IMPACT OF TARGETED NITROGEN AND PHOSPHORUS FERTILIZER MICRO-DOSING ON MAIZE AND COWPEA YIELDS UNDER TWO CROPPING SYSTEMS

A Thesis presented to the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, in partial fulfillment of the requirements for the award of the degree of

DOCTOR OF PHILOSOPHY
IN
SOIL SCIENCE

BY

OKEBALAMA CHINYERE BLESSING
MSc. SOIL SCIENCE

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CERTIFICATION

I hereby declare that this submission is my own work towards the PhD 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 of the University, except where due acknowledgment has been made in the text.

KNUST

Okebalama Chinyere Blessing	....	....
PG 4242110	Signature	Date
Student		

Certified by:

Prof. E.Y. Safo	....	....
(Principal Supervisor)	Signature	Date
Dr. E. Yeboah	....	....
(Co - Supervisor)	Signature	Date
Dr. V. Logah	....	....
(Co - Supervisor)	Signature	Date

Certified by:

Dr. Charles Kwoseh	....	....
(Head of Department)	Signature	Date

DEDICATION

This work is dedicated to Almighty God who in His infinite grace and mercy has supported me all through my academic pursuit, having endowed me with the intellect to complete this PhD thesis successfully.

I also dedicate this work to my beloved parents, Elder and Mrs Simeon U. Okebalama who laid my educational foundation.

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NYANSAPƆ WƆSANE NO BADWENIMA

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ABSTRACT

Maintenance of soil fertility poses a pressing challenge in smallholder farming. Although the routes to increasing soil productivity include optimizing fertilizer use, prevailing fertilizer recommendations are high and beyond the reach of most smallholder farmers. Hence, the need for alternative lower but more efficient and cost-effective fertilizer recommendation. This study focused on determining the influence of fertilizer micro-dosing on nutrient use efficiency (NUE) and yields of maize and cowpea crops on the Gleyic Plinthic Acrisol (at Assin-Kushea) and Plinthic Acrisol (at Twedie) in the semi-deciduous rainforest zone of Ghana. The study consisted of four activities: i. Identifying between N and P, the most limiting soil nutrient to maize crop yield in the study areas. ii. Determining maize yield response to varying rates of N and P fertilizer application. iii. Examining the effect of mineral NPK inputs on yields of maize-cowpea crops, both as sole and in rotation. iv. Assessment of farmers' fertilizer use and management practices in maize and cowpea production. Although the Gleyic Plinthic Acrisol was less fertile than the Plinthic Acrisol, maize response to $N_{120}P_0$, N_0P_{90}, $N_{120}P_{90}$, and N_0P_0 showed better growth and yield parameters at the former than at the latter. On the Gleyic Plinthic Acrisol where maize attained maturity, grain yield ranged from 1.2 to 2.4 t $ha^{-1}$with increases of 10, 77 and 95 % over the control in the $N_{120}P_0$, N_0P_{90} and $N_{120}P_{90}$ treated plots, respectively. The application of N_0P_{90} treatment led to low apparent recovery of P compared to that of N due to $N_{120}P_{90}$ treatment. This study therefore established that P is the major nutrient limiting maize growth and yield on the Gleyic Plinthic Acrisols. Hence, P should be externally supplied. Maize showed differential yield response to the individual application of N and P_2O_5 fertilizers at 0, 30, 60, 90, and 120 kg ha^{-1}. On both soil types, whereas P response was quadratic in function, N response showed no trend. Despite that the highest NUE was obtained under N_0P_{30} treatment plot on both soil types, this study has demonstrated that the critical level of P for optimum maize yield was at N_0P_{60} and N_0P_{90} on the Plinthic Acrisol and Gleyic Plinthic Acrisol, respectively. Therefore, fertilizer P application should not exceed the critical level for the soils. Fertilizer micro-dosing with N, P and K treatment combinations, under continuous maize cropping (CMC) and cowpea/maize rotation (CMR) systems has proven to substantially increase maize yields (33 to 99 %) on the Gleyic Plinthic Acrisols and Plinthic Acrisols. Grain yield increase with micro-dose fertilizer treatments was generally higher on the former than the latter soil type. Remarkably, $N_{20}P_{40}K_{20}$ treatments under CMC which gave the highest maize grain yield and net returns, was thus proposed for increased maize yield in both soils studied. Socio-economic survey was conducted through oral interview with structured questionnaire involving one hundred farmers each at Assin-Kushea and Twedie. About 65 and 80 % of maize and cowpea farmers respectively, identified high cost of fertilizer as a major constraints to fertilizer utilization. Consequently, only 32 % maize farmers and 19 % cowpea farmers used fertilizer with average application rate of 18.45 kg ha^{-1} and 9.05 kg ha^{-1} NPK 15:15:15 (mostly used fertilizer type), respectively. The prevalent fertilizer application method and the fertilizer quantity used by the smallholder farmers were comparable to fertilizer micro-dosing. Awareness of fertilizer micro-dosing among the farmers was very low. The survey results therefore suggested that awareness creation and dissemination of fertilizer micro-dose technology were needed to minimize fertilizer input costs. This would promote fertilizer use, increase maize yield and income and subsequently improve the smallholder farmers' livelihood.

CHAPTER ONE

1.0 INTRODUCTION

In the bi-modal rainfall agro-ecological zones, farmers maximize their land resources by cultivating both in the major and minor cropping seasons. Such continuous cropping of farmland contributes to soil nutrient mining, nutrient losses through run off, leaching and soil erosion due to high rainfall. Among the major soil nutrients, N and P deficiencies usually result from increased pressure on farmland due to continuous cropping (Bationo *et al*., 2003). Subsequently, crop production in the absence of inorganic fertilizers contributes to the large gap between farmers' yields and potential crop yields. For instance, the average farmers' grain yield of maize in Ghana is about 1.7 t ha^{-1}, which is about 70 % less than the 6 t ha^{-1} obtained by researchers in maize yield evaluation trials (MoFA, 2011). The maintenance of soil fertility in Ghana, though a pressing challenge, is critical to increased and sustained crop production in smallholder farming.

Since agricultural production in Ghana is mostly at subsistence level, majority of farmers use little or no soil amendments in crop production despite the poor inherent fertility status of some soils. While nutrient depletion rates in Ghana range from about 40 to 60 kg of N, P and K ha^{-1} yr^{-1} (FAO, 2005a), fertilizer use is approximately 7.2 kg ha^{-1} (IFDC, 2012). Although the routes to increasing productivity include optimizing fertilizer use, the prevailing blanket recommendation of NPK 90:60:60 kg ha^{-1} (maize) for semi-deciduous forest zone soils (FAO, 2005b), is huge and beyond the reach of most smallholder farmers. Hence, the need for alternative lower but more efficient and cost-effective fertilizer recommendation for smallholder farmers. Currently, fertilizer micro-dosing is being promoted as an appropriate technology for smallholder farmers across most countries in West Africa (Sanginga and Woomer, 2009).

Micro-dosing was developed in an attempt to increase the affordability of mineral fertilizer while giving plants enough nutrients for optimal growth (Hayashi *et al*., 2008). It refers to the utilization of relatively low quantities of fertilizer through point placement in cereal-based cropping systems (Sanginga and Woomer, 2009). Benefits associated with micro-dosing include: increased crop yields (43 to 120 %), income (50 to 130 %), harvest index and nutrient use efficiency (NUE), better crop performance and increased food security (Sawadogo-Kaboré *et al*., 2008; Tabo *et al*., 2008; Twomlow *et al*., 2010). Notably, micro-dosing has great potential to improve crop yields in a range of environments and rainfall situations across different agro-ecological zones in West Africa (Tabo *et al*., 2008). Despite the relevance of this technology to increasing cereal production, several farm-level trials were carried out without considering the most major limiting plant essential nutrient(s) before micro-dose fertilization. Moreover, there was no affirmed scientific basis or justification for the choice of fertilizer nutrients applied.

While micro-dosing has been adopted for the production of cereals such as millet and sorghum, food security crops like maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.) however, have received little attention. Maize and cowpea constitute the predominant staple food crops that are mainly produced by smallholder farmers in Ghana. While cowpea is the major legume grown in the semi-deciduous forest zone of Ghana (Gerken *et al*., 2001), the zone is also among the leading maize producing areas. Studies on fertilizer micro-dosing have been limited to sole cereal base cropping system with limited information on the dose and type of fertilizer required in rotation cropping in which legume N input may substitute or increase fertilizer N supply. Knowledge of the roles of micro-dose fertilizer nutrients in different cropping systems is very important for sustainable production of maize and cowpea crops. More so, not much work has been done on fertilizer micro-dosing in Ghana. The few works done were in the northern Ghana (Sawadogo-Kaboré *et al*., 2008), results of which may not be applicable in the semi-deciduous forest zone of Ghana due to differences in soil and climatic conditions. The research will provide vital information on soil fertility and crop yield improvement strategy for dissemination by extension agents. This will help farmers increase and sustain crop production, obtain high incomes, and subsequently improve their livelihood.

The study hypothesis was that targeted fertilizer micro-dosing would increase NUE and yield of maize in rotation than in sole cropping. The main objective of this study was to determine the influence of fertilizer micro-dosing on NUE and yields of maize and cowpea in rotations in the semi-deciduous rainforest zone of Ghana. The specific objectives were to:

i. identify between N and P, the most limiting soil nutrient to maize crop yield in the study areas,
ii. determine maize yield response to varying rates of N and P fertilizer application,
iii. optimize the use of mineral NPK inputs in maize-cowpea production both as sole and in rotation,
iv. examine the effect of cowpea-maize rotation system on soil chemical properties and crop yield indices, and
v. assess farmers fertilizer use and management practices in maize and cowpea producing communities at Assin-Kushea and Twedie in Ghana.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Outlook on soil fertility depletion, restoration and maintenance strategy

Soil degradation has long been recognized as one of the serious environmental problems in Ghana (Hansen *et al*., 1995). As intensive cropping of farmland without fertilizer application increases among smallholder farmers in Africa, soil fertility decline poses a serious threat to soil degradation and food security. In sub-Saharan Africa, Sanchez (2002) estimated soil nutrient depletion rate of 22 kg N, 2.5 kg P and 15 kg K ha^{-1} of cultivated land per year. Though loss of nutrients was estimated to contribute only 9 % of the total causes of land degradation (Dunstan *et al*., 2004), it reduces soil capacity to increase food productivity. Whilst increases in food output has been envisaged to be partly achieved through expansion of arable land area and increased cropping intensity (Alexandrotos, 1995), agricultural researchers have emphatically stated that increased productivity cannot be achieved without application of inorganic fertilizer (Breman, 1990; Sanders and Ahmed, 2001). Reduction in farmers' potential to invest in soil fertility maintenance and restoration options while increasing pressure on land exposes soils to high risk of losing viability to soil infertility. Unfortunately, smallholder farmers who are associated with little or no fertilizer input in crop production are most vulnerable to such advances. With smallholder farmers forming approximately 80 % of the staple food crops producers in Ghana (FTF, 2011), the impact of soil infertility on food security will be devastating if its steady decline is not halted and reversed. Bationo *et al*. (2006) confirmed that soil fertility depletion in smallholder farms is a fundamental biophysical root cause of the declining per capita food production; which has largely contributed to poverty and food insecurity.

Fertilizer, on the other hand, has been identified as the main source of soil nutrients for agricultural production (Manyong *et al*., 2001), but fertilizer use has not been widely adopted (Vanlauwe and Giller, 2006; Abu and Malgwi, 2011). Fertilizer use by smallholder farmers is limited by high fertilizer recommendations (Bationo *et al*., 2006), inaccessibility of fertilizer (IFDC, 2012), unavailability of fertilizer (Thomas *et al*., 2004) and other socio-economic factors. Distance from the farm to the nearest fertilizer agro-dealer also hinders fertilizer use as well as increased farm-gate prices through transport and transaction costs. Compared to the developed countries, farm-level fertilizer costs in Africa are among the highest in the world. Depending on the region, the distance from the farmer to the nearest fertilizer seller in Ghana is between 42 and 197 km (IFDC, 2012). In sub-Saharan Africa, high prices of commercial fertilizers and limited availability of quality organic inputs (manure, crop residues, etc.) contribute to the overall low use of the nutrient inputs (IFDC, 2012). According to Bationo *et al*. (2006), the cost of 1 metric ton of urea, for example is about US$ 90 in Europe, US$ 500 in Western Kenya and US$ 700 in Malawi. As such, correcting soil nutrient deficiency with large applications of inorganic fertilizer is not a viable option for most resource-poor smallholder farmers due to exorbitant prices on the markets after the removal of subsidies (Carr, 1997). The main problem with most fertilizer recommendations is that they target economic gain without consideration of the financial attainability of smallholder households. Moreover, climate change and accelerated land degradation has so changed the biophysical environment and impoverished the soils that the efficiency of blanket application of fertilizers comes under question.

During the past 3 decades, the paradigms underlying the use of fertilizers and soil fertility management research and development efforts have undergone substantial change due to experiences gained with specific approaches and changes in the overall social, economic, and political environment (Sanchez, 1994). Contrary to conventional knowledge, it is vital to acknowledge that the farmers' decision making process is not merely driven by the soil and climate, but by a whole set of factors cutting across the biophysical, socio-economic, and political domain (Izac, 2000). In the light of this consideration, food production for the expanding world population has required the development and application of new technologies, and an intensification management to produce more food per unit of land (Stewart *et al*., 2005). Currently, a holistic approach in soil fertility research and strategy focus on the new paradigm of Integrated Soil Fertility Management (ISFM) which embraces the driving factors and consequences of soil degradation – biological, chemical, physical, social, economic, health, nutrition and political (Bationo *et al*., 2006). The ISFM practices such as fertilizer micro-dosing has been found as an appropriate technology for smallholder farmers in the sahelian region of Africa.

2.2 Fertilizer micro-dosing technology

2.2.1 Origin of fertilizer micro-dosing technology

According to Twomlow *et al*. (2010), fertilizer micro-dosing technology was initiated in the late 1990s, when ICRISAT used crop simulation models as a tool for more effective analysis of technology responses under conditions of high rainfall variability and low inherent soil fertility. In 1999, ICRISAT began a series of modeling workshops in conjunction with the International Maize and Wheat Improvement Center (CIMMYT) and the Agricultural Production Systems Research Unit (APSRU) in which research and extension officers used a simulation model (APSIM - Agricultural Production Systems Simulator Model (Keatinge *et al*., 2003) to evaluate the type of resource allocation questions faced by resource-poor farmers in the semi-arid regions of southern Africa. A common theme started from the proposition that farmers may, at best, initiate investments in small quantities of fertilizer (Rohrbach, 1999). The robustness of the simulated responses to small quantities of N fertilizer was surprising, and contrary to much of the documented soil fertility research results in the region which started with at least 25 kg N ha^{-1} (Mushayi *et al*., 1999; Mafongoya *et al*., 2006). Simulation results for 1951 to 1999 rainfall period in southern Zimbabwe, suggested that farmers could increase their average yields by 50 to 100 % by applying as little as 9 kg N ha^{-1}. These results indicated that farmers were better off applying lower rates of N on more fields, than concentrating a limited supply of fertilizer on one field at the recommended rates (Carberry *et al*., 2004).

On-farm experimentation was then initiated with farmers on micro-dosing alone or in combination with available animal manures (Ncube *et al*., 2007). The on-farm trial results confirmed that farmers could increase their yields by 30 to 100 % by applying approximately 10 kg N ha^{-1} (Rusike *et al*., 2006). Scaling out of micro-dosing was initiated in 2003/2004 with support from the Department for International Development (DFID) and the European Commission Humanitarian Aid Office (ECHO) which encouraged the application of the micro-dosing of ammonium nitrate (AN) fertilizer by more than 160,000 farmers (Rohrbach *et al*., 2005; Twomlow *et al*., 2007). Currently, fertilizer micro-dosing technology has reintroduced fertilizer use by smallholder farmers in Zimbabwe, Mali, Burkina Faso, Niger, Mozambique and in the southern part of the African continent (ICRISAT, 2009; INERA, 2010; Twomlow *et al.,* 2010). This technology establishes a pattern for future productivity as farmers become accustomed to increasing their investments in inputs in order to generate increased returns. It is therefore an entry point for increased use of fertilizers in farmers' fields, which can lead to sustainable development (Tabo *et al*., 2008).

2.2.2 What is fertilizer micro-dosing?

Fertilizer micro-dosing technology is point application of relatively small quantities of fertilizer (2–6 g hill^{-1}) in cereal production. In micro-dosing, fertilizer may be placed next to the plant 2 to 3 weeks after planting (Tabo *et al*., 2008), or applied with the seed at sowing time or as top dressing 3 to 4 weeks after emergence (ICRISAT, 2009). Micro-dosing decreases substantially the recommended amount of fertilizer that smallholder farmers need to apply per hectare i.e., from 200 to 20 kg ha^{-1} in the case of di-ammonium phosphate (Hayashi *et al*., 2008). Twomlow *et al*. (2010) reported significant increases in cereal grain yield with 17 kg N ha^{-1} (approximately 25 % of recommended levels) compared to recommended rates of 55 kg ha $^{-1}$. However, Institut de l'Environnement et de Recherches Agricoles (INERA) has developed a method of micro-dosing which is based on application of only 62 kg of fertilizer per hectare, a reduction of one-third, the recommended rate. The technique requires only about onetenth of the amount typically used on wheat, and one-twentieth of the amount used on corn in the USA (INERA, 2010).

The techniques of applying fertilizer vary depending on soil and climatic conditions. In southern Africa, farmers use fertilizer measured out in an empty soft drink or beer bottle cap, while in western Africa, the farmers measure fertilizer with a three-finger pinch (ICRISAT, 2009). A three-finger pinch is equivalent to 6 gram doses of fertilizer which is about a full soft drink bottle cap. With ammonium nitrate fertilizer for instance, a beer bottle cap is equal to 4.5 g which is equivalent to 17 kg N ha^{-1} (Twomlow *et al*., 2010). Farmers in the Sahel use a soda bottle cap to allocate fertilizer, hence fertilizer micro-dosing is popularly known as the Coca-Cola technique (Tabo *et al*., 2006). Applying fertilizer in micro-dose permits more precise and better timed fertilizer placement and hence appropriate management of fertilizer (Sanginga and Woomer, 2009). This technology may be strategically combined with other practices such as seed priming, water harvesting, zai planting holes, addition of livestock manure or crop residue and compost prepared from household and garden wastes.

2.2.3 Benefits of fertilizer micro-dosing

2.2.3.1 Fertilizer affordability

Fertilizer micro-dosing was developed in an attempt to increase the affordability of mineral fertilizer while giving plants enough nutrients for optimal growth (Hayashi *et al*., 2008). High rates of fertilizer input have been recommended to farmers for a long time to maximize yields, but smallholder farmers could not afford to apply such fertilizer quantities. Small amounts are more affordable for farmers (Bationo and Buerkert, 2001) because of reduced investment cost (Tabo *et al*., 2006, 2007). Hence, the technology minimizes input cost and reduces investments risk while increasing crop yields.

2.2.3.2 Increases in crop yield and harvest index

Tabo *et al*. (2007) observed that sorghum grain yields from micro-dosed treatments were significantly higher than the control plots (1069 kg ha^{-1} verses 728 kg ha^{-1}), while millet grain yields increased from 687 kg ha^{-1} under no-fertilizer treatment to 1212 kg ha^{-1} with fertilizer micro-dosing. In Ghana, maize yield was about 250 kg ha^{-1} without fertilizer as against 1100 kg ha^{-1} with fertilizer micro-dosing (Sawadogo-Kaboré *et al*., 2008).

Some have questioned whether these results could be replicated across different soil types, agro-ecological zones and climates. Tabo *et al*. (2008) confirmed that fertilizer micro-dosing has the potential to greatly increase yields across a range of agro-ecological zones and rainfall situations in West Africa, from the drier Sahelian zone to the wet Sudano-Guinean environment. In Zimbabwe, wide scale testing of the micro-dosing (17 kg N ha^{-1}) consistently showed increased grain yields by 30 to 50 % across a broad spectrum of soil, farmer management and seasonal climatic conditions (Twomlow *et al*., 2010). Also, the findings of Hayashi *et al*. (2008) showed that fertilizer micro-dosing improved the harvest index of millet crop.

2.2.3.3 Increases in income

Profitability of maize to low rates of N fertilizer has been reported (Twomlow *et al*., 2010). Millet under micro-dosing gave net monetary gains which were 68 % higher than the net returns from the traditional practice and 33 % higher than the net gain from the recommended practice (Tabo *et al*., 2008). In Mali, Burkina Faso, and Niger, ICRISAT (2009) reported an increase in sorghum and millet smallholders' family incomes by 50 to 130 %.

2.2.3.4 Increase in nutrient use efficiency (NUE)

Tabo *et al*. (2006) noted that micro-dosing optimizes NUE, while Zougmoré *et al.* (2004) found that the combination of water harvesting technologies and fertilizer improved water and NUE by crops. Report from ICRISAT (2009) showed that implementation of micro-dosing technology enhanced NUE and improves productivity instead of spreading fertilizer over the field. Small amounts of applied fertilizer give an economically optimum (though not biologically maximum) response, and if placed in the root zone of these widely-spaced crops rather than uniformly distributed, result in more efficient uptake (Bationo and Buerkert, 2001). The efficient use of fertilizer by plants depends on mode of application, with the most efficient method being hill placement (Bationo and Waswa, 2011).

2.2.3.5 Better Crop performance

Micro-dosing significantly increased plant height from 19 to 31 % (Aune and Ousman, 2011). Crops under micro-dosing have been observed to perform better under drought conditions because the crops larger root systems are more efficient at exploiting moisture at greater depth later in the season when soil moisture at the surface of the soil is low (ICRISAT, 2009). By correcting soil essential nutrients deficiencies with tiny doses, root systems develop and capture more water, increasing yields. Furthermore, micro-dosing results in more rapid early growth, thus avoiding early season drought and an earlier finish, thereby avoiding or reducing the impact of end-of season drought while increasing crop yields (Tabo *et al*., 2006; 2007).

2.2.3.6 Technology adoptability

By using much lower rates of fertilizer than the recommended rate, in more efficient ways that deliver economically optimum returns, farmers are much more able and inclined to adopt the practice. However, for the introduction and dissemination of micro-dosing to other agro-ecological zones, it is fundamental to first ascertain its adaptability to the farmers' existing farming practices. This is very important because insufficient adaptation of technologies to farmers' condition among others had been recognized as a major constraint to adoption (Sanginga and Woomer, 2009). Other identified major constraints to the widespread adoption of micro-dose technology include access to fertilizer, access to credit, insufficient flows of information and training of farmers, and inappropriate policies (ICRISAT, 2009). Nevertheless, experiences from both western and southern Africa have shown that adoption of micro-dose technology requires supportive and complementary institutional innovation as well as input and output market linkages (Bationo *et al*., 2006).

2.2.3.7 Increased food security

Micro-dosing has the potential for improving food security. Over 100 % yield increases of cereal crops produce of smallholder farmers (Tabo *et al*., 2006; 2007) suggests increased food security and less need for food aid. The findings of Twomlow *et al*. (2010) provided strong evidence that N micro-dosing has the potential for broad-scale impact on food security for a large section of the rural poor across dry regions of southern Zimbabwe. Rohrbach *et al*. (2005) reported that the estimated DFID's support for the distribution of 25 kg of ammonium nitrate fertilizer to each of 160,000 farm households contributed 40,000 additional tons of maize production, valued by the World Food Programme at 5 to 7 million USD.

