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PHOSPHORUS DYNAMICS AND SOLUBILIZING MICROORGANISMS IN ACID SOILS UNDER DIFFERENT LAND USE SYSTEMS IN UYO, AKWA IBOM STATE NIGERIA

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ABSTRACT

A research on phosphorus dynamics and solubilizing microorganism in acid soil of Uyo, Nigeria was carried out with the aim to investigate selected soil properties, forms of phosphorus (P), total P(TP), Inorganic P (P_i) organic P (P_o), available P, (AVP), microbial biomass P (MBP), enzyme activities (acid and alkaline phosphatase), Phosphorus solubilizing bacteria (PSB) and Phosphorus solubilizing fungi (PSF) and their correlation in acid soils (0-15 and 15-30cm depths) under different land use systems (Coconut plantation, upland rice farm, water leaf farm and uncultivated land). The research was conducted in the Department of Soil science and land Resources Management, University of Uyo, Nigeria from march 2022 to May 2023.Three composites soil samples of two different depths (0-15cm and 15-30cm) were collected each different land use systems making 24 samples in all. The samples were divided into two parts; The sample for biochemical studies were stored in a sterile labelled bags and conveyed in a cooler containing ice block and then taken to the laboratory where it was stored in a refrigerator at 4°C for determination of phosphorus cycling enzyme activities, and phosphate solubilizing ability of microorganisms. The second part were processed for selected physical and chemical analyses of the soil in the laboratory. The results showed that sand fraction in all the land use systems varied but not significantly except in coconut plantation that was significantly different from other land use systems at 0-15cm depths but at 15-30cm depth there was no significant difference among the sand fractions. Soil reaction showed strongly acid condition across all the land use systems and in the surface and subsurface layers. The mean data for organic carbon ranged from 0.73% in water leaf land use systems to 1.85% in coconut plantation at the 0-15cm depth whereas at 15-30cm depth it ranged from 0.54% from coconut plantation to 1.75% in uncultivated land. The soil samples in all land use systems differed significantly for the P-forms. Soils in Upland rice (136.77 mg/kg) were best in terms of having Total phosphorus. Soils in coconut plantation (64.66mg/kg) were best in having highest inorganic phosphorus. Soils in waterleaf farming (118.36mg/kg and 81.52mg/kg) had highest organic P and available P respectively. soils in uncultivated soil (7.10 µg P/g soil) had highest microbial biomass P and best in enzyme activities. Uncultivated soil (2.4x10^7 µg PNP g^{-1} h^{-1}soil and 2.4x10^7 µg PNP g^{-1} h^{-1}soil) had highest phosphorus solubilizing bacteria and fungi respectively. PSB and PSF were significantly correlated with all P forms in the soil and P-cycling enzymes with exception to total inorganic phosphorus and alkaline phosphatase. This would lead us to understand the level of phosphorus dynamics and degradation of P pools due to cultivation and other land practices and the suitable management practices needed for soil quality restoration.

Keywords: *Acid Soils–Uyo–Phosphorus–Soil Enzymes–Phosphate solubilizers*

INTRODUCTION

Phosphorus (P) is recorded as the second most important nutrient for plant growth, accounting for 0.2% (w/w) of plant dry weight (Maharajan *et al*., 2018). Phosphorus plays an irreplaceable role in the ecosystem by participating in most aspects of energy metabolism, nucleic acid and protein synthesis (Nesme*et al*., 2018). The average phosphorus content in soil is nearly 0.05% (w/w) with the two main forms being inorganic P (P_i) and organic P (P_o). Phosphorus fixation and precipitation in soils are generally highly dependent on pH and soil type. Low pH in soils leads to fixation of applied phosphorus in arable systems due to high activities of Al and Fe (Bucher *et al*., 2001). The primary source of phosphorus in soils is minerals found in parent material. However, the remains of dead organisms, tree-crown, water deposition, rainfall water deposition and fertilizers, constitute a secondary and internal source of that element (Jonczyk*et al*., 2015). A study carried out by (Jonard*et al*., 2014) indicates that forest ecosystems lose their ability of efficient phosphorus recycling probably due to an excessive nitrogen input and climatic stress. Many studies have reported that the dynamics of phosphorus in soil depends upon pH value (Kim *et al*. 2003), nitrogen or organic matter concentrations (Canellas *et al*., 2010), and soil clay content (Yu *et al*., 2016). Microorganisms are also involved in a variety of processes that affect the transformation of soil phosphorus. They enhance the availability of phosphorus to plants by mineralizing organic phosphorus in soils and by solubilizing precipitated phosphates (Chen *et al*., 2006).

Thus, management of phosphorus solubilizing microorganisms in soils plays a significant role to improve phosphorus availability. Furthermore, the release of phosphorus by phosphates solubilizing microbes from insoluble and fixed/adsorbed forms is extremely important for phosphorus availability in soils. Microorganisms increase the availability of native phosphorus for plants through a variety of mechanisms, like the release of organic acids and hydrogen ions, and phosphatase enzymes to hydrolyze soil organic phosphorus (Surange*et al.*, 1995); Dutton and Evans 1996; Nahas, 1996).

Phosphate solubilizing bacteria (PSBs) convert unavailable P (both Pi and Po) into available P to satisfy the requirements of plants through dissolution and absorption. According to the various P-dissolving patterns, phosphate Solubilizing Bacteria can be divided into two classes:

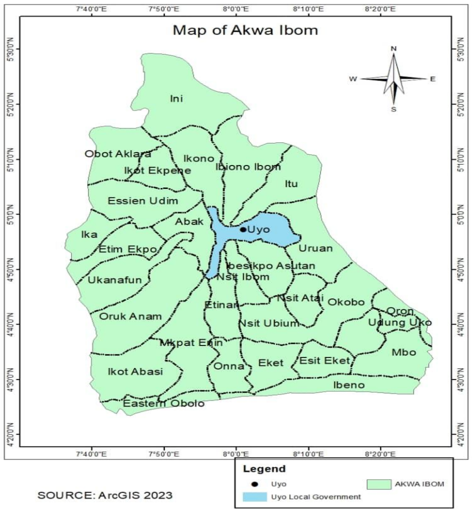
(1) Pi-solubilizing microorganisms that secrete organic acid to dissolve Pi compounds and

(2) Po-mineralizing microorganisms that secrete phosphatase to enzymatically mineralize Po compounds. The application of both classes of phosphorus Solubilizing Bacteria in soil decreases the pH of the soil and forms a P-offering micro climate around the plant rhizosphere, consequently increasing the P supply available to the plant and strengthening the activity of other beneficial microorganisms, such as *Rhizobium* and *Trichoderma*. These applications promote the absorption of nutritive element ions. Many studies have confirmed that soil enzyme activities are affected by soil management practices and land uses (Li *et al*., 2014; Tian *et al*., 2016). However, limited information is available on the impacts of land use on soil P forms and P-cycling enzymes in Uyo Municipal city. Hence, the hypothesis was that Soil P forms would differ under different land use systems and management practice in arable systems. The present study aims to investigate soil physical and chemical properties, P forms (Available P, Total P, Inorganic P, Organic P, Microbial biomass P) and P cycling enzymes (Acid and alkaline Phosphatases) at (0-15) and (15-30) cm, P solubilizing organisms and the relationship among soil P-forms, P-cycling enzyme, P-solubilizing bacteria and MBP in relation to P release and availability in the soil.

