Research Article

Effect of Rock Phosphate Augmented with Humic Acid on Phosphorus uptake and Yield of Wheat (*Triticum aestivum L.*)

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Abstract | Various organic materials like humic acid (HA) can be used to enhance P availability from rock phosphate (RP). To investigate the effect of RP augmented with two levels of HA on the productivity of wheat and P uptake, a field trial was conducted. Treatments used were Control (No RP, No HA), rock phosphate alone (RP), RP mixed with HA @ 5 Kg ha^{-1} (RP+HA-5) and RP mixed with HA @ 10 Kg ha^{-1} (RP+HA-10) and were replicated 3 times randomly in Complete Block Design. Addition of RP significantly increased soil P_2O_5 content, P uptake, total dry matter, grains, and straw yield of wheat over control. Whereas application of RP with increasing amount of HA augmentation further increase these soil and crop parameters over RP alone. The increase in soil P_2O_5 content, P uptake, grains, total dry matter, and straw yield of wheat was in the order RP+HA-10 > RP+HA-5 > RP > Control. This study conclude that RP can be used as P fertilizer efficiently when HA is mixed with it in order to increase P availability, nutrient uptake and wheat productivity.

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Keywords | Rock phosphate, Humic acid, P uptake, Grain yield, Wheat crop

Introduction

Nutrient deficiency is considered a main constraint to crop productivity in Pakistan. After nitrogen, phosphorus deficiency is most widely spread in soils (Balemi and Negisho, 2012). About 80 % soils are accounted for phosphorus (P) deficiency in Pakistan (Nasir *et al*., 1990). Main causes of deficiency of P in these soils are the soils derived from P deficient parent materials or the soils were mined due to the inclusion of exhaustive crops in intensive agriculture without the addition or low application of P from both organic and inorganic fertilizers. To overcome P deficiency in soil, P fertilizers are required for crop production to produce better yield, but P fertilizers are very expensive and has become a big constraint to use P fertilizers as per recommendation. The recent hike up in prices of fertilizers especially that of P fertilizers has further aggravated the problem.

Natural phosphate rocks have been recognized as a valuable alternative for P fertilizer. Rock phosphate is relatively cheap and environmentally friendly as compared to chemical fertilizers. It increases C accumulation, exchangeable Ca, and Mg in soils (Hu *et al*., 1996). Rock phosphate (RP) contains at least 15 to 20% total P which is in the form of tri-calcium phosphate with only a negligible amount of P available when applied to soil. It is mainly used to produce phosphatic fertilizers for the agriculture sector. In Pakistan, rock phosphate deposits are found in Hazara, which is a raw source for phosphate fertilizer production in Pakistan. P solubility from rock phosphate may be increased by augmenting rock phosphate with different organic sources (Sharif *et al*., 2015; Hanafi and Selwa, 1998; Martinez *et al*., 1984). Organic sources contain different types of organic acids which react with the insoluble tri-calcium phosphates and convert it to di and mono-basic phosphates which is soluble in water and available for plant uptake. The amount of P solubilized from RP is strongly affected by using different organic sources because they contain different types and amount of organic acids.

Complex process of chemical and biological transformation of organic matter in soil result in humus formation which contains complex types of organic molecules called humic acids. Humic acids can also be derived from lignite coal (Karaca *et al*., 2006). Humic acids consists of carboxylic (COOH–), phenolic (OH–), alcoholic and carbonyl fractions which act on phosphate ions and increase its availability from RP thus preventing P precipitation and fixation in alkaline soils (Hua *et al*., 2008). Therefore, under saline and high lime content of soils, HA enhances nutrient availability making the soil more fertile and productive thus enhancing nutrient uptake resulting in improved plant performance (Osman and Rady, 2012; Asik *et al*., 2009; Katkat *et al*., 2009; Çelik *et al*., 2008). HA application also improve physical condition of calcareous soils by improving aggregate stability which results in improved soil biological condition, ion exchange capacity and water holding capacity. Improved soil physical condition enhances plant root proliferation, nutrient mobility to plant roots and improved uptake (Mahmoud *et al*., 2011).

Wheat is on top position in major crops of Pakistan. It covers about 40% of the cultivated area of the country and about 80% farmers grow it. Almost all crop rotations of the country contain wheat. in Pakistan, of the total food energy intake, 37% is obtained from wheat. Average wheat yields in Pakistan is 2765 kg ha^{-1} which is far below the potential yield and as well as from the yield of other countries having almost the same agroclimatic conditions. The main constraint to cover this yield gap is low organic matter and soil nutrient deficiencies.

