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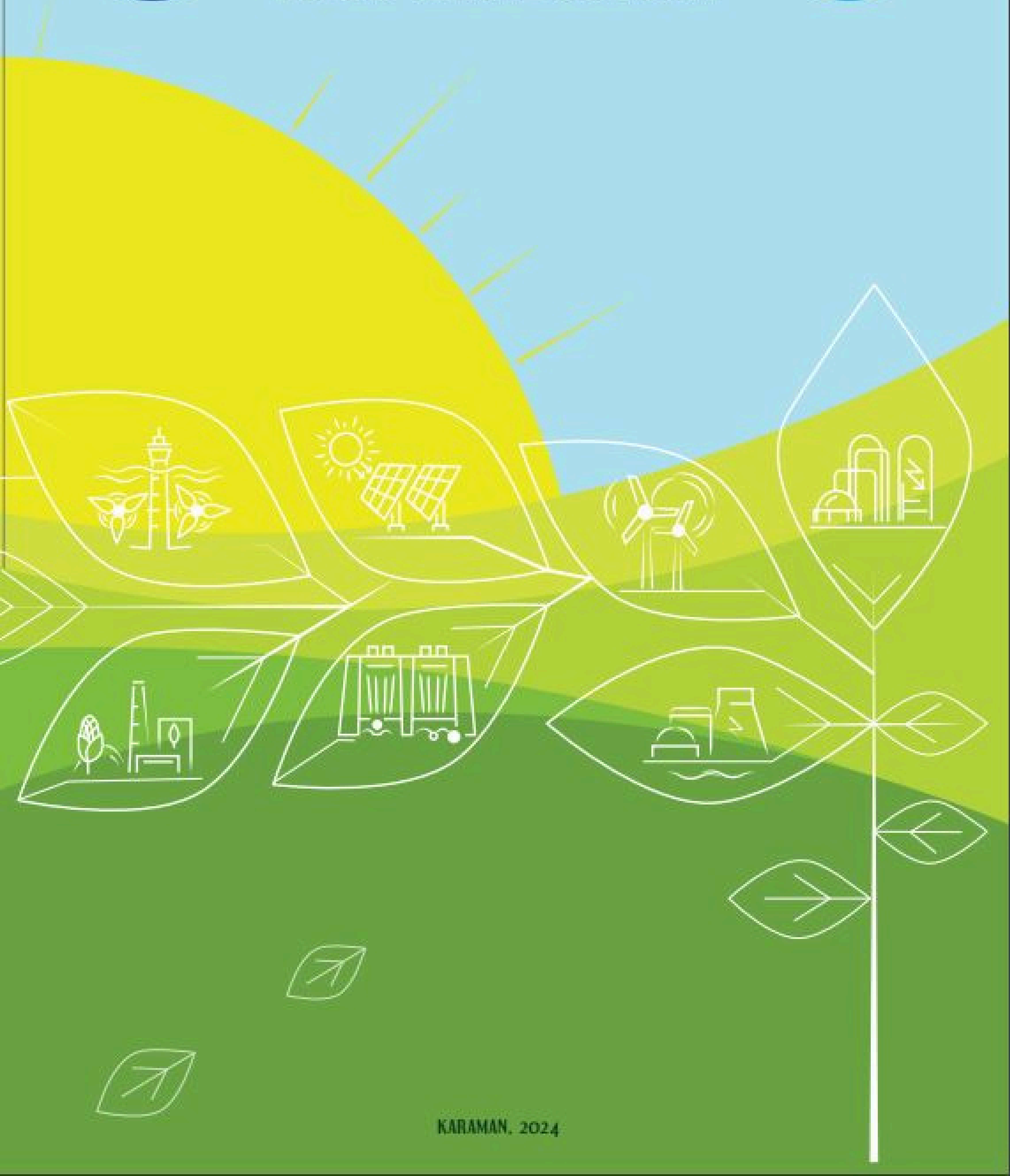

