Eco. Env. & Cons. 28 (January Suppl. Issue) : 2022; pp. (S622-S628)
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ISSN 0971–765X

http://doi.org/10.53550/EEC.2022.v28i01s.087

Phosphorus transformation in root zone environment under semi tropical agro ecosystem in sandy clay loam soil

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(Received 30 August, 2021; Accepted 29 September, 2021)

ABSTRACT

A field experiment was carried out during 2021, at the existing long term fertilizer experiment of TNAU which is in operation since 1972 at Coimbatore, Tamil Nadu with a cropping system of finger millet–maize at field no: 36 F, Eastern farm, TNAU, Coimbatore, Tamil Nadu to evaluate phosphorus transformation in root zone environment under semi tropical agro ecosystem in sandy clay loam soil under long term fertilization in finger millet–maize cropping sequence. The treatments were established in ten treatments namely T_1–50% NPK, T_2–100% NPK, T_3– 150% NPK, T_4– 100% NPK+ Hand weeding, T_5–100% NPK+$ZnSO_4$, T_6–100% NP, T_7–100% N, T_8– 100% NPK+FYM, T_9–100% NPK(–S), T_{10} – Control replicated thrice in a Randomized Block Design. The available P reported a 5.8 percent increased availability in the rhizosphere soil over the non–rhizosphere and followed a decline in plant growth was highest in the 100% NPK+FYM plot, while the total P revealed the same percent rise in the non-rhizosphere soil. Saloid P, Fe–P, Al–P, Ca–P and Reductant soluble P each contributed about 7.18, 10.05, 11.27, 61.38, 10.12 percent to the total inorganic P pools. For the total P, the organic P contributed about 61.19% and inorganic fractions contributed about 38.81%. The competence among the P fraction exhibited the pattern of Ca–P > Al–P > Fe–P > Reductant soluble P > Saloid P in their share in the root zone soil. The results revealed that the fractions of various P pools were dominant in the non rhizospheric soil than rhizospheric environment and followed a declining trend when the crop proceeded towards maturity. Practising various nutrient management system, application of 100% recommended dose of fertilizer along with FYM @ 10 tha^{-1} (T_8) was recorded significant changes in all inorganic (Ca-P, Fe-P, Al-P, Reductant soluble-P, saloid P), organic fractions, available P and also Total P followed by 150% NPK (T_3) in sandy clay loam soil. Phosphorus dynamics in soil are critical for careful phosphorus fertilisation management in order to achieve sustainable agricultural development.

Key words: *Phosphorus, available P, Organic P, Inorganic P, P dynamics*

Introduction

In most parts of the globe, phosphorus is the most significant nutritional element (after nitrogen) limiting agricultural productivity. Mineral fertiliser, particularly Phosphorus, resulted in a significant rise in

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agricultural yields as well as a spatial segregation of production and consumption (Gao *et al.*, 2014). Looking at the worldwide phosphorus journey from "mine to fork," the efficiency appears to be low; only around one-fifth of the phosphorus mined for fertiliser manufacture is eventually eaten by the human population (Cordell *et al.*, 2009). With rising agricultural output demand and a worldwide production peak expected in the next decades, phosphorus (P) is becoming less valuable as a non renewable resource.

Rhizosphere is a vital region of plant ecosystem; 2 mm from the root surface is termed as rhizosphere zone. It governs the chemistry of plant nutrient and affects growth of the plants. Nutrient requirement in agriculture has been rising and is likely to increase further to enhance the agriculture productivity across the globe in order to keep pace with growing food demand. In most of the cases, farmers apply fertilizers without knowing the rhizosphere role in a particular nutrient chemistry in relation to its availability to plants. Sometimes it creates unavailability of a nutrient to the plant showing deficiency symptoms, which result in yield decline. Maintaining an adequate P-supply level at the root zone can improve the efficiency with which plant roots mobilise and acquire P from the rhizosphere. The absorption and use of phosphorus by plants is critical in determining crop output (Shen *et al*. 2011).