Considering RP and HA as an important indigenous and economical source of fertilizer, this study was initiated to determine the effect of RP augmented with different levels of HA on the yield and P availability and uptake of wheat crop.

Materials and Methods

Rock phosphate (RP) with and without the augmentation of different doses of humic acid (HA) were evaluated in a field trial at the research farm of Agriculture Research Institute Tarnab Peshawar in rabi season 2011–2012. RP was augmented with HA @ 5 and 10 Kg ha^{-1} and randomized in complete block design (RCBD). The treatments combinations were Control (No fertilizers); Rock Phosphate (RP); RP+HA–5 (Rock Phosphate applied with Humic Acid (HA) @ 5 Kg ha^{-1}); and RP+HA–10 (Rock Phosphate applied with Humic Acid (HA) @ 10 Kg ha^{-1}).

In total number of 12 plots, Pir Sabaq-2000 variety of wheat was grown using a seed rate of 100 Kg ha $^{-1}$ with the help of tractor driven drill. Plot size of 6×7.5 m^2 was kept with a row to row distance of 30 cm. N, P and K fertilizers were used at the rate of 120–90–60 Kg ha^{-1}, respectively. Before drilling the seed, soil was prepared with cultivator by driving 2 times and after cultivator, rotavator was used to get the soil surface smooth for seed drilling. All the P and K was applied at the time of sowing before seed drilling while N was used in split doses *i.e*. one half at the time of sowing and other half after 2 months of germination. All other management and plant protection practices were carried out uniformly throughout the season for optimum crop growth.

Soil sampling and analysis

Before sowing of wheat, randomly three samples were collected from the experimental area at 0–20 cm soil depth. All the three samples were mixed properly to get a uniform soil sample. A portion from it in the form of composite soil sample was taken into a plastic bag and taken to the laboratory for analysis. The composite soil sample was analyzed for Soil texture (Koehler *et al*., 1984), pH and EC (Soltanpour and Workman, 1981), Soil organic matter (Nelson and Sommers, 1996), Lime content (Ryan *et al*., 2001), Total N (Helrich, 1995), Soil P and K (Soltanpour and Workman, 1979) were determined.

Plant sampling and analysis

At crop maturity, one-meter square area from each treatment was harvested. Dried in oven at 64°C for three days. Total dry biomass/matter was recorded. Grains from biomass were threshed manually and grain weight was recorded. For straw yield, grain weight was subtracted from total biomass. Data on total biomass, grain and straw was converted to Kg ha^{-1}.

After harvesting of wheat, composite soil samples from the surface soil (0–20 cm soil depth) of each plot were collected. Soil samples were analyzed for NO_3-N, P_2O_5 and K_2O contents. Plant samples of straw and grains were also analyzed for total N by Kjeldahl method (Bremner, 1982). P and K concentrations by wet digestion method (Walsh and Beaten, 1977). Nutrient uptake was calculated by multiplying straw and grain yields with their nutrient concentrations and total nutrient uptake was calculated by adding nutrient uptakes of straw and grains.

Statistical analysis

Analysis of variance was applied to the data collected on soil nutrient content, plant nutrient uptake and yield by using MSTATC statistical package. Means of the data were separated using DMR test. Graphs were made in Microsoft Excel 365.

Results and Discussion

Properties of Soil, Rock Phosphate and Humic Acid

Soil under use was calcareous having alkaline pH (7.96) with low EC (0.16 dS m^{-1}). Texture of the soil was silty clay loam with a low soil organic carbon (0.51%). Soil was deficient in total N (0.08%) and soil available P (5.75 mg kg^{-1}). Rock Phosphate applied has 22% total P_2O_5, 0.001% extractable P_2O_5 having pH of 7.92. Humic acid used was contained 3.15% N, 0.18% P and had pH of 7.75.

Soil P, N and K content

Soil P_2O_5, NO_3-N and K_2O contents at post-harvest of wheat are given in Table 1. Soil P_2O_5 content was significantly (p=0.0061) affected by Rock Phosphate application with and without Humic Acid. RP alone significantly increased soil P content by 87% as compared to control which was further increased significantly by 41% when Rock Phosphate combined with 5 Kg ha^{-1} of Humic Acid (RP+HA-5) was applied as compared to RP treatment. When the rate of humic acid augmentation of rock phosphate was increased two-fold (RP+HA-10), P availability further increased with statistically non-significant differences. This increase was only 7% in P availability over RP+HA-5 treatment. These finding agree that organic amendments enhance P availability in calcareous soils (Struthers and Sieling, 1950; Awad and Al-Obaidy, 1989). Sharif *et al.* (2015) also reported significant increase in soil P content when applied with either poultry manure or farmyard manure. Dissociation of H^+ and OH^- from the molecular structure of humic acid in calcareous soils gives rise to the cation exchange sites on the functional groups resulting in chelation of cations which increase solubility of rock phosphate instead of being precipitated with cations (Martinez *et al.*, 1984; Hanafi and Selwa, 1998).

