UNIVERSITY OF EDUCATION, WINNEBA

EFFECT OF LOCALLY AVAILABLE PHOSPHORUS SOURCES ON SOIL PHOSPHORUS FRACTIONS, PHOSPHORUS UPTAKE, MAIZE DRY MATTER PRODUCTION AND GRAIN YIELD ON A *TYPIC PLINTHUSTUULF*

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DECLARATION

STUDENT'S DECLARATION

I, Amankwa Siyyid, hereby declare that except for references to the works of other researchers which have been duly cited, this work is the result of my own original research and that it has neither in whole nor in part been presented for another degree elsewhere.

……………………….. ……………………

Amankwa Siyyid Date

SUPERVISORS' DECLARATION

We hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the University of Education, Winneba.

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Prof. Kofi Agyarko Date
(Principal Supervisor)

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Mr. E. K Asiedu Date
(Co-Supervisor)

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DEDICATION

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ABSTRACT

The study was conducted to assess the effect of different locally available phosphorus sources on agronomic P use efficiency, P utilization efficiency, P recovery efficiency, total dry matter production, grain yield of maize and soil P fractions in a locally available amended *Typic Plinthutuuf* in 2017 and 2018 minor cropping seasons. The study involves nine treatments each replicated three times in a Randomized Complete Block Design (RCBD). The treatment combinations were: No amendment (T1), 1.30 kg/ plot Urea+ 1.92 kg/ plot TSP + 0.38 kg/plot KCl (T2); 49.56 kg/plot EFB Mulch + 0.25kg/plot Urea + 1.03 kg/plot TSP (T3) , 24.80 kg/plot EFB Mulch + 0.25kg/plot Urea + 20.16kg/plot EFB Compost+ 1..05 TSP (T4), 53.76 kg/plot RH Biochar + 0.19 kg/plot Urea + 1.38 kg/plot TSP + 22.68 kg/plot EFB Compost (T5), 28 kg/plot EFB Mulch + 28 kg/plot RH Biochar+ 0.19 kg/plot Urea+ 1.25 kg/plot TSP (T6), 40.6 kg/plot EFB Compost + 0.25 kg/plot Urea + 1.3 kg/plot TSP (T7), 49.2kg/plot RH Biochar + 28.08 kg/plot EFB Compost + 1.91 kg/plot RP (T8) , 21.3 kg/plot EFB Mulch + 28.08 kg/plot EFB Compost + 1.15 kg/plot RP (T9). The data were analyzed by ANOVA and LSD at 5 % level of significance was used to separate the means. The maize grown on T2 enhanced the highest agronomic P use efficiency and grain yield in 2017 as well as total dry matter production and growth parameters in both 2017 and 2018. T5 was also observed to promote maize plant with the highest total P uptake and P recovery efficiency in both 2017 and 2018 minor cropping seasons. The highest soil P fractions, the soil properties as well as the P utilization efficiency and the P harvest index were obtained from organic P sources and integrated P sources. Across all the treatment, maize plant performed better in 2018 minor cropping season than in 2017 minor cropping season probably due to the higher rainfall and temperature in 2018. In conclusion, the application of NPK, rice husk boichar and its compost and rock phosphate promoted the highest grain yield and total dry matter production and therefore is recommended for adoption by all farmers.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Phosphorus (P) in soil is an important limiting nutrient to agricultural production in tropical soils. Owing to its scarcity, P is considered as one of the global environmental challenges of the 21th century (Cordell and Neset, 2014). Most highly soils in tropical and subtropical regions are characterized by low P content due to high P fixing capacity (Guedes *et al*., 2016). Growth and development of plant are affected by inadequate P supply. As one of the essential macro-nutrients required by plants for growth, P is directly involved in energy transfer, respiration, photosynthesis and formation of cellular structure (Richardson *et al.,* 2009). Plant roots take up inorganic P in a form of ($H_2PO_4^-$ or HPO_4^{2-}) which is pH dependent. Due to the equilibrium reaction in soils, P occurs predominantly as $H_2PO_4^-$ in acidic soil and as HPO_4^{2-} in alkaline soils (Rai *et al*., 2016).

Phosphorus is generally available to crops at a soil pH of 6 to 7 (Penn and Camberato, 2019). When P is dissolved in soil solution various reactions such as precipitation, adsorption and sorption take place. According to Bohn *et al.* (2001), some of the reactions P undergo in soils entails several processes like precipitation, adsorption and sorption by soil organic matter. In acidic soil the adsorption of P on surfaces of sesquioxide is primarily responsible for P sorption whereas in calcareous and volcanic soils, precipitation reaction and adsorption of P on the surfaces of Ca ions forming strong calcium phosphate complexes are responsible for P sorption. These reactions therefore result in processes like labile P, moderately labile P and an insoluble non-labile P (Yang and Post, 2011). In highly weathered soils, when inorganic P forms bond to the mineral fractions, it is characterized as labile and non-labile (Rheinheimer *et al*., 2008).

According to Beck and Shanchez (1994) labile P pools which is the P in soil solution is the plant available P that is accessible and available for plant absorption. The moderately labile P which is the Al and Fe P complexations on the soil colloid is the P pool that replenish depleting labile inorganic P stock in the soil solution for plant uptake (Abekoe and Tiessen, 1998). The non-labile P which is the occluded P encapsulated in the matrix of the soil colloid can also be considered as the most recalcitrant and stable P that becomes available for plant use in the long run. According to Syers *et al*. (2008), the concentrations of phosphate ions in soil solution have effect on the availability of P for plant roots and the ability of the soil to replenish them after plant uptake. When the accumulated P in the soil exceed plant uptake and losses by runoff and erosion, it results in the formation of residual P which eventually become available to plant over several years depending on the soil characteristics and management (Batjes, 2011). According to Holford (1997), there are three vital soil components controlling the P supply from the labile pool to replenish crop extraction: i) the concentration of P in the soil solution, ii) the amount of P in the replenishment source that enters into equilibrium with the soil solution phase and iii) P buffering capacity of the soil. Sinclair and Vadez (2002) stated that a good crop yield can be maintained when P is adequate in readily available pools to maintain a critical threshold of P concentration in the soil solution. Therefore, frequent application of inorganic P fertilizer is a conventional way Ghanaian farmers used to maintain readily available P. However, most of the added P remains available for a short period due to sorption effect (Nziguheba *et al*., 1998).

Recent studies have come out with other strategies that can make adsorbed P available to plants (Richardson *et al.,* 2017). For instance P solubilizers have been developed that can make the adsorbed P available to plants. Liming increases the pH in acidic soil, thus making P available for plant uptake (Opala, (2017). Humic acid released from decomposed organic materials can also block P sites thus forming a repulsive negative electrostatic field around the sites as well as preventing the precipitation of phosphate through the complexation of Ca, Fe and Al (Perassi and Borgnino, 2014). Furthermore, humic acid can develop complexes of variable stability with P, which is mediated by metallic cations that gradually stabilize, making P available to plants (Gerke, 2010). There are other organic P sources like compost and biochar, empty fruit bunch mulch which are also necessary for increasing the efficiency of phosphate fertilization in soils. In soils, rock phosphate solubility increases with decreasing pH (Barroso and Nahas, 2005).

1.2 Problem statement

Abekoe (1996) stated that phosphorus is deficient in Ghanaian soils and its deficiency in plant is manifested in stunted growth, reduced yield and delayed maturity. Application of inorganic fertilizers such as triple superphosphate which is mostly used by farmers contain high amount of total P which is vital for meeting the plants' P demand, to bring about sustainability of agriculture and food security. However, the availability of P for plant uptake is highly depended on the pH of the soil.

According to Brady and Weil (2008) about 85-90% of the added inorganic P becomes unavailable to plants in the year of application due to adsorption and precipitation with Fe, Al and Ca in the soil. According to Ahmat *et al.* (2014), most soils in Ghana are acidic and are dominated by sesquioxides and as a result, the high percentage of P applied through fertilizers is sorbed and fixed by soil colloids turning it into unavailable forms. In the light of this, farmers apply triple superphosphate in excess to exceed the sorption capacity to make more P available to plant. This results in accumulation of total P in soil and movement of particulate P into water bodies where it can cause eutrophication (Correl, 1998).

1.3 Justification

Significant quantities of different organic sources of P abound in Kwaebibirem District (Sarku, 2014). These readily available sources of P can promote P availability, uptake and utilization which will enhance total dry matter production and yield of the maize plant (Adjei-Nsia, 2012). The P in the biomass can also be used for soil improvement through the direct application as mulch or recycling of P in the biomass into compost and biochar. The biochar and compost could also help farmers to reduce cost of production and excessive use of chemical fertilizers.

The locally available organic P sources can serve as a reservoir of P and through mineralization can release P into soil solution for plant uptake. The biochar, compost and rock phosphate can also reduce the fixation effect of P on the soil and thus increases the soil pH. The application of P in the form of organic materials such as biochar, compost and rock phosphate provide alternative P sources, by adding phosphorus to the soil and releasing organic acids, which block P adsorbing sites in the soil and changes the soil pH and complexation of soluble Al and Fe (Ayaga *et al*. 2006., Haynes and Mokolobate, 2001)

Biochar contains sufficient amount of P and therefore can directly release P into soil solution to enhance P availability (Atkinson *et al*., 2010). Furthermore, the addition of biochar reduces soil acidity due to its high alkalinity and consequently reduces P precipitation reactions with Fe^{3+} and Al^{3+} (Wang *et al*., 2012)

Dai *et al.* (2016) also stated that the use of rice husk biochar and empty fruit bunch-based compost are the feasible route for the recycling of P in agricultural residue. The recycling of P in agricultural residue is essential for the sustainability of agriculture and food security (Cordell *et al*., 2009).

1.4 Main objective

The study sought to evaluate the effect of locally available sources of phosphorus on soil P fractions and maize P uptake in amended *typic plinthustuulf.*

1.4.1 Specific objectives

- Evaluate the effect of P sources on dry matter production and yield of maize plant.
- Evaluate the effect of the different P sources on P uptake, P utilization and agronomic P use efficiency of maize.
- Determine the P recovery efficiency of maize in the soil amended with different locally available P sources.
- Evaluate the effect of P sources on P fractions (labile and non-labile) in the amended soils.

Hypothesis

- Integrating organic with inorganic P sources will produce the highest total dry matter production and highest grain yield compared to the inorganic P sources.
- The organic P sources will improve on the P uptake, the agronomic P use efficiency, and P utilization efficiency of the maize plant compared to the inorganic P sources.
- Inorganic P sources will improve on P recovery efficiency of the maize plant compared to organic and inorganic P sources.
- Integrating organic with inorganic P sources will significantly enhance soil P fractions (Labile P, Moderately labile P and Non-labile P) as compared to inorganic and organic P sources.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil acidity and their effects on P availability

About 11% of the total soils in the world are acidic with 40-70% being potential agricultural arable land found mostly in humid region (Hede *et al*., 2001). Acidic soils are characterized by low pH below 6.5 and high levels of extractable acidity (Kanyanjua *et al.*, 2002). According to Obiri-Nyarko (2012), a greater proportion of Ghana's agricultural soils are slightly to extremely acidic.

Most tropical soils have high content of Al^{3+} ions that bind to the orthophosphate minerals leading to low availability of the extractable P. As a result of high rainfall, there is a high levels of leaching in these soils which results in low amount of exchangeable basic cations such as Ca^{2+} and Mg^{2+} ions contents in these soil. The organic matter in most of these soils is assume to be high especially soils near the forests or in highlands (Celik, 2005). The presence of organic matter in most of these soils are assumed to be the result of relatively high concentrations of Fe, Cu, Zn and Mn ions. A significant portion of Fe, Cu, Zn and Mn ions reaching the soil remained in the upper layers mainly bound to organic matter. Brun *et al*. (2001) cultivated maize in the vineyard soils with high Cu content and observed that the Cu concentration in the upper part of the maize plant had a high positive correlation with the soil OM.

According to Pati and Mukhopadhyay (2010), soil acidity is described as active acidity, extractable acidity or total acidity. Active acidity is represented as H^+ concentration in the soil solution. Active acidity refers to the actual activity of the H^+ in the soil solution and is measured by the pH meter. Extractable acidity is determined through extraction from a soil to a barium chloride triethanolamine ($BaCl_2$-TEA) solution at pH of 8.2. Total acidity also referred to as titratable acidity. Total acidity includes both exchangeable and titratable acidity and is determined using a strong base such as NaOH (Bergelin *et al*., 2000).

High soil acidity which is caused by an increased Al and Mn accumulation in the soil adversely affect soil fertility thereby reducing the productivity and yield of plant (Tadela (2020), increased health increased risk of folder crops to animals through hypomagnesaemia and hypocalcaemia; leads to deficiency of Mo and P to crops; as well as reducing the nitrifying and organic matter converting microbes (Fontaine *et al*., 2003). High acidification also results in reduced plant water use efficiency especially in the lowlands hence requiring constant recharge.

Crops exhibit varying abilities to tolerate the high Al concentration and increased soil acidity (Ma *et al*., 2001). Plants can therefore be categorized into very tolerant, tolerant, sensitive or very sensitive (Matsumoto, 2000). According to Kanyanjua *et al*. (2002), some of the plants that are tolerant to acidic soils are tea, sweet potatoes, Irish potatoes and chillies. For instance, Cassava, Corn and Egusi are some of the acid tolerant foods that drives well in Ghana as well as in West Africa. Most maize varieties are categorized under medium tolerance to sensitive range together with wheat and peas (Kidd *et al*., 2001). However, most horticultural crops such as onions, carrots, spinach, cauliflower and cabbages are highly sensitive to soil acidity (Canellas *et al* 2015). To reduce these effects, liming has to be done to raise the pH to about 6.5 where crops grow efficiently (Uchida and Hue, 2000). Thus, RP which can be used as a liming material is effective in lowering the acidity and enhancing better crop growth (Nabahungu *et al*., 2007).

Rock phosphate use as a liming material is effective in supplying Ca ions to plants growing in high acidic soils (Basak and Biswas. 2016). Yarzábal (2010). stated that application of RP results in rise in pH in acidic soils thereby improving plant growth. RP application in acidic soils increases the concentration of Ca ions that binds with Al ions in the soil decreasing the amount of extractable Al ions in the soil. According to Yarzábal (2010), when RP is applied to Puerto Rico's Ultisols and Oxisol soils, it results in reduction of extractable Al from 60 - 20% and increased the soil pH from 4.2 to 4.8. This shows the effect of RP in highly weathered tropical soils.

2.2 Forms and reactions of Phosphorus in soil

Soil phosphorus results from pedogenic and anthropogenic activities such as the use of inorganic fertilizer, weathered parent materials and decomposition of organic materials (Scherer and Sharma 2002; Verma *et al*., 2005). Soil P is grouped into organic (Po) and inorganic (Pi) forms. Inorganic phosphorus (Pi) includes apatitic minerals, secondary precipitates formed with Ca, Fe and Al and free phosphate ions ($H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-} all denoted as PO_4-P) attached to sorption surfaces or dissolved in the soil water (Richardson and Vaithiyanathan, 1995).

Organic phosphorus (Po) includes a group of organic molecules having P as a part of their structure. Orthophosphate esters are Po compounds having an ester linkage joining PO_4-P to organic moiety and they are further divided into mono- and di-esters according to the number of ester groups attached to each PO_4-P. According to Turner *et al.* (2002) mono-esters which is the largest group of Po in most soils, include sugar phosphates, phosphoproteins, mononucleotides and inositol phosphates.

Di-esters which usually occur in smaller concentrations in soil than mono-esters include nucleic acids, phospholipids, and teichoic acid and aromatic compounds. Phosphonates form a group of Po that contain a C-P bond. Polyphosphates complicate the simple division of P into organic and inorganic pools, since most of them are inorganic but are of biological origin. However, polyphosphates such as ADP and ATP are chemically organic compounds (Xu *et al*., 2011). In soils the solubility of most of these P forms are very low. Usually, the total soil P concentration is high (around 2000-3000 mg P kg^- soil) but the concentration of available P in soil solution is very low (< 0.01 to 1 mg L^- in highly fertile soils) representing a small percentage (< 1%) of total soil P (Lambers *et al*., 2015).

Plants take up P in soil solution as di-hydrogen phosphate ion ($H_2PO_4^-$) in acidic soils and hydrogen phosphate ion (HPO_4^{2-}) in alkaline soils (Rai *et al*., 2016). Processes influencing the release of orthophosphate anions from organic (Po) and inorganic P (Pi) are usually dissolution-precipitation, sorption-desorption, mineralization- immobilization and soil acidification (Celi *et al*., 2001; Mkhabela and Warman, 2005).

According to Delgado *et al*. (2000), in soils inorganic P are found associated with Al and Fe oxides, Ca, clay minerals and organic matter. Primary minerals like apatite, hydroxyl apatite and francolites are dominant in unweathered or moderately weathered soils with neutral or alkaline pH whilst P associated with Al and Fe oxides are dominant in soils with acidic pH (Sims and Pierzynski, 2005). Therefore, soil properties like pH, concentration of Ca, Al and Fe and soil texture and organic matter content strongly influenced the form and solubility of inorganic P.

Organic P is an important form of P for plant uptake and is about 20-80% of the total soil P (Sharpley and Moyer, 2000). Fuentes *et al*., (2008) stated that soil microorganisms and plant roots (through mineralization of phosphatase) converts organic P to plant available P ((Shen *et al*. 2011) and this is influenced by soil pH, moisture, temperature and surface area of soil particles. Soil microbial biomass functions in P dynamics through biochemical transformation of organic matter (Grandy and Neff, 2008). Several processes in P cycle are mediated by microorganism and thus solubilizes poorly soluble P forms (Sharma *at al.,* 2013). According to Oberson and Jones (2005), microbial biomass P constitute about 0.5 to 26% of total soil P and is likely to be in available P pool.

When organic P is converted to inorganic P it is referred to as mineralization whereas the uptake of P into the microbial biomass with decrease in inorganic P concentrations is immobilization (Badalucco and Kuikman, 2000). The two processes occur simultaneously in the soil (Badalucco and Kuikman, 2000). Redistribution occurs when immobilized P is converted into mineralized P and vice versa (Schmidt *et al*., 1999).

The P cycle in soils is controlled by reactions such as solubilization, precipitation, sorption, desorption, leaching, immobilization and mineralization (Schoumans and Groenendijk, 2000). The primary source of P in soils, Apatitic P is solubilised through weathering processes. Solubilized P can be leached from the soil, sorbed onto Fe and Al oxides and mineral edges of clay particles, precipitate as secondary Ca^{2+}, Fe^{3+} or Al minerals or be taken up by living organisms (Kaiser and Guggenberger, 2000).

Only a small proportion of soluble P is dissolved in soil water (Chantigny, 2003). The negatively charged PO_4^- P can be bound to positively charged surfaces through electrostatic forces; however, the importance of this mechanism is minimal in soil environments compared to ligand exchange (Chan *et al*., 2018). According to Guppy *et al*. (2005) ligand exchange is considered to be the main retention mechanism for inorganic phosphorus in non –calcareous soils as it allows a strong sorption of P. In this reaction, PO_4^-P is chemisorbed onto variably-charged sorption components. The formation of an inner-sphere complex where PO_4 group displaces through its oxygen-bearing group an OH^- or H_2O group from Al or Fe in a hydrous oxide or on the edge surface of a clay mineral is referred to as ligand exchange (Soinne, 2009).

The ligand exchange can take place on a positively, negatively or uncharged surface. According to Yang *et al*. (2006), the positive charge on a sorption surface is increased by H_2O ligand in acidic conditions and is replaced with a PO_4^{3-} group, hence the sorption is increased at low pH. The PO_4^{3-} P in soil solution tries to reach equilibrium with PO_4^- P sorbed onto soil surfaces. Therefore, when PO_4^- P concentration in soil solution increases, P sorption also increase (Jiao *et al*., 2007). At lower concentrations, the formation of binuclear or bidentate complexes, where PO_4 group displaces two coordinated OH^- or H_2O groups from a hydrated surface, is favoured, but as the level of adsorption increases the formation of monodentate structures is preferred and the sorption strength is decreased (Yang *et al*., 2006). The process of PO_4^- P adsorbed onto variably-charged soil oxides and hydroxides are complicated and usually consist of fast sorption reaction, followed by slow process of diffusion of P into the hydroxide (Pratt, 2006).

Desorption of P is enhanced in conditions opposite to those favouring sorption (Marin – Benito *et al*., 2012). As pH increases, desorption of PO_4^- P is enhanced and similarly as PO_4^- P decrease in soil solution, there is further P desorption from the sorption sites (Ariyanto, 2013) . In addition, the P concentration and ionic strength in soil solution and temperature affect sorption and desorption of P (Virkutyte *et al*., 2002). An increase in salt concentration increases the sorption of P and decreases desorption (Setia *et al*., 2013).

According to Yadav and Garg (2011), the reverse reaction to mineral dissolution is precipitation and can be referred to as formation of discrete, insoluble compounds in soil. In soils that are alkaline in nature where Ca is the predominant cation, the soluble PO_4^- P can precipitate, forming Ca phosphates.

In alkaline soils, after the addition of P to soils, the dicalcium phosphate dihydrate ($CaHPO_4.2H_2O$) which is unstable, eventually turn into more stable forms of calcium phosphates. In acidic soils, when conditions are favourable, P can form precipitates with Al and Fe instead of Ca (Penn and Camberato, 2019). Ler & Stanforth (2003) reported detection of separate crystals of Al and Fe phosphates and evidence of the surface precipitation of P.

2.3 Reactions of P in soils

When P is applied to the soil as fertilizer, it undergoes several reactions. Some of the notably reactions are fixation, retention, adsorption and precipitation (Carreira *et al*., 2006).

2.3.1 Retention and Fixation of P in soils

Phosphorus retention is the adsorption of P ions onto soil mineral surfaces due to electrostatic attraction, nonspecific adsorption or through co-adsorption (Chien and Clayton, 1980). These reactions (electrostatic attraction, nonspecific adsorption or co-adsorption) are reversible. Phosphorus fixation on the other hand is due to the linkage of P anions to soil minerals through replacement or displacement of structural OH groups (Johnston and Tombacz, 2002). This type of mechanism is more significant in sesquioxides and 1:1 than in 2:1 clay minerals due to the higher contents of OH groups in the former two (Kome *et al*., 2019).

2.3.1.1 Reactions with oxides of Fe and Al and with silicate clays:

At low pH, the surfaces of oxides Fe and Al and the broken edges of 1:1 silicate clays become protonated (Charlet *et al*., 1993).

$AlOH + H^+ \rightleftharpoons Al\,OH_2^+$

(Clay edge) (Protonated edge)

The protonated surface then adsorbs the $H_2PO_4^-$ that exists in soil solution.

$AlOH_2^+ + H_2PO_4^- \rightleftharpoons AlOH_2H_2PO_4^-$

$Al\,(OH)_2\,H_2PO_4^- \rightleftharpoons Al^{3+} + 2OH^- + H_2PO_4^-$

The reactant being unstable then split into aluminum ion (Al^{3+}), hydroxide ion (OH^-) and orthophosphate ion ($H_2PO_4^-$) and this reaction is reversible

The adsorbed $H_2PO_4^-$ could be held as an outer sphere complex (nonspecific adsorption) and is subject to anion exchange with other anions such as OH^-, $SO4^{2-}$, MoO_4^{2-} and organic acids R-COO- (McDowell *et al.,* 2001).

The protonated surface then reacted with the organic ion (COO^-) that exist in soil solution

$AlOH_2H_2PO_4^- + COO^- \rightleftharpoons Al\,OH_2COO^- + H_2PO_4^-$

By anion exchange, the orthophosphate ($H_2PO_4^-$) on the protonated surface is being replaced by the organic ion and the reaction is reversible.

This anion exchange reaction is P retention as the $H_2PO_4^-$ is held non-specifically and slowly made available to crops. The phosphate anion may also replace structural OH of the clay to form an inner sphere complex. There is ligand exchange between the $H_2PO_4^-$ and the protonated OH^- (OH_2^+) of the sesquioxide or 1:1 silicate clay (Fu *et al.,* 2018). Availability of the $H_2PO_4^-$ may be increased by liming the acidic soil to increase the OH ion in solution or by adding organic matter to increase the RCOO- concentration in soil solution.

The ligand exchange reaction, which is reversible, binds the anion too tightly to the mineral and is availability is very low. Thus, complex formation or chelation reaction and the H_2PO4^- becomes an integral part of the mineral. With time, another structural OH of the mineral and one H of the anion form water which is released into solution. An oxygen of the $H_2PO_4^-$ then binds the anion to the mineral. Release of the anion back into solution thus becomes very difficult as the $H_2PO_4^-$ is buried deep inside the mineral. The P is then termed occluded and is the least available form in most acid soils. This process is termed fixation and exceeds that by retention (Sondergaard *et al*., 2001).

2.3.2 Adsorption

Haynes and Mokolobate (2001), stated that specific adsorption occurs through a ligand exchange when hydroxyl groups on the surface of sesquioxides and hydrous oxides are being replaced by phosphate anion. Since P is not chemically stable in the soil, it readily reacts, largely with aluminum and iron in acid, forming a less soluble and more stable compounds. The reactions mostly take place on the surfaces of soil constituents (clays, oxides of iron and aluminum, organic matter, and aluminum and iron compounds coating surfaces of sands) (Kaiser and Guggenberger, 2000). When the surface reaction has occurred, the adsorbed P diffuses slowly to the interior of the particle and therefore become less available to plants (Bollan and Duraismy, 2003). The slow diffusion of adsorbed P into the soil particles continues even in dry soil (Arai and Sparks, 2007). These dual reactions of adsorption and penetration are all referred to as sorption.

The reaction of phosphorus in soil solution with soil minerals and its sorption and desorption process are influenced by soil aggregate size (McDowell *et al*., 2001). According to Sanchez *et al. (*2003), clay fractions having more than 20% iron or aluminum oxides in their clay- size particles can sorb large quantities of added phosphorus, changing them into slowly soluble iron and aluminium phosphates which are not readily accessible to plants. High clay content shows high phosphorus retention while most sandy red soils do not fall in this category (Sanchez *et al.,* 2003). Most fine to medium textured soils also have high capacities to hold phosphate by adsorption and precipitation because of the large surface area.

Organic Matter (OM) decomposition has been reported to produce hydrogen which is responsible for acidity in soils and therefore accounts for why organic supplements increase P availability in P-fixing soils (Agbenin and Igbokwe, 2006) and humic substances also increase the bioavailability of P fertilizers in acidic soils (Hua and Zhou, 2008).

The addition of OM to soils may increase phosphorus availability by decomposition and mineralization of organic P, or by abiotic processes such as ligand-exchange effects on phosphate adsorption (Olander and Viitousek, 2000). Organic matter content of highly weathered soils has been shown to be negatively correlated with phosphate adsorption by soil and soil OM (SOM) content for 97 highly weathered soils of Western Australia (Yusran, 2018). Stuanes (1982) stressed that organic matter can act in two ways; either by sorbing P or by blocking sorption sites of inorganic particles.

2.3.3 Precipitation of P in soil

In strongly acid soils, Fe and Al become very soluble and exists as free Fe and Al, especially in highly weathered soils like Oxisols, Ultisols and Alfisols (Wagai and Mayer, 2007). The P anion exists in acidic soil mainly as $H_2PO_4^-$ (Smeck, 1985). Under such conditions, the soluble cations chemically precipitate the anion as below:

$$Al^{3+} + H_2PO_4^- + 2H_2O \rightleftarrows 2H^+ + Al(OH)_2H_2PO_4$$

(Soluble) (Insoluble)

The freshly precipitated hydroxy-phosphates are slightly soluble because they have a great deal of surface area exposed to the soil solution. With time, the precipitated hydroxy phosphate matures and becomes less soluble and therefore unavailable to plants.

In alkaline soils (e.g. pH >8), Ca and Mg are very soluble (Smeck, 1985). At pH of >8, HPO_4^{2-}, predominates in soil solution. The two species react as;

$$Ca^{2+} + HPO_4^{2-} \rightleftarrows CaHPO_4$$

(dicalcium P)

The $CaHPO_4$ formed is slightly soluble but further reacts with $CaCO_3$ in the soil as;

$$2CaHPO_4 + CaCO_3 \rightleftarrows Ca_3(PO4)_2 + CO_2 + H_2O$$

(tricalcium P)

The tricalcium phosphate formed is less soluble and precipitates rendering the P unavailable to plants (Penn and Camberato, 2019)

2.4 Soil phosphorus pools

Phosphorus pools in soils are categorized by the quantities of P they contain as well as the time required for the phosphate ions they contain to enter into the soil solution (Pierzynski *et al*, 2005). According to Guo and Yost (1998) the P pool range from the P that can readily be desorbed from the weakly adsorbed colloidal surface plus the P in solution, constituting the labile P and the non-labile stable P retained in an insoluble metallo-organic complexes. Soil solution P is often referred to as the intensity factor, whereas the inorganic and organic labile P are collectively called the quantity factor. The relationship between these pools is defined by the following equilibrium (Johnson *et al*., 2003):

$$\text{Soil solution P} \rightleftarrows \text{Labile P}$$

The quantity of P in any pool depends on the specific characteristics of the soil, its use and management practices applied. Various reactions and processes are involved in the transformation of P between the 3 pools. Results on the effects of soil amendments on P pools can be inconsistent in part because of variability of sites and extraction methods (Thiffault *et al*., 2011).

2.4.1 Soil solution P

Soil solution P is the readily available P that is accessible for plant use. Maintaining solution P concentration or the intensity for adequate P nutrition in the plant is contingent on the ability of labile P (quantity) to replenish soil solution P taken up by the plant (Holford, 1997). Ige *et al. (*2005*)* stated that the capacity factor which is the ratio of intensity to quantity factors can be expressed as the relative ability of the soil to buffer changes in soil solution concentration.