Phosphorus dynamics in soil are critical for careful phosphorus fertilisation management in order to achieve sustainable agricultural development. Different phosphate fractions, available and total phosphorus content under organic, inorganic and integrated nutrient management approaches were investigated in rhizospheric and non rhizospheric soils for sustainable agriculture which necessitates the use of integrated agricultural methods for preserving the natural soil microbiome while increasing crop yield (Dutta *et al*. 2020). With this background, the present study was carried out to assess the effects of long term fertilization on the distribution of phosphorus and its dynamics as different forms in the rhizosphere and non-rhizosphere soil under maize in Coimbatore, Tamil Nadu.

Materials and Methods

Site Description

The present study was carried out to evaluate the P transformation under long term fertilization and manuring with intensive cropping under finger millet-maize cropping sequence in ongoing Long Term Fertilizer Experiment. This Long Term Fertilizer Experiment was started during 1972 by ICAR (All

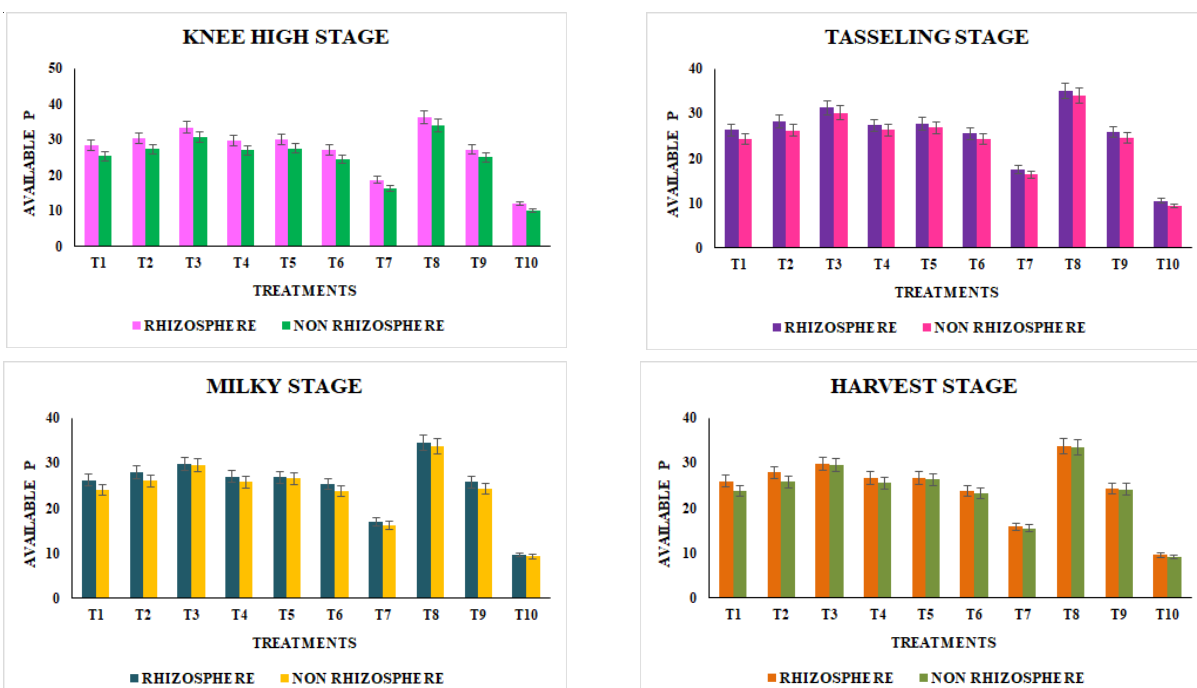

Fig 1. Available P (kg ha^{-1}) in rhizospheric and non rhizospheric soil at critical growth stages of maize

India Coordinated Research Project) and being maintained by Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore. The experimental site is located at 11° North latitude, 77° East longitude with an altitude of 426.7 meter above mean sea level in field no.36 F, Eastern block farm.

The experimental site belongs to the taxonomical classification of Inceptisol-Vertic Ustropept, having calcareous mixed black soil with sandy clay loam texture coming under Periyanaickenpalayam series. For examining the P dynamics, the present study comprises 10 treatments namely 50% NPK, 100% NPK, 150% NPK, 100% NPK + Hand Weeding, 100% NPK + Zinc, 100% NP, 100% N, 100% NPK + FYM, 100% NPK (Sulphur free source) along with Control and replicated thrice in randomized block design. The test crop was maize (COHM 6) and being the continuous experiment, the crop number was 110^{th} under finger millet-maize cropping sequence. Initial soil physico-chemical properties (2020) were analysed and furnished in Table 1.