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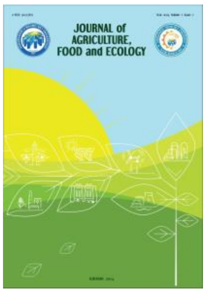

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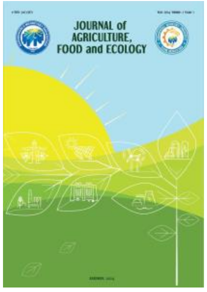

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Assessment of Soil Phosphorus Forms on Oil Palm Plantation in Songhai, Amukpe Delta State, Nigeria

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Abstract

Soil fertility decline due to mismanagement of plant nutrients further exacerbates the arduous task of satisfying the increasing food demands by the growing population. Primary nutrients such as nitrogen (N), phosphorus (P) and potassium (K) are required in very large quantities by most crops. The three primary nutrients (nitrogen, phosphorus and potassium), constitute the basic components of most inorganic NPK fertilizers, but whereas N and K are often readily available to plants, P is frequently not so readily available to plants. Even though, phosphorus happens to be one of the most important nutrients to growing crops, it is however, one of the limiting plant nutrients in most Sub-Saharan African (SSA) soil. Hence, this study was carried out to investigate the assessment of soil phosphorus forms and distribution and its impact on oil palm plantation of the Songhai Delta Amukpe farm project in Sapele Local Government Area of Delta State. A total of five (5) profile pit was dug. Soil samples were collected from each horizons with the aid of a hand trowel. The data obtained were analyzed by Genstat computer package. The difference between the means were separated using Duncan multiple range test at 5% level of probability. From the study, the results shows that the phosphorus contents were significantly different. According to the mean values recorded, phosphorus was below critical level for optimum yield of Oil palm. It also shows that the various forms of P were higher than the active forms indicating high fixation and low availability of P in Songhai Oil Palm plantation, Amukpe, Delta state.

Keywords: Oil palm; phosphorus forms; soil fertility;

1. Introduction

Oil palm is a vital crop in Nigeria, contributing significantly to the country's economy and food security. Phosphorus (P) is essential for oil palm growth and development, influencing yield, fruit quality, and sustainability (1). Phosphorus Requirement Stages: Germination and Seedling Stage: 10-20 kg/ha P_2O_5 (2), Immature Stage (1-

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3 years): 30-50 kg/ha P_2O_5 (3), Mature Stage (4-10 years): 50-80 kg/ha P_2O_5 (4), and Fruiting Stage: 80-100 kg/ha P_2O_5 (5). The depletion of soil fertility resulting from inadequate management of plant nutrients further complicates the challenge of meeting the escalating food needs of a growing population (6). Essential nutrients like nitrogen (N), phosphorus (P), and potassium (K) are vital in substantial amounts for most crops. While nitrogen and potassium are typically accessible to plants, phosphorus often presents availability challenges (7). As recommended by Gilkes and Singh (8), Vance et al. (9), and Richardson and Simpson (10), suitable phosphorus fertilizers include: single super phosphate (SSP): 18% P_2O_5, diammonium phosphate (DAP): 46% P2O5, and triple super phosphate (TSP): 46% P_2O_5. Phosphorus (P) ranks second only to nitrogen (N) as the most crucial macro-nutrient required by plants (11). It plays a pivotal role in enhancing and sustaining agricultural productivity (12) but often acts as a growth-limiting factor in many soil types. The importance of phosphorus is increasingly recognized in the development of nutrient management strategies (13). Despite its significance for crop growth, phosphorus remains one of the most deficient plant nutrients in many soils across Sub-Saharan Africa (SSA). Phosphorus adsorption, defined as the net accumulation of P at the interface between the solid and water-soluble phases of soil, is influenced by the availability of native soil P and the quantity of P supplied through fertilizers [14]. When soluble P compounds are introduced into the soil, they initiate a series of intricate reactions that can diminish the availability of phosphorus to plants like oil palm (1). Adsorption reactions represent a primary mechanism in the retention of phosphorus on soil surfaces (14). In tropical soils, the uptake of phosphorus by plants is notably limited, as evidenced by low recovery rates of P fertilizers ranging from 5% to 25% (15). Given that oil palm cultivation is prevalent in tropical soils, there's a pressing need for sustainable crop production practices. Sustainable crop production endeavors to sustain high crop yields without compromising the ability of ecosystems to meet the needs of both present and future generations (16). Given that phosphorus is the second most growth-limiting macronutrient in agriculture, following nitrogen, its effective management in soil significantly contributes to sustainable crop production. Once this target value is attained, maintaining the available soil phosphorus concentration at a level that can sustain high crop yields can be achieved through maintenance fertilization, which involves replacing only the phosphorus removed from the field along with the harvested crops. Additionally, phosphorus contained in crop residues left in the field can be recycled by incorporating the residues into the soil, while a portion of the phosphorus in crop residues fed to livestock can be reintroduced to the soil in the form of manure or bone meal (17). There is an urgent need to improve the efficiency of phosphorus fertilizer recovery in low-phosphorus tropical soils to prevent the accumulation of recalcitrant soil phosphorus (18). Hence, this study is aimed in assessing the soil phosphorus forms and distribution of Amukpe Songhai Oil palm grove, Delta State in the South-South region of Nigeria.

