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Dynamics of phosphorus fixation in selected tea cropped soils on the Mambilla Plateau in Taraba State, Nigeria

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ABSTRACT

Background: Phosphorus deficiency in tea grown soils is a major factor responsible for the low yield of tea in Nigeria. Fertilizer application is always a remedy for nutrient deficiency in agricultural soils. High P-fixation in tea soils is mainly due to inherent soil acidity, clay content, hydrated oxides of aluminum and iron. This research aims to understand the fate of phosphorus, P-fractional recovery and P-fixation in tea grown soils is required.

Methods: Soil samples were obtained from selected tea farms in Nguroje and Kusuku communities on the Mambilla plateau. The samples were incubated with known concentrations of phosphorus and P-fractional recovery was carried out at 3, 15, 30, 45 and 60 days of incubation.

Results**:** Results showed that, phosphorus fixation was intense in both soils within the first 15 days of incubation. P –fixation was higher in Kusuku soil than Nguroje soil in the first 15 days. Fixation was more progressive in Nguroje soil while it reached a climax in Kusuku soil within the first 15 days of soil incubation before desorption of fixed phosphorus began. Clay, Al, Fe, Ca and Mg contents were the soil properties that contributed to *phosphorus fixation in the investigated soils.*

Conclusion**:** The fact that, fixed phosphorus was gradually recovered was an indication that, P-fixation in tea grown soils on the Mambilla plateau was temporal and not permanent.

Keywords: Tea, Mambilla plateau, phosphorus fixation, fractional recovery.

1.0 INTRODUCTION

Tea (*Camellia sinensis*) is the most widely consumed beverage in the world and ranked second to water as the most consumed drink worldwide [1]. Tea has a significant role as a health drink. It is cultivated in fifty countries with major producers being India, China, Kenya, Sri Lankar, Vietnam, Turkey, Indonesia and Iran [2]. Nigeria is one of the countries in Africa that produce tea. Tea cultivation in Nigeria is mainly done on the Mambilla Plateau in Sardauna Local government area of Taraba State in the Northern part of the country. Report of Food and Agriculture organization (FAO) showed that the world production of tea stands at 5.56 million tons with plantation hectarage of 3.80 million [2]. Production of tea is steadily on the increase globally. In spite of the fact that tea's nativity is traceable to the humid tropics and subtropics, it has been found to have a very wide adaptability and thus can be cultivated in a wide range of climatic conditions and soils. It is also grown across a range of altitude from sea levels up to about 2,200 meters above sea level. Tea cultivation requires a minimum rainfall of 1,200mm per year but thrives optimally with annual rainfall of 2,500 – 3,000Mm. Tea has a productive life span of over 100 years with peak production periods between 30 and 50 years [3]. Being an evergreen bush, it has the capacity to attain a height of 15meters in the wild if not maintained. For economic purposes, tea bush is maintained at a height of 0.6 – 1.0 meter to facilitate harvesting of leaves for tea beverage production [4]. Tea is grown in soils that differ from one country to another with the most important feature being soil pH [3]. The pH requirement for the growth of tea is in the range of 4.5 to 5.6. Optimum soil conditions recommended for tea cultivation include well drained, deep and well-aerated soil with more than 2% organic carbon [4]. Soil depth of less than 50 cm, graveliness of more than 50% and rockiness of 20% affect the growth of tea adversely [3] while tea plants grown on shallow and compacted soils are likely to suffer from drought and water logging. Under favorable climatic condition with adequate management, harvested leaf yield of tea can generally reach 4-5-ton $ha^{-1}year^{-1}$. There have been instances when yields of 6.5-ton $ha^{-1}year^{-1}$ were reported

