IMPACT OF TILLAGE AND PHOSPHORUS APPLICATION ON PHOSPHORUS UPTAKE AND USE EFFICIENCY OF MAIZE (*Zea mays* L.)

BY

BENEDICTA ESSEL

AUGUST, 2014

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CROP AND SOIL SCIENCES

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A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, GHANA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF

MASTER OF SCIENCE

IN

SOIL SCIENCE

AUGUST, 2014

DECLARATION

I hereby declare that this submission is my own work towards the MSc. Degree and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree except where due acknowledgement has been made in the text.

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BENEDICTA ESSEL **DATE**

Certified by:

……………………………….. …………………

DR. VINCENT LOGAH **DATE**

(PRINCIPAL SUPERVISOR)

……………………………….. …………………

PROF. CHARLES QUANSAH **DATE**

(CO-SUPERVISOR)

……………………………….. …………………

DR. CHARLES KWOSEH **DATE**

(HEAD OF DEPT.)

ABSTRACT

There is limited information on the impact of tillage and phosphorus application on phosphorus uptake and use efficiency of maize at different stages of growth and, the implication for crop yield on different soil types in Ghana. To bridge this gap in knowledge, a study was undertaken in the minor rainy season of 2013 on an Orthi-Ferric Acrisol at Anwomaso and Rhodic Lixisol at Ejura in the Semi-deciduous forest and Forest-savannah transition Agro-ecological zones of Ghana, respectively. The experiment was laid out in a split-plot, arranged in Randomized Complete Block Design (RCBD) with three replications at both locations. The treatments used were two tillage systems: conventional tillage (CT) and no-tillage (NT) systems and four phosphorus application rates: 0, 30, 60 and 90 kg P_2O_5 ha^{-1} in the form of triple superphosphate (TSP) designated as P_0, P_{30}, P_{60} and P_{90}, with basal applications of nitrogen and potassium at the rates of 90 kg N ha^{-1} and 60 kg K_2O ha^{-1}. Phosphorus uptake and use efficiency indices such as recovery efficiency (PRE), partial factor productivity (PFP), agronomic efficiency (PAE) and utilization efficiency (PUtE) were evaluated at different stages of crop growth viz: juvenile stage (V6), peak vegetative growth (V12) and at physiological maturity (R6). The results showed tillage to generally influence P uptake and use efficiency of maize in both agro-ecological zones at V12. The different rates of P applied progressively enhanced the total P concentrations of maize plants in the order $P_0 < P_{30} < P_{60} < P_{90}$. Phosphorus was efficiently utilized by the maize crops at P_{60} than at P_{90} on both soils. Significant tillage x phosphorus interactions ($p < 0.05$) were recorded among treatment combinations at V6, V12 and R6 with regards to PRE, PFP, PAE and PUtE at both Anwomaso and Ejura. The P_{60} led to significantly higher PRE and PAE, however, the highest PFP was recorded under P_{30}. The study recorded a high PRE range of 40.90 – 55.20 % at R6 on the Rhodic Lixisol at Ejura and even a

higher value of 64.50 % under NTP_{60}. Though CTP_{60} recorded the highest grain yield on both locations, NTP_{60} recorded grain yield comparable to that of CTP_{60} at Ejura.

DEDICATION

I dedicate this Thesis to my family whose persistent prayers and support has brought me this far in my academic pursuit. Secondly, to all advocates of food security in Africa.

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"Sometimes our light goes out but is blown into flame by another human being. Each of us owes deepest thanks to those who have rekindled this light" (Albert Schweitzer).

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ACT	African Conservation Tillage Network
ANOVA	Analysis of Variance
CRI	Crops Research Institute
CSIR	Council for Industrial and Scientific Research
CT	Conventional Tillage
ECEC	Effective Cation Exchange Capacity
EDTA	Ethylene diamenetetraacetic acid
ESDA	Ejura-Sekyedumasi District Assembly
FAO	Food and Agriculture Organization
HSW	One hundred seed weight
IIRR	International Institute of Rural Reconstruction
ISUE	Iowa State University Extension
KCN	Potassium cyanide
LSD	Least Significant Difference
MoFA	Ministry of Food and Agriculture
MOP	Muriate of potash
NT	No-tillage
OC	Organic Carbon
OECD	Organization for Economic Co-operation and Development
OP	Open pollinated
PAE	Phosphorus Agronomic Efficiency
PFP	Partial Factor Productivity
PRE	Phosphorus Recovery Efficiency
PUE	Phosphorus Use Efficiency

PUtE	Phosphorus Utilization Efficiency
QPM	Quality Protein Maize
RCBD	Randomized Complete Block Design
R6	Physiological maturity
SLS	Soils Laboratory Staff
SRI	Soil Research Institute
SSSA	Soil Science Society of America
TEB	Total Exchangeable Bases
TSP	Triple superphosphate
V6	Sixth-leaf maize growth stage
V12	Twelfth-leaf maize growth stage
WAS	Weeks after sowing

CHAPTER ONE

1.0 INTRODUCTION

Maize is Ghana's most important and widely consumed cereal crop. However, several factors constrain its production in the country. These include declining soil fertility with little or inadequate use of mineral fertilizers, poor weed and pest management, inappropriate tillage practices, and unfavourable climatic conditions (Yeboah, 2013).

Tillage practices are commonly used by farmers to incorporate nutrients into the soil to maximize the availability of nutrients to crop plants. Lal (1983) defined tillage as any physical, chemical or biological manipulation of the soil to optimize conditions for germination, seedling establishment and crop growth. Tillage practices influence soil physico-chemical and biological characteristics, which may consequently influence crop growth and yield (Ozpinar and Cay, 2006; Rashidi and Keshavarzpour, 2009). Crop yield is a function of soil nutrient composition and availability and as such the application of fertilizers is important.

According to Dittoh *et al*. (2012), fertilizer is a component of the technological trinity (improved seed, irrigation and fertilizer) which resulted in the Green Revolution in Latin America and Asia. Its efficient use resulted in food security in these areas. However, poor management practices coupled with inefficient use of fertilizers has generally jeopardized soil quality and health, making food security a problem to contend with in Sub-Saharan Africa. Fertilizer nutrient application in Ghana and Sub-Saharan Africa is approximately 8 kg ha^{-1} (FAO, 2005) and 9 kg ha^{-1} respectively which is far below the global mean of 101 kg ha^{-1} (Camara and Heinemann, 2006). The 'same fertilizer for all soils' practice has also contributed to the inefficient use of fertilizers in Sub-Saharan Africa (Dittoh *et al*., 2012). Therefore, the nutrient status of soils must be taken into consideration and appropriate mechanisms developed in order to enhance efficient use of fertilizer nutrients by crops to increase yield. The dominant use of nitrogen-based fertilizers in developing countries has led to an imbalance of nutrients in soils (Bumb and Baanante, 1996). To improve the efficiency of nitrogen fertilizer use and its associated adverse effect of over-application, nutrient balance should be improved by promoting the use of phosphate and potash fertilizers (Bumb and Baanante, 1996).

The interest and awareness of the public of the need for increasing crop nutrient use efficiency is great but easily misunderstood and misrepresented (Roberts, 2008). According to the author, while most of the focus on nutrient efficiency is on nitrogen, phosphorus efficiency is also of interest because it is one of the least available and least mobile mineral nutrients. Phosphorus is one of the most important nutrients for crop growth and much emphasis should be placed on its efficient use for sustainable crop production for food security (Ryan, 2002) because of the vital roles it plays in plants for energy storage, root development and early maturity (Gupta, 2003). According to Marschner (1995), adequate information on nitrogen and phosphorus accumulation and redistribution patterns in maize under soil tillage systems are necessary to obtain higher yields and to improve their use efficiencies.

Several reports have been made about phosphorus being the second most limiting nutrient in crop production (Ortiz – Monasterio *et al.*, 2002; Kogbe and Adediran, 2003). In Ghana, studies on the effect of P on crop yields started receiving attention in the 1960s and 1970s (Issaka *et al.*, 2008). Much of the focus was on the determination of suitable rates for various crops (SRI, 1964; Ofori, 1965), methods of extraction (Halm, 1964), the importance of various sources of P on crop performance (Ofori, 1966) and the problems associated with fixation (SRI, 1975). The effects of phosphorus application on crop production in Ghana have also been investigated by several scientists (Nyamekye, 1989; Issaka *et al.*, 2003). It has been reported that phosphorus generally has a positive influence on crop yields and that soil P and soil properties such as pH, Al and Fe oxides affect the response of crops to applied phosphorus (Nyamekye, 1989; Issaka *et al*., 2003).

Despite the several research works conducted on phosphorus in Ghana, there is paucity of information on the impact of tillage on its uptake and use efficiency at different stages of crop growth and the implications for crop yield. Maize varieties are known to vary in P uptake and utilization efficiencies, and also in their adaptability to different soil types (Horst *et al*., 1993; Machado *et al*., 1999). Sufficient information on P uptake and use efficiency of maize at different stages of growth under different tillage systems on different soil types will enhance efficient application and utilization of the nutrient under cropping systems. This will cut down cost of fertilizer inputs and mitigate adverse environmental impacts of over–application. It will also help farmers to know the appropriate tillage system and rate of P that will enhance optimum P uptake and use efficiency of crops on a particular soil type, thereby increasing productivity.

Working on the hypothesis that P application under no-tillage and conventional tillage systems significantly influence P uptake and use efficiency of maize at different stages of growth, the objectives of this study were to:

i. investigate the trend of P uptake by maize at various stages of growth under conventional and no–till systems and increasing rate of P application;

ii. evaluate P use efficiency of maize under different rates of P application and two tillage systems using indices such as partial factor productivity and, recovery, agronomic and utilization efficiencies;

iii. determine the effects of P application and tillage systems on growth and yield of maize in the Semi–deciduous forest and Forest-savannah transition zones of Ghana.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Tillage

Tillage forms an integral part of crop production and is defined as any physical, chemical or biological manipulation of the soil to optimize conditions for germination, seedling establishment and crop growth (Lal, 1983). Ahn and Hintze (1990) also defined it as any physical loosening of the soil carried out in a range of cultivation operations, either by hand or by mechanization.

2.1.1 Types of tillage systems

The use of different tillage systems such as no-tillage, conventional, minimum and ridge tillage for crop production is a common practice in soil management.

2.1.1.1 No-tillage

No-tillage refers to a soil management system where a crop is planted directly into the soil with no primary or secondary tillage (SSSA, 2014). It is classified as one of the conservational tillage systems and thus a sustainable way of crop production. No-tillage system has gained increasing interest in Ghana following its introduction to Ghanaian farmers in the 1990s, through a joint programme organized by the Crops Research Institute of the Council for Scientific and Industrial Research, Fumesua, Ghana, Sasakawa Global 2000 and Monsanto (Ekboir *et al*., 2002). It is commonly practiced by maize farmers in Ghana. According to IIRR and ACT (2005), the number of farmers practicing no-tillage increased from 10,000 in 1996 to 350,000 in 2002 in Ghana. In 2008, no-tillage was practiced on 95 million hectares of land worldwide, of which 50 % are in non-OECD countries (Grigoras *et al*., 2011). Compared to conventional tillage systems, no-tillage has been reported to significantly reduce soil erosion and nutrient leaching and run-off (Raczkowski *et al*., 2009).

Dick and Van Doren (1985) observed from their experimental fields that no-tillage practices suffered a greater yield loss in continuous maize as compared to the conventionally tilled plots. In their study, Lal and Ahmadi (2000) recorded 5-10 % lower crop yields under no-tillage systems as compared to ploughed soils with poor drainage and high clay content. However, Blanco and Lal (2008) later reported that no-till does not lead to increment in crop yields in all soils. Crop yields from no-till systems may be higher, lower or equal to crop yields from conventional tillage systems (Blanco and Lal, 2008).

2.1.1.2 Conventional tillage

Conventional tillage is a type of tillage system with a high degree of soil disturbance, involving the mixing of the surface layers of the soil, with the aim of controlling weeds and preparing a suitable soil condition for seed germination and crop growth (FAO, 2001). It involves the use of both primary and secondary tillage implements. Primary tillage implements such as the mould board or disc plough inverts the top soil to incorporate weeds and crop residues, whereas secondary tillage implements like the harrow is used to level the topsoil to create a conducive environment for good germination of seeds and crop growth (FAO, 2001).

Despite the benefits of conventional tillage such as the mechanical control of weeds, burying of crop residues, and the breaking up of shallow compacted layers of soil to encourage root development, it is accompanied by several limitations: higher risks of soil compaction (which hinders infiltration), higher losses of soil moisture, high fuel consumption, higher risks of crusting, erosion as well as inhibition of soil biological activity among many others (FAO, 2001).

2.1.1.3 Minimum tillage

Minimum tillage refers to the minimum use of primary and secondary tillage necessary for meeting crop production requirements under the existing soil and climatic conditions, usually resulting in fewer tillage operations than for conventional tillage (SSSA, 2014). Lal (1990) recommended minimum tillage practices comprising hoe-ridging, hoe-mounding and flat tillage for crops grown in the tropics. The use of minimum tillage enhances a more balanced soil ecology which enables the soil to function as a better medium for plant growth (Brady and Weil, 2004). Dick and Van Doren (1985) observed that maize yield is favoured under minimum tillage practices, even though Eckert (1984) reported earlier that the type of tillage practiced has no influence on maize yields.

2.1.1.4 Ridge tillage

According to SSSA (2014), ridge tillage is a tillage system where ridges are formed on top of cultivated rows formed during the previous growing season. In ridge tillage system, crops are planted on ridge tops, a practice known as ridge planting (Blanco and Lal, 2008). The ridges are usually maintained and annually re-formed for growing crops. Ridge tillage is practiced to reduce tillage costs relative to conventional tillage, improve crop yields, and reduce soil and nutrient losses (Blanco and Lal, 2008).

Gaynor and Findlay (1995) reported that ridge tillage can reduce soil erosion by as much as 50 % as compared to conventional tillage system. This is because residue produced at harvest is left on the soil surface to serve as a protective cover (Blanco and Lal, 2008). Ridge tillage is commonly practiced on poorly drained, clayey soils where no-tillage is difficult to practice (Blanco and Lal, 2008). Crop yields under ridge tillage can be higher than in no-till systems (Blanco and Lal, 2008). According to a report by Laszlo and Gyuricza (2004), ridge tillage can result in lower penetration resistance and lower bulk density values in the upper 20 cm of the soil as compared to conventional tillage and no-tillage.

2.1.2 Factors affecting the choice of tillage systems

Many factors influence the choice of tillage systems and hence choosing the most appropriate tillage system is important for sustainable farming. According to Unger (1984) and FAO (1995), the choice of tillage systems are dependent on the following factors:

i. Soil factors such as relief, erodibility, rooting depth, texture, structure, organic-matter content and mineralogy.
ii. Climatic factors such as rainfall amount and distribution, water balance, length of growing period, ambient temperature, and duration of the dry season.
iii. Crop factors such as growing duration, rooting characteristics, water requirements and type of seed.
iv. Socio-economic factors such as farm size, availability of inputs, family structure and composition, labour situation, access to cash and credit facilities and marketing.
v. Objectives and priorities.
vi. Government policies.

Appropriate tillage system can result in better spatial distribution of roots, enhanced nutrient and water uptakes, as well as improvement in crop productivity (Wlaiwan and Jayasuriya, 2013). It can also lead to alleviation of soil related constraints such as soil erosion, nutrient depletion and soil compaction. However, choosing an inappropriate tillage system may lead to diverse processes of degradation, e.g. accelerated erosion, deterioration in soil structure, depletion of soil organic matter and fertility, etc. (Lal, 1995).

2.1.3 Effects of tillage on soil properties

Tillage has several effects on soil properties which consequently affect crop growth, nutrient availability and crop yields. The effects of tillage on soil physico-chemical properties are a function of soil properties, environmental conditions and the intensity of the tillage system (Ishaq *et al*., 2002). Courtney *et al*. (2008) reported that no-tillage systems influence water infiltration, soil temperature, soil moisture, soil aeration, nutrient distribution or 'stratification' as well as microbial populations and activity.

2.1.3.1 Effects of tillage on soil chemical properties

Soil chemical properties are important factors that determine the nutrient supplying capacity of the soil to plants and microbes (Tilahun, 2007). The manipulation of the soil results in several changes and transformations in its chemical properties especially in the long term.

It is widely established that soils under long-term no-tillage as well as reduced tillage systems generally contain higher amounts of organic carbon in the soil surface as compared to conventional tillage systems (West and Marland, 2002; Freibauer *et al*., 2004; Conant *et al*., 2007; Thomas *et al*., 2007). The increase in the concentration of soil organic carbon is considered to be the result of different interacting factors, such as minimal soil disturbance, increased residue return, reduced surface soil temperature, higher moisture content and decreased risk of erosion (Logan *et al*., 1991; Blevins and Frye, 1993). Al-Kaisi *et al*. (2005) reported that short-term (≤ 10 years) tillage effects on soil C and N dynamics are complex and often variable. West and Post (2002) attested to the fact that soil C sequestration generally increased by no-tillage practices, but had a delayed response, with a dramatic increase in C after 5-10 years.

In the determination of changes in soil chemical properties under conventional, minimum and no-tillage systems from 1994 to 2004, Benito and Sombrero (2006) reported that changes in soil organic matter were very slow until 1998 where there was no significant difference between organic matter values under tillage systems in the upper 15 cm layer of the soil. Similar results were recorded for soil total N (Benito and Sombrero, 2006). The authors observed that minimum and no-tillage plots had a higher level of nitrogen compared to conventionally tilled plots. According to them, the phosphorus content showed significant differences in the 10 cm depth of the soil with higher values in mulch tillage and no- tillage as compared to conventional tillage.