2.2.4 Fertilizer micro-dosing challenges and possible solutions

2.2.4.1 Labour intensive

Farmers have reported that micro-dosing is labourious, time consuming and difficult to ensure each plant gets the right dose of fertilizer (ICRISAT, 2009). In an attempt to address these issues, ICRISAT collaborates with private fertilizer companies in eastern and southern Africa, to identify appropriate fertilizer types and promote the sale of small packs suited to the resource constraints and risk preferences of small-scale farmers. ICRISAT is also exploring the use of seed coating (with fertilizer) as another option of further reducing the quantity of fertilizer to be used as well as the labour constraint. In addition, researchers are looking at packaging the correct dose of fertilizer as a tablet that aids in application (ICRISAT, 2009). Alternatively, with the development of labour-reducing equipment, precise plant hill fertilizer micro-dosing would complement farmers' efforts (Tabo *et al*., 2007).

Hayashi *et al*. (2008) opinioned that delayed fertilizer application strategy for micro-dosing would enable farmers to better manage available labour and also have some flexibility and an additional option in investing in inorganic fertilizer. Accordingly, delayed application allows farmers to push labour usage to later in the season, after planting, when the labour pool is not as limited, thereby reducing the chance of bad results by applying fertilizer after crops have emerged.

2.2.4.2 Financial constraints

Most farmers are faced with lack of financial means at the onset of the rainy season. Abdoulaye and Lowenberg-DeBoer (2000) pointed out that local farmers cannot afford to invest in the purchase of inorganic fertilizer prior to the cropping season due to an insufficient food supply for the household and the need to use cash to purchase family food. Nevertheless, delayed fertilizer application can lessen the financial burden of the local farmers during the sowing period. Delayed fertilizer application offers smallholder farmers opportunity to raise the cash needed to purchase and apply fertilizers only to established plants, thus increasing their chance of producing more grain and economic returns (Hayashi *et al*., 2008). Also, farmers' supportive groups (co-operative) or warrantage/inventory credit strategy as practised in West Africa aims to resolve the farmers' capital constraint. Organized farmer groups provide access to post-harvest credit provided on the basis of storage of grain as collateral (warrantage), enabling farmers to sell crops later in the season for higher prices and higher profits (Bationo *et al*., 2006).

2.2.4.3 Nutrient mining

The possibility of soil nutrient mining arising from fertilizer micro-dosing technology has raised much concern. Some have questioned the logic of micro-dosing, claiming that the use of such a small quantity of fertilizer is not sustainable (Twomlow *et al*., 2010). No doubt, as grain yields increase per unit area and very little organic matter, including crop residues, are put back into the soil, there is the risk that nutrient imbalances will inevitably develop with time (Tabo *et al*., 2007). Therefore, it is important to ensure that organic matter is added and incorporated into these soils to improve their structure and enhance their capacity to store adequate moisture and nutrients even after crops are harvested (Tabo *et al*., 2007).

Finally, it appears that most micro-dose fertilization studies were mainly based on sole cropping of cereals such as wheat, millet and sorghum. Little is known about the impact of fertilizer micro-dosing on performance of other crops such as maize and cowpea, in sole and rotation systems.

2.3 Fertilizer use for maize and cowpea production in Ghana

Of all cereals and legumes, maize and cowpea are the predominant staple food crops and important livestock feeds that are mainly produced by smallholder farmers in Ghana. Both crops are vital sources of carbohydrate, protein, iron, vitamin B, and minerals. While maize adapts to all agro-ecological zones of Ghana, cowpea is mainly grown in the savanna and forest-savanna transitional agro-ecological zones of Ghana (CRI, 2006). Unlike cowpea, maize is known to be highly self-compatible, especially with regard to pests and diseases (Horst and Hardter, 1994). Cowpea is also an important component of the cereal/legume production systems. Return of legume residues benefits the following crop, regenerate fertility and contributes to sustainability (Bationo and

Waswa, 2011). Nonetheless, their production without inorganic fertilizers is characterized not just by soil nutrient depletion but also by low crop yields.

Agriculture in Ghana is predominantly on a smallholder basis, with an average farm size of about 1.2 ha and low use of improved technology (IFDC, 2012). In fact, about 90 % farmers cultivate less than 2 ha of farm size (MoFA, 2011). Maize and cowpea production in Ghana is almost rain-fed with one cropping season (May to September) for the north while the rest of the country has bi-modal rainy seasons that span from March to July and August to November. Across the country, recommended times for fertilizer application is a "basal dressing" at planting and a second "top dressing" application four to six weeks after planting (Kombiok, 2008). As such, NPK 15:15:15 is widely used as a basal dressing fertilizer while urea and sulphate of ammonia are the typical top dressing fertilizers (Banful, 2009). Though these fertilizer types are subsidized, the levels of fertilizer recommendations needed to maximize yields are usually much higher than the purchasing power of a typical smallholder farmer. For instance, the outdated smallholder farmers fertilizer recommendation for maize (NPK 60:40:40 kg ha^{-1}), and cowpea (NPK 0:60:20 kg ha^{-1}); and the current blanket recommendation rate of NPK 90:60:60 kg ha^{-1} (maize) for the semi-deciduous forest zone are large (SRI, 1974; FAO, 2005b).

Unlike other African countries like Egypt, South Africa, Zimbabwe and Kenya with known average fertilizer utilization rate (IFDC, 1996; Okoth *et al*., 2011), there is difficulty in assessing the actual amount of fertilizer used by farmers in Ghana. It is often assumed that the quantity of imported fertilizers, less stock carryovers by dealers, is equivalent to fertilizer utilization rate (IFDC, 2012). And this makes it more difficult to ascertain the proportion of fertilizer input between smallholder and commercial farmers. Available data on average fertilizer import and sales in Ghana depict an increasing trend from 1999 to 2007 (FAO, 2005c; SRID, 2008). However, the boosting fertilizer sales do not necessarily represent fertilizer consumption by smallholder farmers. Hence, there is limited information on the quantity of fertilizer input by smallholder farmers. In Ghana, IFDC (2012) reported current average fertilizer application rate of about 7.2 kg ha^{-1} which is considerably lower than in other countries like Malawi and Kenya with application rates of 22 and 32 kg ha^{-1}, respectively (Fuentes *et al*., 2012). Fertilizer application rates are highest for cash crops such as cocoa, cotton, palm oil and vegetables, while maize accounts for about 40 % of non-cash crop fertilizer use (FAO, 2005a).

Of all the inputs used in crop production, none has received government intervention as fertilizer input that is clearly highlighted in national development plans. Even with the re-introduction of fertilizer subsidy in 2008, the number of households using fertilizer is less than 20 % on average, with about 15 % fertilizer users in the forest agro-ecological zone of Ghana (Quiñones and Diao, 2011). Government of Ghana (2010) reported even lower level of fertilizer adoption (10 %) by smallholders with less than 1.0 ha of farm land. The low adoption of mineral fertilizer contributes to the large difference between farmer's yields and potential yield (Bationo *et al*., 2006). SRID (2010) and Breisinger *et al*. (2011) reported average maize yields of 1.5 mt ha^{-1} as against 2.5 mt ha^{-1} potential yields with 40 % achievable yield gap. Similarly, average cowpea yield is 0.9 mt ha^{-1} as against 1.3 mt ha^{-1} potential yield with 31 % achievable yield gap. There is little data on past rates of fertilizer use on maize and cowpea production. Available data on trends in fertilizer use showed that the average fertilizer use between 2000 and 2007 was 120,000 mt; and later increased to 260,000 mt after the subsidy was re-introduced in 2008 (IFDC, 2012).

2.4 Cropping systems

The term cropping system refers to the crops and crop sequences and the management techniques used on a particular field over a period of years (Nafziger, 2014). Recent concern in the use of land resources is geared towards improving the productivity and sustainability of various cropping systems to boost food security. In Ghana, the most dominant cropping systems are crop rotation, intercropping/mixed cropping and strip cropping, but mixed cropping is typical to farmers in the semi-deciduous forest zone (Fosu and Tetteh, 2008). Though maize and cowpea crops are important components of mixed cropping in most countries (Okigbo, 1982), their cultivation as in monocropping or in rotation is uncharacteristic to most smallholder farmers. While monocropping is mostly associated with larger-scale commercial farms, most food crop farms are intercropped because of the predominance of smallholder farm holdings of less than 2 ha (MoFA, 2011).

There are evidences of higher yield advantage with monocropping and crop rotation system than mixed cropping. For instance, maize yields under maize/cowpea mixed cropping system were significantly lower than in sole cropping (Hardter *et al.*, 1991). Also, rotation of maize and cowpea has been shown to be superior to mixed cropping of maize and cowpea which did not lead to improved use of soil and fertilizer N and P or to an enhanced N_2 fixation (Hardter and Horst, 1991). In the same way, crops grown in rotation affect soil fertility and often have higher yields than those grown in a monoculture (Anderson *et al*., 1997). For long-term agricultural productivity and sustainability, it has been identified that crop rotation; in conjunction with other fertility management practices is essential (Mitchell *et al*., 1991). In view of this research, maize monocropping, as well as maize/cowpea rotation cropping systems were considered in relation to fertilizer micro-dosing.

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2.4.1 Continuous monocropping

Monocropping is the growing of only one crop on a piece of land in a cropping season. Where such a practice persists year after year in the same field, it becomes continuous monocropping. Continuous monocropping of cereals has led to yield decline. Hardter (1989) and Horst and Hardter (1994) reported significant yield decline in maize monocropping system over a period of several cropping seasons. While the latter attributed the yield decline to allelopathic effects, Yakle and Cruse (1984) indicated that the phytotoxic substances produced during the decomposition of the maize plant residues in the soil may retard the growth of the succeeding crop. However, the negative effect of monocropping on yield could partially be offset through N and P application (Hardter, 1989). On the contrary, the result of 2 years on-farm maize monoculture indicated significant yield increases with the addition of micro-dose rate of 2 g NPK and 2 g sulphate of ammonia fertilizer per hill (Sawadogo-Kaboré *et al*., 2008). Similar result was reported by Twomlow *et al*. (2010) who observed grain yield increase in maize monoculture with targeted application of 17 kg N ha^{-1} ammonium nitrate fertilizer.

The effect of continuous cropping on soil fertility has been recognized. It has been reported that continuous cropping results in lower exchangeable Ca, K, Mg, organic C, total N contents and enzyme activities and effective cation exchange capacity (Riffaldi *et al*., 1994; Juo *et al*., 1996). In a related study, surface soil under continuous maize cultivation resulted in soil acidification with lower pH values and higher exchangeable Al and Mn (Juo *et al*., 1996). Most fertilizer micro-dose research results and discussion have focused mainly on yield estimation due to treatment effect without an in depth findings on the interaction of soil properties and applied fertilizer nutrients. There is need to evaluate the impact of micro-dosing on soil chemical properties on different soil types.

2.4.2 Crop rotation

Crop rotation is the sequential cultivation of different crops on the same piece of land. Regular crop rotation is an integral part of farming practices aimed at preserving soil fertility and soil structure, and at providing a measure of pest, disease, and weed control (Negussie, 1995). Rotation of cereals with legumes is gaining importance because of economic and sustainability considerations. Crop rotation offers direct advantages of N supply from the atmosphere and residual sources of organic N in crop residues, roots and nodules (Sanginga and Woomer, 2009). The legumes not only fix N and thus replace fertilizer but also produce an economic crop that small farmers can sell (Bationo and Waswa, 2011). Legumes in farming systems can minimize the losses of nutrients through erosion as some of these legumes form canopy, which reduces the impact of rain drops (Giller and Cadisch, 1995). Hence, the system offers higher yield, greater profits and protects the soil for future use. It also permits better use of land resources because the crops involved have different nutrient requirements for optimal growth.

The increased use of cereal/legume crop rotation has been advocated as a strategy to increase cereal yields of subsistence farmers in West Africa (Alvey *et al*., 2003). It has long been established that crop rotation of maize with various legumes was very beneficial for maize production (Hardter, 1989). Response of maize in rotation with cowpea resulted in significant maize grain yield increase of 42 to 102 % at one-quarter the recommended NPK rate (135 kg N + 24 kg P + 26 kg K ha^{-1}) during the first 3 years, and of 75 % at half the recommended rate in the 4th season (Shumba *et al*., 1990). According to Adetunji (1996), maize grain yields increased significantly when cowpea was rotated with maize as compared with continuous maize. This beneficial effect on maize yields is primarily due to the biological N_2 fixation (BNF) ability of the legume and N transfer to the succeeding maize. Giller (2001) reported as much as 300 kg N ha^{-1} contribution of BNF in grain legumes in a season. Shumba *et al*. (1990) observed that inclusion of cowpea in rotation increased soil N by 32 kg ha^{-1} within four cropping years. Cowpea has been reported to fix about 60 to 70 kg N ha^{-1} from nodules (Rachies, 1985), which can satisfy the crop N requirements (Singh, 1997). Some reports however, have indicated that BNF of cowpea hardly satisfies N requirements in poor soils, and fertilizer addition is required to improve crop performance (Chiezey *et al*., 1990; FAO, 2005c).

In quantifying the N supplying potential of cowpea residue in relation to P availability, Carsky *et al*. (2000) showed that at low-P and moderate-P sites, the N content of cowpea residues after grain harvest was approximately 15 and 30 kg ha^{-1}, respectively. This is in line with the earlier findings of Bruulsema and Christie (1987), who concluded that the beneficial effects on maize yields by preceding legumes were mainly due to factors other than N availability. Besides improvement of the nutrient status for crops succeeding legumes, soil physical properties improvement (McVay *et al*., 1989), and weed load reduction (Kamau *et al*., 1999) have also been associated with maize-cowpea rotation cropping. Some studies have also indicated that cereals may benefit from the high P efficiency of the leguminous component (Horst and Waschkies, 1987). Despite the numerous benefits associated with crop rotation system, much work has not been done on fertilizer micro-dosing in relation to rotation cropping.

2.5 Effects of major fertilizer nutrients on maize and cowpea production

The essential macronutrients (N, P, K, Ca, Mg and S) and micronutrients (B, Cl, Mn, Fe, Zn, Cu and Mo) are required by plants over a wide range of concentrations. Among all the essential nutrients, the primary macronutrients (N, P and K) are utilized in largest quantity by crops, and therefore are the most deficient in most arable soils. However, their deficiencies are mostly corrected with the use of fertilizers. Inorganic fertilizer forms range from single granular types and their blends, to compound (combined), and complete kinds designed to provide balanced combinations of nutrients needed by specific crops (Sanginga and Woomer, 2009). The significant roles these fertilizer nutrients play in plant nutrition cannot be overemphasized.

2.5.1 Nitrogen

Nitrogen is a major component of proteins and protoplasm that plays a vital role in achieving biomass increase and reproduction in plants. In most farming systems, N is the yield-determining nutrient (Goulding *et al*., 2008) and because most non-leguminous plants require 20 to 50 g N taken up by their roots to produce 1 kg of dry biomass, the natural supply of soil N usually limits plant yields (Robertson and Vitousek, 2009). According to Sanginga and Woomer (2009), major causes of N deficiency include insufficient soluble N in the soil solution, pH imbalance hindering nutrient absorption, excess leaching, waterlogging and plant competition for limited N reserves. Nitrogen fertilizer is universally accepted as a key component to high yield and optimum economic return (Amanullah and Lal, 2009). Nitrogenous fertilizers have contributed to the remarkable increase in food production during the past 50 years (Smil, 2001). However, only about half of all anthropogenic N inputs to cropland are taken up by harvested crops and their residues, with the remainder contributing significantly to reactive N enrichment of the atmosphere, ground and surface waters (Smil, 1999). In most annual cropping systems, uptake of N from soil at significant rates lasts for only 8 to 12 weeks. Crop response to N depends on moisture availability and planting density: better moisture availability improves the efficiency of applied N (Christianson and Vlek, 1991). Usually, the crop uses 30 to 50 % of the inorganic N fertilizer applied, while the rest is lost by volatilization, denitrification, or leaching as nitrate into groundwater (Stewart *et al*., 2005). Crop uptake of N is relatively inefficient and often results in average losses of 50 % because of leaching, volatilization or denitrification (Zublena, 1997).

2.5.1.1 Remedial measures to N losses

Maintaining high levels of crop productivity with minimum N input is required for the benefit of smallholder farmers. Fertilizer N applied in excess of crop needs may result when soil inorganic N content is not adequately considered or when predicted yield goals are considerably larger than could be expected for given soil types and climatic conditions (Keeney, 1987). On the other hand, over application of N fertilizer causes nitrate leaching from the root zone while under fertilization limits yields (Randall and Schmitt, 1993). The mismatching of N availability with crop needs is probably the single greatest contributor to excess N losses (Robertson and Vitousek, 2009). Some remedial measures to N loses have been suggested. The use of legumes as intercrop or in rotation with cereals are potentially a cheaper source to inorganic N fertilizers which are expensive and are prone to losses as compared to organic sources (Rehman *et al*., 2010). However, for BNF to proceed to its full potential, it is critical that soil N, and not some other nutrient(s), be limiting (Giller, 2001). Split application of N fertilizer at farm level has also been envisaged as the best agricultural technique to reduce N losses (Amanullah and Lal, 2009). Akbar *et al*. (1999) reported that N application in splits up to silking stage significantly improves the vegetative and reproductive growth of maize except the number of grains per cob. Strategic application of N fertilizers as top-dressings is another means to synchronize N availability and crop demand, particularly when applications are timed to moisture availability (Piha, 1993). Twomlow *et al*. (2010) reported significant increases in cereal grain yield with 17 kg N ha^{-1} applied as targeted topdressing.

2.5.1.2 Nitrogen use efficiency

Improving N use efficiency is critical and has attracted a number of reviews (Hirel *et al*., 2007; Robertson and Vitousek, 2009; Masclaux-Daubresse *et al*., 2010). Defined as the total biomass or grain yield produced per unit of fertilizer N applied, N use efficiency is an integration of N uptake efficiency (referred to as the percentage of fertilizer N acquired by plant) and N utilization (assimilation) efficiency (defined as grain yield per unit N uptake). However, due to the inter-conversions effects of external N addition on the complex N form, the different mobilities of soil N forms, and the gaseous losses of N from the soil/plant canopy, it is difficult to quantify the "real" amount of fertilizer N available or actually acquired by plants (Xu *et al*., 2012). For instance, ammonium or nitrate N uptake by roots commonly results in acidification or alkalization of the rhizosphere, which in turn changes the soil N availability for plants (Marschner, 1995).

Nitrogen utilization efficiency of maize has been shown to vary under different climatic, soil and management conditions (Muchow, 1998; Sawadogo-Kaboré *et al*., 2008; Twomlow *et al*., 2010). Chardon *et al*. (2010) reported that plant responsiveness to N availability depends on both genotype and the interaction of genotype with N fertilization level. It has also been indicated that N is least available under cool, dry conditions and most available in warm, moist soils (Sanginga and Woomer, 2009). Hence, matching the N requirement of maize crop which is dynamic during its growth period is also essential to increase the N use efficiency (Amanullah and Lal, 2009). Generally, N use efficiency often decreases with increasing levels of applied N (Halvorson *et al*., 2005). On the contrary, Hartemink *et al*. (2000) reported increases in N use efficiency with increased N application.

2.5.1.3 Contribution of N to maize and cowpea performance

The efficient use of N for maize production is important for increasing grain yield and maximizing economic return (Gehl *et al*., 2005). Akbar *et al*. (1999) applied N at 3 different times for increasing N use efficiency of maize in terms of above ground dry matter and grain yield. Twomlow *et al*. (2010) and Mariga *et al*. (2000) obtained maize grain increase with increase in N fertilizer levels. Three years on-farm results showed consistent grain yield response and profitability of maize to low rates of N fertilizer (Ncube *et al*., 2007). In addition, APSIM simulation results for a 1951 to 1999 rainfall period in southern Zimbabwe, suggested that farmers could increase their average yields by 50 to 100 % by applying N at 9 kg ha^{-1} (Carberry *et al*., 2004). Recent studies (Abayomi *et al*., 2008; Azarpour *et al*., 2011) have demonstrated the contribution of externally applied N to cowpea growth and grain yield, despite its BNF capability. However, high application of 80 kg N $ha^{-1}yr^{-1}$ has been reported to reduce N_2 fixation of cowpea (Hardter and Horst, 1991).

2.5.1.4 Agronomic efficiency (AE) of N fertilizer

Agronomic efficiency of fertilizer N is also a useful measure of N use efficiency as it provides an integrative index that quantifies the ratio of net increased grain yield due to N fertilization relative to the total amount of fertilizer N applied. The AE of N applied to maize crop ranges from 0 to 35 in Ghana (Heisey and Mwangi, 1996). The AE of N can be increased by increasing plant N uptake and use and by decreasing N losses from the soil-plant system. On the contrary, the findings of Amanullah and Lal (2009) showed a negative relationship of AE with increase in N rate. In addition, adoption of inefficient N management practices was reported to contribute to low AE.

2.5.2 Phosphorus

Phosphorus is a component of key molecules such as nucleic acids, phospholipids, and adenosine triphosphate (ATP), making up about 0.2 % of a plant's dry weight (Schachtman *et al*., 1998). It plays key roles in many plant processes such as energy metabolism, the synthesis of nucleic acids and membranes, photosynthesis, respiration, N fixation and enzyme regulation (Raghothama, 1999). Adequate P enhances flowering, fruiting and root growth during plant development. Plants take up P ions through the soil solution by diffusion. Nonetheless, P availability to crops is influenced by several factors such as tillage methods, soil temperature, soil moisture, soil pH, soil clay content and clay type. The report of NAS (2010) indicated that no-till, minimum tillage and compaction can limit soil aeration thereby limiting root growth, whilst soils that have high clay content can retain high levels of P reserves. In addition, soil P is available to plants in the form of hydrated ortho-phosphate. However, P availability depends on the form it exists in solution which changes according to soil pH. Most studies have indicated that P uptake rates are highest between pH 5.0 and 6.0 (Ullrich-Eberius *et al*., 1984; Furihata *et al*., 1992) while the optimum P availability is at soil pH of 6.0 to 7.0 (NAS, 2010). At both low (< 4) and high (> 8) pH levels, P becomes fairly insoluble (Sanginga and Woomer, 2009). Furthermore, lack of oxygen, insufficient soil moisture, extreme soil temperature and the absence of symbiotic mycorrhizal fungi have been indicated to hinder P uptake by plants.

2.5.2.1 Remedial measures to P deficiency

After N, P is the second most limiting nutrient to crop production. However, crop response to N was found to be minimal until crop P requirements had been satisfied (Traore, 1974). Giller *et al*. (1997) stated that to increase and sustain crop production, replenishment of soil P must be integrated with replenishment of soil N. In many impoverished soils of Africa, P is the yield-limiting nutrient (Goulding *et al*., 2008). In fact, P deficiency has been stated as one of the reasons why sub-Saharan Africa is the only major region in the world where per-capita food production has actually declined in the past three decades (Brady and Well, 2002). Phosphorus deficiency in many soils is largely due to low occurrence of P-containing minerals (Bunemann, 2003) and P-fixation (Van der Eijk, 1997). Fortunately, P deficiency could be over-come by the use of soluble inorganic fertilizers. Despite the fact that P is acute in African soils, local farmers use very low P fertilizers because of high cost and problems with availability (Bationo and Waswa, 2011). Alternatively, use of local phosphate rock has been shown to be more economical than imported P fertilizers (Bationo *et al*., 1987). Fertilizer P does not move far from where it is applied because it reacts rapidly and binds with Fe and Al in the soil and becomes fixed, unavailable to plants, especially with soil pH ($CaCl_2$) < 5.0 (Lines-Kelly, 2002). In the soil, more than 80 % of the P becomes immobile and unavailable for plant uptake because of adsorption, precipitation, or conversion to the organic form (Holford, 1997). Since the rate of diffusion of P is slow (10^{-12} to 10^{-15} m^2s^{-1}), high plant uptake rates leave the root rhizosphere depleted of P (Schachtman *et al*., 1998).

