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# Phosphorus Fractions Evaluation in the Soils of the Southern Guinea Savannah of Nigeria

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## ABSTRACT

**Background and Objective:** The amount of phosphorus (P) available for plant nutrition may be influenced by the different P fractions in the soil. Hence, an investigation of the different fractions of phosphorus in the soils of Jama'a and Samaru Kataf was carried out. **Materials and Methods:** In each location, 10 soil samples were collected and subjected to routine analysis and sequential extraction of phosphorus using the modified Chang and Jackson Method. Data were subjected to descriptive analysis as well as correlation. **Results:** The soils were found to be sandy loam and strongly acidic. The total P was 587.0 mg $kg^{-1}$ and 506.0 mg $kg^{-1}$ in the soils of Jama'a and Samaru Kataf, respectively. The fractions were observed to be in the order residual-P>calcium-P>occluded P>saloid-P>Fe-P>Al-P>occluded Fe and Al-P for soils of Jama'a while for Samaru Kataf, the fractions were residual-P>occluded P>Fe-P>calcium-P> Al-P>saloid-P>occluded Fe and Al-P. Significant and positive correlations was observed between $pH_{KCl}$ Al-P (r = 0.51*), Fe-P (r = 0.50*) as well as occluded Fe and Al-P (r = 0.49*) while the correlation was positive and highly significant with occluded P (r = 0.67**) and Ca-P (r = 0.74**). **Conclusion:** The high percentage of residual P observed in these soils is an indication of a high degree of weathering in both locations

## KEYWORDS

Phosphorus fractions, correlations, soil properties, particle size fraction, CEC



## INTRODUCTION

Phosphorus (P) ranks as the second most essential nutrient after nitrogen and plays a vital role in plant growth, especially in the control of plant biomass under highly weathered soils. The availability of P in the soil depends on the P fractions, which influence the primary productivity of agricultural ecosystems[1]. On the other hand, soil characteristics may also influence the type of phosphorus forms, as well as phosphorus bioavailability and stability[2]. Despite its importance in crop nutrition, the availability of nutrients in soils for plant uptake is limited by several soil factors such as soil pH levels, clay mineralogy, organic matter, free iron and aluminium, calcium carbonate, soil temperatures, and availability of other nutrients[3].

The fertility of the soil may also be evaluated using the different forms of P. This P form may also be used to establish the degree of soil weathering because P is a major element in soil that is supplied by weathering of parent material in unfertilized soils and the relative abundance of the different fractions may reflect the degree of soil weathering and development.

ISSN: 2957-9449 (Online)
ISSN: 2957-9430 (Print)
https://doi.org/10.17311/tas.2023.27.32

Received: 28 Jun. 2022
Accepted: 01 Oct. 2022
Published: 31 Mar. 2023

Most P management strategies in Nigeria are mostly focused on nutrition without regard to its availability. The result of Mustapha *et al*.[4] indicated that, some of the soils of the Southern Guinea Savannah are acidic and long-term P fertilization may result in phosphorus adsorption and be precipitated with either iron, calcium or aluminum thus rendering P unavailable for plant uptake[5]. This research was carried out to determine the different fractions of P in some soils of southern guinea savanna, observe the influence of some soil properties on soil P fractions as well as use these results to predict the degree of weathering of these soils.

## MATERIALS AND METHODS

**Study location:** The study was carried out in the the research and experimental laboratory of the Department of Soil Science, Faculty of Agriculture, Bayero University Kano, from February, 2021 to May, 2021.

**Sampling location:** The soil sampling was carried out in Kaduna state which is located within the Guinea Savanna of Nigeria. The state is characterized by a uni-modal rainfall distribution with an average annual temperature and rainfall of 27.3°C and 1051.7 mm, respectively. The vegetation is an open savanna wood land type comprising mainly of tall grasses, shrubs and trees. Agricultural activities are a major activity in the zone.

**Soil Sampling and preparation:** Soil was sampled from two locations within the state, Samaru Kataf and Jama'a. Ten samples were collected from each location at 0-20 cm soil depth at a distance of 1 km. The samples were air-dried, crushed gently with mortar and pestle and then sieved through a 2 mm sieve mesh.