Apart from soil organic matter, tillage is reported to affect other chemical properties and differences observed between no-tillage and conventional tillage systems with regard to pH, CEC and the concentration of nutrients in the soil. However, these effects are environmentally dependent and therefore different results are reported under different soil types and climates (Limousin and Tessier, 2007; Thomas *et al*., 2007).

2.1.3.2 Effects of tillage on soil physical properties

The aim of tillage is to create a soil physical environment that enhances optimum seed germination and seedling emergence, and the development of roots to enhance crop growth and nutrient uptake (Lal, 1983). The physical properties of soils determine their adaptability to cultivation and the level of biological activity that can be tolerated by the soil (Tilahun, 2007). Tillage affects the soil physical environment through its effect on the physical properties of the soil which is mostly dependent on the inherent characteristics of the soil. However, most farmers practice several tillage operations without being aware of their effects on soil physical properties and crop growth (Ozpinar and Isik, 2004).

Generally, under no-tillage system, bulk density increases as no activity to loosen the soil aggregates are performed (Boguzas *et al*., 2010). No-tillage increases bulk density in the first 5 – 10 cm layer of topsoil (Franzluebbers *et al*., 1995; Unger and Jones, 1998) but sowing in a no- tilled soil reduces bulk density, especially when the organic matter content of the soil is increased (Crovetto, 1998).

2.2 Maize growth, development, climatic and phosphorus requirements

2.2.1 Growth and development stages of maize (V1-R6)

Maize undergoes several distinct developmental stages in its growth to complete its life cycle. A growth stage on a particular field begins when at least 50 % of the cultivated crops have reached or are beyond a certain stage. In this study, the leaf collar method of growth staging by ISUE (2014) was used as outlined below. Leaves with visible collars were used to determine the vegetative growth stages (VE – VT).

VE: This stage occurs within 4 - 5 days after planting in optimal conditions. It is visible when the young shoot emerges from the soil.

V1: The first leaf collar is visible on the lowest leaf with a rounded tip. Subsequent leaves have pointed tips and the growing point is below the ground.

Each successive visible leaf collar is used to determine the growth stage between V1 and VT. A new growth stage occurs every 4 – 5 days between V1 and VT.

V6: This is one of the key stages for development. There are six leaves with visible collars. The growing point is now above the soil surface because the nodal root system is established. All leaves, ears shoots and tassel attain full development. The ability of the maize plant to take up nutrients and water is established at V6.

V10+: At this stage, the lower leaves begin to fall off the plant, making staging very difficult. Therefore, in order to determine the stage, the maize stalks will have to be split as each leaf is attached to a specific node of the maize crop.

V12: At this stage, the number of kernel rows is set. The number of ovules (potential kernels) on each ear and size of ear is also determined. Brace root formation begins stabilizing the upper part of the plant. Large amounts of nitrogen, phosphorous, and potassium are being utilized at this stage.

VT: This is the final vegetative stage and occurs just prior to, or at the same time as silking. The entire tassel is visible producing pollen grains with over 500,000 shed per plant per day at the peak.

After the vegetative growth stage, plants metamorphose to the reproductive stages. During this period, staging is no longer based on the vegetative appearance of the plant, but focuses only on the ear to determine the stage of development attained by the plant. There are six reproductive stages in maize and they are outlined as follows according to ISUE (2014):

R1 (Silking): At this stage, any silk becomes visible outside the leaves of the husk. Maize plants are assumed to have attained this stage when at least 50 % of the plants on the field have one or more silks emerged. There will be shedding of pollen grains on the silks and if receptive, fertilization will take place. The silks are viable and receptive to pollen for at least five days. The maize plants are very sensitive to moisture stress at this stage.

R2 (Blister stage): At this stage, kernels are visible and resemble a blister. The kernels contain approximately 85 % moisture content and hence, if severe stress occur kernel abortion will occur until the plant has adequate supply of carbohydrates for the other kernels. The embryo is barely visible at this stage.

R3 (Milk stage): The moisture content in the kernel reduces to about 80 % and accumulation of starch begins. The kernel develops a yellow colour with the inside containing 'milky' white fluid.

R4 (Dough stage): Stresses reduce the kernel weight and the moisture content to about 70 %. At this stage, the kernel would have thickened to dough and may start denting in at the base of the ear.

R5 (Dent stage) : The moisture content reduces further to about 60 % and the kernels are dented in at the top of the ear, with a 'milk line' separating the liquid and solid (starch) portions.

R6 (Physiological maturity): This is the last stage of maize development. The maize plant is assumed to have attained this stage when the milk line disappears and the starch has reached the base of the kernel causing the kernel to attain a maximum dry matter accumulation. The kernel moisture is about 35 % at this stage.

After this stage, a black layer is formed, serving as a visual verification that the maize plant is fully mature (ISUE, 2014).

2.2.2 Climatic requirements

A number of climatic factors such as rainfall and temperature are known to affect the growth and development of maize**.**

Maize grows in regions with a total annual precipitation of 500 – 5000 mm. However, for short season varieties, 300 mm of rainfall during the growing cycle is adequate for the growth of the crop (Sys *et al*., 1993). Maize can thrive well in areas with a mean minimum and maximum temperatures within the range of 12 – 24 ^{o}C and 26 – 29 ^{o}C, respectively (Sys *et al*., 1993).

2.2.3 Phosphorus requirements

Phosphorus is one of the most essential nutrients required for adequate maize growth and optimum yield. It is a key element essential for physiological, metabolic and biochemical processes in living organisms (Fageria and Baligar, 1997). It is an essential component of adenosine triphosphate (ATP), which is the energy currency of the cell. It plays an important role in cell development and DNA formation. The concentration and uptake of phosphorus in maize plants is influenced by environmental conditions prevailing at where they are cultivated (Gautam *et al*., 2011).

According to Ofori and Fianu (1996), the most deficient nutrients in Ghanaian soils are nitrogen and phosphorus. As a major plant nutrient which is the second most limiting in most Ghanaian soils, the application of phosphorus fertilizers will have a positive effect on crop production if other major nutrients such as nitrogen and potassium are not limiting. Plants require adequate amounts of phosphorus from the very early growth stages in order to enhance optimum crop production (Grant *et al*., 2001).

Phosphorus deficiency is a principal yield-limiting factor for annual crop production in acid soils in the temperate and tropical climates (Fageria and Baligar, 1997). Phosphorus deficiency negatively influences the leaf area index and limits the interception of photosynthetically active radiation by crops thereby resulting in low biomass accumulation (Colomb *et al*., 2000; Pellerin *et al*., 2000) and consequently low yields. The adverse effect of phosphorus deficiency on leaf area index can negatively impact adventitious root emergence and consequently hinder nutrient uptake (Pellerin *et al*., 2000). Characteristic visual symptoms of phosphorus deficiency include stunted growth and a darker green to purple colouration of leaves (Westermann, 2005) usually observed in lower and older leaves of the plants. Other deficiency symptoms include the development of slender stems and delayed maturity of plants.

In most soils of Sub-Saharan Africa, nutrient balances have been displaced by human intervention, leading to soil accumulation or depletion of nutrients. According to Brady and Weil (2002), P deficiency has been one of the principal reasons why Sub-Saharan Africa is the only major region in the world where per capita food production has declined in the past three decades. Although most soils have large reserves of total phosphorus which is 100 times higher than the fraction of soil available P, the phosphorus available for plant use is very low (Al-Abbas and Barber, 1964).

Dzotsi (2007) outlined the following five factors as the problems relating to phosphorus levels in most Sub-Saharan soils:

i. The soils have developed under conditions conducive to advanced weathering, during which extensive P losses occurred resulting in low P soils.

ii. The P compounds usually present in the soils are highly insoluble and have a very low diffusion rate, resulting in low plant P uptake.

iii. When external P in the form of mineral fertilizers are supplied to the soils, the nutrient is either fixed, adsorbed or absorbed and with time tends to return to stable forms of strengite, variscite in acid soils and apatite in alkaline soils. Consequently, the recovery efficiency of P fertilizers is low relative to other major nutrients such as nitrogen and potassium.

iv. Crop harvest and removal exports significant amounts of P from the soil with limited amounts of residues returned to the cropping system.

v. The use of external P inputs in the form of mineral fertilizers or organic manure, for food crop production is not a common practice, because farmers cannot afford the appropriate P fertilizers.

2.2.4 Phosphorus losses from the soil system

Low efficiency of phosphorus fertilizer use is a clear indication that nutrients intended for plant uptake are changed into other forms or eroded and inaccessible to the intended plant. Generally, phosphorus losses from the soil are affected by the type of crop cultivated, tillage systems, soil's level of phosphorus and the rate, time and method of application of inorganic and organic sources of the nutrient (Rehm *et al*., 1997). Tillage can increase soil erosion with its consequent increase in P losses through runoff (Eghball and Gilley, 1999). Leinweber *et al*. (2002) reported that even where soil P levels are at or near the optimum, the loss by erosion of small amounts of P adsorbed on sediments or in solution can lead to eutrophication of freshwaters. Losses of P by adsorption, precipitation and conversion to organic form can lead to a recovery of only 10 – 30 % of the applied phosphate mineral fertilizer by the crop grown (Holford, 1997; Syers *et al*., 2008).

2.3 P-fixing soils

Every soil type possesses specific characteristics which influence the performance of crops grown on it. P-fixing soils are noted for their ability to influence crop response to applied P fertilizers in terms of their retention and release for uptake by crops. The P-fixing capacity of a soil is influenced by factors such as pH, $CaCO_3$, sesquioxides, moisture and clay contents (Nad *et al*., 1975; Ghosal *et al*., 2011). Cambisols, Acrisols and Lixisols are among the major P-fixing soils in Ghana.

2.3.1 Cambisols

Cambisols are young soils in terms of their weathering processes. The abundant clay mineral composition is illite (a 2:1 type with slight or moderate expanding lattice). The cation exchange capacity ranges from 10 – 40 $cmol_{(c)}$/kg clay (Landon, 1991). Cambisols with low CEC can release P much faster for plant uptake than vertisols (Ochola and Omollo, 2010).

2.3.2 Acrisols

Acrisols are characterized as soils that have relatively higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an Argic subsoil horizon (FAO, 2006a). They have an accumulation of low-activity clays and are characterized by low base saturation (FAO, 2006a). The mineralogy of Acrisols are similar to other tropical soils with no or very few weatherable minerals left. However, they have high concentrations of Al and Fe oxides and are dominated by kaolinite (Driessen *et al*., 2001). They have a quite weak micro aggregation due to the depletion of sesquioxides in the upper horizons (Driessen *et al*., 2001). As many other tropical soils, Acrisols have a low fertility status, high capacity for P-fixation and high levels of Al in the soil solution which limits their use for agriculture (Driessen *et al*., 2001).

2.3.3 Lixisols

Lixisols comprise soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an *argic* subsoil horizon. Lixisols have a high base saturation and low-activity clays at certain depths (FAO, 2006a). The normal profile of most Lixisols in Ghana consists of about 30 cm of dark brown to brown, fine sandy loam overlying from 30-152 cm, reddish brown to reddish yellow, fine sandy loam to fine sandy clay loam (Adu and Mensah-Ansah, 1995). It has a moderate level of organic matter and moisture holding capacity (Adu and Mensah-Ansah, 1995).

They are dominated by 1:1 clays and have higher Fe-, Al- and Ti-oxide contents than are normal in less weathered soils. Despite all these properites, Lixisols are generally better than Acrisols because of their higher soil-pH and the absence of serious Al-toxicity. The absolute amount of exchangeable bases is generally not more than 2 $cmol_{(c)}$/kg soil because of the low cation exchange capacity of Lixisols (Driessen *et al*., 2001).

2.4 Phosphorus use efficiency (PUE) in crops

Nutrient use efficiencies are widely used in crop production systems to measure the ability of a crop plant to acquire and utilize nutrients for their biological and grain yields. Smil (2000) and Mosier *et al*. (2004) stated two significant reasons for the efficient use of nutrients; firstly to enhance food production with the same or lower nutrient input, and secondly to reduce nutrient outflows into the environment.

According to Fageria (2008), PUE is a very complex phenomenon affected by a vast number of mechanisms in the plant, and various physiological and biochemical traits associated with P acquisition from the soil and P utilization at the cellular level. Phosphorus accumulates in the soil with long - term applications of fertilizers, which is partly due to low PUE of most crops (Caldecott, 2009).

Phosphorus use efficiency of crops ranges from 10 to 30 % in the year that the P fertilizer is applied (Malhi *et al*., 2002). The PUE of crops is usually less than 25 %

during the year of amendments application (Zhang *et al*., 2004) due to factors such as soil texture, aeration, compaction, temperature, soil pH and $CaCO_3$ contents (Munir *et al*., 2004). According to Munir *et al*. (2004), these factors also influence the dynamics of P in the soil resulting in its conversion into forms unavailable to crops.

Richardson *et al*. (2011) defined phosphorus utilization efficiency as the ability of a plant species to produce higher dry matter per unit of P absorbed. A higher application rate of phosphorus fertilizer may lead to inefficient utilization of P as a high proportion of the applied P is transformed to sparingly soluble forms and that are not readily available for the crop uptake (Abekoe and Sahrawat, 2003). Wang *et al.* (2010) also reported that a higher P utilization efficiency is mainly attributed to efficient translocation and use of the stored P in plants. A higher P utilization efficiency can also be attributed to a higher grain yield per unit of P in the grain and a higher P harvest index (Baligar *et al*., 2001).

Kogbe and Adediran (2003) conducted an experiment to determine the influence of nitrogen, phosphorus and potassium application on the yield of maize in the savannah zone of Nigeria and observed that maize responded positively to P application. The control (0 kg P_2O_5 ha^{-1}) produced the least yield that was significantly lower than other application rates. According to them, application of 40 kg P_2O_5 ha^{-1} appeared to be optimum, since at higher rates; there was decline in grain yield. Studies on the P requirements of crops using a soluble P source such as triple superphosphate (TSP) suggests that crops respond to a rate as little as 10 kg P ha^{-1} (Sahrawat *et al*., 2001).

There are several ways of expressing nutrient use efficiency. Roberts (2008) defined agronomic efficiency as the nutrients accumulated in the above-ground plant parts or the nutrients recovered within the entire soil-crop-root system. Mosier *et al*. (2004)

described four different agronomic indices which are commonly used to describe nutrient use efficiency: agronomic efficiency (AE), apparent recovery efficiency (RE), partial factor productivity (PFP) and physiological efficiency (PE).

Agronomic efficiency and partial factor productivity are most useful measures of nutrient use efficiency as they enhance an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the farming system (Yadav, 2003). According to Cassman *et al*. (1996), PFP of crops can be improved by increasing the amount, uptake and utilization of indigenous nutrients, as well as increasing the efficiency with which applied nutrients are assimilated by the crop and utilized to produce grain.

For P recovery efficiency, Miraj *et al.* (2013) reported that even when farmers use fertilizers, the properties of many tropical soils are such that P recovery rates are very low. The first year recovery of P fertilizer ranges from less than 10 % with the highest being 30 % (Roberts, 2008). In view of this, Akande *et al.* (2010) reported that the extent of recovery of added P by crops should influence the P application rates since increasing levels of P decreased the apparent P recovery. This was because a plant grown in a nutrient deficient soil, exhibited greater competition for nutrient absorption at lower rates (Akande *et al.*, 2010).

2.5 Trend of nutrient uptake by maize plants

The trend of nutrient assimilation in maize is typically nutrient specific and varies in the timing, rate, and duration of uptake as well as the tissues to which nutrients are partitioned (Bender *et al*., 2013). The nutrients also exhibit varying degrees of mobility within the maize plant once assimilated into the plant tissue (Bender *et al*., 2013). Ologunde (1974) reported that nutrient uptake and distribution in different parts of maize plants have been found to vary primarily with the fertility of the native soil, application of chemical fertilizers, the growth stage of the plant and the environmental conditions. Maize varieties are known to vary in P uptake and utilization efficiencies, as well as in adaptability to different soil types (Machado *et al.*, 1999). Wasonga *et al.* (2008) reported that P application is likely to improve the root system and enhance P uptake, in addition to other essential plant nutrients as well as moisture. The P requirement of crops is very high during initial stages of maize growth, and hence, an adequate supply from the soil and fertilizer is necessary (Hellal *et al*., 2013). Karlen *et al*. (1988) noted that P uptake follows a nearly steady, highly predictive rate of uptake from V6 through R6. They also reported that P is highly mobile in maize plant and can begin translocation to maize grains at the R2 growth stage, which consequently influences nutrient uptake partitioned to the maize grains. The P concentration of a healthy maize leaf tissue is very low, ranging from 0.2 to 0.4 % of the dry matter (Brady and Weil, 2002). In general, P uptake by plants is almost complete towards the end of maximum growth (Hellal *et al*., 2013).