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[3]. However, tea yield at lower elevations is higher than that obtained from tea stands at higher elevations in the absence of soil constraints with proper management [5, 6]. Currently in Nigeria, tea cultivation for commercial purpose is only on the Mambilla Plateau in Sardauna Local government area of Taraba State. This is due to the favorable climatic and soil conditions for tea cultivation on the plateau. The climate of the plateau is semi temperate in nature. Outdoor temperature taken by 7.00 am hardly exceeds 19ºC. It can be as low as 13ºC during winter. At noon, temperature ranges between 14 and 30ºC depending on the period of the year [7]. Mambilla Plateau has elevation of 1500-2000m above sea level, covers an area of over 9,389 square kilometers and has an annual rainfall of 2000-3000mm.The soil pH of the Plateau where commercial tea cultivation takes place ranges between 4.45 and 5.50. Tea plant was introduced on the Mambilla Plateau at the Nigerian Beverages Production Company in Kakara Village in the year 1972 [8, 9]. At the time of introduction, four commercial clones (35, 68, 143 and 318) were brought into the country. In 1982, the Mambilla Substation of Cocoa Research Institute of Nigeria, located at Kusuku Village obtained the four clones from the Nigerian Beverages Production Company for research purpose [10]. In recent time, the yield of tea crop on the Mambilla Plateau has been on a decline. This might in part be a consequence of the extremely harsh weather occasioned by global climate change. In addition, the decline in tea production on the Mambilla Plateau may be a consequence of the low level of some macro nutrients in the soil. A recent nutrient auditing of various tea plantations on the Mambilla plateau revealed that, phosphorus was the most limiting macronutrient needed for optimal production in all the investigated tea farms. Apart from the fact that, tea farmers on the plateau don't apply fertilizer to replenish the soil, the considerable level of Al, Fe and Mn in the acidic soils could enhance intense fixation of phosphorus in the soil. Harvesting of tea leaves removes nutrients from the soil. The rate of nutrients removal depends on the duration of plucking rounds and their intensity. Continuous plucking of tea leaves leads to mining of macronutrients N, P and K thus, making it necessary to replenish the nutrients in soil [11]. The influence of applied fertilizer on tea yield arises from its effects on the shoot extension rate and the rate of regeneration [12]. Phosphorus is an essential macro-nutrient and it plays crucial role in the cellular structure and energy metabolism in higher plants [13]. Phosphorus plays major role in the formation of new wood and roots in tea. Its deficiency in tea manifests itself as absence of brightness in matures leaves and dieback of young and old woody stems [6]. Under moderate soil pH of about 5.5 to 7.0, phosphorus availability to plants is high but decreases at pH below 5.5 or above 7.0 [14]. In very acidic soils, phosphorus is adsorbed onto hydroxides of Al and Fe. Consequently, it becomes unavailable for plant uptake. On the Mambilla plateau, most of the tea farms have pH below 5. Analysis of tea grown soils on the Mambilla plateau showed that 97% of the tea farms investigated on the plateau had pH ranging from 4.70 to 5.44 while 3% of the soils had pH ranging from 5.44 to 5.61. None of the tea farms however, had pH above 5.61. A recent study carried out by the author also showed that 100% of sampled tea farms on the Mambilla plateau had available P lower than 15mg/kg which is the critical level of P required for tea cultivation. The low available P content of the soils is in part due to the inherent acidic nature of the soils which promotes P fixation in soil and makes it unavailable for tea plant uptake. In order to overcome phosphorus deficiency in tea soils on the plateau and enhance tea yield, application of phosphorus fertilizer becomes imminent. Information obtained from the farmers indicates that, none of the small-scale tea farmers applies fertilizer in replenishing the soil. Rather, they solely depend on the inherent nutrients in the soils for tea sustainability. On the other hand, the two companies that produce tea on the plateau: Mambila Beverage Company, and Maisamari Integrated Farm apply N:P:K 15:15:15 fertilizer occasionally on their tea plantations. The fertilizer application however, shows little or no difference on tea yield probably as a result of nutrients fixation in soil. For adequate phosphorus fertilizer application to be obtained in acidic soils with high potential for P fixation, it is necessary to understand the chemistry and fate of applied phosphorus in such soils. In addition, recommendation and application of phosphorus fertilizer on acidic soils on the basis of soil test without the consideration of P fixation capacity of the soils will be misleading and may not produce the desired result with respect to tea yield. Owing to lack of adequate information on phosphorus fertilizer factor, phosphorus recovery and P fixation in tea grown soils on the Mambilla plateau, the study was carried out to examine the fate of applied P fertilizer with respect to its fixation and availability for tea uptake.

2.0 MATERIALS AND METHODS

2.1. **Materials**

2.1.1 Soil sample Collection

Soil samples for the experiments were collected from tea plantation (Lat. 6.876; Long. 11.1316) of the Cocoa Research Institute of Nigeria (CRIN) Mambilla Substation in Kusuku, Sardauna Local Government Area, Taraba

State, Nigeria and Zaboka Tea farm (Lat. 6.9734; Long. 11.0994) at Nguroje also in Sardauna LGA. Soil samples were collected with hand trowel at the depth of 0-5cm.