2.5.2.2 Contributions of P to maize and cowpea performance

Agricultural crops show different responses to applied P. Therefore, understanding soil P dynamics can aid in its management to improve its use efficiency. The roles of P in production of legumes such as cowpea have been recognized. Phosphorus is reported to stimulate root and plant growth, initiate nodule formation, as well as influence the efficiency of the rhizobium-legume symbiosis (Bationo *et al*., 2002). With the predominantly infertile soils cultivated by smallholder farmers, P availability has been noted to affect the functioning of BNF system (Chein *et al*., 1993) as well as the productivity of grain legumes (Giller, 2001). Phosphorus, although not required in large quantities is critical to cowpea yield (Muleba and Ezumah, 1985). Magani and Kunchinda (2009) observed a positive interaction between P fertilizer and cowpea grain yield. Owolade *et al*. (2006) observed significant increases in numbers of petioles, pods, nodules, seed/pod, leaf area and yield of cowpea with increased P level. Phosphorus fertilization also improves nodulation and plant growth where P is limiting (Ronner and Franke, 2012). Kang and Nangju (1983) found that P influenced the content of other nutrients in cowpea leaves.

Due to relatively low P level in soil, marked yield responses in maize have been obtained with P application. Soil P availability is critical for early growth and development of maize because it affects root morphological and physiological characteristics that are important for P uptake (Hajabbasi and Schumacher, 1994). Sharif Zia *et al*. (1998) found that maize dry matter yield, P tissue concentration and P uptake were significantly affected by varying rates of P. Consequently, the critical and toxic limits of P for maize growth were found to be below 1.4 mg g^{-1} (0.14 %) and above 3.6

mg g^{-1} (0.36 %) dry matter, respectively. The relative response of maize to NPK fertilizers tended to decrease with increasing soil quality (soil C and extractable P), from a maximum of 4.4 fold to - 0.5 fold relative to the control (Tittonell *et al*., 2008).

2.5.2.3 Influence of cropping systems on P availability

Cropping intensification and diversification also affects both P supply and demand in cropping systems (Grant *et al*., 2002). Continuous cropping without commensurate nutrient replenishment has been reported to contribute to low P content of many soils (Sanchez, 2002; Bunemann, 2003). Mckenzie *et al*. (1992) found that without fertilizer application, continuous cropping resulted in the greatest reduction of almost all soil organic and inorganic P pools. Selles *et al*. (1995) observed a positive effect of cropping on P availability when continuous cropping was coupled with the addition of N and P fertilizers. Imbalanced fertilizer use especially in terms of P compared with N, may affect overall agricultural productivity (FAO, 2007).

2.5.3 Potassium

Potassium plays essential roles in enzyme activation, protein synthesis, photosynthesis, osmoregulation, stomatal movement, energy transfer, phloem transport, cation-anion balance and stress resistance (Marschner, 2011). Though K is not a component of plants chemical structure, its principal metabolic role is in osmotic regulation of cells and transport of photosynthates to storage organs (seeds, tubers, roots and fruits). Out of all the mineral nutrients, K is the most abundant cation in plants and it contributes greatly to the survival of plants that are under various biotic (pathogen and insects) and abiotic stresses (drought, salinity, cold and frost and waterlogging) (Wang *et al*., 2013).

2.5.3.1 Potassium availability to crops

Potassium is relatively immobile in the soil. Though more soluble than P, K moves through the soil via mass flow and diffusion (Schachtman *et al*., 1998). According to Zublena (1997), K removal by crops under good growing conditions is usually high; about three to four times that of P removal and equal to that of N. Though K is absorbed by plants in larger amounts, uptake of K by roots is however, reduced under conditions of poor moisture availability and low temperature. Draining soils of excess moisture helps warm up the soils and improves aeration thereby increasing K availability (Armstrong, 1998). Crop responses to K are frequent particularly on soils with low pH and CEC (Kang, 1983). Potassium retained on the cation exchange complex may be displaced by higher charged cations, particularly Ca and Mg, and subsequently lost to leaching (Sanginga and Woomer, 2009). Due to a low cation exchange capacity (CEC) on coarse sandy soils, there is a potentially high risk of K leaching losses, which have been estimated at between 20 and 50 kg ha^{-1} $year^{-1}$ (Askegaard *et al*., 2004). Even so, there is no evidence of health or environmental problems associated with K leaching, unlike with N and P fertilizers.

2.5.3.2 Contribution of K to maize and cowpea performance

Wendt *et al*. (1994) reported maize yield increase by 40 % over the standard N-P recommendation alone by providing appropriate micronutrients in addition to K on a location-specific basis. Besides increases in crop yields, K plays a significant role in the improvement of crop quality which is essential for profitable production. Accordingly, K deficiency can cause reduced yield potential and quality of crops (Armstrong, 1998). Potassium deficiency has been shown to limit legume growth and restrict N accumulation from BNF (Vanlauwe and Giller, 2006). However, Van Straaten (2011) reported that most soils of Africa are not K deficient. The inherent K concentrations in soils are sufficient for the yield levels of some arable crops. Fertilizer K is often used for K-demanding plants, and in areas where continuous cropping has lead to K deficiency (Van Straaten, 2011). Mallarino and Murrell (1998) reported significant grain yield response of maize and soybean with K fertilization compared with no K fertilization. Potassium is important in BNF by legumes as it influences the amount of N fixed which usually increase with yield level (Armstrong, 1998). Also, fertilizer K has been reported to decrease insect infestation and disease incidence in many host plants (Perrenoud, 1990).

2.5.3.3 Influence of cropping systems on K availability

The intensity of cropping systems in Ghana is presently not high enough to cause widespread K deficiency under the smallholder farming situation (NSFMAP, 1998). However, when K output exceeds input under continuous cropping, management of K fertilizer becomes vital for increased crop yields. Srinivasa *et al*. (1999) reported a significant decline in K release due to continuous cropping. In a soil fertility and land productivity study, Ranamukhaarachchi *et al*. (2005) observed that cropping systems had no significant effects on K content in soils of both highlands and medium highlands.

Recycling of crop residues or applications of high dose K fertilizer may provide a long-term sustainability to cropping systems (Singh *et al*., 2002).

2.5.3.4 Remedial measures to K deficiency

Soil K is often compensated for when decomposed crop remains retained in the field after harvest return K taken up from deeper soil layers. Similarly, the casual slash-and-burn method of land preparation releases K in the ash after burning which may be adequate for a limited cropping period. Nonetheless, soil K deficiency is often corrected with the use of K fertilizers in single formulations such as potash or in blends and compounds with other nutrients. Except for high K demanding plants as banana (Van Straaten, 2011) and cassava (Howeler, 1991), K fertilizer is seldom applied alone to maize and cowpea crops. Fertilizer K is often applied in combination with N and/or P. Potassium is generally under-applied due to the ability of many soils to supply adequate amounts of K (Goulding *et al*., 2008), and owning to the need to save costs (Johnston *et al*., 2001). Potassium does not work alone; rather, it functions with other essential nutrients to improve crop yield. Therefore, the importance of balanced nutrition and efficient use of all plant nutrients must be emphasized.

2.6 Fertilizer use efficiency (FUE)

Efficient fertilizer use can be defined as maximum returns per unit of fertilizer applied (Mortvedt *et al*., 2001). Bationo and Waswa (2011) stated that efficiency of fertilizer use by plants depends on mode of application, with hill placement being the most efficient method. According to Aulakh and Benbi (2008), management practices to enhance FUE include: best fertilizer source, adequate rate and diagnostic techniques, proper method and right time of fertilizer application, balanced fertilization, nutrient interrelationships, integrated nutrient management, time of seeding of crops and utilization of residual nutrients. Since higher fertilizer use efficiency is always associated with low fertilizer rate, cultural practices meant for promoting integrated nutrient management will help to affect saving in the amount of fertilizer applied to the crops and thus improve fertilizer use efficiency (Karim and Ramasamy, 2000). Nevertheless, obtaining maximum profitability lies not only in reducing the amount of fertilizer use per unit area but also in reducing costs per unit crop produce through higher yields. There is therefore the need for economic analysis of fertilizer use.

2.6.1 Economics of fertilizer use

While agronomic fertilizer research often focuses on maximizing response or redressing problems of nutrient depletion in soils, economics of fertilizer considerations is required for drawing conclusions and making fertilizer recommendation for farmers. Unfortunately, most of the fertilizer micro-dose trials-cum-demonstrations are devoid of agronomic economic evaluations after identifying a potential fertilizer dose for recommendation to smallholder farmers. Sanginga and Woomer (2009) noted that smallholder farmers seek to maximize returns per unit input because they are unable to purchase sufficient fertilizer and other inputs, at recommended levels designed to optimize crop production.

Apart from calculating the economically optimal nutrient application rates that are associated with maximum net returns (NR), it is also important to determine the rate of profitability of fertilizer use using value cost ratio (VCR). Application of a unit fertilizer is economical, if the value of the increase in the crop yield due to the quantity of fertilizer added is greater than the cost of fertilizer used. If a unit of fertilizer does not increase the yield enough to pay for its cost, its application will not be economical and will not return profit even after a constant increase in the yield (Singh, 2004). However, maximization of net gains from inputs investment is possible only with optimal investment, correct decisions and favourable weather (Roy *et al*., 2006). For economic analysis of fertilizer use, the two principal considerations are the production increase attributed to fertilizer and the relationships between the cost of fertilizers and the price of produce.

2.6.2 Net returns (NR) versus value cost ratio (VCR)

According to Saleem *et al*. (1986) and Bhatti (2006), NR refers to the value of the increased yield produced as a result of fertilizers applied, less the cost of fertilizer, while VCR is the ratio between the value of the additional crop yield obtained from fertilizer use and the cost of fertilizer used. While VCR is an indicator of rate of gross returns (gross returns/cost); NR is simply gross returns minus cost; where, gross returns consist of sum of items under income. Though VCR is the most commonly used approach to evaluate the financial incentives for a farmer to use a fertilizer treatment that has been identified using non-economic criteria, it has some shortcomings (Kelly, 2005). First, the VCR is a measure of average rather than marginal change in profitability because it does not examine incremental changes in returns as doses increase. Secondly, the costs included in a VCR are generally limited to the expenditure on fertilizer rather than the full range of costs (including labor) associated with fertilizer use. According to (FAO, 2005b), general rules have been established for interpreting VCR.

A VCR < 1 implies a negative return on investment while VCR = 1 is the same as the profit maximizing point which entails positive return on investment but not viable. A VCR < 2 can reliably identify fertilizer recommendations that are unlikely to be adopted by farmers whereas VCR ≥ 2 means a positive return on investment (economically viable). Though a VCR > 2 is the commonly accepted threshold required to encourage risk-averse farmers to invest in fertilizer technology, a VCR = 2 is considered as the minimum requirement for a farmer to adopt fertilizer recommendation. As such, a VCR of 2 represents 100 % return on the money invested on fertilizer. A VCR of 3 or 4 is necessary when production or price risk is high. For farmers with low technology, with no credit availability or limited capital, a fertilizer rate giving a VCR greater than 2 should be recommended. However, fertilizer use is generally profitable with VCR of 2.7 for maize (FAO, 2005b). With recommended N and P fertilizer rates, VCR of between 2.4 and 2.9 were obtained for maize from different soil types (Ho, 1992). Different factors affect the rate of profitability of fertilizer use. Bationo *et al*. (1998) showed that the VCR of directly applied Tahoua phosphate rock was higher than that of SSP. Also, the findings of Amanullah and Lal (2009) indicated that NR and VCR showed a positive relationship with increase in N rate.

Though VCR is commonly used by agricultural scientists to examine profitability of fertilizer use, the absolute net return should also be considered because, at low fertilizer application rates, the VCR may be very high owing to the small cost of the treatment and the associated high rate of response. However, at low application rates, the net return would also be small and unattractive to farmers (Roy *et al*., 2006). Smallholder farmers are profit-oriented and are therefore, interested in net returns than the gross returns. In practice however, not all farmers can aim for the largest net returns because of the generally larger costs involved to other risks associated with farming (Saleem *et al*., 1986). The basic requirement of profitable crop production is to produce an agronomic yield that can maximize net returns. Therefore, in order to maintain optimal economic returns, it is expected that the quantity of fertilizer applied would change with changes in the ratio of crop and fertilizer prices.

2.7 Summary

Continuous cropping of farmland without plant nutrients replenishment contributes to soil nutrient losses, secondary to decline in soil fertility and crop yields. Fertilizer use, particularly on maize and cowpea, is essential to increasing per capita food production and ameliorating soil nutrient deficiencies in the semi-deciduous forest zone of Ghana. Despite the recognized need to apply fertilizers for high yields, the use of mineral fertilizers by smallholder farmers is limited by high fertilizer cost, high fertilizer recommendation and other socioeconomic factors. As such, yields of maize and cowpea crops on smallholder farms are on steady decline. Fertilizer adoption by smallholder farmers could possibly be promoted with micro-dosing technology which involves the use of small amount of fertilizer. Several African smallholder farmers have achieved relatively high crop yields and income through fertilizer micro-dosing technology. Since micro-dosing has great potential to improve crop yields across a range of agro-ecological zones in West Africa, it is anticipated that similar success will be reproduced in the semi-deciduous zone of Ghana with the use of NPK fertilizers. Perhaps, its application in cereal-legume rotation may serve as a cheaper means of improving soil fertility and cereal yield productivity. With the inclusion of legume which is an important source of N for many small-holder farming, cowpea N input may substitute or increase the N fertilizer requirement of maize and hence, further reduce farmers' input cost. In order to determine the rate of profitability of fertilizer use and the likelihood of adoption, economic analysis using NR and VCR is therefore required in making the most profitable fertilizer dose recommendation for smallholder farmers.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area description

3.1.1 Location

The study was conducted at two locations (Figure 3.1) which are:

i) Assin-Kushea, located in the Assin North Municipal District of the Central region of Ghana. It lies within latitude 6 ° 05’ N and 6° 40 S, and longitude 1° 25 W and 1° 05’ E.

ii) Twedie, situated in the Atwima-Kwanwoma in the Ashanti region of Ghana. It lies within latitude 6° 39' N and longitude 1° 44' W.

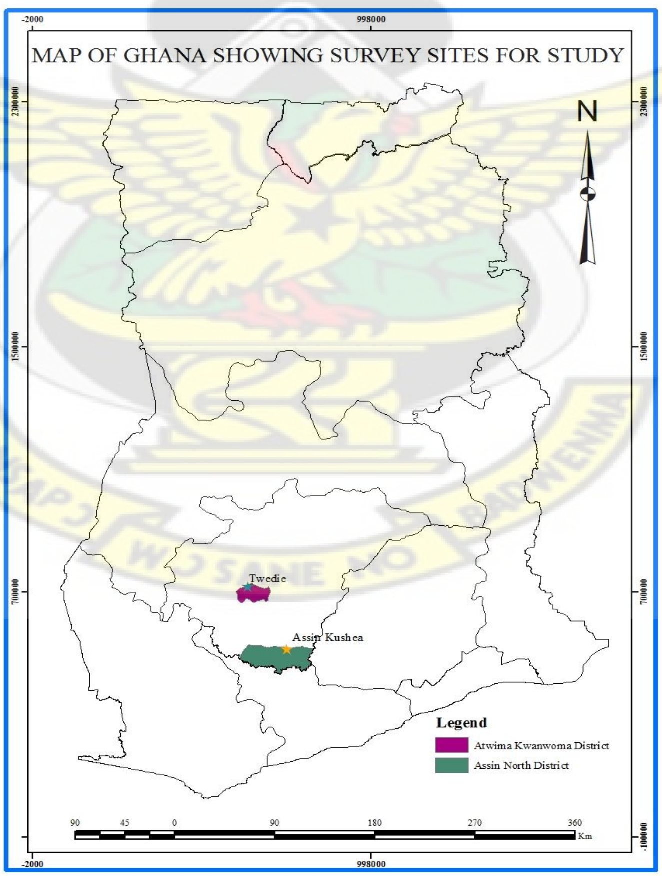

Figure 3.1: Map of Ghana showing Assin-Kushea and Twedie study locations

3.1.2 Climate

Assin-Kushea and Twedie locations fall within the Semi-deciduous forest zone of Ghana. The zone has a bimodal rainfall pattern. With a mean annual rainfall of 1500 mm, the major season spans March to July and the minor, September to November. There is a short dry spell in August. The mean monthly temperatures range from 24 to 28^0 C, while the relative humidity is about 90 % at 0600 hours, and between 60 to 70 % at 1500 hours. Annual potential evapotranspiration is about 1400 mm, and the annual actual evapotranspiration is about 1200 mm (Christensen and Awadzi, 2000). The soil moisture regime is udic whereas the soil temperature regime is isohyperthermic (Van Wambeke, 1982; Soil Survey Staff, 1998). During the study, 2011 rainfall data for Assin-Kushea and Twedie were obtained from the Ministry of Food and Agriculture (MoFA) office at Assin-Fosu and Council for Scientific and Industrial Research -Soil Research Institute (CSIR-SRI), Kwadaso, Kumasi, respectively.

3.1.3 Soil types

According to Fosu and Tetteh (2008), the major soil types of the Semi-deciduous forest are Ferric Acrisols, Ferric Lixisols and Haplic Lixisols, developed over two main parent materials - granite and phyllite. The soils are susceptible to erosion and have medium to high land productivity potential.

3.1.4 Soil profile pit description

Profile pits measuring 1 m x 2 m x 1.62 m and 1 m x 2 m x 1.3 m were dug beside the experimental field at Assin-Kushea and Twedie, respectively. Ten and seven different horizons at Assin-Kushea and Twedie, respectively, were identified, demarcated and described. From each horizon were taken, three core samples for bulk density determination and composite soil samples for the determination of exchangeable cations, effective cation exchange capacity (ECEC), organic carbon (OC) and particle size characterization. Base saturation and total porosity were calculated. Consequently, FAO world reference base system (IUSS, 2006) was used to classify the soil based on the primary data collected on the sites.

3.2 Field Experiments

3.2.1 Field experimental studies and fertilizer amendments used

The field study composed of three different experiments with three different sets of fertilizer amendments (Table 3.1). The field experimental studies were:

i. most limiting major nutrient study (2011 minor season)

ii. N and P fertilizer response study (2012 major season

iii. fertilizer micro-dose study (2012 minor and 2013 major season).

The fertilizers used for the studies were urea (46 % N), triple superphosphate (46 % P_2O_5) and muriate of potash (60 % K_2O). No fertilizer was applied to the control. The fertilizer amendments listed in Table 3.1 were applied to maize crops under the above listed three experimental activities. Blanket 20 kg P_2O_5 ha^{-1} (N_0P_{20}) was generally applied to cowpea plots (except the control) during the 2012 minor season under fertilizer micro-dose experiment.

Table 3.1: Field experiments, fertilizer amendments and application rates

Experimental activity	Fertilizer amendment	Rate of application
(1) Most limiting major nutrient	N_0P_0	Control
	$N_{120}P_0$	120 kg N ha^{-1}
	N_0P_{90}	90 kg P_2O_5 ha^{-1}
	$N_{120}P_{90}$	120 kg N ha^{-1} + 90 kg P_2O_5 ha^{-1}
(2) N and P fertilizer response	N_0P_0	Control
	$N_{30}P_0$	30 kg N ha^{-1}
	$N_{60}P_0$	60 kg N ha^{-1}
	$N_{90}P_0$	90 kg N ha^{-1}
	$N_{120}P_0$	120 kg N ha^{-1}
	N_0P_{30}	30 kg P_2O_5 ha^{-1}
	N_0P_{60}	60 kg P_2O_5 ha^{-1}
	N_0P_{90}	90 kg P_2O_5 ha^{-1}
	N_0P_{120}	120 kg P_2O_5 ha^{-1}
(3) Fertilizer micro-dose		
(a) Minor season	N_0P_0	Control
	N_0P_{20}	20 kg P_2O_5 ha^{-1}
	N_0P_{40}	40 kg P_2O_5 ha^{-1}
	$N_{20}P_{40}$	20 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}
	$N_{90}P_{60}$	90 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1}
(b) Major season	$N_0P_0K_0$	Control
	$N_0P_{20}K_{20}$	20 kg P_2O_5 ha^{-1} + 20 kg K_2O
	$N_0P_{40}K_{20}$	40 kg P_2O_5 ha^{-1} + 20 kg K_2O
	$N_{20}P_{40}K_{20}$	20 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} + 20 kg K_2O
	$N_{90}P_{60}K_{60}$	90 kg N ha^{-1} + 60 kg P_2O_5 ha^{-1} + 60 kg K_2O

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3.2.2 Crop cultivars used

Open pollinated varieties namely: early maturing (90 days) maize cultivar, Dorke SR, and dual purpose cowpea (high grain yield and biomass production), Nhyira which matures in 60 days after planting were used. Both crop seeds were obtained from Council for Scientific and Industrial Research - Crops Research Institute (CSIR-CRI) at Fumesua near Kumasi.

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3.2.3 Selected cropping systems

The two cropping systems selected for the fertilizer micro-dose study were continuous maize cropping (CMC) and cowpea/maize rotation (CMR). The seasonal cropping sequence for the duration of the study is shown in Table 3.2.

Table 3.2: Seasonal cropping sequence

Cropping system	2012 minor season	2013 major season
CMC	Maize	Maize
CMR	Cowpea	Maize

3.2.4 Land preparation and sowing

Land preparation commenced with clearing and removal of above ground biomass from the fields. Thereafter, the field was lined and pegged. For each of the test crops, three seeds were sown per hill and emerged seedlings thinned to two per stand, two weeks after planting (WAP). Plant spacing of 80 x 40 cm and 40 x 40 cm was used for sowing maize and cowpea seeds, respectively. Individual maize plots contained 100 stands with a plant population density of 62,500 stands ha^{-1}, while each cowpea plot contained 200 stands, and a population density of 125,000 stands ha^{-1}.

3.2.5 Experimental design and field layout

The first (most limiting major nutrient) and second (N and P fertilizer response) experiments were carried out in a randomized complete block design (RCBD) with 3 replications, while the third (fertilizer micro-dose) experiment was a split-plot in RCBD with three replications. In the fertilizer micro-dose experiment, the cropping systems constituted the main-plots and the fertilizer amendments were assigned to the sub-plots. Each experiment was carried out on the same site but on different field area. As such, each field was demarcated into 3 blocks (replicates) and spaced 2 m apart with 1 m alley between plots. With each plot measuring 4 x 4 m, the first, second and third experiments had 4, 9 and 10 plots per block, each corresponding to 19 x 4 m, 44 x 4 m and 49 x 4 m, respectively. The total land area measured 304 m^2, 532 m^2 and 592 m^2 for the first, second and third experiments, respectively. Figures 3.2, 3.3 and 3.4 show the field layout and the fertilizer treatment combinations of the three field experiments.

3.2.6 Crop husbandry practices

Basal dressing with one-third (1/3) of the urea fertilizer was applied one week after planting (WAP) while a second top-dressing with the remaining (2/3) was applied six WAP. Triple superphosphate (TSP) was applied one WAP, while muriate of potash (MOP) fertilizer was applied six WAP. For the first and second experiments, urea fertilizer was buried in between two successive plants whilst TSP was broadcasted. All the fertilizer treatments used for the third experiment were buried 2 cm close to the plant hills at 3 cm soil depth (within the root rhizosphere) except for the TSP and MOP for $N_{90}P_{60}K_{60}$ (recommended fertilizer rate) amendment that were broadcast. Atrazine was used for the control of weeds after planting, while manual weed control was subsequently carried out with hand hoe. Lambda-cyholothrin insecticide was sprayed first, at 30 days after planting and subsequently at two weeks intervals until wilting stage to control cowpea pests (aphids). Plants were harvested at physiological maturity.

3.2.7 Growth parameters measured

3.2.7.1 Maize plant height and girth

In the first experiment, eight plants from four hills of two plants per hill were selected at random excluding the border plants and maize height and girth measurements were taken at weekly intervals from 2 WAP until 8 WAP. These designated stands were also used to assess yield.

3.2.7.2 Maize stover and grain yields

In general, grain and stover yields were determined on net plot area basis in all the three experimental studies. With the exclusion of the border plants, maize stover was cut from the base of the plant after removing the cobs. Fresh weight of cobs and stover per plot were measured on the field while their five representative sub-samples (one large, three medium and one small) were selected, put in brown envelopes and transported to the laboratory. The sub-samples were oven dried at 60 °C for 72 h and the dry weights recorded. Shelling of the maize grains were done manually and the weights taken.

