Saudi Journal of Biological Sciences 29 (2022) 255–260

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

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

Ayesha Aimen [a,b,c], Abdul Basit [c], Safdar Bashir [d], Zubair Aslam [e], Muhammad Faheem Shahid [a], Saba Amjad [a], Khadija Mehmood [a,b], Bandar S. Aljuaid [f], Ahmed M. El-Shehawi [f], Ali Tan Kee Zuan [g,*], Shahid Farooq [h], Yunzhou Li [c,*]

[a] Institute of Soil & Environmental Science, University of Agriculture Faisalabad, 38000, Pakistan
[b] Department of Soil Science, University College of Agriculture & Environmental Sciences, The Islamia University of Bahawalpur, 63100, Pakistan
[c] Department of Plant Pathology, College of Agriculture, Guizhou University, Guiyang 550025, Guizhou, China
[d] Department of Soil and Environmental Sciences, Ghazi University, Dera Ghazi Khan, Pakistan
[e] Department of Agronomy, University of Agriculture Faisalabad, Faisalabad 38040, Pakistan
[f] Department of Biotechnology, College of Science, Taif University, P.O Box 11099, Taif 21944, Saudi Arabia
[g] Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[h] Department of Plant Protection, Faculty of Agriculture, Harran University, Şanlıurfa, Turkey

A R T I C L E I N F O

Article history:
Received 4 July 2021
Revised 7 August 2021
Accepted 24 August 2021
Available online 30 August 2021

Keywords:
Maize
Adsorption
Nutrient uptake
Soil type
Diammonium Phosphate

A B S T R A C T

Phosphorous (P) plays the prominent role to promote the plants storage functions and structural roles, as it is recognized as a vital component of ADP, ATP, Cell wall as well as a part of DNA. Soils acts as the sink to supply P to plants because soil pH and its physical condition are the main factor which regulate the solubility and availability P element. Phosphorus is not deficient in Pakistani soils but its availability to plants is the serious matter of concern. A pot experiment was conducted to evaluate P dynamics in two different soil series of Pakistan (Bahawalpur and Lyallpur) using Maize 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}. Soil analysis showed that Bahawalpur soil has sandy clay loam texture with 33% clay and Lyallpur series has sandy loam texture with 15.5% clay; furthermore, these soil contain 4.6 and 2.12% $CaCO_3$ respectively. 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 series which showed more adsorption of P by high clay and $CaCO_3$ amount. Conclusively, the study suggested that soil series play a crucial role in choosing fertilizer source for field application.

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

* Corresponding authors.
E-mail addresses: sabashir@gudgk.edu.pk (S. Bashir), tkz@upm.edu.my (A. Tan Kee Zuan), liyunzhou2007@126.com (Y. Li).

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2021.08.086
1319-562X/© 2021 The Author(s). Published by Elsevier B.V. on behalf of King Saud University.

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). There are different factors that are affecting P availability like soil structure, texture, pH of soil, presence or absence of microbes, iron and calcium compounds (Gerard, 2016; Amanullah et al., 2010).

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 P (Memon et al., 2011). Pakistani soils are mostly calcareous ($CaCO_3$ > 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 $CaCO_3$ 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 decreas 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 (Grantham, 2012; Worstall, 2013).

2. Methodology

2.1. Site and experimental design

A pot study was performed at wire house of Insititute 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 physiochemical 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 (U.S 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 $CaCO_3$ 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
Physico-chemical properties of soil.

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
$CaCO_3$	(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
Sand	%	40.5	27.7
Silt	%	62.5	57.0
Clay	%	33	15

phate of Potash, at recommended rate was applied in three splits (before sowing, at vegetative stage) but P-fertilizer were applied in many splits at different stages which were, before sowing, at three leave stage (V3), At five leave stage V5, At V9, and V15 (Before tasseling). Distilled water was used for fertilizer application and irrigation. Irrigation was given @560 ml at field capacity of soil having 30% and 29.7% moisture percentage. After germination water was maintained at 60% water holding capacity of soils. Weeds were removed by hand if any, during experiment.