MATERIALS AND METHOD

Site Description and Soil Sampling

Uyo, the capital city of Akwa Ibom State located on the north west of the State. It extends from latitude 7^{0} 47^{1} to 8^{0} 03^{1} North and longitude 4^{0} 52^{1} to 5^{0} 07^{1} East. The mean annual temperature in Uyo Urban is 27^{0} C. The relative humidity varies through the year from 70 – 80%. The mean annual rainfall is 2484mm. The city has two distinct seasons, namely; dry and wet seasons. The dry season usually starts from November and ends in March while wet season starts usually from April and end in October.



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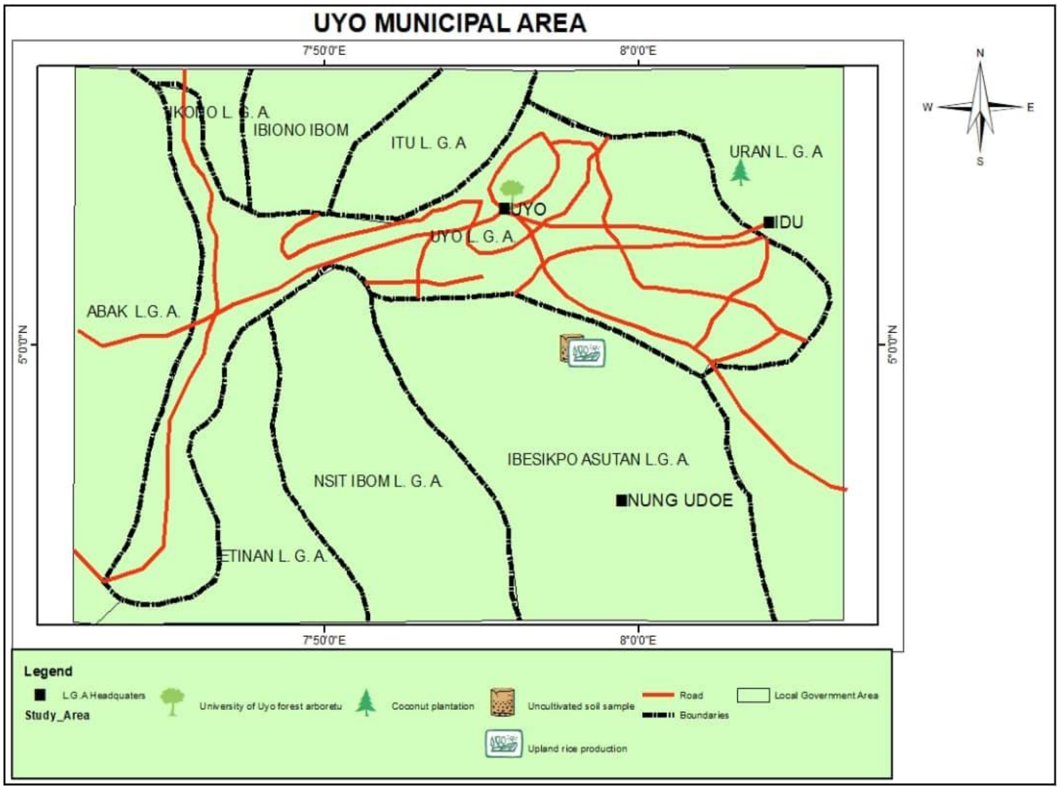


Fig 1: Location of Different Land Use Systems

Soil Collection

The soil samples of two different depths (0-15cm and 15-30cm) were collected from all four different land use systems (viz, uncultivated soil, Coconut Plantation, water leaf farming, Upland Rice Cultivation)Three composites soil samples were collected from each site for each depth. Each samples were divided into two parts; The sample for biochemical studies were stored in a sterile labelled bags and conveyed in a cooler containing ice block and then taken to the laboratory where it was stored in a refrigerator at 4°C for determination of phosphorus cycling enzyme activities, microbial population count and phosphate solubilizing ability of microorganisms. The second part was processed for other selected physical and chemical analyses in the laboratory. The samples were first air dried in the laboratory, pulverized with pestle and mortar, and then passed through a 2mm sieve, after pulverization by a pestle, the samples were stored and preserved in plastic containers for analyses.

Table 1 Description of Different Land Use Systems

Land use systems	Description	GPS
Uncultivated land	Fallow land, no cultivation practices.	N04^{0}36.804^1 E007^{0}36.62^1
Upland rice cultivation	Started in 2004. Input given during land preparation is NPK 20 10 10	N04^{0}56.602^1 E007^{0}56.722^1
water leaf cultivation	Started over 10 years ago. Input given during Land preparation is organic manure e.g. poultry dropping FYM	N05^{0}02.396^{1}E007^{0}55.256^I
Coconut plantation	Input given during land preparation is organic manure (poultry manure)	N04^{0}53.602^1 E008^{0}06.815^1

Soil Chemical Analysis

pH in a soil solution of 1:2.5, using a glass electrode (Jackson 1973); Available P following Olsen *et al*. (1954); Mechanical composition of experimental soils (Proportion of Sand, Silt and Clay size particles) following hydrometer method (Bouyoucos 1962) Total P (TP) in soils were determined by digestion method (Olsen and Sommers 1982); Total Organic P (Po) by ignition method (Saunders and Williams 1955; Walker and Adams 1958); Inorganic P (Pi) content by subtracting organic P from total P in the sample; Microbial biomass P (MBP) following the method proposed by (Brookes *et al*. 1982). Available P in acidic soil was extracted with Bray's P-I (Bray and Kurtz 1945) reagent and alkaline soil was extracted with 0.5M $NaHCO_3$ (Olsen *et al* 1954).

Analyses of Soil Biological Properties

Enzymatic Assay

Phosphatase activity was assayed by the method of Tabatabai and Bremner (1969) using substrate p-nitro phenyl phosphate.

Detection of the phosphate solubilization ability of microorganisms

Phosphate solubilizing ability of microorganisms was detected using plate screening method, in which, phosphate solubilizers produce clearing zones around the microbial colonies in media and these were isolated (Pikovskaya 1948). Then, colonies were isolated and put in Petri-plates containing Pikovskaya's agar medium along with bromo-phenol blue, which produced yellow halos following a pH drop.

Statistical Analysis

The experimental design that was used for this research work was Randomized Completely Block Design (RCBD). Data were assessed using Least significance difference ($P<0.05$). Differences between mean values were evaluated by a two-way analysis of variance (ANOVA) using SPSS software version 20.0. Pearson Correlation analyses were performed using SPSS programme (SPSS version 20.0).

RESULTS AND DISCUSSION

Physical and Chemical Properties of the Soils Under Different Land Use Systems

Sand Fractions

Mean of sand fraction for 0-15cm and 15-30cm soil layers for all land use systems varied but not significantly ($P>0.05$) except in coconut plantation (81.45%) that was significantly ($P>0.05$) higher than all other land use systems at the 0-15cm soil depth. Sand particles at the 15-30cm soil layers, sand fractions were not significantly ($P>0.05$) different across different land use system. The reason for the high percentages of sand fractions across all the land use types and maybe due to the parent materials (Beach ridge sand) that is predominant in the study sites. It is worth noting that the sand content of soil is an important factor that affects soil fertility, water retention capacity, and nutrient availability (Wu *et al*., 2019). Therefore, understanding the variation in soil properties across different land use systems is crucial for effective land use planning and management.

Silt Fractions

Silt content of the soil varied among the different land use systems at the 0-15cm depth with the soil in the upland rice plantation (11.64) being significantly ($P<0.05$) different from all other land use systems at the 0-15cm whereas at the subsurface (0-15cm) depth, soil under water leaf cultivation was significantly ($P<0.05$) different from all other land use systems.

