Sustainable phosphorous management in two different soil series of Pakistan by evaluating dynamics of phosphatic fertilizer source

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Results showed an increase in P concentration in roots (23 mg kg⁻¹) with the application of half dose of TSP in Lyallpur series and lowest in Bahawalpur series (14.6 mg kg⁻¹) at recommended dose of DAP. Concentration of P in shoots responded the same; increase at half dose of TSP (16.7 mg kg⁻¹) and lowest at full dose of DAP in Bahawalpur series as (15.58 mg kg⁻¹). Adsorbed P (17 mg kg⁻¹) was recorded highest in Bahawalpur soil with more clay amount in pot with DAP application but lower in Lyallpur soil series (14 mg kg⁻¹) with the application of applied TSP. The PUE was recorded highest in Lyallpur series with the application of half dose of TSP and it was 61% more than control and was Highest in Bahawalpur series was with the application of recommended dose of DAP is 72% more than control treatment. On estimation; results showed that applied sources made an increase in P availability than control, but TSP gave better P uptake than DAP unless of rates applied. Soil of Lyallpur series showed better uptake of P and response to applied fertilizers than Bahawalpur soil series which showed more adsorption of P by high clay and CaCO₃ amount. Conclusively, the study suggested that soil series play a crucial role in choosing fertilizer source for field application.

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1. Introduction:

Phosphorous is most limiting nutrient regarding plant production due to its unavailability (Cordell and Neset, 2014). It is important for physiological process in plants as it is involved in enzymatic reactions, in cell division because it’s a constituent of nucleoprotein which took part in reproduction. It could have said that P involves in reproduction of cells which would affect yield
of plants, regarding its importance and essentiality from crop growth it is constituent of man fertilizers (Liu et al., 2017). After nitrogen it comes on 2nd number as an essential nutrient which make about 0.2% dry matter of plants it also takes part in genetics as in cell division process (Li et al., 2010; Masood et al., 2011). P deficiency or unavailability by adsorption could lead to reduction in cell ultimate reduction in growth and yield or it could say that P is major limiting nutrient for crop production especially soil having high pH and Ca contents it could (Wang and Liang, 2014). 

Pakistan is located in arid to semi-arid region of world at 24 N–37 N latitude and 61E–77E longitudes (Hussain et al., 2010). P deficiency is mostly found in soils which have low moisture or dry lands (Amanullah et al., 2015) or it could be said that 90% area of Pakistan is under arid to semi-arid region that is why deficient of dry lands (Amanullah et al., 2015) or it could be said that 90% area of Pakistan is under arid to semi-arid region that is why deficient of dry lands (Amanullah et al., 2015). Pakistani soils are mostly calcareous (CaCO₃ > 3.0%) and alkaline (pH > 7.0) in nature as soil having high pH range from 7 to 9 induce high Ca activity and pH which form insoluble di-calcium phosphate, tri-calcium phosphate with high fixation capacity ultimately dynamics of P is managed by Calcite in calcareous soil due to high P fertilization (Barrow, 2015).

Major reason which reduces fertilizer use efficiency is fixation of P and approximately 80% P get fixed (Barbieri et al., 2014). It is not true that Pakistani soils have less P, it has rich amount of P in spite of that 80–90% soils are P deficient because of its availability problem (Govt. of Pakistan, 2015). P sorption is correlated to the clay contents of the soil (Oliveira et al., 2014) this correlation is influenced by Ca and CaCO₃, and with oxides of Al and Fe (Memon et al., 2011; Bortoluzzi et al., 2015). Fixation of P increases by improper application methods like broadcasting of P fertilizer in which fertilizer run off from the field or makes chelates and become unavailable (Shah et al., 2006).

Pakistani soil is deficit of P up to 90% and to optimize its level it is needed to apply P externally (Jamal et al., 2018) as the pH and calcium content decreases the availability of P to crops and increase its fixation. Therefore, type of soil should be in consideration while selecting fertilizer application (Naseer and Muhammad, 2014). Structural stability is greatly influenced by organic matter, soil particle size distribution and extent of calcium carbonate in soils (Amanullah et al., 2010). Soil P relates with P bioavailability, it is determinant of balance between sufficient soil P fertility and offsite P escape. For this soil testing is best management tool to know the need of P fertilization to make sure that soil has adequate supply of P for crop production. It is not true that Pakistani soils have less P, it has rich amount of P in spite of that 80–90% soils are P deficient because of its availability problem (Govt. of Pakistan, 2015).

