalanced fertilizer NPK offtake from the market in Pakistan. In 2011, N:P consumption ratio in the country is several times wider (4.09:1) than the required ratio of 2:1 adopted by many other countries (Anon., 2011). Such alarming situation demands for exploring cheaper sources of P and improved application technologies and strategies to achieve higher P efficiency.

Some researchers reported that the source of P fertilizer has no significant effect on P efficiency in calcareous soils (Leytem & Mikkelsen, 2005). Hence the direct application of locally available Hazara rock phosphate (HRP) could be a sound economical alternative of otherwise unaffordable commercial P fertilizers for resource poor farmers of the country.

Pakistan is endowed with domestic RP deposits occurring in Hazara division of Khyber Pakhtunkhwa which are the only workable sources of raw material for manufacturing water soluble phosphate fertilizers. These phosphorites are of sedimentary origin and are located in a number of localities in Hazara division. Rock phosphate is basically a complex of tri-calcium phosphate $[Ca_3(PO_4)_2]_3.CaCO_3$ which is insoluble in water and hence un-available to plants (Sharif *et al*., 2013). The dissolution of RP to release plant available P is governed by many factors including soil and climatic conditions, granular size, moisture content and time and application techniques (Zoysa *et al*., 2001). In addition to technical considerations, a number of socio-economic factors and policy issues determine RP production, distribution, adoption and use by the farmers. In principle, the use of RP sources should be promoted in countries where they are indigenously available (Anon., 2004). An extensive research work has been carried out for evaluating the effectiveness of direct application of RP all over the world especially in developing countries where indigenous RP deposits are available. However, a little attention has been given in our country to evaluate the effectiveness of direct application of HRP despite the lowest WSP fertilizer consumption as compared to other countries. Dissolution of HRP with organic materials has been reported by Sharif *et al*., (2014) and some other researchers. Composting HRP with organic materials is an effective and environment-friendly technique for RP dissolution but could not be deemed practical due to certain limitations under the prevailing socio-economic conditions where most of the farmers have almost discontinued utilization of WSP fertilizers and rely only on N applications. A drastic decline in WSP fertilizer consumption has been noticed in the country with increase in their prices in the last decade.

To explore the use of HRP for crop production, this study was designed whereby direct and residual effect of different levels of HRP was investigated using wheat as first season and maize as residual crop in alkaline calcareous soil.

Materials and Methods

Site description: The experiments were conducted at the farm of The University of Agriculture Peshawar, Pakistan during 2012 and 2013. The site is located 34.01^o N latitude, 71.35^o E longitude at altitude of 350 m above sea level. Mean annual rain fall ranges from 300 to 500 mm. The soil under study was silty clay loam, alkaline (pH 8.6) calcareous ($CaCO_3$ 16 %), low in organic matter (0.68 %) and AB-DTPA extractable P (1.42 mg kg^{-1}).

Field experiments: Field experiments were conducted to evaluate the direct and residual effect of various levels of un-amended Hazara rock phosphate (HRP) under calcareous soil conditions using wheat as first season and maize as residual test crop. Treatments included HRP at 0, 250, 500, 1000 and 1500 kg ha^{-1} equivalent to 0, 45, 90, 180 and 270 kg P_2O_5 ha^{-1}, respectively, based on 18% acid (H_2SO_4) recoverable P_2O_5 in HRP. The experiment was arranged in RCB design with three replications. The size of experimental plots was 3 x 5 m^2. The soil selected for these experiments was analyzed for lime (Richard, 1954), organic matter (Nelson & Sommers, 1996), pH (McClean, 1982), texture (Gee & Bauder, 1986) and P (Soltonpour & Schwab, 1977) prior to layout of the experiment. Recommended doses of N and K were applied to all plots before seed bed preparation to both wheat and maize crops but no additional HRP or P fertilizer was applied to the latter. The HRP and required amount of N and K were applied on the soil surface to all treatments before seed bed preparation and were thoroughly mixed with soil. Wheat cv. Siren was sown in lines 30 cm apart with seed rate of 120 kg ha^{-1}. All other agronomic practices were applied as per standard procedures. The data regarding growth and yield and P uptake were recorded.