Plant root readily absorbed inorganic P from solution P pool due to its accessibility (Guo and Yost, 1998). P is usually absorbed by plant as inorganic orthophosphate (HPO_4^{2-}, H_2P04^-). Plants and microorganisms meet their P requirements by drawing phosphate ions from this pool mainly through production of CO_2 and organic acids. Phosphorus consumed by plants and microbes is continuously replenished by inorganic and organic forms of P associated with the solid phase (Ross, 1989).

Release of P from mineralization of organic P and microbial biomass also contribute to P concentration in soil solution. Hence, the inorganic P in soil solution is controlled and maintained by organic and microbial P dynamics (Condron *et al*., 2004). Amongst soil microorganisms, mycorrhyzal fungi play a more important role in plant P acquisition (Smith *et al*., 2011).

Another way by which P is released into soil solution is the desorption or dissolution from mineral P associated with AI, Fe, or Ca.

2.4.2 Active P

The active P pool represents P in the solid phase (Augusto *at al.,* 2013) and due to its being weakly adsorbed to the solid phase it is easily released to the soil solution (Wang *et al*., 2015) As plants take up phosphate from the solution pool, the concentration of orthophosphate ions in this pool are lowered (Weihrauch and Opp, 2018), to maintain the equilibrium, phosphate from the active pool is released (Datta, 2002). Solomon *et al*. (2002) stated that the inorganic phosphate adsorbed to clay fraction, organic P that is easily mineralized, and some of the phosphates that are chemically associated with Ca, Al or Fe constitute the active soil P pool.

2.4.3 Fixed P

According to Guo and Yost (1998) the fixed P pool are considered as inorganic phosphate compounds that are very insoluble and organic compounds (organic P, Po) that are recalcitrant to mineralization by microorganisms. The inorganic phosphate compounds in this fixed pool are more crystalline in their structure and less soluble compared to the active P pool. Buehler *et al*. (2002) state that high fixed P pools is an indication of deficiency in soils.

2.5 Extraction and fractionation of soil P

Soil phosphorus has been widely categorized into different inorganic (Pi) and organic (Po) fractions by sequential chemical extraction (Oberson *et al*., 1999). The fractionation procedures (e.g. Chang and Jackson, 1957; Hedley *et al.,* 1983) uses the various chemical extractant to fractionate the soil P Pools. Further, isotopic exchange and sequential P extraction techniques can be combined to investigate the interactions between the labile P pool and the chemical P forms that influence the equilibrium between the solid phase, surface and solution equilibria (Pierzynski *et al*., 2005).

The role of different P fractions in replenishing of available Pi depends on soil properties (Tiessen *et al.,* 1983), weathering intensity and management system (Guo and Yost, 1998). P fractionation methods provide an alternative for characterizing soil P availability and may elucidate some of the problems regarding lack of crop response to P (Guo and Yost, 1998). Increasingly stronger solutions extract P fractions are believed to be increasingly less available to plants (Zhang *et al*., 2004). Based on the important assumption in the sequential extraction the readily available soil P is first removed with mild extracting solutions, followed by using strong acids and alkali solutions to extract less available P pools (Hedley *et al.,* 1983).

2.6 Hedley fractionation method of P pools

The Hedley *et al.* (1982) fractionation scheme, modified by Tiessen and Moir (1993), fractionates soil P into five inorganic P (Pi), three organic P (Po) fractions, and one residual P fraction. The procedure utilizes extracts of differing strengths and composition, and recognizes readily available P forms as resin Pi, $NaHCO_3$-Pi, and $NaHCO_3$-Po. Other fractions like the NaOH-Pi and the Hcl-Pi are considered as less labile or stable forms, but in highly weathered soils, these fractions may contribute significantly to plant available P (Beck and Sanchez, 1994). 30 ml of 0.1 M NaOH is added to the soil sample and shaken end to end for 16 h on a mechanical shaker. The soil suspension is centrifuged and filtered. An aliquot of 10ml of the filtrate is taken and 1.6 ml of 0.9 M H_2SO_4 is added. The clear supernatant is decanted and P determined calorimetrically for the determination of NaOH-Pi extractable P fraction. 30 ml of 1M Hcl is added to the soil sample and shaken overnight in a shaker. It is then centrifuge for 10 min and an aliquot of 5-15ml is taken and analyzed for the determination of Hcl extractable.

The scheme is very important because it determines the P fractions that are readily available and accessible to plant and those that are not readily accessible to plant but will be accessible in a long run. Currently, variants of the Hedley fractionation which include the determination of microbial P, the modified Hedley fractionation scheme by Tiessen and Moir (1993) mostly exclude determination of microbial P and is been used extensively to separate forms of organically bound soil phosphorus from the inorganic fractions (Agbenin and Goladi, 1998, Beauchemin and Simard, 2000). In these approaches, microbial P fraction is assumed to be distributed between the bicarbonate and hydroxide extractions. Further, some methods use concentrated HCl instead of H_2SO_4 (Tiessen and Moir, 1993). Cade-Menum *et al*. (2000) have raised concerns about the suitability of the Hedley procedure for the carbon-rich acid soils because of the difficulty in precipitating organic matter.

2.6.1 Resin – P

Anion exchange resin in bags or on membranes used for extraction is generally assumed to closely estimate P bio-availability than chemical extractions because they accumulate nutrients from soils through exchange reactions by a similar mechanism to the soil-root interface (Tiessen and Moir, 1993). The Blake *et al.* (2003) states that inorganic P (Pi) from the soil solution and the weakly adsorbed on sesquioxides, crystalline minerals or carbonates represent the resin-extractable pool (resin-P). Resin - P originates from the most labile P pool, and is good in determining the plant available P, especially in acid soils (Hedley *et al*., 1983; Beck and Sanchez, 1994).

P fractions that interact with resin-P fraction are likely to act as sources or sinks of solution P. When the resin P fraction decreases, phosphatase enzyme activity can increase, with a corresponding increase in P mineralization of organic P (Schmidt *et al.,* 1996). Conversely, fertilizer P application rates above crop removal increase resin P content, which suppresses phosphatase activity, and consequently suppresses mineralization of organic P (Olander and Vitousek, 2000).

2.6.2 Bicarbonate - P ($NaHCO_3$ - P)

Sodium bicarbonate (0.5 M at pH 8.5) extracts weakly adsorbed Pi and easily mineralizable organic P (Po). $NaHCO_3$ extracting solution (pH 8.5) can affect hydrolysis of surface Al and Fe, therefore releasing Al- and Fe-bound phosphate (Soinne, 2009). The bicarbonate Po fraction composed of compounds like ribonucleic acids and glycerophosphate and these compounds can be assimilated by plants (Buehler *et al.,* 2002). $NaHCO_3$ - P is regarded as labile Po sorbed on the soil surfaces and a small amount of microbial P (Zhang and Mackenzie, 1997).

2.6.3 Sodium hydroxide - P (NaOH- P)

Sodium hydroxide extractable Pi is assumed to be non-occluded P associated with amorphous and some crystalline AI and Fe hydroxides (Fe- and Al-bound Pi) (Buehler *et al.,* 2002). Since the sodium hydroxide Pi is held strongly by chemisorption to Fe and AI components of soil colloids, it is considered as moderately labile soil P (Sharpley, 1985). It is considered to be slowly available to plants by desorption (Zhang and MacKenzie, 1997). In acid soils, this P fraction can act as a sink for P during excess P fertilization, but is also a P source when resin P levels are low (Hedley *et al.,* 1982). In highly weathered P deficient soils, the hydroxide-extractable Pi fraction may be substantially increased by P additions because the high exchangeable Al in these soils results in precipitation of Al phosphates (Buehler *et al.,* 2002). However, when P is applied to relatively fertile soils, other P fractions may accumulate P instead of the NaOH-P (Crews *et al*., 1995).

Organic P (Po) associated with chemically and physically protected organic compounds (e.g. fulvic and humic acids) are also extracted by sodium hydroxide (0.1M NaOH). These organic materials are reported to be stable and involved in long-term soil P transformations (Guppy *et al.,* 2005). Some workers have identified NaOH extractable Po as an important source of P in unfertilized tropical soils (Tiessen *et al.,* 1983; Schmidt *et al.,* 1996).

Beck and Sanchez (1994) used path analysis to compare the role of P fractions in replenishing solution P concentration in non-fertilized and fertilized treatments of a long-term continuous cultivation experiment on a Typic Paleudult. The study determined that organic P (particularly NaOH-Po) was the primary source of plant available P in the non-fertilized system.

2.6.4 Hydrochloric acid - P (HCl - P)

A considerable part of soil phosphorus can be dissolved by hydrolysis of soil with hydrochloric acid. HCI - Pi is relatively stable and bound to Ca (Ca-P) and can be associated with apatite minerals (Sato *et al.,* 2009). The Po removed by this extracting solution may originate from more stable pools from particulate organic matter and as such are considered unavailable to plants (Zhang and Mackenzie, 1997).

2.6.5 Residual - P

Residual P constitutes both inorganic and organic P (Condron and Goh, 1989; Agbenin and Goladi, 1998) and is usually extracted with concentrated sulphuric acid. Long term application of P fertilizer, especially in excess of crop needs, often leads to enrichment of this fraction through occlusion of Pi. In addition, residual P can be converted to soil organic P via plant, animal, and microbial residues. There is often high correlation between residual P fraction and plant available P (Agbenin and Goladi, 1998; Guo and Yost, 1998).

However, such a correlation does not mean that residual P contributes directly to plant uptake (solution P), because the less labile pools can exist in equilibrium with each other, or with moderately labile pools. For example, Agbenin and Goladi (1998) determined that residual-P contributed to resin-P indirectly through bicarbonate-Po ($NaHCO_3$-Po) and hydroxide Po (NaOH-Po) on a savanna Alfisol under continuous cultivation. The failure by conventional soil test P (STP) methods to extract NaOH-Po, for example, can result in excessive fertilization rates recommended. Several other studies have shown that this P fraction can serve as a sink and reservoir for soil phosphorus (Beck and Sanchez, 1994).

2.7 Phosphorus fraction in soils and their functional interpretation

The study of P transformations in soils has been facilitated by the separation of inorganic P (Pi) and organic P (Po) into major chemical groupings, and also into pools of different bioavailability. While the fractionation is an attempt to separate P pools according to their liability, any chemical fractionation can be at best an approximation of biological functions. The major Pi fractions are the resin-Pi, sodium bicarbonate Pi (HCO_3-Pi), sodium hydroxide Pi (OH-Pi), 1.0 M HCl-Pi (Ca-Pi), and residual Pi. Water-Pi could be extracted prior to resin-Pi extraction to obtain the very leachable P.

The Pi fractions in soils are partitioned into labile Pi (plant availability), which is represented by the sum of water-P, resin-P and bicarbonate-Pi and is considered to be immediately bioavailable. The bicarbonate Pi fraction is not comparable to the widely used fertility test (Olsen *et al*., 1954) because the water-extractable P and resin-extractable P pool has already been removed. According to Marks (1977) the sodium hydroxide Pi (OH-Pi) is known to be a sparingly plant availability and the 1.0M HCl-Pi is defined as the stable Ca-bound P.

The quantity of Ca-bound P is low in many weathered soils of the tropics but its proportion may be greater in some parent materials (Lekwa and Whiteside, 1986) and also the semi-arid tropics (Agbenin and Tiessen, 1994). The residual P fraction occurs as occluded P or as a highly recalcitrant Pi which is mainly unavailable. The organic P fractions comprise, the bicarbonate-Po and OH-Po. The Po extracted with bicarbonate is easily mineralizable and contributes to plant available P (Bowman and Cole, 1978), while the OH-Po is moderately available (Tiessen and Moir, 1993). There is rarely any Po in the dilute HCl extract hence no Ca-Po is definable.

The relative abundance of the inorganic P forms has been used as an indicator of the degree of chemical weathering in soils. It is recognized that strongly weathered soils have a relatively higher proportion of both resistant and OH-Pi (Fe-P) forms than the other Pi fractions (Chang and Jackson, 1957). When parent material is homogeneous, the distribution of P fractions in soil profiles will reflect the influence of pedogenesis. Calcium-bound P, mainly apatite, is most abundant in the lowest horizon (Harrison *et al*., 1994) and the relative contents of Al-P, Fe-P and occluded P increases towards the surface of the soil profile (Walker and Syers, 1976; Ridley, 1984). The abundance of Ca-bound Pi in the lowermost horizons of soil profiles corresponds to less developed soils or members of a toposequence while the relative abundance of secondary and occluded Pi towards the surface corresponds to highly weathered soils.

2.8 Scientific errors in phosphorus determination during fractionation

2.8.1 Precipitation of humic acid

Alkali soil extracts such as $NaHCO_3$ and NaOH hold substantial amounts of dissolved organic macromolecules that do not directly interfere with colorimetric determination of inorganic P in diluted soil extracts. Decrease in pH causes precipitation of humic acid due to significant interference upon addition of the acid-molybdate reagent. Mineral acid can be used to bypass the problem when the alkali soil extract is pre-treated with the acid to pH of about 1.5 that will precipitate the humic acid and be removed by centrifugation and decantation before addition of molybdate reagent to the neutralized extract (Tiessen and Moir, 2008).

It is, however, noteworthy that co-precipitation can occur if mineral acid pre-treatment of alkali soil extracts of a heavily loaded organic material is determined (Turner *et al*., 2006). This can result in high variability of repeated measuring of acidified soil alkali extracts especially, $NaHCO_3$-Po and NaOH-Po (Magid *et al*., 1996). Problems associated with determination of Pi are cited in Tiessen and Moir (1993), especially the likelihood that Pi is precipitated along with the organic matter upon acidification and erroneously determined as Po (Pt-Pi).

2.8.2 Hydrolysis of organic matter

The possibility of hydrolysis of portions of dissolved organic P owing to the addition of strong mineral acid to alkaline extracts in the determination of inorganic P can result in the underestimation of the organic P and overestimation of inorganic P (Ivanoff *et al*., 1998). However, other studies have shown little or no hydrolysis of inositol hexaphosphate and glycerophosphate following sequential extraction soil P with concentrated H_2SO_4 (Bowman, 1989).

This acid hydrolysis could occur as a consequence of adding the colour-forming acid-molybdate reagent during determination of inorganic P in a diluted extract. Thus, the Murphy and Riley (1962) method, where 1.25 M sulphuric acid (H_2SO_4) is used can potentially hydrolyse some dissolved organic P. However, Dick and Tabatabai (1977) developed a modified acid-molybdate colorimetric technique, which involved adding citrate-arsenite to complex excess molybdate, which effectively means that any inorganic P released from acid hydrolysis of organic P was not determined by calorimetry. It is also possible that partial hydrolysis of organic P could occur during pre-treatment of alkali extracts to precipitate humic acid, which involves the addition of significant quantities of strong mineral acid (e.g. 0.9 M H_2SO_4) to lower the pH to 1.5 (Tiessen and Moir, 2008).

2.9 Plant-available phosphorus in the soil

Plant available-P is often referred to as the amount of P in soil solution which can be extracted or absorbed by plant roots and utilized for growth and development during its life cycle. Schachtman *et al*. (1998), stated that the concentration of available-P is always low because of continuous plant uptake. According to Holford (1997), when the replenishment of the extracted P to the soil solution by the labile pool is slow the situation become more complex which is determined by the soil P equilibria. This is however, favoured by an application of P-amendment source like fertilizers or manure.

Therefore, the maintenance of plant-available P in the soil is very important to avoid over exploitation of soil P which will lead to P deficiency and subsequently, low plant yield. The maintenance of plant available P being a function of the concentration of P in the labile pool and how readily it is released into the soil solution from the solid phase is also dependent on the P buffering capacity of the soil (Holford, 1997) even though, P buffering capacity may not be directly related to P desorption ability of soil. Phosphorus is released at a faster rate from the labile pool into the soil solution at lower buffering capacity.

2.10 Sources of Phosphorus

Phosphorus in soil comes from different sources. Some of the notable sources are the inorganic fertilizers, organic fertilizers like rock phosphate, empty fruit bunch (EFB), biochar, compost etc.

2.10.1 Inorganic P fertilizers

Inorganic P fertilizer represent potent sources of plant available P in soils. Thus, with the dissolution of inorganic fertilizer in the presence of water, P concentration in the soil solution increases. Soluble P ions migrate away from the location where the inorganic fertilizer was placed and are adsorbed unto the soil particles or combined with Al and Fe in acidic soils and with Ca in the alkaline soils to form poorly soluble compounds (Wang *et al*., 2007; Vu *et al*., 2008). According to Damodar- Reddy *et al*., (1999), plants take up <20% of the applied P in the year of application. Thus, soil properties and environmental conditions determine the fate of inorganic fertilizers in soil (Eghball *et al.,* 1996).

Farmers utilize inorganic P fertilizers like TSP to meet their plant P demands to bring about food security and sustainability of agriculture. However, to meet the plant P demand, more P fertilizer need to be applied to exceed the sorption capacity of the soil. Due to the high cost of the inorganic fertilizer, poor farmers are unable to afford. Furthermore, the over-application of inorganic fertilizers causes accumulation of stable P forms in the soil and can result in environmental damage like eutrophication (Song *et al*., 2007; Maftoun and Moshiri, 2008).

2.10.2 Organic P fertilizers

To increase the sustainability of production and maintenance of natural reserves, it is important to use integrated nutrient management systems in agriculture by combining organic and inorganic fertilizers.

The incorporation of organic waste like manure, plant residue, biochar and compost can increase P and N availability, improve soil structure and water holding capacity, soil aggregation and increase microbial biomass. The increase in P availability of soil amended with organic materials depends on their P content, composition and environmental conditions (Bernal *et al*., 2009).

The P concentration in compost can be increased by co-composting with rock phosphate (Zaharah and Bah, 1997; Akande *et al*., 2008). Organic materials can increase soil P availability through various mechanisms: release of soluble P (inorganic P or organic P), change in soil pH (due to change in ion exchange capacity with increase in organic matter), production and release of organic anions during decomposition, enhanced microbial and enzymatic activities and complexation of Al and Fe ions (Iyamuremye *et al.,* 1996; Ayaga *et al*., 2006; Fuentes *et al*., 2008). Application of organic materials stimulates synthesis of microbial biomass and microbial metabolites. This microbial biomass requires P for cell components and therefore causes immobilization (uptake of P by the biomass). This P becomes plant available during biomass turnover.

2.10.2.1 *Effect of biochar on phosphorus bioavailability in soil*

Increased P availability has been observed in soils amended with biochar (Lehmann *et al.,* 2006). However, others have reported decreased available P content in a soil column studies involving biochar produced from different feedstock (Novak *et al*., 2010). The increase in the pH of acid soils upon biochar application due to its high alkalinity (Ca^{2+}, Mg^{2+}) can lead to increase P availability by reducing P precipitation with Al^{3+} and Fe^{3+} (Steiner *et al*., 2007; Yuan *et al*., 2011; Chintala *et al*., 2014). In contrast, addition of biochar to neutral and alkaline soils were found to decrease P bioavailability as a result of increased P sorption, forming Ca-P and Mg-P compounds (Chintala *et al*., 2014).

Biochar has high native P content and therefore can directly release soluble P and increase its bioavailability in soil solution for plant use (Chan *et al*., 2007). Biochar can influence P dynamics in soil through its adsorbed chelating organic molecules such as phenolic acids and amino acids (Stevenson and Cole, 1999; Kappler *et al*., 2014). The adsorbed organic molecules on biochar surface have the potential to reduce the capacity of Al^{3+}, Fe^{3+} and Ca^{2+} from precipitating P in soil (Xu *et al*., 2014). It is reported that biochar can influence P bioavailability by altering the ion exchange property of soil (Cheng *et al*., 2008).

Newly added biochar to soil mostly has high anion exchange capacity and therefore has the tendency of undergoing competitive reaction with poorly crystalline and crystalline Al and Fe oxides for P sorption (Hunt *et al*., 2007). Decrease in point of zero charge (PZC) and increased negative surface charge potential of soil amended with different biochar types have been observed (Hunt *et al*., 2007). The amount of negative charge on soil surface at pH 7 is explained by CEC (Jiang *et al*., 2012).

Addition of biochar raises the CEC of soils hence decrease P availability as a result of electrostatic repulsion between the negatively charge soil surface and P ($H_2PO_4^-$ or HPO_4^{2-}) (Jiang *et al*., 2015). The carboxylic and phenolic functional groups on biochar surface especially on biochar produced at relatively low temperatures form chemical complexes with Fe and Al oxides and as such serves as a competitor with P for adsorption sites on soil surface (Chen *et al*., 2011; Cui *et al*., 2011).

The quantity and quality, particularly the size and charge, of biochar determine the level of competition (Weng *et al*., 2008). Biochar is usually fine in size and has highly charged humic acids and thus, can act potentially as a very effective competitor for P and can bring more P into soil solution (Liang *et al*., 2006). In this way, it reduces P adsorption by highly weathered tropical soils (Chen *et al*., 2011). Extracted humic acids from maize straw biochar increased P availability twice as much as soil humic acid (Sohi *et al*., 2010). Similar observation in Terra Preta (Lehmann *et al*., 2006) and soil amended with sewage sludge biochar have been reported (Nelson *et al*., 2011).

The biogeochemical cycle of P in soils occurs by the breakdown of organic P and dissolution of inorganically bound P compounds initiated by microbial activities and hydrolytic enzymes released by plant roots. Soil microbes and enzymes are the major determinants of the breakdown of P (Bohme *et al*., 2005). The addition of biochar to soil increases P mineralization by enhancing microbial activities (Bohme *et al*., 2005). Approximately 4% increase in microbial biomass in tropical soils was observed after the addition of water hyacinth biochar at a rate of 0.5% (Jin *et al*., 2016). The hydrolysis of P is largely influenced by pH. In high pH soils, alkaline phosphatase activities are enhanced (Du *et al*., 2014; Jin *et al*., 2016). In an incubation studies, a 3 to 4-fold increase in phosphatase activity was in sandy clay soils amended with corn cob biochar charred at 360ºC (Du *et al.,* 2014).

2.10.2.2 *Compost and its effect on soil P availability*

Direct land application of animal manure and municipal waste to agriculture land is increasing but is problematic because of pathogens or metal contamination of these materials and high transport costs. The process of composting is employed to reduce the pathogen risk, improve handling and storage as well as to reduce the amount of organic material (Benito *et al*. 2006; Bernal *et al*., 2009). Composting with its capacity to transform organic waste into a more uniform and biologically stable product can act as a slow release source of plant nutrients (Kraus and Warren, 2000). Compost is an economic and safe way for treatment of organic waste and has high concentrations of organic matter available nutrients (Hoyos *et al*., 2002; Speir *et al*., 2004).

The increase in P availability increase with compost application depends on type of feedstock, P concentration, particle size, C/P and C/N ratio and environmental conditions. When compost is applied together with inorganic fertilizers, can increase efficiency of inorganic fertilizers and reduce the cost (Sikore and Enkiri, 2000). To reduce the need for manufacturing soluble P fertilizers, direct use of low-grade rock P with organic materials like compost and plant residues may increase plant P availability by increasing the solubility of rock P.

2.10.2.3 *Rock Phosphate Dissolution with Organic acids*

Rock phosphate as a natural source of organic phosphorus has been shown to be less responsive to direct application for plants' uptake. Nishanth and Biswas (2008) have indicated that direct application of rock phosphate is favored only under acidic or low soil pH conditions. Use of rock phosphate combined with animal manure, compost and sludge has been shown to be effective in solubilizing it. Solubilization of rock phosphate is dependent on pH of solubilizing agent, type of the P solubilizer used and concentration of the solubilizing agent.

The pH of solubilizer is one critical aspect when enhancing P availability from rock phosphate. Agyarko *et al.* (2016), used 3 types of manure and found out that P release is related to increased microbial activity which is favored by low pH condition. In their study, they used manure from poultry, cattle and pig dung and realized the best response was with poultry manure which had the lowest pH. The low pH in these organic materials is related to increased presence of organic acids. Organic acids having low pH have high amount of COOH group and this chelates the cations in the rock phosphate making P bound to be available (Singh and Amberger, 1997). Singh and Amberger (1997) compared 2 forms of organic acids; fulvic and humic acid of initial pH 2.74 and 4.43 respectively and found that fulvic acid gave better response than humic with optimum P release of 9.08 and 4.68 µg/ml respectively.

The amount of the RP solubilizer used is also a key factor in enhancing optimum availability of P. Increase in concentration of solubilizer results in increased amount of released P. Singh and Amberger (1997) used varying concentrations of fulvic and humic acids and found that an optimum of 6:1 ratio of fulvic acid to rock phosphate and 4:1 of humic to rock phosphate were the best. As organic manure concentration used to solubilize rock phosphate increased, the efficiency of P release also increases the amount of available P for plant growth and yield (Agyarko *et al.*, 2016). This can be supported by the fact that the more the solubilizer, the higher the microbial agents and COOH groups provided increasing the chelation of rock phosphate. Higher concentrations also counter the high liming effect of rock phosphate to alkaline state which may result in re-precipitation of solubilized P by the calcium, zinc and iron ions.

Various materials have been employed successfully in providing good crop yields together with rock phosphate. Manure, composts, sludge and laboratory organic acids have been tested and shown to effectively enhance P release from rock phosphate (Singh and Amberger, 1997; Akande *et al*., 2008; Nishanth and Biswas, 2008; and Agyarko *et al*., 2016). Agyarko *et al.* (2016) reported that plants grown with amendments from organic manure and rock phosphate perform best in terms of yield and growth compared to the use of manure and rock phosphate only. Manure has high microbial biomass production which creates acidic environments in soil enhancing release of water soluble P (Agyarko *et al*., 2016). An effective way of enhancing P release is composting of plant residue with rock phosphate (Akande *et al.*, 2008).

Kind and rate of decomposition of organic matter affect P solubilization from rock phosphate. Use of different organic matter combined together results in difference in kind and rate of decomposition and solubilization compared to when only one type of material is used for composting. Combination of powdered RP with cow dung facilitated release of P, thus increasing the amount of available P in soil (Akande *et al.* (2008). Juices extracted from lemon and pineapple which has high concentration of organic acid was used to enhance rock phosphate and release of P in available from Akande *et al.* (2008).

2.11 The role of phosphorus in the growth, maturity and development of maize

Phosphorus is very essential in the overall performance of maize production (Onasanya *et al.,* 2009*)*. When P supply to plant is adequate, growth and development of the plant proceed at the normal pace. Phosphorus is directly involved in energy transfer, photosynthesis, respiration and formation of cellular structure (Richardson *et al*., 2009). However, when P is deficient in maize it results in stunted growth with limited root system and poor yield (Hopkins and Hansen, 2019). In many plants, seedlings look stunted and older leaves may turn purple because of the accumulation of anthocyanins or purple pigments. The plants may produce only one small ear containing fewer, smaller kernels than usual. Grain yield is often severely reduced (Pandey *et al*., 2000). Phosphorus also plays a vital role in the vegetative and reproductive growth stages of maize plant (Gavito and Miller, 1998).

2.11.1 The role of phosphorus at the mid-growth of maize

Phosphorus plays an important role in the vegetative growth of maize. According to Taliman *et al.* (2019), phytate accounts for up to 80% of the total P concentration in seeds and its breakdown during germination supplies P and other cations needed for early seedling growth. Phosphorus is a source of ATP for the emergence of seedling. Phosphorus provides energy in a form of ATP which brings about emergence that occurs when the coleoptile (spike) pushes through the soil surface (Ransom and Wiersma 2005).

The vegetative growth stage is determined by counting the visible collars in the sequence; V1, V2, to VN until the tassel emerges (VT) and maximum height is attained (Dlamini, 2015). At the V1 stage leaves are initiated from a growing point below the soil surface before cell elongation happened (Nielsen, 2002). The initial seminal root system continues to grow and expand with branches and hair root. At V3 stage, the stalk (stem) has not elongated much (Fournier and Andrieu, 2000). Root hairs are growing from the nodals roots as seminal roots cease growing. All leaves and ear shoots the plants will ever produce from inside the stalk from V3 to about V5 (Lee, 2012). A tiny tassel forms at the tip of the growing point. Above ground plant height is typically about 20 cm at this stage. The growing point and tassel rise higher above the soil surface at about the V6 stage. The stalk begins to elongate. At this critical stage the plant used all the energy produced by phosphorus to produce the leaves and stalks (Xiao *et al.*, 2006).

2.11.2 Maize reproductive development

Phosphorus is very essential in the reproductive development of maize. It plays fundamental role in the metabolism and energy producing relations in plants (Plaxton and Carswell, 2018) . It is an integral part of the nucleic acids and is essential for the cellular respiration and in the metabolism of the starch, protein and fats. (Niamatullah *et al.*, 2011).

A cross-section dissection at V9 plant growth stage shows ear shoot (Lee, 2012). These develop from every above –ground node except the last six to eight nodes below the tassel. The number of kernel rows is also determined by the growing condition at V9 (Nleya *et al.*, 2013). The tassel begins to develop rapidly. At V10, the time between leaf stages shorten to about every two to three days. The potential number of kernel per row is determined between the V12 and V15 stages (Roth *et al*, 2013). Between these stages, the top ear shoot is still smaller than the lower ear shoot, but many of the upper ears are close to the same size. This is the commencement of the most crucial period in determining grain yield (Carvoca *et al*., 2003; Du Plessis, 2003).

At V17 growth stage, the tips of the upper ear shoots may be visible atop the leaf sheaths (Stages, 2011). The tip of the tassel may also be visible. Just before tasseling, the silk from the basal ear ovules elongate first (Nleya *et al.*, 2013).

2.12 Factors affecting decomposition, mineralization of P from organic matter and its absorption by plant root

There are several factors influencing the rate of decomposition, mineralization of P from organic matter and its subsequent absorption by plant root (Cheng and Kuzyakov, 2005). Notable among them are microbial activity, soil pH, Soil moisture content, Soil temperature, Carbon-Phosphorus ratio.

2.12.1 Microbial activity

The size as well as the activity of the microorganisms plays an important role in the mineralization of organic P (Po) in soil (Chen *et al*., 2002). Biological activities mediate the mineralization of soil Po by phosphatase excreted by plants or microorganism (Magid *et al.,* 1996). Phosphatase excretion by microbes and plants is enhanced under low Pi availability (Plaxton and Carswell, 2018). Inorganic P may be taken up by microorganism or plants.

