***Original Research Article***

**Phosphorus Dynamics and Soil Fertility in Drip-Irrigated Ratoon Sugarcane as Influenced by Fertilizer Regimes and Soil Properties**

**Abstract:**

**Purpose:** To investigate the impact of water-soluble fertilizers on phosphorus dynamics in drip-irrigated ratoon sugarcane. **Methods:** The experiment was conducted at Zonal Agricultural Research Station, V.C. Farm, Mandya during 2020-21. The soil was described as red sandy loam with neutral pH, normal electrical conductivity, medium organic carbon, low available nitrogen and medium phosphorus and potassium content. A Randomized Complete Block Design with three replications was employed. The study involved seven treatments using the VCF-0517 sugarcane variety. Different fertilization methods were used, including the basal application of Single Super Phosphate (SSP) with or without Farm Yard Manure (FYM), as well as the application of water-soluble fertilizers (WSF). **Results:** The results indicated that treatments involving the basal application of SSP with FYM and without FYM led to significantly higher levels of various phosphorus forms (saloid-P, Al-P, Fe-P, RS-P, Occluded-P, and Ca-P) compared to those treated with water-soluble fertilizers.At the grand growth phase (180 days after ratoon), available phosphorus displayed strong positive correlations with various phosphorus forms, suggesting that the application of phosphorus increased its availability to the crop while also enhancing fixation. Available phosphorus showed significant positive associations with electrical conductivity (EC), organic carbon (OC), available potassium and a weaker positive relationship with available nitrogen. **Conclusions:** Basal SSP application, with or without FYM, boosted phosphorus levels over water-soluble fertilizers. Positive correlations between available phosphorus and various forms suggest increased crop availability and fixation. Soil properties (EC, OC, available potassium, pH) impacted phosphorus availability for sugarcane.

**Keywords:** Saloid-P, Reductant soluble P, Occluded P, sorption, Precipitation, Phosphorus dynamics,

**1. Introduction**

Phosphorus is an essential plant nutrient involved in energy transfer for cellular metabolism, structural component of cell membranes and nucleic acids in plants. The total soil P exists in organic and inorganic form. The principal organic P forms present in the soil include inositol phosphate, phospholipids, nucleic acids, phosphate esters and phospho-proteins (Anderson, 1967). Proportion of organic P in mineral soils may vary between 20 to 80 per cent of total P, depending on the age of soil, organic matter content, climate, vegetation, soil texture, land use *etc*. The inorganic phosphates in soil comprise the saloid bound P, iron-P, aluminium-P, calcium-P, reductant soluble P (RS-P) and occluded P (Peterson and Correy,1966). Phosphorus is an essential and limiting nutrient in majority of the Indian soils. The phosphorus availability is limited in acidic, sodic and calcareous soil due to unique characteristic of its lower availability resulted due to slower diffusion and higher fixation in the soils. The phosphorus in sugarcane helps in stimulating bud sprouting, tillering, encourages sugar accumulation and clarification of juice. The demand of P is more during early plant growth stage and generally responds to phosphatic fertilizers. The recovery of P applied through conventional soil application was reported to be very low (10-20 per cent). The main causes for low PUE are sorption and precipitation of P with Fe and Al in acidic soil and Ca in calcareous soils. Pre-plant conventional soil application of P has the advantage of providing higher initial P concentration in the soil solution. However, concentration declines during the growing season due to sorption and precipitation reactions.

Fertigation is an integral part of drip irrigation system where water and nutrients are precisely applied to rhizosphere. The right combination of water and nutrients is the key for higher yield and quality of produce. Sugarcane (*Saccharum officinarum* L.) is highly remunerative commercial crop globally cultivated for the production of sugar, fibre, bio-fuel and manure besides many by-products. The sugarcane yield can be increased by fertigation, besides saving of fertilizer to the extent of 25-30 per cent (Bhoi *et al.,* 1999). A continuous P supply through fertigation on the other hand, may enhance P uptake later in the season. In addition, fertigation minimizes leaching nutrients from the rhizosphere, thus minimizes groundwater contamination and improves resource use efficiency. It is especially important during the early stage where phosphorus required for developing better root system. Unlike conventional band application, fertigation provides P and water to the root zone simultaneously that maximizes P mobility near the root system.