Table 1: *Soil P, N and K concentrations under RP with and without different levels of Humic Acid.*

Treatments	P_2O_5 (mg Kg^{-1})	NO_3-N	K_2O
Control	3.26 c	10.81	123
RP	6.12 b	11.22	122
RP+HA-5	8.63 a	13.33	130
RP+HA-10	9.26 a	15.11	133
LSD ($p \leq 0.05$)	1.371	NS	NS

Means with different letter(s) in columns are significantly different at p ≤ 0.05. Where RP, rock phosphate; RP+HA-5, rock phosphate with humic acid @ 5 Kg ha^{-1}; RP+HA-10, rock phosphate with humic acid @ 10 Kg ha^{-1}.

Both soil NO_3-N and K_2O contents were not significantly (p=0.0598 and 0.0713) affected with treatments. Whereas both soil NO_3-N and K_2O contents were gradually increased with the increasing augmentation of treatments with humic acid. In the treatment where rock phosphate augmented with 5 Kg ha^{-1} of humic acid (RP+HA-5) was applied, soil NO_3-N content was increased by 23% and K_2O content by 6% over control. When rock phosphate mixed with 10 Kg ha^{-1} of humic acid (RP+HA-10) was applied, soil NO_3-N content was further increased by 13% and that of soil K_2O content by 2% over the treatment RP+HA-5. Therefore, these finding showed that increase in soil NO_3-N and K_2O contents were due to the application of humic acid. Sharif *et al.* (2015; 2010) also recorded significantly high soil NO_3-N content over control by applying farmyard manure and humic acid to soil. The increase in soil NO_3-N content due to the application of Rock Phosphate combined with Humic Acid might be attributed to the N content of humic acid which releases it in soil. Whereas increase in K_2O content might be because of the dissociated functional groups of humic acid in calcareous soils which gives rise to the cation exchange sites resulting in chelation of cations which protect the cations from precipitation and slowly release them to increase their availability.

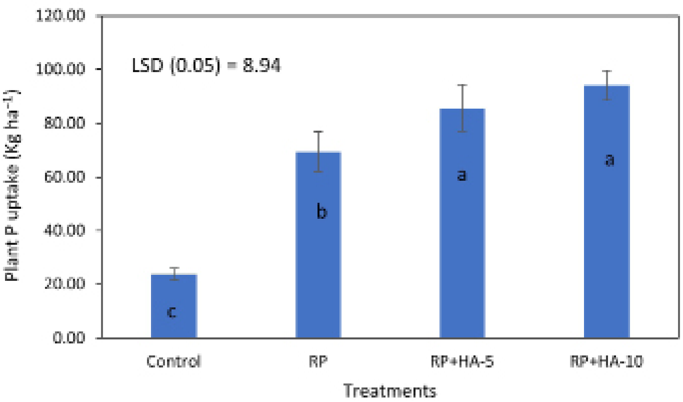

Figure 1: *Effect of rock phosphate with and without different levels of humic acid on P uptake by wheat. Where RP, rock phosphate; RP+HA-5, rock phosphate with humic acid @ 5 kg ha^{-1}; RP+HA-10, rock phosphate with humic acid @ 10 Kg $^{ha-1}$. Bars having different letter(s) are significantly different at $P \leq 0.05$.*

Plant P, N and K uptake

Rock phosphate significantly (p=0.0083) increased plant P uptake either applied alone or in combination with humic acid (Figure 1). All the three treatments i.e rock phosphate alone or mixed with two levels of humic acid gradually increased P uptake in wheat in the order RP+HA-10 > RP+HA-5 > RP as compared to control. RP increased P uptake by 193% over control. When humic acid was mixed with RP @ 5 Kg ha^{-1} (RP+HA-5), it further significantly increased P uptake by 23% over RP treatment. As the humic acid level mixed with RP was increased to 10 Kg ha^{-1} (RP+HA-10), the P uptake was further increased by 10% which was at par with RP+HA-5. Taalab *et al.* (2008) also reported increased P uptake when rock phosphate was applied combined with organic fertilizers. Enhanced P uptake in plant by applying humic acid and P fertilizers to soil were also observed by Erdal *et al.* (2000). Belal *et al.* (2019) also reported increase in P uptake in barley tissue with the application of humic acid. This increase in P uptake by plant may be due to the high availability of P in soil because nutrient uptake in plant tissues depends on soil available nutrients and their ease of mobility towards roots (Belal *et al.*, 2019; Mahmoud *et al.*, 2011). Humic acid improve soil fertility and increases nutrient availability (Osman and Rady, 2012; Rady, 2011) due to the humic acid role in enhancement of processes involved in nutrient uptake and movement within plant tissues (Nardi *et al.*, 2002) thus increasing the uptake of nutrients by wheat plant. Sharif *et al.* (2015) noted the highest P uptake in experimental plots where Rock Phosphate and farm yard manure were applied.