2.6 Summary of literature review

The reviewed literature suggests that there is a knowledge gap on the impact of tillage and phosphorus application on phosphorus uptake and use efficiency at different stages of crop growth on different soil types in Ghana. Tillage practices influence soil physico-chemical characteristics, which may consequently affect crop growth, yield and nutrient uptake. Phosphorus is considered a key nutrient in crop production. However, its deficiency can adversely affect the leaf area index and limit the interception of photosynthetically active radiation by crops which may lead to low biomass accumulation and eventually affect crop yields. Several ways of estimating phosphorus use efficiency in crops were discussed. The literature indicated that the low efficiency of phosphorus fertilizer use is a clear indication that nutrients intended for plant uptake are changed into other forms or eroded and inaccessible to the intended plant. Hence, measures must be taken to reduce these losses. The characteristics of some P-fixing soils were discussed. A study on the trend of nutrient uptake by maize plants indicated that P uptake follows a nearly steady, highly predictive rate of uptake from V6 to R6, and stops towards the end of maximum growth. The observations made from the works by several authors necessitated the formulation of hypothesis for this study and justified its objectives.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study sites

The study was conducted during the minor rainy season of 2013 at two locations: Agricultural Research Station of the Faculty of Agriculture, KNUST at Anwomaso and Crop Research Institute (CRI) outstation at Ejura located within the Semi-deciduous forest and Forest-savannah transition zones respectively.

3.1.1 Location

Both Ejura and Anwomaso are located in the Ashanti Region of Ghana but far apart. The experimental sites at Ejura and Anwomaso are located in the Ejura Sekyedumase district and Kumasi Metropolis respectively. The experimental site at Ejura lies within latitudes $7^{o}9'$ N and $7^{o}36'$ N and longitudes $1^{o}5'$ W and $1^{o}39'$ W and is about 106 km north of Kumasi (MoFA, 2014) whilst that at Anwomaso is located at latitude $06^{o}43'$N and longitude $1^{o}36'$W, about 15 km south of Kumasi.

3.1.2 Climate

Ejura lies within the transition zone with the semi-deciduous forest to its south and Guinea Savannah zone to its north. The area experiences intermediate conditions of the forest and savannah climates. It is marked by a bimodal rainfall pattern that is characteristic of southern Ghana. The rainy season begins in April and ends in November with two distinct growing seasons for annuals of relatively short growing cycle (3 - 4 months). The major (wet) season is between April and late July and the minor between late August and November. The dry season occurs between November and April (ESDA, 2006; MoFA, 2014). The mean annual rainfall is about 1300 mm (ESDA, 2006; MoFA, 2014). High temperatures with a mean monthly temperature of

21 ^{o}C – 30 ^{o}C are generally experienced. Generally, relative humidity as high as 90 % is experienced during the rainy periods (MoFA, 2014).

The site at Anwomaso is located within the Semi-deciduous forest zone and is also characterized by a bimodal rainfall pattern with a peak in June and October. The major rainy season spans between March and July whilst the minor season starts from September and ends in November. The dry season is from December to February. The mean annual rainfall is about 1450 mm.

3.1.3 Soil type

The experiment was conducted on a Rhodic Lixisol (Ejura series) at Ejura (Adu and Mensah-Ansah, 1995) and Orthi-Ferric Acrisol (Asuansi series) (Adu, 1992) at Anwomaso.

3.2 Field experiment

3.2.1 Test crop

Omankwa, an early maturing (90 – 95 days), white, open pollinated (OP), drought tolerant quality protein maize (QPM) variety with a yield potential of 5000 kg/ha (CSIR–CRI, 2011) was used as the test crop. The seeds were obtained from the Cereals Section of Crops Research Institute, Fumesua.

3.2.2 Experimental design/treatments

The experiment was laid out in a split-plot, arranged in a Randomized Complete Block Design (RCBD) with three replications at both locations. The factors considered in the experimental treatments were tillage systems (main plot factor) and levels of P application (sub-plot factor).

The tillage treatments were two and the levels of P application treatments were four as shown in Table 3.1, given as a factor of 2 x 4 treatments. One of eight treatment combinations (Table 3.2) was allocated to each of the 24 subplots at the study locations. The experimental treatments are outlined in Table 3.1 and the treatment combinations outlined in Table 3.2.

Table 3.1: Description of treatments used for the experiment and their plot allocations

Treatment	Plot allocation	Description
Type of Tillage (T)	Main plot	NT: No-tillage
		CT: Conventional tillage
Levels of P	Sub plot	P_0: 0 kg P_2O_5 ha^{-1}
		P_{30}: 30 kg P_2O_5 ha^{-1}
		P_{60}: 60 kg P_2O_5 ha^{-1}
		P_{90}: 90 kg P_2O_5 ha^{-1}

Table 3.2: Treatment combinations applied in the field experiments

Treatment	Treatment details
CTP_0	Conventional tillage + 0 kg P_2O_5 ha^{-1}
CTP_{30}	Conventional tillage + 30 kg P_2O_5 ha^{-1}
CTP_{60}	Conventional tillage + 60 kg P_2O_5 ha^{-1}
CTP_{90}	Conventional tillage + 90 kg P_2O_5 ha^{-1}
NTP_0	No-tillage + 0 kg P_2O_5 ha^{-1}
NTP_{30}	No-tillage + 30 kg P_2O_5 ha^{-1}
NTP_{60}	No-tillage + 60 kg P_2O_5 ha^{-1}
NTP_{90}	No-tillage + 90 kg P_2O_5 ha^{-1}

3.2.3 Land preparation

The experimental fields at the two locations were first slashed with cutlass to clear off the vegetation and tree stumps uprooted. A land area of 28.0 m x 14.0 m (392.0 m^2) was demarcated at the two locations for the research with each main plot measuring 13.5 m x 4.0 m (54.0 m^2) and sub - plots 3.0 m x 4.0 m (12.0 m^2). Alleys of 1 m were left between main plots or blocks and 0.50 m between sub–plots. The field layout is as shown in Fig. 3.1.

For the conventional tillage treatment plots, the land was ploughed and harrowed to a fine tilth with a disc plough and disc harrow, respectively. With the no-tillage treatment plots, the land was prepared by spraying the plots with Glyphosate (Round-up) before sowing.

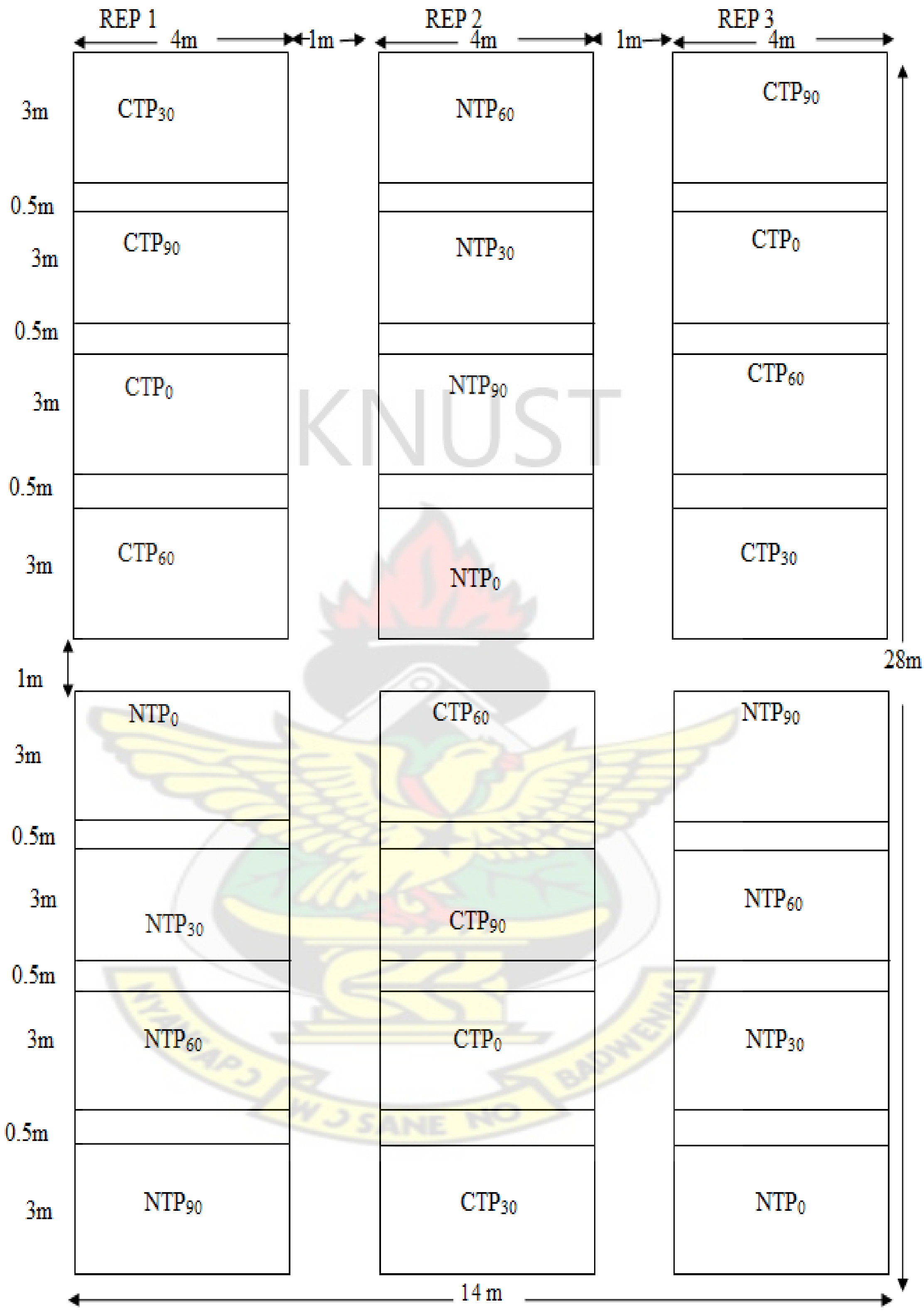

Figure 3.1: Experimental field layout showing treatment combinations

3.2.4 Sowing

Maize seeds were sown manually at a spacing of 80 cm x 40 cm at three seeds/hill and seedlings later thinned to two/hill two weeks after sowing (2 WAS) to give a planting density of 80 plants per sub-plot corresponding to 62,500 plants/ha on each experimental field.

3.2.5 Agronomic practices

3.2.5.1 Weed management

Weeding was carried out manually with hoe at three and six weeks after emergence.

3.2.5.2 Fertilizer application

Straight fertilizers of urea, triple superphosphate (TSP) and muriate of potash (MOP) were applied to the treatment plots. The mode of application to the maize plants was by band placement.

A basal application of urea (60 kg/ha) was carried out at a uniform rate to all the treatment plots, two weeks after sowing (WAS). At 6 WAS, treatment plots were "top dressed" with 30 kg/ha of urea amounting to application of 90 kg/ha N. Triple superphosphate was applied 2 WAS to the maize plants on the respective treatment plots at the following rates: 0, 30, 60 and 90 kg P_2O_5 ha^{-1}. The 0, 30, 60 and 90 kg P_2O_5 ha^{-1} of TSP applied were equivalent to 0, 13.20, 26.40 and 39.60 kg P ha^{-1} respectively. Muriate of potash (MOP) was applied 2 WAS at a rate of 60 kg K_2O ha^{-1} (equivalent to 49.80 kg K ha^{-1}) to make up for the K requirement of the crops. The quantities of fertilizer applied to individual maize plants were computed as shown in appendices 1, 2 and 3.

3.2.5.3 Pest management

Insect pests were controlled by spraying crops with Lamda 2.5 EC.

3.2.6 Measurement of growth and yield parameters of maize

3.2.6.1 Measurement of growth parameters

Five plants were randomly selected from the middle rows of each plot for the measurement of growth parameters of maize.

3.2.6.1.1 Plant height

Plant height was measured at two-week interval from 2 WAS to 10 WAS using a 5 m metallic meter-rule. The average height of five plants randomly selected from each treatment plot was then determined.

3.2.6.1.2 Measurement of dry matter

Three plant stands were randomly selected from a 1 m^2 area within the middle rows of each plot for the determination of dry matter at V6, V12 and R6 growth stages of maize (Plates 1 – 3). Maize plants attained V6, V12 and R6 growth stages at 5 WAS, 7 WAS and 12 WAS respectively, at both experimental sites. The plants were cut at the ground level using a sharp knife and weighed to obtain the total fresh weight. The biomass was later dried in an oven at 80 ^oC for 48 hours to a constant weight to obtain the dry matter.

Plate 1: Field experiment showing maize crops at V6 growth stage

Plate 2: **Field experiment showing maize crops at V12 growth stage**

Plate 3: **Field experiment showing maize crops at R6 growth stage**

3.2.6.2 Yield parameters

3.2.6.2.1 Grain yield

At R6, the grain yield was obtained by shelling the grains from the cobs. They were put in a brown envelope and oven-dried at a temperature of 80 ^{o}C for 48 hours to a constant weight. The dry weight was then recorded to obtain the grain dry matter yield per plot and then extrapolated to kg/ha.

3.2.6.2.2 Hundred seed weight

After oven drying, hundred seeds were counted from each brown envelope representative of each treatment plot and weighed to obtain the hundred seed weight.

3.2.7 Soil sampling and preparation for analysis

The quality of any soil test is largely dependent on reliable soil sampling (FAO, 2006b). In this study, initial soil samples were randomly taken from each experimental field at a depth of 0 – 15 cm with a hand auger. The soil samples were bulked to obtain a composite sample after which 500 g was taken, air-dried, ground and passed through a 2 mm sieve for laboratory analysis. At the end of the experiment, final soil samples were taken from the base of five randomly selected plant stands from each treatment plot and bulked to obtain a composite sample for laboratory analysis.

3.2.8 Plant sampling and preparation for analysis

At V6 and V12 growth stages of the maize plant, the biomass of three randomly selected plant stands from an area of 1 m^2 in each treatment plot were collected using a sharp knife. The samples were thoroughly washed with tap water and distilled water and then dried at room temperature for three days. They were then put in brown envelopes and oven-dried at a temperature of 80 ^{o}C for 48 hours to a constant weight and milled to pass through a 0.5 mm sieve in preparation for analysis to determine their phosphorus contents.

At R6 (physiological maturity), the maize plants were separated into ears, shoots and leaves and analyzed separately for their phosphorus compositions. The values were then summed up to obtain the total phosphorus composition under each treatment. The phosphorus uptake of maize under the different treatments were also determined.

3.3 Laboratory/ analytical methods

The analysis of the physico–chemical properties of the soils and total P determination of plant samples were carried out in the Chemistry Laboratory of the Soil Research Institute of the Council for Scientific and Industrial Research, Kwadaso, Kumasi, Ghana.

The soil samples were analyzed for pH, organic C, total N, available P, exchangeable cations (Ca, Mg, K, Na, Al + H, Fe), particle size distribution and bulk density. The biomass samples were analyzed for total P composition. For the initial soil analysis, duplicate samples were analyzed and the mean determined. The analyzed samples were rated using the standard ratings of the Soil Research Institute of Ghana (Appendix 4).

3.3.1 Physical properties

3.3.1.1 Particle size analysis

Particle size analysis was carried out using the hydrometer method which fundamentally depends on Stokes' Law (Boyoucos, 1962). A sample of soil was air - dried and 50.0 g weighed into a one litre screw lid shaking bottle. Hundred millilitres of distilled water and 50.0 ml of 10 % sodium hexametaphosphate (calgon) was then added. The suspension was shaken for fifteen minutes and was transferred into a

1000 ml measuring cylinder. Distilled water was added to the mixture to make up to the 1000 ml mark.

The cylinder was placed on a flat surface and the first hydrometer and temperature readings recorded after 40 seconds. The suspension was then allowed to stand undisturbed for three hours after which the second hydrometer and temperature readings were recorded.

The percentage (%) sand, silt and clay in the soil samples were determined using the following formulae:

$$\% \text{Sand} = 100 - [(\text{A/W}) \times 100] \tag{3.1}$$

$$\% \text{Clay} = 100 \times (\text{B/W}) \tag{3.2}$$

$$\% \text{Silt} = 100 - (\% \text{sand} + \% \text{clay}) \tag{3.3}$$

where:

A = corrected hydrometer reading at 40 seconds

B = corrected hydrometer reading at 3 hours

W = weight of dry soil

The textural classes of the soil at both experimental fields were then determined from the textural triangle.

3.3.1.2 Soil bulk density

Bulk density in the field was determined by the core sampler method (Blake and Hartge, 1986). A cylindrical steel core of 6.8 cm diameter and 15 cm long was used to sample slightly disturbed soil as it existed *in situ*. The soil in the core sampler was then weighed, oven-dried at 105 ^{o}C for 48 hours after which the final weight was taken. Bulk density of soil was calculated as follows:

$$\rho_b = {Ms}/{Vt} \qquad (3.4)$$

where:

ρ_b = soil bulk density (g cm^{-3})

Ms = mass of the oven dry soil (g)

Vt = total volume of soil (cm^3)

The calculated bulk density was then converted to Mg/m^3.

3.3.2 Chemical analysis

3.3.2.1 Soil pH

The soil pH was determined in a 1:1 (soil: water) ratio using a HI 9017 Microprocessor pH meter. Approximately 25 g of soil sample was weighed into a plastic pH tube to which 25 ml distilled water was added from a measuring cylinder. The suspension was stirred vigorously for 20 minutes and allowed to stand for 30 minutes for the suspended clay particles to settle. After calibrating the pH meter with standard buffer solutions of pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension (Page *et al*., 1982).

3.3.2.2 Soil organic carbon

Soil organic carbon was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982).