Knowledge of P transformation in the soil is of great importance as the availability of the nutrient is governed by the proportion and distribution of various discrete forms of P compounds. Different P fractions have different solubility and the amount of each depends on various soil properties. Since, the soil solid phase phosphate controls the phosphate concentration in soil solution and also reflects the reserve supply of the nutrient, knowledge concerning the forms and amount of phosphorus in a soil is of important in determining the effectiveness of phosphorus availability. Such information is meager particularly in the soils of southern dry zone of Karnataka and therefore the present study is a step in that direction.

**2. Material and methods**

A field experiment was conducted in D block of Zonal Agricultural Research Station, V.C. Farm, Mandya. The station is situated between 12°18’ and 13°04’ North latitude and 76°19’ and 77°20’ East longitude and at an altitude of 697 meters above mean sea level in southern dry zone (Zone–VI of NARP) of Karnataka which falls in southern dry region (Region III) of India. The soil belongs to order *Alfisols* as per USDA classification. Composite soil samples were drawn from the experimental site during the growth stages and samples were air dried, powdered, sieved and analysed for different phosphorus fractions like saloid-P, Al-P, Fe-P, reductant soluble-P, occluded-P, Ca-P were determined by following the method as outlined by Peterson and Correy (1966). Ratoon sugarcane was grown with seven treatments replicated thrice by adopting randomized complete block design. Main crop was sowed during December 2018 and it was harvested during January 2020 from onwards crop kept for ratooning and harvested January 2021.

In brief, One gram of soil was taken into 50 ml polyethylene centrifuge tube, 25 ml 1 M NH4Cl solution was added and shaken for 30 minutes. Supernatant solution after centrifugation was taken for saloid-P determination. The intensity of blue colour developed was read in spectrophotometer at 660 nm. The soil residue left in centrifuge tube in estimation of saloid-P was shaken for one hour with 25 ml 0.5 M NH4F (pH 8.2) and then suspension was centrifuged to get clear solution, intensity of blue colour read at 660 nm to determine Al-P. The soil sediment from Al-P estimation was washed twice with 25 ml of saturated NaCl by shaking and centrifuging for 10 minutes. The soil was then extracted with 0.1 M NaOH and shaken for 17 hours and centrifuged. The supernatant solution was then treated with five drops of concentrated sulfuric acid. Activated charcoal (phosphorus free) was used to remove organic matter and get clear solution. Iron phosphorus was estimated by the same method as followed for determination of Al-P. The soil left out in the centrifuge tube was washed twice with 25 ml of saturated NaCl by shaking and centrifuging. Soil was then suspended in a 15 ml of 0.3 M sodium citrate solution and shaken for 15 minutes with 0.5 g of sodium dithionite. The suspension was then heated in water bath at 80 0C for few minutes and the clear supernatant solution was collected in to container after centrifuge. Soil was then washed twice with saturated NaCl and the washings retuned to sodium citrate dithionite extract which was taken for Red-Sol-P determination. Excess of citrate and dithionite was oxidized by adding 1.5 ml of 0.25 M KMnO4 solution and the reductant soluble phosphorus was estimated by ascorbic acid reagent using spectrophotometer ant 660 nm. The soil residue left out in the estimation of reductant soluble-P was added with 25 ml of 0.1 N NaOH and shaken for one hour. Supernatant solution after centrifugation was taken for estimation of occluded phosphorus by ascorbic acid method at 660 nm. The soil sample after estimation of occluded phosphorus was washed twice with 25 ml saturated NaCl and washings were discarded after centrifuging. Calcium phosphorus was extracted using 0.25 M sulfuric acid for one hour shaking and centrifuging for five minutes. The phosphorus in the solution was estimated as in case of occluded phosphorus. Data obtained are subjected to analysis of variance as per the procedures outlined by Rangaswamy (2010). The level of significance used in ‘F’ and ‘t’ tests were at p ≤ 0.05 and critical difference values were calculated wherever the ‘F’ test was found to be significant. Correlation studies were done to establish relationship between different forms of P at various growth stages adopting suitable prodedure.