Maize ranked fourth most important crop in Pakistan after wheat, rice, and cotton. And not only in Pakistan but it has an equal importance in other countries as staple crop. It belongs to the group that have high growth rate producing high biomass which in return demands for high P (Mengel and Kirkby, 2001). Literally soils are not deficient of P but it becomes unavailable to plants by getting fixed in different forms (Abdu, 2013). It is estimated that crop productivity decreased more than 40% due to P deficiency, its application is beneficial in arid soils for improvement in production (Amanullah et al., 2014). Phosphorous deficiency is mostly found in soils which have low moisture or dry lands (Amanullah et al., 2015).

Worldwide P is being used at very high rates especially from 1961 to 2007 (Elser, 2012) there were many crises due to deficiency of P which boosted researchers to improve the efficiency of P by minimizing its losses in agro-ecosystem (Fernandez-Mena et al., 2016). To maximize agriculture production because of increased food demand with the situation of shortage of fertilizer marked a question for efficient use of fertilizer to its best use (Granatham, 2012; Worstall, 2013).

2. Methodology

2.1. Site and experimental design

A pot study was performed at wire house of Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad to evaluate P dynamics in two different soil series of Pakistan (Bahawalpur series and Lyallpur series) using Maize Hybrid NT-6621 as test crop. The treatments applied were T0: Control (without any fertilizer), T1: Recommended DAP @648 mg pot⁻¹, T2: Half dose DAP @324 mg pot⁻¹, T3: Recommended rate of TSP @900 mg pot⁻¹, T4: Half dose TSP @450 mg pot⁻¹.

2.2. Description of soil samples

The studied soil samples were taken from three different locations of Bahawalpur and Faisalabad and their composite samples were brought to the laboratory; these samples were kept under the shade for air drying and then ground to pass from 2 mm mesh size sieve. For further chemical analysis, soil sample was passed through 0.25 mesh size sieve.

2.3. Soil basic/physiochemical properties

Before filling pots processed soil was used for analyzing physico-chemical properties, texture was determined by Hydrometer method (Bouyoucos, 1962), pH was measured by saturation paste using pH meter (JENCO Model-671P) with help of buffering solutions of pH 4.1 and 9.2 for calibrating the instrument (US Salinity Laboratory staff, 1954), Electrical conductivity of soil extract was measured with help of WTW COND 315 conductivity meter. Instrument was calibrated with 0.01 N KCl solution (US Salinity Laboratory staff, 1954), Soil CaCO₃ was determined by titration method (ICARDA Manual), the method explained by Walkely’s was used to determine soil organic matter (Walkley and Black, 1934), Available potassium was determined by using Flame photometer, and Plant Available Phosphorous by Olsen method (Olsen and Watanabe, 1957). The results of basic pre analysis of soil have been elaborated in Table. 1.

2.4. Experimental detail

Composite soil sample was air dried ground and passed through 2 mm sieve. Soil was mixed thoroughly for homogeneity and then 6 kg sieved soil was poured into plastic pots. Maize seed of Hybrid NT-6621 were sown in pots. Five seeds per pot were sown and three healthy plants were maintained in each pot. Urea and Sul-

Table 1

| Name                  | Unit     | Bahawalpur Soil Series | Lyallpur Soil Series |
|-----------------------|----------|------------------------|----------------------|
| EC                    | (ds m⁻¹) | 0.65                   | 0.59                 |
| pH                    |          | 8.10                   | 7.7                  |
| TSS                   | (mg L⁻¹) | 1.60                   | 1.1                  |
| CaCO₃                 | (mg L⁻¹) | 4.60                   | 2.12                 |
| Saturation percentage | %        | 33                     | 30                   |
| Organic Matter        | %        | 0.62                   | 0.41                 |
| Available K           | (mg kg⁻¹)| 5.20                   | 5.65                 |
| Available P           | (mg kg⁻¹)| 1.6                    | 1.2                  |
| Textural Class        |          | Sandy clay loam        | Sandy loam           |
| Silt                  | %        | 62.5                   | 57.0                 |
| Clay                  | %        | 33                     | 15                   |
Effect of applied phosphorous sources on physiological growth of Maize in two different soil series of Pakistan