Phosphorus taken up by microorganism may be lower equal to or greater than mineralizaed Po (Oberson and Joner, 2004) Immobilization of P is regulated by the growth and the death cycle of microorganism (Kwabiah *et al*. 2003)

2.12.2 Soil pH

Soil pH is a measure of the acidity or basicity of a soil (Stiles, 2004). Soil pH is a key characteristic that can be used to make informative analysis both qualitative and quantitative regarding soil characteristics. Soil pH controls decomposition and mineralization in soils because of its direct effect on the microbial population and their activities (Neina, 2019). This also has implications for the functions of extracellular enzymes that aid in the microbial transformation of organic substrates. According to Rousk *et al.* (2009) soil pH can have major effect on the rate of decomposition and mineralization as well as the composition of the decomposer community in soils. Typically, acidic soils of pH range 3.0 to 5.5 are dominated by fungal communities while neutral soils of pH range 5.5 to 7.5 provide conditions in which bacteria has a competitive advantage (Bartram *et al*, 2014). The rate of decomposition and mineralization of organic matter is slowed down or stopped due to poor microbial activity. Thus, acidic soil impedes the growth and reproduction of soil microbes primarily bacteria and fungi. Also at a higher soil pH, the mineralizable fractions of C and P increase because the bond between organic constituents and clays is broken (Curtin *et al.*, 1998).

Soil pH is considered a master variable in soils as it affects plant nutrient availability by controlling the chemical forms of the different nutrients and influencing the chemical reactions they undergo (Fageria and Stone, 2006). Soils with inherent pH values of 5.5-7.5

are ideal for P availability while pH values below 5.5 and between 7.5 and 8.5 limits P availability to plants due to fixation by aluminum, iron or calcium (Obura, 2008). Thus, plant root absorbed phosphorus in a form of primary orthophosphate ($H_2PO_4^-$) and secondary orthophosphate $H_2PO_4^{2-}$).

2.12.3 Soil moisture content

Soil moisture content indicates the amount of water present in the soil (Zotarelli *et al.*, 2010). It is commonly expressed as the amount (in mm of water depth) present in a depth of one meter of soil. Soil moisture plays a very vital role in decomposition, mineralization of organic matter and absorption of nutrient by plant (Fageria, 2012). A wet soil results in a slower break down because water fills the air spaces in the soil, depriving soil microorganism of oxygen. However, in dry soil, decomposition and mineralization of organic matter decrease as a result of the decline in the activities of soil microorganism. Alternate wetting and drying influence the mineralization of organic matter and can ultimately lead to maximum mineralization of Po and partial mineralization of organic C and P (Mcneil *et al.*, 1998). According to Paul *et al* (2003) decomposition and mineralization rate increased when the soil water content was 60% -80% of field capacity. If the moisture content of a soil is optimum for plant growth, plants can readily absorb nutrient. Thus, soil moisture affects phosphorous availability for plant use.

2.12.4 Soil temperature

Soil temperature is the function of heat flux in the soil as well as heat exchanges between the soil and atmosphere (Elias *et al.,* 2004). It is also defined as the function of the internal energy of the soil (Onwuka and Mang, 2018). The transfer of heat in the soil and the latent heat exchanges at the surface are the primary causes of variations in soil temperature (Zhao *et al*., 2007). The main source of soil temperature is solar radiation. Soil temperature is measured with a thermometer. Soil temperature varies seasonally and daily which may result from changes in radiant energy and energy changes taking place through soil surface (Nwankwo and Ogagarue, 2012).

Soil temperature range of 10 °C - 28 °C influence soil respiration by increasing the activity of extracellular enzymes that degrade polymeric organic matter in soils (Blagodatskaya *et al*., 2016). The increase in the microbial retake of soluble substrates raises microbial respiration rates (Onwuka *et al*., 2016). Increase in soil temperature increases the soil phosphorus mineralization rates due to the increase in microbial activity and increase in the decomposition of organic matter in the soil (Von-Lutzow and Kogel-Knabner, 2009). Soil temperature below freezing point decreases mineralization by inhibiting microbial activity and decreasing diffusion of soluble substrates in the soil (Tilston *et al*., 2010).

At a temperature below 0°C the accumulation of soil organic matter increases due to the slow rate of decomposition (Tilston *et al*., 2010)· Organic matter decomposes slowly at lower temperatures as a result of decrease in microbial activities and biochemical processes (Conant *et al*., 2011). Soil temperature between 2 °C - 38 °C increases the organic matter decomposition by increasing the movement of soluble substrates in the soil and stimulating microbial activities (Blagodatskaya *et al*., 2016; Brown *et al*., 2000)

According to Onwuka and Mang (2018) water-soluble phosphorus increased with soil temperature from 50c-250c due to the increase in the movement of phosphorus in the soil controlled by diffusion. Soils with low temperature have low availability of phosphorus because the release of phosphorus from organic material is hindered by low temperature (Schmidt *et al*., 1999).

2.12.5 Aeration

Aeration is essential for microbial breakdown of organic matter and mineralization of Po (Glendinning, 2000). Aeration increases the rate of organic matter decomposition by increasing microbial activity.

2.12.6 Carbon-phosphorus ratio

The C: P ratio of the soil microbial biomass and plant residue is an important factor that controls the availability of P in soil (Li *et al., 2018)*. As the microbial C: P ratio decrease, the microbes have a higher potential to release P into the soil solution during mineralization and microbial turnover (He *et al*., 1997). Plant residues can have a wide range C: P ratios, depending on the plant species and P nutrition and will differ in P mineralization rate (Damon *et al*, 2014). Plant residues with C: P ratio of 123:1 increased 0.5 M NaHCO3 extractable Pi whilst the plant residue with a C: P ratio of 506:1 decreased it. Residue with low C: P ratio (123:1) released about 2kg P/ha in 15 cm soil during 42 days (Iqbal, 2009).

2.13 Effect of soil electrical conductivity on plant absorption

Soil electrical conductivity (EC) is a measure of the amount of salts in soil **(**Grisso e*t al*., 2005**)**. According to Corwin and Lesch (2003) electrical conductivity can be defined as a measure of the ability of the soil to conduct an electrical current. It is an importan**t** indicator of soil health and its fertility. EC is an indication of the availability of P in the soil. For certain non-saline soils, determining EC can be a convenient and economical way to estimate the amount of phosphorus available for plant growth (Motsara and Roy, 2008). In general, higher EC hinders nutrient uptake by plant due to the increase in the osmotic pressure of the nutrient solution, waste nutrient and increases discharged of nutrients into the environment resulting in environmental pollution. Excessively high salinity of certain ion such as sodium can be toxic to plant and also high osmotic pressure around the roots prevents an efficient nutrient absorption by plant (Safdar et al., 2019). Excess salts also hinder plant growth by affecting the soil water balance. Low EC may severely affect plant health and yield. EC of the nutrient solution is related to the amount of ions available to plants in the root zone (Sumarni *et al*., 2019). The optimal EC is crop specific and depends on environmental conditions (Scarlat *et al*., 2010). Three main factors affecting the conductivity of a solution are the concentrations of ions, the type of ions and the temperature of the solution. For most hydroponic crops, the ideal range of EC for most crops is between1.5 and 2.5 ds/m (Sunar, 2018). Knowledge about EC levels in soil can help plant production and lead to more cost effective use of plant inputs and less shrinkage.

2.14 Phosphorus uptake by crops

According to Havlin *et al. (*1990) plant roots take up nutrients present in the soil solution and are subsequently distributed to aerial portions of the plant. Nutrient uptake is affected mainly by environmental conditions, management practices, the concentration of nutrients and the form in which nutrients are present in the soil (Allen and Coomes, 2007). Phosphorus application significantly increases P uptake. Mashori *et al.* (2013) showed that P uptake by maize was significantly increased as the rate of application increased. P uptake was increased by 53, 48, and 73% in *Ilora*, *Ibadan* and *Epe* soils respectively at the highest rate of 60 kg ha^{-1}.

Growth conditions such as soil and climatic factors as well as biotic factors have influence on crop P uptake. Wasonga *et al.* (2008) observed that sites with unfavorable soil condition of high Al saturation resulted in relatively low P uptake. Low uptake of P can also be attributed to lower biomass production as the P uptake is a product of biomass and P content (Onwonga1 *et al.,* 2013). Furihata *et al. (*1992) reported that P deficiency observed in acid soils is often associated with high P fixation and P uptake rates are highest between pH 5.0 and 6.0 where $H_2PO_4^-$ dominates.

Teng and Timmer (1995) found that P uptake is strongly correlated with grain yield and total dry matter yield. According to the authors, combined use of N and P fertilizers contribute to increase P uptake than the sole P application. This increase of P uptake could be attributed to the synergistic N enhancement of P uptake. Yang and Jacobson (1990) proposed that the decreased efficiency in P uptake following P application was a result of conversion of fertilizer P to relatively insoluble forms.

2.15 Phosphorus in maize production

Phosphorus is a vital nutrient in crops due to its role in many plant physiological processes. It's a constituent of ATP that is important in energy supply to all plant processes of growth. P is also important in enhancement of plants' root growth that results in efficient nutrients uptake from the soil and this is subsequently exhibited by high crop dry matter and increased yields (Nahar *et al.,* 2014). Phosphorus deficiency results in poor root growth and reduced crop vegetative growth and yields.

Maize (*Zea mays*) belongs to the family *Apiaceae* (*Umbelliiferae*). The crop is originated from Afghanistan and spread all across the world (Zyskowky *et al.,* 2010). It is known for its taste, fibre, beta and alpha carotenes which are a source of vitamin A to humans (Ojowi, 2013). Maize crop grows vegetative in the first season and produces seeds in second season after undergoing a vernalization period. Amending the soil with organic materials before planting is highly recommended for maize production (Mbatha *et al.*, 2014). Maize grown in soils with high clay content are prone to forking and rough texture due to high soil compaction, low moisture and high N and temperature. Application of compost manure reverses this soil condition by lowering the soil density and enhancing root penetration. The microorganisms added in the compost also enhance the availability of the nutrients to the crop (Nair and Ngouajio, 2012).

Since maize plant is a moderate feeder, it requires moderate application of nutrients to produce optimum compared to other vegetables such as the alliums (Mbatha *et al.*, 2014). Therefore, P is very important in increasing the root length and diameter, leaf growth and reducing branching (Nahar *et al.*, 2014).

2.16 Phosphorus use efficiency

According to Robert and Johnston (2015), phosphorus used efficiency measures how the plant utilized available P nutrient in soil. It also describes the yield of a plant in-terms of biomass per unit of phosphate fertilizer applied to the plants. Phosphorus use efficiency can also be defined as how plant utilize soil available phosphorus and subsequently resulting in measurable yield or yield parameters such as plant height, leaf development, dry matter and fruit /grain production (Hati *et al.*, 2006). The concept is contingent on how the plant remove the P supplied and available in the soil, translocate it, store, mobilize and utilize for biomass production. Fageria *et al.* (2013) stated that determining phosphorus used efficiency is important for maximizing production in P deficient areas and minimizing over use of phosphate fertilizers for environmental protection, hence improving crop yield. It is composed of Phosphorus Recovery Efficiency (PRE), Phosphorus Utilization Efficiency (PUE), Phosphorus Uptake Efficiency and agronomic P use efficiency (APUE).

2.16.1 Phosphorous Recovery Efficiency

According to Johnston and Syers (2009), phosphorous recovery efficiency (PRE) is evaluated using the balance method as expresses in percentage of the P removal from soil to input ratio.

Mathematically,

$$\text{PRE} = \frac{\text{P removed by plants} \quad {*}100}{\text{P applied to plants}}$$

2.16.2 Phosphorus Utilization Efficiency

One parameter for expressing phosphorus use efficiency is the phosphorus utilization efficiency which according to Johnston and Syers (2009) is mathematically expressed as

$$\text{Phosphorus Utilization Efficiency (PUE)} = \frac{\text{increase in yield} \quad {*}\ 100}{\text{P concentration in the plant biomass}}$$

2.16.3 Agronomic Phosphorus use efficiency

According to Johnston and Syers (2009), agronomic P use efficiency is another parameter for determination of P use efficiency. Mathematically expressed as:

$$\text{Agronomic P use efficiency (APUE)} = \frac{\text{Increase in yield}}{\text{Unit of added P fertilizer}} *100$$

Maize is an exhaustive crop having higher potential than other cereals and absorbs large quantity of nutrients from the soil during growth stages. Among the essential nutients, phosphorus is important for higher yield in larger quantity (Chen and Twilley, 1999) and controls mainly the reproductive growth of plant (Wojnowska and Siekiewiez, 1995).

Application of phosphorus is very important in influencing plant behaviour (Kaya *et al.,* 2002). It is needed for growth, utilization of sugar and starch, photosynthesis, nucleus formation and cell division, fat and albumen formation. The energy from photosynthesis and metabolism of carbohydrates stored in phosphate compounds are subsequently use for growth and reproduction (Ayub *et al*., 2001). It is readily translocated within the plants, mainly from older to younger tissues as the plant forms cells and develops roots, stems and leaves (Ali *et al.,* 2013). Adequate P results in rapid growth and earlier maturity and improves the quality of vegetative growth. Phosphorus deficiency is responsible for crooked and missing rows as kernel twist and produce small ears nubbies in maize (Kumar *et al*., 2017).

Phosphorus use efficiency in maize fields is critically vital, since it constitutes one of the most limiting factors to production (Coelho *et al*., 2002). Determination of Phosphorus used efficiency (PUE) in our study is important in enabling us come up with recommendations on best management practices of RP that leads to high P uptake and utilization in comparison to use of TSP and better understand the PUE of maize crop. According to Fageria *et al.* (2013), to determine the P deficiency or sufficiency for diagnostic purposes, plant are sampled during the growing period at different time intervals and analyzed for P concentration in the plant tissues.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study site

The study was carried out at the Forest and Horticultural Crops Research Centre (FOHCREC) at Kade in the Eastern region of Ghana (Latitude 6.42° N and Longitude 1.34° W).

The soil at the site is Kokofu series according to the interim Ghana classification and Typic Plinthustuulf according to World Reference Base (WRB, 1998) and soil taxonomy system (Soil Survey Staff, 2010). The soil is deeply weathered and has profile which is matured and often shows clay accumulation in the subsoil. It is found in the semi deciduous forest and parts of the forest savannah transition agro-ecological zones of Ghana. The soil temperature regime is isohyperthermic and the soil moisture regime is udic (Soil Survey Staff, 1998).

The rainfall distribution is bimodal and consists of major and minor rainy season. The major season normally begins in March and reaches a peak in July and drop sharply in August while the minor season is from September to November.

The agro-ecological zones also stretch from west to east along the middle portions of the country across the Volta Lake. The zone due to its high bimodal rainfall distribution pattern with a mean ranging from 900 mm to 2500 mm per annum, support the cultivation of large scale plantation crops, such as cocoa (*Theobroma cocoa*), oil palm (*Elaeis guineensis*) and lemon (*citrus spp*) as well as annual crops such as maize (*Zea mays*), cassava (*Manihot utilissima*) and plantain (*Musa sapietum*) (Owusu-Bennoah *et al*., 2000)

The experiments were conducted from September to December, 2017 and 2018 minor cropping seasons. However, since it was a collaborative project work, the two major seasons were done by other researchers in the same project.

3.2 Experimental design and treatments

The design used was randomized complete block design with nine treatments replicated three times. The treatments used were palm empty fruit bunch (EFB) mulch, Rice husk compost, Rice husk biochar, Rock phosphate, Urea, Triple superphosphate and muriate of potash as N, P_2O_5, K_2O kg/ha. The objective of each treatment was to produce 90 kg N, 60kg P and 60 kg K per hectare and this was based on the recommended P application rate for maize. The combined inorganic fertilizers (U, TSP and KCl) in treatment two were analyzed, multiplied by their quantities and applied at a rate to produce 90 kg, 60 kg P, 60 kg K per hectare. In treatment 3 to 7, the organic P fertilizers (Rice husk biochar, Rice husk compost, and Empty fruit bunch) were analyzed, multiplied by their quantities and top up with different rates of the inorganic fertilizers to produce the required level of 90 kg N, 60 kg P and 60 kg K per hectare. Treatments 7 and 8 consist of formulation of combined organic fertilizers which was analyzed and multiplied by their respective quantities to produce the required level 90 kg N, 60 kg P and 60 kg K.

The rice husk used for biochar and compost was prepared from the Kade rice mill while the palm empty fruit bunch mulch was obtained from the Okumani farms, the rock phosphate, the urea and TSP were purchased from Chemico Limited. Maize variety used as test crop was obtained from Council for Scientific and Industrial Research (CSIR).

Table 3.1: Treatment combinations, quantities and rate of application

Treatment Combination	EFB M	Urea	TSP	KCl	Compost	RH Biochar	RP
T1(No amendment)	0	0	0	0	0	0	0
T2(U+TSP+KCL)	0	1.30kg/plot U	1.92kg/plot TSP	0.38kg/plot KCl	0	0	0
T3(EFBM+U+TSP)	49.56kg/plot EFB M	0.25kg/plot U	1.03kg/plot TSP	0.05kg/plot KCl	0	0	0
T4(EFBM+U+TSP+C)	24.80kg/plot EFB M	0.25Kg/plot U	1.20kg/plot TSP	0.03 kg/plot KCl	20.16kg/plot Compost	0	0
T5(RHB+C+U+TSP)	0	0.19kg/plot U	1.38kg/plot TSP	0.01 kg/plot KCl	22.68kg/plot Compost	53.76kg/plot RHB	0
T6(EFBM+RHB+U+TSP)	28kg/plot EFB M	0.I9kg/plot U	1.25kg/plot TSP	0.01 kg/plot KCl	0	28 kg/plot RHB	0
T7(C+U+TSP)	0	0.25kg/plot U	1.3kg/plot TSP	0.03 kg/plot KCl	40.6kg/plot Compost	0	0
T8(RHB+C+RP)	0	0	0	0.01 kg/plot KCl	28.08kg/plot Compost	49.2 kg/plot RHB	1.91kg/plot RP
T9(EFBM+C+RP)	21.3kg/plot EFB M	0	0	0.03 kg/plot KCl	28.08kg/plot Compost	0	1.15kg/plot RP

Table 3.2: Treatment combination and treatment code

Treatment combination	Treatment code
T1 (control)	-
T2 (Urea+ triple superphosphate+ muriate of potash)	U+ TSP+ KCl
T3 (Empty fruit bunch mulch+ Urea+ triple superphophate)	EFB M+U+TSP
T4 (Empty fruit bunch mulch+ Urea+ compost)	EFB M+C+U+TSP
T5 (Rice husk biochar+ Urea+ triple superphosphate+ compost)	RH B +C+U+TSP
T6 (Rice husk biochar + Empty fruit bunch mulch+ Urea +triple superphosphate)	RH B +EFB M+U+TSP
T7 (Compost+ urea+ triple superphosphate)	C+U+TSP
T8 (Rice husk biochar + compost+ rock phosphate)	RH B+C+RP
T9 (Empty fruit bunch mulch+ rock phosphate +compost)	EFB+RP+C

3.3 Land preparation and planting

Land preparation and planting was done on the same piece of land in both 2017 and 2018 minor cropping seasons. The land was prepared with hoe and cutlass before the pegging and lining was done. The plots were demarcated and labelled according to treatments. Apart from the palm empty fruit bunch mulch, the respective quantities of the soil amendments, the organic P fertilizers (rice husk biochar, the rice husk compost) and the inorganic fertilizers were incorporated in the soil. After three weeks, planting was done in the first week of September where the maize variety (Abontem) was sown to a depth of 5 cm with two seeds per hole.

Each experimental plot was 8.0 m x 8.0 m in size with a space of 1.0 m between plots and a space of 2.0 m between replicates. Each plot having ten rows with ten plants within each row. The planting distance was 0.8 m x 0.4 m with a space of the one metre between the rows.

3.4 Agronomic practices

The plots were weeded three times before maturity with hoe and cutlass to avoid competition with plants for nutrient. A recommended composite insecticide Cydim super of emulsifiable concentration containing 36 g cypermethrin and 400 g dimethoate per litre was applied at a rate of 40 ml per 15 L knapsack sprayer to control insects whereas Syngenta -karate Zeon (50 g/L) was applied at a rate of 30 ml per 15 L knapsack sprayer to control fall army worm.

3.5 Soil sampling

The vegetative cover was cleared from the inner portion of the various plots. A randomized composite sampling was done from a depth of 0-20 cm before and after planting using auger. The soil samples were brought to the laboratory, air-dried, crushed, sieved through a 2 mm sieve to remove twigs and plant roots and stored for routine physical and chemical analyses.

3.6 Laboratory analysis of soil samples

3.6.1 Organic Carbon and organic matter

The Wakley- Black (1934) method was used for the determination of organic carbon and organic matter. Ten grams of the prepared soil samples was weighed in a 500 ml conical flask. 10 ml of 1N K_2CrO_7 solution and 20 ml of conc. H_2SO_4 were then added to the sample and was allowed to stand for 30 minutes. After 30 minutes the content was diluted with 200 ml of distilled water plus H_3PO_4 and 0.2 g NaF.1 ml of diphenylamine indicator was then added and titrated with 0.5 N ferrous sulphate until the colour changed from blue to green. The blank titration was also determined.

I. $\text{OC (\%)} = \frac{(B-S)*\text{Normality of FeS}O_4*0.003*100*100}{W*77}$

B =Blank titration

S= Sample titration

W= Weight of soil sample

0.003= 12/4000= milliequivalent weight of carbon (gm)

100/77 = the factor of converting the carbon actually oxidized to total carbon and 100 is the factor to change from decimal fraction to percent.

II. Organic matter (%) = $\frac{\%\ \text{Oganic carbon}*100}{58}$

3.6.2 Available phosphorus not total p

Available phosphorus was determined using the method of Bray and Kurtz (1945). Five grams prepared soil sample was weighed into an extraction bottle. Fifty ml of Bray 1 solution (0.03 M NH_4FIN 0.025 M HCl) was added. The suspension was shaken for 3 minutes on a mechanical shaker after which it was allowed to settle. It was then filtered through No. 42 Whatman filter paper into a 100 ml volumetric flask and made to the volume with distilled water. Phosphorus in the filtrate was determined using molybdate –ascorbic acid color development of Mulphy and Riley (1962). Read on spectrquant Pharo 300 M spectrophotometer at a wavelength of 712 nm.

$$\text{P (mg/kg)} = \frac{\text{Spectrophotometer reading(mg}-\text{l)}\times\text{Volume of the extract}}{\text{Volume of the aliquot}\times\text{Weight of the soil}}$$

3.6.3 Ammonium Nitrogen (NH_4^+ - N)

10 grams of soil was placed in a 250 ml wide mouth Erlenmeyer flask and 100 ml of 2M KCl was added. A stopper was inserted and shaken mechanically for 1 hour. The soil KCl suspension was allowed to settle until the supernatant was clear and filtered and stored in a refrigerator. An aliquot (5 ml) of the filtered 2 MKCl extract was pipetted into a 25 ml volumetric flask. One milliliter of EDTA reagent was added and the content of the flask was mixed and allowed to stand for 1minute. 2 ml of the phenol nitroprusside reagent was added following 4 ml of the buffered hypochlorite reagent, and immediately the content was diluted to a volume (25 ml) with NH_4^+ free water and mixed thoroughly.

The content of the flask was placed in water bath at 40 ºC for 30 minutes. The flask was removed from the bath and cooled at room temperature and the absorbance of the coloured complex at wavelength of 636nm was determined (FAO, 2008) as against ammonia nitrogen standard stock solution (20 mmol/L) made by dissolving 0.6608 g of ammonium sulfate and dried for at least 2 h at 110 ºC in 500 ml ultrapure water, stored at 4 ºC in a refrigerator and later the stock solution was diluted with 25 ml of water to obtain ammonia nitrogen standard solution.

3.6.4 Nitrate – Nitrogen (NO_3^-N)

Five grams of soil was placed in an Erlenmeyer flask and 25 ml nitrate –extracting solution was added and shaken for 10 minutes. 0.2 g of Ca $(OH)_2$ was added and shaken for 5 minutes.

About 0.5 g of $MgCO_3$ was added and shaken for 10-15 minutes. The set up was allowed to settle for few minutes and filtered through number 42 filter paper. 10 ml of clear filtrate was pipetted into a 100 ml beaker and was evaporated to dryness on a hot plate at low heat in a fumehood. The residue was allowed to cool and 2 ml of phenoldissulphonic acid was added to the residue and covered quickly and allowed to stand for 15 minutes. 16.5 ml of cold water was added and the beaker was rotated to dissolve the residue. To get the yellow stable colour 15 ml of dilute NH_4OH was slowly added until the solution was distinctly alkaline after the beaker cooled. 16 and ½ ml of water was added and mixed thoroughly. The concentration of NO_3^- N/mol at 415 nm was read using the standard curve of phenoldissulphonic acid method of determining NO_3^- (FAO, 2008).

3.6.5 Determination of soil pH

The soil pH was determined by the potentiometric method (1:2 soil: water ratio) proposed by Eckert and Sims (1995). A 50 g dried soil was weighed into a plastic flask and 100 ml of distilled water added. The mixture was thoroughly shaken on a reciprocating shaker for one hour. Just before measuring pH, the bottles were shaken by hand. The pH meter was standardized with buffer solutions of pH 4.0 and 7.0. After standardization, the electrode of pH meter was inserted into the upper part of the suspension and the pH read.

3.6.6 Exchangeable bases

The exchangeable base cations (Ca^{2+}, Na^+, K^+, Mg^{2+}) were extracted with NH_4-acetate buffered at pH 7 and measured with Atomic Absorption Spectroscopy using a modified method (Hendershot *et al.*, 2007). 5g soil was weighed into a 50 ml plastic bottle, 20 ml 1

M NH_4-acetate was added, and the solution was agitated for 4 h at 145 rpm on a reciprocating shaker. The solution was then filtered through a Buchner funnel with 9 – 13 µm filter paper into a flask, and the soil on the filter paper was washed by the addition of 10 portions of 10 ml 1 M NH_4-acetate. The solution was finally transferred to a 200 ml volumetric flask, and it was filled to the mark with 1 M NH_4-acetate. An ionization buffer (0.2 ml/ 100 g l^{-1} CsCl to 9.80 ml solution) was added to the solution for the measurement of Na and K. For the measurement of Ca and Mg, a La-salt (0.2 ml LaCl (65 g l^{-1}) to 9.80 ml solution) was added to prevent chemical interferences. The Perkin Elmer atomic absorption spectrometer was calibrated with the appropriate standards for Ca, Mg and Na respectively and the absorbance for each element determined. Exchangeable bases were calculated as:

1. $\text{Ca (cmol kg}^{-1}) = \dfrac{\text{R}\times\text{Vol.of extract}\times 10^{3}(\text{g})\times 10^{2}\ (\text{cmol})\times \text{E}}{\text{wieght of soil}\times\ 10^{6}(\mu\text{g})\times 40}$

R = AAS (Atomic absorption spectroscopy) reading in mL^{-1}

Where 40 = Atomic mass of Ca

E = Charge of Ca

2. $\text{Mg (cmol}_{c}\text{kg}^{-1}) = \dfrac{\text{R}\times\text{vol of extract}\times 10^{3}\ (\text{g})\times 10^{2}\ (\text{cmol})\times \text{E}}{\text{Weight of soil}\times 10^{6}(\mu\text{g})\times 24}$

R= AAS (Atomic absorption spectroscopy) reading in mg L^{-1}

Where: 24 = Atomic mass of Mg

E = Charge of Mg

3. $\text{Na (cmol}_{c}\text{kg}^{-1}) = \dfrac{\text{R}\times\text{Vol. of extract}\times 10^{3}\text{g}\times 10^{2}(\text{cmol})\times \text{E}}{\text{Weight of soil}\ \times 10^{6}\ (\mu\text{g})\times 23}$

Where,

R = AAS (Atomic absorption spectroscopy) reading on mgL^{-1}

23 = Atomic weight of Na

E= Charge of Na

4. K (cmol gkg^{-1}) = $\frac{\text{R×Vol of extract ×}10^6\text{(g)× }10^2\text{(cmol)×E}}{\text{Weight of soil × }10^6(\mu\text{g})\text{×39}}$

Where:

R = AAS (Atomic absorption spectroscopy) reading on mgL^{-1}

39 =Atomic weight of K

E = Charge of K

3.6.7 Determination of exchangeable acidity

The exchangeable acidity was measured using the potassium chloride method as described by Thomas (1982). Ten grams of soil sample was weighed and 25 ml of 1.0 M KCl solution was added in a plastic bottle. The mixture was shaken on a reciprocating shaker for 30 minutes and filtered into a 250 ml Erlenmeyer flask followed with an additional volume of 125 ml of 1.0 M KCl in 25 ml increments to a total of 150 ml. A blank was also included in the titration. About 4-5 drops of phenolphthalein indicator solution was added. The solution was titrated with 0.1 M NaOH until the colour just turned permanently pink.

Calculation:

$$\text{Exchangeable acidity (cmol}^{+}\text{/kg)} = \frac{ml\ NaOH\ sample - ml\ NaOH\ blank}{g\ sample} \times M \times 100$$

Where:

M = Molarity of NaOH

3.7 Soil Phosphorus Fractionation

A soil sieved with less than 2 mm diameter sieved, sampled after 2017 and 2018 minor cropping seasons at a depth of 0 – 20 cm was subjected to chemical sequential P extraction using a modified Hedley fractionation procedure (Hedley *et al*. 1982; Tiessen and Moir, 2008) to determine the most labile phosphorus pool (Resin Pi, $NaHCO_3$- extractable Inorganic (Pi) and organic P (Po)), moderately labile phosphorus pool (NaOH extractable Pi and Po) and stable P (HCl extractable Pi, residual P).