**3. Results and Discussion**

Phosphorus fractions (mg kg-1) of ratoon sugarcane at 90 and 180 DAR as influenced by levels of water-soluble fertilizers through fertigation was represented in Table no.1

**3.1 Saloid-P:**

Basal application of conventional fertilizer (SSP) with FYM (8.95 mg kg-1) and without FYM (9.73 mg kg-1) showed significantly higher saloid bound phosphorus compared to WSF applied treatments during the early stages of crop growth (90 DAR). The levels of WSF application increase the saloid bound phosphorus up to 180 DAR, where significantly higher saloid bound phosphorus was noticed with 150 per cent RDF (11.29 mg kg-1) compared to rest of the treatments. The saloid bound P is the least among the fractions (Dongale 1993; Adhikari and Si, 1994) contributing less than one per cent of total inorganic P. This may be due to higher P fixation capacity of the soil (Sarkar *et al.,* 2017). Lower content of saloid-P, might be due to the higher phosphorus sorption, precipitation and transformation of soluble forms of P into relatively less soluble forms over a period of time. The increase in saloid bound-P up to 180 DAR in drip fertigation treatments may be due to the application of inorganic fertilizers along with FYM might increased solubilization and mineralization of phosphorus. Similar results were reported by Sihag *et al.,* (2005).

**3.2 Aluminium-P**

The aluminium bound P content at early stage of sugarcane was simultaneously higher with the basal application of conventional fertilizer (SSP) with FYM (15.45 mg kg-1) and without FYM (16.02 mg kg-1). At 180 DAR, the WSF application increased the Al-Pcontent at higher levels, where significantly higher aluminium bound phosphoruswasnoticed in 150 per cent RDF (15.06 mg kg-1) compared to rest of the treatments.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Saloid-P** | | **Al-P** | | **Fe-P** | | **Red sol-P** | | **Occl-P** | | **Ca-P** | | |
| DAR | **90DAR** | **180DAR** | **90DAR** | **180DAR** | **90DAR** | **180DAR** | **90DAR** | **180DAR** | **90DAR** | **180DAR** | **90DAR** | **180DAR** |
| **T1: Control** | 5.20 | 4.29 | 5.08 | 4.88 | 9.95 | 8.54 | 6.09 | 5.63 | 6.01 | 5.78 | 7.05 | 6.95 |
| **T2: RDF through conventional fertilizers +No FYM** | 9.73 | 8.19 | 16.02 | 14.28 | 20.24 | 18.89 | 13.46 | 11.31 | 15.08 | 13.09 | 15.82 | 14.09 |
| **T3: RDF through conventional fertilizers + FYM** | 8.95 | 7.62 | 15.45 | 13.93 | 19.21 | 17.96 | 12.84 | 10.13 | 14.48 | 12.84 | 15.15 | 12.91 |
| **T4: 150% RDF through water soluble fertilizers + FYM** | 7.76 | 11.29 | 11.03 | 15.06 | 16.08 | 21.82 | 8.85 | 14.95 | 9.91 | 14.88 | 10.92 | 14.81 |
| **T5: 125% RDF through water soluble fertilizers + FYM** | 7.60 | 11.00 | 10.93 | 14.62 | 15.87 | 21.31 | 8.54 | 14.03 | 9.77 | 14.37 | 10.40 | 14.56 |
| **T6: 100% RDF through water soluble fertilizers + FYM** | 7.47 | 10.95 | 10.74 | 14.44 | 15.65 | 20.50 | 8.01 | 13.40 | 9.63 | 14.09 | 10.17 | 13.74 |
| **T7: 75% RDF through water soluble fertilizers + FYM** | 7.42 | 9.69 | 10.60 | 13.84 | 15.44 | 19.49 | 7.67 | 12.36 | 9.49 | 13.84 | 9.96 | 12.97 |
| **S.Em ±** | 0.45 | 0.23 | 0.46 | 0.26 | 0.55 | 0.42 | 0.52 | 0.43 | 0.56 | 0.61 | 0.53 | 0.44 |
| **CD (*p*≤0.05)** | 1.40 | 0.72 | 1.42 | 0.79 | 1.70 | 1.31 | 1.60 | 1.31 | 1.71 | 1.87 | 1.62 | 1.37 |