Maize (Baber) crop was then grown on the same lay out after wheat harvest. The recommended doses of N and K were applied to all the plots except P. Maize was sown in lines 75 cm apart and plants 20 cm apart. The data on yield and growth parameters and P uptake were recorded. The soil samples were analyzed for water soluble P at tillering, anthesis and post-harvest stages of wheat crop and knee height, silking and post-harvest stages of maize to observe changes in the P status of soil with time and crop growth. The plant samples were also analyzed for P concentration at maturity to determine P uptake by both crops. Soil samples were collected from 0-20 cm depth from each individual plot and were air dried at room temperature, ground, sieved and analyzed for water soluble P through the method described by Admas (1974) with spectrophotometer (Kuo, 1996). Plant samples were analyzed by wet digestion method (Benton *et al*., 1991). Grain yield, biomass, grains and grain weight spike^{-1}, cob weight and grain weight cob^{-1} were recorded for wheat and succeeding maize crop. The data was analyzed using ANOVA as described by Steel & Torrie (1980) and Least Significant Difference (LSD) test was performed for comparison at given level of probability.

Results and Discussion

Grain yield and biomass of wheat and succeeding maize crop: Application of straight Hazara rock phosphate (HRP) significantly ($p<0.05$) increased grain and biomass yield of wheat in the first season of application as well as that of succeeding maize with residual P (Table 1). Grain yield of wheat increased from 2483 kg ha^{-1} in control to 2900 with application of 250 kg HRP ha^{-1} showing an increase of 16.8 % over control. Additional increments of HRP at the rate of 500, 1000 and 1500 kg ha^{-1}, increased grain yield by 22 to 27 % over control (Fig. 1). However these differences were not statistically different from one another at $p<0.05$. Similarly, the biomass of wheat also had significantly higher values than control in HRP treated plots but the differences among various levels of HRP were statistically similar.

Table 1. Effect of HRP on grain and biomass yield of wheat and succeeding maize crop under calcareous soil conditions.

HRP	Wheat		Maize	
	Grain yield	Biomass	Grain yield	Biomass
kg ha^{-1}	kg ha^{-1}			
0	2483.3 b	6684.7 b	2990 b	8775 c
250	2900.3 ab	7626.7 a	3059 b	9341 c
500	3027.7 a	7786.7 a	3312 b	10501 b
1000	2964.3 a	7795.7 a	3729 a	11360 ab
1500	3164.3 a	8053.3 a	3833 a	11826 a
LSD (p<0.05)	464.3	844	394	1112