Modified Hedley fractionation procedure

Phosphorus pool	Extraction Procedure
Resin-Pi	2g soil sample +27 resin strips + 30 ml deionized water
	Shake for 16 h and Centrifuge
	Resin + 0.5 M $NaHCO_3$ - shake for 1 h
	↓
	Sample + 0.5 M $NaHCO_3^-$ - Shake for 16 h and centrifuge
$NaHCO_3$ -Pi	15ml Aliquot of 0.5 M $NaHCO_3^-$ + 0.9 M H_2SO_4
$NaHCO_3$ -Pt	8ml Aliquot + 8M H_2SO_4 + 0.2g $K_2S_2O_8$ digestion
$NaHCO_3$ -Po	Total P minus inorganic P
	↓
	Sample + 0.1 M NaOH - Shake for 16 h and centrifuge
NaOH-Pi	10ml Aliquot of 0.1M NaOH +0.9 M H_2S0_4
NaOH-Pt	10ml Aliquot of 18 M H_2SO_4 + 0.2g $K_2S_2O_8$ digestion
NaOH-Po	Total P minus inorganic P
	↓
HCl-Pi	Sample + 1 M HCl - Shake for 16 h and centrifuge
	↓
Residual P	Sample + 20ml of conc. H_2SO_4 – Digestion (360 °C)

Pi, Po and Pt means inorganic, organic and total phosphorus respectively

3.7.1 Resin-Pi

Anion exchange resin membrane (AEM) (ANION 204UZRA, 1 cm x 6 cm) was used to extract resin- Pi. The AEM strips were charged using 0.5 M $NaHCO_3$ and finally rinsed with deionized water. Two (2) g samples were weighed into 50 ml centrifuge tube containing 30 mL deionized water in quadruple and shaken end-to-end for 16 hours on an electrical shaker overnight. Soil particles adhered to the resin strips after shaking were washed off with deionized water. The strips were then placed in centrifuge tubes containing 30 ml of 0.5 M $NaHCO_3$ and was shaken for 1 h. An aliquot of 15 ml of the extract was taken and phosphate was determined colourimetrically by the method of Bray and Kurtz (1945).

3.7.2 $NaHCO_3$ extractable P fraction- Pi

The sample suspension obtained after the removal of the resin strips was centrifuged for 10 min at 3500 rpm and the clear supernatant decanted. Thirty ml of 0.5 M $NaHCO_3$ was added to the treatment and then shaken end to end for 16 h on an electrical shaker at room temperature. The soil suspension was centrifuged for 10 minutes at 3500 rpm and filtered using a 0.45 µm filter paper. An aliquot of 15 ml was pipetted into a centrifuged tube and 6 ml of 0.9 M H_2SO_4 was added and kept in a fridge for 30 minutes to precipitate the organic matter. This was then centrifuged at 3500 rpm for another 10 minutes. The clear supernatant was then decanted into 50 ml volumetric flask and then analysed for $NaHCO_3$ extractable inorganic-P as under 3.7.1.

3.7.3 $NaHCO_3$ extractable-total P (Pt) and organic P

Eight (8) ml aliquot of the filtrate obtained under 3.7.2.was pipetted into an autoclave tube. One ml of 18 M H_2SO_4 was added, followed by 0.2 g potassium persulphate ($K_2S_2O_8$) and autoclaved for 1 h at 121 ºC. Eight (8) mL of the digested sample was taken for P determination, as $NaHCO_3$ extractable total-P ($NaHCO_3$ extractable-Pt). Organic $NaHCO_3$

extractable-P was calculated as difference between the total amount and the inorganic P as under 3.7.1.

3.7.4 NaOH extractable P fractions-Pi

Residual samples obtained under section 3.7.3 was weighed to determine the amount of $NaHCO_3^-$Pi transferred to the subsequent P extraction. Thirty ml of 0.1 M NaOH was added to the sample residue and then shaken end to end for 16 h on a mechanical shaker at room temperature. The sample suspension was then centrifuged for 10 minutes at 3500 rpm and filtered through 0.45 µm filter paper. An aliquot of 10 ml of the filtrate was pipetted into a centrifuge tube and 1.6 ml of 0.9 M H_2SO_4 was added and kept in a fridge for 30 minutes to precipitate the organic matter. This was then centrifuged at 3500 rpm for another 10 minutes. The clear supernatant was then decanted into 50 ml volumetric flask and then analysed as under 3.7.1, as NaOH extractable inorganic-P (NaOH extractable-Pi).

3.7.5 NaOH extractable-total P (Pt) and organic P

Ten (10) ml aliquot of the filtrate obtained under 3.7.4 was pipetted into clean screw cap glass test tube. One ml of 18 M H_2SO_4 was added, followed by 0.2 g potassium persulphate ($K_2S_2O_8$) and autoclave digestion during 1 h at 121 ºC. The digested sample was decanted into 50 ml volumetric flask for P determination, as NaOH extractable total-P (NaOH extractable-Pt). NaOH extractable organic-P (NaOH-Po) was calculated as difference between the total amount and the inorganic P as under 3.7.1

3.7.6 HCl extractable-P

Residual samples obtained under section 3.7.5 was weighed to determine the amount of $NaHCO_3^-$Pi transferred to the subsequent P extraction. Thirty (30) ml of 1 M HCl was added to the sample residue obtained and then shaken end to end for 16 h on a mechanical shaker at room temperature. The soil suspension was then centrifuged for 10 minutes at 3500 rpm and filtered. An aliquot of 5 – 15 mL was pipetted into a 50 ml volumetric flask and then analyzed as under 3.7.1.

3.7.7 Residual P

Thirty (30) mL of deionized water was added to the sample residue in the tubes obtained under section 3.7.6 and then shaken for 1hr, centrifuged and the supernatant decanted prior to the extraction of the subsequent the residual P. The sample residue was then transferred into a 250 ml Kjeldahl flask and 20 ml of concentrated H_2SO_4 was added. The mixture was digested until the digest became clear after which 1 ml of 30 % of H_2O_2 was added to clarify the digest. The flask was then cooled and the digest filtered through 0.45 µm filter paper in a 100 ml volumetric flask and made to volume with distilled water. The residual P was analyzed as under 3.7.1.

3.8 Plant Sampling and preparation for Nutrient Analysis

50 % net plant population were harvested. Plant from the two middle rows were harvested from the net plot. Maize grain and stover parts sampled at harvest were kept in paper envelopes, air dried at room temperature of a moisture content of 15 %, milled and passed through 1 mm sieve. 1.0 g samples were weighed into a crucible and put into a furnace at a

temperature of 75 ºC for 48 hrs to turn into ash. The ash was then used to prepare a solution for the determination of phosphorus.

3.8.1 Determination of phosphorus in plant tissue

Plant samples were wet digested following the procedure described by Richard (1993). 0.5 g of the dried plant material was put into 50 ml volumetric flask and 2.5 ml of concentrated sulphuric acid and one ml of hydrogen peroxide were added. The mixture was swirled and placed on hot plate and heated at 270 ° C for 10 minutes. The flask was removed from the plate and allowed to cool for 10 minutes after which 1.0 ml H_2O_2 was added and heated for 10 minutes at the same temperature. Heating, cooling and addition of 0.5 ml of H_2O_2 were undertaken, until a colorless solution was observed. The solution was removed from the hot plate and the volume was made up to 50 ml with distilled water and the digest used to determine P.

Total phosphorus was determined using the Technicon Auto Analyzer, manifold P Bray-1.

Calculation:

$$\% \text{ P} = \frac{(a-b)\times 50}{\text{Weight of plant sample} \times 10000}$$

Where:

a = P for plant sample

b = P for blank

50 ml = final diluted volume for digestion

10000 = coefficient for conversion from ppm to percentage P

3.9 Plant data collection

3.9.1 Vegetative data

3.9.1.1 *% crop establishment*

Four hundred plant populations emerged out of the expected total number of 800 after planting in each plot for all the 27 plots giving an estimation of 50% plant establishment.

3.9.1.2 *Plant Height*

Ten plants were randomly selected from each plot and tagged for plant height measurement. Plant heights were taken at 8 WAP and 12 WAP using meter rule as a vertical distance from the plant collar to the tip of the apical leaf and the average recorded.

3.9.1.3 *Chlorophyll Content Index*

The chlorophyll content of ten leaves each from the two tagged plants per plot were measured at 8 WAP and 12 WAP using chlorophyll meter CCM-200 plus from OPTI-SCIENCES and their averages were recorded.

3.9.1.4 ***Number of leaves Per Plant***

Number of leaves of ten tagged plants per plot was counted at 8 WAP and 12 WAP and their average recorded.

3.9.1.5 *Stem Diameter*

Stem diameter of ten tagged plants per plot taken from the base to the top of the stalk three centimeters were measured using a Vernier caliper at 8 WAP and 12 WAP and their average recorded.

3.9.1.6 *Number of ear per plant*

Numbers of ears of ten tagged plants per plot were counted at 8 WAP and 12 WAP and their average recorded (Adebo and Olaoye, 2010; Adetimirin *et al.,* 2000).

3.9.1.7 *Leaf Area*

Leave area of ten tagged plants per plot were measured using a planimeter at 8 WAP and 12 WAP and their average recorded.

3.10 Harvest data

3.10.1 Harvesting

Maize was harvested at the physiological maturity where the whole corn plant had a dry matter of 32 to 38 percent and the corn kernel contained about 62 to 65 percent dry matter. Two middle rows from each plot were harvested to evaluate grain yield and above biomass.

3.10.2 *Grain Yield (kg/ha)*

Grains harvested from 4 m² inner rows per plot of about 15 % moisture content were sampled, enveloped and dried in an oven at 75 ºC for 48 hrs, weighed and the readings used to determine the grain yield or dry weight of the grain (kg/ha). The moisture content was determined by subtracting the initial grain weight from the oven dry weight.

3.10.3 1000 Grain Weight (g)

From each plot, 1000 grains of about 15 % moisture content were randomly selected and weighed. The readings were recorded in grams.

3.10.4 Stover Dried Weight (kg)

Stovers were harvested from 2 × 2 m^2 inner rows per plot, cut into pieces, weight and subsampled. The subsamples were dried at 75 °C for 48 hrs in a forced oven. Then the ratio of the weight of subsample to the Stover dried weight was calculated.

3.10.5 Growth Parameters measured

Grain yield per plot was converted to kg ha^{-1} using the formula:

Grain yield (kg ha^{-1}) = kg grain yield m^{-2} × 10,000 m^2.

The grain yield obtained within an area was converted to the standard unit of measurement (kg/ha) by multiplying with 10,000 m^2.

Above ground biomass per plot was also converted to kg ha^{-1} using the formula:

Biomass yield (kg ha^{-1}) = kg Biomass yield m^{-2} × 10,000 m^2.

The following were computed from the biomass yield data.

3.11 Determination of phosphorus use efficiency

The following parameters considered to measure phosphorus use efficiency were phosphorus recovery efficiency, agronomic P use efficiency and P utilization efficiency. These parameters were calculated according to Mengel *et al.* (2006)

3.11.1 Phosphorus Recovery Efficiency (PRE)

The PRE was calculated as the percentage of P accumulated from fertilized Plot –P accumulated from unfertilized plot per the amount of P applied.

$$\text{PRE} = \frac{\text{P uptake (f)} - \text{P uptake (c)}}{\text{Amount of P applied}}$$

Where the indices f and c denotes 'fertilized crop and unfertilized control' unamended plot respectively.

3.11.2 Phosphorus Utilization Efficiency (PUE)

P utilization efficiency was calculated as the increase in yield in terms of biomass production per P concentration in plant biomass:

$$\text{PUE:} \quad \frac{\text{Grain Yield (f)} - \mathit{Grain\ Yield}\ (c)}{\text{P uptake (f)} - \text{P uptake (c)}}$$

3.11.3 Agronomic P use efficiency (APUE)

Agronomic P use efficiency was defined as the ratio of grain production to the P fertilizer applied.

$$\textbf{APUE} = \frac{\textbf{Grain Yield (f)} - \boldsymbol{Grain\ Yield}\ (\boldsymbol{c})}{\textbf{Amount of P applied}}$$

Also, P uptake was calculated as

P uptake = Cp * DMY

Where the indices f and c denotes 'fertilized crop and unfertilized control' unamended plot respectively. Cp – P concentration, DMY – dry matter yield

3.12 Total Dry Matter production

4 m^2 inner rows per plot of the entire maize plant were harvested by cutting at the ground level and weighted to represent the total fresh weight. A sample was randomly selected and weighed. The sub sample (stover +ear) were then enveloped and oven dried at 60°C for 48 hours to estimate the total dry matter production.

The total dry matter can be computed as follows:

$$TDM = \frac{DM_S * TFW}{FW_s}$$

TDM = total dry matter weight

DM_s = sample dry matter weight

TFW = total fresh weight

FW_s = sample fresh weight

3.13 Phosphorus Harvest index

Stovers and ears of maize plant were harvested from 4 m^2 inner rows per plot at ground level and weighed to give the total weight. The pods were shelled and grains were weighed. The weight of the grain was expressed as a percentage of total weight of the plants (stover and ear) to give the P harvest index (Ion *et al*., 2015).

$$\text{P harvest index} = \frac{Grain\ Yield}{Biological\ Yield} * 100$$

The economic yield = weight of seeds

The biological yield = total dry weight

3.14 Statistical Analysis

Genstat version 11 was used to analyze the data for the growth parameters, the efficiencies and the soil P fractionations. The analysis of variance (ANOVA) was run and LSD at 5 % level of significance was used to separate means obtained. Correlation analyses were used to established relationship between the growth parameters and the soil P fractions.

CHAPTER FOUR

4.0 RESULTS

4.1 Climatic conditions at the experimental site

The actual weather data (rainfall, relative humidity and temperature) observed between 2017 and 2018 cropping seasons are presented in Table 4.3a and b. All climatic data were recorded at the Forest and Horticultural Crops Research Centre at Kade.

Table 4.1a: Climatic Conditions during the 2017 cropping season at Kade

	Total Monthly Rainfall (mm)	Mean Monthly Relative Humidity (%)		Mean Monthly Temperature (°C)	
Month		Maximum	Minimum	Maximum	Minimum
January	0.00	67.41	43.90	33.42	21.46
February	27.18	69.12	40.92	35.20	22.76
March	65.27	72.75	42.76	35.85	22.43
April	156.21	74.75	53.92	34.15	22.22
May	129.54	79.20	55.83	33.48	22.18
June	261.97	82.45	64.35	31.52	22.53
July	209.75	80.23	65.60	32.80	22.89
August	61.97	68.52	45.82	29.24	21.87
September	190.03	82.79	65.94	30.32	21.98
October	201.89	81.59	63.20	31.50	22.01
November	136.85	79.32	58.64	32.72	21.67
December	37.59	76.69	53.52	32.30	21.41
Total	1478.26				

(FOHCREC Weather station at Kade, 2017)

Table 4.1b: Climatic Conditions during the 2018 cropping season at Kade

Month	Total Monthly Rainfall (mm)	Mean Monthly Relative Humidity (%)		Mean Monthly Temperature (ºC)	
		Maximum	Minimum	Maximum	Minimum
January	1.27	69.20	44.28	35.98	21.22
February	46.23	72.00	42.96	35.50	23.18
March	105.66	74.67	49.36	34.85	22.25
April	119.38	76.77	53.65	34.25	22.52
May	240.79	80.89	61.81	32.45	22.20
June	262.65	81.07	62.14	31.75	21.97
July	230.53	79.50	60.38	30.55	22.60
August	86.62	69.12	46.08	30.49	21.69
September	278.38	81.91	63.50	31.49	22.33
October	225.02	78.15	64.27	32.37	21.63
November	153.25	75.92	59.03	31.92	20.75
December	45.56	74.10	52.94	31.05	21.83
Total	1795.33				

(FORCHREC Weather Station at Kade, 2018)

In 2017, the highest monthly rainfall (261.97 mm) was recorded in June and the lowest (0.00 mm) was registered in January. During the minor cropping season, the highest monthly rainfall was obtained in October (201.89 mm) while the lowest (37.59 mm) was registered in December.

The maximum monthly relative humidity in 2017 ranged from 67.41 % to 82.79 %. During the minor cropping season, the highest maximum monthly relative humidity (82.79 %) was obtained in the month of September and the least (76.69 %) was in December. The minimum monthly relative humidity in 2017 minor cropping season ranged from 40.92 % to 65.94 %. During the minor cropping season, the highest monthly relative humidity (65.94 %) was registered in September while the lowest (53.52 %) was in a month of December.

The maximum monthly temperature in 2017 ranged from 29.24 ºC to 35.85 ºC. During the minor cropping season, the highest monthly temperature (32.72 ºC) was observed in November while the least (30.32 ºC) was recorded in September. Also, the minimum monthly temperature ranged from 21.41 ºC to 22.76 ºC. During the minor cropping season, it was observed that the highest monthly temperature (22.01 ºC) was in a month of October and the least (21.41 ºC) being in the month of December.

In 2018, the lowest monthly rainfall (1.27 mm) was obtained in January while the highest (262.65 mm) was June. During the minor cropping season, September registered the highest monthly rainfall (218.38 mm). While the lowest monthly rainfall (45.56 mm) was recorded in December.

The maximum monthly relative humidity in 2018 ranged from 69.20 % to 81.91 %. During the minor cropping season, the highest monthly relative humidity of 81.91% was recorded in September and the least (74.10 %) was in December. Again, the minimum monthly relative humidity in 2018 minor cropping season ranged from 42.96 % to 64.27 %. During the minor cropping season, the highest monthly relative humidity (64.27 %) was obtained in October while the lowest (52.94 %) was in December.

The maximum monthly temperature in 2018 ranged from 30.49 ºC to 35.98 ºC. During the minor cropping season, the maximum monthly temperature (32.37 ºC) was obtained in the month of October with the least (31.05 ºC) being in the month of December. February recorded the highest monthly temperature of 23.18 ºC while the least (20.75 ºC) was in a month of November. During the minor cropping season, it was observed that the highest monthly temperature of 22.33 ºC was recorded in September while the least (20.75 ºC) was in November.

4.2 Initial physical and chemical properties of soil

Some of the physico- chemical characteristics of the initial soil samples are shown in Table 4.2.

Table 4.2: Initial physico-chemical properties of the soil at the experimental site before the application of the amendments

Soil properties	Value
Clay (%)	7.50
Silt (%)	42.01
Sand (%)	50.40
Texture Class	Loam
pH (H_20)	5.62
% N	0.11
% C	1.73
Organic Matter (g/kg)	0.70
Exchangeable bases (Cmol/kg)	
Na^+	0.01
K^+	0.27
Ca^{2+}	2.31
Mg^{2+}	1.46
NH_4- N (mg/kg soil)	9.33
NO_3 -N (mg/kg soil)	4.08
Avail. P (mg/kg soil)	4.65
EC (µS/m)	35.3

EC - Electrical conductivity

In accordance with the USDA (2003) system of classification, the textural class of the Kokofu series was loam. The particle size distribution for sand was 50.40 %, for silt was 42.01 % and for clay was 7.5b% respectively. The soil pH was found to be 5.62 % and the available P was 4.65 mg/kg. The recorded % N and % P were 0.11 % and 1.73 % respectively. The values for the exchangeable Ca^{2+}, exchangeable K^+ and exchangeable Mg^{2+} were 2.33 cmol/kg, 0.27 cmol/kg and 1.47 cmol/kg. The NH_4^+ N as well as NO_3^- N content of the soil was found to be 9.33 mg/kg and 4.08mg/kg respectively. The electrical conductivity was 35.3 µS/m.

4.3 Initial quantities of P sources used and its % P contributions to available P in soil solution

Some of the initial quantities of P sources used and their % P contributions to available P in soil solution are shown in Table 4.2.

Table 4.2: Quantities of P sources Used and their % P contributions to available P in soil solution

Treatment	EFB M (g)	Compost (g)	RH Biochar (g)	Rock phosphate (g)	TSP (g)
T1(Control)	0	0	0	0	0
T2 (U+TSP +Kcl)	0	0	0	0	1.92 (100%)
T3 (EFB M+U+TSP)	49.60 (24%)	0	0	0	1.03 (76%)
T4 (EFB M+C+U+TSP)	24.80 (18%)	20.16 (12%)	0	0	1.20 (70%)
T5 (RH B+C+U+TSP)		22.68 (7%)	53.76 (50%)	0	1.38 (43%)
T6 (EFBM+RHB+U+TSP)	28.00 (14%)	0	28 (34%)	0	1.25 (52%)
T7 (C+U+TSP)	0	40.60 (23%)	0	0	1.30 (77%)
T8 (RH B+C+RP)	0	28.10 (9%)	49.20 (49%)	1.91 (42%)	0
T9 (EFB M+RP+C)	21.30 (20%)	28.10 (21%)	0	1.15 (59%)	0

Where EFB M- Empty fruit Bunch Mulch, TSP -Triple Superphosphate, C- Compost, RP-Rock Phosphate, RHB- Rice Husk Biochar, U- Urea

Through mineralization, the organic amendments as well as the inorganic fertilizers respectively contributed their % P to the available P in soil solution. The triple superphosphate in T2 without any organic P source contributed about 100% P which affected positively the P availability in soil solution. The 100% P contribution from T2 without any organic amendment was different from the TSP in T3 with organic amendment as well as the other integrated treatment combinations.

Accordingly, the organic P sources in treatments 8 and 9 also had different % P contributions. The empty fruit bunch mulch in treatment 3 with a quantity of 49.60g contributed 24% P to available P in soil solution and its contribution was different from the empty fruit mulch in treatment 4 with a quantity of 24.80 and a % P contribution of 18%.

4.4 Effect of different P sources on Total P Uptake, Agronomic P use efficiency, P recovery efficiency and P utilization efficiency in 2017 and 2018 minor cropping seasons

The effect of different P sources on Agronomic P use efficiency, P recovery efficiency and P utilization efficiency of maize plant in 2017 and 2018 minor cropping seasons are presented in Table 4.4. The Total P uptake, the Agronomic P use efficiency, the P recovery efficiency and P utilization efficiency of the maize produced in the amended plots was significantly ($P<0.05$) higher than the un-amended plot.

Table 4.3: Effect of P sources on total P uptake, Agronomic P use Efficiency, P recovery Efficiency and P utilization efficiency in 2017 and 2018 minor cropping seasons

Treatment	Total P uptake (kg P/ha)		Agronomic P use Efficiency (%)		P recovery efficiency (%)		P utilization Efficiency (%)	
	2017	2018	2017	2018	2017	2018	2017	2018
T1 (Control)	1192.00^{a}	1058.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}
T2 (U+TSP+KCL)	2579.00^{f}	2330.00^{cd}	17.85^{e}	16.50^{b}	23.13^{de}	21.19^{c}	0.80^{c}	0.77^{de}
T3 (EFBM+U+TSP)	2128.00^{cd}	2381.00^{cd}	11.93^{d}	13.57^{b}	15.61^{cd}	22.04^{c}	0.82^{c}	0.60^{cde}
T4 (EFBM+C+U+TSP)	1878.00^{b}	2219.00^{cd}	8.24^{c}	16.30^{b}	11.43^{bc}	19.35^{c}	0.87c	0.80^{de}
T5 (RHB+C+U+TSP)	2684.00^{f}	2718.00^{d}	8.90^{c}	14.99^{b}	24.87^{e}	27.66^{d}	0.38^{abc}	0.53^{c}
T6 (EFBM+RHB+U+TSP)	2272.00^{de}	2345.00^{d}	12.97^{d}	45.31^{d}	18.00^{cde}	21.45^{c}	0.61^{abc}	0.78^{de}
T7 (C+U+TSP)	2062.00^{b}	1636.00^{b}	13.73^{d}	35.96^{c}	14.50^{c}	9.63^{b}	0.36^{abc}	0.64^{cde}
T8 (RH B+C+RP)	2229.00^{d}	2682.00^{d}	13.10d	56.13^{e}	17.29^{cde}	27.05^{d}	0.73bc	0.88^{e}
T9 (EFB M+RP+C)	2134.00^{cd}	2644.00^{d}	3.46b	40.22^{cd}	15.71^{cd}	26.44^{d}	0.24^{ab}	0.30^{b}
Mean	2128.67	2223.67	10.01	26.56	15,62	19.42	0.53	0.59
LSD(P<0.05)	201.90	400.10	1.85	6.25	8.15	4.24	0.51	0.20
CV (%)	5.50	6.20	10.70	13.70	30.40	12.70	55.70	19.90

Means followed by the same letter for each treatment in a column are not significantly different ($P > 0.05$).
U= Urea, TSP= Triple Superphosphate, KCL = Muriate of potash, EFB= Empty fruit bunch, M= Mulch, RHB= Rice husk biochar, C= Compost, RP= Rock phosphate

In 2017 minor cropping season, the uptake in T5 produced the highest total P uptake in the maize plant. However, T5 was not significantly different from T2 but it was observed to be significantly ($P < 0.05$) different from T1, T3, T4, T6, T7, T8 and T9.

Similarly in 2018 minor cropping season, the uptake in T5 yielded the highest total P uptake in the maize plant. Treatment 5 which had the highest total P uptake was observed to be significantly ($P < 0.05$) different from the control as well as treatment seven.

The total P uptake was observed to be higher in 2018 minor cropping season than in 2017 minor cropping season. In 2017 minor cropping season, T2 recorded the highest agronomic P use efficiency and was significantly ($P < 0.05$) different from all the treatments. However, in 2018 minor cropping season, the uptake in T8 produced the highest agronomic P use efficiency which was significantly ($P < 0.05$) higher than the rest of the treatments. The 2018 minor cropping season produced higher agronomic P use efficiency of the maize plant as compared to the 2017 minor cropping season. In 2017 minor cropping season, maize grown in T5 produced the highest P recovery efficiency of the maize plant. T5 which produced the highest P recovery efficiency was observed not to be significantly ($P > 0.05$) different from T2, T6 and T8. But was significantly different from T1, T3, T4, T7 and T9.

Similarly, in 2018 minor cropping season, maize grown in T5 produced the highest P recovery efficiency of the maize plant and was significantly not different from T8 and T9. But was, however, statistically different from T1, T2, T3, T4, T6 and T7. It was observed that the P recovery efficiency produced in 2018 cropping season was higher than in 2017 minor cropping season. In 2017 minor cropping season, T4 produced the highest P utilization efficiency and was statistically ($P > 0.05$) similar to T2, T3, T5, T6, T7, T8. But T4 was, however, observed to be significantly ($P < 0.05$) different from T9 and T1.

In 2018 minor cropping season, the highest P utilization efficiency obtained in T8 was not significantly different from T2, T3, T4, T6 and T7. T8 was also observed to be significantly different from T1, T5 and T9. Generally, the P utilization efficiency produced in 2018 cropping season was relative higher than in 2017 minor cropping season.

4.5 Effect of different P sources on Total Dry Matter Production, Grain Yield and P harvest index in 2017 and 2018 minor cropping seasons

The effect of different P sources on total dry matter production, grain yield and P harvest index of maize plant in 2017 and 2018 minor cropping seasons are presented in Table 4.4

The Total dry matter production, Grain yield, P harvest index of the maize produced in the amended plots was significantly higher than the un-amended plot.

Table 4.4: Effect of P sources on total dry matter production and grain yield in 2017 and 2018 minor cropping seasons

Treatment	Total Dry matter production(kg/ha)		Grain Yield (kg/ha)		PHI	
	2017	2018	2017	2018	2017	2018
T1(Control)	6261a	7553a	1369.00a	2579.00a	0.30a	0.6a
T2(U+TSP +Kcl)	11541.0f	12196.0e	2440.00f	3570.00d	0.43bcd	0.70c
T3(EFB M+U+TSP)	9702.0de	9716.0c	2085.00d	3393.00cd	0.51d	0.73cd
T4(EFB M+C+U+TSP)	9376.0cd	10128.0cd	1864.00c	3510.00d	0.48bcd	0.75de
T5(RH B+C+U+TSP)	9096.0c	8617.0b	1903.00c	3479.00d	0.32a	0.64b
T6(EFBM+RHB+U+TSP)	10020.0e	10263.0cd	2148.00de	3368.00cd	0.49bcd	0.74de
T7(C+U+TSP)	9702.0de	10310.0cd	2193.00de	2806.00ab	0.41bc	0.65b
T8(RH B+C+RP)	9218.0c	10023.0cd	2155.00de	4017.00e	0.50d	0.75de
T9(EFB M+RP+C)	8584.0b	10585d	1577.00b	3062.00bc	0.49bcd	0.77e
Mean	9277.8	9932.3	1970.44	3309.33	0.44	0.70
LSD (P<0.05)	400.32	606.90	118.30	337.60	0.08	0.03
CV (%)	1.6	1.5	1.6	1.9	6.70	1.10

Means followed by the same letter for each treatment in a column are not significantly different (P > 0.05)

U= Urea, EFB=Empty fruit bunch, M= Mulch, TSP=Triple Superphosphate, KCL= Muriate of potash, RHB= Rice husk biochar, C= Compost, RP = Rock Phosphate

In 2017 minor cropping season, it was observed that the highest total dry matter production was obtained from T2 and which was significantly higher than the rest of the treatments. The control treatment registered the lowest total dry matter production (Table 4.4).

A similar trend was observed in 2018 minor cropping season. Where T2 produced maize plant with the highest total dry matter production and was significantly higher all the treatments. However, the control treatment produced maize plant which gave the lowest total dry matter production. It was observed generally that the total dry matter production of the maize plant yielded in the 2018 minor cropping season was higher than in 2017 cropping season.

In 2017 cropping season, T2 produced the highest grain yield and which was significantly higher than the rest of the treatments. However, in 2018 minor cropping season, the highest grain yield was obtained from T8 and was significantly higher than the rest of the treatments. It was also observed that the control yielded the lowest grain yield and was statistically lower than the rest of the treatments.

In 2017 minor cropping season, T3 produced the highest P harvest index but this was not significantly ($P > 0.05$) different from T2, T4, T6, T8 and T9. T3 was however observed to be significantly different from T1, T5 and T7. In 2018 minor cropping season, T9 produced the highest P harvest index which was not significantly different from T4, T6 and T8. Generally, the P harvest index of the maize plant produced in the 2018 minor cropping season was higher than in 2017 cropping season.