2.5. Harvesting and data collection

Agronomic parameters like plant height, root length, plant fresh and dry biomass were recorded when crop was harvested at tasseling stage at about 165 days after germination. Plant height was measured with meter rod and to measure plant root length pots were saturated overnight to loosen soil then roots removed by water, length was measured by meter scale. Likewise, plant fresh biomass of roots and shoots were observed using digital balance and both roots and shoots were washed with distilled water and dried by tissue paper then samples were placed in oven for dry weight at 65C° until constant weight and dry mass was determined by weighing oven dried plant samples using weighing balance.

2.6. Phosphorous analysis

Dry plant matter was ground and digested plant samples were processed to analyze different P forms as P concentration in roots and shoots were observed on spectrophotometer absorbance at 420 nm (Chapman and pratt, 1961), extractable at 882 nm wavelength on spectrophotometer, Organic P 882 nm wavelength absorbance, P adsorption isotherm was measured by Graetz and Nair method, data obtained was fitted to linear form Freudlich equation as described below.

2.7. Langmuir equation

$$Q = aC1/n$$

where:
Q (mg kg^{-1}) = Amount of P adsorbed to soil at equilibrium
C = Conc. of Phosphorous after 24 h of equilibrium

2.8. Phosphorous use efficiency

PUE was measured using following formula

$$PUE\ (\%) = \frac{(P\ in\ control) - (P\ conc\ in\ plant)}{(applied\ P\ in\ the\ pot) \times 100}$$

2.9. Statistical analysis

Collected data was processed using CRD factorial design using 8.1. software. Analysis of variance and LSD test was applied to evaluate treatment difference.

3. Results

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, root and shoot fresh and dry biomass than 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 long 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 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} by T1; (Recommended dose of DAP) in Bahawalpur soil series while 25 mg kg^{-1} & 5.2 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	BWP	FSD	BWP	FSD	BWP	FSD
Control	81.66c	82.66c	45.66d	46.32 cd	83.45b	82.95b	13.57e	14.41e	15.23d	15.99d	2.80d	2.94d
T1	100.6ab	101.33ab	61.3ab	59.66abcd	89.04b	84.58b	23.14c	23.55bc	19.08abcd	18.05bcd	4.93a	4.59ab
T2	99.66ab	105.33a	56.55abcd	58.22abcd	81.97b	98.93a	21.44d	24.51ab	18.86abcd	19.13abc	3.43 cd	4.57ab
T3	97.33ab	101.66ab	49.66bcd	59.77abcd	60.4c	98.34a	20.80d	23.65bc	17.92bcd	20.57abcd	2.98d	3.87bc
T4	100.6ab	105.66a	64.33a	60.46abc	59.93c	97.86a	21.61d	25.22a	19.66abc	22.34abcd	3.93bc	5.21a

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.

Table 3
Effect of applied phosphorous sources on P concentration and P uptake of Maize in two different soil series.

Treatments	Root P Conc. (mg kg^{-1})		Shoot P Conc. (mg kg^{-1})		Shoot P uptake (mg kg^{-1})		Root P uptake (mg kg^{-1})		Total P uptake (mg kg^{-1})	
	BWP	FSD	BWP	FSD	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	5.0bc	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	13.16 cd	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.

izer. While on other hand P uptake by root and shoot have shown similar trend Total P uptake found to be highest 20.57 mg kg^{-1} with T4; (Half dose of TSP) in Lyallpur soil series and 19.08 mg kg^{-1} with T1; (Recommended DAP) in Bahawalpur soil series than control treatment in both soil, Overall Faisalabad with less Ca and more amount of K gave better uptake of P with TSP than that of Bahawalpur soil with high amount of Ca and less available K.

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 (high source of P binding) source should be selected according to soil condition.

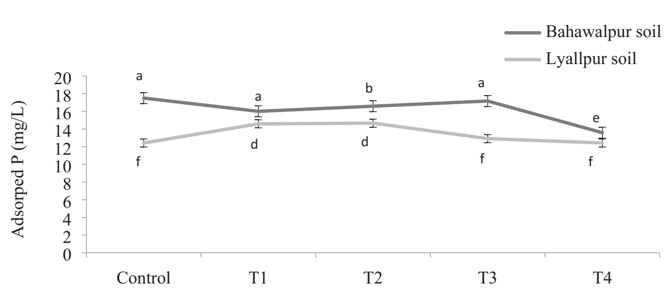

Fig. 1. Effect of phosphorous fertilization on adsorption of P in two different soil series of Pakistan. T0: Control (without any fertilizer), T1: Recommended DAP @648 mg pot^{-1}, T2: Half dose DAP @324 mg pot^{-1}, T3: Recommended rate of TSP @900 mg pot^{-1}, T4: Half dose TSP @450 mg pot^{-1}.