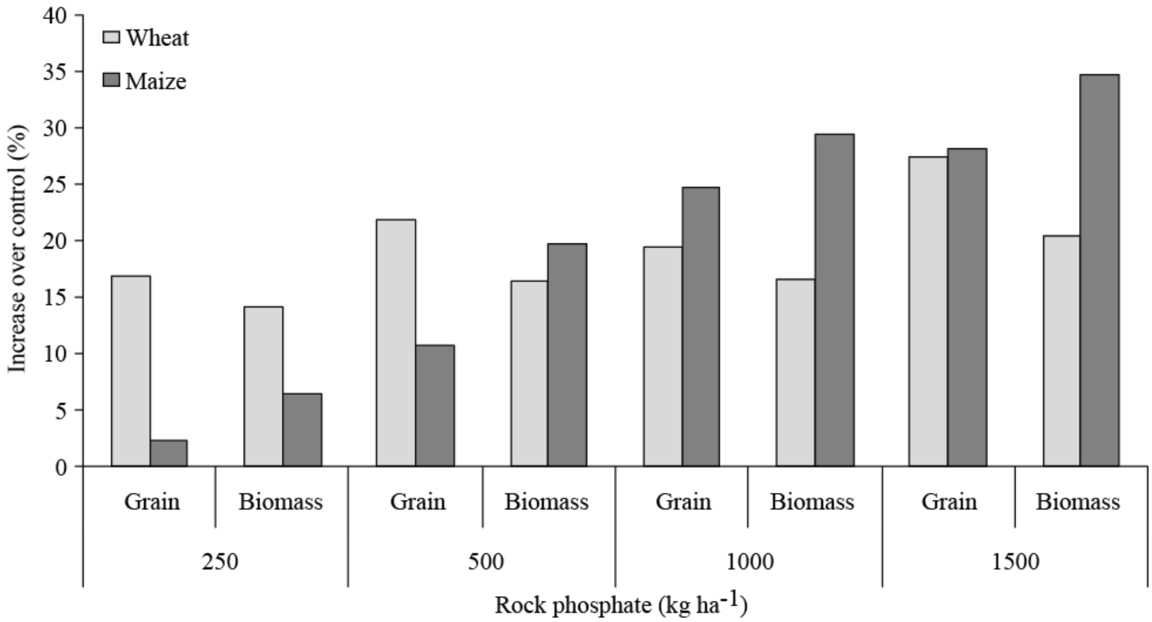

Fig. 1. Grain and biomass yields of wheat and residual maize as influenced by different levels of HRP under alkaline calcareous soil.

Substantial yield increases in wheat crop over control with application of HRP suggest its potential for direct use as P fertilizers. Menkeni *et al*., (1991) also reported significantly higher crop yields with application of RP in some soils of Morogoro, Tanzania. Similar results were reported by Diatta *et al*., (2002) on Ultisols soils where both the direct and residual P from Mali RP corrected P deficiencies and improved productivity of upland rice. The non-significant variations in grain yield and biomass among the treatments observed in present study reflected the slow dissolution of HRP which probably replenished the soil solution with a steady rate of the P required at initial stages of wheat crop regardless of their levels. As cereals take up about 75% of their required P within 40 days after emergence (Ross & Middleton, 2013), increasing the level of a slow release P source (HRP) above certian level could decrease the apparent P recovery in the first season of application. As such the lower levels of HRP could produce as much grain and biomass yields as could be obtained with higher levels of HRP in the first season. In succeeding maize crop the addition of 250 and 500 kg ha^{-1} HRP showed non-significant ($p<0.05$) but with upper levels (1000 and 1500 kg HRP ha^{-1}) significant increases of 24.7 and 28.2 %, respectively, were produced (Table 1). Biomass also followed the same trend with the highest value of 11826 kg ha^{-1} recorded with the highest level of HRP. Increase in succeeding maize yield at lower rate of HRP were much lower, only 2.3 and 10.8 % as compared to 10.8 and 27.9 % in wheat grain yield at equal level of 250 and 500 kg ha^{-1}. This observation suggests that the P supplied by residual HRP at 250 to 500 kg h^{-1} was not adequate for promoting crop growth but when does was enhanced to 1000 and 1500 kg ha^{-1} the residual HRP supplied enough P to soil solution and produced increases at par with initial application to wheat. On the basis of these reports, there is good possibility that the residual release of P by HRP may become effective in subsequent cropping. This observation is supported by earlier studies. Akande *et al*., (2010) and Ghosal *et al*., (2013) reported higher crop yields of subsequent second year crop than first crop with the application of un-amended RP. Tang *et al*., (2008) also reported that P fertilizers added to wheat crop can maintain higher yields in succeeding maize crops without further applications. Ndung *et al*., (2003) observed that one time application of Minijingu rock phosphate (MRP) at the rate of 60 kg ha^{-1} significantly increased maize yields up to the fourth season with the highest yield from first residual crop.

Grain and grain weight spike^{-1} of wheat and cob and grain weight cob^{-1} of succeeding maize: Number of grains and grain weight spike^{-1} in wheat and cob weight and grain weight cob^{-1} in residual maize significantly increased over control with application of HRP (Table 2). The grains spike^{-1} of wheat increased significantly ($p<0.05$) from 48.3 in control to 55.6 with 1500 kg HRP ha^{-1} but the differences among the given HRP levels were non-significant at $p<0.05$. The grains spike^{-1} and cob weight and grain weight cob^{-1} in maize were statistically superior in treatments receiving HRP at 1000 kg ha^{-1}. The cob weight and grain weight cob^{-1} in maize observed at 250 and 500 kg ha^{-1} were statistically similar to each other, higher than control but lower than 1000 and 1500 kg ha^{-1} HRP which were similar to each other (Table 2). Figure 2 illustrates that the grain weight cob^{-1} of residual maize was increased by 49 % over control against the maximum increase of 18 % in grains weight spike^{-1} of wheat at similar level of 1500 kg HRP ha^{-1}.