3.1. Effect of applied phosphorous sources on physiological growth of maize in two different soil series of Pakistan

The response of maize to applied phosphorous (DAP and TSP) in two different soil series has been elaborated in Table 2. In both soils series fertilization of P resulted in increased plant height, root length, shoot and root dry matter and dry biomass but the control treatment. No significant difference was observed between half doses and full doses of applied P sources but the Highest of plant height was recorded (105 cm) triggered by T4; (half dose of TSP) in Lyallpur soil series and (100 cm) by T1; (Recommended dose of DAP) in Bahawalpur soil series resulted in increased stature plant as compared to control treatment having short statured plant, while Root length increased of maize was (61 cm) by T1; (Recommended dose DAP) in Bahawalpur soil series and (60 cm) by T4; (TSP in Lyallpur soil series). The same way shoot & root dry matter increase was 23 mg kg⁻¹ & 4.9 mg kg⁻¹ respectively by T4; (TSP in Lyallpur soil series). Depending on the texture of soil two sources (DAP and TSP) responded different in different soil, it has been recorded that physiological parameters (plant height, shoot fresh weight, shoot dry weight, root fresh weight & root dry weight) with the application of half doses on P gave almost same result as that full doses. DAP performed better in Bahawalpur soil series (high amount of clay) but TSP (supplying Ca) could not rather it gave better results in Lyallpur soil series.

### 3.2. Effect of applied phosphorous sources on P concentration and P uptake of Maize in two different soil series

The Concentration of P in maize and P uptake response to applied phosphorous (DAP and TSP) in two different soil series has been elaborated in Table 3. All the treatments have shown in increased shoot P concentration but maximum concentration was recorded 16.77 mg kg⁻¹ with T4; (Half dose of TSP) in Lyallpur soil series and 15.58 mg kg⁻¹ with T1; (Recommended DAP) in Bahawalpur soil series while root P concentration Bahawalpur series don't show any significant increase but Lyallpur series showed an increase of 23.6 mg kg⁻¹ with T4; (Half dose of TSP). It could be said that soil characteristics matters for better response of fertil-

### Table 2

Effect of applied phosphorous sources on physiological growth of Maize in two different soil series.

| Treatments | Plant height (cm) | Root length (cm) | Shoot fresh weight (g pot⁻¹) | Shoot dry weight (g pot⁻¹) | Root fresh weight (g pot⁻¹) | Root dry weight (g pot⁻¹) |
|------------|------------------|-----------------|----------------------------|---------------------------|---------------------------|--------------------------|
|            | BWP              | FSD             | BWP                        | FSD                       | BWP                       | FSD                      |
| Control    | 81.66c           | 82.66c          | 45.66d                     | 46.32 cd                  | 83.45b                    | 82.95b                   |
| T1         | 100.6ab          | 101.33ab        | 61.3ab                     | 59.66abcd                 | 89.04b                    | 84.58b                   |
| T2         | 99.66ab          | 105.33a         | 56.55abcd                  | 58.22abcd                 | 81.97b                    | 98.93a                   |
| T3         | 97.33ab          | 101.66ab        | 49.66bcd                   | 59.77abcd                 | 60.4c                     | 98.34a                   |
| T4         | 100.6ab          | 105.66a         | 64.33a                     | 60.46abc                  | 59.93c                    | 97.86a                   |

**Notes:**
- T0: Control (without any fertilizer), T1: Recommended DAP @648 mg pot⁻¹, T2: Half dose DAP @324 mg pot⁻¹, T3: Recommended rate of TSP @900 mg pot⁻¹, T4: Half dose TSP @450 mg pot⁻¹.
- Means that are not sharing same letters in common are significantly different from each other at 0.05 probability level.
- Data shown are mean for three replicates.
Effect of applied phosphorous sources on P concentration and P uptake of Maize in two different soil series.