**Table 1: Phosphorus fractions (mg kg-1) of ratoon sugarcane at 90 and 180 DAR as influenced by levels of water-soluble fertilizers through fertigation**

Aluminium bound P is second dominant P-fraction which might be due to the presence of sesquioxides and transformation of added P into different forms (Harrell and Wang, 2006). Increase of Al-P with increased fertilizer levels application is due to application of acidic fertilizers resulting in lowering of soil pH and build-up of Al-P fraction. Conventional fertilizer application reduced Al-P with lapse of time (after 90 DAR) because basal application of phosphatic fertilizer (SSP) after 90 DAR resulted in decrease of Al-P due to mineralization and uptake by the plant. The higher content of Al-P in slightly acidic or neutral soil might be due to phosphorus get immobilized or precipitated as Al-P in the soils (Lawrence *et al.,* 1970). Doddamani and Seshagiri Rao (1988) reported higher Al-P in *Alfisols* and ascribed to the chemical indices of weathering of mineral and concomitant release of aluminium, favouring the conversion to Al-P.

**3.3 Iron-P**

During the initial stage of ratoon sugarcane, the Fe bound P content was simultaneously higher with the basal application of conventional fertilizer (SSP) with FYM (19.21 mg kg-1) and without FYM (20.24 mg kg-1). At 180 DAR, the WSF application increased the Fe-Pcontent at higher levels, where significantly higher iron bound phosphoruswasnoticed in 150 per cent RDF (21.82 mg kg-1) compared to rest of the treatments.Rajukkannu and Ravi Kumar (1975) also reported higher Fe-P fraction in red soils. Increase of Fe-P with increase of fertilizer application in drip fertigation due to lowering of soil pH because of application of acidic fertilizer which contributed to fixation of P as Fe-P. Presence of higher amount of sesquioxide in red soil results in higher amount of added P transformed into Fe bound P as reported by Harrell and Wang (2006). Higher Fe-P fraction contribution to total inorganic P is due to presence of more sesquioxide on surface layer of the soil. Higher Fe content in these soils might have fixed the P applied by inorganic P source. These results were similar to the findings of Bhattacharyya *et al.* (2015).Higher Fe-P was might also be due to greater organic carbon content of surface soil because of addition of trash during the initial stage of crop growth which could helped in release of organic acids and solubilize iron to ferrous form along with phosphates resulting in precipitation as ferrous phosphate. These results were similar to the findings of Chang and Juo (1963). The solubilized forms of phosphates (saloid bound P) may form complexes with sesquioxide results in the formation of insoluble fractions. Similar findings were observed in Manthan and Biju (1998).