Clay Fractions

There was variation in clay fraction among the land use systems. Clay fractions under uncultivated land (14.99%) was significantly ($P<0.05$) higher than clay fractions in all other land use systems, at 0-15cm depth, whereas at subsurface (15-30cm) depth, there was no significant ($P>0.05$) different among all the land use systems.

Soil Reaction (pH)

Soil pH showed remarkable variations among the land use systems at the surface soil (0-15cm) depth with soils under water leaf and coconut plantation (4.4% and 4.2%) not significant (P>0.05) different from each other but significantly (P<0.05) different from soil soil under uncultivated land and upland rice respectively at the subsurface (15-30cm) depth. There were variations among different land use systems but were not significantly (P>0.05) different from each other.

Table 2 General characteristics of the surface soil (0-15cm) and sub-surface (15-30) soil in different land use systems.

Properties	Uncultivated land	Upland rice	Water leaf	Coconut plantation
(0-15cm)				
Sand (%)	73.50^{c}	73.60^{c}	75.26^{b}	81.45^{a}
Silt (%)	11.51^{b}	11.64^{a}	9.88^{c}	7.65^{d}
Clay (%)	14.99^{a}	14.76^{b}	14.86^{c}	10.90^{d}
Texture	Sandy loam	Sandy loam	Loamy sand	Loamy sand
pH	3.8^{b}	3.5^{b}	4.4^{a}	4.2^{a}
EC (dSm^{-1})	0.008^{c}	0.06^{bc}	0.13^{a}	0.077^{ab}
Organic C (%)	1.03^{b}	1.02^{b}	0.73^{c}	1.85^{a}
EA	2.31^{c}	2.41^{b}	4.12^{a}	2.42^{b}
Mg	1.98^{d}	2.07^{c}	2.41^{b}	4.41^{a}
Ca	1.21^{c}	1.14^{c}	1.42^{b}	2.22^{a}
Na	0.06^{a}	0.04^{c}	0.43^{b}	0.04^{c}
K	0.05^{a}	0.004^{c}	0.009^{c}	0.02^{b}
15-30cm				
Sand (%)	79.77^{a}	79.32^{a}	76.70^{a}	77.44^{a}
Silt (%)	7.80^{b}	7.70^{b}	9.4^{a}	7.7^{b}
Clay (%)	12.38^{a}	12.98^{a}	14.94^{a}	14.85^{a}
Texture	Loamy sand	Loamy sand	Loamy sand	Loamy sand
pH	4.07^{a}	4.10^{a}	4.23^{a}	4.30^{a}
EC (dSm^{-1})	0.04^{a}	0.03^{a}	0.06^{a}	0.04^{a}
Organic C (%)	1.75^{a}	1.74^{a}	1.58^{a}	0.54^{b}
EA	2.42^{c}	2.41^{c}	3.84^{a}	2.86^{b}
Mg	3.02^{a}	2.07^{b}	1.77^{c}	2.17^{b}
Ca	3.78^{a}	0.79^{a}	3.60^{a}	0.79^{a}
Na	0.03^{c}	0.04^{c}	0.07^{a}	0.06^{b}
K	0.007^{a}	0.03^{a}	0.009^{a}	0.01^{a}

Means with same lowercase letters within a column are not significantly different at P<0.05 according to LSD.

Organic Carbon (OC)

The mean organic carbon (OC) values varied significantly for both surface and subsurface soil layers at (P<0.05). at surface soil, soils under uncultivated land and upland rice had no significant difference (Table 2) while at the subsurface soil, uncultivated land, upland rice and water leaf farming had no significance difference. The organic carbon values ranged from 0.73% to 1.03% for surface soil with soils under water leaf farming having the lowest organic C values while soils under uncultivated soils had the highest organic carbon content of 1.03. for the subsurface soil, soils fallow land (1.75%) had highest organic carbon while soils under coconut plantation (0.54%) had the least organic carbon content (Table 2). The control soil had the highest organic carbon content of for surface and sub-surface soil. The organic carbon content of the upland rice production and water leaf plant soils were similar while the coconut plantation soil had the highest organic carbon content for surface and sub-surface soil. According to a study by Behera *et al*. (2018), the organic carbon content of soil can be influenced by land use practices such as vegetation cover, crop rotation, and residue management. They found that land use change from forest to agriculture led to a decrease in soil organic carbon content. This could explain the lower organic carbon content observed in the water leaf farming and coconut plantation compared to the control. In another study by Ogunwole *et al*. (2019), it was observed that organic carbon content in soil decreased with increasing salinity levels. This could be a possible explanation for the lower organic carbon content observed in the coconut plantation, which has a higher salinity level than the other land use systems. Furthermore, a study by Kaur *et al*. (2018) found that the organic carbon content in soil can also be influenced by the type of crop grown

Soil P Forms

Total P

The mean values of the total P for surface soil (0-15cm) and subsurface soil (15-30cm) soil layers for all land use varied significantly (P<0.05). Soils (0-15 and 15-30cm layers) under upland rice (137.87mg/kg and 123.75mg/kg) had highest TP followed by waterleaf farming (136.77mg/kg and 103.61mg/kg) and the lowest was in soils under uncultivated land (Fig 2).These results may be attributed to the use of phosphate fertilizers and organic amendments in these agricultural lands (Nesheim*et al*., 2019). The study revealed that surface soil (0-15cm) had higher TP than subsurface soil (15-30cm) by 10, 24.25, 33.06% for upland rice, water leaf farming and coconut plantation respectively with uncultivated land having 16.13% less than the subsurface soil. This is probably due to the fact among major nutrients, P is the least mobile element. This is one of the main reasons for its low availability in the 15-30cm soil layer as organic inputs and fertilizer application activities are done at soil surface.

Total organic P

The mean values of Organic P for both surface soil (0-15cm) and subsurface soil (15-30cm) soil layers varied significantly ($P<0.05$). Surface soil contained 26.95, 8.27% higher organic phosphorus than subsurface soil (15-30cm) for water leaf farming and coconut plantation respectively while subsurface soil had 12.00, 11.40% higher organic phosphorus than surface soil (0-15cm) for uncultivated soil and upland rice farming respectively. The mean organic P for all the land use varied from 32.27mg/kg to 118.42mg/kg in the surface soil layer and varied from 34.16mg/kg to 97.84mg/kg for subsurface soils. Soils under water leaf farming (118.42mg/kg) had more organic P as compared to the other land use systems in the 0-15cm soil surface layer while the soil under uncultivated land (32.27mg/kg) had the lowest total organic P. For the subsurface soil (15-30cm), soils under upland rice farming (97.84mg/kg) had more organic P content. The soils under the uncultivated land having the lowest organic P content (Fig3) The organic P in the 0-15cm depth followed the order: water leaf farming > coconut plantation > upland rice farming > uncultivated land (Fig 3). The high organic phosphorus in water leaf farming could be due to the fact that fertilizer application in water leaf farming often involves the use of organic fertilizers, such as compost or manure, which can contribute to elevated organic phosphorus in the soil. It is also worth noting that the levels of phosphorus in the uncultivated soil (control) were relatively low compared to the other land use systems. These findings are consistent with previous researches that have shown that phosphorus availability in soil is influenced by the type of crop or vegetation present. For example, a study by Thapa *et al*. (2015) found that soil under rice cultivation had higher levels of organic phosphorus compared to soil under other crops. Similarly, a study by Landoni*et al.* (2017) found that soil under water leaf had higher levels of organic phosphorus compared to soil under other vegetables.