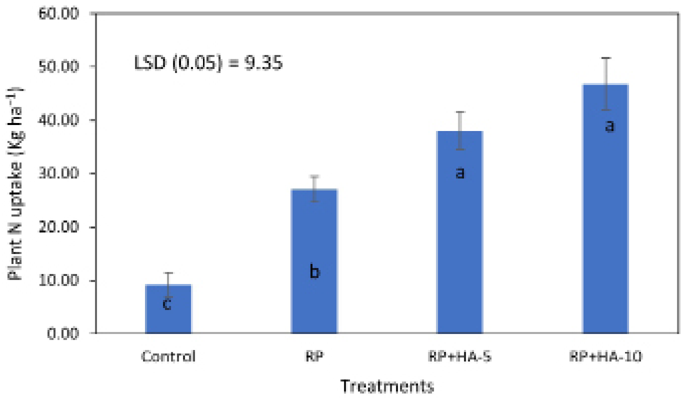

Figure 2: *Effect of rock phosphate with and without different levels of humic acid on N uptake by wheat. Where RP, rock phosphate; RP+HA-5, rock phosphate with humic acid @ 5 kg ha^{-1}; RP+HA-10, rock phosphate with humic acid @ 10 Kg $^{ha-1}$. Bars having different letter(s) are significantly different at $P \leq 0.05$.*

Plant N uptake under different treatments of rock phosphate and humic acid was also significantly (p=0.0221) affected (Figure 2). RP alone significantly increased plant N uptake by 194% as compared to control. Whereas humic acid treated rock phosphate further increased plant N uptake significantly as compared to RP alone treatment. Rock phosphate treated with humic acid @ 5 Kg ha^{-1} (RP+HA-5) increased plant N concentration by 41% over RP treatment which was further increased by 23% when humic acid was mixed with rock phosphate @10 Kg ha^{-1} (RP+HA-10). The significant increase of N uptake in wheat tissue under RP treatments might be due to the synergistic effect of high available soil P_2O_5 content on the N absorption and translocation within plant (Sumner and Farina, 1986; Terman *et al.*, 1977). Mutual synergistic effects of both P and N stimulate plant growth resulting in enhanced uptake of these nutrients (Sumner and Farina, 1986). In the humic acid augmented treatments, further significant increase in plant N uptake is due to the synergistic effect of more and more soil P availability and due to humic acid which releases itself N into soil and also stimulate root absorption capacity for nutrients (Mahmoud *et al.*, 2011). Similar results were observed by Erdal *et al.* (2000) that nutrients uptake by plants were increased by integrated use of chemical fertilizers with organic materials. Increased accumulation of N in plant was observed when rock phosphate mixed with organic fertilizers was applied (Taalab *et al*., 2008). N uptake by plants was also increased significantly in a study conducted by Awaad *et al.* (2009) using rock phosphate mixed with organic fertilizers. Sharif *et al.* (2015) observed similar results and noted higher N uptake by wheat plants when applied rock phosphate mixed with farmyard manure. This increase in N uptake may be attributed to the increased availability of N in soil because nutrient uptake by plant tissues depends on soil nutrients availability and their ease of mobility towards roots (Belal *et al*., 2019; Mahmoud *et al*., 2011).

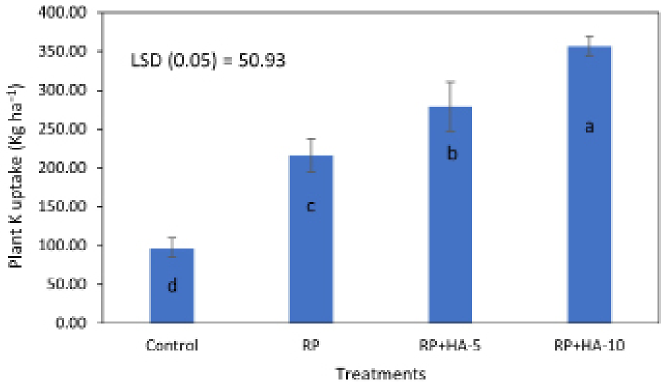

Figure 3: *Effect of rock phosphate with and without different levels of humic acid on K uptake by wheat. Where RP, rock phosphate; RP+HA-5, rock phosphate with humic acid @ 5 kg ha*$^{-1}$*; RP+HA-10, rock phosphate with humic acid @ 10 Kg ha*$^{-1}$ *Bars having different letter(s) are significantly different at P ≤ 0.05.*