**Laboratory analysis:** Soil pH was measured using a glass combination pH meter in the supernatant of 1: 2.5 soil to solution ratio of $H_2O$. Soil organic carbon was determined following the procedures outlined by Mustapha[6]. Cation Exchange Capacity (CEC) of the soil was determined from 1 M ammonium acetate saturated samples using similar procedures as Mustapha *et al*.[7]. Exchangeable K and Na were determined by flame photometer, whereas, exchangeable Ca and Mg were determined by atomic absorption spectrophotometer from 1 M ammonium acetate extract. Fractionation of inorganic P was performed by successive extraction procedure as used by Chulo[8]. All forms of P in the extracts were determined by calorimetry using molybdate ascorbic acid, as described by Mustapha[9].

**Data analysis:** Descriptive analysis was used for the results of the routine analysis and the different forms of P that were determined. Pearson correlation carried was out to determine the relationship between the different soil properties and P fractions using the JMP statistical package.

## RESULTS AND DISCUSSION

The physical and chemical properties of the soils of Jama'a and Samaru Kataf are as shown in Table 1. Variations were observed in particle size fraction between the different locations. Jama'a had a sand content of 64.96% while Samaru Kataf had a content of 58.79%. The content of silt and clay in Jama'a (16.86 and 18.18%, respectively) and Samaru Kataf (20.25 and 20.96%, respectively). The result shows that the Jama'a was strongly acidic in KCl (4.4) and moderately acidic in water (5.4), while Samaru Kataf was slightly acidic in water and KCl (5.70 and 5.10%, respectively). The organic carbon content observed across both Jama'a and Samaru Kataf was medium (10.70 and 11.30 g $kg^{-1}$, respectively). The content of available P was low in both locations (<10 mg $kg^{-1}$). The CEC was low in Jama'a and Samaru Kataf (4.17 and 5.96 cmol $kg^{-1}$ respectively).

Table 1: Physical and chemical properties of soils of Jama'a and Samaru Kataf

| | Jama'a | | Samaru Kataf | |
|---|---|---|---|---|
| Soil physical properties | Range | Mean | Range | Mean |
| Sand (%) | 52.40-74.40 | 64.96 | 33.12-79.12 | 58.79 |
| Silt (%) | 13.28-21.28 | 16.86 | 12.56-31.28 | 20.25 |
| Clay (%) | 12.32-28.32 | 18.18 | 5.60-46.32 | 20.96 |
| Soil textural class | Sandy loam | | Sandy loam | |
| $pH_w$ | 4.9-6.919 | 5.40 | 5.3-6.5 | 5.70 |
| $pH_{KCl}$ | 3.8-4.8 | 4.40 | 4.7-5.5 | 5.10 |
| EC (dS $m^{-1}$) | 0.02-0.06 | 0.03 | 0.02-0.25 | 0.06 |
| Organic carbon (g $kg^{-1}$) | 9.70-13.80 | 10.70 | 10.50-12.9 | 11.30 |
| Total nitrogen (g $kg^{-1}$) | 0.07-0.21 | 0.14 | 0.07-0.49 | 0.15 |
| Available P (mg $kg^{-1}$) | 2.83-5.12 | 3.88 | 0.12-10.13 | 3.67 |
| Exchange acidity (cmol $kg^{-1}$) | 0.50-0.83 | 0.77 | 0.50-0.83 | 0.63 |
| **Exchangeable bases (cmol $kg^{-1}$)** | | | | |
| Ca | 1.52-6.92 | 3.56 | 1.52-6.92 | 0.63 |
| Mg | 0.28-0.56 | 0.40 | 0.28-0.56 | 0.40 |
| Na | 0.03-0.04 | 0.04 | 0.04-0.06 | 0.05 |
| K | 0.14-0.30 | 0.17 | 0.12-0.53 | 0.23 |
| CEC (cmol $kg^{-1}$) | 2.01-7.44 | 4.17 | 2.72-8.62 | 5.96 |

Table 2: Different forms of P in soils of Jama'a and Samaru Kataf

| Parameters | Jama'a (mg $kg^{-1}$) | Samaru Kataf (mg $kg^{-1}$) | SED |
|---|---|---|---|
| SB-P | 18.00 | 18.10 | 5.56 |
| Al-P | 4.40 | 19.30 | 3.39 |
| Fe-P | 6.10 | 101.30 | 12.36 |
| Occ-P | 50.80 | 116.20 | 7.05 |
| Occ Fe and Al-P | 3.63 | 5.60 | 3.26 |
| Ca-P | 310.00 | 44.00 | 24.80 |
| Résiduel-P | 644.00 | 498.00 | 30.20 |
| Total P | 587.00 | 506.00 | 40.60 |