Soil Sampling and Analysis

The representative soil samples were collected by excavating the soil along with the plant roots from, (20 cm diameter and 30 cm depth) cut. The rhizosphere soil was collected from the soil tightly adhering to the roots (Baoru *et al*. 2019). The soil was shade dried and sieved under 2mm sieve and used for analysis. Phosphorus fraction in the rhizosphere and non rhizosphere soil were estimated by the methodology given by Petersen and Corey (1966), Mehta *et al.* (1954), available phosphorus by Olsen (1954) and total P by Jackson (1973). All those parameters were analysed in both the soils in knee high, tasselling, milky and harvest stage of the crop.

Statistical Analysis

The recorded data were analyzed statistically using SPSS Statistics 23.0 with the appropriate variance techniques for Randomized Block Design (RBD). The means were compared by least significant difference test (CD < 5%).

Results and Discussion

Effect of long term fertilization on P dynamics under rhizospheric and non rhizospheric soil of maize crop Available Phosphorus (Fig. 1)100% NPK+FYM plots (36.3 kg ha^{-1}) was substantially greater than 100% NPK plots (30.3 kg ha^{-1}), indicating that phosphorous fertilizer combined with organic manure addition resulted in a massive accumulation of available P in the rhizosphere and bulk soil. The generation of organic acids during manure decomposition, which results in the solubilization of soil P reserves, may be responsible for increased P availability as ascribed by Fageria and Stone (2006). The available phosphorus was found to record the highest in the knee high stage of cropping period of maize and then began to fall in the corresponding stages of crop growth. The lowest availability was seen in the harvest stage of maize. When looking into the significant differences among the rhizosphere and non rhizosphere soil, the former was pertained to show 5.8% more P availability than the later irrespective of the crop growth period which was in line with Phillips and Yanai, (2004). Increased organic matter decomposition caused by increased microbial populations in the

Table 1. Initial soil properties during the experiment (2020)

Soil properties	Value	Soil properties	Value
Clay (%)	32.6	NH_4OAc K (kg ha^{-1})	640
Silt (%)	11.8	Exchangeable Ca (c mol (p^+) kg^{-1})	10.6
Fine sand (%)	15.1	Exchangeable Mg (c mol (p^+) kg^{-1})	6.50
Coarse sand (%)	39.4	Available Zn (mg kg^{-1})	0.94
pH	8.25	Available Mn (mg kg^{-1})	0.93
EC (dSm^{-1})	0.57	Available Cu (mg kg^{-1})	5.41
CEC (c mol (p^+) kg^{-1})	27.6	Available Fe (mg kg^{-1})	1.95
Organic carbon (g kg^{-1})	4.8	Saloid P (mg kg^{-1})	12
Total P (mg kg^{-1})	504.3	Reductant soluble P (mg kg^{-1})	20.2
$KMnO_4$ N (kg ha^{-1})	203	Fe-P (mg kg^{-1})	21.1
Olsen P (kg ha^{-1})	22.3	Al-P (mg kg^{-1})	19.2
		Ca-P (mg kg^{-1})	125.8
		Organic P (mg kg^{-1})	261.2

rhizosphere might have resulted in higher nutrient concentrations in the rhizosphere solution were found in alignment with Leyval and Berthelin, (1993); Drever and Vance, (1994); Wang and Zabowski, (1998). Dotaniya and Meena (2015) found that the nutrient supply in soil has been altered owing to rhizosphere impact, which assessed the nutrient conversion of non–labile pools to accessible form, which is useful for improving biochemical activities and nutrient absorption in plants. The rows that got an appropriate quantity of P fertiliser had more recoverable P than the ones that only obtained N fertiliser and the absolute control. It might be related to the depletion of P from the soil to fulfil crop demands (Devau *et al.*, 2010).