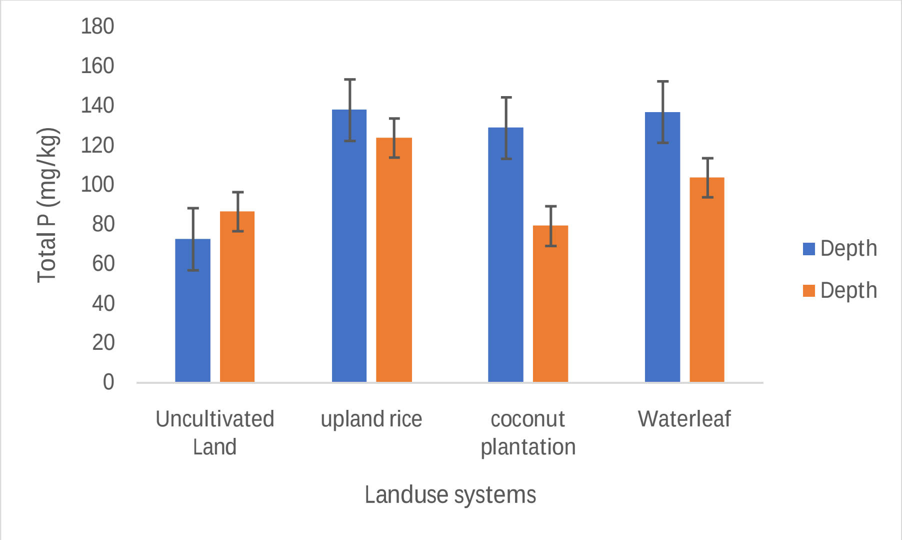


Fig 2: Total P (mg/kg) in soils under two depths.

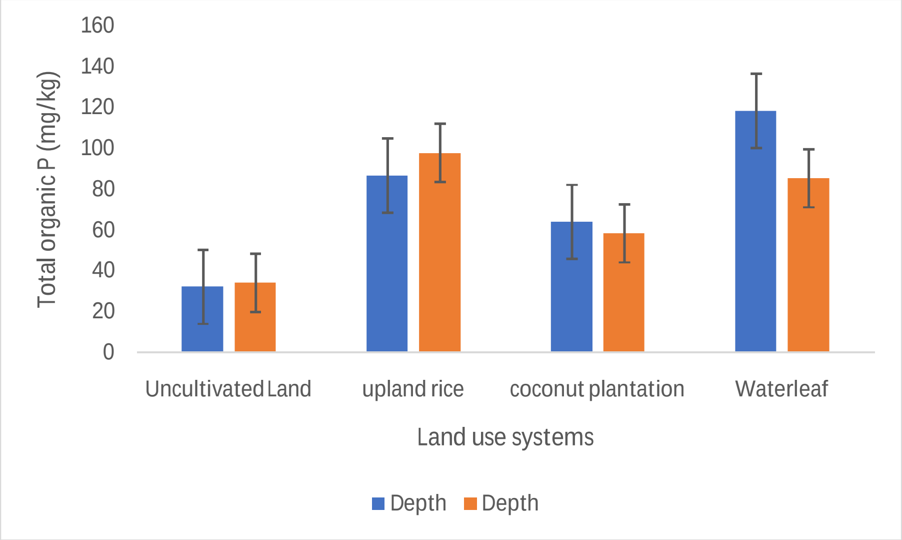


Fig 3: Total organic P (mg/kg) in soils under two depths.

Total Inorganic P

The mean values of Inorganic P for both surface soil (0-15cm) and subsurface soil (15-30cm) soil layers varied significantly (P<0.05). Mean of inorganic P under different land use systems varied from 18.68mg/kg to 64.66mg/kg in the 0-15cm soil layer. Soils (0-15cm) under coconut plantation contained more inorganic phosphorus (64.66mg/kg) than both upland rice (51.17mg/kg), waterleaf farming (18.68mg/kg) and uncultivated land (40.29mg/kg). soils under waterleaf farming had the least content of total inorganic P in subsurface soils (15-30cm) under uncultivated land (52.35mg/kg) contained more inorganic P than the other land use systems. They were a decrease in the inorganic P content at the 15-30cm for all land use systems except for the uncultivated land that had an increase in its inorganic P content (Fig 4). Uncultivated soil had relatively higher levels of phosphorus in both surface and sub-surface soils compared to the other land use systems. This could be attributed to the absence of agricultural activities that may have depleted the soil nutrients, leading to the accumulation of phosphorus over time. This is consistent with the findings of a study by Li *et al*. (2020), which showed that long-term cultivation of crops could significantly reduce soil phosphorus levels. The upland rice farm had relatively higher levels of phosphorus in the surface soil compared to the sub-surface soil. This could be due to the fact that most of the applied fertilizers and other soil amendments are usually applied to the surface soil, leading to higher nutrient concentrations compared to the sub-surface soil. It can also be because microbial activity is higher at the surface soils, leading to the mineralization if organic matter than at the subsurface soil. This is consistent with the previous study by Zhang *et al*. (2017), they showed that the application of fertilizers could significantly increase soil phosphorus levels in the surface soil. Coconut plantation had relatively higher levels of phosphorus in the surface soil compared to the sub-surface soil. This could be due to the fact that, immobilization of phosphorus in the coconut rhizosphere by microorganisms for their structural build up to mineralize the organic residues added to in the soil (Xavier *et al*. 2011). Another reason could be that there are more microorganisms in the rhizosphere of coconut plant to solubilize inorganic phosphate in the soil. Surface soil contained significantly higher inorganic P than subsurface soil and the difference were, 49.97, 2.89, 67.85% for upland rice, water leaf and coconut plantation respectively.

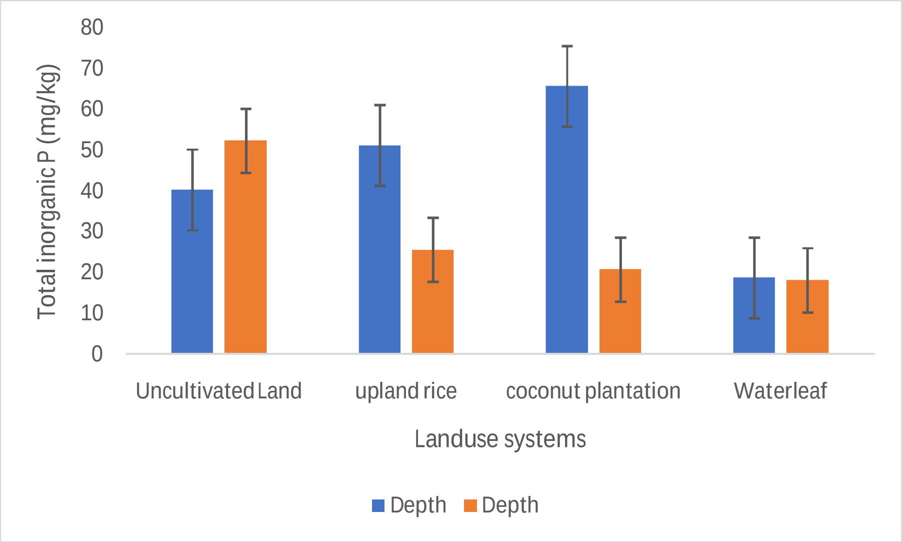


Fig 4: Total inorganic P (mg/kg) in soils under two depths.