**3.4 Reductant soluble P**

Application of conventional fertilizer (SSP) with FYM (12.84 mg kg-1) and without FYM (13.46 mg kg-1) during early growth stages (90 DAR) showed significantly higher reductant soluble phosphorus content compared to WSF applied treatments. The levels of WSF application increased the reductant soluble phosphorus content up to 180 DAR, where significantly higher reductant soluble phosphorus noticed in 150 per cent RDF (14.95 mg kg-1) compared to rest of the treatments.This fraction was found to be lower among the fractions except Saloid-P indicating less amount of phosphorus bound in Red Sol-P. This may be due to soil type and weathering sequence in the soil. Similar results were reported by Chang and Jackson (1957) where highly weathered soils contained appreciable amount of reductant soluble phosphorus. Basal application of conventional fertilizer decreases reductant soluble phosphorus with time (after 90 DAR) associated with basal application of full dose of phosphatic fertilizer (SSP) during the initial crop growth stage might resulted in reduced reductant soluble phosphorus at later time due to mineralization into soluble form and uptake by plant or transformed into more recalcitrant pools.

**3.5 Occluded-P**

During the early stages of crop growth (90 DAR) basal application of conventional fertilizer (SSP) with FYM (14.48 mg kg-1) and without FYM (15.08 mg kg-1) showed significantly higher occluded phosphorus content compared to WSF applied treatments. The levels of WSF application increased the occluded phosphorus content up to 180 DAR, where significantly higher occluded phosphorus noticed in 150 per cent RDF (14.88 mg kg-1) compared to rest of the treatments. The increase in occluded phosphorus up to 180 DAR in WSF applied treatments due to application of inorganic fertilizers and their combined use with FYM resulted in increasing the decomposition and degradation of organic matter. Similar results were reported by Kolambe (1992). Manimaran (2014) investigated dynamics of P under the influence of inorganic phosphorus supply and revealed that graded levels of P application gradually increased the concentration of different fractions of P due to higher P fixing capacity of the soils exhibited a rise with increased levels of applied P. Presence of appreciable amount of occluded phosphorus indicate higher occluded phosphorus in oxides of iron and aluminium by Sharpley and Smyth, (1985).

**3.6 Calcium-P**

Basal application of conventional fertilizer (SSP) with FYM (15.15 mg kg-1) and without FYM (15.82 mg kg-1) showed significantly higher calcium bound phosphorus content compared to WSF applied treatments during the early stages of crop growth (90 DAR). The levels of WSF application increased the calcium bound phosphorus content up to 180 DAR, where significantly higher calcium bound phosphorus noticed in 150 per cent RDF (14.81 mg kg-1) compared to rest of the treatments. The increase in Ca-P might be attributed to the higher content of free CaCO3 and slightly saline soil reaction. Similar results were reported by Bapat *et al.,* (1965) and Kothandraman and Krishnamoorthy (1977). Dominance of Ca-P in conventional fertilizer (SSP) without FYM (11.97 mg kg-1) and with FYM (11.09 mg kg-1) might be attributed to application of complete dose of single super phosphate at one time. It contains calcium around 19-21 per cent. Dominance of Ca-P in these soils might be attributed to the presence of higher amounts of exchangeable and soluble Ca which on reaction resulted in the formation of Ca-Phosphates. This observation also attests to earlier reported by Tandon, (1987).

**Table 2: Relationship of phosphorus forms and soil chemical properties**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameters** | **Sal-P** | **Al-P** | **Fe-P** | **RS-P** | **Occl-P** | **Ca-P** | **Available P** |
| **pH** | 0.911\*\* | -0.431 | -0.493 | -0.493 | -0.488 | 0.497 | -0.968\*\* |
| **EC** | 0.842\* | 0.500 | 0.537 | 0.531 | 0.543 | 0.539 | 0.929\*\* |
| **O.C.** | 0.655 | 0.074 | 0.025 | 0.045 | 0.013 | 0.020 | 0.906\*\* |
| **Available N** | 0.472 | 0.744 | 0.693 | 0.747 | 0.694 | 0.680 | 0.553 |
| **Available P** | 0.886\*\* | 0.234 | 0.306 | 0.295 | 0.297 | 0.312 | 1 |
| **Available K** | 0.967\*\* | 0.622 | 0.699 | 0.669 | 0.696 | 0.707 | 0.877\*\* |