Two grams of air-dried soil was weighed out into a clean and dry 500 ml Erlenmeyer flask. A reference sample as well as a blank sample were included. Ten millilitres of 1.0 *N* $K_2Cr_2O_7$ was added to the soil and the blank flask from the burette. With the aid of a dispenser, 20 ml of concentrated sulphuric acid (H_2SO_4) was dispensed into the soil suspension. The flask was then swirled vigorously to ensure that the solution is in contact with all the soil particles. The flask together with its contents was allowed to stand for 30 minutes in a fume cupboard. Approximately 250 ml of distilled water and 10 ml concentrated orthophosphoric acid (H_3PO_4) were added to the mixture to cool. The excess dichromate ions ($Cr_2O_7^{2-}$) in the mixture was back titrated with 1.0 *M* $FeSO_4$ solution using diphenylamine indicator until the colour changed to blue and then to a stable green end-point. The volume of $FeSO_4$ solution used was recorded and % organic carbon (OC) calculated.

Calculation:

The organic carbon content of soil was calculated as follows:

$$\%\,\mathrm{OC} = \frac{M \text{ x } 0.39 \text{ x mcf } (\mathrm{V_1} - \mathrm{V_2})}{\mathrm{w}} \qquad (3.5)$$

where:

M = molarity of ferrous sulphate

V_1 = Ferrous sulphate required for blank (ml)

V_2 = Ferrous sulphate solution required for sample (ml)

w = weight of air-dry sample (g)

$$\text{mcf} = \text{moisture correcting factor} = \frac{(100 + \%\,\text{moisture})}{100}$$

0.39 = 3 x 0.001 x 100 % x 1.3 (3 = equivalent weight of carbon, 1.3 = compensation factor for incomplete oxidation of the organic carbon)

3.3.2.3 Total nitrogen

The total nitrogen content of the soil samples were determined by the Kjeldahl digestion and distillation procedure as described in Soils Laboratory Staff (1984).

Digestion

An air-dried soil sample of 0.5 g was weighed into a 500 ml long-necked Kjeldahl digestion flask. Five millilitres of distilled water was added and left to stand for 30 minutes to moisten the soil solution. One spatula full of Kjeldahl catalyst (mixture of 1 part Selenium + 10 parts $CuSO_4$ + 100 parts Na_2SO_4) and 5 ml concentrated H_2SO_4 was then added. The sample was digested for three hours until it became clear and colourless. The flask was further allowed to cool. The supernatant solution was then decanted into a 100 ml volumetric flask. Distilled water was subsequently added to make up to the 100 ml mark.

Distillation

An aliquot of 25 ml of the solution was transferred into the Kjeldahl distillation apparatus by means of a pipette. Ten millilitres of 40 % NaOH was added and the distillate collected over 10 ml of 2 % boric acid. Bromocresol green was used as an indicator for the titration. The presence of nitrogen resulted in a light blue colour.

Titration

The collected distillate was titrated with 0.02 *N* HCl till the blue colour changed to grey and then to pink. A blank determination was also carried out without the soil sample to take care of the traces of nitrogen in the reagents and the water used in the titration.

Calculation

The percentage of total nitrogen in the soil sample was calculated as follows:

$$\%\ \mathrm{N} = \frac{N \text{ x } (\mathrm{a} - \mathrm{b}) \text{ x } 1.4 \text{ x mcf}}{\mathrm{w}} \qquad (3.6)$$

where:

N = concentration of HCl used in the titration

a = volume of HCl used in the titration (ml)

b = volume of HCl used in the blank titration (ml)

w = weight of air-dried soil sample (g)

$$\text{mcf} = \text{moisture correcting factor} = \frac{(100 + \%\ \text{moisture})}{100}$$

3.3.2.4 Available phosphorus (Bray's No. 1 phosphorus)

The available phosphorus in the soil samples was extracted with Bray's No.1 extracting solution (0.03 *M* NH_4F and 0.025 *M* HCl) as described by Bray and Kurtz (1945). Phosphorus in the extract was determined by the blue ammonium molybdate method using a spectrophotometer with ascorbic acid as the reducing agent.

A 5.0 g soil sample was weighed into a 50 ml shaking bottle and 35 ml Bray's No. 1 extracting solution added. The mixture was shaken vigorously for 10 minutes on a reciprocating shaker and filtered through a No. 42 Whatman filter paper into a suitable container. Aliquots of 5 ml each of the blank and the extract, were pipetted into separate test tubes and 10 ml of the colouring reagent (ammonium molybdate and tartarate solution) added and shaken vigorously. The solution was allowed to stand for 15 minutes for a blue colour development. The absorbance was measured on a spectronic 21D spectrophotometer at a wavelength of 660 nm at medium sensitivity.
A standard series of 0, 1, 2, 3, 4 and 5 mg P/L was prepared from 20 mg/L phosphorus stock solution.

Calculation:

$$\text{P (mg/kg soil)} = \frac{\text{(a - b) x 35 x 15 x mcf}}{\text{w}} \qquad (3.7)$$

where:

a = P in sample extract (mg/L)

b = P in blank solution (mg/L)

35 = volume of extracting solution (ml)

15 = volume of final sample solution (ml)

$$\text{mcf} = \text{moisture correcting factor} = \frac{(100 + \%\ \text{moisture})}{100}$$

w = weight of soil sample (g)

3.3.2.5 Exchangeable cations determination

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 *M* ammonium acetate (NH_4OAc) extract (Black, 1986) whereas the exchangeable acidity (hydrogen and aluminium) was determined in 1.0 *M* KCl extract (Page *et al*., 1982).

3.3.2.5.1 Extraction of exchangeable bases

A 5.0 g soil sample was weighed into a leaching tube and leached with 100 ml of buffered 1.0 *M* NH_4OAc solution at pH 7. After leaching, the supernatant solution was filtered through No. 42 Whatman filter paper. The aliquots of the extracts were used for the determination of calcium, magnesium, potassium and sodium.

3.3.2.5.1.1 Determination of calcium and magnesium

For the determination of calcium and magnesium in the soil samples, a 25 ml aliquot of the extract was transferred into an Erlenmeyer flask. Afterwards, 1 ml of hydroxylamine hydrochloride, 1 ml of 2.0 % potassium cyanide (KCN), 1 ml of 2.0 % potassium ferrocyanide, 10 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solutions were added. The mixture was then titrated with 0.01 *M* EDTA solution from a red to a pure turquoise blue end point.

3.3.2.5.1.2 Determination of calcium only

A 25 ml aliqout of the extract was transferred into a 250 ml Erlenmeyer flask and the volume made up to 50 ml with distilled water. After that, 1 ml each of hydroxylamine, 2.0 % KCN and 2.0 % potassium ferrocyanide solution were added. After a few minutes, 5 ml of 8.0 *M* potassium hydroxide solution (KOH) and a spatula of murexide indicator were added. The resultant solution was titrated with 0.01 *M* EDTA (Ethylene diamine tetraacetic acid) solution from a red to a pure blue end point.

Calculations:

$$Ca^{2+} + Mg^{2+}\ (\text{or } Ca^{2+})(\text{cmol/kg soil}) = \frac{0.01 \times (V_a - V_b) \times 1000}{w} \qquad (3.8)$$

where:

V_a = volume of EDTA used in the sample titration (ml)

V_b = volume of EDTA used in the blank titration (ml)

w = weight of the air-dried soil (g)

0.01 = concentration of EDTA used

3.3.2.5.1.3 Determination of exchangeable potassium and sodium

Potassium and sodium in the soil extract were determined by flame photometry. Standard solutions of potassium and sodium were prepared by diluting both 1000 mg/l K and Na solutions to 100 mg/l. In doing this, 25 ml portion of each solution was taken into 250 ml volumetric flask and made up to the volume using distilled water. Portions of 0, 5, 10, 15, 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks. One hundred millilitres of 1.0 *M* NH_4OAc solution was added to each flask and made to the volume with distilled water. This resulted in standard series of 0, 2.5, 5.0, 7.5, 10 mg/l for K and Na. Potassium and sodium were measured directly in the soil extract by flame photometry at wavelengths of 766.5 and 589.0 nm, respectively.

Calculations:

$$\text{Exchangeable K (cmol/kg soil)} = \frac{\text{(a - b) x 250 x mcf}}{\text{39.1 x w x 10}} \tag{3.9}$$

$$\text{Exchangeable Na (cmol/kg soil)} = \frac{\text{(a - b) x 250 x mcf}}{\text{23 x w x 10}} \tag{3.10}$$

where:

a = mg/l K or Na in the diluted sample

b = mg/l K or Na in the diluted blank sample

w = weight of air – dried soil sample (g)

$$\text{mcf} = \text{moisture correcting factor} = \frac{(100 + \%\ \text{moisture})}{100}$$

39.1 = atomic weight of potassium

23 = atomic weight of sodium

3.3.2.5.2 Exchangeable acidity (Al^{3+} and H^{+})

Al^{3+} + H^{+} was extracted from the soil samples with 1.0 *M* KCl and quantified by titration (McLean, 1965).

Ten grams of soil sample was put into a shaking bottle and 50 ml of 1.0 *M* KCl solution added. The mixture was shaken for two hours and then filtered. Twenty-five millilitres portion of the filtrate was then transferred into an Erlenmeyer flask after which a few drops of phenolphthalein indicator solution was added. The solution was titrated with 0.025 *N* NaOH until the colour turned pink. The amount of base used was equivalent to exchangeable acidity ($Al^{3+} + H^{+}$).

Calculation:

$$\text{Exchangeable } Al^{3+} + H^{+} \text{ (cmol/kg soil)} = \frac{\text{(a - b) x } N \text{ x 2 x 100 x mcf}}{\text{w}} \tag{3.11}$$

where:

a = volume of NaOH used in the sample titration (ml)

b = volume of NaOH used in the blank titration (ml)

N = normality of NaOH used for the titration

2 = 50/25 (filtrate/ pipetted volume)

$$\text{mcf} = \text{moisture correcting factor} = \frac{(100 + \%\ \text{moisture})}{100}$$

w = weight of air – dried soil sample (g)

3.3.2.6 Effective cation exchange capacity (ECEC)

Effective cation exchange capacity was obtained by the summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) and exchangeable acidity (Al^{3+} and H^{+}).

3.3.2.7 Determination of extractable iron and exchangeable aluminium

The extractable iron contents of the soils were determined using Atomic Absorption Spectrometry (Olson, 1982). Five grams of soil sample was weighed and the sample prepared by evaporating NH_4OAc extract to dryness in a beaker on a steam hot plate. A 3.5 ml of 1.0 *N* HCl was added to the solution and warmed. The solution was then transferred into a 50 ml volumetric flask and made to the volume with deionized water. Calibration curves were prepared by using standard solutions in the range of 0, 1, 2, 3 to 4 ppm of Fe, made up in 0.07 *N* HCl. The extractable Fe in the soil samples were then determined using a BUCK Scientific atomic absorption spectrophotometer, model 210 VGP.

The exchangeable Al contents of the soils were determined using unbuffered 1.0 *M* KCl as described by McLean (1965).

3.3.2.8 Total plant phosphorus determination

For the determination of total phosphorus in the maize plants, 0.5 g each of milled maize biomass from each treatment plot was ashed in a muffle furnace, after which the ash was dissolved in 1.0 *M* HCl solution and filtered. The filtrate was diluted to 100 ml with distilled water and analyzed for total phosphorus.

A 5.0 ml aliquot of the filtrate was taken into a 25 ml volumetric flask. Following this, 5.0 ml of ammonium vanadate solution and 2.0 ml stannous chloride solution were added and the solution made up to the 25 ml mark with distilled water and allowed to stand for 10 minutes for full colour development. A standard curve was plotted with phosphorus concentrations ranging from 0, 1, 2, 5, 10 to 20 mg P/kg organic material. The absorbance of the sample and standard solutions were read on a spectrophotometer at a wavelength of 470 nm. Phosphorus concentration of the biomass samples were then determined from the standard curve.

3.4 Calculation of phosphorus uptake and use efficiencies

Calculations of P uptake, recovery efficiency, partial factor productivity, agronomic efficiency and utilization efficiency were carried out using formulae by Dobbermann (2005).

$$\text{P uptake (kg ha}^{-1}) = \text{P contents (\%) in plant part (dry matter) x Yield (kg ha}^{-1}) \quad (3.12)$$

where: Yield = biomass dry weight of plant part or grain yield

$$\text{P Recovery Efficiency (PRE)} = \frac{\text{(P uptake(fert) - P uptake(cont) (kg P ha}^{-1})}{\text{TSP fertilizer applied (kg P ha}^{-1})} \text{ x } 100 \quad (3.13)$$

where: fert = fertilized plot; cont = control plot

$$\text{Partial Factor Productivity (PFP)} = \frac{\text{Yield (fertilized) (kg ha}^{-1})}{\text{TSP fertilizer applied (kg P}_2\text{O}_5\text{ ha}^{-1})} \quad (3.14)$$

$$\text{P Agronomic Efficency (PAE)} = \frac{\text{(Yield (fertilzed) - Yield (control) (kg ha}^{-1})}{\text{TSP fertilizer applied (kg P}_2\text{O}_5\text{ ha}^{-1})} \quad (3.15)$$

$$\text{Phosphorus Utilization Efficiency (PUtE)} = \frac{\text{Yield (kg ha}^{-1})}{\text{P uptake (kg ha}^{-1})} \quad (3.16)$$

where: Yield = biomass dry weight of plant part or grain yield

3.5 Statistical analysis

Data on all parameters obtained from the study were subjected to Analysis of Variance (ANOVA) using General Statistical Software Package (GenStat, 2009). The Least Significant Difference (LSD) method was used for the separation of treatment means at 5 % probability. Regression analysis was carried out to establish the correlation between principal parameters.

CHAPTER FOUR

4.0 RESULTS

4.1 Initial soil characterization at the experimental sites

The results of the initial physico-chemical properties of the Orthi-Ferric Acrisol at Anwomaso and Rhodic Lixisol at Ejura are presented in Tables 4.1 and 4.2.

Table 4.1: Initial physico-chemical properties of soil (0-15 cm) at Anwomaso

Soil property	Min	Max	Mean	SD	CV
Chemical properties					
Soil pH (1:1 H_2O)	6.85	7.08	6.97	0.16	2.34
Soil organic carbon (%)	1.35	1.56	1.46	0.15	10.21
Total N (%)	0.15	0.16	0.16	0.01	4.56
Available P (mg/kg soil)	4.94	5.58	5.26	0.45	8.60
Exchangeable bases ($cmol_{(c)}$/kg soil)					
Ca^{2+}	4.01	4.01	4.01	-	-
Mg^{2+}	1.34	1.34	1.34	-	-
K^+	0.12	0.12	0.12	-	-
Na^+	0.06	0.06	0.06	-	-
Exchangeable acidity (Al^{3+} + H^+) ($cmol_{(c)}$/kg soil)	0.05	0.08	0.07	0.02	32.64
ECEC ($cmol_{(c)}$/kg soil)	5.58	5.61	5.60	0.02	0.38
Extractable Fe (mg/kg soil)	113.30	124.90	119.10	8.20	6.89
Physical properties					
Sand (%)	68.96	72.02	70.49	2.16	3.07
Silt (%)	19.98	23.04	21.51	2.16	10.06
Clay (%)	8.00	8.00	8.00	-	-
Texture	Sandy loam				
Bulk density(Mg/m^3)	1.15	1.30	1.23	0.11	8.66

Values are means of duplicate sample analyses. SD = Standard deviation, CV = Coefficient of variation expressed as a percentage, ECEC = Effective cation exchange capacity

The soil bulk density of the Orthi-Ferric Acrisol ranged from 1.15 – 1.30 Mg/m^3 with a CV of 8.66 %. This bulk density falls within the normal range for sandy loams and un-compacted mineral soils (Landon, 1991). The soil was neutral with low mean organic carbon content of 1.46 %. The total nitrogen content was moderate with a mean value of 0.16 %. The effective cation exchange capacity and available P content were low with values ranging from 5.58 – 5.61 $cmol_{(c)}$/kg soil and 4.94 – 5.58 mg/kg respectively. In general, the Orthi-Ferric Acrisol had a low fertility status. The extractable Fe contents of the soil at the beginning of the study ranged from 113.30 – 124.90 mg/kg soil.

Table 4.2: Initial physico - chemical properties of soil (0-15 cm) at Ejura

Soil property	Min	Max	Mean	SD	CV
Chemical properties					
Soil pH (1:1 H_2O)	5.09	5.28	5.19	0.13	2.59
Soil organic carbon (%)	0.46	0.48	0.47	0.01	3.01
Total N (%)	0.03	0.05	0.04	0.01	35.36
Available P (mg/kg soil)	29.81	33.72	31.77	2.76	8.70
Exchangeable bases ($cmol_{(c)}$/kg soil)					
Ca^{2+}	1.07	1.34	1.21	0.19	15.84
Mg^{2+}	0.53	0.53	0.53	-	-
K^{+}	0.05	0.05	0.05	-	-
Na^{+}	0.01	0.01	0.01	-	-
Exchangeable acidity (Al^{3+} + H^{+}) ($cmol_{(c)}$/kg soil)	0.35	0.35	0.35	-	-
ECEC ($cmol_{(c)}$/kg soil)	2.01	2.28	2.15	0.19	8.90
Extractable Fe (mg/kg soil)	32.10	35.70	33.90	2.55	7.51
Physical Properties					
Sand (%)	76.30	78.60	77.45	1.63	2.10
Silt (%)	15.40	17.70	16.55	1.63	9.83
Clay (%)	6.00	6.00	6.00	-	-
Texture	Loamy sand				
Bulk density(Mg/m^3)	1.20	1.43	1.32	0.16	12.37

Values are means of duplicate sample analyses. SD = Standard deviation, CV = Coefficient of variation expressed as a percentage, ECEC = Effective cation exchange capacity.