Available P

The mean values of Available P at both surface soil (0-15cm) and subsurface soil (15-30cm) soil layers varied significantly ($P<0.05$). Soils under upland rice, water leaf plant, coconut plantation contained 25.99, 58.22, 37.52% more available P, respectively, than uncultivated land in the 0-15cm surface soil. The mean value of available P content showed wide variations (from34.06mg/kg in uncultivated land to 81.51mg/kg in water leaf farming) in surface soil. Water leaf farming had highest available P, followed by coconut plantation (54.51mg/kg). In the subsurface soil, water leaf farming (71.52mg/kg) had the highest available P followed by upland rice farming (47.00mg/kg). coconut plantation (43.69mg/kg) had the lowest available P. The results showed that the available P levels varied significantly among the land use systems, with soils under the water leaf plant having the highest available P levels. On the other hand, the lower P levels in the coconut plantation's sub-surface soil could be attributed to the high rainfall and leaching in the area, leading to P loss from the soil, as noted by Hou *et al*. (2018). The upland rice farm's available P levels were higher than the uncultivated soil, indicating that the rice crop's cultivation had a positive impact on soil P availability. This could be due to the rice plant's ability to mobilize P from unavailable forms through root exudates and microbial activities, as reported by Niu*et al*. (2016).

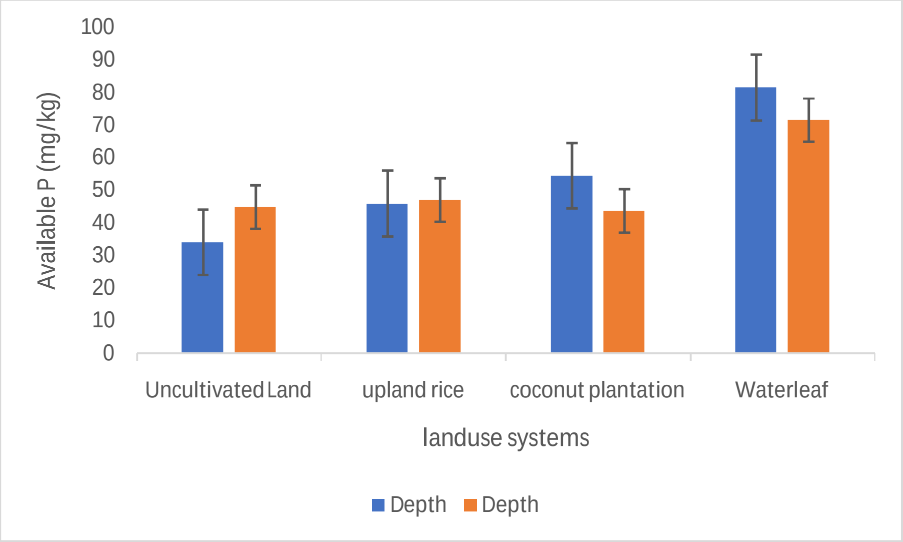


Fig 5: Available P (mg/kg) in soils under two depths.

Microbial biomass P

The mean values of Microbial biomass P (MBP) both surface soil (0-15cm) and subsurface soil (15-30cm) soil layers varied significantly ($P<0.05$). At the surface and subsurface soil, soils under uncultivated land and upland rice production had no significant difference. The surface soil contained 7.6, and 7.5% higher MBP than sub-surface soils for uncultivated soil and upland rice respectively and also contained 67.55 and 23.74%lower MBP than subsurface soils for water leaf plant and coconut plantation respectively. The mean data of MBP varied from 4.06 µg P g^{-1} soil (water leaf farming) to 7.6 µg P g^{-1} soil (uncultivated land) in the soil surface. In subsurface soil, water leaf farming (12.75 µg P g^{-1} soil) had the highest MBP content while upland rice farming (4.0 µg P g^{-1} soil) had the lowest MBP content (Fig 6). The control soil had higher levels of MBP compared to the agricultural lands, which is consistent with previous studies that have reported lower levels of microbial biomass in cultivated soils (Li *et al.,* 2015; Wang *et al*., 2015). The upland rice farm had similar levels of MBP as the control soil, which could be attributed to the minimum tillage practice in rice farm that minimize soil disturbance and chemical inputs (Suriyagoda *et al*., 2011). In contrast, the water leaf plant had significantly lower levels of MBP in the surface soil, which could be attributed to the high nitrogen demand of the plant, leading to lower levels of available phosphorus in the soil (Bremner and Blackmer, 1980). However, the sub-surface soil of the water leaf had higher levels of MBP, which could be attributed to the deep root system of the plant, allowing it to access deeper soil layers with higher levels of available phosphorus (Fageria*et al.,* 2011). Similarly, the coconut plantation had lower levels of MBP in the surface soil compared to the control soil, which could be attributed to the high demand for phosphorus by the coconut plant (Cruz *et al.,* 2019). However, the sub-surface soil of the coconut plantation had higher levels of MBP, which could be attributed to the fact that coconut trees have deep root systems that can access nutrients from deeper soil layers (Jutamanee *et al*., 2012). Additionally, Deng *et al*. (2017) highlighted that Nitrogen addition stimulated the sequestration of P in both plant and litter biomass. This may significantly lead to decrease in soil phosphorus.

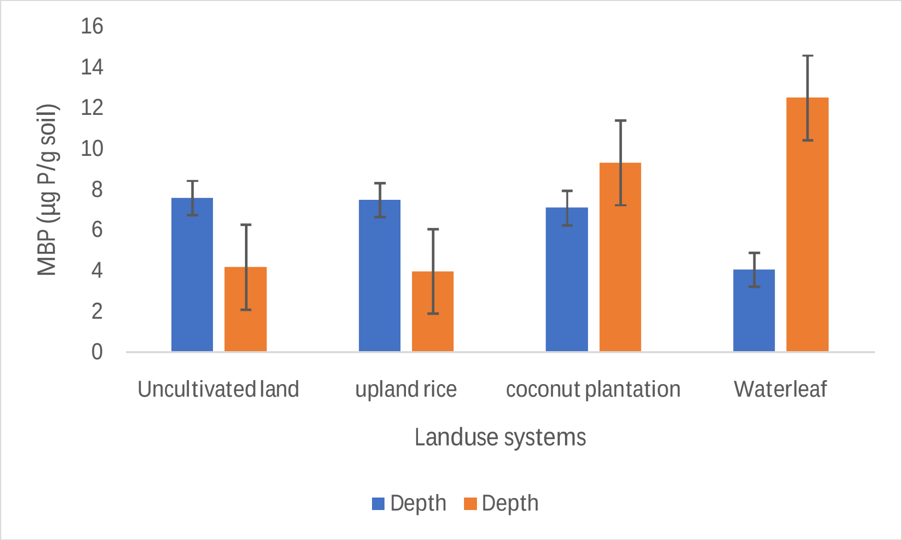


Fig 6: MBP (µg P/g soil) in soils under two depths.