2. Materials and Methods

Site description: This study was carried out at the Songhai Delta Amukpe farm project, in Sapele Local Government Area of Delta State. Located within Latitude 05°49'34.96" N to 05°52'00.66" N and Longitude 05°42'14.30" E to 05°47'00.54" E, the site lies along the Amukpe-Eku road, just about 7 km from the center of Sapele main town. Figure 1 shows the location map of study site.

Field survey: Field survey was carried out at a detailed scale in an area measuring about 94 hectares, using the rigid grid systematic soil survey method. An auger point was placed at 100 m intervals along horizontal and vertical traverses from a predetermined baseline. An auger point was examined at depth intervals of 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm respectively. Soil samples from the corresponding depths were described morphologically on the field (soil colour, texture by feel, presence or absence of mottles, concretions, etc.). Areas with similar properties and characteristics on the landscape will be grouped to produce various soil mapping units, each represented by a pedon. Each pedon was described and a soil sample was collected from each horizon for laboratory physical and chemical analysis.

Climate: The study area was located in the tropical rainforest zone of Nigeria, with average rainfall of 1900 mm per annum. Mean annual temperature ranges between 23 °C and 37 °C, while relative humidity ranges from 89% in the morning (10.00 am) to 75% in the evening (4 pm), recorded over a period of 18 years (2).

Parent material: The soil is formed from Sombreiro-Warri Deltaic Plain (SDP) – sand, clay and swamp (NGSA, 2008 (19)).

Vegetation: The vegetative pattern of the study area is largely dominated by plantations and farm lands. Some portions of the study area have been left fallow for some time, leading to the formation of secondary forest.

Sample collection: A total of five (5) profile pit was dug. Soil samples were collected from each horizon with the aid of a hand trowel, they include:

Pedon 1: A (0-22 cm), BA (22-62 cm), Bw1 (62-105 cm), Bw2 (105-145 cm), and Bw3 (145-180 cm). Pedon 2: A (0-19 cm), Bt1 (19-43 cm), Bt2 (43-80 cm), Bt3 (80-130 cm), and Bt4 (130-180 cm). Pedon 3: A (0-29 cm), BA1 (29-56 cm), BA2 (56-112 cm), and Bt1 (112-190 cm). Pedon 4: AP (0-24 cm), A (24-46 cm), Bt1 (46-75 cm), Bt2 (75-128 cm), and Bt3 (128-180 cm). Pedon 5: A (0-18 cm), BA1 (18-45 cm), BA2 (45-75 cm), Bt1 (75-103 cm), Bt2 (103-178 cm) respectively. Soil samples were brought to the laboratory for analysis.