2.2. Methods

2.2.1. Physicochemical properties

The incubation study was conducted in the Soil laboratory of the Mambilla Substation of CRIN located at Kusuku in Sardauna local government area of Taraba State, Nigeria. Soil samples were collected from selected tea plantations at Nguroje and Kusuku with soil auger at the depth of 0-15cm. The samples were air-dried in the laboratory and thereafter sieved with 2mm sieve. The physicochemical properties of the soil samples were carried out with wet chemistry. The samples were leached with 1N ammonium acetate. Each leachate was analyzed for exchangeable cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) determination [15]. Soil particle size was measured by the Boyocous hydrometer method. Soil pH was determined with glass electrodes in 1:2.5 soil-water suspensions. The organic carbon was quantified according to [16] protocol. Total Nitrogen was determined by the Macro Kjedahl method [17]. Available Phosphorus was determined using [18].

2.2.2 Fractional recovery

Liquid phosphorus fertilizer was prepared in the analytical laboratory of Mambilla Substation in accordance with a modification of [19] method. To obtain 70 mg P L^{-1}, 1.54g of KH_2PO_4 was prepared in 500ml of distilled water as stock solution. Five (5) sorption treatment solutions (A-E) were prepared by diluting 10, 20, 40, 80 and 100ml of the stock solution to 100ml as shown in Table 1. A 6.0g of each soil sample was weighed into 80ml plastic cups in tray racks and 3ml of each of the five sorption solutions was added to the soil samples to arrive at 35, 70, 140, 280 and 560mg P kg^{-1}soil accordingly. Distilled water was thereafter added to the soil samples to keep the soil moisture at field capacity. The experimental set up was made in triplicate. The treated soil and the control samples were incubated for a period of 3, 15, 30, 45 and 60 days under moist condition by adding distilled water when necessary. At the end of each incubation period, the treated samples and the counterpart control samples were air-dried and 3g of each subsample extracted with 18 ml of Mehlich 3 solution for phosphorus determination. Colorimeter was thereafter used to quantify the recovered phosphorus after soil incubation. Fractional recovery, fertilizer factor and P fixation were calculated from the data obtained from P extraction.

The linear regression that expresses the relationship between fractional recovery and rates of P addition was calculated for the soils at the different incubation periods as

$Y = a + bx$……………………………(1)

Where: Y = P extracted in mgkg-1 after incubation; X = rate of P addition to soil; A = P extracted at zero addition

b = Fractional recovery

Phosphorus fixing capacity (PFC) was obtained from the relationship:

$PFC = (1-FR)100$

Where: FR = Fractional recovery

Table 1: Concentration of P in treatments' solution

	Vol of stock diluted to 100ml	Conc. of P in sorption solution	Weight of soil sample (g)	Vol. of sorption solution added to soil (ml)	Rate of P added to soil (mg/kg)
A	10	70	6	3	35
B	20	140	6	3	70
C	40	280	6	3	140
D	80	560	6	3	280
E	100	1120	6	3	560

2.2.3: Statistical Analysis

Statistical analysis of the obtained data was done using mean and standard deviation.

3.0 RESULTS

3.1 Soil physico-chemical properties

Data on the physic-chemical properties of the soils are presented in Table 2. Nguroje soil had total nitrogen of 0.42% while Kusuku tea grown soil had 0.29% of total N. Exchangeable calcium was 0.69cmol/kg in Nguroje tea grown soil while Kusuku soil had 2.07 cmol/kg calcium. Magnesium was 0.84 cmol.kg in Nguroje soil while it was 1.75cmol/kg in Kusuku soil. Exchangeable potassium was 0.28cmol/kg in Nguroje soil while Kusuku soil had 0.51cmol/kg. exchangeable sodium was 0.68 cmol/kg in Nguroje soil while Kusuku tea soil had 0.37cmol/kg sodium. Exchangeable acidity was 0.15cmol/kg in Nguroje tea soil while Kusuku tea soil had exchangeable acidity of 0.10cmol/kg. The available phosphorus in Nguroje soil was 8.16 mg/kg while kusuku soil had available P of 8.18mg/kg. Organic carbon was 7.61% in Nguroje tea grown soil while the obtained tea grown soil from Kusuku community had 5.05% organic carbon. Soil pH in Nguroje tea grown soil was 4.77 while soil obtained from Kusuku tea grown soil had a pH of 5.01. Clay fraction of the soil particle analysis of Nguroje tea grown soil was 160g/kg soil while Kusuku tea grown soil had 340g of clay/kg soil. Silt in Nguroje soil was 72g/kg soil while Kusuku tea soil had silt fraction of 132g/kg soil. Sand fraction of Nguroje tea grown soil was 768g/kg soil while Kusuku soil had 528g sand /kg soil.