Plant K uptake was also significantly (p=0.0131) affected by different treatments (Figure 3). Rock Phosphate alone (RP treatment) significantly increased plant K uptake by 122% as compared to control. The significant increase in K uptake in wheat under RP treatment might be due to the balanced availability of N and P with K in soil. Balanced nutrition availability to plants enhances nutrients uptake by plant due to the interactive synergistic effect of nutrients (Fageria, 2001). Li *et al.* (2019) and Wang *et al.* (2011) also reported similar results that at low or optimum application rates the interaction between P and K is synergistic. Plant K concentration was also significantly increased by rock phosphate applied in combination with humic acid as compared to both RP and control treatments. Rock Phosphate combined with 5 Kg ha^{-1} of Humic Acid (RP+HA-5) increased plant K uptake by 29% over RP treatment. When Rock Phosphate was applied along with 10 Kg ha^{-1} of Humic Acid (RP+HA-10), plant K uptake was further increased significantly by 28% as compared to the treatment RP+HA-5. But the increase in plant K uptake among rock phosphate treatments may be attributed to humic acid application which increased soil K_2O content due to the dissociation of H^+ and OH^- from the molecular structure of humic acid in calcareous soils. The dissociation of H^+ and OH^- from the molecular structure of humic acid in calcareous soils resulting in chelation of cations which protect the cations from precipitation and slowly release them to increase their availability in soil. Therefore, increase in K uptake may be attributed to the increased availability of K in soil because nutrient uptake by plant depends on soil available nutrients and their ease of mobility towards roots (Belal *et al*., 2019; Mahmoud *et al*., 2011).

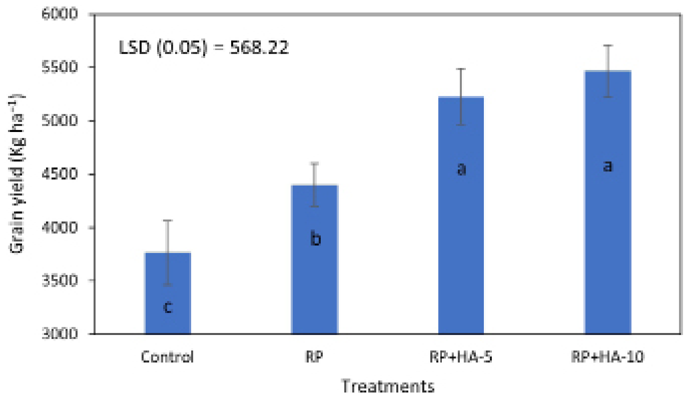

Figure 4: *Effect of rock phosphate with and without different levels of humic acid on grain production of wheat. Where RP, rock phosphate; RP+HA-5, rock phosphate with humic acid @ 5 kg ha*$^{-1}$*; RP+HA-10, rock phosphate with humic acid @ 10 Kg ha*$^{-1}$ *Bars having different letter(s) are significantly different at P ≤ 0.05.*

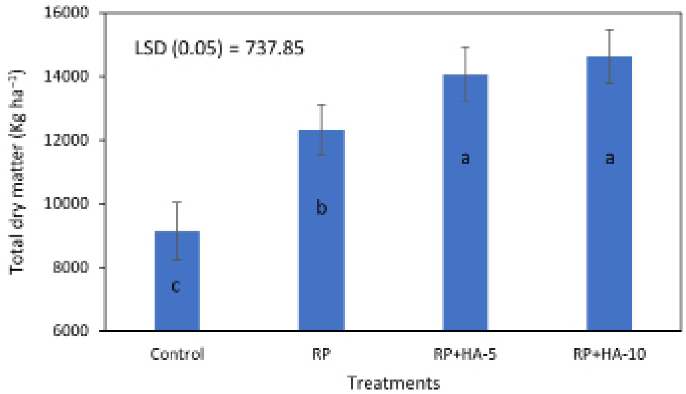

Figure 5: *Effect of rock phosphate with and without different levels of humic acid on total dry matter production of wheat. Where RP, rock phosphate; RP+HA-5, rock phosphate with humic acid @ 5 kg ha*$^{-1}$*; RP+HA-10, rock phosphate with humic acid @ 10 Kg ha*$^{-1}$ *Bars having different letter(s) are significantly different at P ≤ 0.05.*