4.6 Effect of P sources on growth parameters of maize plant in 2017 and 2018 cropping seasons

The effects of P sources on growth parameters of maize plant in 2017 and 2018 minor cropping seasons are shown in Table 4.5a-b. In 2017 minor cropping season, T2 yielded the highest plant height at 8 WAP and was significantly different from the control. However, at 12 WAP, T2 produced the highest plant height and was not significantly different from the T3, T5, and T8.

In 2018 minor cropping season, T2 yielded the highest plant height at 8 WAP and was significantly different from T9 and the control. However, at 12 WAP, T2 produced the highest plant height which was not significantly different from the T7 and T8. The plant height produced in 2018 minor cropping season at 8 WAP and 12 WAP was higher than in 2017 minor cropping season.

In 2017 minor cropping season, T2 yielded the highest chlorophyll content of maize plant at 8 WAP and was not significantly different from T3, T4, T5 and T7. Furthermore, treatment two yielded the highest chlorophyll content at 12 WAP and was not significantly ($P < 0.05$) different from T4 and T5. It was observed in 2018 minor cropping season that, T2 yielded the highest chlorophyll content at 8 WAP and was not significantly different from T3, T4 and T5. Also, it was observed that at 12 WAP, T2 produced the highest chlorophyll content which was not significantly different from T4.

Generally, the chlorophyll content of the maize plant produced at both WAP in 2018 minor cropping season was higher than in 2017 minor cropping season. In 2017 minor cropping season, T2 produced maize plant with the highest stem diameter at 8 WAP and was significantly different from the control as well as T9. Additionally, at 12 WAP, T2 produced maize plant with the highest stem diameter and was not significantly ($P > 0.05$) different from T3 and T4.

It was observed in 2018 minor cropping season that, T2 produced maize plant with the highest stem diameter and was not significantly different from T3 and T4 at 8 WAP. At 12 WAP, the highest stem diameter of the maize plant was obtained from T2 and was not significantly different from T3, T4 and T5.

Generally, the stem diameter of the maize plant produced at both WAP in 2018 minor cropping season was higher than in 2017 minor cropping season. In 2017 minor cropping season, the highest leaf area of the maize plant was obtained from the T2 and was statistically similar to all the treatments except the control at 8 WAP. Moreover, at 12 WAP, the highest leaf area of the maize plant was also obtained from T2 and was not significantly ($P > 0.05$) different from T3 and T5.

It was observed in 2018 minor cropping season that, T2 produced maize plant with the highest leaf area and was not significantly different from T3, T4 and T7 at 8 WAP. At 12 WAP, the highest leaf area of the maize plant was obtained from T2 and was not significantly different from T3, T4, T5 and T7.

Generally, the leaf area of the maize plant produced in 2018 minor cropping season was higher than in 2017 minor cropping season. In 2017 minor cropping season, T2 yielded the highest number of leaves at 8 WAP and was significantly different from all the other treatments. However, at 12 WAP, T2 produced the highest number of leaves and was not significantly different from the T5 and T7 ($P > 0.05$).

In 2018 minor cropping season, T2 yielded the highest number of leaves at 8 WAP and was significantly different from T9 and the control ($P < 0.05$). However, at 12 WAP, T2 produced the highest number of leaves and was not significantly ($P > 0.05$) different from T7. The number of leaves of maize plant produced in 2018 minor cropping season at both WAP was higher than in 2017 minor cropping season.

In 2017 minor cropping season, T2 yielded the highest number of ears of maize plant at 8 WAP and was significantly different from the control. However, at 12 WAP, T2 produced maize plants with the highest number of ears and was not significantly ($P > 0.05$) different from the T4, T5 and T7.

It was observed in 2018 minor cropping season that, T2 produced maize plant with the highest number of ear and was not significantly different from T3, T4, and T5 at 8 WAP. At 12 WAP, maize plant with the highest number of ear was also obtained from T2 and was not significantly different from T4 and T7.

Generally, the number of ears of maize plant produced at both WAP in 2018 minor cropping season was higher than in 2017 minor cropping season.

Table 4.5a: Effect of P sources on growth parameters of maize plant in 2017 minor cropping seasons

Treatment	Plant Height(cm) 8 WAP	12 WAP	Chlorophyll content(µg/g) 8 WAP	12 WAP	Stem diameter(mm) 8 WAP	12 WAP	Leaf Area(cm^2) 8 WAP	12 WAP	No of Leaves 8 WAP	12 WAP	Number of ear 8 WAP	12 WAP
T1(Control)	91.9^{a}	94.2^{a}	22.2^{a}	25.4^{a}	5.3^{a}	5.5^{a}	312.8^{a}	351.4^{a}	8.1^{b}	12.3^{a}	0.8^{a}	1.0^{a}
T2(U+TSP+KCL)	113.8^{b}	115.5^{d}	34.8^{d}	36.6^{c}	6.6^{b}	6.9^{d}	451.1^{b}	470.3^{e}	9.7^{e}	14.7^{c}	1.2^{b}	2.2^{b}
T3(EFBM+U+TSP)	110.0^{b}	113.6^{d}	26.6^{abcd}	27.7^{ab}	6.2^{b}	6.4^{cd}	449.4^{b}	456.1^{de}	8.7^{c}	12.7^{ab}	1.0^{ab}	1.1^{a}
T4(EFBM+C+U+TSP)	105.7^{ab}	108.0^{bc}	33.6^{cd}	34.8^{c}	6.2^{b}	6.5^{cd}	393.0^{ab}	411.9^{c}	9.0^{d}	13.3^{ab}	1.0^{ab}	1.6^{ab}
T5(RHB+C+U+TSP)	112.4^{b}	114.5^{d}	30.8^{abcd}	32.2^{bc}	6.2^{b}	6.3^{bc}	431.1^{b}	463.8^{e}	9.1^{d}	13.7^{bc}	1.0^{ab}	2.0^{b}
T6(EFBM+RHB+U+TSP)	103.8^{ab}	104.3^{b}	25.7^{abc}	26.3^{a}	6.1^{ab}	6.4^{bc}	368.6^{ab}	375.0^{ab}	8.7^{c}	13.3^{ab}	0.9^{ab}	1.2^{a}
T7(C+U+TSP)	104.8^{ab}	107.3^{bc}	26.0^{abcd}	28.5^{ab}	5.9^{ab}	6.4^{bc}	382.6^{ab}	391.2^{bc}	8.9^{c}	13.7^{bc}	1.0^{ab}	1.7^{ab}
T8(RHB+C+RP)	103.6^{ab}	110.9^{cd}	24.2^{ab}	26.2^{a}	6.0^{ab}	6.4^{bc}	400.7^{ab}	417.6^{c}	8.6^{c}	12.6^{ab}	0.90^{ab}	1.1^{a}
T9(EFBM+RP+C)	105.7^{ab}	106.0^{bc}	22.2^{a}	23.6^{a}	5.5^{a}	5.7^{a}	353.6^{ab}	363.5^{ab}	8.5^{a}	12.5^{ab}	1.0^{ab}	1.2^{a}
Mean	105.7	108.3	27.3	29.0	6.0	6.3	393.7	411.2	8.8	13.2	0.8	1.5
LSD ($P<0.05$)	15.5	6.5	8.9	5.9	0.7	0.5	102.8	29.4	0.3	1.2	0.3	0.7
CV (%)	8.5	3.5	18.9	11.9	7.1	4.3	15.2	4.2	2.3	5.2	17.1	28.0

Means followed by the same letter for each treatment in a column are not significantly different ($p>0.05$)

U= Urea, EFB=Empty fruit bunch, RHB= Rice husk biochar, KCL= Muriate of potash, TSP= Triple Superphosphate, M= Mulch, RP= Rock phosphate, C= Compost.

Table 4.5b: Effect of P sources on growth parameters of maize plant in 2018 minor cropping season

Treatment	Plant Height(cm) 8 WAP	12 WAP	Chlorophyll content(µg/g) 8 WAP	12 WAP	Stem diameter(mm) 8 WAP	12 WAP	Leaf Area(cm^2) 8 WAP	12 WAP	No of Leaves 8 WAP	12 WAP	Number of ear 8 WAP	12 WAP
T1(Control)	234.2^{a}	240.7^{a}	23.0^{a}	24.2^{a}	5.7^{a}	6.2^{a}	640.7^{a}	671.2^{a}	9.2^{a}	12.5^{a}	0.8^{a}	1.1^{a}
T2(U+TSP+KCL)	285.0^{c}	290.4^{g}	36.9^{c}	38.0^{f}	6.9^{d}	7.5^{c}	851.6^{c}	887.4^{c}	10.6^{c}	15.2^{c}	1.3^{b}	2.6^{c}
T3(EFBM+U+TSP)	271.1^{bc}	275.1^{cd}	28.9^{abc}	31.0^{cd}	6.7^{d}	7.3^{c}	766.7^{bc}	799.9^{bc}	9.9^{abc}	13.0^{ab}	1.1^{ab}	1.2^{a}
T4(EFBM+C+U+TSP)	267.8^{bc}	272.0^{c}	31.9^{bc}	35.6^{ef}	6.6^{cd}	7.1^{bc}	773.4^{bc}	811.1^{bc}	9.9^{abc}	13.5^{ab}	1.2^{b}	2.1^{bc}
T5(RHB+C+U+TSP)	278.2^{bc}	283.0^{ef}	28.9^{bc}	32.7^{de}	6.4^{c}	6.9^{abc}	662.1^{a}	859.7^{bc}	10.2^{bc}	14.0^{ab}	1.0^{ab}	1.6^{ab}
T6(EFBM+RHB+U+TSP)	274.5^{bc}	279.6^{de}	24.9^{ab}	26.1^{ab}	6.4^{c}	6.7ab	718.4^{ab}	745.6^{ab}	9.8^{abc}	13.3^{ab}	0.9^{a}	1.4^{ab}
T7(C+U+TSP)	277.8^{bc}	284.9^{fg}	25.5^{ab}	27.3^{abc}	6.2^{bc}	6.5ab	753.5^{bc}	779.4^{abc}	10.1^{bc}	14.1^{abc}	0.9^{a}	1.7^{abc}
T8(RHB+C+RP)	267.4^{bc}	287.1^{fg}	24.3^{ab}	27.2^{abc}	6.3^{bc}	6.6^{ab}	741.1^{ab}	768.7^{ab}	9.8^{abc}	13.2^{ab}	0.9^{a}	1.2^{a}
T9(EFBM+RP+C)	251.4^{ab}	261.7^{b}	25.2a	27.2^{a}	5.9^{ab}	6.4^{ab}	642.2^{a}	681.4^{a}	9.5^{ab}	13.3^{ab}	0.9^{a}	1.2^{a}
Mean	267.5	274.9	27.7	29.9	6.3	6.8	727.7	778.3	9.9	13.4	1.0	1.6
LSD(P<0.05)	29.1	5.8	8.4	4.5	0.4	0.8	108.6	119.7	0.9	1.1	0.3	0.9
CV (%)	6.3	1.2	17.9	8.8	3.4	6.9	8.7	9.0	5.4	0.4	16.9	31.8

Means followed by the same letter for each treatment in a column are not significantly different (p>0.05)

U= Urea, EFB=Empty fruit bunch, RHB= Rice husk biochar, KCL= Muriate of potash, TSP= Triple Superphosphate, M= Mulch, RP= Rock phosphate, C= Compost

4.7 Effect of amendments on soil chemical properties in 2017 and 2018 minor cropping seasons

The effect of amendments on soil chemical properties in 2017 and 2018 minor cropping seasons are presented in Table 4.6.

Table 4.6: Effect of amendments on soil chemical properties in 2017 and 2018 minor cropping seasons

	Ca^{2+}		CEC (mol/kg)		pH		OC(%)		TP (ppm)	
Treatment	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
T1(Control)	5.8^{a}	6.75^{a}	16.00^{a}	17.50^{a}	5.83^{b}	6.09^{b}	1.65^{a}	1.76^{a}	54.30^{a}	272.90^{a}
T2(U+TSP+KCL)	9.93^{b}	10.61^{b}	16.11^{a}	20.25^{b}	5.64^{a}	5.90^{a}	2.02^{c}	2.64^{d}	149.20^{d}	332.57^{c}
T3(EFBM+U+TSP)	10.67^{c}	11.72^{c}	16.43^{b}	19.67^{b}	6.19^{d}	6.49^{cd}	2.15^{d}	2.74^{d}	124.90^{c}	343.63^{d}
T4(EFBM+C+U+TSP)	13.17^{d}	14.13^{d}	18.71^{c}	19.48^{b}	6.26^{e}	6.62d^{e}	1.87^{b}	2.05^{b}	158.40^{d}	343.63^{d}
T5(RHB+C+U+TSP)	23.53^{g}	18.09^{e}	28.60^{f}	30.07^{f}	6.46^{g}	6.78^{f}	1.83^{b}	3.16^{f}	190.20^{e}	358.15^{e}
T6(EFBM+RHB+U+TSP)	18.09^{f}	25.01^{i}	24.42^{d}	26.11^{d}	6.15^{c}	6.36^{cd}	2.05^{cd}	2.39^{c}	223.80^{f}	387.55^{f}
T7(C+U+TSP)	18.08^{f}	20.03^{h}	25.03^{e}	22.51^{c}	6.29^{e}	6.43^{c}	2.15^{d}	3.05^{e}	105.20^{b}	408.92^{g}
T8(RHB+C+RP)	17.44^{e}	19.49^{g}	28.81^{f}	30.05^{f}	6.43^{g}	6.77^{ef}	2.73^{e}	3.19f	109.70^{b}	442.42^{h}
T9(EFBM+RP+C)	17.92^{ef}	19.06^{f}	18.94^{c}	26.24^{d}	6.33^{f}	6.60^{d}	2.75e	2.32c	265.00^{g}	329.73^{b}
Mean	14.96	16.10	10.29	11.30	6.18	6.45	2.05	2.48	153.41	357.72
LSD($P<0.05$)	0.49	0.12	0.25	1.16	0.03	0.15	0.04	0.10	14.40	2.45
CV (%)	1.9	0.4	0.70	2.90	0.3	1.4	1.20	2.5	5.5	0.4

Means followed by the same letter for each treatment in a column are not significantly different ($P > 0.05$).

U= Urea, EFB=Empty fruit bunch, RHB= Rice husk biochar, KCL= Muriate of potash, TSP= Triple Superphosphate, M= Mulch, RP= Rock phosphate, C= Compost

The exchangeable calcium was observed to be inconsistent throughout the two cropping seasons. However, the amendments were higher than the control.

In 2017 minor cropping season, it was observed that the highest exchangeable calcium obtained in T5 was significantly ($P < 0.05$) higher than the rest of the treatments. In 2018 minor cropping season, the highest exchangeable calcium predominant in T6 was significantly higher than the other treatments. Generally, the exchangeable calcium produced in 2018 minor cropping season was higher when compared to 2017 minor cropping season.

The CEC produced in T2 was inconsistent throughout the two cropping seasons. Across the seasons, the CEC produced in 2018 minor cropping season was relatively higher than in 2017 cropping season.

In 2017 minor cropping season, the highest CEC was recorded in T8 and was statistically similar to T5 but was observed to be significantly different from T1, T2, T3, T4, T6, T7, and T9. However, in 2018 minor cropping season, the highest CEC was obtained from T5 and was statistically similar to T8. This was however, significantly different from T9, T7, T6, T4, T3, T2 and T1. In the two cropping seasons the soil pH was consistent. Across the seasons the pH of the soil produced in 2018 minor cropping season was relatively higher than in 2017 minor cropping season.

In 2017 minor cropping season, the highest pH was obtained from T5 and which was not significantly different from T8. However, it was also observed to be significantly different from T9, T7, T6, T4, T3, T2 and T1. Similarly, in 2018 minor cropping season, the highest pH obtained from T5 was not significantly different from T8. However, this was observed to be significantly different from T1, T2, T3, T4, T6, T7 and T9. In both seasons, among the amended plots the least pH was produced in treatment two.

In the two cropping seasons, the OC was inconsistent. Across the seasons, the % OC was relatively higher in 2018 than in 2017. However, the amendments were better than the control. In 2017 minor cropping season, the highest OC predominant in T9 was observed not to be significantly different from T8. However, this was observed to be significantly different from the rest of the treatments.

In 2018 minor cropping season, the highest organic carbon predominant in T8 was statistically similar to T5. However, this was significantly different from T9, T7, T6, T4, T3, T2 and the control. The total phosphorus was inconsistent throughout the two cropping seasons. Generally, the total phosphorus produced in 2018 minor cropping season was higher than in 2017 minor cropping season. However, the amended soils did better than the control.

In 2017 minor cropping season, T9 which produced the highest total P was observed to be significantly ($P<0.05$) higher than the other treatments. In 2018 minor cropping season, T8 produced the highest total phosphorus which was significantly higher than the other treatments.

4.8 Effect of P sources on soil P pools in 2017 and 2018 minor cropping seasons

The effect of different P sources on soil phosphorus pools are presented in Table 4.7. The soil P pools were significantly ($P < 0.05$) affected by the various P amendments.

In 2017 minor cropping season, T8 which produced the highest resin Pi concentration was not significantly different from T4, T5 and T7. However, this was significantly different from T9, T6, T3, T2 and the control. In 2018 minor cropping season, T5 produced the highest resin Pi concentration and was statistical similar to T7 and T8. The resin Pi concentration produced in 2018 minor cropping season was relatively higher than in 2017 minor cropping season.

It was observed that in 2017 minor cropping season, T8 produced the highest $NaHCO_3$-Pi concentration and was not significantly different from T7. T8 was also observed to be significantly different from T9, T6, T5, T4, T3, T2 and T1. A similar trend was observed in 2018 minor cropping season, T8 produced the highest $NaHCO_3$-Pi concentration and was not significantly different from T7 but significantly higher than the values of the other treatments ($P < 0.05$).

The $NaHCO_3$- Pi concentration produced in 2018 minor cropping season was relatively higher than in 2017 minor cropping season. In 2017 minor cropping season, it was observed T8 produced the highest sum of resin- Pi and $NaHCO_3$-Pi concentration and was not significantly different from T7 but significantly different from the mean values of the other treatments.

A similar trend was observed in 2018 minor cropping season, T8 produced the highest sum of resin –Pi and $NaHCO_3$-Pi concentration and was not significantly different from T5 and T7 ($P > 0.05$). The sum of resin-Pi and $NaHCO_3$- Pi concentration produced in 2018 minor cropping season was relatively higher than in 2017 minor cropping season. In 2017 minor cropping season, T5 produced the highest NaOH-Pi concentration and was significantly different from T3 and T2 as well as the control. In 2018 minor cropping season, T5 produced the highest resin Pi concentration and was significantly different from T2 and T1, but not significantly ($P < 0.05$) different from the other treatments.

The NaOH-Pi concentration produced in 2018 minor cropping season was relatively higher than corresponding values in 2017 minor cropping season. In 2017 minor cropping season, it was observed that T9 produced the highest sum of organic P pools and was not significantly different from T8, T7, T6 and T5 but significantly different from T1, T2, T3, T4 ($P < 0.05$).

In 2018 minor cropping season, T8 produced the highest sum of organic pools and was not significantly different from T9, T7, T6 and T5. The sum of organic P pools produced in 2018 minor cropping season was relatively higher than in 2017 minor cropping season. In 2017 minor cropping season, T5 produced the highest HCl-Pi concentration and was not significantly different from T6, T8 and T9 but significantly ($P \leq 0.05$) different from values of T1, T2, T3 and T4. In 2018 minor cropping season, T6 produced the highest HCl- Pi concentration and was not significantly different from T5, T8 and T9. The HCl-Pi concentration produced in 2018 minor cropping season was relatively higher than in 2017 minor cropping season.

In 2017 minor cropping season, it was observed T4 produced the highest residual P and was significantly ($P \leq 0.05$) different from the control. Similarly, in 2018 minor cropping season, T4 produced the highest residual P and was statistically similar to all the treatments. The Residual P produced in 2018 minor cropping season was relatively higher than in 2017 minor cropping season.

Table 4.7: Effect of P sources on P pools in 2017 and 2018 minor cropping seasons

Treatment	Solution P Resin -Pi (mg/kg)		Replenish P $NaHCO_3$-Pi (mg/kg)		Available P $\sum$(Resin-Pi+ $NaHCO_3$-Pi) (mg/kg)		Moderately Labile P NaOH-Pi (mg/kg)		Sum of organic pools $\sum$($NaHCO_3$-Po+NaOH-Pi) (mg/kg)		Non Labile P HCl-Pi (mg/kg)		Non-Labile Residual P (mg/kg)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
T1 (Control)	4.25^{a}	5.14^{a}	8.90^{a}	10.08^{a}	13.25^{a}	15.20^{a}	58.10^{a}	64.65^{a}	36.37^{a}	45.03^{a}	8.95^{a}	11.50^{a}	173.30^{a}	188.80^{a}
T2 (U+TSP+KCL)	10.70^{c}	11.71^{c}	14.35^{bc}	14.68^{ac}	25.05^{c}	26.30^{b}	66.35^{abc}	66.70^{ab}	45.78^{ab}	57.38^{ab}	10.55^{ab}	14.60^{abc}	187.00^{ab}	212.80^{a}
T3 (EFBM+U+TSP)	8.10^{bc}	11.08^{c}	11.70^{ab}	12.92^{ab}	19.80^{b}	24.00^{ab}	62.55^{ab}	69.75^{abc}	70.73^{cd}	80.40^{cd}	11.00^{ab}	14.23^{ab}	185.00^{ab}	210.50^{a}
T4 (EFBM+C+U+TSP)	14.80^{d}	16.25^{d}	19.35^{de}	20.86^{de}	34.15^{d}	37.11^{c}	73.95^{bcd}	80.61^{c}	58.00^{bc}	68.89^{bc}	10.40^{ab}	14.05^{ab}	213.80^{b}	234.60^{a}
T5 (RHB+C+U+TSP)	17.60^{d}	20.15^{e}	20.80^{e}	22.78^{e}	38.40^{de}	43.29^{cd}	80.10^{d}	81.92^{c}	80.57^{de}	90.35^{de}	16.55^{d}	20.96^{de}	181.60^{ab}	202.90^{a}
T6 (EFBM+RHB+U+TSP)	6.65^{ab}	7.41^{ab}	16.60^{cde}	17.78^{cd}	23.25^{bc}	25.19^{b}	75.05^{cd}	78.81^{c}	90.32^{e}	99.52^{de}	15.40^{d}	21.97^{e}	193.70^{ab}	215.20^{a}
T7 (C+U+TSP)	16.10^{d}	17.24^{de}	26.85^{f}	29.36^{f}	42.95^{ef}	46.60^{cd}	$71.75b^{cd}$	75.81^{abc}	89.38^{e}	94.75^{de}	12.25^{bc}	16.05^{abcd}	176.60^{ab}	192.00^{a}
T8 (RHB+C+RP)	17.75^{d}	19.40^{de}	28.90^{f}	31.49^{f}	46.65^{f}	50.89^{d}	74.75^{cd}	76.21^{abc}	91.90^{e}	105.83^{e}	15.55^{d}	20.55^{de}	191.20^{ab}	212.60^{a}
T9 (EFBM+RP+C)	8.85^{bc}	10.56^{bc}	14.10^{bc}	15.04^{bc}	22.95^{bc}	25.60^{b}	74.65^{cd}	77.93^{c}	98.08^{e}	104.18^{e}	14.95^{cd}	18.04^{bcde}	179.10^{ab}	195.50^{a}
Mean	11.64	13.20	17.95	19.44	29.61	32.69	70.80	74.71	73.46	82.92	12.84	16.89	186.81	207.17
LSD	3.28	3.52	4.48	4.67	5.19	9.61	11.54	11.54	18.60	21.32	3.12	5.31	39.47	48.50
CV (%)	16.4	8.90	14.50	14.00	10.2	8.90	9.50	9.10	14.80	15.00	14.20	10.90	12.30	12.10

Means followed by the same letter for each treatment in a column are not significantly different ($P > 0.05$)

U= Urea, EFB=Empty fruit bunch, RHB= Rice husk biochar, KCL= Muriate of potash, TSP= Triple Superphosphate, M= Mulch, RP= Rock phosphate, C= Compost

4.9 Relations between soil P fractions and soil attributes at 2017 and 2018 cropping season

The relations between P fractions and soil attributes at 2017 and 2018 cropping seasons are presented in Tables 4.9a-b.

Table 4.8a: Pearson correlation coefficients between soil P fractions and soil attribute in 2017 cropping season

P Fractions	Soil attributes				
	OC (%)	pH	CEC (Cmol/kg)	Ca^{2+}(Cmol/kg)	TP (ppm)
Resin Pi	0.51*	0.56*	0.17	0.59*	-0.03
$NaHCO_3$-Pi	0.68*	0.53	0.39	0.78*	-0.07
∑(Resin-Pi+ $NaHCO_3$-Pi	0.64*	0.57*	0.31	0.74*	-0.06
NaOH-Pi	0.20	0.54	0.37	0.63*	0.48
∑($NaHCO_3$-Po+ NaOH-Po	0.45	0.59*	0.67*	0.82*	0.52
HCl-Pi	0.37	0.51	0.5	0.74*	0.55
Residual P	-0.25	-0.12	-0.23	-0.23	-0.02

*P<0.05

TP- Total P CEC -Cation Exchange Capacity

Table 4.8b: Pearson correlation coefficients between soil P fractions and soil attribute in 2018 cropping season

P Fractions	Soil attributes				
	OC (%)	pH	CEC (Cmol/kg)	Ca^{2+}(Cmol/kg)	TP (ppm)
Resin Pi	0.44	0.52	0.20	0.2	0.42
$NaHCO_3$-Pi	0.62*	0.55	0.45	0.45	0.52
∑(Resin-Pi+$NaHCO_3$-Pi	0.58*	0.57	0.37	0.37	0.51
NaOH-Pi	-0.05	-0.53	0.38	0.38	-0.07
∑($NaHCO_3$-Po+NaOH-Po	0.50	0.75	0.63*	0.63*	0.25
HCl-Pi	0.27	0.50	0.48	0.48	0.36
Residual P	-0.34	-0.22	-0.27	-0.27	-0.16

* P<0.05

TP- Total P CEC -Cation Exchange Capacity

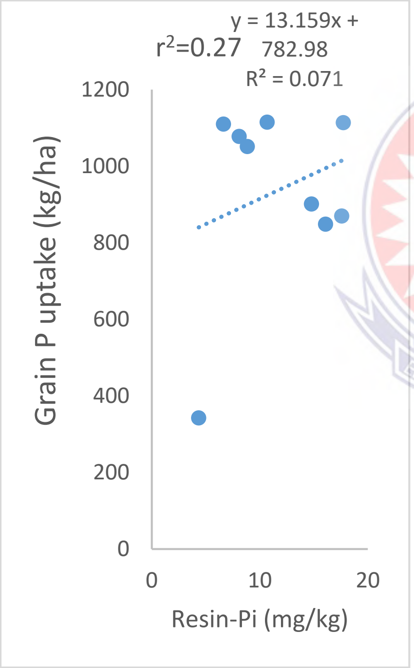
In the 2017 cropping season, there were a positive correlation that existed among the resin-Pi and pH, organic carbon, cation exchange capacity and exchangeable Ca^{2+} content. However, a negative correlation existed between the Resin Pi and the total P. There was also a positive correlation between $NaHCO_3$-Pi and pH, organic carbon, cation exchange Capacity and Ca^{2+}. However, the negative correlation existed between $NaHCO_3$-Pi and total P was weak.

The sum of Resin-Pi and $NaHCO_3$-Pi correlated positively with pH, Organic Carbon, Ca^{2+}, Cation Exchange Capacity but was negatively correlated with total P. There was also a positive correlation existing between NaOH-Pi and the soil attributes (OC, CEC, TP, Ca^{2+} and pH). A positive correlation was observed to exist between the sum of Organic Pools (∑ ($NaHCO_3$-Pi+ NaOH-Pi) and the soil attributes (OC, pH, CEC, $Ca^{2+}$and TP). The calcium bound P (Hcl-Pi) established a significant positive correlation with exchangeable Ca^{2+} and positively with other soil attributes (CEC, TP, pH and OC). The residual P also established a negative correlation with the soil attributes (OC, TP, pH, CEC, Ca^{2+}).

In 2018 cropping season, there was a positive correlation between the resin-Pi and the soil attributes (OC, pH, CEC, Ca^{2+}, and tp). Likewise, $NaHCO_3$-Pi established a positive correlation with Organic Carbon, Cation Exchange Capacity, pH. Ca^{2+} sand total P. A positive correlation was also observed to exist between the sum of the labile pool (∑Resin-Pi + $NaHCO_3$-Pi and the soil attributes (OC, TP, pH, CEC, Ca^{2+}). It was also found out that NaOH-Pi correlated positively with the pH, CEC and Ca^{2+} but was observed to have established a negative correlation with the Organic Carbon and total P. A positive correlation was also observed to have been established between the sum of the organic pools ∑ ($NaHCO_3$-Po + NaOH-Pi) and the soil attribute (OC, pH, CEC, Ca^{2+} and total P). The calcium bound P (Hcl-Pi) also established a positive correlation with the soil attributes (OC, pH, CEC, Ca^{2+} and total P).

4.10 Relationship between Resin-Pi, $NaHCO_3$-Pi and P uptakes in Grain, Stover, Husk and Cob at the 2017 and 2018 minor cropping seasons

The relationship between Resin-Pi, $NaHCO_3$ –Pi concentration and P uptake in Grain, Stover, Husk and Cob in 2017 and 2018 minor cropping seasons are shown in Figs 4.1-4.4.