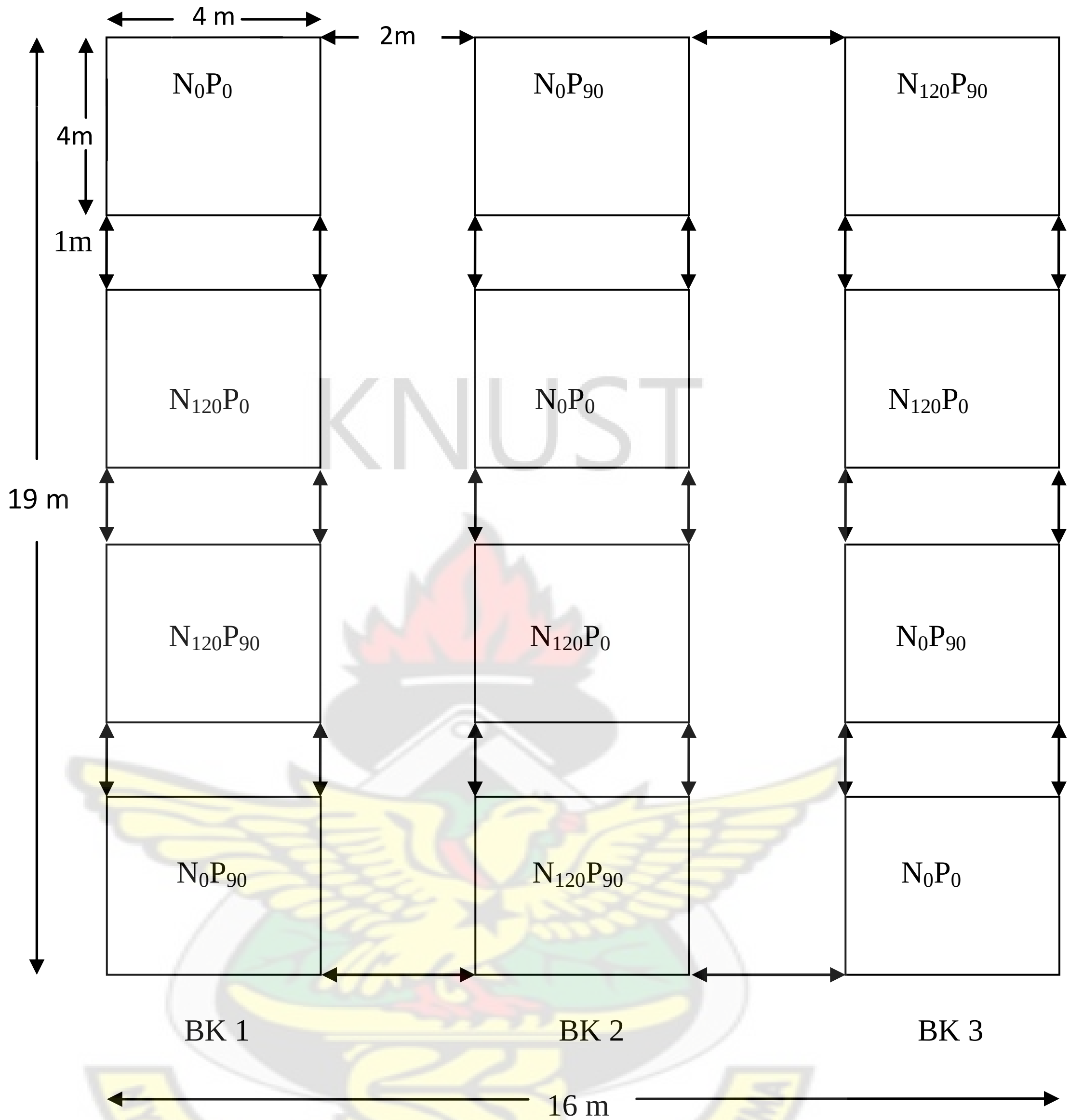

Figure 3.2: Field layout of 1st experiment

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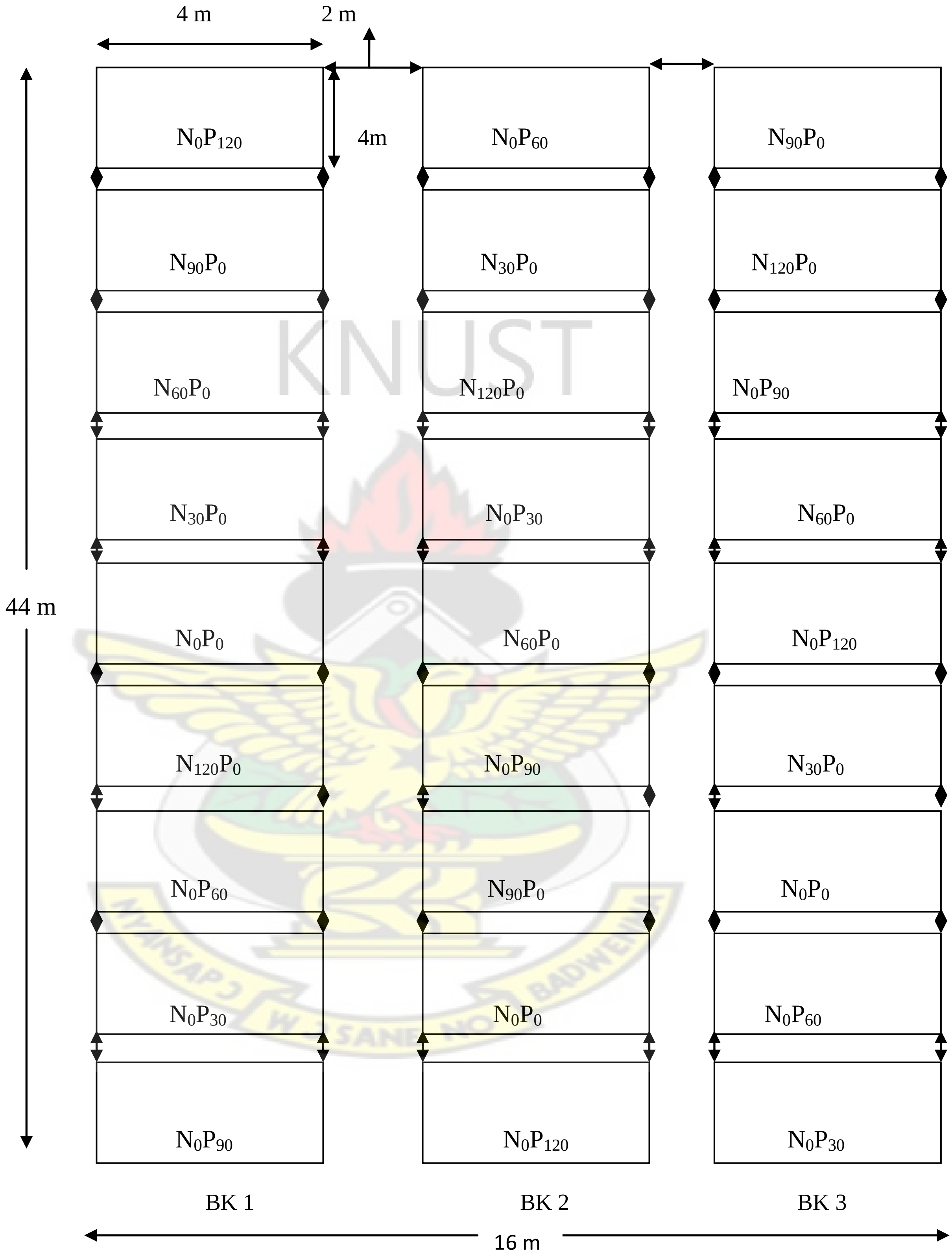

Figure 3.3: Field layout of 2nd experiment

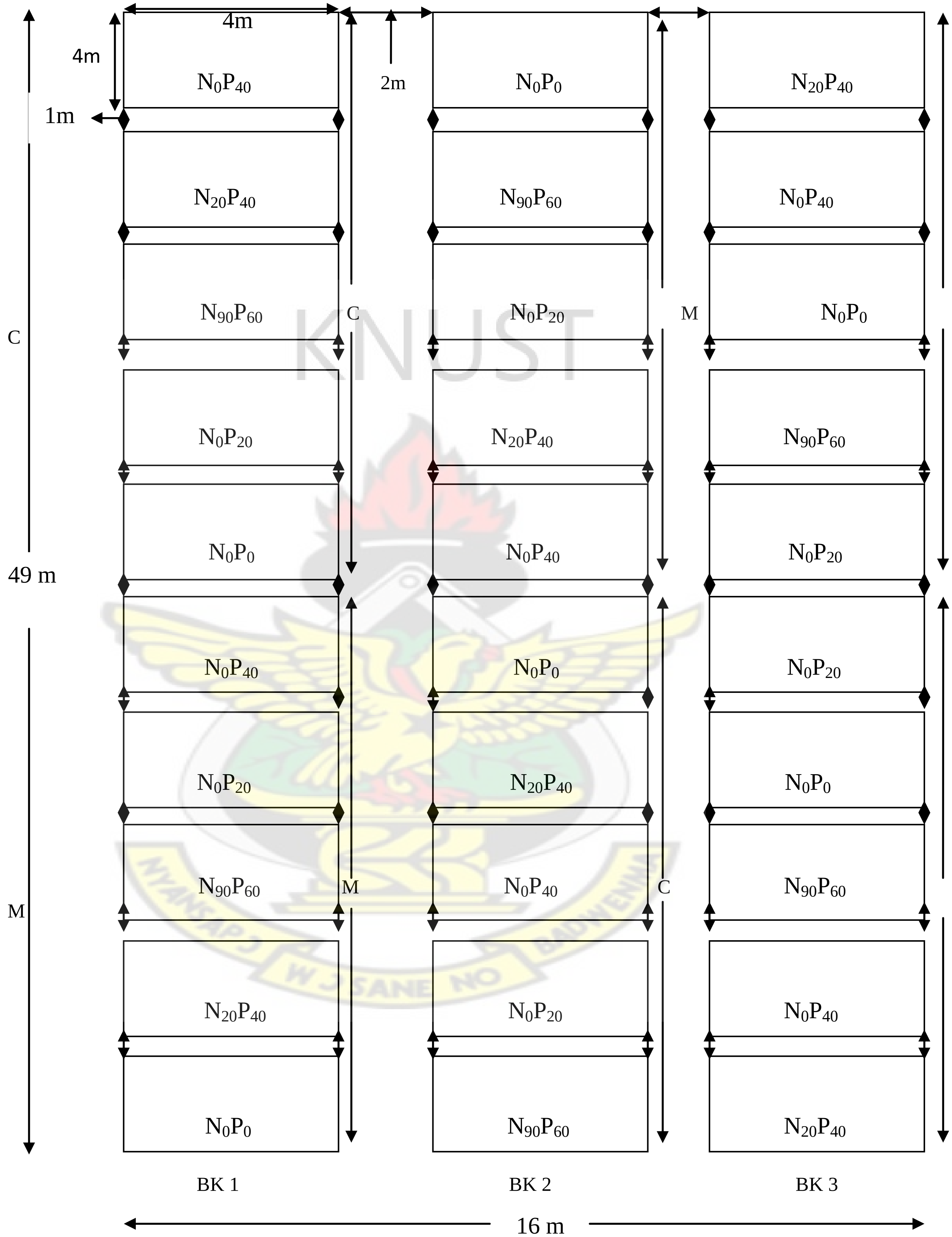

Figure 3.4: Field layout of 3rd experiment

The dry weights were then used to estimate the grain yield and stover yield per hectare in the following calculations:

$$\text{Grain yield (t ha}^{-1}\text{)} = \frac{\text{Total cob fresh wt (kg)} * \left(\dfrac{\text{grain subsample oven dry wt (g)}}{\text{cob subsample fresh wt (g)}}\right)}{\text{Harvest area (m}^2\text{)}} * 10$$

$$\text{Stover yield (t ha}^{-1}\text{)} = \frac{\text{Total stover fresh wt (kg)} * \left(\dfrac{\text{stover subsample oven dry wt (g)}}{\text{stover subsample fresh wt (g)}}\right)}{\text{Harvest area (m}^2\text{)}} * 10$$

where

wt = weight

3.2.7.3 Cowpea plant

3.2.7.3.1 Nodule count

Ten plants each were harvested from the two border rows on each side of a plot at 50 % flowering. The plants were cut at about 5 cm above the ground. The roots were carefully dug out, put in polythene bags, together with detached nodules collected from the soil. The roots were then put in a 1 mm mesh sieve and washed under running tap water to remove adhered soil particles. The nodules were gently removed and counted. Average number of nodules per plot was calculated.

3.2.7.3.2 Biomass yield

At 50 % flowering, ten plants were harvested from second to the border rows of each cowpea plot. The plants shoots were cut at the ground level, put in brown envelopes and oven dried for 72 h at 60 °C. The dry weights were determined and used to estimate the biomass yield per hectare.

Calculation:

$$\text{Biomass yield (t ha}^{-1}\text{)} = \frac{\text{Total weight of harvested biomass}}{\text{Harvested area (m}^2\text{)}} \times 10{,}000$$

3.2.7.3.3 Pod and grain yield

Dried cowpea pods were harvested from ten consecutive plants from the two middle rows of each plot. The pods were removed from the plants and the total weight of pods from the respective net plots was recorded before shelling. The pod weights were then extrapolated to total pod yield per hectare basis as stated above. The grains were oven dried at 60 °C for 72 h and the dry weights recorded. The dry weights were then used to estimate the grain yield per hectare.

To compare treatment effects in cowpea grain yield, percentage yield increase relative to the control was calculated:

Calculation:

$$\text{Percentage yield increase} = \frac{\text{Yield (treatment)-Yield (control)}}{\text{Yield (control)}} \times 100$$

3.2.8 Soil sampling

3.2.8.1 Initial soil sampling

To assess the nutrient status of the soils, initial soil samples for the first and second experiments were taken with soil auger at 0-20 cm soil depth from 5 spots (along the Z-plane) of each treatment plot. Additional core samples for bulk density determination were randomly taken from three points within each plot. Soil samples for the third experiment were randomly collected from each plot and bulked as a composite sample, representative of the experimental area. The soil samples were air-dried and sieved through a 2 mm sieve.

3.2.8.2 Final soil sampling

With the exclusion of the border plants, soil samples were randomly taken from five plant hills around the root rhizosphere within each plot, and bulked as a composite sample, representative of the plot. In all the three experiments, soil samples were collected immediately after crop harvest for determination of soil chemical properties. The samples were air-dried and passed through a 2 mm sieve.

3.3 Laboratory analytical methods

The physical and chemical properties of the soils were determined at the Soil Science Laboratory, Faculty of Agriculture, KNUST, Kumasi, Ghana.

3.3.1 Physical analysis

3.3.1.1 Particle size analysis

Particle size determination of < 2 mm soil was by the hydrometer method as described by Gee and Bauder (1986). A 50 g of air-dried soil was weighed into a plastic shaking bottle and 50 ml of 5 % sodium hexamethaphosphate (dispersing agent) added and allowed to stand for 20 minutes. The suspension was shaken in a Stuart reciprocal shaker (SSL2) for an hour and then transferred into 1 litre measuring cylinder. The suspension was made up to the marked volume with distilled water while a hydrometer was suspended in the cylinder. The cylinder with its content was agitated to allow the particles to be in suspension. The suspension was allowed to stand and the corrected hydrometer and temperature readings at 40 seconds and 3 hours taken. The percent sand, silt and clay were calculated as follows:

Calculation:

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

$$\% \text{ clay} = 100 \times (B/W)$$

$$\% \text{ silt} = 100 - (\% \text{ sand} + \% \text{ clay})$$

where

A= corrected hydrometer reading at 40 seconds

B = corrected hydrometer reading at 3 hours

W = weight of dry soil

The textural class was determined from the textural triangle.

3.3.1.2 Soil bulk density and total porosity

Using an electronic balance, the mass (M_o) of an empty cylindrical core sampler of inner radius 2.5 cm and of height 5.0 cm was determined. The core sampler was used to take moist soil sample at a depth of 0 - 15 cm from each plot. The mass of the moist soil (M_t) was derived by subtracting the mass of empty core sampler (M_o) from the mass of empty core sampler (M_o) + mass of moist soil (M_t). The dry mass (M_s) of soil sample was determined (after drying the moist soil sample to equilibrium in an oven at 105^o C) by subtracting mass of water (M_w) from Mt.

The volume (V_t) of soil sample taken was derived from the relation:

$$V_t = \pi r^2 h$$

where

$\pi = 22/7$

r = inner radius (cm) of the cylindrical core sampler

h = height (cm) of the cylindrical core sampler

Dry bulk density (*Pb*) was then determined from the equation:

$$Pb \text{ (g cm}^{-3}\text{)} = \frac{\text{mass of dry soil sample } (M_3)}{\text{volume of soil } (V_t)}$$

Total porosity was determined from the equation:

$$\text{Total porosity} = \frac{Pb}{2.65}$$

where

Pb = Dry bulk density (g cm^{-3})

2.65= soil particle density (g cm^{-3})

3.3.1.3 Soil moisture content

Soil moisture content was determined from the same core sample used for bulk density and total porosity. Both the wet and oven dry weights were measured and the soil moisture content was thus derived.

Calculation:

$$\text{Soil moisture content (\%)} = \frac{\text{wet weight (g)} - \text{oven dry weight(g)}}{\text{oven dry weight(g)}} \times 100$$

3.3.2 Chemical analysis

3.3.2.1 Soil pH

Soil pH was determined in a 1:2.5 suspension of soil to water ratio using a EUTECH pH 510 meter. A 10 g soil sample was weighed into glass beaker and 25 ml water added from a measuring cylinder. The suspension was stirred frequently for 30 minutes and allowed to settle for another 30 minutes. After calibrating the pH meter with buffer solutions of pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

3.3.2.2 Organic carbon (OC)

The modified Walkley-Black wet oxidation procedure as described by Nelson and Sommers (1982) was used to determine OC. Two grams of soil sample was weighed into a conical flask. A blank sample was included. Ten milliliters of 0.1667 *M* (1.0 N) potassium dichromate solution was added to the sample and the blank flasks. Concentrated sulphuric acid (20 ml) was carefully added to the soil from a measuring cylinder, swirled and allowed to stand for 30 minutes on an asbestos sheet. Distilled water (250 ml) and 10 ml concentrated orthophosphoric acid were added and allowed to cool. A diphenylamine indicator (1 ml) was then added and titrated with 1.0 *M* ferrous sulphate solution.

Calculation:

$$\% \text{ organic carbon} = \frac{\text{M x 0.39 x mcf } (\text{V}_1 - \text{V}_2)}{\text{w}}$$

where

M = molarity of ferrous sulphate solution

V_1 = ml ferrous sulphate solution required for blank titration

V_2 = ml ferrous sulphate solution required for sample titration

w = weight of air - dry sample in gram

mcf = moisture correcting factor (100 + % moisture) / 100)

0.39 = 3 × 0.001 × 100 % × 1.3 (3 = equivalent weight of carbon)

1.3 = compensation factor for incomplete oxidation of the organic matter)

The OC pool content was calculated using the equation of Lal *et al*. (1998).

Calculation:

$$\text{OC pool (Mg ha}^{-1}) = \frac{(\% \text{ OC x } Pb \text{ x d x } 10000)}{100}$$

Where

OC pool (Mg ha^{-1}) = mega gram organic carbon per hectare (1 Mg = 10^6g)

% OC = percentage of C given by laboratory results

Pb (Mg m^{-3}) = soil bulk density (Megagram per cubic meter) d (m) = depth in meters

10000 (m^2 ha^{-1}) = diameter of one hectare

3.3.2.3 Total nitrogen (N)

Total N was determined by the micro Kjeldahl digestion and distillation procedure as described by Soils Laboratory Staff (1984). A 10 g soil sample was weighed into a Kjeldahl digestion flask and 5 ml distilled water added. After 30 minutes, concentrated sulphuric acid (5 ml) and selenium mixture were added and mixed carefully. The sample was then digested for 3 hours until a clear digest was obtained. The digest was diluted with 50 ml distilled water, mixed well and allowed to cool. The digest was made to 100 ml with distilled water and mixed thoroughly. A 25 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of 40 % NaOH solution added followed by distillation. The distillate was collected in 2.0 % boric acid and was titrated with 0.02 *M* HCl using bromocresol green as indicator. A blank distillation and titration was also carried out to take care of the traces of N in the reagents as well as the water used.

Calculation:

$$\% \text{ N} = \frac{M \text{ x } (\text{a}-\text{b}) \text{ x } 1.4 \text{ x mcf x v}}{\text{w x t}}$$

where

M = mole of HCl used in titration

a = ml HCl used in sample titration

b = ml HCl used in blank titration

w = weight of air-dry soil sample

mcf = moisture correcting factor (100 % + % moisture) /100)

1.4 = 14 × 0.001 × 100 % (14 = atomic weight of N)

v = total volume of digest

t = volume of aliquot taken for distillation

3.3.2.4 Available phosphorus

The soil available phosphorus was extracted with Bray's No.1 solution (0.03 *M* NH_4F and 0.025 *M* HCl) as described by Olsen and Sommers (1982). Phosphorus in the sample extract was determined by the blue ammonium molybdate method using a spectrophotometer with ascorbic acid as the reducing agent. A 5 g soil sample was weighed into a 50 ml shaking bottle and 35 ml of Bray-1 solution added. The mixture was shaken for 10 minutes on a Stuart reciprocating shaker (SSL2) and filtered through No. 42 Whatman filter paper. An aliquot of 5 ml of the filterate was pipetted into 25 ml flask and 10 ml colouring reagent (ammonium molybdate) was added followed by a pinch of L-ascorbic acid. After mixing well, the mixture was covered and allowed to stand for 15 minutes to develop a blue colour. The percent absorbance was measured at 600 nm wavelength using Jenway 6051 colorimeter. The available phosphorus was extrapolated from a standard curve.

A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6.0 mg P/l was prepared by pipetting respectively 0, 10, 20, 30, 40 and 50 ml of 12.0 mg P/l in 100ml volumetric flask and made up to mark with distilled water.

Calculation:

$$P\ (\text{mg kg}^{-1}\ \text{soil}) = \frac{(a-b) \times 35 \times 15 \times \text{mcf}}{w}$$

where

a = mg l^{-1} P in sample extract

b = mg l^{-1} P in blank

mcf = moisture correcting factor

35 = volume of extracting solution

15 = final volume of sample solution

w = sample weight in gram

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3.3.2.5 Exchangeable cations

Exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) in the soil were determined in 1.0 *M* ammonium acetate extract (Black, 1986) whilst the exchangeable acidity (hydrogen and aluminium) was determined in 1.0 *M* KCl extract (Page *et al*., 1982).

3.3.2.6 Exchangeable bases extraction

A 10 g soil sample was weighed into plastic shaking bottle and 100 ml buffered 1.0 *M* ammonium acetate solution (pH 7) was added. The mixture was shaken for 90 minutes on a Stuart reciprocating shaker (SSL2) and filtered through No. 42 Whatman filter paper.

3.3.2.7 Determination of calcium and magnesium

A 10 ml aliquot of the filtrate was transferred into a 100 ml conical flask. To this were added 5 ml of ammonium chloride-ammonium hydroxide buffer solution, 1 ml of triethanolamine buffer, 1 ml of 2.0 % potassium cyanide solution and 0.2 ml Eriochrome

Black T solution. The mixture was titrated with 0.02 *M* EDTA (ethylene diamine tetraacetic acid) solution to a pure turquoise blue colour. The titre value was recorded. The titre value of calcium was subtracted from this value to obtain the titre value for magnesium.