Grains, Straw and Total Dry matter yield

Application of Rock Phosphate (RP) significantly (p=0.0034; p=0.0113; p=0.0072) increased grain, total dry mater and straw yield of wheat (Figure 4, 5, and 6) over control. RP increased grain, total dry mater, and straw yield of wheat by 17, 35 and 47% over control, respectively. When Rock Phosphate was applied combined with Humic Acid, these yield parameters were further increased significantly. Rock Phosphate with 5 Kg ha^{-1} of Humic Acid (RP+HA-5) increased grain yield by 19%, total dry matter by 54% and straw yield by 64% over RP treatment. Whereas Rock Phosphate with 10 Kg ha^{-1} of Humic Acid (RP+HA-10) furthermore increased 5, 4 and 4% in grain, total dry mater and straw yield of wheat respectively as compared to treatment RP+HA-5 which was a statistically non-significant increase. Similar results have been reported by Phiri *et al.* (2010), Awaad *et al.* (2008), and Sharif *et al.* (2015, 2014 and 2013) who found a significant increase in wheat grain yield with the application of rock phosphate mixed with humic acid. A prominent increase in total dry matter of wheat with the application of rock phosphate with humic acid and other organic sources (Amanullah *et al.*, 2010; Awaad *et al.*, 2008). Ibrahim *et al.* (2008) and Phiri *et al.* (2010) also reported a significant increase in wheat yield when used Rock Phosphate with various organic materials. This increase in wheat yield is attributed to the enhanced availability of nutrients in soil resulting in increased nutrients uptake.

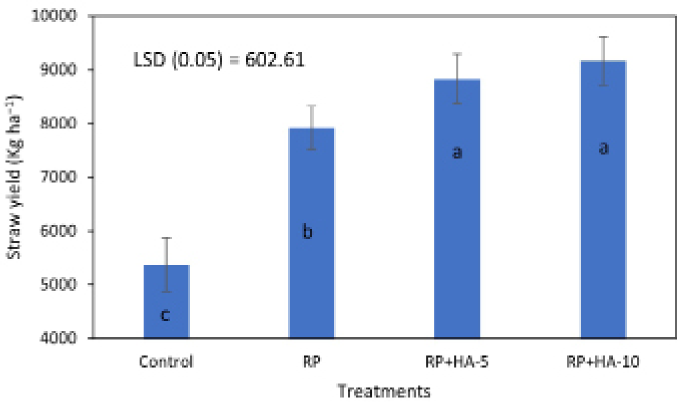

Figure 6: *Effect of rock phosphate with and without different levels of humic acid on straw production of wheat. Where RP, rock phosphate; RP+HA-5, rock phosphate with humic acid @ 5 kg ha^{-1}; RP+HA-10, rock phosphate with humic acid @ 10 Kg ha^{-1} Bars having different letter(s) are significantly different at $P \leq 0.05$.*

Conclusions and recommendations

Humic acid increased P availability from rock phosphate in soil which increased N, P and K uptake and yield of wheat. The results of this study proved that rock phosphate can be used as P source when augmented with humic acid and has a potential to enhance crop production. More research work is needed to investigate the degree and extent of P solubility from RP by mixing with different organic material and determine their effect on yield and P uptake of different crops in various agro-ecological zones of Pakistan.

Novelty Statement

Humic acid enhances P release in soil from rock phosphate and has potential to enhance crop production.

Author's Contribution

Sonia Sumreen: Contributed to the paper.
Muhammad Sharif: Supervised the experimental trial.
Tariq Sultan: Proof read and suggested in manuscript write-up
Ijaz Ali: Analyzed Data and wrote manuscript.

Conflict of interest

The authors have declared no conflict of interest.

References

Amanullah, M. Asif and K. Nawab. 2010. Impact of phosphatic fertilizer source on the growth analysis of maize. Pak. J. Bot., 42: 2349–2357.

Asik, B.B., M.A. Turan, H. Celik and A.V. Katkat. 2009. Effects of humic substances on plant growth and mineral nutrients uptake by wheat (*Triticum Durum* L. Salihli cv.) under conditions of salinity. Asian J. Crop Sci., 1(2): 87–95. https://doi.org/10.3923/ajcs.2009.87.95

Awaad, M.S., A.A. Rashad and M.A. Bayoumi. 2009. Effect of Farmyard Manure Combined with Some Phosphate Sources on the Productivity of Canola Plants Grown on a Sandy Soil. Res. J. Agric. Biol. Sci., 5(6): 1176–1181.

Awad, K.M. and K.S. Al-Obaidy. 1989. Effect of organic residues on phosphate adsorption by some calcareous soils. Mesopotamia J. Agric., 21: 53–67.