P-cycling enzymes

The mean values of P-cycling enzyme activities (acid and alkaline phosphatase) for both 0-15cm and 15-30cm soil layers varied significantly ($P<0.05$). The mean data of acid phosphatase activity in the surface soil layer ranged from 1.49 µg PNP g^{-1} h^{-1} in the coconut plantation to 2.10 µg PNP g^{-1} h^{-1} in uncultivated land in surface soil (0-15cm). All land use systems showed higher acid phosphatase activity in the 0-15cm depth and a decrease in lower depth (15-30cm) was observed (Fig 7). Thus, the acid phosphatase activities under different land use systems in 0-15cm followed the order: uncultivated soil > upland rice farming > water leaf farming > coconut plantation. the highest levels of acid phosphatase were found in the uncultivated soil, with surface soil having a higher level than sub-surface soil. In this study, it was observed that acid phosphatase activity was seen to be much higher than alkaline activity. This may be due to the acidic nature of the soils. Previous investigations by Mandal *et al*. (2007) highlighted that phosphatase activity was strongly affected by soil pH. Usually, higher plants and microorganism lack alkaline phosphatase (kremer and Green (2000). The improved activity of soil enzyme in uncultivated land use systems may be due to undisturbed nature of the soil. Continuous leaf fall and dead plants that lead to increase organic Carbon concentration in the soil and high population of microorganisms. Similarly, because of the organic manure and Farm yard manure applied to the water leaf farm also contributed to the increased enzyme activity and high population of microorganisms. Masto *et al* (2006) also observed that addition of manure and farm yard manure to soil aids for C source, greater microbial biomass and phosphatase activity. Acid phosphatase was more in the land use systems receiving manure and was supported by Haynes and Swift (1988). Who reported decreased acid phosphatase activity of soils with fertilization.

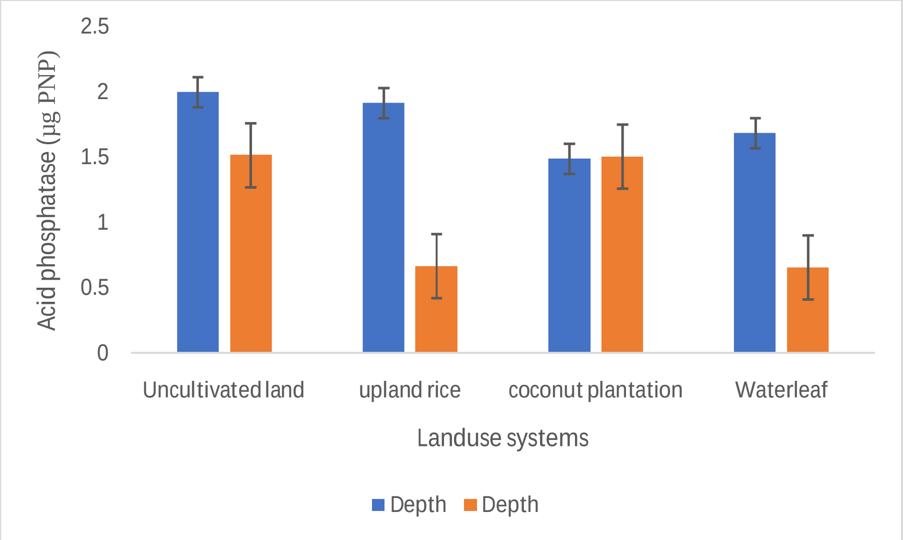


Fig 7: Acid phosphatase (µg PNP g^{-1} h^{-1}soil) in soils under two depths.

The mean alkaline phosphatase activity ranged from 0.66 µg PNP g^{-1} h^{-1}in the upland rice farming to 3.50 µg PNP g^{-1} h^{-1} in soils under uncultivated land (Fig 8) Alkaline phosphate activities under different land use system in the 0-15cm soil depth followed the order: uncultivated land > water leaf farming > coconut plantation > upland rice farming. The Alkaline phosphatase activity in the uncultivated soil was higher than that of the other land use systems. The significantly greater activity of alkaline phosphatase in the uncultivated land may be due to the undisturbed soil, leaf falls that lead to increase organic matter and microbial activity. Parharm*et al*. (2002), reported that manure addition to soil changes the presence of soil enzyme. The decreased activities of both enzymes with increasing depth maybe due to the decline microbial activity with depth. The decline microbial activity with depth was more in water leaf and upland rice land use systems. This may be due to decreased rhizosphere effect with small increase in soil depth. Wu *et al*. (2020) in their research suggested that the use of various agrochemicals can impact soil enzyme activity. In this stud, acid phosphatase was higher at both 0-15 and 15-30cm depths in coconut plantation than alkaline phosphatase. This may likely be because coconut is an acid temperant plant. This may probably be due to the fact that soil that has not been disturbed tends to have higher levels of Alkaline phosphatase activity as reported by Devi *et al.*, 2021. The upland rice farm had the lowest Alkaline phosphatase activity compared to the other land use systems. This could be due to the fact that rice farming involves the use of various agrochemicals, which may impact soil enzyme activity (Wu *et al*., 2020). The water leaf plant had significant Alkaline phosphatase activity, which could be attributed to the fact that it is a fast-growing and high-nutrient-demanding crop that requires regular fertilization (Oseni *et al.,* 2020). The Alkaline phosphatase activity in the coconut plantation was significant and similar for both the surface and sub-surface soil. This finding could be due to the fact that coconut farming involves the application of organic fertilizers and the practice of intercropping, which can enhance soil enzyme activity (Mendes *et al.,* 2021).

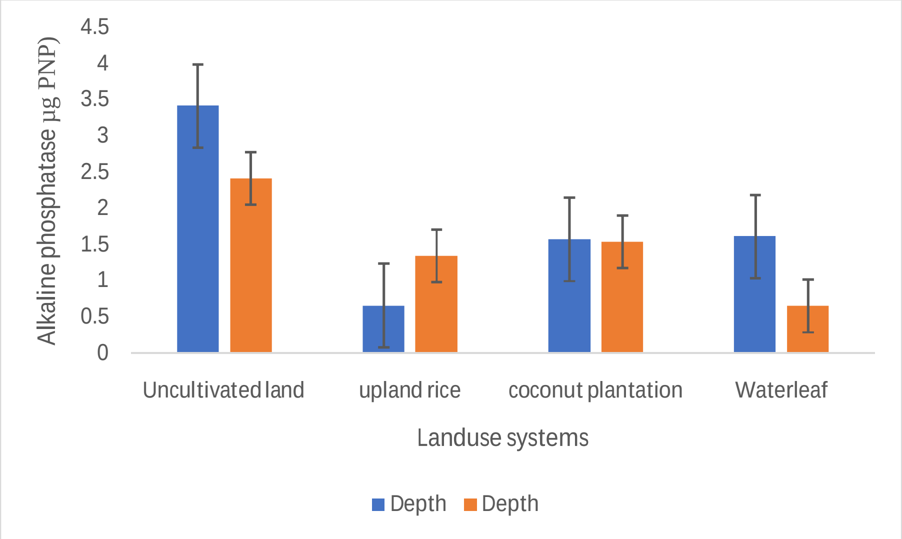


Fig 8: Alkaline phosphatase (µg PNP g^{-1} h^{-1}soil) in soils under two depths

Phosphate solubilizing microorganisms

The mean values of P solubilizing microorganism (PSB and PSF) for both 0-15cm and 15-30cm soil layers varied significantly ($P<0.05$). Population of phosphate solubilizing microorganisms (PSM) has been recorded from their growth on the culture media in petri-plates. In the surface soil, uncultivated land ($2.4x10^7$ CFU g-^{1} soil) had highest PSB count. water leaf farming ($0.2x10^6$ CFU g-^{1} soil) had the lowest PSB count. In the subsurface soil, uncultivated land ($1.7x10^7$ CFU g-^{1} soil) had highest PSB count, water leaf farming ($0.1x10^6$ CFU g-^{1} soil) had the lowest PSB count (Fig11)