Table 3

| Treatments      | Root P Conc. (mg kg⁻¹) | Shoot P Conc. (mg kg⁻¹) | Root P uptake (mg kg⁻¹) | Shoot P uptake (mg kg⁻¹) | Total P uptake (mg kg⁻¹) |
|-----------------|------------------------|------------------------|-------------------------|--------------------------|--------------------------|
|                 | BWP                    | FSD                    | BWP                    | FSD                      | BWP                      | FSD                      |
| Control         | 12.9b                  | 13.6b                  | 12.16d                 | 12.17d                   | 16.50 h                  | 23.57 g                  | 3.69c                    | 4.08bc                   | 15.99 h                  | 15.23 g                  |
| T1              | 14.6b                  | 16.8b                  | 15.58b                 | 14.00c                   | 28.52f                   | 32.98de                 | 5.08bc                   | 6.59bc                   | 19.08a                   | 17.92d                  |
| T2              | 14.6b                  | 18.9b                  | 13.50c                 | 16.08ab                  | 33.64d                   | 9.845b                 | 6.95bc                   | 9.28b                    | 22.34e                   | 19.66b                  |
| T3              | 14.1b                  | 23.1a                  | 13.33c                 | 15.58b                   | 28.07f                   | 36.83c                 | 4.21bc                   | 8.59bc                   | 18.05f                   | 18.86c                  |
| T4              | 16.2b                  | 23.6a                  | 13.16cd                | 16.77a                   | 30.46ef                  | 42.33a                 | 6.30bc                   | 7.83a                    | 19.13d                   | 20.57ef                 |

T0: Control (without any fertilizer), T1: Recommended DAP @648 mg pot⁻¹, T2: Half dose DAP @324 mg pot⁻¹, T3: Recommended rate of TSP @900 mg pot⁻¹, T4: Half dose TSP @45 mg pot⁻¹.

Means that are not sharing same letters in common are significantly different from each other at 0.05 probability level. Data shown are mean for three replicates.

3.3. Effect of applied phosphorous sources on P adsorption

Data elaborating adsorption ration has been demonstrated in Fig. 1. The maximum adsorbed P was recorded in Bahawalpur soil series with higher clay contents. The Pots applied with full doses gave more adsorption to the sites so gave more adsorbed P concentration than the pots having the treatment with half doses of both sources (DAP and TSP). The minimum extracted P was found by T4; (half dose of TSP) @14 mg kg⁻¹ in Lyallpur soil series and maximum concentration was 17 mg kg⁻¹ by T1; (recommended dose of DAP) in Bahawalpur soil series.

3.4. Effect of applied phosphorous sources on PUE of maize

Phosphorous use efficiency (PUE) was recorded to be high in all treatments than that of control as shown in Fig. 2. All treatments showed increased PUE of maize but DAP showed more significant result at T1; (recommended DAP) as 72% increase in Bahawalpur soil series while 61% increase by T4; (half dose TSP) in Lyallpur series. PUE was found to be increased on application of both sources in Lyallpur series as compared to Bahawalpur soil. Overall fertilization of P increased the phosphorous uptake and its efficiency in both soils, but different sources affected its availability according to the soil characteristics and fertilizer composition. As TSP providing Ca along with phosphorous didn’t give better result in Bahawalpur soil series that already possessed high amount of Ca

Fig. 2. Effect of phosphorous fertilization on phosphorous use efficiency of maize cultivated in two different soil series of Pakistan. T0: Control (without any fertilizer), T1: Recommended DAP @648 mg pot⁻¹, T2: Half dose DAP @324 mg pot⁻¹, T3: Recommended rate of TSP @900 mg pot⁻¹, T4: Half dose TSP @450 mg pot⁻¹. (high source of P binding) source should be selected according to soil condition.

4. Discussions

Phosphorous is the most important essential nutrient for the plant growth that’s why it is component of fertilizers in most regions (Liu et al., 2017). It is the most limited nutrient causing serious reduction in yield of crops its unavailability is major challenge for 21st century (Fink et al., 2016). Pakistani soils are mostly calcareous (CaCO₃ > 3.0%) and alkaline (pH > 7.0) in nature as soil having high pH range from 7 to 9 induce high Ca activity and pH which form insoluble di-calcium phosphate, tri-calcium phosphate with high fixation capacity ultimately dynamics of P is managed by Calcite in calcareous soil due to high P fertilization (Barrow, 2015). Along with that surface broadcast of banded application fertilizers result in less availability and more fixation along with uneven distributions results in low fertility (Duiker and Beegle, 2006). To minimize this loss, there is dire need to develop strategy for maximum availability of phosphorous for this purpose. Phosphorous fertilization was done by using various P sources to evaluate the PUE of Maize Crop grown in BWP and FSD soil series of Pakistan.