Balemi, T. and L. Negisho. 2012. Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. J. Soil Sci. Plant Nutr., 12(3): 547–562. https://doi.org/10.4067/S0718-95162012005000015

Belal, E.E., D.M. El-Sowfy and M.M. Rady. 2019. Integrative Soil Application of Humic Acid and Sulfur Improves Saline Calcareous Soil Properties and Barley Plant Performance. Commun. Soil Sci. Plant Anal., 50(15): 1919–1930. https://doi.org/10.1080/00103624.2019.1648497

Bremner J.M. 1982. Nitrogen-Total. P. 1085-1121. In: D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnston and M. E. Sumner. Methods of Soil Analysis: Part 3 Chemical Methods. American Society of Agronomy. Madison.

Çelik, H., A.V. Katkat, B.B. Aşık and M.A. Turan. 2008. Effects of soil application of humus on dry weight and mineral nutrients uptake of maize under calcareous soil conditions. Arch. Agron. Soil Sci., 54(6): 605–614. https://doi.org/10.1080/03650340802294303

Erdal, I., M.A. Bozkurt, K.M. Cimrin, S. Karaca and M. Salgam. 2000. Effects of humic acid and phosphorus fertilizer application on growth phosphorus uptake of maize (*Zea mays* L.) grown on a calcareous soil. Turk. J. Agric. For., 24(6): 663–668.

Fageria, V.D. 2001. Nutrient interactions in crop plants. J. Plant Nutr., 24(8): 1269–1290. https://doi.org/10.1081/PLN-100106981

Hanafi, M.M. and H. Salwa. 1998. Influence of HA Addition on Soil Properties and Their Adsorption. Commun. Soil Sci. Plant Anal., 29 (11–14): 1933–1947. https://doi.org/10.1080/00103629809370083

Helrich, K. (ed.). 1995. Official Methods of Analysis of the AOAC. Association of Official Analytical Chemists, Arlington, VA, USA.

Hu Hong-Qing, Li Xue-Yuan, Liu Jung-Fu, Xu Feng-Lin, Liu Jungand Liu Fan. 1996. The effect of direct application of phosphate rock on increasing crop yield and improving properties of red soil. Nutr. Cycling Agroecosyst., 46: 235–239. https://doi.org/10.1007/BF00420558

Hua, Q.X., J.Y. Li, J.M. Zhou, H.Y. Wang, C.W. Du and X.Q. Chen. 2008. Enhancement of phosphorus solubility by humic substances in ferrosols. Pedosphere, 18: 533–538. https://doi.org/10.1016/S1002-0160(08)60044-2

Ibrahim, M., Anwar-ul-Hassan, M. Iqbal and E.E. Valeem. 2008. Response of wheat growth and yield to various levels of compost and organic manure. Pak. J. Bot., 40(5): 2135–2141.

Karaca, A., O.C. Turgay and N. Tamer. 2006. Effects of a humic deposit (gyttja) on soil chemical and microbiological properties and heavy metal availability. Biol. Fertil. Soils, 42: 585–592. https://doi.org/10.1007/s00374-005-0056-3

Katkat, A.V., H. Celik, M.A. Turan and J.B.B. Asik. 2009. Effect of soil and foliar application of humic substances on dry weight and mineral uptake of wheat under calcareous soil conditions. Aust. J. Basic Appl. Sci., 3 (2): 1266–1273.

Koehler, F.E., C.D. Moudre and B.L. McNeal. 1984. Laboratory manual for soil fertility. Washington State University Pluman, USA.

Li, Z., R. Zhang, S. Xia, Li Wang, C. Liu, R. Zhang, Z. Fan, F. Chen and Yi Liu. 2019. Interactions between N, P and K fertilizers affect the environment and the yield and quality of satsumas. Global Ecol. Conserv., 19: e00663. https://doi.org/10.1016/j.gecco.2019.e00663

Mahmoud, M.M., A.H.A. Hassanien, S.F. Mansour and A.M. Khalefa. 2011. Effect of soil and foliar application of humic acid on growth and productivity of soybean plants grown on a calcareous soil under different levels of mineral fertilizers. J. Soil Sci. Agric. Engin. Mansoura, 2(8): 881–90. https://doi.org/10.21608/jssae.2011.55674

Martinez, M.T., C. Romero and J.M. Gavilon. 1984. Solubilization of phosphorus by humic acids from lignite. Soil Sci., 138: 257–261. https://doi.org/10.1097/00010694-198410000-00001

Nardi, S., D. Pizzeghello, A. Muscolo and A. Vianello, 2002. Physiological effects of humic substances on higher plants – A review. Soil Biol. Biochem., 30 (5&6): 621–634. https://doi.org/10.1080/00103629909370232

Nasir A., S.M. Tahir and I.J. Twyford. 1990. Symposium on the role of Phosphorus in crop production. Islamabad, Pakistan.