The results of the laboratory analysis of the Rhodic Lixisol at Ejura were generally indicative of low fertility status except for available P. The soil had a loamy sand texture. The bulk density ranged from 1.20 – 1.43 Mg/m^3 with a CV of 12.37 %. Like the Orthi-Ferric Acrisol, the bulk density falls within the normal range for un-compacted mineral soils (Landon, 1991). The mean soil pH, organic carbon and total nitrogen contents were 5.19, 0.47 % and 0.04 %, respectively. The ECEC was very low and ranged from 2.01 – 2.28 $cmol_{(c)}$/kg soil with a co-efficient of variation of 8.90 %.

The available phosphorus was however high ranging from 29.81- 33.72 mg/kg. The mean extractable iron recorded was 33.90 mg/kg soil.

4.2 Effects of tillage and phosphorus application on P concentration in maize

Maize plants were sampled at V6, V12 and R6 growth stages to determine their total P concentrations. The results obtained from the statistical analysis are presented in Table 4.3.

Table 4.3: Effects of tillage and P application on P concentration of maize plants at V6, V12 and R6 growth stages

Treatment	P concentration (%)					
	Anwomaso			Ejura		
	V6	V12	R6	V6	V12	R6
Tillage						
CT	0.27	0.20	0.27	0.28	0.26	0.40
NT	0.29	0.18	0.25	0.29	0.28	0.44
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	4.00	2.70	1.50	2.00	5.40	9.90
Rates of P application (kg P_2O_5 ha^{-1})						
P_0	0.19	0.14	0.20	0.21	0.21	0.29
P_{30}	0.26	0.18	0.23	0.26	0.24	0.37
P_{60}	0.31	0.20	0.28	0.31	0.29	0.44
P_{90}	0.37	0.25	0.33	0.36	0.35	0.59
LSD (0.05)	0.03	0.02	0.01	0.02	0.03	0.03
CV (%)	2.40	3.20	2.40	2.00	3.00	3.00
Interaction						
CTP_0	0.18	0.16	0.20	0.20	0.21	0.29
CTP_{30}	0.26	0.19	0.25	0.26	0.24	0.35
CTP_{60}	0.31	0.21	0.29	0.32	0.27	0.40
CTP_{90}	0.34	0.24	0.35	0.34	0.33	0.57
NTP_0	0.21	0.12	0.20	0.21	0.21	0.29
NTP_{30}	0.26	0.17	0.22	0.26	0.24	0.38
NTP_{60}	0.31	0.19	0.27	0.30	0.31	0.48
NTP_{90}	0.40	0.26	0.30	0.37	0.36	0.60
LSD (0.05)	0.03	0.02	0.02	0.03	0.03	0.05
CV (%)	7.10	7.00	4.40	6.80	7.80	6.10

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0 = 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

Tillage generally did not significantly ($p > 0.05$) affect the total P concentration of the above-ground maize parts. The different rates of P applied progressively enhanced the total P concentrations of maize plants with every 30 kg/ha increment of P. The total P concentrations of maize plants increased in the order $P_0 < P_{30} < P_{60} < P_{90}$. There was a decline in the P concentration of maize plants at V12 which was followed by a rise at R6 on both soils.

Significant tillage x phosphorus interactions were recorded in the total P concentration at all growth stages on both soils with values ranging from 0.12 – 0.60 %.

4.3 Effects of tillage and phosphorus application on P uptake in maize

Table 4.4 shows the effects of tillage and phosphorus application on uptake of P at the vegetative (V6, V12) and reproductive stages (R6) of maize plants during the minor growing season. Apart from V6 stage at Anwomaso and R6 at Ejura, maize plants under conventional tillage recorded a significantly higher P uptake than those under no–tillage on both sites. P uptake by maize plants significantly increased over the control (P_0) due to P application (Table 4.4). At almost all the growth stages, there was no significant difference between P uptake in the plants when 90 kg P_2O_5 ha^{-1} and 60 kg P_2O_5 ha^{-1} were applied. Significant ($p < 0.05$) tillage x phosphorus interactions were recorded among treatments at V6, V12 and R6 at both Anwomaso and Ejura. The P uptakes generally ranged from 0.37 – 2.64 kg P_2O_5 ha^{-1} at V6, 1.58 – 21.02 kg P_2O_5 ha^{-1} at V12 and 3.10 – 23.04 kg P_2O_5 ha^{-1} at R6 at both sites.

Table 4.4: Effects of tillage and phosphorus application on P uptake of maize at V6, V12 and R6 growth stages

Treatment	P uptake (kg ha^{-1})					
	Anwomaso			Ejura		
	V6	V12	R6	V6	V12	R6
Tillage						
CT	1.89	9.10	9.62	1.43	13.42	16.08
NT	1.83	7.01	6.75	1.19	8.19	14.69
LSD (0.05)	NS	1.38	0.11	0.10	0.97	NS
CV (%)	4.30	7.70	2.30	1.20	6.60	15.70
Rates of P application (kg P_2O_5 ha^{-1})						
P_0	1.00	3.98	3.56	0.44	3.06	6.29
P_{30}	1.47	6.41	6.68	1.02	6.14	11.69
P_{60}	2.43	10.68	11.37	1.92	17.81	20.86
P_{90}	2.56	11.15	11.13	1.87	16.20	22.72
LSD (0.05)	0.24	1.57	0.87	0.08	2.09	1.52
CV (%)	4.10	4.90	0.40	2.10	2.60	3.70
Interaction						
CTP_0	1.05	5.73	4.02	0.51	4.54	8.01
CTP_{30}	1.59	7.16	7.67	1.12	8.60	13.17
CTP_{60}	2.45	12.10	13.46	2.08	21.02	20.11
CTP_{90}	2.48	11.40	13.35	2.03	19.50	23.04
NTP_0	0.95	2.23	3.10	0.37	1.58	4.57
NTP_{30}	1.34	5.65	5.69	0.92	3.68	10.21
NTP_{60}	2.40	9.26	9.28	1.75	14.60	21.60
NTP_{90}	2.64	10.90	8.92	1.72	12.89	22.40
LSD (0.05)	0.32	2.01	1.06	0.11	2.59	2.09
CV (%)	10.20	15.50	8.40	4.70	15.40	7.90

Values are means of triplicate samples. CT = Conventional tillage, NT = No – tillage, P_0 = 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$.

4.4 Phosphorus use efficiencies of maize under different rates of P application at V6, V12 and R6 growth stages of maize

Indices of use efficiencies of phosphorus in maize were determined at V6, V12 and R6. These included phosphorus recovery efficiency, partial factor productivity, agronomic efficiency and phosphorus utilization efficiency.

4.4.1 Phosphorus recovery efficiency (PRE) and partial factor productivity (PFP) of maize

Phosphorus recovery efficiency (PRE) was calculated based on the P uptake at the various stages of growth divided by the rate of phosphorus fertilizer applied expressed as a percentage. The effects of tillage and phosphorus application on the recovery efficiency of maize are presented in Table 4.5. Tillage significantly influenced ($p < 0.05$) the PRE of maize at R6 at both Anwomaso and Ejura (Table 4.5). At Anwomaso, PRE at R6 was significantly higher under CT than NT but the reverse occurred at Ejura. Phosphorus recovery efficiency was influenced by application of P at all stages of crop growth except at V12 at Anwomaso. PRE increased with time from V6 to V12 at both sites but did not follow any particular trend as regards the rates of P applied. The application of 60 kg/ha P_2O_5 consistently recorded significantly higher ($p < 0.05$) phosphorus recovery efficiency than the applications of 90 and 30 kg P_2O_5 ha^{-1}. Significant tillage x phosphorus interactions ($p < 0.05$) were also recorded among treatment combinations at all the stages of crop growth at both sites. The phosphorus recovery efficiencies of maize generally ranged from 3.02 – 5.98 % at V6, 10.80 – 62.40 % at V12 and 14.68 – 64.50 % at R6 at both sites. Generally PRE of maize at Ejura were greater than that of Anwomaso at R6.

Table 4.5: Effects of tillage and P application on PRE of maize at V6, V12 and R6

Treatment	PRE (%)					
	Anwomaso			Ejura		
	V6	V12	R6	V6	V12	R6
Tillage						
CT	4.32	16.40	28.99	4.81	43.70	41.00
NT	4.27	24.80	19.23	4.28	31.20	50.80
LSD (0.05)	NS	8.28	3.30	NS	NS	4.58
CV (%)	5.60	14.10	8.00	3.40	2.90	3.30
Rates of P application (kg P_2O_5 ha^{-1})						
P_0	-	-	-	-	-	-
P_{30}	3.54	18.40	23.64	4.41	23.30	40.90
P_{60}	5.41	25.40	29.56	5.60	55.90	55.20
P_{90}	3.93	18.10	19.12	3.63	33.20	41.50
LSD (0.05)	1.24	NS	4.14	0.60	9.46	7.42
CV (%)	8.40	11.40	3.90	8.10	10.10	2.80
Interaction						
CTP_0	-	-	-	-	-	-
CTP_{30}	4.06	10.80	27.66	4.62	30.80	39.10
CTP_{60}	5.31	24.10	35.75	5.98	62.40	45.90
CTP_{90}	3.59	14.30	23.56	3.84	37.80	38.00
NTP_0	-	-	-	-	-	-
NTP_{30}	3.02	25.90	19.62	4.20	15.90	42.80
NTP_{60}	5.51	26.60	23.37	5.22	49.30	64.50
NTP_{90}	4.27	21.90	14.68	3.42	28.60	45.00
LSD (0.05)	1.53	10.32	4.95	1.02	12.68	8.73
CV (%)	21.70	30.60	12.90	9.80	19.00	12.20

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0= 0 kg ha^{-1}, P_{30} = 13.20 kg P ha^{-1}, P_{60} = 26.40 kg P ha^{-1}, P_{90} = 39.60 kg P ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

Tillage significantly affected ($p < 0.05$) the PFP of maize at the growth stages under consideration, with crops under conventional tillage recording significantly higher ($p < 0.05$) values than crops under no-tillage system at both sites (Table 4.6). Under the different rates of P applied, 30 kg P_2O_5 ha^{-1} consistently recorded the highest PFP at all the growth stages, except at V12 at Ejura where the application of 60 kg P_2O_5 ha^{-1} recorded a significantly higher PFP than the other application rates. There were significant ($p < 0.05$) tillage x phosphorus interaction effect on PFP at V6, V12 and R6 at both Anwomaso and Ejura. The partial factor productivities of the maize crops ranged from 5.22 - 20.62 kgkg^{-1} P_2O_5 ha^{-1} at V6, 39.80 - 127.90 kgkg^{-1} P_2O_5 ha^{-1} at V12 and 35.90 – 142.70 kgkg^{-1} P_2O_5 ha^{-1} at R6. Generally, PFP were highest under CTP_{30} on both soils.

Table 4.6: PFP of maize under tillage and P application at V6, V12 and R 6

Treatment	PFP (kgkg^{-1} P_2O_5 ha^{-1})					
	Anwomaso			Ejura		
	V6	V12	R6	V6	V12	R6
Tillage						
CT	14.02	92.60	80.00	10.63	104.40	94.70
NT	12.56	79.90	63.10	8.95	56.90	80.70
LSD (0.05)	1.58	10.29	10.24	0.20	12.65	7.84
CV (%)	3.10	5.70	10.10	3.80	3.00	5.60
Rates of P application (kg P_2O_5 ha^{-1})						
P_0	-	-	-	-	-	-
P_{30}	18.99	119.20	103.20	13.19	85.60	124.00
P_{60}	13.17	89.70	69.40	10.30	103.60	86.70
P_{90}	7.71	49.70	42.00	5.89	52.70	52.50
LSD (0.05)	1.12	10.78	9.97	0.91	9.38	8.17
CV (%)	3.40	3.40	4.10	0.60	4.50	2.50
Interaction						
CTP_0	-	-	-	-	-	-
CTP_{30}	20.62	127.90	111.70	14.38	119.40	142.70
CTP_{60}	13.33	97.00	80.20	10.96	128.20	87.90
CTP_{90}	8.10	52.80	48.10	6.56	65.60	53.50
NTP_0	-	-	-	-	-	-
NTP_{30}	17.36	110.60	94.70	12.00	51.80	105.30
NTP_{60}	13.02	82.50	58.60	9.63	79.00	85.50
NTP_{90}	7.32	46.60	35.90	5.22	39.80	51.40
LSD (0.05)	1.50	13.17	12.32	1.05	12.42	9.99
CV (%)	6.30	9.40	10.50	7.00	8.70	7.00

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0= 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at p > 0.05

4.4.2 Phosphorus agronomic efficiency (PAE) of maize as affected by tillage and phosphorus application

Tillage did not significantly (p > 0.05) affect the agronomic efficiency of maize at V6 and R6 (Table 4.7). However, at V12 growth stage, there was significant difference in PAE under both tillage systems at both sites. The different rates of P applied had significant influence on the PAE of maize at all growth stages at both sites (Table 4.7). Plants under P_{60} application recorded higher PAE than the other rates of P applied except at R6 at Anwomaso. P_{90} generally has the lowest PAE. It was observed that the PAE at V12 was generally about 10 times higher than that at V6. There were significant ($p < 0.05$) tillage x phosphorus interactions among treatment means at all growth stages.

Table 4.7: Effects of tillage and P application on PAE of maize at V6, V12 and R6

Treatment	PAE (kgkg^{-1} P_2O_5 ha^{-1})					
	Anwomaso			Ejura		
	V6	V12	R6	V6	V12	R6
Tillage						
CT	2.15	20.90	41.80	5.55	59.70	35.50
NT	3.23	42.00	34.40	5.44	41.40	43.90
LSD (0.05)	NS	11.41	NS	NS	17.73	NS
CV (%)	1.10	20.40	19.40	6.30	7.00	20.10
Rates of P application (kg P_2O_5 ha^{-1})						
P_0	-	-	-	-	-	-
P_{30}	1.64	29.70	48.50	6.16	36.40	45.40
P_{60}	4.50	45.00	42.00	6.78	79.00	47.40
P_{90}	1.92	19.80	23.80	3.55	36.30	26.30
LSD (0.05)	0.85	9.95	10.60	1.01	9.77	6.96
CV (%)	24.00	10.30	13.00	10.80	10.00	18.70
Interaction						
CTP_0	-	-	-	-	-	-
CTP_{30}	1.21	10.70	49.20	6.06	46.30	45.80
CTP_{60}	3.62	38.40	48.90	6.81	91.60	39.40
CTP_{90}	1.62	13.70	27.30	3.79	41.20	21.20
NTP_0	-	-	-	-	-	-
NTP_{30}	2.08	48.60	47.80	6.26	26.50	45.00
NTP_{60}	5.38	51.50	35.20	6.75	66.30	55.30
NTP_{90}	2.22	25.90	20.30	3.31	31.30	31.30
LSD (0.05)	1.75	12.58	15.24	1.67	14.83	20.74
CV (%)	23.90	23.70	20.90	13.80	14.50	13.20

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0 = 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

4.4.3 Phosphorus utilization efficiency (PUtE) of maize

From Table 4.8, it can be observed that the higher the rate of P application, the lower the PUtE. This implies that the efficiency of maize plants in the utilization of phosphorus decreased as the P fertilizer rate was increased. On the average, the highest PUtE was recorded under P_0 at the three stages of growth on both soils. During the growing season, it was observed that maize plants recorded the highest PUtE at V12 (Table 4.8).

Table 4.8: Effects of tillage and P application on PUtE of maize at V6, V12 and R6

Treatment	PUtE (kgkg^{-1} P ha^{-1})					
	Anwomaso			Ejura		
	V6	V12	R6	V6	V12	R6
Tillage						
CT	394.90	514.00	397.80	372.10	394.40	293.40
NT	363.70	590.00	422.20	366.80	377.60	291.80
LSD (0.05)	NS	78.00	NS	NS	NS	NS
CV (%)	6.90	3.40	5.80	2.70	5.50	9.00
Rates of P application (kg P_2O_5 ha^{-1})						
P_0	525.60	730.00	461.30	483.30	484.00	387.00
P_{30}	393.40	564.00	467.20	388.80	419.90	321.70
P_{60}	326.50	512.00	367.90	323.40	348.20	250.60
P_{90}	272.30	401.00	343.60	282.30	292.00	210.90
LSD (0.05)	46.55	75.60	40.80	39.37	38.60	33.19
CV (%)	4.00	4.10	3.70	3.10	4.00	3.50
Interaction						
CTP_0	564.30	614.00	470.10	493.60	488.80	369.80
CTP_{30}	394.70	538.00	438.60	387.40	417.10	329.60
CTP_{60}	326.40	485.00	357.50	315.90	366.00	263.00
CTP_{90}	294.30	417.00	324.90	291.50	305.60	211.10
NTP_0	485.70	846.00	452.50	473.10	479.10	404.30
NTP_{30}	392.20	590.00	495.80	390.10	422.70	313.80
NTP_{60}	326.60	538.00	378.30	330.90	330.40	238.30
NTP_{90}	250.30	386.00	362.20	273.00	278.40	210.70
LSD (0.05)	62.28	99.10	56.23	51.56	53.90	43.91
CV (%)	9.80	11.00	7.90	8.50	7.90	9.00

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0= 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

Generally, tillage did not have any significant effect on PUtE except at V12 growth stage at Anwomaso. Significant ($p < 0.05$) tillage x phosphorus interactions were observed at the three growth stages of maize considered in the study.