Soil sample preparation for laboratory analysis: Soils collected from each pit profile were air-dried, crushed and passed through a 2 mm sieve to fine-tilth. The soil samples were air-dried for four (4) weeks because the terrain where the samples was collected was a very wet terrain and samples were collected under rain. The soil samples were stored in polythene bags ready for laboratory analysis.

Soil phosphorus forms analysis of soil samples: For total P, one of the most widely used methods for total P content extraction in the soils is digestion with $HClO_4$. 2 g of finely ground soil was weighed into 100 ml conical flask. 30 ml of $HClO_4$ was added. The flask was heated in a hot plate in fume cupboard at 130 °C until solution became clear. Temperature of hot plate was increased and soil residue became white. It was not allowed to dry. The flask was removed and allowed to cool. 50 ml of distilled water was added and filtered into 100 ml volumetric flask and stored in 100 ml plastic reagent bottle for colorimetric determination of P. For Organic P, 2 g of soil was weighed into crucible of known weight, carefully placed in a muffle furnace and ignited at 550 °C for 1 hour. It was removed after one hour and allowed to cool. 30 ml of 0.1M H_2SO_4 was added to ignited soil sample and also to unignited soil. They were filtered into 100 ml standard flask and stored in for colorimetric determination of organic P in a spectrophotometer. While for Inorganic P, 1g of soil was weighed into 100 ml conical flask. 10 ml of concentrated hydrochloric acid (HCl) was added. It was mixed by swirling and heated for 10 minutes in a water-bath at 70 °C. Additional 10 ml concentrated HCl was added and was allowed to stand for 1 hour at room temperature. 50 ml of distilled water was added and was centrifuged at 2000 rpm for 5 - 10 minutes. The supernatant was collected into a 250 ml volumetric flask. 30 ml of suspension was centrifuged and supernatant containing organic matter was filtered into volumetric containing HCl extract and 60 ml of 0.5 N NaOH was added at 90 °C for 8 hours in an oven. The suspension was filtered after cooling and P was determined colorimetrically in a spectrophotometer. The occluded P content (inactive P) was calculated as the difference between total P content and the active P content.

Statistical Analysis: The data obtained were analyzed by Genstat computer package. The difference between the means were separated using Duncan multiple range test at 5% level of probability.

3. Results

Influence of soil phosphorus forms on oil palm plantation: As indicated in the (Table 1 and 2), in the study, soil phosphorus forms have significant ($p<0.05$) effect on oil palm plantation soil. The result revealed a significant decrease in available P content with increasing soil depth in each pedon, ranging from 17.92 mg/kg to 21.05 mg/kg. A similar trend was observed for inorganic P content in Pedons 3, 4, and 5, while Pedons 1 and 2 exhibited constant values. The organic P content decreased with depth in all pedons, with Pedon 5 recording the highest mean value (83.52 mg/kg) and Pedon 1 recording the lowest mean value (65.58 mg/kg). The occluded P content and total P content followed similar trends, decreasing with soil depth. Pedon 5 had the highest mean value of occluded P content (153.12 mg/kg), while Pedon 3 had the lowest mean value (94.40 mg/kg). Similarly, Pedon 5 had the highest mean value of total P content (336.74 mg/kg), while Pedon 1 had the lowest mean value (280.74 mg/kg). These results suggest that Pedon 5 had the highest mean values for organic P, occluded P, and total P content, while Pedon 1 had the lowest mean values for these parameters.