Total P (mg kg^{-1}) Total Phosphorus was in a reversible relationship with both organic and inorganic P fractions of the soil (Guo *et al.*, 2016). The total phosphorus was 5.81% hiked in the non rhizosphere region when weighed against rhizosphere soil. The nutrient concentration in the bulk soil will be higher than that of rhizosphere soil when plant root uptake and root induced elemental precipitation are dominant (Pradhan *et al.*, 2021). In the cropping period, the knee high stage which is 30 DAS holds good for total P when taking other stages like tasseling, milky and harvest into account. Regardless of fertilizer, Lee *et al.* (2004) discovered that continual fertilization enhanced the overall P level in the plough layer.

The combination of 100% NPK with FYM had the maximum total P (814.1 mg kg^{-1}) and during crop growth, a significant decrease in P reserve was detected in the control plot (232.7 mg kg^{-1}). The P released may have been absorbed by the soil humic material, accounting for the soil's total P increase (Jun *et al.*, 2010). Prasad and Mathur (1997) observed a large increase in total P reserve on organic manuring, which they related to the release of P from organic manures via mineralization (Adhami *et al.*, 2013). Although total P gives a total nutrient storage in the soil, it is a poor predictor of availability since the majority of the P may be fixed or unavailable to the plants (Ohno *et al.*, 2011). Inorganic Phosphorus Fractions (Pi) (mg kg^{-1} In all four phases of crop growth, saloid P had high content in non rhizosphere than rhizosphere region revealing an increase of 11.39 %, and it was the lowest of the inorganic P portions contributing 7.18%. This was consistent with the findings of Ramya *et al.* (2018), who discovered that the lowest proportion of saloid P (1 percent of total P).Its share to the total P is about 3.01% only since the applied P fertilizers got transformed into saloid P which led to the formation of dicalcium phosphate in the furrow region which was not under the root zone area. The treatment plot with 100 percent NPK + FYM had the greatest saloid P at the non rhizospheric soil (29.2 mg kg^{-1} at knee high stage and decreased towards maturity). The FYM treated plots had the lowest P fixation, which might be owing to organic molecules emitted from the decaying manure inhibiting the P fixation sites (Purohit *et al.*, 2020).

In the total inorganic P fraction the reductant soluble P accounted for 10.12 % and 4.25% of total P. At the non–rhizospheric soil, the optimal fertiliser dose along with FYM plot had the highest reductant soluble P (34.5 mg kg^{-1} at knee high stage and declined towards harvest). Reductant soluble P concentration was 18.4% higher in the non–rhizosphere zone than rhizosphere region. Application of mineral fertilizers and manures led to increase the P fractions including reductant soluble P or occluded P and the same results was observed by Aswitha *et al.,* 2019 who observed the addition of P fertilizers significantly increased the fixation and transformation in the soil so that, the solubility would be decreased.

The non rhizosphere region exhibited 65.45 % more Fe–P than rhizosphere soil at entire cropping period constituting 10.05% of total inorganic P pools and 4.22% to the total P. Fe–P fraction was found to be higher for the application of FYM along with chemical fertilizers (100% NPK) plot revealing 37.9 mg kg^{-1} at knee high stage and dropped thereafter. Relative abundance of this fraction was high next to Ca–P, which dominates all the inorganic fractions of P and due to the calcareousness nature of the soil. This was supported by the findings of Soremi *et al.*

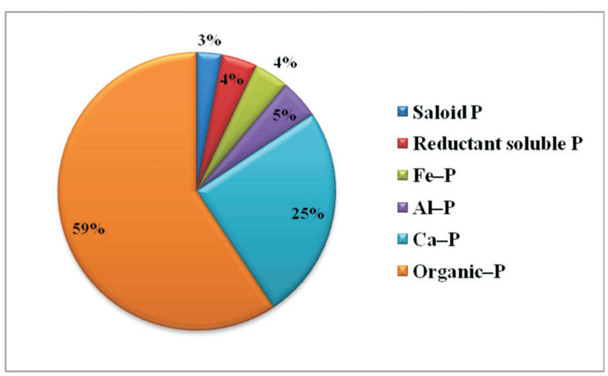

Fig 2. P fraction distribution in total P

(2017) who stated that, applied P could be mineralized and converted in to three active inorganic P fractions. In many soils, phosphorus released as a result of mineralization of organic manure and inorganic fertilisers can be transformed to Fe–P (Udo and Uzu, 1972).