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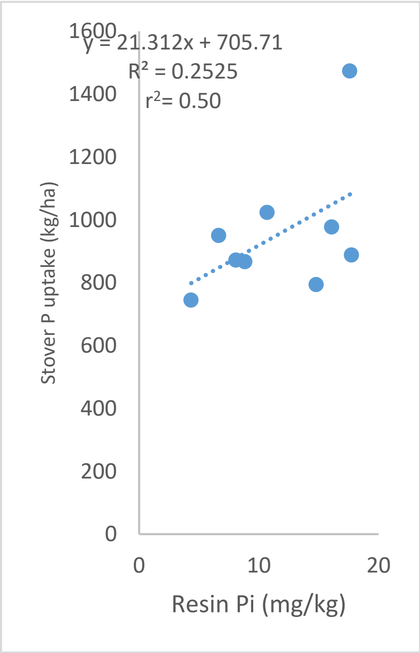

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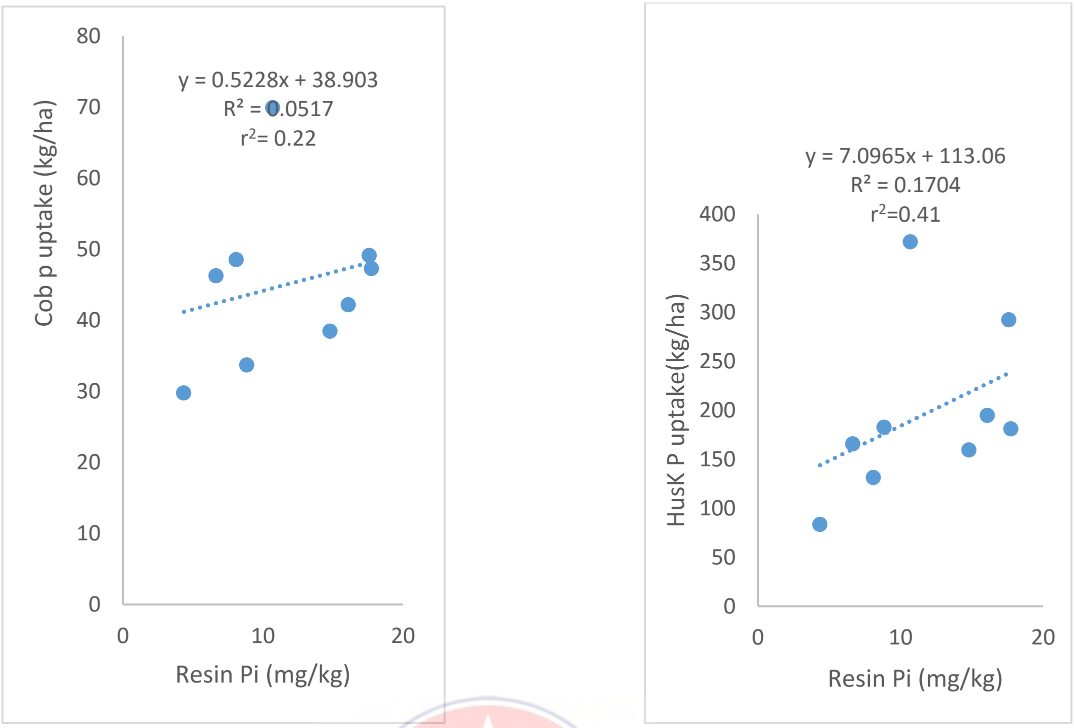

c.

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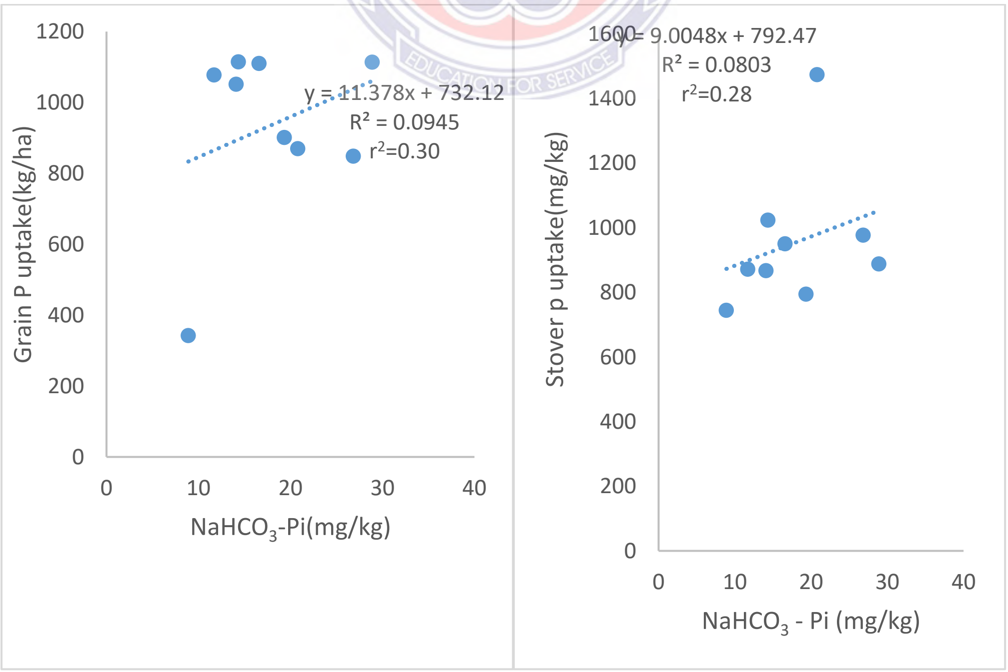
Fig. 4.1: The relationship between the Resin-Pi and P uptake in Grain, Stover, Cob and Husk in 2017 minor cropping season



a.

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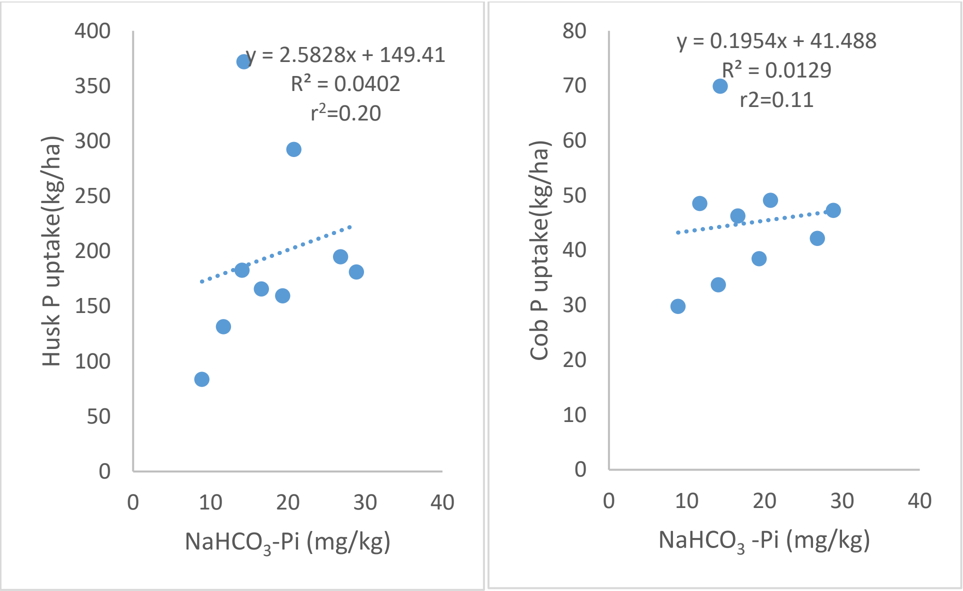
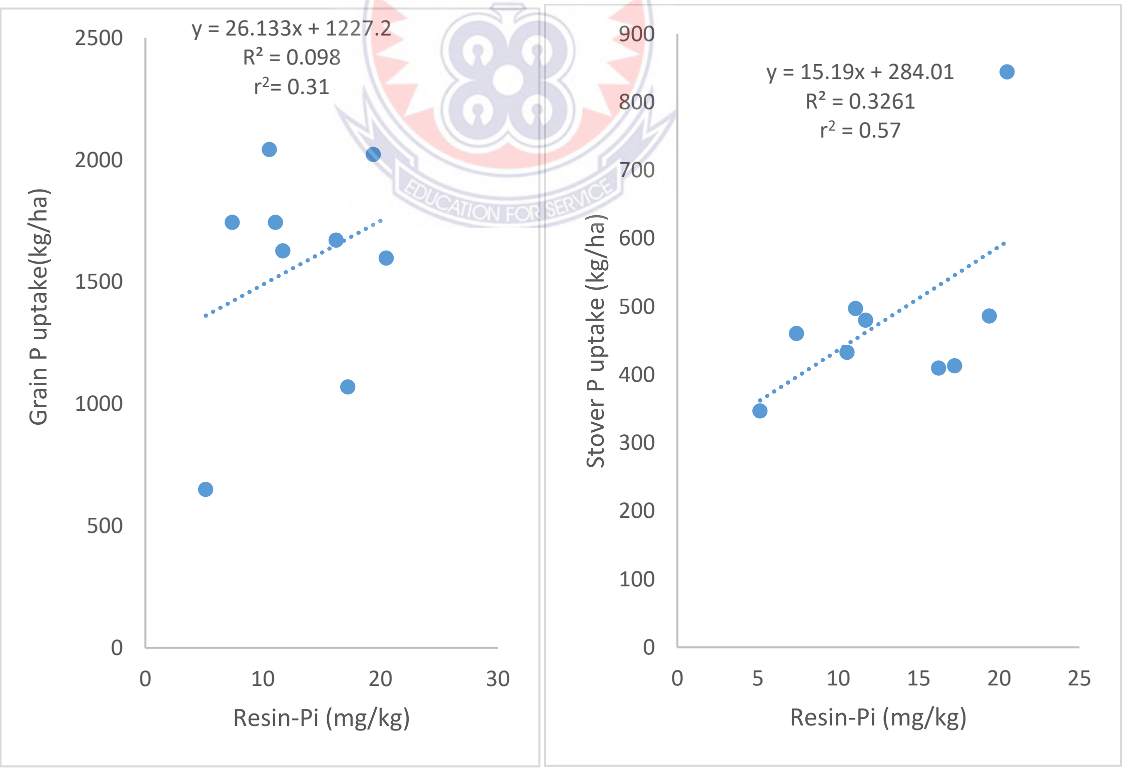


c

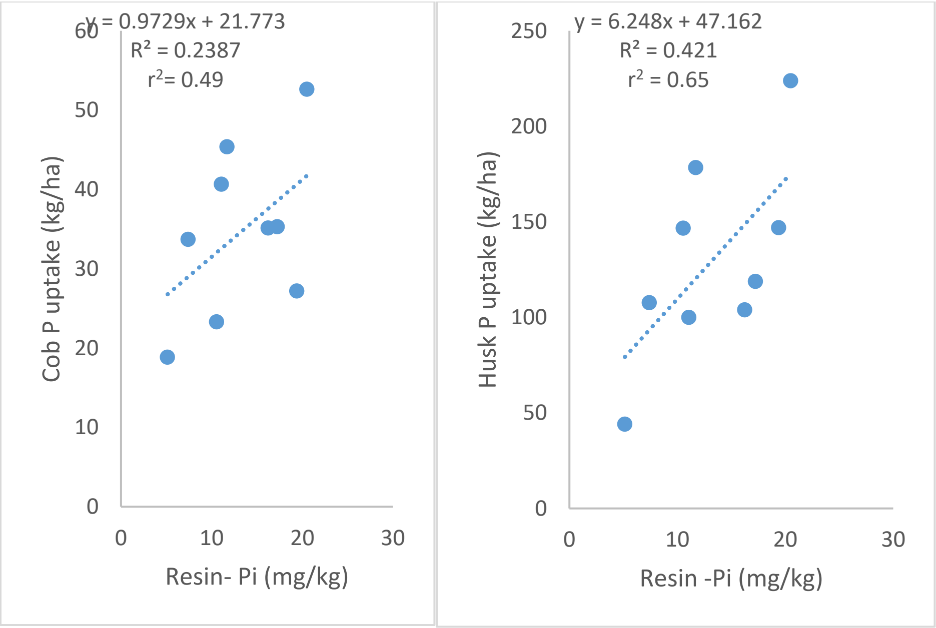
d.

Fig. 4.2: Relationship between the NaHCO$_3$-Pi and P uptake in grain, stover, cob, husk in 2017 minor cropping season



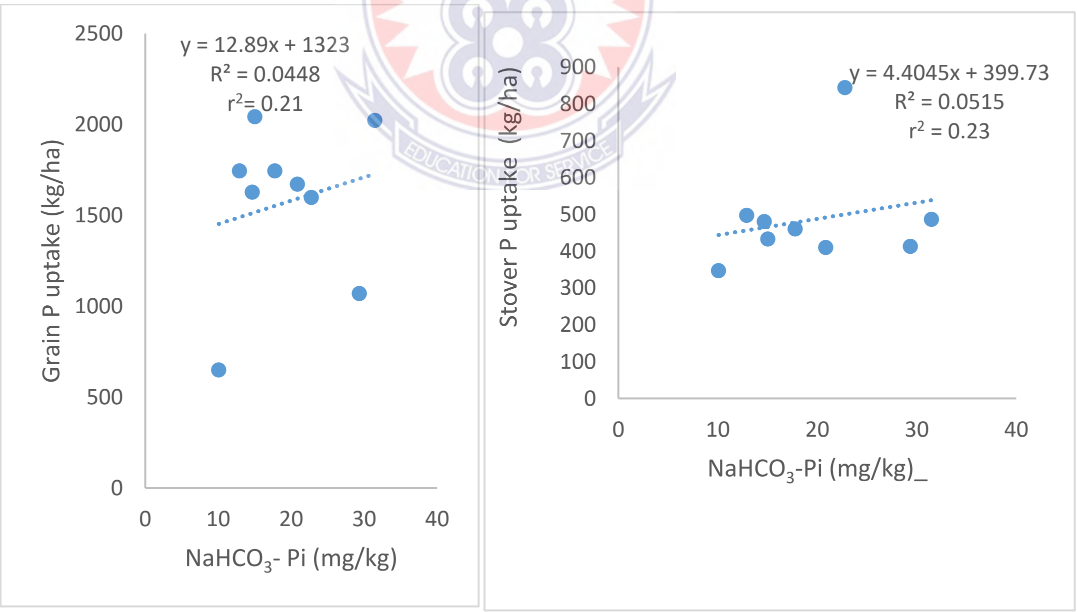
a.

b

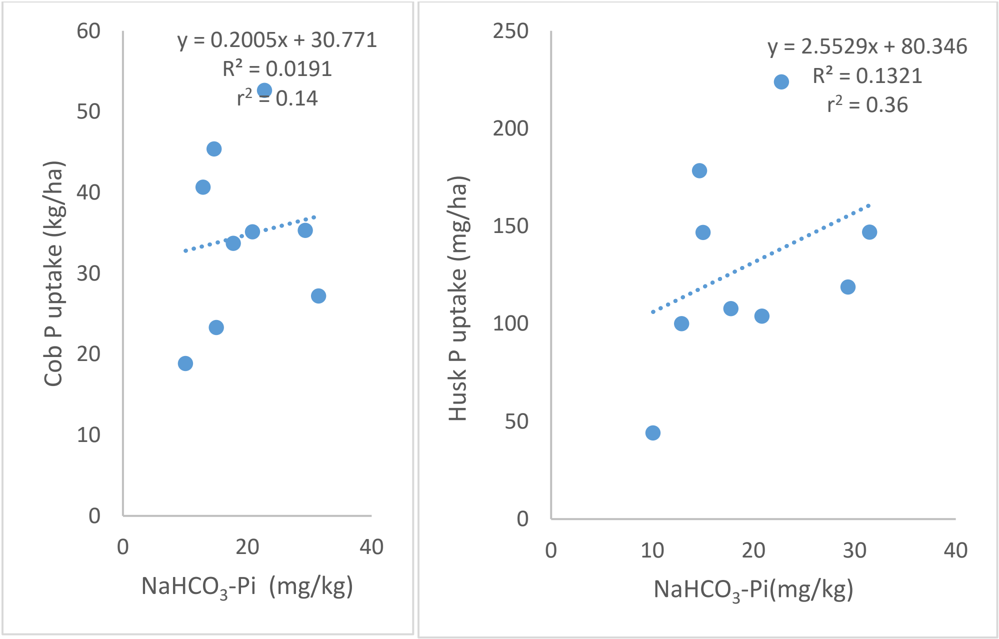


c. d.

Fig. 4.3: Relationship between resin-Pi P and uptakes in Grain, Stover, Cob and Husk in 2018 minor cropping season



a. b.



c d

Fig. 4.4: The relationship between NaHCO$_3$-Pi and P uptakes in Grain, Stover, Cob and Husk in 2018 minor cropping season

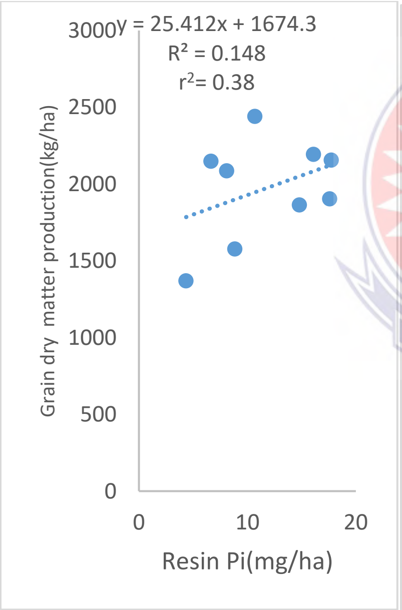
In 2017 minor cropping season, the relationship between the Resin-Pi and the P uptake in Grain, Stover, Husk and Cob followed a positive linear pattern with a weak correlation coefficient (r^2) of 0.27, 0.22, and 0.41 with Grain, Cob and Husk and a moderate correlation coefficient (r^2) of 0.5 with Stover respectively.

The relationship between the NaHCO$_3$-Pi and the P uptake in Grain, Stover, Husk and Cob followed a positive linear pattern with a weak correlation coefficient (r^2) of 0.30, 0.28, 0.11 and 0.20 for grain, stover, husk and cob respectively. In 2018 minor cropping season, it was observed that the relationship between the Resin-Pi and the P uptake in grain, stover, husk and cob followed a positive linear pattern with a weak correlation coefficient (r^2) of 0.31 and 0.49 for grain and cob and a moderate correlation coefficient (r^2) of 0.57 and 0.65 with stover and husk respectively.

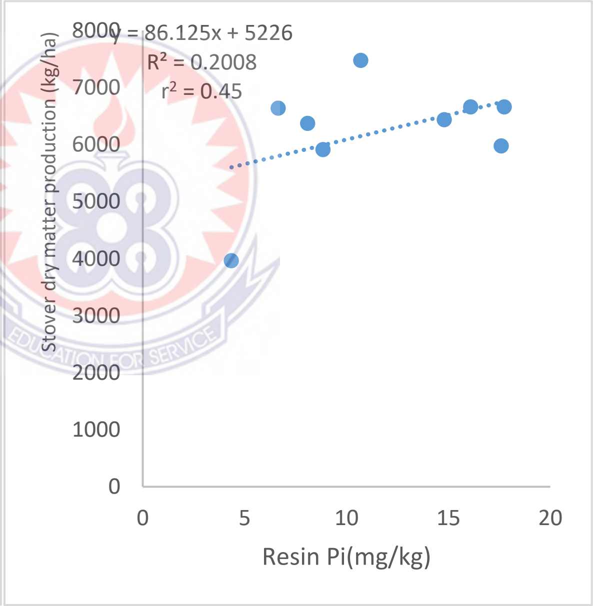
The relationship between the NaHCO$_3$-Pi and the P uptake in grain, stover, cob and husk followed a positive linear pattern with a weak correlation coefficient (r^2) of 0.20, 0.23, 0.14 and 0.36 with grain, stover, cob and husk respectively.

4.11 Relationship between Resin-Pi, NaHCO$_3$-Pi and dry matter production in Grain, Stover, Husk and Cob in the 2017 and 2018 minor cropping seasons

The relationship between Resin-Pi, NaHCO$_3$–Pi concentration and dry matter production in grain, stover, husk and cob in 2017 and 2018 minor cropping seasons are shown in Figs 4.5- 4.8.



a.



b.

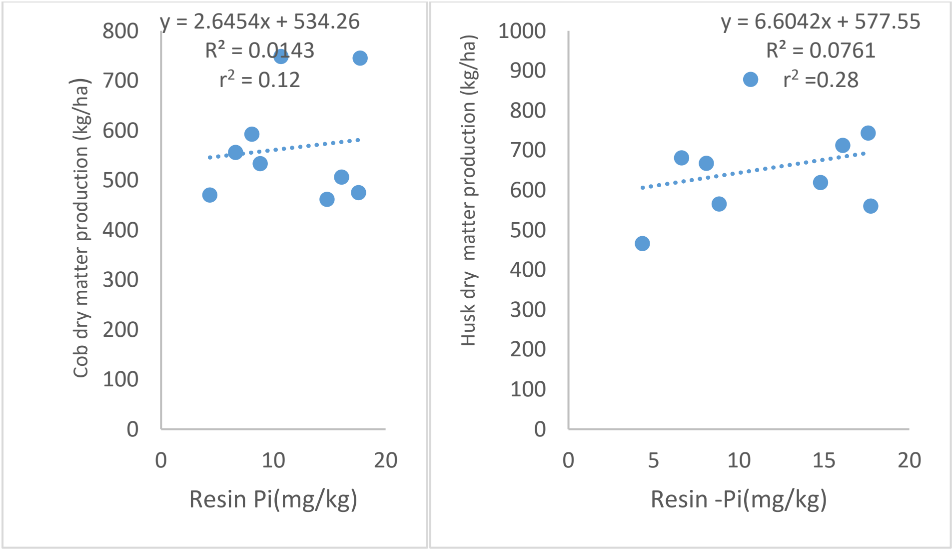


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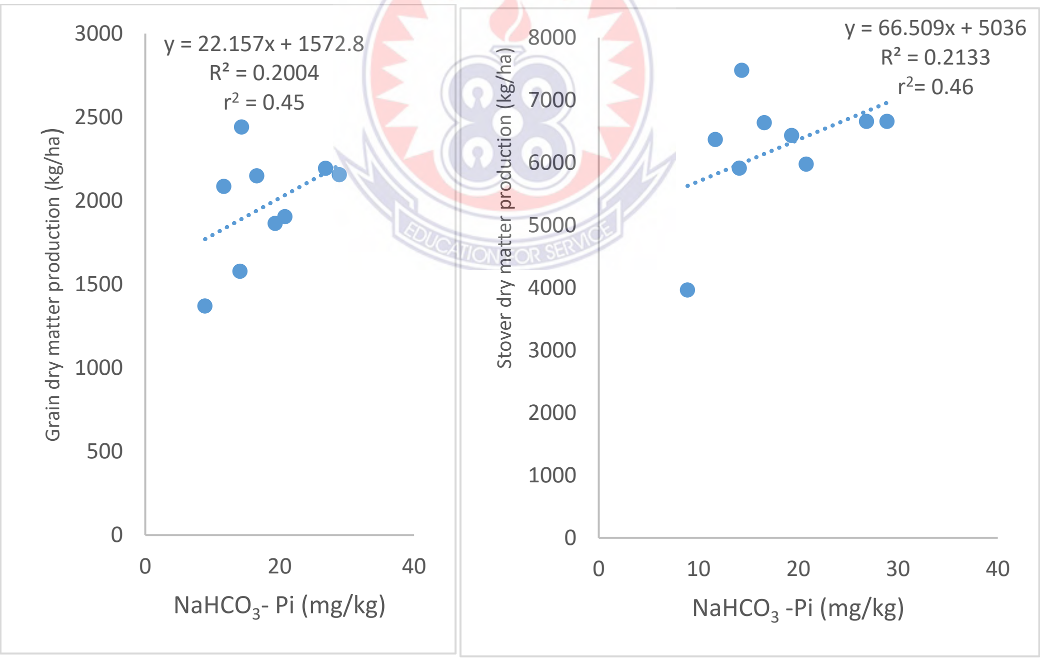
Fig 4.5: The relationship between Resin Pi and dry matter production in Grain, Stover, Cob and Husk in 2017 minor cropping season



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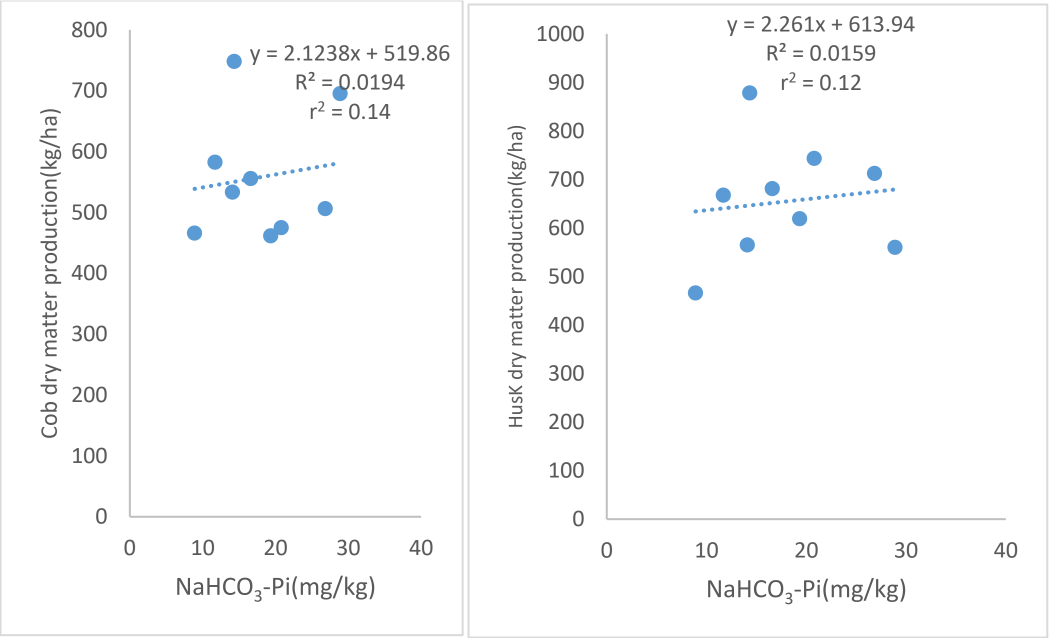

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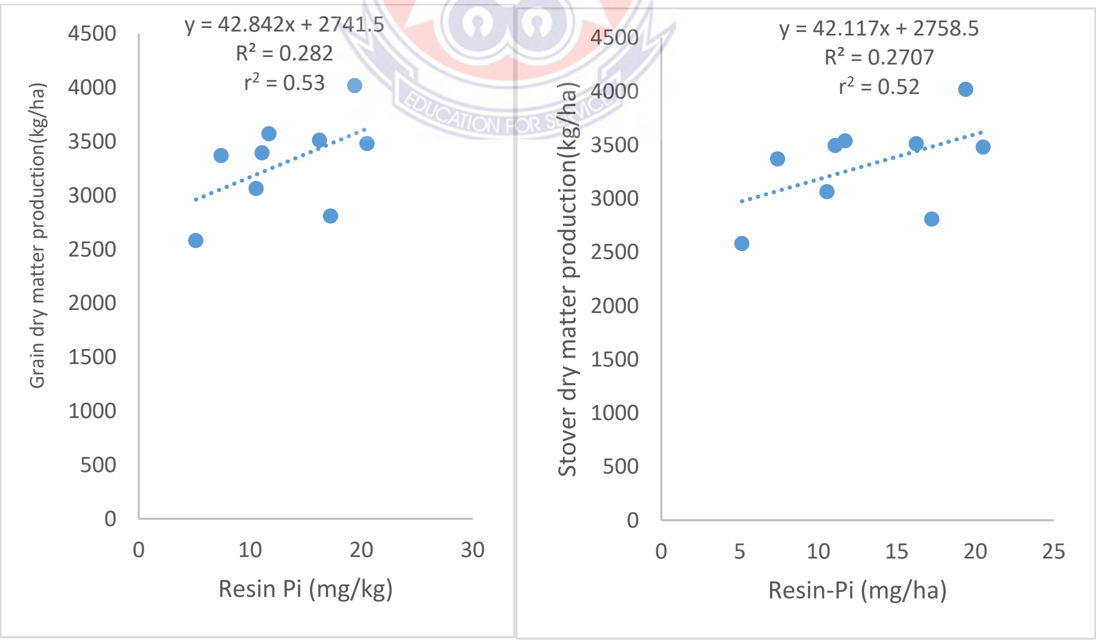
Fig 4.6: Relationship between NaHCO$_3$-Pi and dry matter production in Grain, Stover, Cob and Husk in 2017 minor cropping season



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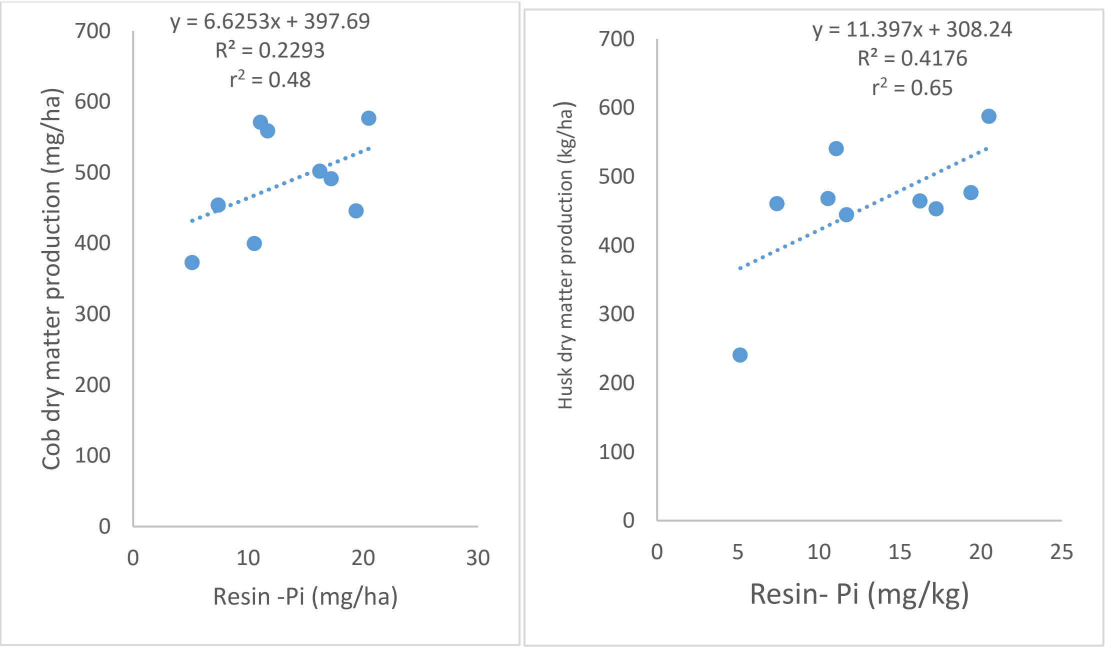