3.3.2.8 Determination of calcium only

A 10 ml aliquot of the filterate was transferred into a 100 ml conical flask and 10 ml of 10 % potassium hydroxide, 1 ml triethanolamine, 1 ml of 2.0 % potassium cyanide solution and few drops of cal-red indicator were added and mixed thoroughly. The resultant red coloured mixture was titrated with 0.02 *M* EDTA solution to a pure blue colour. The titre value of calcium was recorded.

Calculation:

$$\text{Ca + Mg (or Ca) (cmol}_+\text{ kg}^{-1}\text{ soil)} = \frac{0.02 \text{ x } (\text{Va}-\text{Vb}) \text{ x } 1000}{\text{w}}$$

where

w = weight (g) of air-dry soil used

Va = ml of 0.02 *M* EDTA used in sample titration

Vb = ml of 0.02 *M* EDTA used in blank titration

0.02 = concentration of EDTA

1000 = conversion factor from g to $\text{cmol}_+ \text{ kg}^{-1}$

3.3.2.9 Determination of exchangeable potassium and sodium

Potassium (K^+) and sodium (Na^+) in the filtrate was determined by flame photometry. A standard series of potassium was prepared by diluting both 1000 mg l^{-1} K

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and Na solutions to 100 mg l^{-1}. In doing this, 25 ml portion of each solution was taken into 250 ml volumetric flask and made up to the volume with distilled water. Portions of 0, 5, 10, 15, 20 ml of the 100 mg l^{-1} standard solution were put into 200 ml volumetric flasks, respectively. A 100 ml of 1.0 *M* NH_4OAc solution was added to each flask and made up to the marked volume with distilled water. A standard series of 0, 2.5, 5.0, 7.5, 10.0 mg l^{-1} for K and Na were obtained. Potassium and Na were measured directly in the filtrate using Jenway PFP7 flame photometry at wavelengths of 766.5 and 589.0 nm, respectively.

Calculation**:**

$$\text{Exchangeable K (cmol}_{+}\text{ kg}^{-1}\text{ soil)} = \frac{(a-b) \times 250 \times mcf}{10 \times 39.1 \times w}$$

$$\text{Exchangeable Na (cmol}_{+}\text{ kg}^{-1}\text{ soil)} = \frac{(a-b) \times 250 \times mcf}{10 \times 23 \times w}$$

where

a = mg l^{-1} K in the diluted sample percolate

b = mg l^{-1} K in the diluted blank percolate

w = weight (g) of air-dry sample

mcf = moisture correcting factor

3.3.2.10 Determination of exchangeable acidity (Al^{3+} and H^{+})

These were determined by titration method as described by Page *et al*. (1982). Five grams of soil sample was weighed into a 200 ml plastic bottle and 100 ml of 1.0 *M* KCl solution added. The mixture was shaken on Stuart reciprocating shaker for 2 h and filtered. For Al^{3+} determination only, an aliquot of 50 ml of the filterate was measured into a 250 ml Erlenmeyer flask and 100 ml of distilled water, followed by 3 drops of phenolphthalein indicator solution were added. The mixture was titrated with 0.05 *N* NaOH to a permanent pink colour and the titre value was recorded. To the titrated mixture, 0.05 *N* HCl was used to bring the pink colour back to colourless mixture. Ten millilitres of NAF was then added while 0.05 *N* HCl was used to titrate the mixture to a colourless end point. The titre value of Al^{3+} was subtracted from this value to get the titre value for H^+.

Calculation:

$$\text{Exchangeable acidity (cmol/kg soil)} = \frac{(a-b) \times M \times 2 \times 100 \times \text{mcf}}{w}$$

where

a = ml NaOH used to titrate with sample

b = ml NaOH used to titrate with blank

M = molarity of NaOH solution

w = weight (g) of air-dry sample

2 = 100/50 (filterate/aliquot volume)

mcf = moisture correcting factor (100 + % moisture)/100

3.3.2.11 Effective cation exchange capacity (ECEC)

This was calculated by summation of exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and exchangeable acidity (Al^{3+} and H^+).

3.3.3 Plant biomass analysis

Maize and cowpea residues were retained on all fertilizer amended plots at harvest. The representative sub-samples taken after harvest were dried in the oven at 60^0 C for 72 h and milled to pass through a 1 mm sieve. Total nitrogen, phosphorus, potassium contents were determined as a proxy assessment of the NPK uptake by the maize stover and grain while only nitrogen content in cowpea biomass was determined and used to assess its contribution to the nutrient status of the soil.

3.3.3.1 Plant nitrogen

Total N was determined by the Kjeldahl method. Using a Kjeldahl flask, a 0.5 g milled sample was oxidized in a10 ml concentrated sulphuric acid and hydrogen peroxide with selenium mixture as catalyst. The oxidized mixture was digested for about 3 hours until a clear digest was obtained. The resulting clear digest was transferred into a 100 ml conical flask and made up to the mark with distilled water. A 5 ml aliquot of the sample and a blank were measured into the Kjeldahl distillation apparatus separately and 10 ml of 40 % NaOH solution was added followed by distillation. The evolved ammonia gas was trapped in a 25 ml of 2 % boric acid. The distillate was titrated with 0.1 *M* HCl solution with bromocresol green-methyl red as indicator.

Calculation:

$$\% \text{ N/DM} = \frac{(\text{a} - \text{b}) \text{ x } M \text{ x } 1.4}{\text{w}}$$

where

a = ml HCl used for sample titration

b = ml HCl used for blank titration

M = molarity of HCl

1.4 = 14 × 0.001 × 100 % (14 = atomic weight of N)

DM = dry matter

w = weight of sample

3.3.3.2 Ashing and determination of plant phosphorus and potassium

One gram each of milled maize grain or stover and cowpea biomass was weighed into a dry porcelain crucible and ashed for 4 hours at a temperature of 450^0 C in a muffle furnace. The crucible containing a grayish white ash was allowed to cool in a dessicator, after which the ash was dissolved in 5 ml of 8 M HCl solution and 2 ml distilled water. The solution was filtered into a 100 ml volumetric flask using No. 42 Whatman filter paper and made up to the mark with distilled water.

3.3.3.2.1 Plant phosphorus

A 5 ml aliquot of the filtrate was taken into a 25 ml volumetric flask. Five millilitres of ammonium vanadate solution and 2 ml stannous chloride solution were added. The volume was made up to 25 ml with distilled water and allowed to stand for 15 minutes for full colour development. A standard curve was developed concurrently with phosphorus concentrations ranging from 0, 5, 10, 15 to 20 mg P l^{-1} solution. The absorbance of the sample and standard solutions were read on Jenway 6051 colorimeter at a wavelength of 470 nm. The absorbance values of the standard solutions were plotted against their respective concentrations to obtain a standard curve from which phosphorus concentrations of the samples were calculated.

3.3.3.2.2 Plant potassium

Potassium in the filtrate was determined using Jenway PFP7 flame photometer. Standard solutions of potassium were prepared with concentrations of 0, 20, 40, 60, 80 and 100 mg l^{-1} of solution. The emission values which were read on the flame photometer were plotted against their respective concentrations to obtain a standard curve.

3.4 Yield assessment indices

3.4.1 Percentage grain yield increase over control

This is the ratio of net increase in grain yield due to fertilization relative to the total grain yield from unfertilized plot.

Calculation:

$$\text{Grain yield increase over control} = \frac{Yf - Yc}{Yc}$$

where

Yf = amount of grain yield from N or P or K fertilized plot

Yc = amount of grain yield from unfertilized plot

3.4.2 Harvest index

Harvest index is the ratio of the crop economic yield (grain yield) to the total crop yield at harvest (grain and biomass yields). Harvest index (HI) of both maize and cowpea crops were calculated by method of Bange *et al*. (1998).

Calculation:

$$HI = \frac{\text{Economic yield}}{\text{Total crop yield}}$$

where

Economic yield = grain yield

Total crop yield = grain and biomass yields.

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3.4.3 Agronomic efficiency

Agronomic efficiency (AE) is the ratio of net increase in grain yield due to fertilization relative to the total amount of fertilizer applied. The AE of applied fertilizer to both maize and cowpea crops were calculated as described by Vanlauwe *et al*. (2010).

Calculation:

$$AE = \frac{Yf - Yc}{f}$$

where

Yf = amount of grain yield from N or P or K fertilized plot

Yc = amount of grain yield from unfertilized plot

f = amount of N or P or K fertilizer nutrient applied

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3.4.4 Nutrient use efficiency

Nutrient use efficiency (NUE) is the total biomass or grain yield produced per unit of fertilizer applied. The NUE of both maize and cowpea crops were calculated thus:

$$NUE = \frac{\text{Total grain or biomass yield}}{\text{Fertilizer nutrient applied}}$$

3.4.5 Nitrogen, phosphorus and potassium uptake

The N, P and K uptake in maize grain and stover were calculated as follows:

$$\text{N or P or K uptake (kg ha}^{-1}\text{)} = \frac{(\%\ \text{N or P or K x yield})}{100}$$

where

Yield = grain or stover yield (kg ha^{-1})

% N or P or K = their content in either grain or stover as determined in sections 3.3.3.1, 3.3.3.2.1 and 3.4.3.2.2, respectively.

3.4.6 Apparent nitrogen, phosphorus and potassium recovery efficiency

Apparent recovery efficiency (RE) is the ratio of nutrient taken up due to fertilization relative to the nutrient applied. The RE of applied N, P and K fertilizer by maize plant was calculated according to Vanlauwe *et al*. (2001).

Calculation:

$$\text{Apparent N, P or K recovery efficiency} = \frac{(a - b)}{c} \times 100$$

where

a= total N or P or K uptake from treated plots (kg)

b = total N or P or K uptake from the control (kg)

c = total N or P or K applied (kg)

3.4.7 Economic analysis

3.4.7.1 Net return

Net return (NR) refers to the value of the increased yield produced as a result of fertilizers applied, less the cost of fertilizer. The net returns to fertilizer use in maize and cowpea cultivation were calculated as follows:

Calculation:

$$NR = x - z$$

where

x = value of crop produced from fertilized plots

z = cost of fertilizer

3.4.7.2 Value cost ratio

Value cost ratio (VCR) is the ratio between the value of the additional crop yield obtained from fertilizer use and the cost of fertilizer used. The gross rate of returns from fertilizer application to maize and cowpea crops, represented by the VCR, was calculated according to Roy *et al*. (2006).

Calculation:

$$VCR = \frac{x - y}{z}$$

where

x = value of crop produced from fertilized plots

y = value of crop produced from unfertilized plots

z = cost of fertilizer

3.5 Survey of farmers' fertilizer use and management practices in the semi-deciduous rainforest zone of Ghana

3.5.1 Survey methodology

Between December 2011 and January 2012, a preliminary survey of farmers' fertilizer use and management practices was carried out in the two study locations. One hundred smallholder farmers growing maize and/or cowpea were orally interviewed at each location. Accordingly, structured socio-economic questionnaire (Appendix 1) which addressed the farmer's demography, farm size, cropping systems, fertilizer use/management practices and farmers' awareness of fertilizer micro-dose technology was used to seek information on current fertilizer use and its management. In addition, personal field observations and interviews with extension officers as key informants were conducted using a check list. A draft questionnaire was pre-tested on 20 farmers in each study location. The outcome of the pre-testing helped in making adjustments to incorporate omitted, missing or additional relevant questions, and to rephrase questions that seemed vague to the respondents.

3.5.2 Questionnaire administration in the survey area

Community entry to the two communities involved meeting with the extension officers who informed the assemblyman and the 2011 best farmer Award winner of the Districts about the survey and solicited for their assistance in organizing the farmers' for administering the questionnaire. A random household sampling technique was adopted in each community. Enumerators were recruited and trained to help the author in the questionnaire administration.

3.5.3 Survey data Collection

Qualitative and quantitative data were collected from both primary and secondary sources. Primary data collected through oral interviews with structured socio-economic questionnaire was the main source of information. Secondary data included valuable inputs from research works, books and journal articles which were used in the preparation of the questionnaire for the study.

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3.5.4 Limitations of the survey

Due to lack of record keeping, the interviewed farmers had difficulties in recalling how much fertilizer was applied per cropping season. More so, the exact crop yields obtained by the farmers were difficult to estimate because part of the harvested crop produce was consumed by the farmers. Owning to the predominant mixed cropping practice in the study communities, it was not easy to calculate the exact farm size for maize and cowpea crops. The enumerators interpreted the questions in the local languages for better understanding by the respondents. The author had to make periodic checks on the enumerators to ensure that they followed proper interview procedure.

3.6 Statistical analysis

The data obtained from the fertilizer survey was analysed using Statistical Package for Social Sciences (SPSS 16.0, 2007). The field experimental data was analyzed with GenStat 9th edition (2007), using general linear model (GLM) analysis of variance (ANOVA) or mixed model as appropriate. The various levels of significance (5 %) and the standard errors of difference of means were determined. Orthogonal comparison contrasts were used for specific treatment defined comparisons. The choice of mixed model allows for incorporation of additional random factors (soil type and block) in the model and the need to determine the sources of variation. Cropping system was included in the fixed model for experiment 3 (fertilizer micro-dose) so that differences between cropping systems could be tested. Correlation and regression analyses were performed to determine the degree of relationship between and among variables.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Soil description and classification

4.1.1 Results

Table 4.1 shows some key physical properties of the soils at the two locations. In general, the two soils differ in particle size distribution; hence the soil of Assin-Kushea was loamy sand while Twedie soil was loam. Soil bulk density was relatively higher at Assin-Kushea than at Twedie. The physico-chemical properties of the individual soil horizons (Appendix 2) showed that all the chemical indices of soil fertility status were generally low in both soils. Assin-Kushea recorded increased organic carbon stock in the sub-soil than the top soil horizons. The soil profile pit description (Appendices 3 and 4) revealed that the soil at Twedie is Plinthic Acrisol developed from in-situ weathered phyllite at upper slope (3 to 5 %). The soil is deep, well drained silt loam over silty clay loam with common to many (10 to 20 %) quartz gravels in the sub-soil. The soil at Assin-

Table 4.1: Selected soil physical properties of the study sites before the field study

Soil Properties	Assin-Kushea	Twedie
% sand	79	47
% silt	16	34
% clay	5	19
Textural class	Loamy sand	Loam
Bulk density (g cm^{-3})	1.48	1.38
Porosity (%)	44	48
Soil moisture content (%)	21	24
Soil type	Gleyic Plinthic Acrisol	Plinthic Acrisol

Kushea is Gleyic Plinthic Acrisol developed in colluvium moved from granites. The soil at middle to lower slope (< 1 %), is deep, imperfectly drained, non-gravelly, and non-concretionary sandy loam over sandy clay loam.

4.1.2 Discussion

The classification of the soil at Assin-Kushea as Gleyic Plinthic Acrisol explains its hydromorphic properties which distinguish it from the Plinthic Acrisol of Twedie. Plinthic Acrisols are those Acrisols having plinthite within 125 cm of the surface (FAO, 2001). Notably, the soils represent one of the two major benchmark soils (Acrisols and Lixisols) in the semi-deciduous forest zone, developed over two main parent materials - granite and phyllite (Fosu and Tetteh, 2008). Chemical characteristics common to both soil types include high Fe and Al contents, low OC and poor CEC, which thereby contribute to the poor natural soil fertility (FAO, 2001). The differences in the OC pool between the topsoil and subsoil horizons may be related to the clay content of the soils relative to silt and sand particles. The low OC pool of the topsoil in both soil types may have resulted from the low rate of biomass production, C input and mineralization (Lal *et al.*, 2007), and increased rate of C loss through erosion (Tans *et al.*, 1990). Though the soils are susceptible to erosion (Fosu and Tetteh, 2008); the hilly topography (3 to 5 % slopes) at Twedie may have contributed to more nutrient losses via runoff (sheet erosion) than the lower slope (< 1 %) at Assin-Kushea. Conversely, with the sandy nature (texture) and higher bulk density of the soil at Assin-Kushea, nutrient leaching losses may have been higher compared to that at Twedie which was structurally less dense and, hence, more porous. This implies greater root penetration and more favourable soil aeration and drainage at Twedie. In addition, the higher proportion of clay content (which has implication on nutrient adsorption and release soil) at Twedie compared to Assin-Kushea explains its higher soil moisture content. Lack of oxygen and insufficient moisture availability has been indicated to hinder the efficiency of applied N and plant P uptake (Sanginga and Woomer, 2009; Christianson and Vlek, 1991). Considering the differences between the soils chemical characteristics using Landon (1991) ratings, the findings suggest that Twedie is more favourable than Assin-Kushea in terms of desirable soil characteristics for maize growth. The generally lower fertility status of the soil at Assin-Kushea compared to Twedie could be attributed to the coarser soil at the former with its associated high leaching potential.

Adequate levels of NPK are known to increase crop yield, but compared with P and N, responses to K are often weak in Sub-Saharan Africa (Piéri, 1986). The same cannot be said for N and P as large proportion of N and P taken up by crop plants is removed in the harvested grain (Ritchie *et al*., 1993), hence their rapid depletion from the soil with grain crop farming. More importantly, N and P utilization efficiency of maize has been shown to vary under different climatic, soil and management conditions (Sawadogo-Kaboré *et al*., 2008; Twomlow *et al*., 2010). The discussion of fertilization in maize production therefore ought to be dominated by the crop's requirement of N and P under different soil types and rainfall situations. A good starting point would be to ascertain how the sole and combined application of N- and P-based fertilizers would affect the performance of maize grown in typically degraded Acrisols of poor natural soil fertility (FAO, 2001).

4.2 The most limiting soil nutrient (between N and P) to maize growth and yield

4.2.1 Monthly rainfall received at Assin-Kushea and Twedie in 2011

4.2.1.1 Results

The monthly rainfall received at Assin-Kushea and Twedie during the study period is shown in Figure 4.1. At Assin-Kushea, a total of 359.8 mm of rainfall was received during the first half of the season (September and October), out of which the maize plants received 159.4 mm in the first 4 WAP. In the later part of the season (November), 71.4 mm of rainfall was received after which there was no rain in December. A total of 664.4 mm of rainfall was received at Twedie during the first half of the season (September and October), out of which the maize plants received 330.1 mm in the first 4 WAP. There were three dry weeks of no rain. Thereafter a total of 43.9 mm of rainfall was received in the later part of the season (November and December) lasting about eight weeks.

4.2.1.2 Discussion

Maize performance was better in Gleyic Plinthic Acrisol compared to Plinthic Acrisol, despite the less favourable soil physico-chemical conditions of the former compared to the latter. This suggests that more favourable microclimate for maize growth prevailed at Assin-Kushea, as exemplified by the amount of rainfall received which sustained maize growth till maturity on the Gleyic Plinthic Acrisol but not on the Plinthic Acrisol. As such, large portion of nutrients (both soil reserve and applied fertilizer) taken up by the plants was not partitioned into economic yield (grain). Also the inadequate

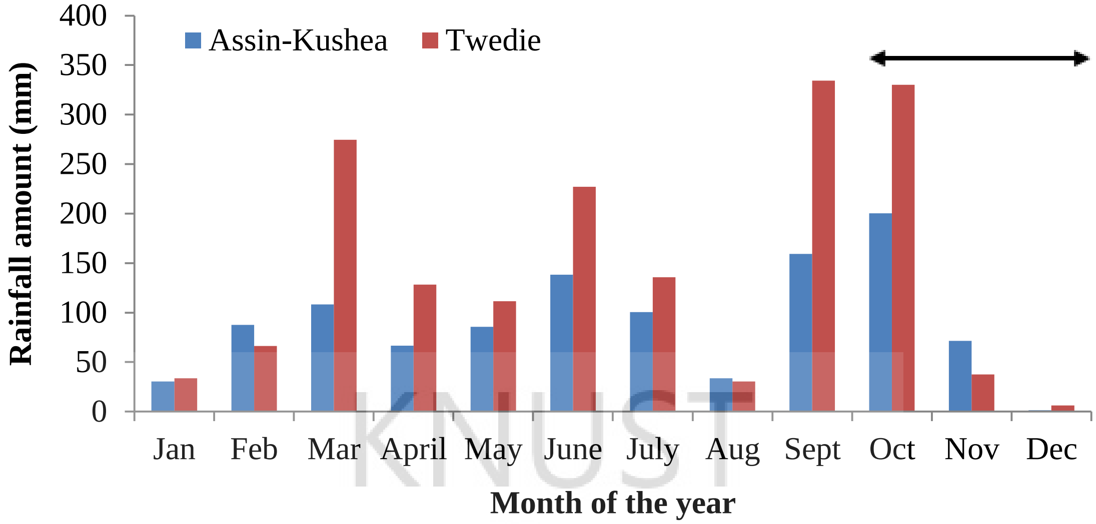

Figure 4.1: Monthly rainfall (mm) received during 2011 minor cropping season (Sept. to Dec.) at Assin-Kushea and Twedie

The arrow bar indicates the duration of maize crop in the field from seeds sowing to harvest.

rainfall at Twedie from 4 WAP might have impeded the release of plant nutrients (especially from the N-fertilizer applied at 6 WAP) and their subsequent uptake and translocation, thereby interfering with normal growth of maize (Rimski-Korsakov *et al.*, 2009). Insufficient moisture availability has been indicated to hinder the efficiency of applied N and plant P uptake (Sanginga and Woomer, 2009; Christianson and Vlek, 1991). Hence, it is possible to infer that the two soil types under study had unequal production potential due to unreliable low and short rainfall. On the other hand, Michael (1981) noted that with adequate nutrient supply, plants that are limited in growth due to moisture stress would have a higher mineral nutrient concentration than plants under comparable fertility but not limited in growth by moisture supply. This implies better soil fertility for the succeeding crop(s) except if the stover is removed for silage or animal feed. Therefore, following the 90 days growing period that defines the minor cropping season of the semi-deciduous agro-ecological zone of Ghana (MOFA, 2011), early planting at Twedie would have averted the risk of crop failure resulting from drought.

4.2.2 Soil chemical characterization of treatment plots before fertilizer application and after maize harvest

4.2.2.1 Results

The initial soil chemical properties of the various treatment plots before amendment as shown in Table 4.2 indicated that all the soil chemical properties evaluated generally showed statistically similar values among the treatment plots in both soil types. The OC contents were generally lower in the Gleyic Plinthic Acrisol than in the Plinthic Acrisol. Considering such other indices of soil fertility as total N, available P, exchangeable bases and acidity, ECEC and BS, Gleyic Plinthic Acrisol was inherently less fertile than that of Plinthic Acrisol.

The soil chemical properties at the end of the field study (Table 4.3) indicated that fertilizer treatment had no significant effect on soil pH, OC and total N levels in both soil types. Conversely, available P was significantly higher in N_0P_{90} plots than the other treatment plots except in the $N_{120}P_{90}$ treated plot of the Gleyic Plinthic Acrisol.