4.5 Soil physico-chemical properties after harvest

The effects of tillage and phosphorus application on bulk density, organic carbon, total nitrogen, available phosphorus and exchangeable potassium in the soils after crop harvest at physiological maturity at the experimental sites are reported in subsections 4.5.1 and 4.5.2.

4.5.1 Soil bulk density

At the end of the study, tillage did not have any significant ($p > 0.05$) impact on bulk density on both soils at the experimental sites. However, bulk density under conventional tillage was slightly higher than that under no-tillage system. There was a significant tillage x phosphorus interaction effect on soil bulk density ($p < 0.05$) at Ejura where CTP_{90} recorded lower value (1.33 Mg/m^3) than all the treatment combinations (Table 4.9).

Table 4.9: Effects of tillage and phosphorus application on soil bulk density after harvest

Treatment	Soil bulk density (Mg/m^3) Anwomaso	Ejura
Tillage		
CT	1.26	1.46
NT	1.24	1.44
LSD (0.05)	NS	NS
CV (%)	1.00	1.70
Rates of P application (kg P_2O_5 ha^{-1})		
P_0	1.32	1.48
P_{30}	1.23	1.46
P_{60}	1.24	1.47
P_{90}	1.21	1.39
LSD (0.05)	NS	NS
CV (%)	3.10	2.90
Interaction		
CTP_0	1.32	1.52
CTP_{30}	1.25	1.49
CTP_{60}	1.23	1.49
CTP_{90}	1.22	1.33
NTP_0	1.32	1.44
NTP_{30}	1.20	1.43
NTP_{60}	1.24	1.44
NTP_{90}	1.20	1.46
LSD (0.05)	NS	0.12
CV (%)	9.10	3.90

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0 = 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

4.5.2 Some soil chemical properties as affected by tillage and phosphorus application

4.5.2.1 Anwomaso (Asuansi series, Orthi-Ferric Acrisol)

The results clearly indicated that the tillage systems did not significantly affect C, N, P and K contents of the soil even though there was a general increase in the chemical composition of the soil over the initial values (Table 4.10). The extractable Fe concentration of the Anwomaso site increased from 119.10 mg/kg soil (Table 4.1) to 145.15 mg/kg soil at the end of the study (Table 4.12).

Soil organic carbon and total N values were similar ($p > 0.05$) under the various rates of P applied. The application rates however influenced significantly ($p < 0.05$) the residual available P levels in the soil (Table 4.10). The highest rate of P application (90 kg P_2O_5 ha^{-1}) resulted in a high residual P (44.54 mg/kg) in the soil with the control (0 kg P_2O_5 ha^{-1}) recording the least value (8.51 mg/kg). The exchangeable K content of the soil was also significantly ($p < 0.05$) affected by P application.

Significant tillage x phosphorus interaction was observed ($p < 0.05$) in the organic carbon and exchangeable K content of the Orthi-Ferric Acrisol at the end of the study. The interaction between tillage and P application produced a significant ($p < 0.05$) effect on soil available P at the end of the growing season. The residual P increased in the order of increasing P application under the various treatment combinations. NTP_{90} and NTP_0 recorded the highest (45.09 mg/kg) and least available P levels (6.12 mg/kg) respectively.

Table 4.10: Effects of tillage and phosphorus application on selected soil chemical properties after harvest (Anwomaso)

Treatment	Organic Carbon (%)	Total Nitrogen (%)	Available Phosphorus (mg/kg)	Exchangeable Potassium ($cmol_{(c)}$/kg soil)
Tillage				
CT	1.88	0.20	27.56	0.15
NT	1.70	0.18	22.11	0.13
LSD (0.05)	NS	NS	NS	NS
CV (%)	2.90	10.80	2.60	6.10
Rates of P application (kg P_2O_5 ha^{-1})				
P_0	1.86	0.19	8.51	0.17
P_{30}	1.74	0.20	21.60	0.11
P_{60}	1.73	0.17	24.68	0.12
P_{90}	1.83	0.21	44.54	0.16
LSD (0.05)	NS	NS	2.36	0.04
CV (%)	5.10	9.10	8.50	8.80
Interaction				
CTP_0	1.96	0.21	10.91	0.19
CTP_{30}	1.82	0.18	25.84	0.11
CTP_{60}	1.83	0.18	29.51	0.14
CTP_{90}	1.89	0.22	43.99	0.15
NTP_0	1.76	0.18	6.12	0.15
NTP_{30}	1.67	0.21	17.36	0.11
NTP_{60}	1.62	0.16	19.85	0.11
NTP_{90}	1.76	0.19	45.09	0.16
LSD (0.05)	0.26	NS	5.67	0.05
CV (%)	6.90	27.70	7.60	20.20

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0 = 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

4.5.2.2 Ejura (Ejura series, Rhodic Lixisol)

The results obtained at Ejura were similar to those recorded at Anwomaso (Table 4.11). There were no significant differences in organic carbon, total N and available P contents recorded under the tillage systems. There was however, a general increase in the chemical composition of the soil (with reference to C, N, and P) over the initial values of 1.46 % C, 0.16 % N, 5.26 mg/kg P on the Orthi-Ferric Acrisol at Anwomaso (Table 4.1) and 0.47 % C, 0.04 % N and 31.77 mg/kg P on the Rhodic Lixisol at Ejura (Table

4.2). The extractable Fe contents also increased from 33.90 mg/kg soil (Table 4.2) to 46.80 mg/kg soil at the end of the study (Table 4.12).

Table 4.11: Effects of tillage and phosphorus application on selected soil chemical properties after harvest at Ejura

Treatment	Organic Carbon (%)	Total Nitrogen (%)	Available Phosphorus (mg/kg)	Exchangeable Potassium ($cmol_{(c)}$/kg soil)
Tillage				
CT	0.71	0.15	54.80	0.17
NT	0.70	0.14	44.60	0.15
LSD (0.05)	NS	NS	NS	NS
CV (%)	0.60	13.10	4.40	13.70
Rates of P application (kg P_2O_5 ha^{-1})				
P_0	0.60	0.16	25.80	0.19
P_{30}	0.85	0.13	49.80	0.14
P_{60}	0.58	0.16	48.50	0.18
P_{90}	0.80	0.12	74.80	0.15
LSD (0.05)	0.09	NS	12.23	NS
CV (%)	2.00	9.2	15.40	13.00
Interaction				
CTP_0	0.64	0.19	25.50	0.20
CTP_{30}	0.82	0.12	76.90	0.15
CTP_{60}	0.52	0.16	58.60	0.20
CTP_{90}	0.85	0.11	58.30	0.14
NTP_0	0.56	0.12	26.10	0.17
NTP_{30}	0.87	0.14	22.60	0.13
NTP_{60}	0.63	0.16	38.40	0.15
NTP_{90}	0.75	0.13	91.30	0.16
LSD (0.05)	0.12	0.06	21.54	NS
CV (%)	10.60	23.50	19.60	23.60

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0 = 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

Application of phosphorus significantly ($p < 0.05$) affected the residual available P in the soil with the 90 kg P_2O_5 ha^{-1} recording the highest value. Unlike the situation at Anwomaso, the exchangeable K content of the soil was not significantly influenced by

P application. It was rather the organic carbon content of the soil which was significantly ($p < 0.05$) affected by P application.

Similar to the results obtained on the Orthi-Ferric Acrisol at Anwomaso, the interaction between tillage and P application produced a significant ($p < 0.05$) effect on the available P in the soil. The highest available P was recorded in NTP_{90} treatment (91.30 mg/kg) whilst the lowest was recorded under treatment NTP_{30} (22.60 mg/kg) which was statistically similar ($p > 0.05$) to NTP_0 (26.10 mg/kg) (Table 4.11). The total nitrogen and organic carbon contents of the Rhodic Lixisol at Ejura were significantly influenced by tillage x phosphorus interactions at the end of the experiment.

Table 4.12: Final extractable iron and exchangeable aluminium contents at Anwomaso and Ejura

Soil property	Min	Max	Mean	SD	CV
Anwomaso					
Fe (mg/kg soil)	105.30	185.00	145.15	56.36	38.83
Al ($cmol_{(c)}$/kg soil)	0.10	0.13	0.12	0.02	0.17
Ejura					
Fe (mg/kg soil)	44.90	48.70	46.80	2.69	5.78
Al ($cmol_{(c)}$/kg soil)	0.23	0.23	0.23	-	-

Values are means of duplicate sample analyses. SD = Standard deviation, CV = Coefficient of variation expressed as a percentage

4.6 Growth and yield parameters of maize under tillage systems and phosphorus application

4.6.1 Plant height

The results from Table 4.13 did not show any significant difference ($p > 0.05$) in plant height between the two tillage systems used at Anwomaso though the tallest plants were generally observed under the conventional tillage system. In comparing the different rates of phosphorus applied, it was observed that the fertilizer rates significantly enhanced plant height following 4 WAS until maturity. The highest values were mostly recorded for maize plants which received 90 kg P_2O_5 ha^{-1}. The values were however, not significantly different ($p > 0.05$) from those recorded under P_{60} treatments. Significant ($p < 0.05$) tillage x phosphorus interactions were observed on plant height of the maize variety at Anwomaso throughout the growing cycle except at 2 WAS (Table 4.13).

Table 4.13: Plant height under tillage and phosphorus amendments at Anwomaso

	Plant height (cm)				
Treatment	2 WAS	4 WAS	6 WAS	8 WAS	10 WAS
Tillage					
CT	18.34	51.07	112.40	203.70	215.60
NT	17.99	44.15	107.10	197.00	213.90
LSD (0.05)	NS	NS	NS	NS	NS
CV (%)	3.10	6.20	6.30	3.30	4.10
P-level (kg P_2O_5 ha^{-1})					
P_0	17.78	42.08	79.40	176.20	188.10
P_{30}	17.44	45.08	106.00	195.90	209.90
P_{60}	18.92	50.78	123.00	215.30	229.30
P_{90}	18.53	52.49	130.50	213.90	231.90
LSD (0.05)	NS	4.38	11.37	17.45	12.34
CV (%)	8.20	7.10	3.80	2.80	1.60
Interaction					
CTP_0	17.07	45.53	83.70	192.10	196.60
CTP_{30}	17.65	49.65	103.30	193.10	210.00
CTP_{60}	19.30	54.07	122.30	216.30	228.90
CTP_{90}	19.34	55.02	140.10	213.20	227.10
NTP_0	18.50	38.63	75.10	160.30	179.60
NTP_{30}	17.23	40.50	108.70	198.70	209.70
NTP_{60}	18.53	47.50	123.70	214.30	229.70
NTP_{90}	17.71	49.95	120.90	214.70	236.70
LSD (0.05)	NS	9.14	15.66	23.28	16.08
CV (%)	8.10	7.30	8.20	6.90	4.60

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0 = 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

Table 4.14: Effects of tillage and phosphorus amendments on plant height at Ejura

Treatment	Plant height (cm)				
	2 WAS	4 WAS	6 WAS	8 WAS	10 WAS
Tillage					
CT	17.31	43.14	98.50	162.80	168.50
NT	15.78	35.66	62.60	148.90	158.10
LSD (0.05)	NS	3.05	2.17	NS	NS
CV (%)	6.60	2.70	1.80	1.30	1.90
P-level (kg P_2O_5 ha^{-1})					
P_0	16.70	32.39	60.40	128.00	137.70
P_{30}	16.44	37.18	75.00	153.70	156.30
P_{60}	15.73	41.32	84.40	160.10	166.70
P_{90}	17.30	46.73	102.60	181.60	192.50
LSD (0.05)	NS	2.99	12.32	7.16	8.70
CV (%)	12.80	2.20	0.80	3.90	2.20
Interaction					
CTP_0	17.89	35.83	72.40	141.20	148.00
CTP_{30}	16.80	40.55	91.30	157.10	160.60
CTP_{60}	16.27	45.01	99.80	165.30	171.30
CTP_{90}	18.27	51.18	130.70	187.90	194.10
NTP_0	15.52	28.94	48.30	114.90	127.50
NTP_{30}	16.09	33.81	58.70	150.40	152.00
NTP_{60}	15.19	37.63	69.10	154.90	162.20
NTP_{90}	16.33	47.28	74.40	175.40	190.90
LSD (0.05)	NS	3.91	15.11	16.44	12.32
CV (%)	19.40	6.00	12.20	3.70	4.20

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0 = 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

From Table 4.14, it can be observed that tillage systems did not significantly influence maize plant height at Ejura except at 4 WAS and 6 WAS. Comparable to the results obtained at Anwomaso, the different rates of P applied significantly influenced plant height except at 2 WAS. Application of 90 kg P_2O_5 ha^{-1} produced significantly taller plants than the other rates of P applied. Unlike what was observed at Anwomaso, treatments P_{60} and P_{90} were significantly different in terms of plant height. Comparatively, significant tillage x phosphorus interactions ($p < 0.05$) were also recorded throughout the growing cycle at Ejura except at 2 WAS.

4.6.2 Effects of tillage and phosphorus application on dry matter of maize plants at V6, V12 and R6

With reference to data on dry matter of maize plants at V6, V12 and R6 (Table 4.15), tillage significantly affected the dry matter accumulation throughout the growing cycle at both Anwomaso and Ejura. Maize plants under conventional tillage system produced a significantly greater dry weight as compared to those cultivated under no-tillage system.

Like the tillage system, phosphorus application had a significant impact on the above-ground biomass dry matter of maize on both soils. The biomass dry matter increased in the order of $P_0 < P_{30} < P_{90} < P_{60}$ at V6, V12 and R6.

Significant tillage x phosphorus interactions were observed among treatment combinations at the three growth stages considered (V6, V12 and R6) at the two experimental sites. Generally, the highest biomass dry matter was recorded under CTP_{60} and the least under NTP_0 at both sites.

Table 4.15: Dry matter of maize plants as affected by tillage and phosphorus application at V6, V12 and R6 growth stages

Treatment	Dry matter ($kg\ ha^{-1}$)					
	Anwomaso			Ejura		
	V6	V12	R6	V6	V12	R6
Tillage						
CT	682.4	4481.0	9046.0	482.2	4843.0	10202.0
NT	604.7	3579.0	7425.0	395.1	2659.0	7759.0
LSD (0.05)	66.64	414.00	570.90	42.11	668.60	780.50
CV (%)	2.00	5.10	4.60	2.50	3.20	7.90
Rates of P application ($kg\ P_2O_5\ ha^{-1}$)						
P_0	520.4	2688.0	5179.0	210.9	1478.0	5488.0
P_{30}	569.8	3577.0	7840.0	395.7	2569.0	8093.0
P_{60}	790.4	5385.0	10705.0	617.7	6215.0	12213.0
P_{90}	693.5	4471.0	9218.0	530.3	4742.0	10129.0
LSD (0.05)	39.50	560.80	424.80	31.77	452.80	681.80
CV (%)	2.90	2.90	2.00	2.70	5.10	2.50
Interaction						
CTP_0	582.5	3517.0	5698.0	249.5	2195.0	7078.0
CTP_{30}	618.7	3837.0	8543.0	431.3	3583.0	9480.0
CTP_{60}	799.9	5820.0	11873.0	657.9	7692.0	13102.0
CTP_{90}	728.7	4750.0	10070.0	590.4	5903.0	11148.0
NTP_0	458.4	1858.0	4660.0	172.4	761.0	3897.0
NTP_{30}	520.9	3318.0	7138.0	360.1	1555.0	6706.0
NTP_{60}	781.0	4949.0	9538.0	577.6	4738.0	11323.0
NTP_{90}	658.4	4191.0	8366.0	470.2	3580.0	9110.0
LSD (0.05)	59.61	708.70	589.80	43.94	647.80	910.50
CV (%)	4.90	11.10	4.10	5.80	9.60	6.00

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0 = 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

4.6.3 Maize grain yield and hundred seed weight

The type of tillage system used significantly affected ($p < 0.05$) the grain yield of maize at Anwomaso in the Semi-deciduous forest zone and Ejura in the Forest-savannah transition agro-ecological zone of Ghana with conventional tillage producing higher grain yield than no-tillage (Table 4.16). Grain yield was significantly ($p < 0.05$) affected by the different rates of phosphorus applied. The highest grain yield at Anwomaso (4163 kg ha^{-1}) was produced by P_{60} followed by P_{90} (3780 kg ha^{-1}). The values recorded under application of 60 kg and 90 kg P_2O_5 ha^{-1} were statistically at par with each other ($p > 0.05$). At Ejura, the highest grain yield was also obtained on P_{60} treatment plots (5200 kg ha^{-1}) followed by P_{90} (4721 kg ha^{-1}) with the lowest yield on the control plot. Generally, it was observed that the grain yields recorded at Ejura were higher than those recorded at Anwomaso.

The combination of different tillage systems and rates of P applied significantly affected ($p < 0.05$) the grain yields on the two soils with CTP_{60} producing a significantly higher grain yield than the other treatments. However, interaction between NT and P_{60} recorded grain yield comparable to that of the CTP_{60} at Ejura.

The effect of the different rates of P applied on hundred seed weight (HSW) of maize was significant ($p < 0.05$) at both locations with 60 kg P_2O_5 ha^{-1} producing higher values than the other rates of P applied and the control. Significant tillage x phosphorus interactions were observed in the HSW at Ejura and Anwomaso. The least HSW (14.16 g) was recorded under NTP_0 at Anwomaso.