The higher response by maize than wheat yield could be associated to consistent depletion of P in soil solution in control treatment with successive two crops and to the slow release of P from HRP sources accounted for the improvement in visible manner. This is supported by the water soluble P (WSP) data provided in Table 3 showing similar pattern to crops yield. These results were in agreement with those of White *et al*., (1999) who reported that the RP dissolution increased with time and its residual P increased rice yield more as compared to the first season crop. Jones (1990) was also of the view that due to slow release of P from RP optimum yield of forage legumes could not be expected in the first cut. Akande *et al*., (1998) obtained higher yield from second year maize crop with residual P from Sokoto rock phosphate (SRP) and concluded that the residual effect of SRP was superior to fresh application due to slow releases of P.

Water soluble P (WSP) concentrations: The gradual and slow release from HRP at all levels was indicated from the results which decreased with time due to simultaneous plants uptake and conversion to insoluble forms (Table 3). The highest WSP concentration at tillering stage was observed in treatment of HRP 1500 kg ha^{-1} (1.24 mg kg^{-1}) followed by HRP 1000 kg ha^{-1} (1.12 mg kg^{-1}). All the treatments were significantly superior to control except the HRP 250 kg ha^{-1}. However, at anthesis and post-harvest stages the WSP concentrations of all the treatments were significantly higher than that of control. Regardless of the level of HRP the WSP increased from tillering stage to anthesis stage and again decreased at post-harvest stage in wheat crop which indicated a gradual slow release from HRP and unavailable P already present in the soil and simultaneous conversion to insoluble P compounds and the plant uptake. The increases in WSP ranged from 62-82 % over control by 250 HRP to 119-143 % by 1500 HRP kg ha^{-1} at the given stages of the crop (Table 3).

Table 2. Number of grain and grain weight spike^{-1} of wheat and cob weight and grain weight cob^{-1} of residual maize at the given HRP levels under calcareous conditions.

HRP added (kg ha^{-1})	Wheat		Maize	
	Number of grains spike^{-1}	Grain weight spike^{-1} (g)	Cob weight (g)	Grain weight cob^{-1} (g)
0	48.3 b	2.12 c	108.33 d	71.83 c
250	53.0 a	2.38 ab	118.33 c	81.28 b
500	53.0 a	2.34 b	126.67 b	89.17 b
1000	55.0 a	2.49 a	136.00 a	102.33 a
1500	55.6 a	2.50 a	139.33 a	107.04 a
LSD ($p < 0.05$)	3.9	0.14	7.47	8.54