4.2.2.2 Discussion

In both soil types, fertilizer treatment affected the soil chemical properties in a definite pattern. The results for OC content in particular, point to the ineffectiveness of inorganic fertilizers for enhancing OC status in tropical soils with low OC concentrations

Table 4.2: Selected soil chemical properties of treatment plots before application of the treatments

Soil type	Treatment Plot	Soil pH (H_2O) 1:2.5	OC (%)	Total N (%)	Avail. P (mg kg^{-1})	Exch Ca^{2+}	Exch Mg^{2+}	Exch Na^{+}	Exch K^{+}	Exch Al^{3+}	Exch H^{+}	ECEC	BS (%)
						(cmol$_+$ kg^{-1})							
GPA	N_0P_0	5.82	0.84	0.12	2.77	2.10	1.03	0.14	0.09	0.80	3.53	7.70	43.66
	$N_{120}P_0$	5.94	0.73	0.11	2.78	2.30	0.48	0.15	0.11	0.60	3.87	7.51	40.50
	N_0P_{90}	5.96	0.93	0.10	2.68	2.17	1.03	0.15	0.11	0.67	3.73	7.87	43.53
	$N_{120}P_{90}$	5.89	0.94	0.10	2.75	2.33	0.97	0.15	0.10	0.73	3.80	8.08	43.75
	Mean	5.90	0.86	0.11	2.75	2.23	0.88	0.15	0.10	0.70	3.73	7.79	42.86
PA	N_0P_0	6.26	1.50	0.24	5.90	9.80	3.73	0.19	0.22	0.53	3.93	18.41	73.44
	$N_{120}P_0$	6.09	1.47	0.18	2.96	6.13	4.13	0.19	0.17	0.67	3.67	14.96	70.85
	N_0P_{90}	5.95	1.36	0.19	2.90	5.57	4.50	0.18	0.15	0.60	3.87	14.87	69.19
	$N_{120}P_{90}$	5.81	1.40	0.16	2.86	4.40	4.13	0.20	0.14	0.67	3.80	13.34	65.81
	Mean	6.03	1.43	0.20	3.66	6.48	4.13	0.19	0.17	0.62	3.82	15.39	69.82
	P values	0.33	0.84	0.16	0.37	0.27	0.87	0.90	0.53	0.73	0.98	0.29	0.71
	SED	0.11	0.09	0.02	1..01	1.32	0.58	0.02	0.02	0.03	0.09	1.25	2.39

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol; SED = standard error of differences of mean

Table 4.3: Selected soil chemical properties as affected by treatment after maize harvest

Soil type	Treatment	Soil pH (H_2O) 1:2.5	OC (%)	Total N (%)	Avail. P (mg kg^{-1})
GPA	N_0P_0	6.05	1.28	0.10	1.30
	$N_{120}P_0$	6.07	1.00	0.10	1.11
	N_0P_{90}	5.95	1.28	0.10	2.01
	$N_{120}P_{90}$	5.98	1.22	0.10	1.57
PA	N_0P_0	6.38	2.13	0.23	1.52
	$N_{120}P_0$	5.79	2.11	0.21	1.31
	N_0P_{90}	6.56	2.14	0.23	1.91
	$N_{120}P_{90}$	6.14	2.11	0.19	1.80
	P values	0.20	0.29	0.56	< 0.001***
	SED	0.16	0.09	0.02	0.15

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol

(Obi and Ofoduru, 1997) and over short cropping periods. The generally low OC content and hence low fertility status of the Gleyic Plinthic Acrisol compared to the Plinthic Acrisol could be attributed to the coarser soil of the former and the associated high leaching potential. Considering the overall lower fertility status of the Gleyic Plinthic Acrisol compared to the Plinthic Acrisol, the better response of maize to applied fertilizers on the former compared to the latter would be understandable. The significant differences in soil available P after maize harvest among the treatment plots was probably due to a greater uptake of available P by maize grown in N_0P_{90} and $N_{120}P_{90}$ plots particularly, with the fairly low fertility status of the Gleyic Plinthic Acrisol. This would explain the taller plants in such plots in this soil type (Figure 4.2a), as also evident in

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Table 4.4. It is common knowledge that P promotes cell division in plants which normally translates into enhanced plant growth.

4.2.3 Effect of treatments on maize plant height at 2 to 8 weeks after planting (WAP)

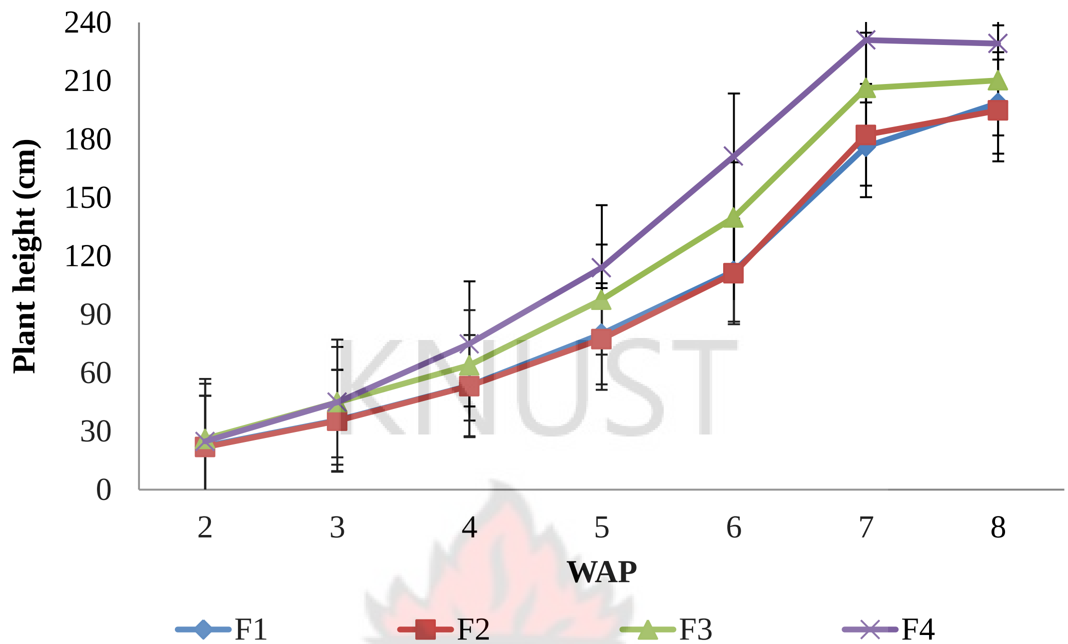
4.2.3.1 Results

The maize plant heights at three different growth stages: early growth (2 to 4 WAP), rapid growth (4 to 7 WAP) and reproductive growth stage (above 7 WAP) are represented in Figure 4.2. Notably, the maize plant height from 2 to 8 WAP showed a wider range in the Gleyic Plinthic Acrisol (23.8 to 208.2 cm) than in the Plinthic Acrisol (21.0 to 147.2 cm), and this was mostly evident during the rapid growth stage when the range was as wide as 49.9 to 160.6 cm in the Gleyic Plinthic Acrisol but as narrow as 44.5 to 111.3 cm in the Plinthic Acrisol. In Gleyic Plinthic Acrisol, plant height differed ($P < 0.05$) consistently from 3 to 7 WAP, in the order of $N_{120}P_{90} > N_0P_{90} > N_{120}P_0$ and control; whereby results under $N_{120}P_0$ and control did not differ significantly from each other. In the Plinthic Acrisol, the fertilizer treatments had no significant effect on plant height, though tallest and shortest plants were consistently observed in plots amended with N_0P_{90} and $N_{120}P_0$, respectively during 3 to 8 WAP.

4.2.3.2 Discussion

Remarkably, the plants on the control plots in the Plinthic Acrisol were comparably taller than the plants under $N_{120}P_0$ treatment plot. This observation notwithstanding, the widely known positive effect of N on vegetative growth of plants,

(a) Gleyic Plinthic Acrisol



(b) Plinthic Acrisol

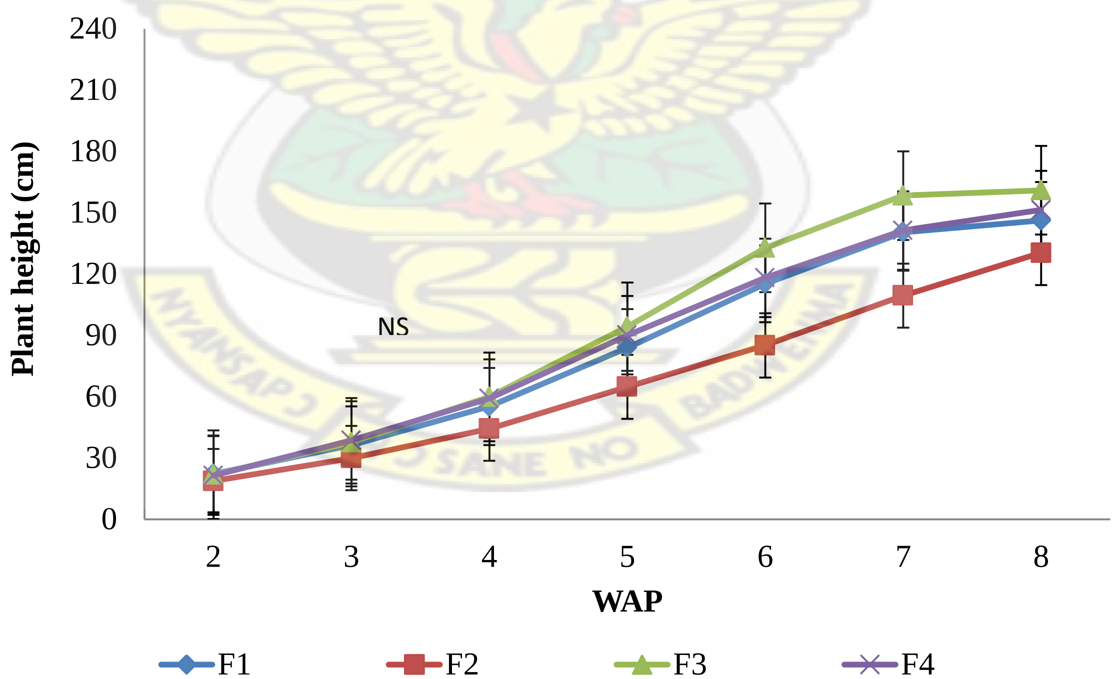


Figure 4.2: Maize plant heights at 2 to 8 weeks after planting (WAP)

F1, F2, F3 and F4 = N_0P_{90}, $N_{120}P_0$, N_0P_{90} and $N_{120}P_{90}$, respectively.

differences in plant height were not significant. Notably, $N_{120}P_{90}$ and N_0P_{90} treatments proved to be more effective in enhancing maize growth than $N_{120}P_0$ and N_0P_0, particularly in the Gleyic Plinthic Acrisol. Evidence that P tends to be more limiting to plant growth than N has been reported (Traore, 1974). However, the consistently taller plants under $N_{120}P_{90}$ than N_0P_{90} and the similarity in effects of $N_{120}P_0$ and N_0P_0 (control) in the Gleyic Plinthic Acrisol suggest that P has a synergistic effect on the role of N in vegetative growth of maize in low-fertility soils. De Magalhaes *et al.* (2000) and Delve *et al*. (2009) showed that deficiency of soil P could reduce the efficiency of N use by crops.

4.2.4 Effect of fertilizer treatments on maize yields and some yield assessment indices

4.2.4.1 Results

Maize plants grew to maturity on the Gleyic Plinthic Acrisol but not on the Plinthic Acrisol due to insufficient rains during the second half of the growing season. It was therefore possible to assess fertilizer treatment effect on grain yield of maize only in the Gleyic Plinthic Acrisol for which data is shown (Table 4.4). Differences in grain yield due to treatments in this soil were not significant. However, relative to the control, maize grain yield increased by about 10, 77 and 95 % in plots fertilized with $N_{120}P_0$, N_0P_{90}, and $N_{120}P_{90}$, respectively.

Economic evaluation of the fertilizer input to maize as based on value-cost ratio (VCR) indicated negative return on investment with $N_{120}P_0$, but economically viable positive returns was obtained with N_0P_{90} and $N_{120}P_{90}$ (Table 4.4). Although maize grain yield was slightly higher under $N_{120}P_{90}$ than N_0P_{90} treatment, the VCR of applied

Table 4.4: Effect of treatments on maize stover and grain yields, value-cost ratio (VCR) of fertilizer input and some yield assessment indices of maize

Soil type	Treatment	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	% grain increase over control	VCR	Harvest index	NUE (%)	AE (%)
GPA	N_0P_0	2.44	1.24	-	-	0.41	-	-
	$N_{120}P_0$	2.78	1.31	10.28	0.93	0.38	10.95	0.63
	N_0P_{90}	2.98	2.03	76.50	6.73	0.49	51.33	20.03
	$N_{120}P_{90}$	4.90	2.45	95.01	5.85	0.41	15.31	7.55
PA	N_0P_0	2.54						
	$N_{120}P_0$	2.34						
	N_0P_{90}	2.66						
	$N_{120}P_{90}$	3.19						
	P values	< 0 .01**	0.26	-	-	0.75	0.08	0.51
	SED	0.43	0.62	-	-	0.11	13.76	15.48

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol

fertilizer showed that application of N_0P_{90} was more economically viable than $N_{120}P_{90}$. In all the agronomic yield indices evaluated in this study, N_0P_{90} was superior to the other treatments. The lowest and highest values for agronomic efficiency, nutrient use efficiency (NUE) and harvest indices (HI) were obtained from plots treated with $N_{120}P_0$ and N_0P_{90}, respectively. Remarkably, the control and the $N_{120}P_{90}$ treatment showed same values of HI.

The maize stover yield under the different fertilizer treatments in both soil types is also shown in Table 4.4. Stover yield was significantly higher ($P < 0.01$) in plots fertilized with $N_{120}P_{90}$ compared to the other treatment plots in both soil types; however, stover yield due to $N_{120}P_{90}$ treatment was significantly higher in the Gleyic Plinthic Acrisol than that obtained in the Plinthic Acrisol. Except for the control, stover yield showed same decreasing order under the treatments ($N_{120}P_{90}$ > N_0P_{90} > $N_{120}P_0$) in both soil types, with generally higher values in the Gleyic Plinthic Acrisol than in the Plinthic Acrisol. The variance component analysis (Table 4.5) indicated that soil types contributed 18 % of the total variation in stover yield while blocking accounted for only 1 %.

Table 4.5: Variance component analysis of maize stover yield in both soil types

Random term	Component	Standard error	% variance
Soil type	0.13	0.25	18.09
Block within soil type	0.01	0.12	0.76
Residual	0.56	0.21	81.15

4.2.4.2 Discussion

The difference in maize grain yield (Gleyic Plinthic Acrisol) between N_0P_{90} and $N_{120}P_{90}$ treatments were not significant. From a similar study with maize in southern Nigeria, Onasanya *et al.* (2009) also reported no differences in grain yield under sole application of 60 kg P (SSP) and its combination with 60 or 120 kg N (urea). This shows that inappropriate fertilizer combination may successfully lead to good vegetative growth without necessarily translating to optimum crop grain yield. Nonetheless, the 77 and 95 % increase in maize grain yield over the control with the application of N_0P_{90} and $N_{120}P_{90}$ treatments, respectively, is substantially comparable to that of $N_{120}P_0$ treatment.

Therefore, recommending the addition of N_0P_{90} and $N_{120}P_{90}$ means an increase in farmers' income and an addition to the national maize production. For instance, the price of maize was \$320 MT^{-1} in 2011 (USAID-EAT, 2012); assuming a farmer obtained 1 MT ha^{-1} maize grain without fertilizer addition, applying N_0P_{90} and $N_{120}P_{90}$ will translate to monetary increase of \$246 and \$304 MT ha^{-1}, respectively, over no fertilizer application. This implies more food for the populace, reduction or no importation of maize grain into the country, and even diversification of maize use (bio-diesel). Above all, application of N_0P_{90} gave higher HI, AE and proved to be economically more viable than application of $N_{120}P_{90}$. In fact, the over 50 % NUE of N_0P_{90} treatment indicates that P rather than N is more critical for maize production in the Gleyic Plinthic Acrisol.

Evidence of the relevance of combined fertilizer application of $N_{120}P_{90}$ treatment can be seen in the maize stover yield obtained in both soils. The involvement of N in achieving biomass increase in plants is well known; but N in combination with P fertilizer had a synergistic benefit effect on stover yield. Hence, $N_{120}P_{90}$ was more favourable in increasing stover yields than using $N_{120}P_0$ or N_0P_{90} alone. Considering the contribution of soil type and block to the overall variation in treatment response, the block to block effect may not be different but the contribution of soil type (18 %) is substantial. As such, the differences in stover yield due to $N_{120}P_{90}$ treatment as obtained in both soil types could be attributed to leaching losses of nutrients due to the hilly topography of the Plinthic Acrisol site.

4.2.5 Maize grain and stover N, P and K uptake

4.2.5.1 Results

The uptake of nutrients (N, P and K) in Table 4.6 shows that both maize grain and stover N uptake was consistently highest in $N_{120}P_{90}$ compared to the other treatments. The concentration of P in maize grain in the Gleyic Plinthic Acrisol was significantly higher ($P < 0.05$) in $N_{120}P_{90}$ and N_0P_{90} than in $N_{120}P_0$ and the control plots. In addition, the concentration of K in maize grain was significantly higher in $N_{120}P_{90}$ than the other treatments except N_0P_{90}. The combined application of N and P gave greater apparent N recovery and hence, higher crop N recovery efficiency compared to sole application of N in the Gleyic Plinthic Acrisol (Table 4.7). However, such combination did not result in greater apparent P recovery as was also obtained with the sole application of P.

4.2.5.2 Discussion

Higher N in maize stover with $N_{120}P_{90}$ compared to the other treatments in both soil types lends credence to the synergistic effect of P on maize use of N in low fertility soils, earlier alluded to. The greater maize stover N uptake in Gleyic Plinthic Acrisol over that of Plinthic Acrisol is probably because of the insufficient rainfall in Assin-Kushea during the study period (Rimski-Korsakov *et al*., 2009). The observation that maize grain P uptake in Gleyic Plinthic Acrisol was higher in $N_{120}P_{90}$ and N_0P_{90} than in $N_{120}P_0$ and N_0P_0 suggests that sole application of inorganic N at 90 kg ha^{-1}may not influence P uptake by maize grains. This agrees to the findings of Hussaini *et al*. (2008) that fertilizer N application up to 60 kg N ha^{-1} significantly increased N and P concentrations in maize grain, but beyond this application level, the concentration of each of these nutrients either

Table 4.6: Nitrogen, phosphorus and potassium uptake in maize grain and stover

Soil type	Samples	Treatments	N	P	K
			------------------ ($kg\ ha^{-1}$)	---------------------	
GPA	Grain	N_0P_0	17.91	0.34	13.30
		$N_{120}P_0$	22.32	0.40	13.33
		N_0P_{90}	26.20	1.65	24.18
		$N_{120}P_{90}$	40.19	1.63	40.72
		P values	0.14	0.002**	0.04*
		SED	8.33	0.23	8.03
GPA	Stover	N_0P_0	14.83	0.70	60.45
		$N_{120}P_0$	21.74	0.89	55.70
		N_0P_{90}	16.04	2.68	39.26
		$N_{120}P_{90}$	37.45	2.93	43.94
PA	Stover	N_0P_0	15.32	1.55	32.72
		$N_{120}P_0$	16.20	1.20	34.83
		N_0P_{90}	13.08	1.43	17.75
		$N_{120}P_{90}$	22.81	1.04	36.26
		P values	< 0.001***	0.31	0.45
		SED	3.73	0.68	12.53

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol

Table 4.7: Percentage N and P recovery rates of fertilizer treatments in Gleyic Plinthic Acrisol

Treatments	Apparent N recovery	Apparent P recovery	Crop N recovery efficiency	Crop P recovery efficiency
	------------------------------------ %	--		
$N_{120}P_0$	9.43	--	7.86	--
N_0P_{90}	--	8.54	--	21.55
$N_{120}P_{90}$	39.14	9.32	32.62	23.53

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declined or remained unchanged. Although the K uptake under $N_{120}P_{90}$ (40.7 kg ha^{-1}) and N_0P_{90} (24.2 kg ha^{-1}) would appear to suggest that the agronomic benefits of $N_{120}P_{90}$ over N_0P_{90} included facilitated K release and uptake in maize grain, these values did not differ significantly. These results imply that the two fertilizer application options are similar with respect to nutritional values of P and K.

The apparent N and P recovery efficiencies of $N_{120}P_0$ and N_0P_{90} were too low compared to $N_{120}P_{90}$ treatment. Low nutrient recoveries of applied fertilizer by crops of about 10 to 15 % (P), and 10 to 20 % (N and K), has been reported (Africa Fertilizer Summit, 2006). Results suggest that in Gleyic Plinthic Acrisol, $N_{120}P_0$ and N_0P_{90} treatments were inefficient in absorbing N and P, respectively. However, $N_{120}P_{90}$ treatment was efficient in absorbing more N than P. The rather low apparent recovery of P may be attributed to the fact that P was critical (Saiduo *et al*., 2003). Low crop N recovery efficiency of $N_{120}P_0$ treatment compared to $N_{120}P_{90}$ and N_0P_{90} treatments could have resulted in low N uptake by the crops and/or losses via leaching. Crop uptake of N is relatively inefficient and often results in average losses of 50 % because of leaching, volatilization or denitrification (Zublena, 1997). Krupnik *et al*. (2004) reported a range of 10 to 59 % N recovery in maize crop with average N fertilizer application of 121 kg ha^{-1} for Africa.

Having identified the most critical nutrient limiting maize crop yield in both soils studied, it thus, becomes necessary to determine maize yield response to varying rates of N and P fertilizers on the Gleyic Plinthic Acrisol and the Plinthic Acrisol. Okalebo *et al*. (2006) stated that maize response to nutrient inputs varied widely within and across agro-ecological zones. Understanding the concepts of ideal soil fertility level and responses to nutrient provide practical guidelines for improving nutrient management (Wang *et al*., 2007).

4.3 Maize yield response to varying rates of N and P fertilizer application

4.3.1 Soil chemical characterization of treatment plots before fertilizer application and after maize harvest

4.3.1.1 Results

Some selected chemical properties of the treatment plots before addition of amendments are presented in Table 4.8. Generally, all the chemical properties evaluated did not differ significantly among the treatments nor between the two soil types, except the soil available P. The soils were slightly to moderately acid with low levels of OC, N, P and K contents. The percent BS of the Plinthic Acrisol was however, very high compared to the Gleyic Plinthic Acrisol. The soil chemical properties after maize harvest are shown in Table 4.9. Fertilizer treatments had no significant effect on the total N and available P contents of the treatment plots after maize harvest in both soil types.