3.2 Fractional recovery

Fractional recovery of phosphorus in Nguroje soil treated with 35mg Pkg^{-1} soil decreased from 0.038 at 3 days after incubation to 0.0013 at 60 days after incubation (Table 3). Similarly, the fractional recovery of phosphorus in Kusuku soil treated with $35mgPkg^{-1}$ soil also decreased from 0.0191 at 3 days after incubation to 0.0006 after 30 days of incubation. However, result showed an increase in phosphorus recovery in Kusuku soil at 45 days after incubation. Result indicated a progressive decrease in phosphorus fractional recovery from 0.0286 to 0.0016 during 3 and 60 days after incubation respectively was also observed in Nguroje soil treated with 70 mg P kg^{-1} soil (Table 3). In Kusuku soil, the progressive decrease in P recovery was only sustained in the first 15 days after incubation. Phosphorus fractional recovery declined from 0.014 at 3 days after incubation to 0.0030 at 15 days after incubation.

Table 2: Physicochemical properties of investigated soil samples

Parameters	Nguroje soil	Kusuku soil	Critical level
Total N (%)	0.42±0.12	0.29±0.21	0.34 %
Exc. Ca ($cmolkg^{-1}$)	0.69±0.10	2.07±0.14	2.3 $cmolkg^{-1}$
Exc. Mg ($cmolkg^{-1}$)	0.84± 0.22	1.75±0.39	
Exc. K ($cmolkg^{-1}$)	0.28±0.06	0.51±0.1	3.6 $cmolkg^{-1}$
Exc. Na ($cmolkg^{-1}$)	0.68±0.12	0.37±0.10	
Exc. acidity ($cmolkg^{-1}$)	0.15±0.04	0.10±0.02	
Available P (mg kg^{-1})	8.16±1.31	8.18±2.1	15 $mgkg^{-1}$
Org C (%)	7.61±2.1	5.05±2.5	3.0 %
Fe ($mgkg^{-1}$)	14.65±3.4	17.55±3.2	
Mn ($mgkg^{-1}$)	6.45±1.7	13.05±1.1	
pH	4.77±1.10	5.01±1.20	4.5 – 5.6
Org Matter	13.10±2.31	8.70±2.62	
Cu ($mgkg^{-1}$)	0.15±0.08	1.35±0.12	
Zn ($mgkg^{-1}$)	3.16±0.07	29.68±5.10	
Clay (gkg^{-1})	160±6.6	340±7.4	
Silt (gkg^{-1})	72±4.62	132±8.62	
Sand (gkg^{-1})	768±5.83	528±6.12	

Table 3: Fractional recovery of P in investigated soil samples

	Fractional recovery									
Mg P/kg soil	Nguroje	Kusuku	Nguroje	Kusuku	Nguroje	Kusuku	Nguroje	Kusuku	Nguroje	Kusuku
	3 days		15days		30days		45days		60days	
35	0.0380	0.0191	0.0014	0.0037	0.0251	0.0006	0.0017	0.0015	0.0013	0.0004
70	0.0286	0.0140	0.0014	0.0030	0.0063	0.0034	0.0019	0.0014	0.0016	0.0007
140	0.0238	0.0047	0.0026	0.0019	0.0035	0.0073	0.0034	0.0021	0.0024	0.0010
280	0.0202	0.0060	0.0052	0.0013	0.0046	0.0096	0.0040	0.0036	0.0038	0.0028
560	0.0048	0.0024	0.0026	0.0060	0.0032	0.0054	0.0023	0.0020	0.0031	0.0018

Table 4: Phosphorus fixation in investigated soil samples

Mg P/kg soil	Nguroje	Kusuku	Nguroje	Kusuku	Nguroje	Kusuku	Nguroje	Kusuku	Nguroje	Kusuku
	3 days		15days		30days		45days		60days	
	% of P fixed in soil									
35	96.20	98.09	99.86	99.63	97.45	99.94	99.83	99.85	99.87	99.96
70	97.14	98.60	99.86	99.70	99.37	99.66	99.81	99.86	99.84	99.93
140	97.62	99.52	99.74	99.81	99.65	99.27	99.66	99.79	99.76	99.90
280	97.98	99.40	99.48	99.87	99.54	99.04	99.93	99.64	99.59	99.72
560	99.53	99.76	99.74	99.94	99.68	99.46	99.88	99.80	99.62	99.82