The greatest possible Al–P value was found in T_8 (37.5 mg kg^{-1} at knee high stage) non rhizosphere soil, which received 100 percent NPK+ FYM. The non–rhizosphere soil seemed to have the highest (5.14 %) of Al–P than the rhizosphere soil irrespective of the treatments. Al–P made 11.27 % of inorganic P fraction and 4.73% of total P. Due to the calcareous nature, the unutilised part of the applied P fertilizers gone to bounds with native Ca, Fe and Al ions(Wu and Zhang *et al.*, 2017). While in rhizosphere region the root exudates and other organic acid would interfere the soil pH and make the ions dissolute in to the solution phase and easily exchange with root hair H^+ ions and others (Viswanatha and Doddamani, 1991). Therefore the bulk soil had high Al–P than root zone of the plants (Rengel and Marschner, 2005).

Ca–P, which makes a significant contribution of 61.38 % to the inorganic P pool and 25.78% to the total P, was found in a wide range of 3.48 % more in the non rhizosphere soil region than the rhizosphere soil exhibited the maximum Ca–P in the non rhizosphere soil of T_8 plot which is 194.5 mg kg^{-1} at the knee high period and followed a decreasing trend as the crop proceeded towards the harvest stage in both soil regions. Due to calcareousness of the soil; P was retained as Ca–P irrespective of sources and doses of fertilizers and manures due to more stabilized nature of calcium system under high pH (Safirzadeh *et al.*, 2021). The labile nature of Ca– P was high in INM treatment in over all crop growth stages might be due to addition of manures along with chemical fertilizers and this results was in–line with the findings of Yin and Liang (2013) and low amount of Ca– P in the rhizosphere was due to the rapid uptake of P by plant roots, which was facilitated by the organic exudation enhancing P in the soil (Saeid *et al.*, 2018).

Organic Phosphorus Fractions (Po) (mg kg^{-1})

The Organic–P fraction supplied the most of 61.19% to the soil P pool, demonstrating that it is the most significant of all the P fractions. When the crop came nearer to the harvest, the Organic–P store was depleted and it was detected significantly (2.48%) in non rhizosphere region than it was in rhizosphere region and it was supported by Lu *et al.* (2020). The maximum organic P was recorded in the INM treatment (100% NPK+ FYM) followed by super–optimal fertilization (150% NPK) eventhough, the inorganic fertilizer added contributes to the inorganic pool rather than the organic pool and it was favoured by Costa *et al.* (2016). This might be due to the added organic amendments because organic C and organic bounded P were directly related with each other (Chen *et al.*, 2019). In P mineralization, the organic C get mineralized and C: P_o ratio might have declined and steady state of supply of P to labile pool (Xin-Bin *et al.*, 2012). The lowest organic P was extracted from the rhizosphere soil of the control plot and followed by 100% N plot.

Conclusion

The lack of knowledge on the impact of long-term fertilization and continuous cropping on phosphorus, affecting plant nutrient uptake and its interaction to alter nutrient dynamics at the rhizosphere scale, that limits our ability to provide recommendations and increase the nutrient use efficiency in agroecosystem. Bulk soil had high total P and P fractions (organic and inorganic) than rhizhosphere region, while available P was higher in rhizosphere soil. At both the regions, application of FYM @ 10 t ha^{-1} with 100% NPK showed highest available P, total P, Po as well as Pi fraction in soil. The findings of this investigation demonstrated unequivocally that rhizosphere profiling with reference to P dynamics were closely related with crop growth stages, rhizosphere effect and input on a long–term basis. The up regulation of P dynamics in the root zone environment as a result of the combined application of manure and fertilizer boosted nutrient rotation and the transformation of additional nutrients into distinct labile pools under continuous and intense cropping. Importantly, the current study emphasises the critical necessity of rhizosphere–based strategic actions and integrating organic manure in the fertilizer regime for increasing yield and sustaining soil fertility in order to perpetuate soil productivity over time.

Acknowledgements

The authors were grateful to Indian Council of Agricultural Research (ICAR) and Tamil Nadu Agricultural University for the financial support during

this study.

Conflict of interests

The authors declare that there is no competing interest.

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