Table 4.16: Maize grain yield and hundred seed weight under tillage and P application

Treatment	Anwomaso		Ejura	
	Grain yield (kg ha^{-1})	100-seed weight (g)	Grain yield (kg ha^{-1})	100-seed weight (g)
Tillage				
CT	3592	17.82	4319	22.88
NT	2748	16.72	3680	21.69
LSD (0.05)	34.40	NS	NS	0.63
CV (%)	8.70	2.40	7.30	4.40
Rates of P application (kg P_2O_5 ha^{-1})				
P_0	1640	14.46	2357	17.74
P_{30}	3096	17.30	3719	21.17
P_{60}	4163	19.48	5200	26.10
P_{90}	3780	17.48	4721	24.12
LSD (0.05)	393.40	0.82	362.90	1.30
CV (%)	0.30	6.00	4.80	0.80
Interaction				
CTP_0	1875	14.77	2905	19.00
CTP_{30}	3351	17.91	4281	22.97
CTP_{60}	4810	19.96	5271	25.59
CTP_{90}	4331	18.63	4817	23.95
NTP_0	1405	14.16	1809	16.48
NTP_{30}	2841	16.69	3158	19.36
NTP_{60}	3517	18.99	5129	26.61
NTP_{90}	3228	17.04	4625	24.29
LSD (0.05)	482.00	2.94	571.90	1.62
CV (%)	9.90	3.80	7.20	4.60

Values are means of three replicates. CT = Conventional tillage, NT = No – tillage, P_0 = 0 kg P_2O_5 ha^{-1}, P_{30} = 30 kg P_2O_5 ha^{-1}, P_{60} = 60 kg P_2O_5 ha^{-1}, P_{90} = 90 kg P_2O_5 ha^{-1}, LSD = Least significant differences of means, CV = Coefficient of variation, NS = Not significant at $p > 0.05$

4.7 Relationship among measured plant and soil parameters

The interrelationship among plant height, total above ground biomass dry matter, total P concentration in maize plants, P uptake and P utilization efficiency of the maize plants at V6, V12 and R6 growth stages in the two agro-ecological zones are presented in Tables 4.17 to 4.22. Significant positive correlations were observed among plant height, dry matter, total plant P concentration, grain yield and P uptake at all the three stages considered at both sites. However, plant height, dry matter of maize, total P concentration and P uptake of maize were negatively correlated with phosphorus utilization efficiency (Tables 4.17 to 4.22).

There was a very strong positive correlation between the rates of phosphorus fertilizer applied and the available P remaining in the soil after harvest at both locations (Figure 4.1 and 4.2). The coefficient of correlation (r) were comparable for both sites.

Table 4.17: Pearson correlation coefficient (r) showing the linear interrelationships among plant parameters at V6 at Anwomaso

	Plant height	Dry matter	Total P	P uptake	PUtE
Plant height	1				
Dry matter	0.64*	1			
Total P	0.46*	0.61*	1		
P uptake	0.59*	0.86*	0.93*	1	
PUtE	-0.43*	-0.63*	-0.96*	-0.90*	1

n = 24, NS = not significant,* represents statistical significance at 5 % level of probability.

Table 4.18: Pearson correlation coefficient (r) showing the linear interrelationships among plant parameters at V6 at Ejura

	Plant height	Dry matter	Total P	P uptake	PUtE
Plant height	1				
Dry matter	0.77*	1			
Total P	0.73*	0.76*	1		
P uptake	0.81*	0.97*	0.89*	1	
PUtE	-0.71*	-0.80*	-0.98*	-0.90*	1

n = 24, NS = not significant, * represents statistical significance at 5 % level of probability.

Table 4.19: Pearson correlation coefficient (r) showing the linear interrelationships among plant parameters at the V12 growth stage of maize as affected by tillage and phosphorus amendments at Anwomaso

	Plant height	Dry matter	Total P	P uptake	PUtE
Plant height	1				
Dry matter	0.71*	1			
Total P	0.73*	0.65*	1		
P uptake	0.78*	0.93*	0.87*	1	
PUtE	-0.75*	-0.73*	-0.95*	-0.86*	1

n = 24, NS = not significant,* represents statistical significance at 5 % level of probability.

Table 4.20: Pearson correlation coefficient (r) showing the linear interrelationships among plant parameters at the V12 growth stage of maize as affected by tillage and phosphorus amendments at Ejura

	Plant height	Dry matter	Total P	P uptake	PUtE
Plant height	1				
Dry matter	0.75*	1			
Total P	0.45*	0.53*	1		
P uptake	0.76*	0.97*	0.72*	1	
PUtE	-0.48*	-0.60*	-0.98*	-0.76*	1

n = 24, NS = not significant,* represents statistical significance at 5 % level of probability.

Table 4.21: Pearson correlation coefficient (r) showing the linear interrelationships among plant parameters at the R6 growth stage of maize as affected by tillage and phosphorus amendments at Anwomaso

	Plant height	Dry matter	Grain yield	Total P	P uptake	PUtE
Plant height	1					
Dry matter	0.73*	1				
Grain yield	0.79*	0.96*	1			
Total P	0.74*	0.78*	0.80*	1		
P uptake	0.74*	0.95*	0.94*	0.91*	1	
PUtE	-0.49*	-0.65*	-0.55*	-0.84*	-0.77*	1

n = 24, NS = not significant, * represents statistical significance at 5 % level of probability.

Table 4.22: Pearson correlation coefficient (r) showing the linear interrelationships among plant parameters at the R6 growth stage of maize as affected by tillage and phosphorus amendments at Ejura.

	Plant height	Dry matter	Grain yield	Total P	P uptake	PUtE
Plant height	1					
Dry matter	0.67*	1				
Grain yield	0.75*	0.96*	1			
Total P	0.83*	0.56*	0.69*	1		
P uptake	0.83*	0.86*	0.92*	0.90*	1	
PUtE	-0.79*	-0.75*	-0.82*	-0.91*	-0.94*	1

n = 24, NS = not significant, * represents statistical significance at 5 % level of probability.

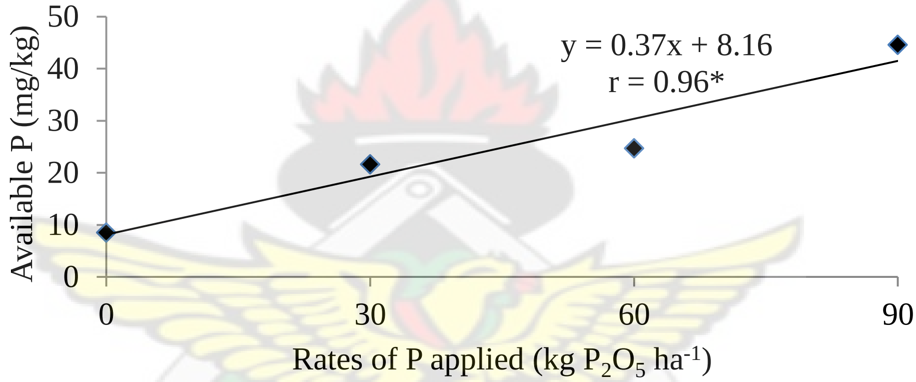

Figure 4.1: Correlation between phosphorus application and available P at R6 at Anwomaso

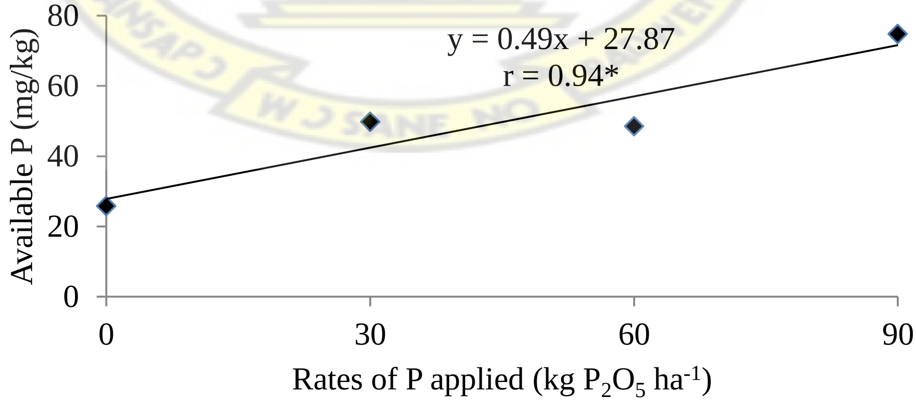

Figure 4.2: Correlation between phosphorus application and available P at R6 at Ejura

CHAPTER FIVE

5.0 DISCUSSION

5.1 Initial soil characterization at the experimental sites

The overall soil fertility status of the experimental sites was generally low. This observation is similar to earlier report by Acquaye (1986) that most soils in Ghana are characterized by poor nutrient retention due to the dominance of low activity clay and low organic matter content. This observation also attests to earlier reports by Benneh *et al*. (1990) and Adu (1995) that the soils of the major maize growing areas are low in organic carbon (< 1.5%), total nitrogen (< 0.2 %), exchangeable potassium (< 0.26 $cmol_{(c)}$ /kg) and available phosphorus (< 10 mg/kg) contents.

The acidic pH value recorded at Ejura could be due to the low levels of basic cations observed, possibly due to leaching out of the top soil. The low ECEC recorded at both experimental sites was probably due to the low organic carbon and clay content of the soils, and type of clay which must have influenced low exchangeable cations concentrations recorded. The low soil organic carbon content could be due to high temperatures prevailing at the experimental sites which resulted to rapid organic carbon decomposition and the length of fallow period.

5.2 Effects of tillage and phosphorus application on P concentration in maize

Plant tissue analysis has been used to predict the deficiency, adequacy or toxicity of nutrient elements in a soil-plant system (Hussaini *et al*., 2008). Unfortunately, a serious limitation to the use of such data is the dynamic nature of nutrient concentration in plant tissues in relation to their availability in the soil, either in the native state or through their addition to the soil in fertilizer form (Hussaini *et al*., 2008). Despite the limitations, plant tissue analysis cannot be overlooked due to the important role it plays in decisionmaking (Hussaini *et al*., 2008). The different rates of P applied progressively enhanced the total P concentrations of maize plants with every 30 kg/ha increment of P in the order $P_0 < P_{30} < P_{60} < P_{90}$ (Table 4.3). This implies that phosphorus composition in the maize plants varied with the quantity of phosphorus fertilizer supplied to the soil indicating that the greater P applied, the greater its abundance in the root zone of the plant for uptake.

The reduction in P concentration in maize plants from V6 to V12 on both soils was not surprising since nutrient concentration in plants usually decrease with the age of the plant. This is attributable to an analogous dilution effect caused by increased plant size and the translocation of nutrients from the vegetative part to reproductive parts. Similar observations have been documented by Bélanger *et al*. (2012) and Zhang *et al.* (2013). Also, it was generally observed that P concentration in maize plants at various stages of growth at Ejura were greater than that of Anwomaso. This could be due to the higher soil available P content recorded at Ejura than at Anwomaso (Table 4.10 and 4.11).

According to Bortolon *et al*. (2010), tillage practices and soil amendments play a key role in P dynamics and distribution in soils and eventually P uptake by plants. The significant tillage x phosphorus interaction observed at all stages of growth in this study implies that tillage enhanced plant P accumulation on both soil types with conventional tillage generally recording higher values than the no-till system.

5.3 Effects of tillage and phosphorus application on P uptake in maize

Phosphorus uptake by crops refers to the total amount of P concentrated in the plant as a fraction of the dry weight at sampling or harvest. According to Ologunde (1974), nutrient uptake has been found to vary primarily with the fertility status of the native soil, application of chemical fertilizers, the growth stage of the plant and environmental conditions. As expected, fertilizer rates significantly enhanced P uptake. P uptake by maize plants significantly ($p < 0.05$) increased over the control (P_0) due to P application (Table 4.4). The observation attests to earlier findings by Laghari *et al.* (2010) and Saha *et al.* (2014) that P uptake significantly increased with increasing levels of phosphorus application. Whilst P concentration in maize decreased from V6 to V12 as indicated earlier, there was a tremendous increase in P uptake from V6 to V12. This was possibly due to enhanced growth and dry matter production. There were significant positive correlations between total P concentrations and dry matter of maize at V6 and V12 (Table 4.17 to 4.22).

Significant ($p < 0.05$) tillage x phosphorus interactions were recorded at V6, V12 and R6 at both Anwomaso and Ejura. Maize plants under conventional tillage generally recorded a significantly higher P uptake than those under no-tillage at both sites (Table 4.4.). According to Lynch (1995), absorption of P by plants is enhanced by tillage practices. This might have caused a higher P uptake under conventional tillage relative to no-tillage. Under the no-tillage system, nutrient stratification in the top 0 - 15 cm layer of the soil could have resulted in the lower P uptake due to the lower mobility of phosphorus in the soil.

5.4 Phosphorus use efficiencies of maize under different rates of P application at V6, V12 and R6 growth stages of maize

The results obtained from the various use efficiencies considered; PRE, PFP, PAE and PUtE have been discussed in the subsequent sections.

5.4.1 Phosphorus recovery efficiency (PRE) and partial factor productivity (PFP) of maize

Phosphorus recovery efficiency in the soils at both sites increased when the rate of P applied increased from 30 to 60 kg/ha but decreased when rate increased from 60 to 90 kg/ha. For example, whereas only 3.54 % P was recovered at V6 when 30 kg P_2O_5 ha^{-1} was applied, P_{60} recovered 5.41 % at V6 at Anwomaso (Table 4.5). Contrary to this, when P application was increased from 60 to 90 kg P_2O_5 ha^{-1}, PRE reduced. This is because plants can take a maximum amount of nutrients at any given time and therefore application of nutrients beyond the 60 kg P2O5 ha^{-1} limit is less efficient. Akande *et al*. (2010) obtained similar results where at increasing levels of P, the PRE decreased due to the fact that the plant is able to exhibit greater efficiency for more nutrients at lower rates of fertilizer application in a nutrient deficient soil. There are more losses at higher rates of application. Contrary to earlier reports by Roberts (2008) that the first year recovery of fertilizer P normally range from 10 % with the highest being 30 %, and also claims by Miraj *et al.* (2013) that even when farmers used fertilizers, the properties of many tropical soils result in lower PRE, the current study recorded a high PRE range of 40.90 – 55.20 % at R6 at Ejura and even a higher value of 64.50 % under NTP_{60} (Table 4.5). This may be due the method of P application (band placement). Syers *et al.* (2008) reported that generally, applying P fertilizer by band placement increases the readily available P forms in the soil after the initial soil-P interactions have taken place. Band placement of P fertilizer significantly improves PRE, especially in the year of application (McKenzie and Roberts, 1990).

Partial factor productivity of the maize generally declined with increasing levels of P application at both experimental sites (Table 4.6). Bagayoko (2012) observed a similar trend on his rice experimental plots in Mali where the highest PFP of rice (105.5 kg) was observed with minimum P application and the lowest PFP (12.3 kg) with the highest fertilizer rate.

According to Yadav (2003), PFP is a useful measure of nutrient use efficiency as it enhances an integrative index that quantifies total output relative to the utilization of all nutrient resources in the farming system. With this, it can be inferred that the lower rates of P applied were beneficial in producing a higher yield relative to the higher rates of P applied. This could probably be due to the fact that as maize biomass and grain yields increased with increasing amounts of P applied, P was less efficiently assimilated and utilized by the maize plants. Singh *et al*. (1999) and Bagayoko (2012) reported that if a unit of fertilizer does not increase the yield enough to cover its cost, then its application becomes uneconomical. It is pertinent to note that the tillage systems used and the different rates of phosphorus applied on the treatment plots consistently and interdependently influenced the PFP of maize at the various growth stages considered.

5.4.2 Phosphorus agronomic efficiency (PAE) of maize as affected by tillage and phosphorus application

As already reviewed, agronomic efficiency is a measure of nutrient use efficiency that quantifies total output in terms of yield difference relative to the utilization of all nutrient resources in the farming system (Yadav, 2003). It is a production efficiency index, giving an estimate of the marginal response in production in response to added fertilizer estimated by difference to the control treatments (Norton *et al*., 2012).

From the results obtained, the different rates of P applied generally had a significant influence on the PAE of maize, with the application of 60 kg P_2O_5 ha^{-1} recording a higher PAE than the other rates of P applied (Table 4.7). This was due to the fact that P_{60} generally produced a higher dry matter at all the growth stages at both Anwomaso and Ejura, which translated into greater yields making P_{60} produce a higher economic output relative to the control. These results are contrary to results obtained by Panayotova *et al*. (2013) that the agronomic efficiency of durum wheat decreased with increasing levels of triple superphosphate application in Bulgaria. They also reported that the sole application of P at rates exceeding 80 kg P_2O_5 ha^{-1} was inefficient. In this study, the highest agronomic efficiency of P (91.60 kg dry weight kg^{-1} P_2O_5 ha^{-1} applied) was recorded at V12 at Ejura under CTP_{60}.

5.4.3 Phosphorus utilization efficiency (PUtE) of maize

P utilization efficiency was used as an index to measure the amount of maize grain produced per unit of P absorbed by the plant in kg ha^{-1}. Gromove *et al*. (1994) reported that the efficiency of utilization of nutrients from fertilizers applied to soil depends on weather conditions, biological characteristics of the crops and fertilizer rates. It can be inferred from Table 4.8 that the efficiency of maize in P utilization decreased at all growth stages as the P fertilizer rate increased. This was probably as a result of intense competition by the plant roots at the lower P application rates (P_0, P_{30}) leading to an efficient exploitation of P in the soil. This confirms an assertion by Abekoe and Sahrawat (2003) that higher application rates of fertilizers may lead to inefficient utilization of nutrients as a high proportion of the applied P may be transformed to sparingly soluble forms which will be subjected to P losses from the soil system.