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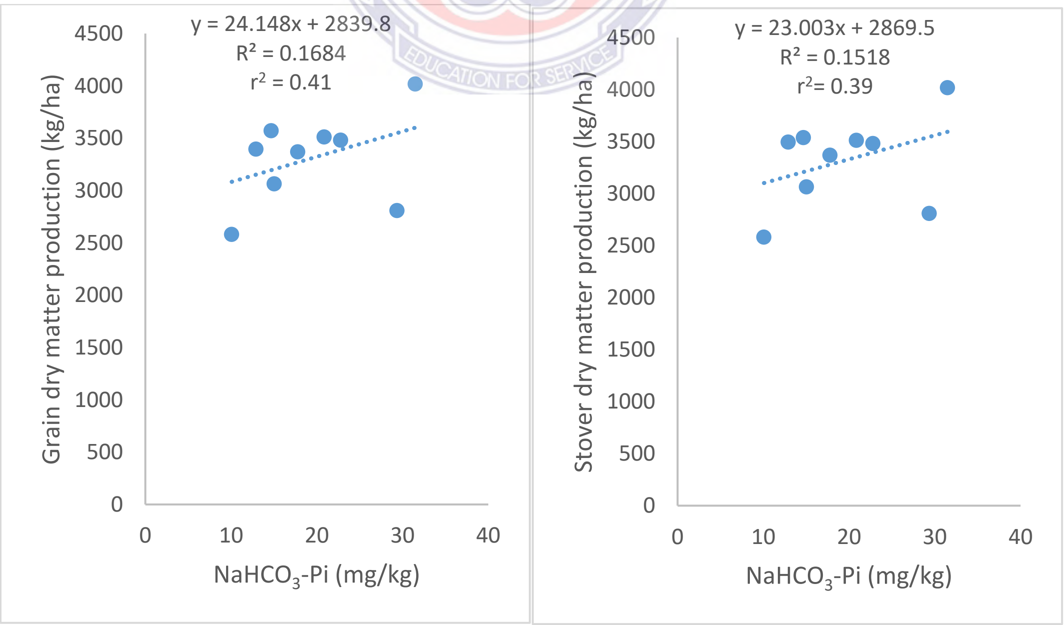
Fig 4.7: Relationship between Risen Pi and dry matter production in Grain, Stover, Cob and Husk in 2018 minor cropping season



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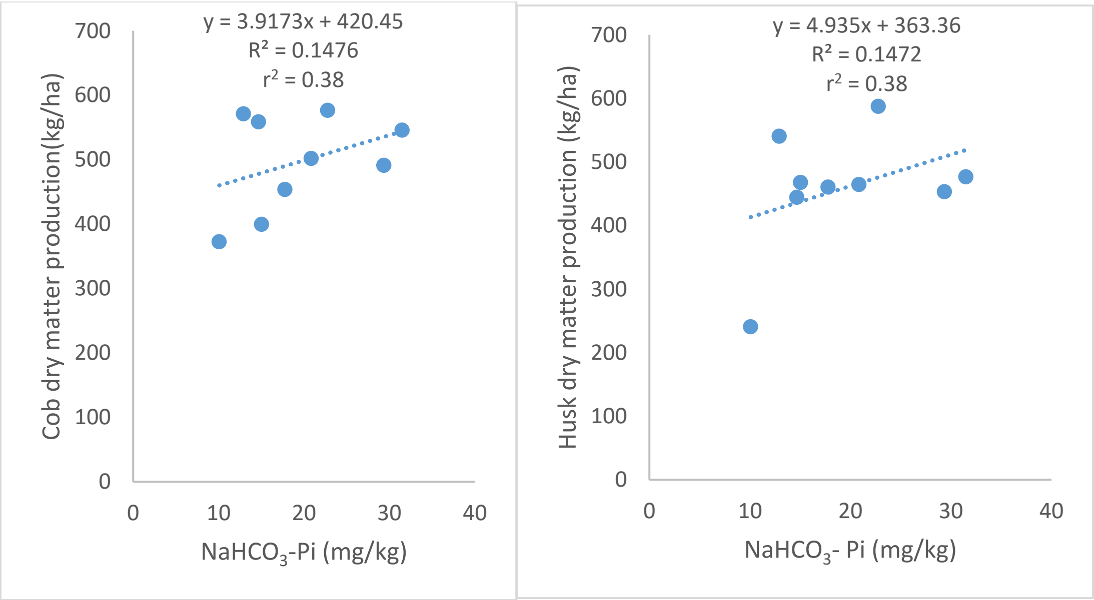

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Fig 4.8: Relationship between $NaHCO_3$-Pi and dry matter production in Grain, Stover, Cob and Husk in 2018 minor cropping season

In 2017 minor cropping season, the relationship between the Resin-Pi and the dry matter production in grain, stover, cob and husk followed a positive linear pattern with a weak correlation coefficient (r^2) of 0.38, 0.45, 0.12, and 0.28 for grain, stover, cob and husk respectively.

The relationship between the $NaHCO_3$-Pi and the dry matter production in grain, stover, cob and husk followed a positive linear pattern with a weak correlation coefficient (r^2) of 0.45, 0.46, 0.14 and 0. 12 for grain, stover, cob and husk respectively. In 2018 minor cropping season, it was observed that the relationship between the Resin-Pi and the dry matter production in grain, stover, cob and husk followed a positive linear pattern with a moderate correlation coefficient (r^2) of 0.53, 0.52, 0.48, and 0.65 with grain, stover, cob and husk respectively.

The relationship between the $NaHCO_3$-Pi and the P uptake in grain, stover, cob and husk followed a positive linear pattern with a weak correlation coefficient (r^2) of 0.41, 0.39, 0.38 and 0.38 with grain, stover, cob and husk respectively.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Initial soil characterization at the experimental site

The overall fertility status of the soil at the experimental site was generally low. Mehlich (1993) employed the use of Mehlich-3 soil test method and interpreted that low soil fertility shows a range of 0 – 24, 0 – 40, 0 – 45 for phosphorus, potassium and magnesium respectively. Thus, these ranges conform to the current study (Table 4.2). The low fertility status of the soil could be attributed to the effects of intensive and continuous cultivation that may aggravate OM oxidation and their consequent leaching or erosion (Pieri, 2012). The pH value of 5.65 exhibited by the soil suggested that it was moderately acidic and was probably dominated by sesquioxide which indicated that the soil had high P fixing capacity (Owusu- Bennoah *et al*., 2000)

The soil was characterized by low organic carbon due to fast decomposition rates of the organic matter as a result of high temperature (Bationo *et al*., 2003). According to Brown *et al*., (2000) the range of temperature for accelerated decomposition of organic matter are 2 °C – 36 °C which conform to the temperature at the study area (Table 4.3a – b). The available P content of the soil which was low (4.65 mg/kg) could be attributed to the high P fixing capacity of the soil. According to Abekoe and Sahrawat (2001), low amount of P in semi- deciduous and evergreen high rain forest (kokofu) could be attributed to low levels of mineral apatite of the parent materials and also Fe and Al phosphate precipitation at low soil pH. The low of exchangeable Cation (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) content may be due to excessive leaching of basic cations down the soil profile (Owusu-Bennoah *et al*., 2000). The low total nitrogen content (0.11 %) as well as low NH_4^-N

(9.33 mg/kg) and NO_3^-N (4.08 mg/kg) of the soil could probable be due to low organic carbon content (Abekoe and Sahrawat, 2001). The electrical conductivity of the soil was low (Table 4.2). This showed that in the study area the low CEC as well as the low EC was an indication of the low nutrient availability. Therefore, farmers can ensure sustainable nutrient management by incorporating organic matter into the soil to improve some of the soil physical properties and fertility of the soil.

5.2 Effect of P sources on Total P uptake, Agronomic P use efficiency, P recovery efficiency and P utilization efficiency

5.2.1 Effect of P sources on Total P uptake

In the two cropping seasons, the total P uptake produced in T5 was consistent throughout (Table 4.3). Probably be due to the percent P contributions of the individual component of the treatment combinations which positively affected the mineralization of organic P source and P availability in the soil. Across the cropping seasons the total P uptake produced in T5 was relatively higher in 2018 than in 2017 probably due to higher rainfall and temperature which enhanced microbial activities and a speedy decomposition and mineralization of organic P source and absorption of phosphorus in plant (Table 4.1). Soil moisture plays a very vital role in decomposition, mineralization of organic matter and absorption of nutrient by plant (Fageria, 2012). However, the amended soils were higher in total P uptake than the un-amended soil. Maize grown in T1 had the lowest total P uptake compared to the rest of the treatments. The deficiency of Zinc in the other treatments inhibited the absorption of phosphorus in both cropping seasons hence resulted in low total P uptake. According to Mousavi (2011), deficiency of zinc inhibits the absorption of phosphorus in maize plant.

In 2017 minor cropping season, the highest total P uptake obtained from T5 was significantly different from the rest of the treatments except T2. Similar trend was observed in 2018 minor cropping season, where T5 which recorded the highest total P uptake of the maize plant was observed not to be significantly different from T2, T3, T4, T6, T8, T9. This was also observed to be significantly different from T7 and T1.

The highest total P uptake may probably be due to the respective % P contribution of TSP in T5 which was 43 % and its effect on the P availability in the soil solution was different from 100 % contribution of TSP from T2 as well as the other integrated P sources. However, over the cropping seasons the rice husk biochar and the compost with variable C/P ratio might have mineralized completely and the slow release of their % P contributions to soil solution for plant use were 7 % and 50 %.

In addition, there was a possible enrichment of the soil with phosphorus from the organic amendments which was a source of available P resulted in the highest total P uptake. These results are in agreement with the findings of Turner (2008) who reported that organic P sources release P slowly which enriched the soil to act as a source of P for plant use.

The slow release of P nutrient from the organic amendments is responsible for the increase in crops yields in the subsequent years (Tittarelli *et al*., 2017). These results are also consistent with the findings of other authors who reported that high total P uptake is as a result of the supply of available P from the combined application of the organic and inorganic amendment (Sandana, 2016; Girma *et al.,* 2017).

5.2.2 Effect of P sources on Agronomic P use efficiency

The agronomic P use efficiency gives an indication of how much grain yield improved in response to the P fertilizer applied. Agronomic P use efficiency which was inconsistent in the two cropping seasons (Table 4.3) probably may be due to the % P contributions of the individual components of the treatment combinations which increased the P availability in soil. But generally, the amendments were better than the control.

In 2017 minor cropping season, the statistical results showed that T2 had the highest agronomic P use efficiency which was statistically different from all the treatments. This may probably be due to the phosphorus rich TSP which contributed 100 % P and quickly dissolved in soil solution for plant use. This enhanced effective root exploitation and growth hence highest agronomic P use efficiency. This is consistent with the findings of Simpson *et al.* (2011) who stated that inorganic fertilizer easily releases available P for plant absorption thereby increase growth and agronomic P use efficiency.

However, in 2018 minor cropping season, it was observed that the highest agronomic P use efficiency was obtained from T8. This was significantly higher than the rest of the treatments. This may probable be due the effect of the inherent soil pH which enhances the effective microbial activities. This accelerated the rate of decomposition and mineralization of organic matter and the released of phosphorus. According to Neina (2019), soil pH controls decomposition and mineralization of organic matter in soils because of its direct effect on the microbial population and their activities (Neina, 2019). The solubility of these organic P sources allowed for more bioavailability of P for plant use and this resulted in the highest agronomic P use efficiency. This is consistent with the findings of Costa *et al*. (2016) who reported that the solubility of organic P sources allow for bioavailability of P in soil solution. Chien *et al*. (2011) also reported that organic P sources decomposed and mineralized to produce available P for plant use which produced better growth and increase agronomic P use efficiency.

The agronomic P use efficiency of the maize produced in 2018 minor cropping season was relatively higher than in 2017 minor cropping season. This might probably be due to higher rainfall and temperature which facilitated the rate of decomposition and mineralization of organic sources and hence the released of phosphorus (Table 4.1). According to Paul *et al.* (2003) decomposition and mineralization rate increased when the soil water content was 60 % -80 % of field capacity. If the moisture content of a soil is optimum for plant growth, plants can readily absorb phosphorus and this promoted the highest agronomic P use efficiency in the 2018 minor cropping season as well as the major season. The deficiency of zinc in the other treatments was a major inhibiting factor for the low agronomic P use efficiency.

5.2.3 Effect of P sources on P recovery efficiency

In both minor cropping seasons, the P recovery efficiency produced was consistent throughout (Table 4.3). This may probably be due to the respective % P contributions of the individual components of the treatment combination. The rice husk biochar and the compost in the combination provide a large surface area for microbial growth and this enhance effective microbial activities and mineralization of organic P source. According to Husni and Samsuri (2012), biochar and compost provide large surface area for microbial growth and this accelerate the rate of mineralization of organic P source for plant P uptake. Across the seasons the P recovery efficiency in 2018 was relatively higher than in 2017 probably due to higher rainfall and temperature (Table 4.1) (2018) and the residual effect of the P nutrient in the soil. However, the amended soils were higher than the un-amended soil.

In 2017 minor cropping season, the highest P recovery efficiency obtained from T5 was not significantly ($P > 0.05$) different from T2, T6 and T8. T5 was however observed to be significantly different from T1, T3, T4, T7 and T9. Similar trend was observed in 2018 minor cropping season, where the maize plant grown in T5 showed the highest P recovery efficiency of the maize plant was observed to be statistically similar to T8 and T9 and was significantly different from T1, T2, T3, T4, T6 and T7. This may be attributed to the respective % P contribution from TSP in T5 which was 43 % and this affected the mineralization of the organic P source and P availability in the soil solution. However, this was different from 100 % contribution of TSP from T2 as well as the other integrated P sources.

The compost over the cropping seasons might have mineralized completely and the slow release of their % P contributions to soil solution for plant use was 7 %. According to Steiner *et al*. (2008), the biochar may enhance microbial growth by providing pores as a refuge or just larger surface to grow on. This may explain why increased plant growth is sometimes only observed a few years after the application of biochar (Major *et al*., 2010). In addition, the nutrient from the organic P source enriched the soil with phosphorus which acted as a source of P for plant use. These results are in agreement with the findings of Turner (2008) who reported that organic P sources release P slowly which enriched the soil to act as a source of P for plant use. The slow release of P nutrient is responsible for the increase in crops yields in the subsequent years (Tittarelli *et al*., 2017). Due to the soil fixation, the enriched soil slowly released P into soil solution for plant uptake. According to Shah *et al*. (2013) integrated use of organic and inorganic P sources enhances better growth, yield and high P recovery efficiency. Integrated P sources were able to meet plants' P demand which was sufficient to improve yield and high P recovery efficiency.

It was observed that the P recovery efficiency obtain from rice husk biochar, compost and triple super phosphate in 2018 minor cropping season was higher than in 2017 minor cropping season. This might probable be due to higher rainfall and temperature. According to Paul *et al.* (2003) soil water content of 60 % - 80 % field capacity encourages microbial activities which promoted high rate of decomposition and mineralization of organic P source hence high phosphorus uptake and high P recovery efficiency.

The P recovery gives farmers an indication of the portion of the phosphorus that the maize plant had absorbed to increase yield as a result of the phosphorus fertilizer applied to the soil (Mengel *et al*., 2006). This is in relation to the current study because the soil is characterized by high P fixing capacity which adsorbed most of the applied P fertilizer and the plant only used a portion of the applied fertilizer for its growth and efficiency.

5.2.4 Effect of P sources on P utilization efficiency

Generally, in the two cropping seasons, there was inconsistency in the P utilization efficiency of the maize plant (Table 4.3). This may probably be due to the % P contributions of the individual component of the treatment combination which positively affected the mineralization of the organic P source and P availability in soil. But generally, the amendments performed better than the control.

In 2017 minor cropping season, it was observed that T4 which produced the highest P utilization efficiency was statistically similar to T2, T3, T6, T7 and T8. T4 was, however significantly different from T1, T5 and T9. This could be attributed to the fact that the % P contribution from TSP in T4 was 70 % and was different from the 100 % P contribution from the TSP in T2 as well as the rest of the inorganic P sources. Over the cropping seasons the compost and the empty fruit bunch with variable C/P would have completely mineralized and correspondingly their % P contributions were 18 % and 12 % respectively which were different from the organic amendments in other integrated P sources. This enhanced effective root development and growth hence resulted in highest P utilization efficiency. This is consistent with the findings of Reddy *et al*. (1999) who reported that integrated use of organic and inorganic fertilizer promotes effective root utilization, growth and increase P utilization efficiency in maize plant.

In 2018 minor cropping season, maize grown in T8 showed the highest P utilization efficiency and was statistically similar to T2 and T4. However, T8 was significantly ($P < 0.05$) different from T9, T7, T6, T5, T3 and T1. However, over the cropping seasons, the compost would have mineralized completely and their % P contributions together with the rock phosphate were 9 % and 42 %. The biochar may enhance microbial growth by providing pores as a refuge or just larger surface to grow on (Steiner *et al*., 2008). This may explain why increased plant growth is sometimes only observed a few years after the application of biochar (Major *et al*., 2010). The phosphorus in microbial biomass is probably not directly available to plants, but may become available as the microbes die. The solubility of these organic P source allowed for more bioavailability of P for plant use and this resulted in the highest P utilization efficiency. This is consistent with the findings of Costa *et al*. (2016) who reported that the solubility of organic P sources allow for bioavailability of P.

T9 recorded the lowest value after control. This may be due to the low soil P availability for plant use as a result of conversion of soluble P into insoluble Al and Fe phosphate in the experimental soil. Applied phosphorus absorbed by plants root is considerable small because most form complexation with Fe and Al oxide in acid soils (Toro, 2007).

Due to the higher rainfall and temperature recorded in 2018 relative to 2017 minor cropping season, the P utilization efficiency was high (Table 4.1). Microbial activities were enhanced and this promoted high rate of decomposition, mineralization and release of P nutrient and utilization by plant. The yield increase in relation to the increase in P crop uptake in the above parts of the plant gives an indication of the P utilization efficiency of the maize plant (Rose and Wissuwa, 2012).

5.3 Effect of P sources on P harvest index

The P harvest index was inconsistent throughout the cropping seasons (Table 4.4). This might be attributed due to the % P contributions of the individual component of the treatment combination which affected the mineralization of the organic P source and the P availability in the soil. However, the maize plant grown in the amended plots performed better than the control.

In 2017 minor cropping season, T3 produced maize plant with the highest P harvest index and which was significantly higher but statistically ($P \geq 0.05$) similar to T2, T4, T6, T8 and T9. This could be attributed to the fact that the % P contribution from TSP in T3 was 76% and was different from the 100% P contribution from TSP in T2 as well as the rest of the integrated P sources.

Over the cropping seasons, as the pH increased the microbial activities also increased and this resulted in the complete mineralization of the empty fruit bunch mulch. According to Curtin *et al*. (1998), the mineralizable fractions of C and P increase because the bond between organic constituents and clays is broken as result of high soil pH. Therefore the % P contribution of the mineralized empty fruit bunch mulch was 24 % and was different from the organic amendments in other integrated P sources.

This enhanced extensive root system and efficient P uptake as well as P translocation to the plant organs which resulted in the highest P harvest index (Mazlouzi *et al*., 2020). This is consistent with the findings of other authors who reported that integrated P sources promote better phosphorus uptake and shows the efficiency of converting biological yield into economic yield (Kusalkar *et al*., 2003; Rengel, 1999).

In 2018 minor cropping season, the highest P harvest index was obtained from T9. T9 was significantly higher than the rest of the treatments but was statistically similar to T8, T6 and T5. However, over the cropping seasons, due to the pH effect on the microbial activities, the empty fruit bunch, the compost would have mineralized completely and coupled with the rock phosphate, the slow released of their % P contributions were 49 %, 9 % and 42 % and the solubility of the nutrient from the organic P sources allowed for more bioavailability of P for plant use and this resulted in the highest P harvest index. This is consistent with the findings of Costa *et al*. (2016) who reported that the solubility of organic P sources allow for bioavailability of P. The slow release of P nutrient from the organic P source is responsible for the increase in crops yields in the subsequent years (Tittarelli *et al*., 2007). The effective P uptake and P translocation to the maize organs resulted in the highest P harvest index. These results are also in accordance with the findings of other researchers who stated those organic P sources which promote high efficiency of P fertilization depends on P uptake from the soil and P translocation to plant organs (Rengel 1999; Kusalkar *et al*., 2003).

Generally, the higher rainfall and temperature (Table 4.1) as well as the residual effect of the P nutrient in 2018 minor cropping season promoted higher P harvest index relative to 2017 minor cropping season.

5.4 Effect of P sources on Total Dry Matter production and Grain Yield of the maize plant in 2017 and 2018 minor cropping seasons

5.4.1 Effect of P sources on Total Dry Matter Production

Throughout the two cropping seasons, the total dry matter production of maize grown in T2 was consistent (Table 4.5). Probably due the % P contributions of the individual component of the treatment combination which had effect on P availability in the soil. However, the amended soils were higher than the un-amended soil. The total dry matter production in 2018 was relatively higher than in 2017 probably due to higher rainfall and temperature (Table 4.1).

In 2017 and 2018 minor cropping seasons, the statistical results showed that the highest total dry matter production obtained from T2 was significantly higher than the values of the other treatments ($P < 0.05$). This may be attributed to the 100% contribution of the phosphorus rich triple superphosphate which readily dissolved to supply more available

P in soil solution for plant use. This enhanced effective root exploitation and P uptake as well as greater availability of photosynthates, metabolites which resulted in the highest total dry matter production. This is inconsistent with the findings of Mashori *et al.* (2013), who reported that integrated use of organic and inorganic P fertilizer promotes growth, yield and yield components of maize plant hence high total dry matter production. The integrated P fertilizers are able to sustain the maize plant throughout its vegetative and reproductive growth stages.

Therefore, our findings prove that the triple superphosphate was more efficient in improving total dry matter production in 2017 and 2018 minor cropping seasons. The presence of Zn deficiency in the other treatments might have inhibits growth, yield and total dry matter production. According to Eteng *et al.* (2014) Zn deficiency is an inhibiting factor in growth, yield and total dry matter production in maize.

5.4.2 Effect of P sources on maize grain yield

Throughout the two cropping seasons, the grain yield produced was inconsistent (Table 4.1). Probably due the % P contributions of the individual component of the treatment combination which had a positive effect on the mineralization of organic P and P availability in the soil. Maize grown in 2018 was relatively higher than in 2017 which may be attributed to higher rainfall and temperature (Table 4.1)

In 2017 minor cropping season, the maize plant grown in T2 produced the highest grain yield and was significantly higher than the rest of the treatments. This may be attributed to the 100 % contribution of the phosphorus rich triple superphosphate which readily dissolved to supply more P bioavailability in soil solution for plant use. This enhanced effective root exploitation and P uptake as well as greater availability of photosynthates, metabolites which resulted in the highest total dry matter production. This is inconsistent with the findings of Mashori *et al.* (2013), who reported that integrated use of organic and inorganic P fertilizer promotes growth, yield and yield components of maize plant hence high total dry matter production.

However, in 2018 minor cropping season, the highest grain yield predominated in T8. T8 was however significantly higher than the rest of the treatments. This could be attributed to the fact that over the cropping seasons, as the pH increased the microbial activities also increased and this resulted in the complete mineralization of the empty fruit bunch mulch. According to Curtin *et al*. (1998) the mineralizable fractions of C and P increase because the bond between organic constituents and clays is broken as result of high soil pH. Therefore, the compost, the rice husk biochar would have completely mineralized and coupled with the rock phosphate, their % P contributions towards the available P in soil solution was 9 %, 49 % and 42 %. This enhanced efficient root exploitation, effective P uptake and P translocation which resulted in the highest gain yield. This is consistent with the findings of Ojiem *et al.* (2004) who stated that the combined application of organic and inorganic P fertilizer promotes growth and increased grain yield.

The low maize yield in the other treatments might probably be due to the lack or insufficient supply of Zn. According to Subedi and Ma (2009) due to the physiological role of Zn in maize, lack or an insufficient supply of Zn reduces maize yield by 10 %.

5.5 Effect of P sources on growth parameters of Maize plant

5.5.1 Effect of P sources on Plant height

Maize grown in T2 was observed to produce the highest plant height throughout the two cropping seasons (Table 4.5a-b). Plant heights of maize from the amended soils were higher than those in the control. In 2017 minor cropping season, it was observed that plant height obtained from T2 at 8 WAP was the highest and was statistically different from the control. T2 however, was observed not to be significantly different from T3, T4, T5, T6, T7, T8 and T9. This could be due to the % P contribution of the TSP which dissolved quickly to release more available P into soil solution to improve root development and P absorption. This greatly affected the overall plant growth performance which eventually resulted in the tallest plant height at 8 WAP. According to Adebo and Olaoye (2010) 8 WAP represent one of the vegetative stages of growth and development of maize plant.

Also, at 12 WAP, the available P from the T2 continuously supported the growth of the plant and this resulted in tallest plant height. These findings are consistent with the findings of previous researchers who reported that application of inorganic P fertilizer promote growth and increase plant height (Memon and Puno, 2005; Dewal and Pareek, 2004).

In 2018 minor cropping season, it was observed that the highest plant height of maize was predominant in T2. T2 was however not significantly ($P > 0.05$) different from T3, T4, T5, T6, T7 and T8. T2 was also observed to be significantly different from T9 and T1. This observation could be attributed to the TSP as a readily source of P in releasing available P faster in soil solution for plant use. This enhanced effective root exploitation and overall growth performance of the maize plant and this resulted in highest plant height at 8 WAP.

Also, at 12 WAP, the available P from the T2 sustainably supported the plant throughout its growth stages hence resulted in highest plant height. The results are consistent with the findings of other researchers who reported application of inorganic P fertilizer promote growth and increase plant height (Memon and Puno, 2005; Dewal and Pareek, 2004). According to Adetimirin *et al*. (2000) 12 WAP represent one of the reproductive stages of growth and development of maize plant.

The plant height produced in 2018 minor cropping season were generally higher than in 2017 minor cropping season. This may be attributed to the residual effect of the P as well as higher rainfall and temperature (Table 4.1). The low maize yield in the other treatments might probably be due to the lack or insufficient supply Zn. According to Subedi and Ma (2009) due to the physiological role of Zn in maize, lack or an insufficient supply of Zn reduces maize yield by 10 %.

5.5.2 Effect of P sources on chlorophyll content

Maize grown in T2 was observed to produce the highest plant height throughout the two cropping seasons (Table 4.5). Chlorophyll content of maize from the amended soils was higher than those in the control. In 2017 and 2018 minor cropping season, T2 produced maize plants with the highest chlorophyll content at 8 WAP and 12 WAP. T2 was, however, not significantly different from T3, T4and T5 at 8 WAP but it was observed to be significantly different from T1, T6, T8 and T9. Similarly, at 12 WAP, T2 was observed to be significantly ($P < 0.05$) different from T1, T3, T6, T7, T8, T9 and statistically similar to T4.

This may be due to the 100 % P contribution of the triple superphosphate to produce more bioavailability of P in soil solution P for plant use. This enhanced growth and overall performance of the plant hence resulted in highest chlorophyll content at 8 WAP. According to Adebo and Olaoye (2010) 8 WAP represent one of the vegetative stages of growth and development of maize plant.

Furthermore, at 12 WAP the triple superphosphate efficiently supported the maize plant throughout its growth stage hence resulted in the highest chlorophyll content. According to Adetimirin *et al*. (2000) 12 WAP represent one of the reproductive stages of growth and development of maize plant.

The results were consistent with the findings of Wamalwa *et al.* (2019), who reported that inorganic P fertilizer increased yield and chlorophyll content of maize plant. The chlorophyll contents of the maize plants produced in 2018 minor cropping season were relatively higher than in 2017 minor cropping season. Probable reason could be the higher rainfall and temperature (Table 4.1). The presence of Zn deficiency in the other treatments might have inhibits growth, yield and chlorophyll content in maize. According to Eteng *et al*. (2014) Zn deficiency is an inhibiting factor in growth, yield and chlorophyll content in maize.

5.6.3 Effect of P sources on stem diameter

Maize grown in T2 was observed to produce the highest stem diameter throughout the two cropping seasons (Table 4.5). Stem diameter of maize from the amended soils was higher than those in the control.

In 2017 minor cropping season, from the statistical result it was observed that T2 produced maize plant with the highest stem diameter. This could be attributed to the effectiveness of the inorganic P fertilizer in treatment two as compared to the other treatment combinations to easily released readily available P in soil solution which improved root development and P absorption. This eventually impacted greatly on the plant growth performance which resulted in the highest stem diameter at the 8 WAP. However, at 12 WAP, the available P obtained from the inorganic P fertilizer sustainably supported the growth of the maize plant throughout its growth hence resulted in highest stem diameter of the maize plant.

In 2018 minor cropping season, treatment two produced a maize plant with the highest chlorophyll content. This may be attributed to the triple superphosphate which was a phosphate rich salt and therefore release more available P in the soil for effective root exploitation and P uptake. This resulted in overall maize performance which resulted in the highest stem diameter at 8 WAP. At 12 WAP, the available P from the inorganic P fertilizer continuously supported the maize plant throughout its growth stages. Hence resulted in the highest stem diameter of the maize plant. The results are consistent with the findings of Law-Ogbomo and Law-Ogbomo (2009) who stated that inorganic P fertilizer promotes growth and overall plant performance hence increased stem diameter of maize plant.