* Means followed by same letter (s) in a column do not differ at $p \leq 0.05$

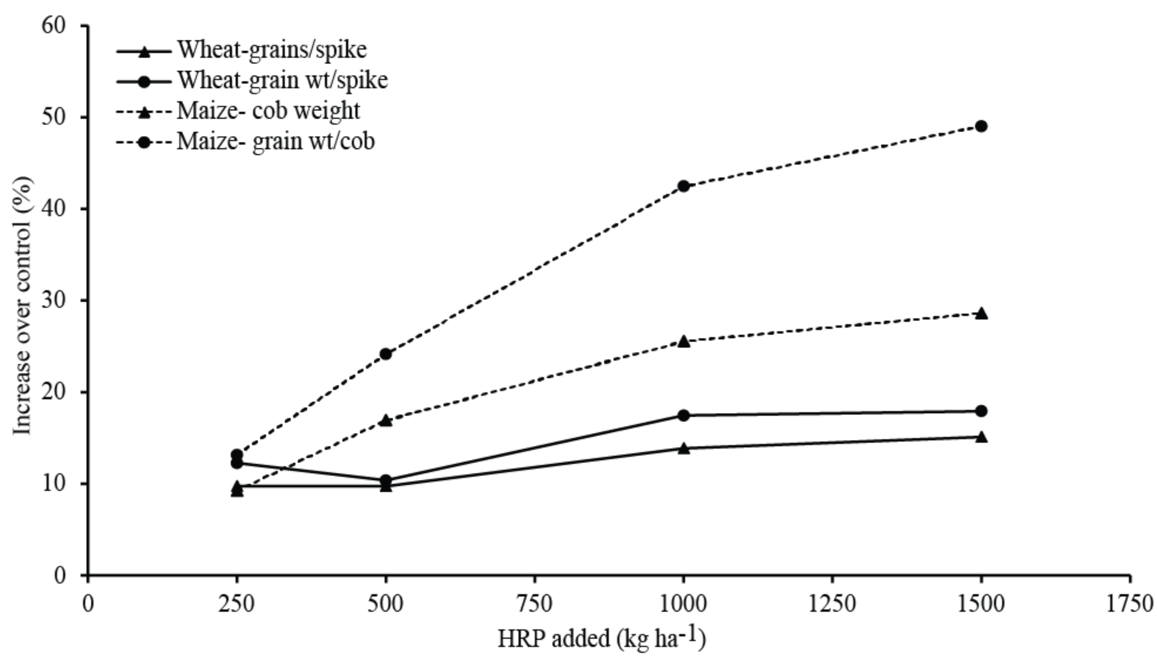

Fig. 2. Influence of HRP on number of grains and grain weight spike^{-1} of wheat in the first season and cob weight and grain weight cob^{-1} of residual maize in alkaline calcareous conditions.

Table 3. Water soluble P at different stages of wheat and succeeding maize crop as influenced by HRP added to silty clay loam calcareous soil.

Rock phosphate (kg ha^{-1})	Wheat			Maize		
	Tillering	Anthesis	Post-harvest	Knee height	Silking	Post-harvest
	(mg kg^{-1})					
0	0.21 b	0.29 c	0.13 c	0.43 b	0.13 c	0.26 c
250	0.81 ab	0.53 b	0.52 b	0.47 ab	0.17 bc	0.36 bc
500	0.75 a	0.85 b	0.85 a	0.48 ab	0.18 b	0.37 bc
1000	1.12 a	1.20 ab	0.81 ab	0.54 ab	0.23 a	0.38 b
1500	1.24 a	1.31 a	0.88 a	0.57 a	0.26 a	0.51 a
LSD ($p<0.05$)	0.61	0.44	0.29	0.12	0.048	0.10

*Means followed by same letter (s) in a column do not differ at $p<0.05$

Table 4. Total P uptake by wheat and maize crops (kg ha^{-1}).

Rock phosphate (kg ha^{-1})	P uptake (kg ha^{-1})			
	Wheat	% increase over control	Maize	% increase over control
0	15.63 b		14.67 c	
250	18.25 a	16.8	16.71 bc	13.9
500	19.81 a	26.7	20.39 abc	39.0
1000	19.25 a	23.2	21.85 ab	48.9
1500	19.76 a	26.4	24.45 a	66.7
LSD ($p<0.05$)	2.46		6.09	

* Means followed by same letter (s) in a column do not differ at $p<0.05$

In succeeding maize crop which did not receive HRP, the significantly higher (33 %) WSP concentration than control at knee height stage was observed only with HRP 1500 kg ha^{-1}. At silking stage the WSP with 500, 1000 and 1500 kg ha^{-1} HRP was significantly higher than that of control. The 250 kg ha^{-1} HRP was statistically similar to HRP 500 kg ha^{-1} as well as to control. The maximum increase of 108 % over control was recorded with 1500 kg ha^{-1} followed by 79% with HRP 1000 kg ha^{-1}. Like wheat season, the overall WSP concentrations decreased at post-harvest stage as compared to earlier stages of knee height. At the end of study (post-harvest), the significantly higher WSP was maintained by HRP 1000 and 1500 kg ha^{-1} with the values of 0.38 and 0.51 mg kg^{-1}, against 0.26 mg kg^{-1} in control plots, respectively. It confirmed that HRP can slowly release WSP for several succeeding crops into the soil solution as reported by earlier researchers.