4. Discussions

The results in Tables 1 and 2 indicate significant variations in soil phosphorus forms across all pedons. The decrease in available phosphorus content with depth in most pedons can be attributed to the limited mobility of phosphorus within the soil system, as reported by Brady and Weil (20). The classification of inorganic P fractions into active and inactive forms, as proposed by Osadeke and Uba (21), is supported by the relative proportions of the various P forms presented in Tables 1 and 2. The ranges of P forms in each pedon are as follows: Pedon 1: 81.20-94.93 mg/kg (mean: 85.64 mg/kg), pedon 2: 73.80-95.83 mg/kg (mean: 85.62 mg/kg), pedon 3: 79.50-103.33 mg/kg (mean: 91.01 mg/kg), pedon 4: 75.90-112.95 mg/kg (mean: 88.85 mg/kg), and pedon 5: 70.90-98.40 mg/kg (mean: 83.11 mg/kg). This result is in agreement with the findings of other researchers (22). The soil organic-P ranged from 48.80-81.53 mg/kg, 79.40-85.40 mg/kg, 63.80-79.40 mg/kg, 72.90-91.77 mg/kg and 73.60-97.50 mg/kg with mean values of 65.58 mg/kg, 82.12 mg/kg, 74.03 mg/kg, 80.35 mg/kg and 83.52 mg/kg in Pedon 1, 2, 3, 4 and 5 respectively. The soil organic-P did not decrease with increased soil depth in Pedon 1, 2, 3 and 5 while in Pedon 5, the soil organic P decreased with increased soil depth and this was in agreement to Ibia and Udo (23) who also reported a decreasing organic-P with depth in line with the trend in organic carbon distribution. The decrease in organic-P with increasing depth can be as a result of the higher concentration of organic carbon and microorganism within the soil surface horizon (20). The soil occluded-P ranged from 77.50-241.30 mg/kg, 86.40-126.80 mg/kg, 88.30-102.31mg/kg, 89.80-126.50 mg/kg and 79.80-188.40 mg/kg with mean values of 122.43mg/kg, 100.48mg/kg, 94.40mg/kg, 106.57mg/kg and 153.12mg/kg in Pedon 1, 2, 3, 4 and 5 respectively. The soil occluded-P decreased with increased soil depth in most soils of the studied area. The total-P content of the soil ranged from 227.20-419.30 mg/kg, 251.80-337.40 mg/kg, 259.80-311.90 mg/kg, 252.60-356.80 mg/kg and 251.10-404.90 mg/kg with mean values of 290.21 mg/kg, 285.52 mg/kg, 280.74 mg/kg, 295.44 mg/kg and 336.74 mg/kg in Pedon 1, 2, 3, 4 and 5 respectively. The results presented in Tables 1 and 2 reveal an interesting trend in the total phosphorus (Total-P) content with respect to soil depth. Specifically, Pedons 1, 2, and 5 did not exhibit a significant decrease in Total-P content with increasing soil depth. In contrast, Pedons 3 and 4 showed a notable decrease in Total-P content with depth, which is in agreement with the observations of Orhue and Kingsly (22). This suggests that the distribution of Total-P content with soil depth can vary significantly depending on the pedon, highlighting the importance of pedon-specific characterization in soil fertility studies.

Table 1: Forms of Phosphorus in Soil in Pedon 1, 2 and 3

		Av.p	Inorganic-P	Organic-P	Occluded-P	Total P
		←	(mg/kg)			→
Pedon 1	Horizon Depth					
A	0-22	25.93a	94.93a	63.80c	241.30a	419.30a
BA	22-62	20.50b	89.50b	59.60d	123.60b	293.00b
Bw1	62-105	17.50c	75.00e	48.80e	85.90c	227.20e
Bw2	105-145	15.30d	81.20d	74.20b	83.80c	254.50d
Bw3	145-180	10.40e	87.60c	81.53a	77.50d	257.00c
	MEAN	**17.92**	**85.64**	**65.58**	**122.43**	**290.21**
Pedon 2						
A	0-19	27.37a	95.83a	85.40a	126.80a	337.40a
Bt1	19-43	24.30b	91.40b	82.40b	101.40b	299.50b
Bt2	43-80	18.40c	73.80e	79.40d	97.20c	251.80e
Bt3	80-130	15.30d	87.60c	82.80b	90.60d	276.30c
Bt4	130-180	12.60e	79.50d	80.60c	86.40e	262.10d
	MEAN	**19.52**	**85.62**	**82.12**	**100.48**	**285.52**
Pedon 3						
A	0-29	27.19a	103.33a	77.95b	102.31a	311.90a
BA1	29-56	25.00b	86.40c	75.00c	96.40b	282.80b
BA2	56-112	19.40c	94.80b	63.80d	90.60c	268.60c
Bt1	112-190	12.60d	79.50d	79.40a	88.30d	259.80d
	MEAN	**21.05**	**91.01**	**74.03**	**94.4**	**280.74**