4.3.1.2 Discussion

The differences in soil available P content of the treatment plots before amendments suggest that the plots with significantly ($P < 0.05$) higher P values would outperform others since P has been identified as a more critical plant nutrient for maize growth and yield. According to Landon (1991) ratings, the soil P values fall within the low range of P. Considering the ECEC and BS percentage as an indication of soil

Table 4.8: Some selected chemical properties of the treatment plots before application of fertilizer treatments

Soil type	Treatment	Soil pH (H_2O) 1:2.5	OC (%)	Total N (%)	Avail. P (mg kg^{-1})	Exch Ca^{2+}	Exch Mg^{2+}	Exch Na^{+}	Exch K^{+}	Exch Al^{3+}	Exch H^{+}	ECEC	BS (%)
						(cmol+ kg^{-1})							
GPA	N_0P_0	6.25	1.34	0.16	2.95	2.40	2.73	0.13	0.20	0.60	0.73	6.80	77.46
	$N_{30}P_0$	6.00	1.29	0.14	3.01	2.80	1.00	0.08	0.24	0.73	0.53	5.39	75.06
	$N_{60}P_0$	6.14	1.14	0.13	3.07	2.43	1.05	0.11	0.22	0.74	0.57	5.12	73.82
	$N_{90}P_0$	5.80	1.20	0.12	3.05	2.54	0.97	0.10	0.23	0.79	0.50	5.13	73.85
	$N_{120}P_0$	5.95	1.20	0.13	3.86	1.93	1.20	0.12	0.20	0.80	0.33	4.58	75.59
	N_0P_{30}	6.52	1.47	0.17	2.89	5.40	1.20	0.12	0.24	0.93	0.33	8.22	81.77
	N_0P_{60}	5.91	0.94	0.11	3.55	2.13	0.93	0.11	0.22	0.67	0.80	4.87	69.97
	N_0P_{90}	5.96	1.19	0.14	2.78	2.47	0.87	0.12	0.19	0.67	0.73	5.03	72.12
	N_0P_{120}	5.90	1.14	0.13	2.85	1.80	1.27	0.08	0.17	0.67	0.87	4.85	67.44
PA	N_0P_0	6.70	1.76	0.23	3.20	7.65	1.95	0.12	0.20	0.52	0.85	11.29	87.59
	$N_{30}P_0$	6.78	1.84	0.23	3.19	6.57	1.62	0.09	0.15	0.74	0.79	9.97	84.39
	$N_{60}P_0$	6.66	1.62	0.19	3.12	6.14	1.71	0.09	0.14	0.87	0.73	9.69	83.33
	$N_{90}P_0$	6.80	1.81	0.23	3.63	6.72	1.70	0.09	0.17	0.69	0.78	10.16	85.15
	$N_{120}P_0$	6.66	1.73	0.20	3.19	6.60	1.60	0.08	0.15	1.07	0.73	10.23	82.29
	N_0P_{30}	6.79	1.66	0.20	3.33	6.23	1.61	0.09	0.14	0.78	0.79	9.63	83.63
	N_0P_{60}	6.82	1.75	0.21	4.00	6.60	1.63	0.09	0.16	0.72	0.80	10.00	84.54
	N_0P_{90}	6.63	1.72	0.22	3.44	7.07	1.67	0.08	0.14	0.60	0.80	10.35	86.33
	N_0P_{120}	6.81	1.27	0.24	3.45	8.13	2.07	0.12	0.21	0.47	0.93	11.93	87.98
	P values	0.82	0.21	0.49	0.04*	0.74	0.61	0.16	0.18	0.43	0.59	0.90	0.79
	SED	0.22	0.15	0.02	0.25	1.09	0.50	0.01	0.03	0.15	0.19	1.33	3.61

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol

Table 4.9: Soil total nitrogen and available phosphorus as affected by treatment after maize harvest

Soil type	Treatment	Total N (%)	Avail. P (mg kg^{-1})
GPA	N_0P_0	0.11	2.84
	$N_{30}P_0$	0.11	2.70
	$N_{60}P_0$	0.10	2.63
	$N_{90}P_0$	0.11	2.71
	$N_{120}P_0$	0.10	2.67
	N_0P_{30}	0.13	2.99
	N_0P_{60}	0.10	2.83
	N_0P_{90}	0.11	2.68
	N_0P_{120}	0.10	2.71
PA	N_0P_0	0.20	2.88
	$N_{30}P_0$	0.21	2.65
	$N_{60}P_0$	0.19	2.94
	$N_{90}P_0$	0.22	2.87
	$N_{120}P_0$	0.21	2.90
	N_0P_{30}	0.21	3.01
	N_0P_{60}	0.20	2.84
	N_0P_{90}	0.18	2.73
	N_0P_{120}	0.18	3.42
	P values	0.65	0.51
	SED	0.02	0.19

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol

fertility, the Plinthic Acrisol was inherently more fertile than the Gleyic Plinthic Acrisol. The non significant effect of fertilizer treatment on N and P in both soil types after maize harvest was probably due to the short period of study. Such effects are normally observed after long repeated fertilizer application on the same soil. Horst and Hardter (1994) reported comparable soil nitrate contents before and after maize harvest.

4.3.2 Effect of fertilizer treatment on maize yields and some yield assessment indices

4.3.2.1 Results

Table 4.10 shows the effect of treatment on maize yields and some yield indices. The stover and grain yields under the various treatments in both soil types were not significantly different. Nonetheless, ANOVA comparisons contrasts of maize grain and stover yields (Appendix 5) indicated significant difference between the N and P fertilizer. Also, the P fertilizer showed evidence of a quadratic function (P = 0.08) for both grain and stover yields. Graphically, there was essentially no trend for N fertilizer at all levels in both soil types as illustrated in Figure 4.3a. On the contrary, though maize grain yield increased significantly in the range of 0 to 120 kg ha^{-1} of applied P fertilizer in both soil types, the Gleyic Plinthic Acrisol with a co-efficient of determination (R^2) of 0.63 was superior in producing more grain yields compared to the Plinthic Acrisol with R^2 of 0.92. Figure 4.3b showed that maximum grain yield was obtained with the application of N_0P_{60} and N_0P_{90} treatments on Plinthic Acrisol and Gleyic Plinthic Acrisol, respectively.

Table 4.10: Effect of treatment on grain and stover yields and some yield assessment indices of maize

Soil type	Treatment	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	Agronomic efficiency (%)	Nutrient use efficiency (%)
GPA	N_0P_0	2.43	1.82	-	-
	$N_{30}P_0$	2.91	2.13	10.24	70.90
	$N_{60}P_0$	2.84	1.80	-0.29	30.04
	$N_{90}P_0$	1.80	1.11	-7.84	12.38
	$N_{120}P_0$	2.42	1.67	-1.24	13.92
	N_0P_{30}	2.56	2.70	67.01	204.87
	N_0P_{60}	2.32	2.41	22.41	91.34
	N_0P_{90}	3.84	3.28	36.98	82.94
	N_0P_{120}	2.34	2.46	12.22	46.68
PA	N_0P_0	1.53	1.35	-	-
	$N_{30}P_0$	1.70	1.08	-8.92	36.05
	$N_{60}P_0$	1.90	1.79	7.29	29.77
	$N_{90}P_0$	2.22	1.80	5.03	20.02
	$N_{120}P_0$	2.05	1.34	-0.10	11.14
	N_0P_{30}	2.18	2.27	69.43	171.65
	N_0P_{60}	4.19	2.41	40.19	91.30
	N_0P_{90}	2.82	2.04	17.49	51.57
	N_0P_{120}	2.96	1.66	5.94	31.50
	P values	0.21	0.24	< 0.001***	0.04*
	SED	0.60	0.56	20.11	22.02

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol

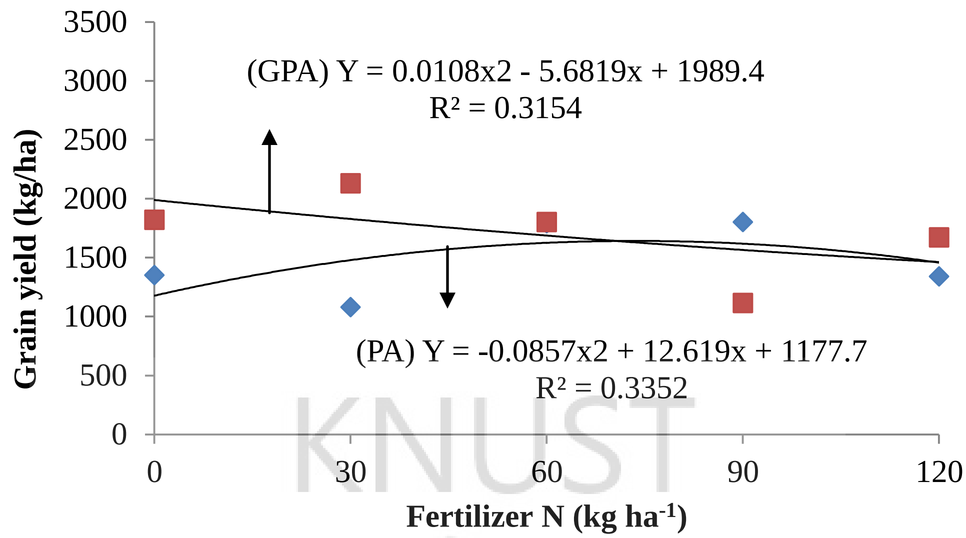

Figure 4.3a: Relationship between nitrogen application rate and grain yield on both soil types

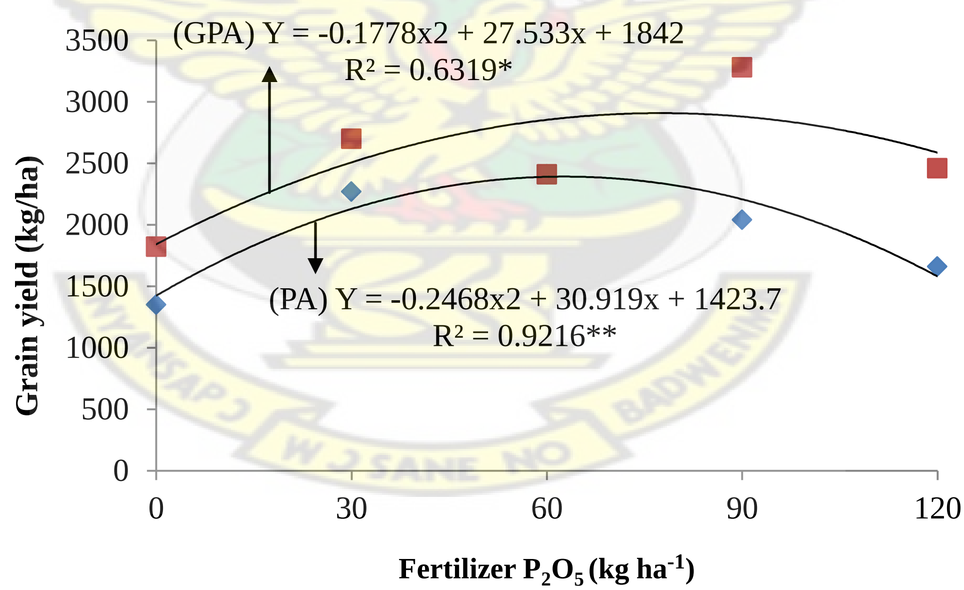

Figure 4.3b: Relationship between phosphorus application rate and grain yield on both soil types

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol

The variance component analysis in Table 4.11 pointed out that among the various treatments, blocking contributed 20 and 17 % to the total variation in maize grain and stover yields across soil types, respectively.

In both soil types, the plots fertilized with the various levels of P were in general, statistically agronomically efficient than those plots that received N fertilizer (Table 4.10). Of the two soil types, the lowest and highest agronomic efficiency (AE) values were obtained from plots treated with N_0P_{120} and N_0P_{30}, respectively. Lower levels of P fertilizer (N_0P_{30} and N_0P_{60}) were however, more agronomically efficient than the higher levels (N_0P_{90} and N_0P_{120}) in both soil types. The efficiency of P utilization was in general, significantly higher than N utilization except with $N_{30}P_0$ of the Gleyic Plinthic Acrisol. Across soil types, N and P use efficiencies decreased significantly as the applied nutrient rates increased from 0 to 120 kg ha^{-1}.

Table 4.11: Variance component analysis of maize grain and stover yields in both soil types

	Grain yield (t ha^{-1})			**Stover yield (t ha^{-1})**		
Random term	Component	S.E	% variance	Component	S.E	% variance
Soil type	0.00	0.14	0	0.00	0.08	0
Block within soil type	0.22	0.22	20	0.20	0.22	17
Residual	0.88	0.19	80	1.01	0.22	83

4.3.2.2 Discussion

The differences in maize stover and grain yields in both soil types were not significant. Similar studies (Christianson and Vlek, 1991; Twomlow *et al*., 2010; Fosu-

Mensah *et al*., 2012) on the contrary, have shown increased maize grain response to increased N fertilizer rates under broad range of soils and climatic conditions. The significant difference in maize grain and stover yields obtained between N and P fertilizer (ANOVA comparisons contrast) confirms their roles in increasing growth and yield functions in maize production (Onasanya *et al*., 2009). Each of the treatment though very important to plant nutrition, plays different roles in maize crop growth and development (Hajabbasi and Schumacher, 1994). More so, the contribution of blocking to the total variation in maize grain and stover yields between N and P fertilizer was substantial and should not be overlooked. The blocking effect arising from field heterogeneity, particularly due to the differences in available soil P of the treatment plots (before application of fertilizer treatments) may positively and negatively influence P and N response, respectively (Smalberger *et al*., 2006).

Contrary to P response, it was impossible to determine the trend of maize grain yield response to applied N (across the five N rates) by a quadratic function in both soil types. Nonetheless, there is a possibility of obtaining a trend for N response which may be non-polynomial (for example, exponential), even though, not relevant in this study. The non-quadratic response to applied N fertilizer signifies that other factors rather than N are limiting maize yield. This deduction is in part attributed to the general low N use efficiency due to depleted P status in both soil types. Phosphorus deficiency reduces crop response to N input (MacCarthy *et al*., 2009) through its negative influence on crop photosynthetic activity, resulting in poor yield. As such, NUE of applied N decreased with increasing N levels. This observation confirms the findings of Halvorson *et al*. (2005) who reported that N use efficiency decreased with increasing level of available N.

This may be attributed to the low fertility of the soils which gave a large yield response with small rate of applied nutrient. The N fertilizer application at the various rates was generally agronomically inefficient in both soils. Reported AE for maize in Ghana ranged from 0 to 35 (Heisey and Mwangi, 1996).

The positive grain yield response to increasing rates of P confirms the earlier established observation that P is the yield limiting nutrient in both soil types. Phosphorus has been recognized as a primary limitation in most forest, weathered and tropical soils (Lynch, 2007). Across the five P rates, Gleyic Plinthic Acrisol produced higher grain yields of 43 to 47 % and 80 to 124 % compared to Plinthic Acrisol at lower and higher rates of applied P, respectively. The superiority of the Gleyic Plinthic Acrisol compared to the Plinthic Acrisol may be associated with P losses via runoff due to the landscape (hilly topography) characteristic of Plinthic Acrisol which tends to hinder the efficiency of P uptake by maize plant. This assertion is evident in the comparatively higher P use efficiency amongst the treatment in Gleyic Plinthic Acrisol than Plinthic Acrisol. The application of N_0P_{60} and N_0P_{90} treatments marks the plateau where P no longer determines maize yield in Plinthic Acrisol and Gleyic Plinthic Acrisol, respectively. Those rates appeared to be optimum since at higher rates, the yields were depressed. As such, there are no achievable additional yields for operating at P levels greater than the critical level appropriate to the maize crop-soil system. Even though maize response to P peaked at those moderate rates; both NUE and AE of maize were highest with N_0P_{30} treatment in both soil types. The over 100 % NUE value obtained with N_0P_{30} treatment in both soil types signifies that the quantity of applied P was less than the plant needs. Hence, the plants mined some of the nutrient from the soil reserve.

4.4 Fertilizer micro-dosing in maize and cowpea under sole and rotation cropping

4.4.1 Soil chemical characterization of treatment plots before fertilizer application

4.4.1.1 Results

The mean values of some selected chemical properties of the treatment plots before amendments application are presented in Table 4.12. All the chemical properties determined showed relatively similar values in both soil types. Both soils were moderately acid with low levels of OC, N, P and K contents. However, the values of ECEC and BS percentage were higher in the Plinthic Acrisol than in the Gleyic Plinthic Acrisol.

4.4.1.2 Discussion

The soil chemical properties of the sites used for this experiment were similar to the other experimental sites in this study. The two soil types showed low levels of the major plant nutrients: N, P and K, including OC. Similar low values of these parameters on Ferric Acrisol of the semi-deciduous zone, Ghana has been reported by Fening *et al*. (2011) . However, though the values of ECEC in both soil types were low, their BS percentage was very high.

Table 4.12: Soil chemical properties of treatment plots before fertilizer application

Soil type	Soil pH (H_2O) 1:2.5	OC (%)	Total N (%)	Avail. P (mg kg^{-1})	Exch Ca^{2+}	Exch Mg^{2+}	Exch Na^+	Exch K^+	Exch Al^{3+}	Exch H^+	ECEC	BS (%)
					(cmol$_+$ kg^{-1})							
GPA	5.62	1.86	0.12	1.96	2.50	3.00	0.05	0.04	0.20	0.40	6.19	90
PA	5.96	1.34	0.22	3.44	7.30	1.94	0.16	0.12	0.40	0.20	10.12	94

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol

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4.4.2 Effect of N and P fertilizer treatments on maize and cowpea yield and some yield assessment indices in the minor season

4.4.2.1 Results

The maize and cowpea yields under the various N and P treatments in both soils are shown in Table 4.13. Maize stover yield was significantly (P < 0.001) higher in plots fertilized with $N_{20}P_{40}$ and $N_{90}P_{60}$ compared to the other treatment plots in both soils; however, stover yield due to $N_{20}P_{40}$ micro-dose treatment was significantly higher in the Plinthic Acrisol over that obtained in the Gleyic Plinthic Acrisol. Nonetheless, stover yield showed same decreasing order with the micro-dose fertilizer treatments and the control ($N_{20}P_{40} > N_0P_{40} > N_0P_{20} > N_0P_0$) in both soil types, with generally higher values in the Plinthic Acrisol than the Gleyic Plinthic Acrisol. Maize grain yield was also significantly higher in plots fertilized with $N_{20}P_{40}$ and $N_{90}P_{60}$ compared to the other treatment plots in both soils. Relative to the control, maize grain yield increased by over 47 and 68 % in plots fertilized with $N_{20}P_{40}$ and $N_{90}P_{60,}$ respectively, with yield difference between $N_{20}P_{40}$ and $N_{90}P_{60}$ of 16 % in the Gleyic Plinthic Acrisol and 39 % in the Plinthic Acrisol. The variance component analysis (Table 4.14) indicated that soil type contributed 15 and 19 % of the total variation in maize stover and grain yields, respectively. Differences in agronomic efficiency due to treatments in both soil types were not significant (Table 4.13). However, the utilization efficiency of applied fertilizer was significantly (P < 0.001) higher with the single fertilizer micro-dose treatments than the combined N and P fertilizer treatments. The lowest and highest values for NUE were obtained from plots treated with $N_{90}P_{60}$ and N_0P_{20}, respectively.

The application of N_0P_{20} to cowpea crop gave significantly higher stover yield than the control plot in both soil types, with averages of 0.70 and 1.03 t ha^{-1} for Gleyic Plinthic Acrisol and Plinthic Acrisol, respectively (Table 4.13). Conversely, N_0P_{20} treatment had no significant effect on cowpea grain yield in both soil types.

Table 4.13: Effect of N and P fertilizer treatments on maize and cowpea yields and some yield indices in the minor season

Soil type	Crop	Treatment	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	% grain yield increase	NUE (%)	AE (%)
GPA	Maize	N_0P_0	2.70	2.44	-	-	-
		N_0P_{20}	3.47	1.80	- 26	20.48	7.20
		N_0P_{40}	4.35	2.62	7	14.88	3.36
		$N_{20}P_{40}$	4.78	3.72	52	9.88	3.40
		$N_{90}P_{60}$	5.48	4.10	68	3.52	1.43
PA		N_0P_0	3.51	2.53	-	-	-
		N_0P_{20}	4.41	2.95	17	33.50	4.74
		N_0P_{40}	4.65	3.06	21	17.39	3.01
		$N_{20}P_{40}$	6.10	3.73	47	9.93	3.19
		$N_{90}P_{60}$	5.58	4.71	86	4.05	1.87
		P value	< 0.001***	< 0.001***	-	< 0.001***	0.74
		SED	0.52	0.40	-	0.03	0.04
GPA	Cowpea	N_0P_0	0.59	0.26	-		
		N_0P_{20}	0.70	0.22	- 15		
PA		N_0P_0	0.90	0.24	-		
		N_0P_{20}	1.03	0.17	- 29		
		P value	0.046*	0.34	-		
		SED	0.03	0.12	-		

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol

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Table 4.14: Variance component analysis of maize grain and stover yields in both soil types in the minor season

	------- Grain yield (t ha^{-1}) --------			------- Stover yield (t ha^{-1}) -------		
Random term	Component	S.E	% variance	Component	S.E	% variance
Soil type	0.08	0.15	15	0.19	0.34	19
Block within soil type	0.00	0.06	0	0.00	0.12	0
Residual	0.48	0.15	85	0.82	0.26	81

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4.4.2.2 Discussion

The increasing order of maize stover yield with increasing amount of micro-dose fertilizer treatments in both soil types signifies the additional benefit of P fertilization to plant growth. The application of $N_{20}P_{40}$ and $N_{90}P_{60}$ treatments which significantly influenced maize yields (stover and grain) compared to the other treatments in both soil types, lends credence to the interactive synergistic benefit of N and P fertilizers over P alone. Horst and Hardter (1994) obtained increased maize yield with the application of N and P. Since both treatments were of similar stover and grain yields production potential, a farmer who targets maize stover for animal feed production (forage) are better off with application of $N_{20}P_{40}$ than $N_{90}P_{60}$ treatments, taking into account the economics of applied fertilizer. The application of $N_{20}P_{40}$ micro-dose treatment increased grain yield by 47 % in the Plinthic Acrisol and 52 % in the Gleyic Plinthic Acrisol, which is significant and thus attractive to smallholder farmers. For middle class farmers, the grain yield difference between $N_{20}P_{40}$ than $N_{90}P_{60}$ treatments of 16 % (Gleyic Plinthic Acrisol) and 39 % (Plinthic Acrisol) is substantial. The superiority of the Plinthic Acrisol producing more maize stover and grain over the Gleyic Plinthic Acrisol, points to the better soil fertility status, particularly the BS percentage earlier alluded to. Hence, the variation in maize yield producing capacity of both soils by 15 % (stover) and 19 % (grain) is substantial.

The NUE of the micro-dose fertilizer treated plots were significantly higher than that of the recommended fertilizer rate ($N_{90}P_{60}$). Small amounts of applied fertilizer optimize NUE resulting in more efficient uptake (Bationo and Buerkert, 2001). From the results, though the lower micro-dose treatments (N_0P_{20} and N_0P_{40}) gave higher NUE values, their efficient uptake did not give optimum maize yield compared to $N_{20}P_{40}$ and $N_{90}P_{60}$ treatments with lower NUE. This indicates that the impact of single application of P fertilizers alone on maize yield is not evident in both soil types under study, until when complemented with N fertilizer. This is because N and P are very essential for good vegetative growth and grain development in maize production (Onasanya *et al.*, 2009).

The application of N_0P_{20} treatment to cowpea plots had a significant influence on stover yield but not grain yield. In their study, Magani and Kunchinda (2009) observed a positive interaction between P fertilizer and cowpea grain yield. Even though higher N fixation are usually associated with increase in yield level of legumes, application of N in addition to P fertilizer may be necessary for improvement of cowpea grain yield in both soils under study. The contribution of applied N to cowpea growth and grain yield, despite its BNF capability has been demonstrated (Azarpour *et al.*, 2011).

4.4.3 Effect of P fertilizer treatment on cowpea nodulation in the minor season

4.4.3.1 Results

The assessment of treatment effect on the weight of effective cowpea nodules showed a significant regression analysis (Appendix 6). Differences in effective cowpea nodules due to N_0P_{20} treatment were not significant (Table 4.15). However, the differences between treatments varied with soil type. Consequently, with reference to the control, there was twice higher response on effective nodule in the Plinthic Acrisol than in the Gleyic Plinthic Acrisol. More importantly, effective cowpea nodules response with N_0P_{20} treatment was twice in Plinthic Acrisol than with N_0P_0 treatment in Gleyic Plinthic Acrisol. Hence, effective cowpea nodules response function of applied P can be described by the equation, where Y is the quantity of effective cowpea nodules and X is the level of P fertilizer (kg ha^{-1}):

$Y = 2.59 + 0.16\,X + 0.91\,X^2 + 0.73X^3$

Table 4.15: Estimates of parameters on effective cowpea nodules in both soil types

Parameter	Estimate	Standard error	T pr.	Antilog of estimate
Constant	2.59	0.16	< 0.001***	13.33
Treatment (N_0P_{20})	0.16	0.17	0.35	1.18
Treatment (N_0P_0). Soil type .Plinthic Acrisol	0.91	0.18	< 0.001***	2.48
Treatment (N_0P_{20}). Soil type .Plinthic Acrisol	0.73	0.09	< 0.001***	2.07

Factor - Reference level
Treatment - N_0P_0
Soil type - Gleyic Plinthic Acrisol

$Y = 2.59_{\,(<0.001)} + 0.16\,X_{\,(0.35)} + 0.91\,X^2_{\,(<0.001)} + 0.73X^3_{\,(<0.001)}$

4.4.3.2 Discussion

The application of N_0P_{20} treatment to cowpea plots had a significant influence on effective nodulation. Phosphorus fertilizer has been noted to improve nodulation and plant growth where P is limiting (Ronner and Franke, 2012). Hence, with P limitation in both soils, the effectiveness of N_0P_{20} treatment in responding to nodulation of cowpea is understandable. Fertilizer treatment and soil type interaction showed the superiority of the Plinthic Acrisol over the Gleyic Plinthic Acrisol in responding to more effective nodulation. Since effective nodulation is a qualitative means of assessing N fixation in cowpea, greater enrichment with N (from BNF) and other nutrients (from residue decomposition) in the Plinthic Acrisol than the Gleyic Plinthic Acrisol is expected considering the differences in cowpea stover yield and the production of effective nodules. This would subsequently, contribute to the improvement of soil fertility for the succeeding crop(s). Rachies (1985) has showed that cowpea can fix up to 60 - 70 kg ha^{-1} of N.