Nelson D.W., L.E. Sommer, 1982. Total carbon, organic carbon and organic matter. p. 539-577. In A.L. Page., R.H. Miller and D.R. Keeny, (ed) Methods of Soil Analysis, Part 2 2nd edition. American Society of Agronomy. Madison. World International Organization, New Delhi, India.

Osman, A.S. and M.M. Rady. 2012. Ameliorative effects of sulphur and humic acid on the growth, antioxidant levels, and yields of pea

(Pisum sativum L.) plants grown in reclaimed saline soil. J. Hort. Sci. Biotech., 87 (6): 626-32. https://doi.org/10.1080/14620316.2012.11512922

Phiri, A.T., P.N. Joyce, Y.K. George, S. Sieglinde and W.L. Max. 2010. Maize yield response to the combined application of Tundulu rock phosphate and Pigeon Pea residues in Kasungu, Central Malawi. African J. Agric. Res., 5(11): 1235-1242.

Rady, M.M. 2011. Effects on growth, yield, and fruit quality in tomato (Lycopersicon esculentum Mill.) using a mixture of potassium humate and farmyard manure as an alternative to mineral-N fertiliser. J. Hort. Sci. Biotech, 86: 249-54. https://doi.org/10.1080/14620316.2011.11512757

Ryan, J., G. Estefan and A. Rashid. 2001. Soil and Plant Analysis Laboratory Manual. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. 172 p.

Sharif, M., M.Arif, T. Burni, F. Khan, B. Jan and I. Khan. 2014. Growth and P uptake of sorghum plants in salt affected soil as affected by organic materials composted with rock phosphate. Pak. J. Bot., 46(1): 173-180.

Sharif, M., M. Khan, M. A. Khan, F. Wahid, K.B. Marwat, A.M. Khattak and M. Naseer. 2015. Effect of rock phosphate and farmyard manure applied with effective microorganisms on the yield and nutrient uptake of wheat and sunflower crops. *Pak.* J. Bot., 47(SI): 219-226.

Sharif, M., T. Burni, F. Wahid, F. Khan, S. Khan, A. Khan and A. Shah. 2013. Effect of rock phosphate composted with organic materials on yield and phosphorus uptake of wheat and mung bean crops. Pak. J. Bot., 45(4): 1349-1356.

Soltanpour, P.N. and S.M. Workman. 1979. Modification of the NH_4HCO_3-DTPA soil test to omit carbon black. Comm. Soil Sci. Plant Anal., 10: 1411–1420. https://doi.org/10.1080/00103627909366996

Soltanpour, P.N. and S.M. Workman. 1981. Soil testing methods used at Colorado State University Soil Testing Laboratory for the evaluation of fertility, salinity, sodicity and trace element toxicity. Colorado State University Experiment Station, Fort Collins, CO., USA. Technical Bulletin. pp. 142, 22.

Struthers, P.H. and D.H. Sieling. 1950. Effect of organic anions on phosphate precipitation by iron and aluminum as influenced by pH. Soil Sci., 69: 205-2013. https://doi.org/10.1097/00010694-195003000-00005

Sumner, M.E. and M.P.W. Farina. 1986. Phosphorus Interactions with Other Nutrients and Lime in Field Cropping Systems. Adv. Soil Sci., 5: 201-236. https://doi.org/10.1007/978-1-4613-8660-5_5

Taalab, A.S., F.A. Hella and M.A. Abou-Seeda. 2008. Influence of Phosphate Fertilizers Enriched with Sulfur on Phosphorus Availability and Corn Yield in Calcareous Soil in Arid Region. Ozean J. Appl. Sci., 1(1): 105-115.

Terman, G.L., J.C. Noggle and C.M. Hunt. 1977. Growth Rate-Nutrient Concentration Relationships During Early Growth of Corn as Affected by Applied N, P, and K. Soil Sci. Soc. Am., 41: 363-368. https://doi.org/10.2136/sssaj1977.03615995004100020039x

Walsh, L.M. and J.D. Beaton. 1977. Soil testing and plant anal. Soil Sci. Am. Inc., Madison. WI.

Wang, W.N., J.W. Lu, Y.Q. He, FX.K. Li and H. Li. 2011. Effects of N, P, K fertilizer application on grain yield, quality, nutrient uptake and utilization of rice. Chinese J. Rice Sci., 25: 645-653.