Mean value(s) with the same letters(s) in the column are not significantly different from one another at 5% level of probability.
Av.p = Available phosphorus

Table 2: Forms of Phosphorus in Soil in Pedon 4 and 5

		AV.p	Inorganic-P	Organic-P	Occluded-P	Total-P
		(mg/kg)				
Pedon 4	Horizon Depth					
AP	0-24	26.99b	112.95a	91.77a	126.50a	356.80a
A	24-46	28.00a	88.30b	85.20b	122.60b	319.10b
Bt2	46-75	19.50c	86.30c	78.40c	99.40c	283.60c
Bt2	75-128	16.20d	80.80d	73.50d	94.60d	265.10d
Bt3	128-180	14.00e	75.90e	72.90d	89.80e	252.60e
MEAN		**20.93**	**88.85**	**80.35**	**106.57**	**295.44**
Pedon 5						
A	0-18	30.20a	98.40a	87.90b	188.40a	404.90a
BA1	18-45	27.03b	83.28c	77.31d	176.10b	362.00b
BA2	45-75	20.40c	84.80b	81.30c	156.30d	342.80c
Bt1	75-103	15.60d	78.20d	97.50a	79.80e	251.10e
Bt2	103-178	13.40e	70.90e	73.60e	165.00c	322.90d
MEAN		**21.33**	**83.11**	**83.52**	**153.12**	**336.74**

Mean value(s) with the same letters(s) in the column are not significantly different from one another at 5% level of probability.
Av.p = Available phosphorus

5. Conclusion

This study investigated the distribution and forms of phosphorus in soils from five pedons in the studied area. The results revealed significant variations in soil phosphorus forms across all pedons, with available-P decreasing down the profile due to its relatively low mobility. The inorganic-P content fractions ranged from 73.80-112.95 mg/kg, while soil organic-P content varied between 48.80-97.50 mg/kg. Occluded-P content and total-P contents also showed significant variations. The study's key findings include: Available-P content decreased with increased soil depth in most pedons., soil organic-P did not decrease with depth in most pedons, except Pedon 5, occluded-P content decreased with increased soil depth in most soils, and total-P content did not decrease with depth in Pedons 1, 2, and 5. These results are consistent with previous studies (22-23) and highlight the importance of understanding phosphorus dynamics in soils for effective fertilizer management and sustainable agriculture.

Implications

The findings of this study have significant implications for soil fertility management and phosphorus fertilizer application strategies in the studied area. Understanding the distribution and forms of phosphorus in soils can inform: Targeted fertilizer application to optimize phosphorus availability, soil conservation practices to minimize phosphorus loss, and sustainable agriculture practices to maintain soil fertility.

Recommendations

Future studies should investigate:

The impact of fertilizer application on phosphorus dynamics in these soils.

The relationship between soil organic carbon and phosphorus availability.

The development of site-specific fertilizer recommendations based on soil phosphorus forms. By addressing these knowledge gaps, this research contributes to improving soil fertility management and promoting sustainable agriculture practices in the studied area.

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Conflicts of Interest

There is no conflict of interest between the article authors. We sought the permission of the Songhai Amukpe Oil plam plantation farm management, Delta State before sampling. We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the Concept, Design, Data Collection or Processing, Statistical Analyses, Literature Search, Writing, Review and Editing of the manuscript.

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