**Note: Sal-P- Saloid-P, Al-P- Aluminium P, Fe-P- Iron P, RS-P- Reductant soluble P, Occl-P- Occluded P, Ca-P- Calcium P.**

\*- Significant at 5 % , \*\*- Significant at 1%

From the data presented in Table 2, observed a positive relationship of saloid-P was with OC (r = 0.655) and available nitrogen (r = 0.472). Positive correlation of saloid-P with OC noticed by Devra *et al.* (2015). Positive correlation of saloid-P with organic carbon explains the availability of P in soils with increased organic matter (Tek Chand and Tomar, 1992). Highly significant correlation of saloid-P with available P indicates P availability proportionable to saloid form.

Negative relationship of Al-P with pH (r = -0.431) was noticed due to lower aluminium activity at higher pH, results in lower precipitation indicating increased soil pH is associated with decreased Al-P content (Jaggi, 1991). Negative relationship of Fe-P with pH (r = -0.493) reveals that iincreased pH is associated with decrease in Fe-P content. Fe-P had a positive correlation with organic carbon may be due to the mineralization of organic-P and conversion into Fe-P. When soluble-P is added, it reacts with Fe and Al of soil clay minerals to form insoluble Fe-P and Al-P (Kanwar and Grewal, 1990).

Negative relationship of Red sol-P with pH (r = -0.493) resulted in decrease in Red sol-P content (Jaggi, 1991) at higher pH due to decreased iron and aluminium bound P content and rise in the content of calcium bound P. These results are in conformity with Sharma and Tripathi (1992) and Trivedi *et al*. (2010). The reduction of RS-P with application of FYM might be due to dissolution of iron oxide coating with organic acids released during decomposition of FYM causing reduction of RS–P in the soil. These results are in line with Singaram and Kothandaraman (1991). Negative relationship of Occluded-P with pH (r = -0.488) resulted in decrease in Occluded-P content (Jaggi, 1991) with increased pH. Occluded-P had a positive correlation with organic carbon may be due to the mineralization of organic-P and conversion into occluded-P.

At higher pH, higher Ca-P noticed due to higher CaCO3 content of surface soil might have reacted with P resulting in higher Ca-P. Islam and Khan (1967) and Kothandaraman and Krishnamoorthy (1977) have also made similar observations that increase in CaCO3 content has resulted in increased Ca-P form. Available P showed negative relationship of available P with pH (r = -0.431).

**Table 3: Relationship between forms of phosphorus and available phosphorus at various growth stages**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Parameters** | **Sal-P** | **Al-P** | **Fe-P** | **RS-P** | **Occl-P** | **Ca-P** |
| **BIT available P** | -0.424 | -0.010 | -0.131 | -0.252 | -0.127 | -0.307 |
| **90 DAR P** | 0.290 | 0.250 | 0.329 | 0.021 | 0.089 | 0.068 |
| **180 DAR P** | 0.970\*\* | 0.939\*\* | 0.984\*\* | 0.980\*\* | 0.977\*\* | 0.943\*\* |
| **270 DAR P** | 0.889\*\* | 0.485 | 0.664 | 0.867\* | 0.565 | 0.381 |
| **Harvest P** | 0.886\*\* | 0.234 | 0.306 | 0.295 | 0.297 | 0.312 |

**Note: BIT-Before imposition of treatments, DAR-days after ratoon, Sal-P- Saloid-P, Al-P- Aluminum P, Fe-P- Iron P, RS-P- Reductant soluble P, Occl-P- Occluded P, Ca-P- Calcium P.**

\*- Significant at 5 %, \*\*- Significant at 1%

Before imposition of treatment, available phosphorus showed negative correlation with saloid-P (r = -0.424), Al-P (r = -0.010), Fe-P (r = -0.131), RS-P (r = -0.252), Occl-P (r = -0.127) and Ca-P (r=-0.307) indicating fractions of phosphorus decreased might be because of reduced application of P before imposition of treatments. Over a period of time, increased in concentration of phosphorus in different fractions was noticed.