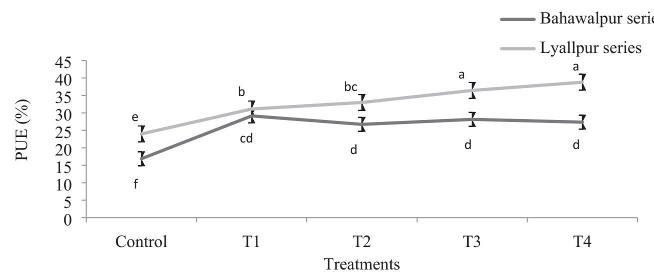

Fig. 2. Effect of phosphorous fertilization on phosphorous use efficiency of maize cultivated in two different soil series of Pakistan. T0: Control (without any fertilizer), T1: Recommended DAP @648 mg pot^{-1}, T2: Half dose DAP @324 mg pot^{-1}, T3: Recommended rate of TSP @900 mg pot^{-1}, T4: Half dose TSP @450 mg pot^{-1}.

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 ($CaCO_3$ > 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 legth 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

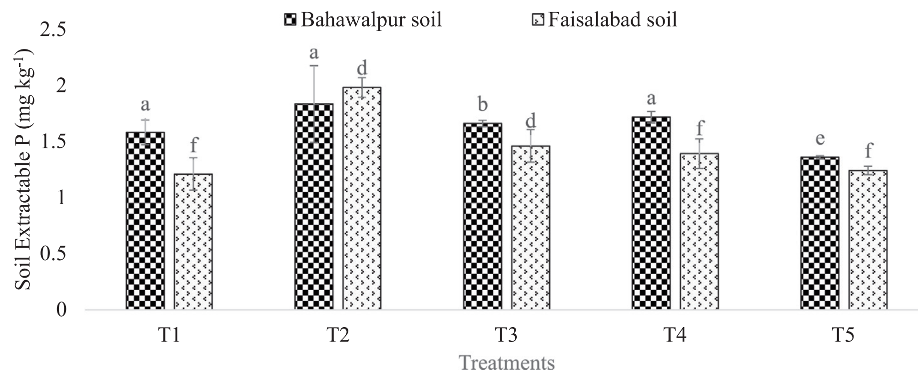

Fig. 3. Effect of phosphorous fertilization on phosphorous use efficiency of maize cultivated in two different soil series of Pakistan. T0: Control (without any fertilizer), T1: Recommended DAP @648 mg pot^{-1}, T2: Half dose DAP @324 mg pot^{-1}, T3: Recommended rate of TSP @900 mg pot^{-1}, T4: Half dose TSP @450 mg pot^{-1}.

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 phosphorous 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 leave 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 doze 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. P concentration in roots and shoot were recorded maximum with applied TSP in Lyallpur soil series and maximum with applied DAP in Bahawalpur soil series, it could be due to higher uptake by roots that ultimately resulted in high concentration of P in roots and shoots, it might be explained by statement that in P stress, root acquisition of P increases and higher P uptake results in high concentration/ accumulation in roots and shoots

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.

Acknowledgment

This work was supported by projects of the national Nature Science Foundation (No. 32060679) and projects of Guizhou University (No. GuidapeiYU[2019]52 and No. [2017]50). The current work was funded by Taif University Researcher Supporting Project number (TURSP-2020/245). Taif University. Taif, Saudi Arabia.

References

Abdu, N., 2013. Formulation of a first-order kinetic model and release of added phosphorus in a savanna soil. Arch. Agron. Soil Sci. 59 (1), 71–81.