4.0 DISCUSSION

The obtained data on the physical and chemical properties of Nguroje and kusuku soils is an indication that, both Kusuku and Nguroje soils are acidic in nature. Total nitrogen in Kusuku soil was lower than the critical level of nitrogen (0.34%) required for tea cultivation. On the other hand, Nguroje tea soil had adequate total nitrogen content. The higher total N value in Nguroje soil compared with Kusuku soil may not be unconnected with the level of soil organic matter in the former. Organic matter decomposition produces humus which is a valuable reservoir of nitrogen. Aside the fact that humus contains 10% N, the higher organic matter in Nguroje soil could also contribute to the adsorption of nitrogen in the soil. Though Kusuku tea soil was higher in clay, its contribution to the retention of nitrogen in soil in an environment where annual rainfall is up to 3000 mm might be negligible considering the solubility of nitrate in water. As nitrate is negatively charged, it is not attracted to clay particles (negatively charged surfaces) and consequently prone to leaching during precipitation. Humus has an anion exchange capacity and therefore can hold some nitrate which reduces leaching. The values obtained for calcium in Nguroje soil and Kusuku were below the critical value (2.3 $cmolkg^{-1}$) required for adequate tea cultivation [20]. The grossly low calcium content of Nguroje tea soil is expected due to its inherent low pH. The values obtained for K in Nguroje and Kusuku soils were grossly lower than the critical level of K (3.6 $cmolkg^{-1}$) required for tea cultivation. The obtained values for Magnesium in Nguroje and Kusuku soils respectively were below the critical level of Mg required for tea cultivation according to [21, 20]. Deficiency of magnesium in tea grown soils on the Mambilla plateau is a long age challenge as [22] had earlier reported a deficiency in magnesium content of tea cropped soils on the Mambilla plateau.

Phosphorus fractional recover and fixation: The available phosphorus in Nguroje and Kusuku soils were grossly lower than the critical level of phosphorus (15 $mgkg^{-1}$) required for tea cultivation. The low available P content of the studied soils is an indication that tea plantations on the Mambilla plateau are deficient of phosphorus. The deficiency might be due to a number of factors which include but not limited to weathering, high phosphorus fixation, non-application of fertilizer to replace nutrient mined by tea plant annually. The progressive reduction in phosphorus recovery as incubation period increased suggests continuous fixation of phosphorus unto soil components as the incubation period increases. The observed progressive reduction in P fractional recovery with incubation time is in consonance with the report of [23] and [24]. The decline in phosphorus recovery was indicative of fixation of a proportion of applied phosphorus in soil solution. Desorption of adsorbed P was observed at 30 days after incubation which resulted in increase of P fractional recovery. The redistribution of P in terms of desorption that took place at 30 days of P treatment indicates that, a proportion of phosphorus that was adsorbed between 3 and 15 days of treatment was released back into soil solution for uptake by tea plant. This suggests that, the chemistry of phosphorus in soil is dynamic and not static. As the concentration of P in solution increased beyond 70 mg kg^{-1}, a progressive decline in P recovery with time reached a climax at 15 days after incubation in both Nguroje and Kusuku soils. The decline in P adsorption in both soils at solution P concentration of 70 $mgPkg^{-1}$ soil suggests saturation of sorption sites on the soil surfaces. Phosphorus fractional recovery was lower in Kusuku soil compared with Nguroje soil. This implies higher phosphorus fixation in Kusuku soil.