The stem diameters of the maize plants produced in 2018 minor cropping season were relatively higher than in 2017 minor cropping season. This may be attributed to the residual effect of the P as well higher rainfall and temperature recorded in 2018 relative to 2017 minor cropping season (Table 4.1). Microbial activities were enhanced and this promoted high rate of decomposition, mineralization and release of P nutrient and utilization by plant hence resulted in higher stem diameter.

5.5.4 Effect of P sources on Leaf Area

Maize grown in T2 was observed to produce the highest leaf area throughout the two cropping seasons (Table 4.6). Leaf area of maize from the amended soils was higher than those in the control. In 2017 minor cropping season, from the statistical result it was observed that T2 produced maize plant with the highest leaf area and was statistically similar to all the treatments except T1. This could be attributed to the efficacy of the triple superphosphate in T2 to quickly dissolve and release readily available P in soil solution which improved root development and P absorption. This impacted greatly on the overall plant growth performance which resulted in the highest leaf area at 8 WAP.

However, at 12 WAP, T2 which was statistically similar to T3 and T5 was also observed to be significantly different from T1, T2, T3, T7, T8 and T9. This may be due to the available P from the inorganic P fertilizer which was able to support the plant throughout its growth stage hence resulted in the highest leaf area.

In 2018 minor cropping season, treatment two which produced a maize plant with the highest leaf area was not significantly different from T3, T4 and T7. This was however significantly different from treatments T1, T5, T6, T8 and T9. This may be due to the efficacy of the phosphate rich triple superphosphate to quickly dissolve in soil solution to release more available P for effective root exploitation and P uptake. This enhanced the overall maize performance which resulted in the highest leaf area at 8 WAP. At 12 WAP, T2 which was observed to be statistically similar to T3, T4, T5 and T7 was also observed to be significantly different from T9, T8, T6 and T1. This could be attributed to the fact the available P from the inorganic P fertilizer was able to support the maize plant throughout its growth stage. Hence resulted in the highest leaf area of the maize plant.

This result agreed with the findings of Okwuowulu (1995) who reported that inorganic P fertilizer promotes growth, yield and increased leaf area of maize plant. Leaf area of maize plants produced was higher in 2018 cropping season than in 2017 cropping season, probably due to the residual effect of the P as well as higher rainfall and temperature (Table 4.1).

5.5.5 Effect of P sources on Number of Leaves

Maize grown in T2 was observed to produce the highest number of leaves throughout the two cropping seasons (Table 4.6). Number of leaves of maize from the amended soils was higher than those in the control. Probably due to the 100% P contribution of the TSP to available P in soil solution.

In 2017 minor cropping season, maize grown in T2 produced the highest number of leaves. It was observed that T2 was significantly different from the rest of the treatment at 8 WAP. Similarly, at 12 WAP, treatment two was significantly different from T1, T2, T3, T4, T6, T8 and T9. This was however not significantly different from T5 and T7.

Probable reason might be that the triple superphosphate was more efficient in dissolving quickly in soil solution for plant use as compared to the rest of the treatments. This enhanced growth and overall performance of the plant hence resulted in highest number of leaves at 8 WAP. Furthermore, due to the efficacy of the triple superphosphate the available P produced continuously supported the maize plant throughout its growth stages hence resulted in the highest number of leaves at 12 WAP. This result is agreeable with the findings of other authors who reported that inorganic P fertilizer promotes yield and luxuriant growth of leaves (Stefano *et al.,* 2004; Masood *et al.,* 2011).

In 2018 minor cropping season, the highest number of leaves of maize plant produced was recorded in treatment two. At 8 WAP treatment two was observed to be significantly different from T1 and T9 and statistically similar to T3, T4, T5, T6, T7 and T8. Similarly, T2 was however significantly different from T7 but it was statistically similar to T1, T3, T4, T5, T6, T8 and T9 at 12 WAP. This probably may be due to the 100 % P contribution of the triple superphosphate which dissolved quickly to increase the bioavailability of P in soil solution for plant use. This enhanced effective root exploitation and P uptake hence resulted in the highest number of leaves at 8 WAP. Similarly, at 12 WAP, due to the efficacy of the triple superphosphate, the maize was supported throughout its growth stages to develop luxuriant leaves. This observation was consistent with the findings of other authors who reported that inorganic P fertilizers promote yield and luxuriant growth of leaves (Stefano *et al.,* 2004; Masood *et al.,* 2011).

Generally, the observation that the number of leaves of maize plant was higher in 2018 minor cropping season than in 2017 minor cropping season may be attributed to the residual effect of the P nutrient in the soil as well higher rainfall and temperature (Table

4.1). According to Paul *et al.* (2003) soil water content of 60 % – 80 % field capacity encourages microbial activities which promoted high rate of decomposition and mineralization of organic P source hence high phosphorus uptake and more number of leaves.

5.5.6 Effect of P sources on Number of ears

Maize grown in T2 produce the highest number of ear throughout the two cropping seasons (Table 4.6). The amendments did well than the un-amended soil. In 2017 and 2018 minor cropping seasons, the highest number of ears of maize plant was predominant in T2. At 8 WAP it was observed that T2 was significantly similar to T3, T4 and T5. However, this was significantly different from the control. Similarly, at 12 WAP, treatment two was statistically similar to T4 and T7. However, it was observed to be significantly different from T1, T6, T7, T8 and T9. This may be attributed to the 100 % P contribution of the TSP to effectively dissolve in soil solution to promote growth, yield which resulted in the highest number of ear of maize at both 8 WAP and 12 WAP. This observation was at variance with the findings of other authors, who reported that integrated use of organic and inorganic P fertilizer promotes growth, yield and increased number of ear of maize plant (Makinde and Ayoola 2010; Yosefi *et al*., 2011).

Ear numbers of maize plants produced were higher in 2018 cropping season than in 2017 cropping season may be due to high rainfall and the residual effect of the P as well as higher rainfall and temperature (Table 4.1)

5.6 Effect of amendments on soil chemical properties in 2017 and 2018 minor cropping seasons

5.6.1 Effect of amendments on Exchangeable Calcium

Throughout the two cropping seasons, the exchangeable calcium was observed to be inconsistent (Table 4.6). According to Bartram *et al.* (2014), typical soils of pH range of 3.0 to 5.5 are dominated by fungal communities and this increases the microbial activities. This process resulted in the increase in the rate of decomposition and the mineralization of the organic amendments which released locked up Calcium in the tissue and the Calcium from the TSP in the soil. However, the amendments were better than the un-amended soils.

In 2017 minor cropping season, it was observed that the highest exchangeable Calcium obtained in T5 was significantly ($P < 0.05$) higher than the rest of the treatment. However, in 2018 minor cropping season, the highest exchangeable Calcium recorded in T6 was significantly ($P < 0.05$) higher than the other treatments.

This might due to the fact that over the cropping seasons the organic amendments might have decomposed and mineralized completely to released locked up Calcium in its tissues and coupled with the Calcium from the TSP increased the pool of exchangeable Calcium in the soil from 2.31 Cmol/kg to 23.53 and 25.01 Cmol/kg in 2017 and 2018 respectively (Table 4.6). This might have resulted in the highest exchangeable Calcium in the soil. Calcium influences the availability of P depending on the pH. High pH was an indication that more Calcium was available and therefore there was an adsorption which led to Calcium-Phosphate complexation which reduced the bioavailability of P in soil solution.

Conversely when the pH is low Ca phosphates are unstable and in favourable conditions, P can form precipitates with Al and Fe instead of Ca.

This result is in line with the findings of other authors who stated that different amendments contain significant amount of Calcium which increased the Calcium pool and bind P to insoluble forms and therefore P precipitate as Calcium phosphates reducing its availability (Shrivastava and Kumar, 2015; Fageria *et al*., 2011; Niste *et al*., 2014).

5.6.2 Effect of amendments on Cation Exchange Capacity

The variation in CEC produced was inconsistent throughout the two cropping seasons (Table 4.7). This might be attributed to the decomposition and the mineralization of organic amendments which released locked up Cations in the tissues thereby increased the CEC in the soil. Across the seasons, the CEC produced in 2018 minor cropping season was relatively higher than in 2017 minor cropping season. Probably due to the residual effect of the basic cations in the soil. However, the amendments were better than the control.

In 2017 minor cropping season, the highest CEC was predominant in T8. T8 was however statistically similar to T5 and significantly ($P < 0.05$) different from the other treatments. However, in 2018 minor cropping season, T5 which enhanced the highest CEC was statistically similar to T8. This was, however, significantly different from T9, T7, T6, T4, T3, T2 and T1. This may be attributed to the fact that over the cropping seasons, the organic amendments from T5 and T6 might have decomposed and mineralized completely to release more cations which increased the pool of CEC in the soil. This might have resulted in the highest CEC in the soil. According to Bartram *et al.* (2014), typical acidic soils of pH range of 3.0 to 5.5 are dominated by fungal communities and this increases the microbial activities. This process coupled with increased temperature resulted in the increase in the rate of decomposition and the mineralization of the organic amendments. Increase in soil temperature increases the soil phosphorus mineralization rates due to the increase in microbial activity and increase in the decomposition of organic matter in the soil (Von Lutzow and Kogel-Knabner, 2009)

These findings are consistent with the findings of Larney and Angers (2012) who reported that the increase in CEC may primarily be due to the long-lasting decomposition process of organic amendments.

5.6.3 Effect of amendments on soil pH

The pH of the soil obtain in T5 was consistent throughout the two cropping seasons. Probably due to the decomposition of the organic amendments which produced organic acids which caused a decreased in the pH of the soil. However, across the seasons, the pH of the soil produced in 2018 minor cropping season was relatively higher than in 2017 minor cropping season. This could be attributed to the residual effect of the basic cations (Eckert, 1987) as well as higher rainfall and temperature.

In 2017 minor cropping season, the highest pH was obtained from T5 and was observed not to be significantly different from T8. However, it was also observed to be significantly different from T9, T7, T6, T4, T3, T2 and the control.

Similarly, in 2018 minor cropping season, T5 which promoted the highest pH was not statistically similar to T8. However, this was observed to be significantly different from T9, T7, T6, T4, T3, T2 and control. Yaduvanshi (2001) observed a decrease in soil pH after the use of organic materials which was attributed to the production of organic acid (amino acid, glycine, humic acid) during mineralization (ammonization and ammonification) of organic materials by heterotrophs and this caused a decrease in soil pH. Similar observation was made by Walker *et al.* (2003) who reported that addition of compost decreases soil pH. However, these observations were contrary to the current result which reported that the addition of empty fruit bunch mulch increased the soil pH. This is consistent with the findings of Angelova *et al*. (2013) who reported that the addition of vermiompost increased soil pH and the pH increased with the higher dose of vermiompost. Also, the addition of organic amendments such as green waste compost and sedge peat increased soil pH probably due to the high content basic cations (Pocknee and Sumner, 1997). This might have resulted in the highest pH in T5.

5.6.4 Effect of amendments on organic carbon (OC)

It was observed that throughout the two cropping seasons, the organic carbon was inconsistent (Table 4.6). Across the seasons, the organic carbon of the soil in 2018 minor cropping season were higher than in 2017 minor cropping season. This could be attributed to attribute the residual effect of the organic carbon in the soil and higher temperature and rainfall recorded in 2018 (Table 4.1). However, all the amended soils performed significantly better than the un-amended soil.

In 2017 minor cropping season, the highest OC obtained in T9 was observed not to be significantly different from T8. However, this was observed to be significantly different from the rest of the treatment. However, in 2018 minor cropping season, the highest organic carbon obtained from T8 was statistically similar to treatment five. However, this was significantly different from T9, T7, T6, T4, T3, T2 and the control. According to Angelova *et al*. (2013) the increase in soil organic carbon with the addition of organic amendments to soil is caused by high organic matter content of compost and vermicompost. The application of organic amendments led to a significant increase in organic carbon content, compared to its initial level. This is consistent with the current findings that the addition of organic amendments such as compost, and empty fruit bunch mulch to the soil led to a significant increase in organic carbon compared to its initial level (Table 4.6). Fortuna *et al.* (2003) also argued that the vermicompost amendment could increase the carbon contents up to 45 g.kg^{-}1 of the original levels, and thus contribute to increase the soil structural stability, particularly that of the macro-aggregates.

5.6.5 Effect of amendments on Total Phosphorus in the soil

It was observed that throughout the seasons, the total phosphorus was inconsistent (Table 4.6). Probably due to the % P contributions of the individual component of the treatment combinations which positively affected the mineralization of organic P sources and P availability in the soil. Soil pH controls decomposition and mineralization of organic matter in soils because of its direct effect on the microbial population and their activities (Neina, 2019). Generally, the total phosphorus produced in 2018 minor cropping season were higher than in 2017 minor cropping season probably due to the higher rainfall and temperature (Table 4.1) as well as the residual effect of the P nutrient in the soil. However, the amended soils did better than the control.

In 2017 minor cropping season, T9 which produced the highest total P was observed to be significantly ($P < 0.05$) different from all the treatments. This may be attributed to the fact that over the cropping seasons the compost as well as the empty oil palm fruit bunch mulch would have completely mineralized and coupled with the rock phosphate the slow release of their % P contributions to available P were 21 % and 20 % and 59 % respectively which affected the availability of P and resulted in the highest total P of the soil.

In 2018 minor cropping season, T8 produced the highest total phosphorus which was significantly different from the other treatments. However, the replacement of the empty oil palm fruit bunch with biochar almost doubled the % P contributions of the components of treatment eight which resulted in the highest total phosphorus in the soil. This result is consistent with the findings of Chan *et al.* (2007) who reported that rice husk biochar has a native phosphorus and therefore can directly release soluble P and increase its bioavailability in soil solution.

5.7 Effect of P sources on P pools

5.7.1 Effect of P sources on Labile P pools

The labile P, defined as the Resin-P and $NaHCO_3$-P are plant available P. According Gatiboni *et al*. (2007), resin-Pi and $NaHCO_3$- Pi represent the P forms considered as labile and have a similar buffering capacity as P absorbed by the plants.

The resin-Pi was inconsistent throughout the two cropping seasons probably due to the % P contributions of the individual component of the treatment combinations which positively affected the mineralization and P availability of the soil (Table 4.7). Across seasons, 2018 minor **c**ropping season was always observed to be higher than 2017 minor **c**ropping season probably due to the residue effect of the P nutrient as well as higher temperature and rainfall (Table 4.1). However, the amendments were better than the control.

In 2017 minor cropping season, the highest resin-Pi which was predominant in T8 was statistically similar to T7, T5 and T4. However, over the cropping seasons, the biochar, the compost would have mineralized completely and their % P contributions together with the rock phosphate were 49 %, 9 % and 42 % and also the degree of solubility of these organic P sources which allowed for more bioavailability of P for plant use. This resulted in the highest resin Pi.

Also, in 2018 minor cropping season, the highest resin-Pi which was predominated in T5 was observed not to be significantly different from treatments T7 and T8. This was, however, significantly different from T1, T2, T3, T4, T6 and T9. Similarly, T5 and T8 were also observed to promote the highest CEC and organic carbon.

In 2017 and 2018 minor cropping seasons, T8 was observed to produce the highest $NaHCO_3$- Pi and was significantly ($P < 0.05$) different from all the treatments except T7. However, T8 was also observed to promote the highest CEC and organic carbon which was statistically similar to T5. Similar observation was done by Eduah *et al.* (2019) who reported that the interaction of biochar with soils resulted in an increase in the readily available P (Resin–P & $NaHCO_3$-Pi) which made P more available for plant uptake. The increase in available P with organic fertilizers may be due to the production of organic and humic acids which compete for the adsorption sites, thus releasing P into soil solution (Adler and Sikora, 2003). The organic and humic acids from the organic P fertilizer makes the soil medium acidic. The low soil pH increased P adsorption therefore decreasing the plants available P in soil solution. According to Guppy *et al.* (2005), the organic and humic acid produced as a result of decomposition of organic P fertilizer increases the adsorption of P and therefore reduces the availability of P in soil solution.

The Resin- Pi and the $NaHCO_3$-Pi concentration was further explained by the positive correlation existing between the soil organic carbon and the labile P pools as compared to the other treatments. This implied that the increase in soil organic carbon led to an increase in the plant available P. The Competitive sorption reaction of the carboxylic acid of the organic carbon with P at the soil exchange site could be the results of the increased in the bioavailability of P in the soil solution. Schneider and Haderlein (2016) indicated that the organic carbon improves plant available P in most tropical soils.

It was also evident in the positive correlation between CEC and labile P pool. High CEC showed that the colloidal site had net negative charges which might be an indication of the repulsive nature of the phosphate anion in solution which increased the bioavailability of P for plant use.

The other treatments with low CEC had less negative charges on the surface of the colloids and therefore less P were repelled into soil solution compared to T8 and T5 which enhanced more available P pools. Therefore, T5 and T8 had the possibility of increasing labile P pools in tropical soils for plant uptake.

5.7.2 Effect of P sources on Moderately Labile P

Moderately labile P, defined as Fe – P and Al – P complexation that replenish depleting labile inorganic P stock in soil solution for plant uptake (Abekoe and Tiessen, 1998). The moderately labile P pool was consistent throughout the 2 cropping seasons (Table 4.8). Probably due to the % P contributions of the individual components of the treatment combination.

In both 2017 and 2018, it was observed that the moderately labile P pools in the amended soils were higher than the control. However, across the seasons, the moderately labile P pools in 2018 minor cropping season were higher than in 2017 minor cropping season which might be attributed to the residual effect of the P nutrient in the soil and high rainfall registered in 2018 minor cropping season. According to Adamu *et al.* (1989) soil pH and CEC are positively correlated. With low pH adsorption of P is favoured and CEC is decreased. Similarly, when pH increases CEC is also increased and more available P becomes accessible for plant uptake.

In 2017 minor cropping seasons, the highest NaOH-Pi was recorded in T5. T5 in 2017 minor cropping season was significantly ($P < 0.05$) different from T1, T2 and T3 but was observed not to be significantly different from T4, T6, T7, T8 and T9. Similarly, in 2018 minor cropping season, T5 was observed to be statistically similar ($P > 0.05$) to T4, T6, T7, T8 and T9.

This might be attributed to the fact that the % P contributions of the TSP was 43% as compared to the 100 % P contributions of TSP in treatment two and was different from the TSP in the other integrated P sources. However, over the cropping seasons the compost as well as the biochar with variable C/P ratio might have mineralized completely which contributed 7 % and 50 % P to soil solution.

However, T5 was also observed to promote the highest soil pH. This was further explained by the negative correlation between pH and NaOH-Pi. Generally, low soil pH increased P adsorption capacity, favoring reactions with Fe and Al hydroxides, contributing to high Fe – P and Al – P complexation. Conversely at high pH, there was a reduced form of Fe and Al – P complexation at the exchange site which allows more P into soil solution increasing the available P pools for plant use.

However, in the current study, it was observed that as pH increased the NaOH-Pi also increased which contradicted previous findings. The probable reason might be that the addition of organic amendments from treatment five had an inherent Fe and Al complexation which produced adsorption effect on soil thus increased the formation of NaOH-Pi compared to the other treatments. These results are consistent with the findings of Xu *et al.* (2016) who reported that NaOH –Pi in the soil increased after addition of biochar which could be related to the adsorption of dissolved P from the biochar onto the Fe and Al oxides.

5.8 Effect of P sources on sum of organic P pool (∑ ($NaHCO_3$-Pi + NaOH-Pi)

Throughout the two seasons, it was observed that the sum of organic P pools were inconsistent (Table 4.7). Probably due to the % P contributions of the individual component of the treatment combination. However, the sum of organic P pool in 2018 minor cropping season was relatively higher than in 2017 minor cropping season probably due to the residual effect of the P as well as high rainfall which enhanced microbial activities and a speedy decomposition and mineralization of organic P source. Generally, the amendment performed better than the control. However, the sum of organic pools in 2018 was relatively higher than in 2017 minor cropping season. This may be attributed to the residual effect of the P in the soil as well as the higher rainfall and temperature registered in 2018 minor cropping season (Table 4.1).

In 2017 minor cropping season, T9 predominated the organic P pools and was observed not to be significantly ($P > 0.05$) different from T8, T7, T6, T5 but was significantly different from T1, T2, T3 and T4. Previous studies also have shown that the application of different types of P source significantly increased organic P pools and this increase was due to addition of organic fertilizers compared to inorganic fertilizers (Reddy *et al*., 2005; Gichangi *et al.,* 2009).

In 2018 minor cropping season, it was also observed that the highest organic P pool was obtained from T8. This was however not significantly different from T9, T7, T6 and T5. It was also observed to be significantly different from T1, T2, T3 and T4. T9 and T8 were also observed to promote the highest organic carbon in the soil. This was evident in the positive correlation between the organic carbon from the amendment and the organic P pools in the soil.

This implied that high level of organic carbon in the soil increased organic P pools of the soil. Our findings are also consistent with the previous results from other researchers that organic phosphorus sources predominately possesse high phosphorus concentration which can have stimulating effects for increasing the organic P pools in soils (Gichangi *et al.,* 2009; Reddy *et al.,* 2005). This increase in organic P pool by T8 and T9 might be due to the slow release of phosphorus from organic materials that can play a pivotal role in the cycling of the soil phosphorus.

5.9 Effect of P sources on Non-Labile P pool

The non-labile P pools refers to the Calcium bound P (Hcl-Pi) and the residual P which are the most recalcitrant and non- labile insoluble P that becomes available for plant use in a long run.

It was observed that non labile P pools concentration produced in 2018 minor cropping season were higher compared to 2017 minor cropping season. This probably may be due to the residual effect of the P nutrient in the soil as well as the higher rainfall and temperature recorded in 2018 minor cropping season (Table 4.1). However, the non-labile P pools produced in the amended soils were higher than the un-amended soil.

The Calcium bound P was consistent throughout the cropping season (Table 4.7). Probably due to the % P contributions of the individual component of the treatment combination. Across the season the Calcium bound P produced in 2018 minor cropping season was higher as compared to 2017 minor cropping season.

In 2017 and 2018 minor cropping seasons, the highest Hcl-Pi (calcium bound P) was obtained from T5. This was observed to be statistically similar to T6, T8 and T9. However, T5 was statistically different from T1, T2, T3, T4 and T7. This finding is in-line with the findings of Meason *et al.* (2009) who reported that integrated use of organic and inorganic fertilizers adsorbed onto the primary minerals can play an important role in increasing the Hcl pool.

Correspondingly the highest exchangeable calcium was predominated in T5. This was evident in the positive correlation between the exchangeable Ca^{2+} and the Hcl-Pi concentration. High exchangeable Ca^{2+} in soil implied high calcium bound P. The high exchangeable calcium in soil adsorbed and precipitate more available phosphorus in soil solution thus increased the calcium bound P and reduced the labile P pools.

In 2017 and 2018 minor cropping seasons, the highest Hcl-Pi concentration was obtained from treatment five. This was observed to be statistically similar to T6, T8 and T9. However, T5 was statistically different from T1, T2, T3, T4 and T7. This finding is in-line with the findings of Meason *et al.,* (2009) who reported that integrated use of organic and inorganic fertilizers adsorbed onto the primary minerals can play an important role in increasing the Hcl pool. The concentrated HCl-Pi represent the unavailable form of P pools in the soil and may be converted to moderately labile or labile phosphorus pools over time (Aulakh *et al*., 2003).

This was further explained by the positive correlation between the exchangeable Ca^{2+} and the Hcl-Pi concentration. High exchangeable Ca^{2+} indicated the inorganic phosphate in this fixed pool was more crystalline in their structure and less soluble. The residual P was consistent throughout the cropping season probably due the % P contributions of the individual component of the treatment combinations (Table 4.7). The residual P yielded in 2018 minor cropping season was higher than in the 2017 minor cropping season. Probably due to the residual effect of the P in the soil as well as the higher rainfall and temperature recorded in 2018 minor cropping season.

In 2017 and 2018 minor cropping seasons. The highest residual P concentration recorded in T4 was statistically similar to all the treatments. Possibly due to excessive fertilization effects from the % P contributions of the empty fruit bunch mulch (18 %), Compost (12 %) and TSP (70 %) which resulted in the saturation of P in the form of residuals that may be later converted to the moderately labile or labile phosphorus pools over time. These findings are in agreement with the findings of Ahmed *et al*. (2019) who stated that integrated use of organic and inorganic excessive fertilization can lead to P saturation in a residual form that can later be converted into either moderately labile or labile phosphorus pools over time.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- The NPK, rice husk biochar and its compost, empty oil palm fruit bunch mulch and rock phosphate amendments on the soil significantly improved the P use efficiency of the maize plant in two consecutive minor cropping seasons (2017 and 2018).
- The NPK fertilizer produced higher total dry matter production compared to combine application of organic and inorganic P source application in the second cropping season (2018).
- The rock phosphate and rice husk boichar and its compost promoted the highest grain yield in the second minor cropping season (2018).
- The combined application of NPK, rice husk biochar and its compost promoted the highest total P uptake compared to only NPK in both cropping season (2017 and 2018).
- The rock phosphate and the combined application of NPK, rice husk boichar and its compost and empty oil palm fruit bunch mulch significantly enriched and sustained the concentration of the soil P fractions compared to only NPK in both cropping seasons (2017 and 2018).

6.2 Recommendations

- Based on the significant increase in the Total P uptake and P recovery efficiency promoted by treatment five (T_5) which comprised of Rice Husk Biochar, Compost, Urea and Triple Superphosphate, it can therefore be recommended to all farmers and for future experimental trials.

- Due to the improvement in grain yield promoted by treatment eight (T_8) which comprised of rice husk biochar and its compost and rock phosphate and it is recommended that all farmers should adopt.
- Due to the improvement in total dry matter production enhanced by NPK it can therefore be recommended to all farmers and for experimental trial.
- Due to the significant increase in the resin Pi and the agronomic P use efficiency promoted by T8 (rock phosphate and rice husk biochar and its compost), it should therefore be recommended to all farmers.

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APPENDENCES

APPENDIX A

Climatic Conditions during the 2017 cropping season at Kade

	Rainfall (mm)	Relative Humidity (%)		Temperature(°C)	
		Maximum	Minimum	Maximum	Minimum
January	0.00	67.41	43.90	33.42	21.46
February	27.18	69.12	40.92	35.20	22.76
March	65.27	72.75	42.76	35.85	22.43
April	156.21	74.75	53.92	34.15	22.22
May	129.54	79.20	55.83	33.48	22.18
June	261.97	82.45	64.35	31.52	22.53
July	209.75	80.23	65.60	32.80	22.89
August	61.97	68.52	45.82	29.24	21.87
September	190.03	82.79	65.94	30.32	21.98
October	201.89	81.59	63.20	31.50	22.01
November	136.85	79.32	58.64	32.72	21.67
December	37.59	76.69	53.52	32.30	21.41
Total	1478.26				

(FOHCREC Weather station at Kade,2017)

Climatic Conditions during the 2018 cropping season at Kade

Month	Total Monthly Rainfall (mm)	Mean Monthly Relative Humidity (%)		Mean Monthly Temperature (°C)	
		Maximum	Minimum	Maximum	Minimum
January	1.27	69.20	44.28	35.98	21.22
February	46.23	72.00	42.96	35.50	23.18
March	105.66	74.67	49.36	34.85	22.25
April	119.38	76.77	53.65	34.25	22.52
May	240.79	80.89	61.81	32.45	22.20
June	262.65	81.07	62.14	31.75	21.97
July	230.53	79.50	60.38	30.55	22.60
August	86.62	69.12	46.08	30.49	21.69
September	278.38	81.91	63.50	31.49	22.33
October	225.02	78.15	64.27	32.37	21.63
November	153.25	75.92	59.03	31.92	20.75
December	45.56	74.10	52.94	31.05	21.83
Total	1795.33				

(FORCHREC Weather Station at Kade,2018)

APPENDIX B

Treatments, Composition and Rate of application

Treatments	EFB (Kg/plot)	C (kg/plot)	RH Bio (kg/plot)	RP (kg/plot)	Urea (kg/plot)	TSP (Kg/plot)	KCl (kg/plot)
T1(No amendment)	0	0	0	0	0	0	0
T2(Urea,TSP,KCl)	0	0	0	0	1.3	1.92	0.38
T3(EFB, Urea,TSP)	49.56	0	0	0	0.25	1.03	0.05
T4(EFB,U,TSP,COMP)	24.8	20.16	0	0	0.25	1.2	0.03
T5(Bio, C, Urea,TSP)	0	22.68	53.76	0	0.19	1.38	0.01
T6(EFB,U,TSP,RHBio)	28	0	28	0	0.19	1.25	0.01
T7 (C, U,TSP)	0	40.6	0	0	0.25	1.3	0.03
T8(Bioc,C,Rock phos)	0	28.1	49.2	1.91	0	0	0.01
T9(EFB,C, Rock phos	21.3	28.1	0	1.15	0	0	0.03

APPENDIX C

Analysis of variance for Agronomic P use, P Recovery Efficiency and P Utilization Efficiency in 2017 cropping season

Variate: APUE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	734.492	91.812	79.17	<.001
Residual	18	20.874	1.160		
Total	26	755.367			

Analysis of variance

Variate: PRE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	1239.26	154.91	6.87	<.001
Residual	18	406.00	22.56		
Total	26	1645.26			

Analysis of variance

Variate: PUE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	2.19714	0.27464	3.11	0.022
Residual	18	1.59190	0.08844		
Total	26	3.78904			

APPENDIX D

Analysis of variance for Agronomic P use, P Recovery Efficiency and P Utilization Efficiency in 2018 cropping season

Analysis of variance

Variate: APUE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	8146.44	1018.31	80.89	<.001
Residual	18	226.61	12.59		
Total	26	8373.05			

Analysis of variance

Variate: PRE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	1987.715	248.464	43.37	<.001
Residual	18	103.112	5.728		
Total	26	2090.827			

Analysis of variance

Variate: PUE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	1.91809	0.23976	17.47	<.001
Residual	18	0.24707	0.01373		
Total	26	2.16516			