Amanullah, I., Khan, A., Jan, M.T., Jan, S.K., Khalil, Z., Shah, Z., Afzal, M., 2014. Compost and nitrogen management in influence productivity of spring maize (Zea mays L.) under deep and conventional tillage systems semiarid regions. Comm. Soil Sci. Plant Anal. 46, 1566–1578.

Amanullah, I., Khan, A., Jan, M.T., Jan, S.K., Khalil, Z., Shah, Z., Afzal, M., 2015. Compost and nitrogen management in influence productivity of spring maize (*Zea mays* L.) under deep and conventional tillage systems semiarid regions. Commun. Soil Sci. Plant Anal. 46, 1566–1578.

Amanullah, R., Zakirullah, M., Khalil, S.K., 2010. Timing and rate of phosphorous application influence maize phenology, yield and profitability in Northwest Pakistan. Int. J. Plant Product. 4, 281–292.

Barbieri, P.A., Sainz Rozas, H.R., Covacevich, F., Echeverría, H.E., 2014. Phosphorus placement effects on phosphorous recovery efficiency and grain yield of wheat under no-tillage in the humid pampas of Argentina, Int. J. Agron. 2014.

Barrow, N.J., 2015. Soil phosphate chemistry and the P-sparing effect of previous phosphate applications. Plant Soil. 397 (1-2), 401–409.

Bortoluzzi, E.C., Pérez, C.A.S., Ardisson, J.D., Tiecher, T., Caner, L., 2015. Occurrence of iron and aluminum sesquioxides and their implications for the P sorption in subtropical soils. Appl. Clay Sci. 104, 196–204.

Bouyoucos, G.J., 1962. Hydrometer method improves for making particle size analysis of soils. J Agron. 53, 464–465.

Buresh, R.J., Tian, G., 1997. Soil improvement by trees in sub-Saharan Africa. In: Directions in Tropical Agroforestry Research. Springer, Dordrecht, pp. 51–76.

Chaudhry, E.H., Ranjha, A.M., Gill, M.A., Mehdi, S.M., 2003. Phosphorus requirement of maize in relation to soil characteristics. Int. J. Agric. Biol. 5, 625–629.

Cordell, D., Neset, T.-S.-S., 2014. Phosphorus vulnerability: a qualitative framework for assessing the vulnerability of national and regional food systems to the multidimensional stressors of phosphorus scarcity. Global Environ. Change. 24, 108–122.

Devau, N., Le Cadre, E., Hinsinger, P., Gerard, F., 2010. A mechanistic model for understanding root-induced chemical changes controlling phosphorous availability. Ann Bot. 105, 1183–1197.

Duiker, S.W., Beegle, D.B., 2006. Soil fertility distributions in long-term no-till, chisel/ disk and moldboard plow/disk systems. Soil Till. Res. 88, 30–34.

Elser, J.J., 2012. Phosphorus: a limiting nutrient for humanity? Curr. Opin. Biotechnol. 23 (6), 833–838.

Fernandez-Mena, H., Nesme, T., Pellerin, S., 2016. Towards an Agro-Industrial Ecology: a review of nutrient flow modelling and assessment tools in agro-food systems at the local scale. Sci. Total Environ. 543, 467–479.

Fink, J.R., Inda, A.V., Bavaresco, J., Barrón, V., Torrent, J., Bayer, C., 2016. Adsorption and desorption of phosphorus in subtropical soils as affected by management system and mineralogy. Soil Tillage Res. 155, 62–68.

Gerard, F., 2016. Clay minerals, iron/aluminum oxides, and their contribution to phosphate sorption in soils – a myth revisited. Geoderma. 262, 213–226.

Govt. of Pakistan, 2015. Ecnomice survey of Pakistan 2014-15, Ministry of food, Agriculture and livestock (Fedral Bureau of Statistics), Islamabad P.23-44.

Grantham, J., 2012. Be persuasive. Be brave. Be arrested (if necessary). Nature 491.

Hinsinger, P., 2001. Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. Plant soil. 237 (2), 173–195.

Hussain, A., A. Ali, J. Akhter and M. Yasin. 2010. Effect of phosphorous in combination with Rhizobium inoculation on growth and yield parameters of Mungbean (Vignaradiata L.) crop Environ., 1: 53-56.