At critical crop growth stage (180 DAR) available phosphorus showed highly significant positive correlation with saloid-P (r = 0.970\*\*), Al-P (r = 0.939\*\*), Fe-P (r = 0.984\*\*), RS-P (r = 0.980\*\*), Occl-P (r = 0.977\*\*) and Ca-P (r = 0.943\*\*). Al-P significantly correlated with available-P at surface suggesting that it plays a major role in providing phosphorus to growing crop on dissolution. Halstead (1967) correlated Al-P content in soils to plant uptake and thus, established it as an important source of P for plant nutrition in soils. The positive association of Fe-P with available-P confirmed it as an active P form in the soil controlling P availability. Similar correlations has been reported by Krishna and Satyanarayana (1996). Kothandaraman and Krishnamoorthy (1979) observed significant positive correlation of occluded-P with available P in soils of Tamil Nadu. Positive correlation of available phosphorus with saloid-P (r = 0.886\*\*), Al-P (r = 0.234), Fe-P (r = 0.306), RS-P (r = 0.295), Occl-P (r = 0.297) and Ca-P (r = 0.312) was noticed after harvest of ratoon sugarcane crop.

**4. Conclusion**

Basal application of conventional fertilizer (SSP) with FYM (6.40, 11.12, 16.60, 9.18, 11.62 and 11.09 mg kg-1, respectively) and without FYM (6.91, 12.0, 17.93, 10.10, 11.93 and 11.97 mg kg-1, respectively) showed significantly higher saloid-P, Al-P, Fe-P, RS-P, Occluded-P and Ca-P compared to WSF applied treatments.At critical ratoon sugarcane growth (180 DAR) available phosphorus showed highly significant positive correlation with saloid-P (r = 0.970\*\*), Al-P (r = 0.939\*\*), Fe-P (r = 0.984\*\*), RS-P (r = 0.980\*\*), Occl-P (r = 0.977\*\*) and Ca-P (r = 0.943\*\*).Available P showed highly significant and positive relationship with EC (r = 0.929\*\*), OC (r = 0.906\*\*), available nitrogen (r = 0.553), and available potassium (r = 0.877\*\*). Available phosphorus showed negative relationship with soil pH (r = -0.431).

**5. References**

Adhikari M, Si SK. Distribution of inorganic P fraction in some soils of West Bengal. J Indian Soc Soil Sci. 1994;42(3):459-461.

Anderson. Phase changes in upper mantle. J Sci. 1967;157(3793):1165-1173.

Bapat MV, Padoley GC, Totey NG, Bedekar VG. Forms of phosphorus in Vidarbha soils. J Indian Soc Soil Sci. 1965;13:31-36.

Bhattacharyya P, Nayak AK, Shahid M, Tripathi R, Mohanty S, Kumar A, et al. Effects of 42-year long-term fertilizer management on soil phosphorus availability, fractionation, adsorption–desorption isotherm and plant uptake in flooded tropical rice. Crop J. 2015;3:387-395.

Bhoi PG, Bankar MC, Raskar BS, Shinde SK. Effect of fertigation and planting technique on yield and quality of suru sugarcane under drip irrigation. Indian Sugar. 1999:487-492.

Chang HL, Juo PJ. Long-term effects of fertilization on the forms and availability of soil phosphorus fraction in rice paddy. Chemosphere. 1963;26:299-304.

Chang SC, Jackson ML. Fraction of soil phosphorus. Soil Sci. 1957;84:133-144.

Devra P, Yadav SR, Gulati IJ. Impact of crop management system on phosphorus fractions in soils of Western plain of Rajasthan. Ann Plant Soil Res. 2015;17(3):262-265.