SB-P: Saloid bond P, Al-P: Aluminium bond P, Fe-P: Iron bond P, OC-P: Occluded P, OC Fe and Al-P: Occluded iron and aluminum P and Ca-P: Calcium bond P

**Quantification and forms of P:** The amount and concentration of different forms of P are as presented on Table 2. In both locations, the highest amount of P was found to be residual-P with values of 644 and 498 mg $kg^{-1}$ in Jama'a and Samaru Kataf, respectively. The amount of Fe bond P, occuluded P and Occluded Fe and Al P was found to be higher in the soils of Samaru Kataf with values of 101.30, 116. 20 and 5.60 mg $kg^{-1}$, respectively when compared to the values of 6.1, 50. 80 and 3.63 mg $kg^{-1}$ observed in the soils of Jama'a. Calcium bound P in Jama'a was observed to be 310.0 mg $kg^{-1}$ and far higher than the 44.0 mg $kg^{-1}$ observed in the soils of Samaru Kataf.

The results of the Pearson correlation analysis between the soil properties and different P fractions are presented on Table 3. Significant relationships were observed between most of the soil properties and P fractions. Highly significant and significant correlations were observed between sand and residual P (0.58**), silt and residual P (-0.48*) and clay and Residual P (-0.47*) as well $pH_w$ and Residual P (-0.46*). Significant and positive correlations was observed between $pH_{KCl}$ Al-P (0.51*), Fe-P (0.50*) as well as occuluded Fe and Al-P (0.49*) while the correlation was positive and highly significant with occluded P (0.67**) and Ca-P (0.74**). Significant correlations was oserved between exchange acidity and Ca-P (0.53*).

The properties of these soils have be extensively discussed in by Mustapha *et al.*[4]. The phosphorus in soils can be transformed into different types based on soil types and rate of P fertilization[10]. The micro fauna communities especially bacteria also play a great role in these transformations and may make use of the different types of P pools. Earlier works of Mustapha *et al.*[11] had reported high amount of Fe in these soils which may the reason for the high amount of Fe-P observed in the soil as suggested by Yan *et al.*[12].

Table 3: Pearson correlation of soil properties and different P fractions

| | Sand | Silt | Clay | $pH_w$ | $pH_{KCl}$ | EC | OC | TN | Av. P | EA | CEC | SB-P | Al-P | Fe-P | OC-P | OC Fe and Al-P | Ca-P | Residual_P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sand | 1.00 | | | | | | | | | | | | | | | | | |
| Silt | -0.65** | 1.00 | | | | | | | | | | | | | | | | |
| Clay | -0.90*** | 0.25 | 1.00 | | | | | | | | | | | | | | | |
| pHw | 0.07 | -0.11 | -0.02 | 1.00 | | | | | | | | | | | | | | |
| $pH_{KCl}$ | -0.26 | 0.43 | 0.09 | 0.28 | 1.00 | | | | | | | | | | | | | |
| EC | 0.33 | -0.27 | -0.27 | -0.15 | -0.06 | 1.00 | | | | | | | | | | | | |
| O.C | -0.35 | 0.49* | 0.17 | -0.17 | 0.38 | 0.13 | 1.00 | | | | | | | | | | | |
| TN | 0.30 | -0.28 | -0.22 | -0.041 | -0.05 | 0.09 | -0.10 | 1.00 | | | | | | | | | | |
| Av. P | 0.05 | -0.11 | -0.00 | 0.22 | 0.07 | 0.29 | -0.09 | 0.05 | 1.00 | | | | | | | | | |
| E.A | -0.36 | 0.13 | 0.38 | -0.41 | -0.55* | -0.11 | -0.10 | -0.09 | -0.14 | 1.00 | | | | | | | | |
| CEC | -0.50* | 0.29 | 0.47* | 0.27 | 0.48* | -0.13 | 0.27 | 0.05 | 0.32 | 0.06 | 1.00 | | | | | | | |
| SB-P | 0.32 | -0.41 | -0.17 | -0.08 | -0.04 | 0.18 | -0.41 | 0.10 | -0.09 | -0.27 | -0.23 | 1.00 | | | | | | |
| Al-P | -0.38 | 0.44 | 0.24 | 0.13 | 0.51* | -0.37 | 0.08 | -0.12 | 0.19 | -0.40 | 0.34 | 0.22 | 1.00 | | | | | |
| Fe-P | -0.17 | 0.26 | 0.07 | 0.16 | 0.50* | -0.34 | 0.19 | 0.18 | -0.15 | -0.42 | 0.29 | 0.06 | 0.74*** | 1.00 | | | | |
| OC-P | -0.22 | 0.23 | 0.15 | 0.15 | 0.67** | -0.30 | 0.35 | -0.07 | 0.02 | -0.36 | 0.56* | 0.10 | 0.64** | 0.72*** | 1.00 | | | |
| OC Fe and Al-P | -0.22 | -0.06 | 0.32 | 0.27 | 0.49* | -0.19 | 0.06 | 0.027 | 0.017 | -0.27 | 0.34 | 0.15 | 0.55* | 0.68** | 0.63** | 1.00 | | |
| Ca-P | 0.24 | -0.38 | -0.09 | -0.35 | -0.74** | 0.34 | -0.39 | -0.04 | 0.076 | 0.53* | -0.27 | 0.13 | -0.64** | -0.79*** | -0.70** | -0.72** | 1.00 | |
| Residual_P | 0.58** | -0.48* | -0.47* | -0.46* | -0.48** | 0.59** | -0.17 | 0.057 | 0.055 | 0.16 | -0.53* | 0.12 | -0.65** | -0.61* | -0.56** | -0.458 | 0.69** | 1.00 |