The mean PSF count ranged from $1.2x10^6$ CFU g-^{1} soil in upland rice farming to $1.4x10^7$ CFU g-^{1} soil in uncultivated land in surface soil layer. In the subsurface soil layer, uncultivated land ($1.1x10^7$ CFU g-^{1}) had highest PSF count, while upland rice farming ($1.3x10^6$ CFU g-^{1} soil) had the lowest PSF count (Fig12)

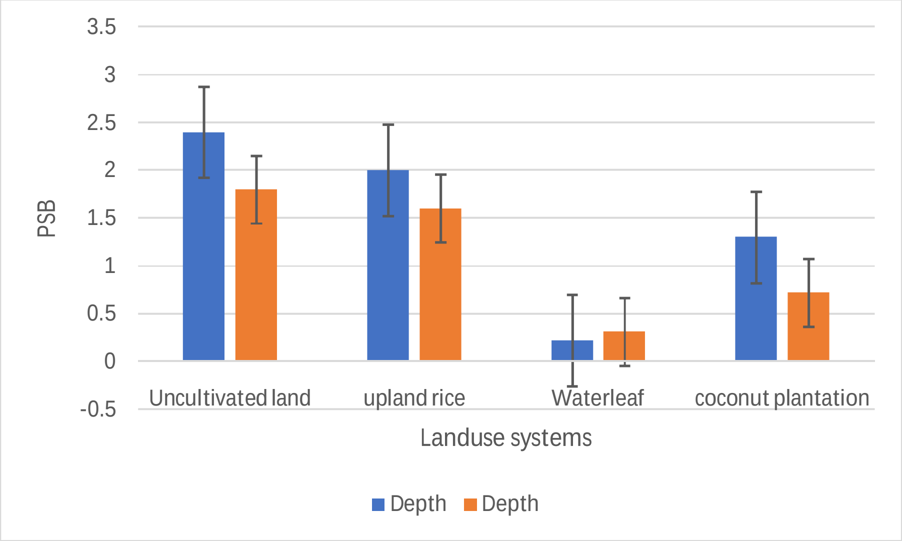


Fig 11: Phosphate solubilizing bacteria (CFU g^{-1} soil) in soils under two depths

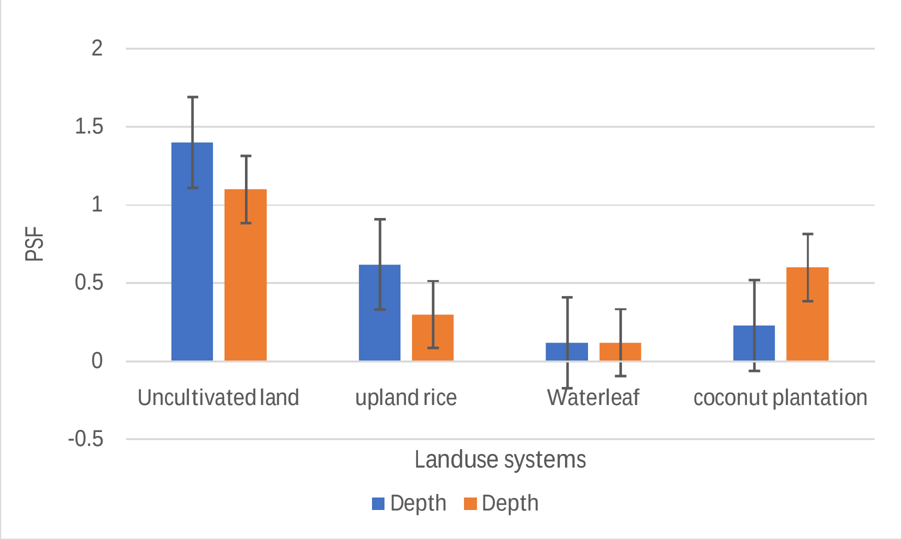
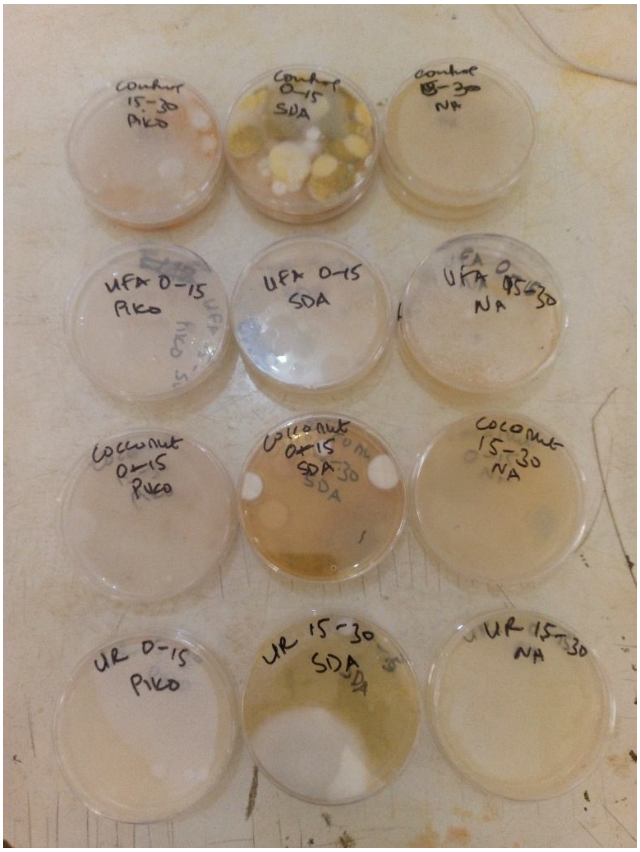


Fig 12: Phosphate solubilizing Fungi (CFU g^{-1} soil) in soils under two depths

The population of PSB in the soil can have significant effects on plant growth and yield as these bacteria can solubilize insoluble phosphate compounds and make them available to plants. The results indicate that the population of PSB varied significantly across the different land use systems. The highest population of PSB was found in the uncultivated soil. This could be attributed to the fact that uncultivated soil is undisturbed, and therefore, the microbial community had time to establish, leading to high microbial diversity and abundance. This finding is consistent with previous studies that have shown that uncultivated soils have a higher microbial biomass and diversity than cultivated soils (Lupwayi *et al*., 2012). In contrast, the upland rice farm had lower population of PSB. This could be attributed to management practice in upland rice cultivation which involves ploughing, this can disrupt the soil microbial community structure, leading to a reduction in microbial biomass and diversity (Zhang *et al*., 2019). Additionally, the application of chemical fertilizers and pesticides in upland rice cultivation may have negative effects on soil microbial communities (Bhattacharyya and Jha, 2012). The water leaf plant had significant population of PSB. This maybe because water leaf is a vegetable that is often cultivated using organic farming practices, which can promote the growth of soil microorganisms (Ferri*et al*., 2021). The coconut plantation had the second-highest population of PSB. Coconut cultivation involves minimal soil disturbance, and coconut husks, which are used as mulch, can promote the growth of soil microorganisms (Kumar *et al.,* 2019).

The uncultivated soil (control) had the highest population of phosphate solubilizing fungi in both surface and sub-surface soil. This may be due the undisturbed soils which made it possible to have higher microbial diversity and abundance than disturbed soils (Delgado-Baquerizo*et al.,* 2018). Soils under the upland rice farming had the lowest population of phosphate solubilizing fungi in both surface and sub-surface soil. This may be due to management practice and the input of fertilizer and pesticides in upland rice cultivation involves ploughing and disturbance of the soil, which can reduce microbial populations and diversity (Doran and Zeiss, 2000). The water leaf plant had relatively high population of phosphate solubilizing fungi in the sub-surface soil compared to the surface soil. This finding may be attributed to the shallow root system of the water leaf plant, which may provide a more favorable environment for microbial growth and activity (Wang *et al.,* 2016). The coconut plantation had a significant population of phosphate solubilizing fungi in both surface and sub-surface soil. This finding may be due to the fact that coconut plantations are typically established on previously disturbed land, which can affect soil microbial populations (Delgado-Baquerizo*et al.,* 2018).