Doddamani VS, Seshagiri Rao T. Forms of phosphorus in soils of Karnataka. Indian J Agric Sci. 1988;58:760-765.

Dongale JH. Depth distribution of different forms of phosphorus in lateritic soils of coastal region. J Indian Soc Soil Sci. 1993;41(1):62-66.

Halstead RL. Chemical availability of native and applied phosphorus in soils and textural fractions. Soil Sci Soc Am Proc. 1967;31(3):414-419.

Harrell DL, Wang JJ. Fractionation and sorption of inorganic phosphorus in Louisiana calcareous soils. Soil Sci. 2006;171:39-51.

Islam MR, Khan A. Acid soil phosphorus fractionation in Lakkatura Tea garden, Sylhet, Bangladesh. J Soil Nat. 1967;9(1):11-16.

Jaggi RC. Inorganic phosphate fractions as related to soil properties in some representative soils of Himachal Pradesh. J Indian Soc Soil Sci. 1991;39(3):567-568.

Kanwar, Grewal. Phosphorus fractions in relation to soil properties and genesis in Alfisols and Inceptisols of Himachal Pradesh. J Indian Soc Soil Sci. 1990;28(1):75-79.

Kolambe BN. Phosphorus adsorption desorption characteristics and P requirement of sorghum in some vertisols and associated soils of Maharashtra. Ph.D. Thesis submitted to MPKV, Rahuri; 1992.

Kothandaraman GV, Krishnamoorthy KK. Forms of inorganic phosphorus in Tamil Nadu soils. Indian Soc Soil Sci Bull. 1977;12:243-248.

Krishna TG, Satyanarayana T. Evaluation of soil tests for phosphorus and its relation to inorganic P forms in Vertisols. J Indian Soc Soil Sci. 1996;44(1):89-93.

Lawrence MD, Sheard RW, Miller MH. Availability of reaction products of fertilizer phosphorus to alfalfa and bromegrass seedlings. Can J Soil Sci. 1970;50:141-149.

Manimaran M. Dynamics of phosphorus in soil under the influence of inorganic phosphorus supply. Int J Inf Res Rev. 2014;12:79-80.

Manthan CK, Biju J. Influence of different fertilizer sources on phosphorus dynamics. J Indian Soc Soil Sci. 1998;46(4):686-688.

Peterson GW, Corey RB. A modified Chang and Jackson procedure for routine fractionation of inorganic soil phosphates. Soil Sci Soc Am Proc. 1966;30:563-565.

Rajukkannu K, Ravikumar V. Fractions of inorganic phosphorus and their relation to availability in soil. Madras Agric J. 1975;62:435-438.

Sarkar D, Rakesh S, Sinha AK, Mukhopadhyay P. Forms of phosphorus in some acidic Entisols of subtropical eastern India. Int J Plant Soil Sci. 2017;19(3):1-9.

Sharma, Tripathi BR. Fractions of phosphorus from acid hill soils of northwest. J Indian Soc Soil Sci. 1992;40:59-62.

Sharpley AN, Smyth SJ. Fractionation of inorganic and organic phosphorus in Virgin and cultivated soils. Soil Sci Soc Am J. 1985;40:127-130.

Sihag D, Singh JB, Mehta DS, Bhoradwas KK. Effect of integrated use of fertilizer and organic materials on the distribution of difference forms of N and P. J Indian Soc Soil Sci. 2005;53:80-84.

Singaram P, Kothandaraman GV. Residual effect of different phosphatic fertilizers on available P of soil in a cropping sequence. J Indian Soc Soil Sci. 1991;40(1):213-215.

Tandon HLS. Phosphorus research and agricultural production in India. Fertilizer Development and Consultation Organization, New Delhi, India; 1987. p. 160.

Tek Chand, Tomar NK. Effect of soil properties on the forms of inorganic phosphate in acid soils. J Indian Soc Soil Sci. 1992;40(4):843-845.