The water soluble P (WSP) concentrations showed a linear relationship with the levels of HRP both in wheat and maize crops irrespective of growth stages. Similar results have been reported by Ahmad *et al*., (2013) in the same study area while evaluating the best level of WSP fertilizer for maize crop. The dissolution pattern of HRP observed in this study was found similar to the kinetics of RP dissolution as described by Anon., (2004) in their fertilizer and plant nutrition bulletin. According to this report the RP dissolves in two phases, during the first phase, RP dissolves at faster rate providing short term efficient supply while the second phase is slow dissolution phase which realizes the long term effects of RP applications. Ghosal *et al*., (2013) also found higher concentrations of available P from a non-reactive MRP in second year than in the third soil solution. They also found a good reserve of soil available P after three cropping seasons with application of high doses of MRP as compared to control. It was further reported that mineral dissolution of RPs is not an immediate process and depends on certain factors which make their residual effect usually superior to the short term effect. Akintokun *et al*., (2003) reported a substantial residual contribution of available P with the application of rock phosphate sources. Takeda & Knight (2003) stated that high pH and $CaCO_3$ in calcareous soils limit the effectiveness of RPs. However, plant and microbial exudates acidify the rhizosphere by producing (H+) as a result of cation uptake consequently increasing the availability of P in the rhizosphere.

The soil used in this study is strongly calcareous containing 16 % $CaCO_3$ with pH value of 8.6. Therefore the process of formation of insoluble Ca-phosphate simultaneously takes place and slow release of P by HRP attains critical role in crop production.

Phosphorus uptake by wheat and residual maize: The P uptake by wheat crop significantly increased with all HRP treatments over control (Table 4). Application of 250 kg HRP ha^{-1} produced uptake of 18.25 kg P ha^{-1}

against the 15.63 kg P ha^{-1} in control while additional HRP rates showed slight non-significant increases.

In residual maize, each increment of HRP levels demonstrated higher total P uptake than the corresponding lower levels. Although in some cases these differences were not significant ($p<0.05$), application of 250, 500, 1000 and 1500 kg ha^{-1} resulted in 13.9, 39.0, 48.9 and 66.7 % increases over control, respectively. The increase in total P uptake over control was more in residual maize than fresh wheat as commonly reported for yield. The higher P uptake by residual maize corroborates the phenomenon of slow releases from HRP to the succeeding crop in adequate amount throughout the growing season.

Phosphorus uptake is the amount of P taken up by plants to produce a particular biomass. The higher uptakes by wheat and maize crops as compared to control in the present study indicated that the applied HRP was dissolved, though slowly, and has fulfilled the crops requirements up to an extent. The dissolution of HRP could be associated to acidifying effect of wheat and maize roots which would have solubilized the HRP in the rhizosphere. Dissolution of RP through root acidification has been reported by several researchers including Ramirez *et al*., (2001), Flach *et al*., (1987), and Hoffland *et al*., (1989). Gill *et al*., (1994) also reported the same mechanism and stated that the ATPase pumps in the plasma membrane released protons during nutrient uptake which solubilized P from RP to fulfill plant growth requirements. It was observed that plant P uptake of wheat cultivar increased with decrease in pH of root medium which was assumed to be due to H+ efflux from their roots. The work of Liu *et al*., (2004) also reflected the same mechanism for P uptake. It was found that the dissolution of RP was significantly higher in rhizosphere soil as compared to bulk soil probably due to acidification, higher alkaline phosphatase activities and oxlate production in the rhizosphere. Ashraf *et al*., (2009) compared seven wheat varieties in hydroponics for their ability to utilize RP and found that some varieties dissolved and utilized P from RP efficiently through acidifying effect of their roots. The role of naturally occurring phosphate solubilizing soil microorganisms (PSM) in dissolving HRP in the present study can also not be ignored as the dissolution of insoluble P has been reported in a substantial research work since long (Sharif *et al*., 2013; Yaseen *et al*., 2013; Ziadi *et al*., 2009; Sims & Pierzynski; 2005, Maliha *et al*., 2004; Whitelaw, 2000 & Goldstein, 1994).

Conclusion

Hazara rock phosphate (HRP) has the potential to maintain better crop yields but might not compete with commercial water soluble P fertilizers in achieving greater productions especially from high yielding hybrid varieties of wheat and maize in alkaline calcareous soils. In view of the substantial increases in wheat yield and subsequent maize yield its utilization may be encouraged in areas where consumption of costly WSP fertilizers has drastically declined due to their unaffordable prices. The high levels of HRP can prove much beneficial in terms of crop yields especially in residual crops but due to slow dissolution, for high fertilizer efficiency HRP may be supplemented with basal fertilizer dose or used with some acidification in high pH calcareous soil.

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