(a) Uncultivated land (control)

(b) Water leaf farming

(c) Coconut plantation

(d) Upland rice farming

Fig. 13: Appearance of colonies of different groups of phosphate solubilizing microorganisms on Pikovskaya's agar plate (selective medium) in soils (0-15cm depth) of different land use systems of Uyo, Akwa Ibom State, Nigeria.

Relationship among soil P forms, P-cycling enzymes and P solubilizing Microorganism.

Pearson correlation matrix was used to investigate the relationship between soil P-forms, p cycling enzymes and P solubilizing microorganism. From the correlation it was discovered that PSB was significantly correlated with all forms of P in the soil and P-cycling enzymes with exception to total inorganic phosphorus and alkaline phosphatase. PSF significantly correlated with all P-forms in the soil with exception to total organic P. the alkaline phosphatase significantly correlated with total P and total organic P at the surface soil (0-15cm). Acid phosphatase significantly correlated with total P and available P. MBP significantly correlated with other forms of P in the soil with exception to total P as seen in table 2. At the sub-surface soil (15-30cm), PSB significantly correlated with inorganic P, available P, MBP, alkaline phosphatase and PSF. PSF significantly correlated with all the P forms in the soil with exception to MBP and also correlated with the P-cycling enzymes activities. Alkaline phosphatase significantly correlated with all the P forms with exceptions to total P. Acid phosphatase significantly correlated with three forms of P in the soil (Total P, organic P, AVP) as seen in Table 3.

Generally, the different forms of phosphorus (P) in the soil, including total P, inorganic P, organic P, microbial biomass P, and available P, can be related to various enzymes and microorganisms involved in P cycling, such as acid phosphatase, alkaline phosphatase, and phosphate-solubilizing bacteria and fungi. Acid phosphatase is an enzyme that hydrolyzes organic P compounds, releasing inorganic P. It is produced by plants, fungi, and bacteria and is particularly active in acid soils. Studies have shown a positive correlation between acid phosphatase activity and organic P content in soil (Liu *et al*., 2017). Inorganic P, on the other hand, is the form of P that is directly available to plants and can be measured through different methods, such as extraction with water or chemical reagents. Studies have shown a positive correlation between alkaline phosphatase activity and available P content in soil (Xiao *et al*., 2021). Phosphate-solubilizing bacteria (PSB) and fungi

Table 2: Pearson correlation matrix among P solubilizing organisms, P pools and soil enzyme activities in the surface soil (0-15cm layer) under different land uses.

Properties	TP	T. Inorg	T.Org	AVP	MBP	Acid.ase	Alk.ase	PSF	PSB
TP	1	.032	$.843^{**}$	$.673^{*}$	-.442	$-.645^{*}$	$-.944^{**}$	$-.897^{**}$	$-.636^{*}$
T. Inorg		1	-.511	-.569	$.784^{**}$	-.235	-.210	.052	.496
T. Org			1	$.886^{**}$	$-.803^{**}$	-.429	$-.699^{*}$	$-.800^{**}$	$-.815^{**}$
AVP				1	$-.948^{**}$	$-.608^{*}$	-.407	$-.844^{**}$	$-.988^{**}$
MBP					1	.399	.163	$.634^{*}$	$.924^{**}$
Acid.ase						1	.456	$.854^{**}$	$.688^{*}$
Alk.ase							1	$.713^{**}$	.350
PSF								1	$.860^{**}$
PSB									1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

(PSF) are involved in the solubilization of P from inorganic and organic phosphorus. They produce various organic acids, including citric, lactic, and gluconic acids, that lower the pH of the soil solution, leading to the dissolution of insoluble P compounds. Several studies have reported a positive correlation between PSB and PSF populations and available P content in soil (Liu *et al.,* 2017). Moreover, PSB and PSF can also produce alkaline and acid phosphatases, contributing to the release of P from organic and inorganic sources. Microbial biomass P is the P content of soil microorganisms, and it can be used as an indicator of microbial activity and P availability. Studies have shown a positive correlation between microbial biomass P and organic P content in soil (Wu *et al.,* 2019). Moreover, microbial biomass P can also be related to the activities of acid and alkaline phosphatases and PSB and PSF populations, as microorganisms are directly involved in P cycling processes in soil. The different forms of P in soil, including total P, inorganic P, organic P, microbial biomass P, and available P, can be related to different enzymes and microorganisms involved in P cycling, such as acid phosphatase, alkaline phosphatase, and PSB and PSF. Understanding these relationships can help in developing effective soil management practices to improve P availability and plant productivity.

Table 3: Pearson correlation matrix among P solubilizing organisms, P pools and soil enzyme activities in the surface soil (15-30cm layer) under different land uses.

Properties	TP	T. in org	T. Org	AVP	MBP	Acid.ase	Alk.ase	PSF	PSB
TP	1	-.281	.847**	.277	-.235	-.889**	-.462	-.599*	.178
T. in org		1	-.748**	-.464	-.685*	.544	.895**	.905**	.788**
T. Org			1	.451	.219	-.917**	-.817**	-.917**	-.315
AVP				1	.747**	-.656*	-.782**	-.626*	-.684*
MBP					1	-.220	-.736**	-.568	-.981**
Acid.ase						1	.781**	.830**	.257
Alk.ase							1	.959**	.785**
PSF								1	.657*
PSB									1

PSB Phosphate solubilizing bacteria, PSF Phosphate solubilizing fungi, AVP Available P, Org-P Organic P, Inorg-P inorganic P, TP Total P, MBP Microbial Biomass P, Ac-ase Acid Phosphatase, Alk-ase Alkaline phosphatase

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

CONCLUSIONS

Thus, P forms viz, All P forms viz., total P, inorganic P, organic P, available P and microbial biomass P in the soils were significantly affected by land use changes. Soils in Upland rice were best in terms of having TP. Soils in coconut plantation were best in having highest inorganic phosphorus. Soils in waterleaf cultivation had highest organic and available P and total heterotrophic bacteria count. soils in uncultivated soil had highest microbial biomass P and best in enzyme activities. Uncultivated soil had highest phosphorus solubilizing bacteria and fungi. soils in coconut plantation and soils in upland rice cultivation had highest total heterotrophic fungi count. Correlation matrices among different parameters of enzyme activities, P pools and PSM were positive while some showed a negative correlation indicating that they were strongly associated in soils irrespective of the land use and crop management practices. A good population of PSM has been observed in almost all systems thus, this study has generated information on the extent of P-forms, enzyme activities and P solubilizers of different land use systems in Uyo, Akwa Ibom State, Nigeria. Further research may concentrate on impacts of other land use systems on soil P dynamics in dry and rainy seasons of Uyo, Akwa Ibom State with more sampling areas. Also, there is need for isolation and identification of PSM in this area to provide information of new species, which may have high potential to enhance P solubilization from fixed or mineral-P in the acid soils of the region, and subsequently use as P-biofertilizers. Further research should be conducted to investigate the factors that contribute to the positive and negative correlations observed between the different forms of phosphorus, P-cycling enzymes, and PSM. This will help to improve our understanding of the dynamics of phosphorus in acid soils and provide insight into ways to optimize soil fertility in these environments.

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