Fixation of nutrients in soil is hardly ascribed to a single mechanism or a single soil constituent. This in itself is largely due to the heterogeneous nature of soil matrix. However, the higher P fixation in Kusuku soil compared with Nguroje soil may not be unconnected with the higher clay content of Kusuku soil compared with Nguroje soil. In addition to higher clay content of Kusuku soil, it also had higher Fe than Nguroje soil. Phosphate ions are chemically unstable in soil solution and readily react with oxides and hydroxides of Al and Fe found on clay surfaces for acidic soils [23]. Correlation of soil physicochemical properties of the investigated soils with fractional recovery showed that P fixation increased significantly with clay, Fe, Zn and Mn. In a similar study conducted by [23], it was reported that P fixation increased with clay, organic carbon, Fe and Mn in selected cocoa soils in Nigeria. [26] reported that Fe oxides and clay were the main factors contributing to P fixation in soils. [27] report showed that phosphate sorption was highly correlated with clay and free Fe_2O_3. Hydrous oxides of Fe and Al have the ability to fix phosphate through adsorption on their surfaces. They occur in soils as discrete particles or films on other soil particles. They occur in the form of amorphous and crystalline hydroxyl compounds in soil. However, when aluminum and iron oxides in soil are less crystalline, the phosphate fixing capacity of the soil increases due to greater surface area available for adsorption. On the other hand, crystalline hydrous oxides fix more phosphate in soil than layer silicates. Clay fraction of soil is the main site of phosphorus fixation. The nature of clay minerals is also a factor that determines the capacity and intensity of phosphorus fixation in any soil. Phosphorus is retained in soil to a greater extent by clays of the 1:1 type (Kaolinite) than the 2:1 type clays (montmorillonite, illite, vermiculite) [28]. According to [29], Fe and Al appear to be the most likely soil constituents that fix P by chemical precipitation in acid soils when Fe and Al combine in equivalent. In most soils of the world where tea is cultivated, aluminum is a key soil constituent that contributes to soil acidity. Tea is a good accumulator of aluminum as an essential micronutrient required for optimum yield. Aluminum promotes the growth of tea bushes [30, 31]. Aluminum is only available to plants under a low pH of 5.5 and below [3]. In acid soils, Al becomes increasingly available, leading to toxicity for most plants except tea and other accumulator specie [3]. When Fe and Al are combined in equivalent quantities, fixation occurs between pH 2 and 3. In the presence of excess Fe, there is a tendency to extend the range of P fixation to pH 4. On the other hand, phosphorus fixation increases when Al and P are combined in equivalent quantities at pH 4. But in the presence of excess Al in soil solution, the range of P fixation extends from 4 to 7. The Fe and Al silicates and sesquioxides are the primary sources of Fe^{2+} and Al^{3+} leading to the formation of chemically precipitated Fe and Al phosphate in acid soils.

Clay factor: Phosphorus fixing capacity of the clay minerals is mainly due to the replacement of OH ions from the clay minerals surface and reaction with soluble Al originating from the exchange sites and from the lattice dissociation of clay minerals to form insoluble P compounds. The sesquioxides present in the free and hydrated state are considered the main causes of P fixation in acid soils. Certain reports have validated the influence of sesquioxides on P fixation. [32] reported an increase in P fixation with increase in HCl extracted sesquioxides in red soils. [33] reported a considerable reduction in P fixing power of an acidic soil through de-activation of Fe and Al by means of 8-hydroxyquinoline. In addition, an account of [34] showed that 90% of fixed phosphate in soil was recovered as Fe and Al phosphate. Other chemical constituents of the soil that might have enhanced higher P fixation in Kusuku soil compared with Nguroje soil is the Ca and Mg contents of the soil. Result showed that calcium content of Kusuku soil was thrice the value of Ca in Nguroje soil while the value of Mg in Kusuku soil was twice that of Nguroje soil. The nature of the exchangeable Cations present on the colloidal complex of the soils plays an important role in P fixation. [35] reported an increase in P fixation capacity with the increase in exchangeable Ca, exchangeable bases and total cation exchange capacity. The exchangeable Ca ions act as bridge between phosphate ions and clay surfaces. According to [36], about 30% of P fixation in acidic soils of Himachal Pradesh was due to exchangeable Ca and Mg. The rate at which P fixation proceed in soils is an important factor to be considered when assessing P availability to the growing plants. The observed increase in P fixation with reaction time is in agreement with the report of [34] in which P fixation increased from 45% and 85% at 6 hours after incubation to 70 and 95% respectively 6 weeks after incubation in soils of Dacca (pH 5.2) and Berhampur (pH 4.6). Evaluation of phosphorus fixation with reaction time shows a rapid adsorption 96.20 and 98.09% in Nguroje and Kusuku soils respectively at three days after incubation. According to the report of [37] most of the applied soluble P was fixed up in 24 hours but gradually increased up to