Hussaini, M.A., Ogunlela, V.B., Ramalan, A.A., Falaki, A.M., 2001. Growth and development of maize (Zea mays L.) in response to different levels of nitrogen, phosphorus and irrigation. Crop. Res. (*Hisar*) 22 (2), 141–149.

Hussaini, M.A., Ogunlela, V.B., Ramalan, A.A., Falaki, A.M., 2008. Mineral composition of dry season maize (Zea mays L.) in response to varying levels of nitrogen, phosphorus and irrigation at Kadawa, Nigeria. World J. Agric. Res. 4 (6), 775–780.

Jamal, A., Hussain, I., Sarir, M.S., Fawad, M., 2018. Phosphorous transformation as influenced by different levels of phosphorous alone and in combination with humic acid. World Scientific News. 102, 173–179.

Li, Y., Wang, T., Li, J., 2010. Effect of phosphorous on celery growth and nutrition uptake under different calcium and magnesium levels in substrate culture. Horti. Sci. 37, 99–108.

Liu, S., Meng, J., Jiang, L., Yang, X., Lan, Y., Cheng, X., Chen, W., 2017. Rice husk biochar impacts soil phosphorous availability, phosphatase activities and bacterial community characteristics in three different soil types. Agric. Ecosyst. Environ. 116, 12–22.

Masood, T., Gul, R., Munsif, F., Jalal, F., Hussain, Z., Noreen, N., Khan, H., Nasiruddin and H. Khan, 2011. Effect of different phosphorus levels on the yield and yield components of maize. Sarhad J Agr. 27, 167–170.

Memon, M., Akhtar, M.S., Memon, K.S., Stuben, D., 2011. Phosphorus forms in the Indus River alluvial and loess, shale and lime stone derived alluvial soils. Asian J Chem. 23, 1952–1962.

Mengel, K., Kirkby, E.A., Kosegarten, H., Appel, T. (Eds.), 2001. Principles of Plant Nutrition. Springer Netherlands, Dordrecht.

Naseer, M., Muhammad, D., 2014. Direct and residual effect of hazara rock phosphate (HRP) on wheat and succeeding maize in alkaline calcareous soils. Pak. J. Bot. 46, 1755–1761.

Oliveira, C.M.B., Gatiboni, L.C., Miquelluti, D.J., Smyth, T.J., Almeida, J.A., 2014. Maximun phosphorus adsorption capacity and binding energy constant of an oxisol fitting different Langmuir models. Rev. Bras. Cienc. Solo. 38 (6), 1805–1815.

Olsen, S.R., Watanabe, F.S., 1957. A method to determine a phosphorus adsorption maximum of soil as measured by the Langmuir isotherm. Soil Sci. Soc. Am. Proc. 21, 144–149.

Onasanya, R.O., Aiyelari, O.P., Onasanya, A., Oikeh, S., Nwilene, F.E., Oyelakin, O.O., 2009. Growth and yield response of maize (*Zea mays* L.) to different rates of nitrogen and phosphorus fertilizers in southern Nigeria. World J. Agric. Res. 5 (4), 400–407.

Rashid, M., Iqbal, M., 2012. Effect of phosphorus fertilizer on the yield and quality of maize (*Zea mays* L.) fodder on clay loam soil. J. Animal Plant Sci 22 (1), 199–203.

Shah, K.H., Aslam M., Khan P., Memon M.Y., Imtiaz M., Siddiqui S.H., Nizamuddin, 2006. Effect of different methods and rates of phosphorus application in mungbean. Soil Environ. 25, 55–58.

Uddin, Riaz, Baloch, Parwaiz, Iqbal, Sajid, Ali, Qazi, Ahmed, Akhlaq, Bhutto, Muhammad, Qadri, Syed, 2017. Phosphorus adsorption capacity of four soil series for P requirement of wheat (*Triticum aestivum* L). J. Basic Appl. 13, 12–16.

Walkley, A., Black, C.A., 1934. An examination of the method for determining soils organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37, 29–38.

Wang, L., Liang, T., 2014. Effects of exogenous rare earth elements on phosphorus adsorption and desorption in different types of soils. Chemosphere 103, 148–155.

Worstall, T., 2013. Mineral demands: a shortage of fertilizer resources? Nature 493.