At higher application rates, maize plants utilized smaller proportions of the applied fertilizer resulting in low PUtE values. The highest PUtE was observed at 0 kg P_2O_5 ha^{-1} with a value of 730 and 484 kg kg^{-1} at V12 growth stage at Anwomaso and Ejura respectively. The highest PUtE of 730 kg kg^{-1} at Anwomaso indicates that for each kg of P absorbed by the maize plant at P_0 at V12 growth stage, maize plants produced 730 kg biomass yield. The recorded PUtE of maize decreased by 48 % and 42 % respectively at V6 at both Anwomaso and Ejura from the lowest (P_0) to the highest level (P_{90}) of P applied. At V12, PUtE of maize biomass decreased by 45 % and 40 % at Anwomaso and Ejura respectively from P_0 to P_{90}. However, at R6, the highest relative decrease in PUtE of maize grains was recorded at Ejura. The PUtE decreased by 46 % from P_0 to P_{90}. These results are similar to the findings of Kogbe and Adediran (2003) who concluded that the efficiency of maize in P utilization decreased as the rate of P application increased.

5.5 Soil physico-chemical properties after harvest

5.5.1 Soil bulk density

Tillage did not significantly ($p > 0.05$) influence the soil bulk density at the end of the study, even though a higher bulk density was recorded under conventional tillage than in no-tillage system (Table 4.9). From the initial soil analysis, the bulk densities before imposition of treatments were 1.23 and 1.32 Mg/m^3 at Ejura and Anwomaso respectively (Tables 4.1 and 4.2). The bulk densities increased slightly at the end of the study though insignificant among treatments. Franzluebbers *et al*. (1995) and Unger and Jones (1998) reported that bulk density in the first 5 - 10 cm of the topsoil may increase after no-tillage. Boguzas *et al*. (2010) also reported that in the first year of no-tillage, bulk density may increase as no activity to loosen the soil aggregates are performed afterwards. However, in this study, the bulk density recorded under no-tillage system was relatively lower that observed under conventional tillage possibly due to spatial variability in the soil during sampling.

5.5.2 Soil residual P

The application of P fertilizer significantly increased the available P contents of the soils at both experimental sites after harvest (Tables 4.10 and 4.11). The residual P contents in the soil increased with increasing levels of P fertilizer applied. Kombiok and Elemo (2004) recorded similar trends where soil analysis after harvest showed increasing levels of residual N and P corresponding to increasing rates of fertilizer application under maize/rice intercropping system at Samaru in northern Nigeria. According to the aforementioned authors, the significant increase in the soil residual nutrients was as a result of higher amount of the nutrient in the soil than required by the plant because after higher levels of nutrient application, there will be an excess in the soil pool when the plant requirements are met, if nutrient losses do not occur. Baskar *et al*. (2000) also reported that the magnitude of residual effect depends on the rate and type of fertilizer used, the cropping and management system followed and to a greater extent on the soil type.

The higher level of residual available P observed at Ejura than Anwomaso after harvest was expected because of the higher initial available P at Ejura. Generally, the residual amount of P in both soils were high according to the ratings used at Soil Research Institute of Ghana (Appendix 4). Prasad and Power (1997) indicated that the bulk of P applied remains in soils due to very slow diffusion and immobilization. The two soil types; Orthi-Ferric Acrisol (at Anwomaso) and Rhodic Lixisol (at Ejura) possess different properties that influenced their ability to retain or release nutrients.

5.6 Growth and yield parameters of maize under tillage systems and phosphorus application

5.6.1 Plant height and biomass dry matter

According to Yin *et al*. (2011), plant height is a key indicator of plant growth and is linked to plant nutrition more especially during the vegetative growth stage of maize plants. Tillage practices have been reported to optimize the physical, chemical or biological conditions of soils for germination, seedling establishment and crop growth (Lal, 1983). Significant ($p < 0.05$) tillage x phosphorus interactions were observed on plant height of the maize at Anwomaso and Ejura, except at 2 WAS (Table 4.13 and 4.14). The taller plants observed under conventional tillage plots as compared to shorter plants in no-tillage plots could be due to the loosening effect and improved soil aeration produced under the conventional tillage system thereby creating favourable soil conditions for maize growth, nutrient translocation and use by the crops. Phosphorus in addition to the adequate N and K applied possibly enhanced balanced nutrition and nutrient absorption by maize plants resulting in significant impact on the overall performance of the plants.

Maize plants under conventional tillage system had significantly greater biomass dry matter than those cultivated under no-tillage system. Zorita (2000) reported a higher biomass dry matter in conventionally tilled plots as compared to no-tilled plots on a sandy loam soil. Dry matter of maize plants increased with increased rates of P fertilizer applied at both experimental sites. Colomb *et al*. (2000) and Pellerin *et al*. (2000) reported that increase in dry matter production following application of P fertilizers is as a result of improved root system, increased leaf area index and its subsequent effect on photosynthetically active radiation absorption and carbohydrate nutrition of plants. The extensive root system possibly developed under the higher rates of application enhanced the ability of the maize plants to absorb more water and nutrients from the soil, which consequently influenced the production of more assimilates and the resultant higher biomass.

5.6.2 Maize grain yield and hundred seed weight

No-till recorded lower yields at both Anwomaso and Ejura as compared to conventional tillage. This could be due to the lack of soil loosening under the NT system to provide conditions favourable to crop growth. These results lend credence to earlier findings by Ishaq *et al*. (2001) and Videnovic *et al*. (2011) that higher yields were obtained under conventional tillage. Agbede *et al.* (2008) however reported that zero tillage was most suitable for cereals in the forest-savannah transition zone of Nigeria in the medium term over three seasons from 2004 to 2006.

Okalebo and Probert (1992) and Sahoo and Panda (2001) reported that P application to maize increased yield and yield components over the control plots. The highest grain yields observed in this study were produced by maize crops which received 60 kg P_2O_5 ha^{-1} (Table 4.16). This observation followed a pattern similar to that of the dry matter yields suggesting that increasing P application to 90 kg P_2O_5 ha^{-1} on both soil types might be excessive and uneconomical to maize production since P application at this rate resulted in no yield advantage. Maize responded positively to P application with the control plots producing the least yield. Phosphorus uptake and utilization by plants plays a vital role in determination of final crop yield (Shen *et al*., 2011) and therefore the increase in P uptake with increasing levels of P application (Table 4.4) could be responsible for the subsequent higher grain yields recorded since the P uptake significantly correlated with grain yields at both locations (Tables 4.21 and 4.22).

Grain yield is a function of soil nutrient composition and availability. Since soil organic carbon and total N contents were higher in the Orthi-Ferric Acrisol at Anwomaso than in the Rhodic Lixisol at Ejura (Tables 4.10 and 4.11), it is not misleading to state that the higher soil available P content recorded on the Rhodic Lixisol than on the Orthi-Ferric Acrisol partly accounted for the higher grain yield observed on the former.

The lowest hundred seed weight was observed on the control plots (0 kg P_2O_5 ha^{-1}) compared to the treated plots. Phosphorus directly influenced HSW of maize grains due to the function it plays in grain formation and filling in cereal crops. Because the control plots did not receive any P amendment, crop uptake was basically from the native P in the soil. This resulted in lower uptake and hence the least HSW in plots which did not receive any P.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary and conclusions

There has been increased concerns about agriculture's ability to feed the ever increasing population due to several factors constraining crop production among which are declining soil fertility with little or inadequate mineral fertilizer usage and inappropriate tillage practices. In view of this, the current research sought to investigate the impact of tillage and phosphorus application on phosphorus uptake and use efficiency by maize in the Semi-deciduous forest and Forest–savannah transitional agro-ecological zones of Ghana.

The different rates of P applied progressively enhanced the total P concentrations of maize plants with every 30 kg/ha increment in P_2O_5. The total P contents of maize plants increased in the order $P_0 < P_{30} < P_{60} < P_{90}$. It was observed that tillage generally influenced P uptake and use efficiency at both experimental sites at V12. The interaction between tillage and different rates of P contributed to the uptake of P in the maize at all stages of growth at both locations.

As hypothesized, fertilizer rates significantly enhanced P uptake. This led to a resultant tremendous increase in P uptake by the maize plants from V6 to V12. The various indices of estimating use efficiencies of P in maize were generally higher at lower rates of P than at higher rates at all stages of crop growth. Significant tillage x phosphorus interactions ($p < 0.05$) were recorded among treatment combinations at V6, V12 and R6, with regards to PRE, PFP, PAE and PUtE at Anwomaso and Ejura. Phosphorus was more efficiently utilized by the maize crops at 60 kg P_2O_5 ha^{-1} than at 90 kg P_2O_5 ha^{-1}. Under the different rates of P applied, whereas the application of 60 kg P_2O_5 ha^{-1}

led to significantly higher PRE and PAE, the highest PFP was recorded under 30 kg P_2O_5 ha^{-1}.

Growth and yield components of maize on at the two locations were significantly affected by the rate of P applied under tillage systems. Generally, the highest biomass dry weight, grain yield and hundred seed weight were recorded under CTP_{60} in both agro-ecological zones. Though the application of 60 kg P_2O_5 ha^{-1} under conventional tillage recorded the highest grain yield at both sites, application of 60 kg P_2O_5 ha^{-1} under no-tillage system recorded grain yield comparable to that of CTP_{60} in the Forest-savannah transitional zone at Ejura.

The study has added to knowledge on the impact of tillage and phosphorus application on P uptake and use efficiencies of maize at different stages of growth in two agro-ecological zones in Ghana.

6.2 Recommendations

Based on the results of this study, it is recommended that for maize production, farmers can apply 60 kg P_2O_5 ha^{-1} under conventional tillage systems for a higher PRE, PAE, PUtE and grain yield on soils similar to those of the study location (eg. Acrisols and Lixisols). However, application of 60 kg P_2O_5 ha^{-1} under no-tillage system, at Ejura can produce grain yield comparable to that under conventional tillage. The experiment should, however, be repeated in the major season and over a long-term period at different locations in the agro-ecologies to validate findings. Prospective studies could be carried out on other tillage systems and cereal crops on different soil types in Ghana.

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APPENDICES

Appendix 1: Calculations of the quantity of urea applied to maize plants on treatment plots

Recommended rate for N application = 90 kg ha^{-1}

Urea contains 46 % N

First split application (60 kg ha^{-1})

46 kg N = 100 kg urea

$$60\ \text{kg N} = \frac{60\ \text{kg N x } 100\ \text{kg urea}}{46\ \text{kg N}}$$

= 130.43 kg ha^{-1} urea

If 1 ha (10,000 m^2) = 130.43 kg urea

Then a plot size of 3 m x 4 m (12 m^2)

$$= \frac{12\ \text{m}^2\ \text{ x } 130.43\ \text{kg urea}}{10{,}000\ \text{m}^2}$$

= 0.15652 kg

= 156.52 g

Number of plants per 12 m^2 = 40 hills or 80 plants

Quantity of urea required per hill

$$= \frac{156.52\ \text{g}}{40}$$

= 3.91 g urea per hill

Second split application (30 kg ha^{-1})

46 kg N = 100 kg urea

$$30\ \text{kg N} = \frac{30\ \text{kg N x } 100\ \text{kg urea}}{46\ \text{kg N}}$$

= 65.22 kg ha^{-1} Urea

If 1ha (10,000 m^2) = 65.22 kg urea

Then a plot size of 3 m x 4 m (12 m^2)

$$= \frac{12\ \text{m}^2\ \text{x } 65.22\ \text{kg urea}}{10{,}000\ \text{m}^2}$$

= 0.07826 kg

= 78.26 g

Number of plants per 12 m^2 = 40 hills or 80 plants

Quantity of urea required per hill

$$= \frac{78.26\ \text{g}}{40}$$

= 1.96 g urea per hill

Appendix 2: Calculations of the quantity of triple superphosphate (TSP) applied to maize plants on treatment plots

TSP contains 46 % P_2O_5

For 30 kg P_2O_5 ha^{-1} treatment plots

46 kg P_2O_5 = 100 kg TSP

$$30\ \text{kg}\ P_2O_5 = \frac{30\ \text{kg}\ P_2O_5\ \text{x}\ 100\ \text{kg TSP}}{46\ \text{kg}\ P_2O_5}$$

= 65.22 kg TSP ha^{-1}

If 1ha (10,000 m^2) = 65.22 kg TSP

Then a plot size of 3 m x 4 m (12 m^2)

$$= \frac{12\ \text{m}^2\ \text{x}\ 65.22\ \text{kg TSP}}{10{,}000\ \text{m}^2}$$

= 0.078264 kg TSP

= 78.26 g TSP

Number of plants per 12 m^2 = 40 hills or 80 plants

Quantity of TSP required per hill

$$= \frac{78.26\ \text{g}}{40}$$

= 1.96 g TSP per hill

For 60 kg P_2O_5 ha^{-1} treatment plots

46 kg P_2O_5 = 100 kg TSP

$$60\,\text{kg}\,P_2O_5 = \frac{60\,\text{kg}\,P_2O_5 \times 100\,\text{kg TSP}}{46\,\text{kg}\,P_2O_5}$$

= 130.43 kg TSP ha^{-1}

If 1ha (10,000 m^2) = 130.43 kg TSP

Then a plot size of 3 m x 4 m (12 m^2)

$$= \frac{12\,\text{m}^2 \times 130.43\,\text{kg TSP}}{10{,}000\,\text{m}^2}$$

= 0.1565 kg TSP

= 156.52 g TSP

Number of plants per 12 m^2 = 40 hills or 80 plants

Quantity of TSP required per hill

$$= \frac{156.52\,\text{g}}{40}$$

= 3.91 g TSP per hill

For 90 kg P_2O_5 ha^{-1} treatment plots

46 kg P_2O_5 = 100 kg TSP

$$90\,\text{kg}\,P_2O_5 = \frac{90\,\text{kg}\,P_2O_5\ \text{x}\,100\,\text{kg TSP}}{46\,\text{kg}\,P_2O_5}$$

= 195.65 kg TSP ha^{-1}

If 1ha (10,000 m^2) = 195.65 kg TSP

Then a plot size of 3 m x 4 m (12 m^2)

$$= \frac{12\,m^2\ \text{x}\,195.65\,\text{kg TSP}}{10{,}000\,m^2}$$

= 0.2348 kg TSP

= 234.8 g TSP

Number of plants per 12 m^2 = 40 hills or 80 plants

Quantity of TSP required per hill

$$= \frac{234.8\,\text{g}}{40}$$

= 5.87 g TSP per hill

Appendix 3: Calculations of the quantity of muriate of potash (MOP) applied to maize plants on treatment plots

Recommended rate for K application = 60 kg ha^{-1}

MOP contains 60 % K_2O

60 kg K_2O = 100 kg MOP

If 1ha (10,000 m^2) = 100 kg MOP

Then a plot size of 3 m x 4 m (12 m^2)

$$= \frac{12\ m^2\ x\ 100\ kg\ MOP}{10{,}000\ m^2}$$

= 0.12 kg

= 120 g MOP

Number of plants per 12 m^2 = 40 hills or 80 plants

Quantity of MOP required per hill

$$= \frac{120\ g}{40}$$

= 3 g MOP per hill

Appendix 4: Soil chemical parameters and their ratings

Soil Parameter	Rating
Soil pH	
< 5.0	Very Acidic
5.0 – 5.5	Acidic
5.6 – 6.0	Moderately Acidic
6.1 – 6.5	Slightly Acidic
6.6 – 7.0	Neutral
7.1 – 7.5	Slightly Alkaline
7.6 – 8.5	Alkaline
> 8.5	Very Alkaline
Nitrogen (%)	
< 0.1	Low
0.1 – 0.2	Moderate
> 0.2	High
Phosphorus, P (mg/kg) – Bray's No. 1	
< 10	Low
10 – 20	Moderate
> 20	High
Calcium, Ca ($cmol_{(c)}kg^{-1}$) (Mg = 0.25 Ca)	
< 5	Low
5 – 10	Moderate
> 10	High
Exchangeable Potassium ($cmol_{(c)}kg^{-1}$)	
< 0.2	Low
0.2 – 0.4	Moderate
> 0.4	High
ECEC ($cmol_{(c)}kg^{-1}$)	
< 10	Low
10 – 20	Moderate
> 20	High

Source: Soil Research Institute of Ghana (CSIR)

Organic Carbon Content Walkley – Black method (% of soil by weight)	Rating
> 20	Very high
10 – 20	High
4 – 10	Medium
2 – 4	Low
< 2	Very low

Source: Landon (1996)

Appendix 5a: Mean monthly weather data at Anwomaso during the period of the study

Month	Temperature (^0C)		Relative humidity (%)	Total monthly rainfall (mm)
	Min	Max		
Sept	22.20	30.63	88.00	189.10
Oct	22.20	30.89	85.81	221.30
Nov	22.53	31.78	85.07	43.60
Dec	21.47	31.51	74.22	13.90

Source: KNUST weather station

Appendix 5b: Mean monthly weather data at Ejura during the study period

Month	Temperature (^0C)		Relative humidity (%)	Total monthly rainfall (mm)
	Min	Max		
Sept	22.48	-	82.00	0.40
Oct	22.90	-	80.81	220.30
Nov	23.24	-	81.50	89.30
Dec	20.75	-	66.10	18.20

Source: Ejura weather station