30 to 45 days in soils depending upon the type of soil and thereafter remains constant. In acidic soils of Baruijpur in West Bengal, [38] reported a gradual adsorption of phosphorus up to 5 days before reaching a steady state at 18 days after incubation. In alluvial soils of Madhaya Pradesh, P fixation increased with time up to 60 days before reaching a steady state [39]. The first stage where P fixation is rapid is attributed mainly to exchangeable Al and Ca ions while the second stage of slow P fixation is attributed to the non-exchangeable Al presumably dissociated from the non-exchangeable sites [36]

5.0 CONCLUSION

The study reveals that, phosphorus fixation in soil progresses from the point of application up till a plateau is reached and the fixed P gets desorbed and made available for plant uptake slowly. Phosphorus fixation and desorption in agricultural soil is dynamic and not static as fraction of fixed P ultimately returns back into soil solution where it is being utilized by plant. This depicts that, P fixation in agricultural soil is not permanent but temporary. Soil physic-chemical properties are major factors that determine the intensity and magnitude of phosphorus fixation in soil.

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Conflicts of Interest

The author disclares that there is no conflict of interest in the publication.

Contribution of the authors

The author conceived the research idea, designed the experiment, conducted the experiment and prepared the manuscript.

REFERENCES

[1] Mukhtar H, Ahmad N. Tea polyphenols: prevention of cancer and optimizing health. Am J Clin Nutr. 2000; 71:1698S–702S.

[2] FAO. Working group on organic tea: Inter-seasonal meeting of the Intergovernmental group on tea Rome, 2014;5-6

[3] Hajiboland Roghieh, Environmental and Nutritional requirements for tea cultivation. Folia Horticulturae 2017; 29(2): 199-220

[4] De Costa WJ, Mhotti A, and Wijeratne M, Ecophysiology of tea. Braz J. Plant Physiol. 2007; 19(4): 299-332

[5] Carr, M. K. V., & Stephens, W. (1992). Climate Weather and the Yield of Tea. In K. C. Willson, & M. N. Clifford (Eds.), Tea: Cultivation to Consumption (pp. 87-135)

[6] TRFK (Tea Research Foundation of Kenya) Tea Growers' Handbook, 5th edition Kijabe Printing Press, Kijabe, Kenya. 2002

[7] Aikpokpodion Paul E. Eucalyptus Agroforestry in Tea plantation on the Mambilla Plateau: Influence on Carbon sequestration and organic carbon. Nig J. of Pharma and Appl Sci. Res. 2020; 9(1): 25-30

[8] Hainsworth E, Tea production on the Mambilla Plateau, Gongola state (now Taraba State), Nigeria. A report on the project by the consultant for the Nig. Beverages Prod. Co. Ltd.1981; 26

[9] Omolaja SS, and Esan EB. Yield evaluation of high altitude tea (*Camellia Sinencis* (L) O. Kuntze) in lowland ecologies of Nigeria. Nig. J. of Hort. Sci.2005; 10 (1): 87- 93

[10] CRIN (Cocoa Research Institute of Nigeria). Annual Report from the Mambilla Substation of CRIN at Kusuku, Taraba State, Nigeria. 1982; 120pp

[11] Tabu IM, Kekana VM, and Kamau DM. Effects of varying ratios and rates of enriched cattle manure on leaf nitrogen content, yield and quality of tea (*Camellia sinensis*). J. of Agric. Sci. 2015; 7(5):175-181

[12] Mokaya, B.N. Effects of Varying Rates of Organic and Inorganic Fertilizers on Growth, Yield and Nutrients Use Efficiency of Clonal Tea (Camellia sinensis L. (O) Kuntze). MSC Thesis, University of Nairobi, Nairobi. 2016

[13] Hawkesford M, Horst W, Kichey T, Lambers H, Schjoerring J. Skrumsager Moller I, and White P. Functions of macronutrients In: marschner's Mineral Nutrition of higher plants. P. Marschner (Ed) , Academic Press, UK:2012; 135-189

[14] Hamid FS. Yield and quality of tea under varying conditions of soil and nitrogen availability. PhD. Dissertation, Quaid-i-Azam University Islamabad, Pakistan. 2006

[15] Schollenberger CJ, and Simeon LA. Multipurpose extractant for Na, K, Ca, Mg. Soil Sci. 1945; 45: 12

[16] Walkey A, and Black IA. Methods of soil analysis. Sci, 1934; 37: 29-38

[17] Bremner JM, Nitrogen total. In Methods of soil analysis, Part 3: Chemical Methods; Sparks, D.L. (ed); Soil Sci. Soc. of Ame: Madison, Wisconsin, 1996; 1085-1121