Fertilization of Phosphorous resulted in increased plant height and root length, Highest of stature was observed in Lyallpur soil series with application of TSP, and maximum height in Bahawalpur soil was recorded with applied DAP, both fertilizers gave an increase in root and shoot length as compared to control treatment (Onasanya et al., 2009). Also observed an increase in plant height and leaves. The results by (Masood et al., 2011). In spite of that results by (Rashid and Iqbal, 2012) also showed an increase in plant height by phosphorous influence, root length increase followed the same manner, this increase could be better explained with statement that Phosphorous application stimulated the root production and increase in root hairs ultimately increases the root
and shoot length, which increased P absorbing capacity resulting in high dry matter production (Hussaini et al., 2001).

Plant dry matter showed an increase on application phosphorus fertilizer in both soil as compared to control treatment however both sources behaved different in different soil but it was recorded in all physiological parameters (plant height, shoot fresh weight, shoot dry weight, root fresh weight root dry weight) that the application of half doses of both fertilizer DAP and TSP gave almost the same response as that of full doses. It might be due to the release of proton from roots that increases under P deficiency: this will facilitate acquisition of P from rhizosphere soil, especially in soil retains Ca-phosphates just like neutral and calcareous soils fertilized with phosphate (Hinsinger, 2001). Another research by (Hussaini et al., 2008) further reported that by increasing P will significantly increase leaf and grain yield, further elaborated that increase in P levels will increase nutrient concentration that will result in more dry matter production.

On comparison of both soils Lyallpur soil series gave better results and showed better response to P fertilizer as compared to Bahawalpur soil series. It might be due to the texture as there were more clay contents in Bahawalpur soil series and more will be the clay in the soil more will be the adsorption process of the P as described by (Chaudhry et al., 2003) who compared different soil series to check P requirement and suggested that P requirement was increased by increase in clay contents.

P uptake by roots and shoots were found to be more in the soil applied with TSP in Lyallpur soil series than that of applied DAP which resulted in better uptake in Bahawalpur soil series. Both of fertilizers with half dose and full dose application showed almost same response as I mean that half dose applied pot gave same uptake ratio as that of full doses of applied fertilizer but overall TSP gave better results in Lyallpur soil series with less Ca and more amount of K gave better uptake of P than that of Bahawalpur soil series with high amount of Ca and less available K.

The uptake might be due to synergistic effect of K with P which reduces the chances of fixation and increase proton release along with Lyallpur series had less amount of Ca and clay contents to which P will adsorb. Buresh and Tian (1997) reported that the more will be the availability of P more will be uptake by roots. As (Devau et al., 2010) reported that P get adsorbed not only by clay but the Ca present in the soil as the Adsorbed P (Fig. 3.) data showed that Bahawalpur soil with high clay and Ca amount showed more Adsorption of P 22% by TSP, while lowest by DAP @18% by DAP. Uddin et al. (2017) also concluded on base of his experiment done on four different soil series that the soil with High clay amount gives more adsorption.

Data regarding PUE of maize (Fig. 2) elaborates the significant effect of applied phosphorous, that have shown increase by both fertilizers than control treatment but highest efficiency was by T1; (Recommended dose of DAP) in Bahawalpur soil series and same way in Lyallpur series highest efficiency was by T4; (half dose of TSP).

5. Conclusion

On the basis of experimental results, it has been concluded that P sources applied in two different soil prominently improved plant growth up to optimum level as compared to control treatment but TSP in comparison performed better in Lyallpur series and DAP in Bahawalpur series as the TSP with Ca availability show less response in Bahawalpur soil already rich in Ca contents and clay. While comparing soil, Lyallpur soil series showed better response to applied fertilizer than Bahawalpur soil which showed more adsorption of P due to its high Ca and clay contents. So, can be concluded that fertilizer recommendation should involve soil characteristic evaluation for better response of applied fertilizer.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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