$pH_w$: pH water, $pH_{KCl}$: pH KCl, EC: Electrical conductivity, OC: Organic carbon, TN, Total nitrogen, Av.P: Available P, CEC: Cation excahange capacity , SB-P: Saloid bond P, Al-P: Aluminum bond P, Fe-P: Iron bond P, OC-P: Occluded P, OC Fe and Al-P: Occluded iron and aluminum P, Ca-P: Calcium bond P

Aluminium bound P is more readily available than other P forms and its uptake of Al-P may also be attributed to the low amount observed in these soils in comparison to the Fe-P[12]. Precipitation reactions involving the replacement of Al by Ca on exchange sites as well as the fixation of phosphorus by calcium could be could occur have led to the high amount of Ca-P observed in both soils[8]. The amount of Residual P fraction made up of insoluble and stable forms of P, such as Ca-, Fe- and Al-bounded P representing the unavailable forms of P pools in the soil was high in both locations. The high amount may be as a result of complexation and reaction of both organic and inorganic released P with the clay surface either by ligand exchange and or surface complexation[5,8].

The low contents of the occluded P (Fe and Al) may be due to the transformation of the fractions into non labile forms. The amount of total P was observed to be in the high range for soils of the tropics and could be due to the high amount of P in the parent materials, ability of clay minerals to retain and adsorb P as coatings on Al and Fe oxides as well as fixation[11].

Soil texture influences the distribution of residual P as seen by the positive correlation result between residual P and all the particle size fractions. Phosphorus is found in association with soil and concentration increases with the increasing finesse of the soil[1]. The significant result between Al-P, Fe-P and occluded P and pH was attributed to the effect of pH on soil P mineralization and availability. Increasing the concentration of reactive phosphate in soils with increasing pH is expected as the increase in pH favours P desorption by changing the electrostatic potential of metal oxides surface or by increasing the concentration of ions that increase P solubility[1].

## CONCLUSION

In this study, the different fractions of P were identified and quantified as well as the relationship between some soil properties on the different pools identified. The fractions were observed to be in the order residual-P>calcium-P>occluded P>saloid-P>Fe-P>Al-P>occluded Fe and Al-P for soils of Jama'a while for Samaru Kataf, the fractions were residual-P>occluded P>Fe-P>calcium-P>Al-P>saloid-P>occluded Fe and Al-P. Residual P was higher than most forms of P thus indicating the soil has undergone a high degree of weathering. Hence P management strategies should be guided towards reducing fixation and increasing availability due to high level of Fe as well as the acidic nature of the soil.

## SIGNIFICANCE STATEMENT

This study evaluated the different forms of phosphorus in the soils of the Southern Guinea Savannah. The soils of this area are acidic and knowledge of the different fractions could serve as a guide in phosphorus management, by reducing adsorption with the different fractions as well as reducing the possibles losses either by leaching or run-off.

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