[18] Bray RA, and Kurtz LT, Determination of total organic and available forms of phosphorus in soils. Soil Sci. 1945; 59: 39-45

[19] Hunter A.H., Laboratory and Greenhouse Technique for nutrient survey to determine the soil amendment required for optimum plant growth. Int Soil Fert. Ev. Imp Project NC. University, Raleigh NC. 1975

[20] Ipinmoroti RR, Iremiren GO, Olubamiwa O, Fademi AO, and Aigbekan EO. (2011) Effects of inorganic and organic based fertilizers on growth performance of tea and cost implications in Kusuku, Nigeria. Journal of Life Sciences 2011; 5: 536-540

[21] Othieno CO. (1981) Effect of pruning removal on nutrient uptake and yield of tea, Tea 1981; 2 (1): 20-25

[22] Obatolu CR. (1999) Correction of Magnesium deficiency in tea plant through foliar application. Comm. in soil Sci. and Plant Anal. 1999; 20(11-12): 1649-1656

[23] Ogunlade MO, Ibiremo OS, Ipinmoroti RR, Iloyanomon CI, and Aikpokpodion PE. Determination of Phosphorus and Potassium fixation capacities and fertilizer factors in soils of three cocoa growing areas of Nigeria. J. of soil and Nat.2011; 5(1): 11-16

[24] Mallikarjuna G, Sudhir K, Srikanth K, Srinivasamurthy CA. Phosphorus fixation capacity and its relationship with the soil characteristics in laterite soils of Karnataka. J. of the Indian Soc. of Soil Sci. 2003; 51(1): 23-25

[25] Bolland MDA, Allen DG, Barrow NJ (2003) Sorption of phosphorus by soil, Government of Western Austrialia, Dept. of Agric. Bull. 2003; 4591:1-30

[26] Thomizi MD, Mello FAF, Arzolla S, and Mello FA. Phosphate fixation in soils of the Piracicaba Municipality. *Revista de Agricultura* 1990; 65 (1): 45-53

[27] Owusu Bennoah E, and Acquaye DK. Phosphate sorption characteristics of selected major Ghanian soils. Soil Sci. 1989; 148(2): 114-123

[28] Idris OAA, and Ahmed HS. Phosphorus sorption capacity as a guide for phosphorus availability of selected Sudanese soil series. Afr. Crop Sci. 2012; 20(1): 59-65

[29] Dean LA, Fixation of soil phosphorus. Adv. Agron, 1949;1: 391-411

[30] Ghanati F, Morita A, and Yokota H, Effects of Aluminum on growth of tea plant and antioxidant defense system. *Plant Soil* 2005; 276: 133-141

[31] Hajiboland R, Bahrami-Rad S, Barcelo J, and Poschenrieder C, Mechanism of aluminium induced growth stimulation in tea (Camellia Sinensis). Journal of Plant Nutrition and Soil Sci. 2013; 176: 616-625

[32] Raychaudhuri SP, and Mukerjee MK. Studies on Indian red soils. II. Fixation of phosphate. Indian J. of Agric. Sci. 1941; 11: 205-219.

[33] Ghani MO. The use of 8-hydroxy quinoline as means of blocking active and alluminium in the determination of available phosphoric acid of soils by dilute acid extractions. Indian J. Agric Sci. 1943; 13:562-565

[34] Ghani MO, and Islam MA, (1946) Phosphorus fixation in acid soils and its mechanism. Soil Science 1946; 62: 293-306

[35] Patel DK, and Vishwanath D. Comparative studies on Indian soils. XI. Phosphate fixation capacities of soils, Indian *J. of Agric. Sci*. 1946; 16: 428-434

[36] Kanwar JS, and Grewal J. Phosphorus fixation in India soils. 2nd edition. New Delhi, India: Indian Council of Agricultural Research. 1990

[37] Gupta AP. Studies on the distribution, fixation and availability of phosphate in soils of sugarcane growing tracts of Bihar and Uttar Pradesh, Agra Univ. J. Res. 1965; 14: 191-194

[38] Basu S.N. and Mukerjee SK, Solubility of added phosphates in a phosphate saturated soil. J. of Indian Soc. Soil. Sci. 1972; 20: 7-11.

[39] Dravid MS, and Apte BC, Effects of various phosphatic fertilizers on the availability of phosphorus in black and alluvial soils of Madhya Pradesh. J. Indian Soc. Sci 1975; 23: 56-60

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