4.4.4 Maize grain N, P and K uptake in the minor season

4.4.4.1 Results

The uptake of nutrients (N, P, and K) presented in Table 4.16 explains that average N concentration in maize grain among the treatments and across both soil types was generally high compared to P and K contents. Compared to the other treatments, grain N uptake was significantly higher under $N_{20}P_{40}$ and $N_{90}P_{60}$ treatments in the Gleyic Plinthic Acrisol, and under $N_{90}P_{60}$ treatment in the Plinthic Acrisol. However, N uptake due to $N_{90}P_{60}$ treatment was significantly higher in Plinthic Acrisol than that obtained in Gleyic Plinthic Acrisol. The grain P uptake in both soil types was significantly higher in N_0P_{40}, $N_{20}P_{40}$ and $N_{90}P_{60}$ treatments than in N_0P_{20} treatment and the control. The grain K uptake was relatively similar among the treatments and across soil types.

Table 4.16: Nitrogen, phosphorus and potassium uptake by maize grain in the minor season

Soil type	Treatment	N	P	K
		------------------	($kg\ ha^{-1}$)	--------------------
GPA	N_0P_0	34.14	1.86	18.75
	N_0P_{20}	25.13	1.40	8.97
	N_0P_{40}	34.08	3.43	17.09
	$N_{20}P_{40}$	50.79	3.48	26.93
	$N_{90}P_{60}$	63.31	4.56	31.55
PA	N_0P_0	40.22	1.48	12.41
	N_0P_{20}	39.93	1.57	26.04
	N_0P_{40}	45.63	3.03	26.43
	$N_{20}P_{40}$	49.11	3.58	25.07
	$N_{90}P_{60}$	76.70	3.58	39.96
	P value	< 0.001***	< 0.001***	0.06
	SED	6.39	0.58	6.97

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol; CMC = continuous maize cropping; CMR = cowpea-maize rotation

4.4.4.2 Discussion

The order of the evaluated nutrients (N > K > P) concentrations in maize grain is of great agronomic importance to the farmer. While nutrient uptake is an indication of the availability and accessibility of soil nutrients in plant, grain nutrient uptake gives a reflection of both quantity and quality of the grain produced. In this experiment, maize grain N uptake was about twice that of K uptake and over ten times more than P uptake. Varying levels of N and P were found to significantly influence the concentration of NPK in maize grain (Hussaini *et al*. 2008).The generally low P uptake compared to N uptake, among the treatments and across both soil types, signifies low availability of soil P due to the relatively low inherent P level of the soils. The uptake of nutrients and their partitioning to maize plant parts have been reported to vary with the fertility of the native soil (Ologunde, 1974). The lowest grain P uptake in N_0P_{20} treatment and the control is suggestive of insufficient P below the critical value. The higher N uptake with the N and P combined fertilizer treatments compared to the single based fertilizer treatments gives credibility to the synergistic effect of P on maize grain N uptake. As such, the application of $N_{20}P_{40}$ and $N_{90}P_{60}$ increased grain N uptake by over 15 and 25 %, respectively, which translated into higher grain yields than the other treatments.

4.4.5 Effect of N, P and K fertilizer treatments on maize yields in the major season

4.4.5.1 Results

The effect of NPK fertilizer treatments on maize yield under continuous maize cropping (CMC) and cowpea-maize rotation (CMR) cropping systems on both soil types is presented in Table 4.17. In general, differences in stover and grain yields amongst the treatments across cropping systems and soil types were highly significant ($P < 0.001$). Though stover and grain yields among the treatments showed generally higher values in CMR than CMC, treatment x cropping system interaction was not significant ($P > 0.05$). Accordingly, on the Gleyic Plinthic Acrisol, stover yield in both cropping systems was significantly higher with all the fertilized plots than the control. The recommended fertilizer rate ($N_{90}P_{60}K_{60}$) however, gave the highest stover yield compared to other fertilizer treatments in both soil types. In a decreasing order, the stover yield obtained among the treatments followed similar and different arrangement under cropping systems and soil types, respectively. As such, stover yield was in the order of $N_{90}P_{60}K_{60}$ > $N_0P_{40}K_{20}$ > $N_{20}P_{40}K_{20}$ > $N_0P_{20}K_{20}$ > $N_0P_0K_0$ in Gleyic Plinthic Acrisol; and $N_{90}P_{60}K_{60}$ > $N_{20}P_{40}K_{20}$ > $N_0P_{40}K_{20}$ > $N_0P_{20}K_{20}$ > $N_0P_0K_0$ in the Plinthic Acrisol.

Table 4.17: Effect of fertilizer treatments on maize yields in the major season

		Stover yield (t ha^{-1})		Grain yield (t ha^{-1})		% grain yield increase	
Soil type	Treatment	CMC	CMR	CMC	CMR	CMC	CMR
GPA	$N_0P_0K_0$	2.79	2.90	2.08	2.65	-	-
	$N_0P_{20}K_{20}$	3.65	4.25	3.07	4.62	48	74
	$N_0P_{40}K_{20}$	4.17	5.40	3.93	4.54	89	71
	$N_{20}P_{40}K_{20}$	4.10	4.94	4.14	4.04	99	52
	$N_{90}P_{60}K_{60}$	4.83	5.97	4.63	5.09	122	92
PA	$N_0P_0K_0$	2.69	3.68	2.97	3.75	-	-
	$N_0P_{20}K_{20}$	3.49	3.82	2.54	3.55	- 15	- 5
	$N_0P_{40}K_{20}$	3.99	4.78	3.92	5.47	32	46
	$N_{20}P_{40}K_{20}$	4.49	5.18	5.24	5.03	76	34
	$N_{90}P_{60}K_{60}$	5.83	6.19	3.22	5.98	8	59
	P value (trt)	< 0.001***		< 0.001***			
	P value (trt x crop. systm)	0.220		0.174			
	SED (trt)	0.49		0.30			
	SED (trt x crop. systm)	1.05		0.54			

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol; CMC = continuous maize cropping; CMR = cowpea-maize rotation; trt = treatment

In both cropping systems, maize grain yield was significantly higher in all the fertilized plots than the control in the Gleyic Plinthic Acrisol. However, while grain yield increased followed the order of $N_{90}P_{60}K_{60}$ > $N_{20}P_{40}K_{20}$ > $N_0P_{40}K_{20}$ > $N_0P_{20}K_{20}$ > $N_0P_0K_0$ under CMC, it was in the order of $N_{90}P_{60}K_{60}$ > $N_0P_{20}K_{20}$ > $N_0P_{40}K_{20}$ > $N_{20}P_{40}K_{20}$ > $N_0P_0K_0$ under CMR. Compared to the other treatments, grain yield was significantly higher with $N_0P_{40}K_{20}$ and $N_{20}P_{40}K_{20}$ treatments under CMC and with $N_{90}P_{60}K_{60}$, $N_{20}P_{40}K_{20}$ and $N_0P_{40}K_{20}$ treatments under CMR in the Plinthic Acrisol. Relative to the control, maize grain yield increase due to $N_{90}P_{60}K_{60}$ treatment (recommended rate) in CMC and CMR was 122 and 92 %, respectively, in Gleyic Plinthic Acrisol, and 8 and 59 %, respectively, in Plinthic Acrisol. Amongst the micro-dose treatments, the highest grain yield increase was obtained with $N_{20}P_{40}K_{20}$ treatment under CMC but with $N_0P_{40}K_{20}$ treatment under CMR.

4.4.5.2 Discussion

The interactive effect of NPK fertilizer on yield of maize signifies the benefits of applied fertilizer across both cropping systems and soil types. Both soil types have similar capacity in producing stover yields under CMR and CMC systems. In addition, $N_0P_{40}K_{20}$ and $N_{20}P_{40}K_{20}$ micro-dose fertilizer treatments were comparable to the recommended fertilizer rate in producing significantly similar stover yield across both cropping systems and soil types.

Among the treatments, while the Gleyic Plinthic Acrisol produced higher grain yield under CMC than CMR, the reverse was the case with the Plinthic Acrisol. Significant higher grain yields have been associated to maize rotated with cowpea than maize monoculture (Adetunji, 1996; Anderson *et al*., 1997). This could be attributed to the greater BNF due to higher response to effective nodulation from cowpea cultivated during the minor season, which in combination to the applied fertilizer treatment translated to more grain yield in the Plinthic Acrisol. This suggests that N was a yield determining factor in the Plinthic Acrisol (Goulding *et al*., 2008) but not in the Gleyic Plinthic Acrisol. This inference is supported by the reports of Chiezey *et al*. (1990) and FAO (2005c) which indicated that BNF of cowpea hardly satisfies N requirements in poor soils.

Remarkably, the application of the micro-dose fertilizer treatments increased maize grain yields by 33 to 99 % across cropping systems and soil types, which reflected maize grain yields levels obtained in northern Ghana (over 50 %), where NPK fertilizer micro-dosing was used (Sawadogo-Kaboré *et al*., 2008). This observation is in agreement with the report of Tabo *et al.* (2008) who confirmed that fertilizer micro-dosing has the potential to greatly increase cereal grain yields across a range of agro-ecological zones and rainfall situations in West Africa. With this observation, the controversy over the efficacy of fertilizer micro-dosing in forest agro-ecological zone has been justified. Increase in crop yield due to micro-dose fertilizer could be attributed to the fertilizer placement method which in addition to reducing nutrient losses, helps the plant to establish roots that can explore for more nutrients deep down the soil. In this study, grain yield increase with micro-dose fertilizer treatments was generally better in the Gleyic Plinthic Acrisol than in the Plinthic Acrisol. Accordingly, the highest grain yields increase of 76 and 99 % in the Plinthic Acrisol and the Gleyic Plinthic Acrisol, respectively, were obtained with applied $N_{20}P_{40}K_{20}$ treatment under CMC. Whereas 46 %

with $N_0P_{40}K_{20}$ treatment and 74 % with $N_0P_{20}K_{20}$ treatment were obtained in the Plinthic Acrisol and the Gleyic Plinthic Acrisol, respectively, under CMR system. Hence, the application of $N_{20}P_{40}K_{20}$ under CMC in both soil types as opposed to the promising micro-dose treatments under CMR system would be attractive to a smallholder farmer.

4.4.6 Effect of N, P and K fertilizer treatments on NUE and AE in the major season

4.4.6.1 Results

The effect of fertilizer treatments on NUE and AE as shown in Table 4.18 points that, whereas AE only differed significantly ($P < 0.001$) among the treatments, NUE differed significantly ($P < 0.001$) among the treatments and treatment x cropping systems interaction in both soil types. Though the NUE of the applied fertilizer treatments were generally poor; the result showed that across cropping systems and soil types, NUE decreased significantly from the lowest fertilizer treatment combination rate ($N_0P_{20}K_{20}$) to the treatments with the highest fertilizer combination rate ($N_{90}P_{60}K_{60}$). In addition, NUE among the treatments was significantly higher under CMR than that obtained under CMC in both soil types. More so, under both cropping systems, the lower fertilizer treatment combination rates ($N_0P_{20}K_{20}$ and $N_0P_{40}K_{20}$) gave significantly higher nutrient utilization efficiency in the Gleyic Plinthic Acrisol than in the Plinthic Acrisol. Conversely, NUE of the treatments with higher fertilizer combination rates ($N_{90}P_{60}K_{60}$ and $N_{20}P_{40}K_{20}$) were significantly higher in the Plinthic Acrisol than in the Gleyic Plinthic Acrisol. Similar to the NUE values, AE values among the treatments and across both cropping systems and soil types were generally low. Except for $N_0P_{20}K_{20}$ treatment under

CMR system (Plinthic Acrisol), the lower fertilizer treatment combination rates were agronomically more efficient than the higher fertilizer treatment combination rates in both soil types. In view of that, the lowest and highest AE across both cropping systems and soil types were obtained with $N_{90}P_{60}K_{60}$ and $N_0P_{40}K_{20}$ treatments, respectively.

Table 4.18: Effect of fertilizer treatments on some yield assessment indices in the major season

		------- NUE (%) ------		-------- AE (%) ---------	
Soil type	Treatment	CMC	CMR	CMC	CMR
GPA	$N_0P_0K_0$	-	-	-	-
	$N_0P_{20}K_{20}$	14.35	16.72	3.44	5.32
	$N_0P_{40}K_{20}$	12.20	15.78	4.10	7.31
	$N_{20}P_{40}K_{20}$	7.56	9.12	2.45	3.77
	$N_{90}P_{60}K_{60}$	3.63	4.49	1.55	2.31
PA	$N_0P_0K_0$	-	-	-	-
	$N_0P_{20}K_{20}$	13.74	15.04	3.16	1.10
	$N_0P_{40}K_{20}$	11.67	13.98	3.81	3.21
	$N_{20}P_{40}K_{20}$	8.29	9.56	3.33	2.76
	$N_{90}P_{60}K_{60}$	4.38	4.65	2.36	1.88
	P value (treatment)	< 0.001***		0.004**	
	P value (treatment x cropping system)	< 0.001***		0.751	
	SED (treatment)	0.01		0.01	
	SED (treatment x cropping system)	0.01		0.01	

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol; CMC = continuous maize cropping; CMR = cowpea-maize rotation

4.4.6.2 Discussion

Similar to the NUE obtained during the minor cropping season, these micro-dose treatments ($N_0P_{20}K_{20}$ and $N_0P_{40}K_{20}$) with higher utilization efficiency, did not lead to optimum maize yield compared to $N_{20}P_{40}K_{20}$ and $N_{90}P_{60}K_{20}$ treatments with lower NUE. The NUE superiority of $N_{20}P_{40}K_{20}$ and $N_{90}P_{60}K_{20}$ treatments in the Plinthic Acrisol over that in the Gleyic Plinthic Acrisol could have resulted from inefficient uptake and assimilation of nutrients due to the coarser soil texture and the associated high leaching potential at the latter soil type. Based on the result obtained, the hypothesis of this study (page 3) on increase in NUE of maize under CMR than under CMC was therefore accepted. The higher NUE under CMR than CMC indicates the additional benefit of the contribution of BNF to the utilization of applied P and K in both soil types. The micro-dose fertilizer treatments were generally more agronomically efficient than the recommended fertilizer rate treatment. This could be attributed to the little amount of fertilizer associated with fertilizer micro-dosing which translated to increased yield. The AE superiority of $N_0P_{40}K_{20}$ treatment over other treatments in both cropping systems deemphasized the relevance of N in achieving optimum grain yield of maize across both soil types under study.

4.4.7 Maize grain N, P and K uptake in the major season

4.4.7.1 Results

In Table 4.19, maize grain N, P and K uptake differed significantly ($P < 0.001$) among the treatments and treatment x cropping systems interaction in both soil types. Accordingly, grain N, P and K uptake among the treatments were significantly ($P <$

Table 4.19: Nitrogen, phosphorus and potassium uptake in maize grain in the major season

Soil type	Cropping system	Treatment	N	P	K
			----------------	(kg ha^{-1})	----------------
GPA	CMC	$N_0P_0K_0$	36.79	2.44	17.60
		$N_0P_{20}K_{20}$	27.41	1.72	16.58
		$N_0P_{40}K_{20}$	40.45	2.29	21.66
		$N_{20}P_{40}K_{20}$	56.02	4.41	37.76
		$N_{90}P_{60}K_{60}$	65.03	5.30	58.25
	CMR	$N_0P_0K_0$	9.38	0.49	5.15
		$N_0P_{20}K_{20}$	14.64	1.47	15.35
		$N_0P_{40}K_{20}$	8.47	0.70	7.12
		$N_{20}P_{40}K_{20}$	9.38	0.64	6.33
		$N_{90}P_{60}K_{60}$	9.01	0.79	8.71
PA	CMC	$N_0P_0K_0$	37.32	2.77	19.43
		$N_0P_{20}K_{20}$	40.64	2.08	22.38
		$N_0P_{40}K_{20}$	40.90	2.83	22.97
		$N_{20}P_{40}K_{20}$	53.89	3.82	38.70
		$N_{90}P_{60}K_{60}$	66.63	4.78	36.10
	CMR	$N_0P_0K_0$	12.19	0.79	7.35
		$N_0P_{20}K_{20}$	15.30	1.16	11.22
		$N_0P_{40}K_{20}$	13.54	0.78	7.62
		$N_{20}P_{40}K_{20}$	11.54	0.68	8.93
		$N_{90}P_{60}K_{60}$	17.44	1.00	10.16
		P value (treatment)	< 0.001***	< 0.001***	0.001***
		P value (treatment x cropping system)	< 0.001***	< 0.001***	< 0.001***
		SED (treatment)	3.22	0.34	4.02
		SED (treatment x cropping system)	4.56	0.48	5.69

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol; CMC = continuous maize cropping; CMR = cowpea-maize rotation

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0.001) higher under CMC than CMR cropping system. In addition, while the grain uptake of N, P and K under CMC system generally increased significantly with increase in the fertilizer nutrient treatment combination rates in both soil types; N, P and K uptake followed no definite trend with treatments under CMR cropping. Under CMR, the differences in the uptake of N, P and K among the treatments varied with soil types. As such, the lowest and highest N uptake under CMR cropping was obtained from $N_0P_{40}K_{20}$ and $N_0P_{20}K_{20}$ treatment plots, respectively, in the Gleyic Plinthic Acrisol, and from $N_{20}P_{40}K_{20}$ and $N_{90}P_{60}K_{60}$ treatment plots, respectively, in the Plinthic Acrisol. In both soil types, whereas P and K uptake under CMR were highest with $N_0P_{20}K_{20}$, $N_{20}P_{40}K_{20}$ treatment gave the lowest P and K uptake, in exception of $N_0P_{40}K_{20}$ treatment with lowest K uptake in the Plinthic Acrisol.

4.4.7.2 Discussion

In this experiment, the grain uptake of N, P and K was superior under CMC over that under CMR. This observation was unexpected particularly, the grain N uptake, considering the increased soil N due to the previous cropping of cowpea under CMR. This may be attributed to the relatively poor availability and accessibility of soil N which in turn influenced grain P and K uptake. It could as well have resulted from imbalance in NPK ratio which may have reduced nutrient absorption by the maize plants (FAO, 2007). As such, the NPK concentration in maize grain was better under CMC than CMR despite the relatively higher grain yield associated with the latter. Also under CMC, NPK concentration in maize grain was better with $N_{90}P_{60}K_{60}$ and $N_{20}P_{40}K_{20}$ treatments compared to the other treatments. Accordingly, the application of $N_{20}P_{40}K_{20}$ and

$N_{90}P_{60}K_{60}$ under CMC increased grain N uptake by about 18 and 29 %, P uptake by 2 and 3 %, and K uptake by 20 and 30 %, respectively, across both soil types. The low P uptake compared to N and K uptake gives credence to the relatively low extractable P status of the soils, which according to Landon (1996) indicates P deficiency. Nonetheless, the high interactive effect of NPK fertilizer nutrients on P uptake under CMC signifies greater soil P exploitation due to improved root morphological and physiological characteristics that are important for P uptake (Hajabbasi and Schumacher, 1994), despite the relatively poor accessibility of the soil P. On the other hand, the effect of cropping on soil pH from moderately acid under CMC to slightly acid under CMR in the Plinthic Acrisol has some implication regarding P availability and uptake. Studies have indicated that P uptake rates are highest between pH 5.0 and 6.0 (Furihata *et al*., 1992), which is within the moderately acid range. This explains the lower grain P uptake observed with $N_{90}P_{60}K_{60}$ treatments under CMR as compared to that under CMC.

4.4.8 Effects of fertilizer treatments on selected soil chemical properties after maize harvest in the major season

4.4.8.1 Results

After two cropping seasons, fertilizer treatments had no significant effect ($P > 0.05$) on all the soil chemical properties evaluated (Table 4.20). However, difference in soil pH among the treatments was found to vary significantly with treatment x cropping system interaction. Hence, soil pH due to $N_{90}P_{60}K_{60}$ was statistically ($P < 0.05$) higher under CMR than CMC cropping system in both soil types.

Table 4.20: Selected soil chemical properties as affected by fertilizer treatments after maize harvest in the major season

Soil type	Cropping system	Treatment	Soil pH (H_2O) 1:2.5	OC (%)	Total N (%)	Avail. P (mg kg^{-1})	Exch. K ($cmol_+$ kg^{-1})
GPA	CMC	$N_0P_0K_0$	5.76	1.24	0.10	1.97	0.15
		$N_0P_{20}K_{20}$	5.39	1.00	0.09	4.50	0.17
		$N_0P_{40}K_{20}$	5.36	1.06	0.08	2.98	0.14
		$N_{20}P_{40}K_{20}$	5.55	1.04	0.10	1.73	0.15
		$N_{90}P_{60}K_{60}$	5.15	0.98	0.09	2.21	0.13
	CMR	$N_0P_0K_0$	5.64	1.08	0.10	1.72	0.14
		$N_0P_{20}K_{20}$	5.47	1.06	0.08	1.48	0.13
		$N_0P_{40}K_{20}$	5.33	1.09	0.10	3.21	0.13
		$N_{20}P_{40}K_{20}$	5.39	0.99	0.08	2.46	0.13
		$N_{90}P_{60}K_{60}$	5.53	0.99	0.08	2.21	0.14
PA	CMC	$N_0P_0K_0$	6.06	2.13	0.20	2.21	0.50
		$N_0P_{20}K_{20}$	6.15	2.14	0.20	2.21	0.42
		$N_0P_{40}K_{20}$	6.10	2.07	0.19	2.21	0.46
		$N_{20}P_{40}K_{20}$	6.10	2.14	0.20	2.46	0.46
		$N_{90}P_{60}K_{60}$	5.91	2.02	0.19	2.21	0.37
	CMR	$N_0P_0K_0$	6.10	2.16	0.19	2.45	0.46
		$N_0P_{20}K_{20}$	6.42	2.19	0.21	2.70	0.50
		$N_0P_{40}K_{20}$	6.37	2.17	0.21	2.45	0.46
		$N_{20}P_{40}K_{20}$	6.13	2.03	0.19	2.70	0.54
		$N_{90}P_{60}K_{60}$	6.55	2.18	0.21	2.96	0.71
		P value (treatment)	0.83	0.13	0.85	0.88	0.94
		P value (treatment x crop. system)	0.04*	0.28	0.22	0.57	0.24
		SED (treatment)	0.11	0.05	0.01	0.08	0.05
		SED (treatment x crop. system)	0.16	0.07	0.01	0.11	0.07

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol; CMC = continuous maize cropping; CMR = cowpea-maize rotation

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4.4.8.2 Discussion

At the end of the second cropping season, the fertilizer treatments had no significant effects on soil N, P and K across both cropping systems and soil types. However, the significantly ($P < 0.05$) higher pH value of $N_{90}P_{60}K_{60}$ treatments under CMR than CMC suggests that large dose of fertilizer treatment have an influence on the soil buffering capacity and hence soil pH than small micro-dose fertilizer treatment. Remarkably, the observed significant pH change due to $N_{90}P_{60}K_{60}$ however, was within the moderately acid range and was similar to the soil pH before fertilizer treatment application in the Gleyic Plinthic Acrisol.

4.4.9 Economic analysis of applied fertilizer

4.4.9.1 Results

The profitability of applied fertilizer input as assessed by value cost ratio (VCR) and net returns (NR) is presented in Table 4.21. With the exception of $N_0P_{20}K_{20}$ treatment under CMC and CMR of the Plinthic Acrisol with negative VCR values, application of the micro-dose fertilizer treatments generally gave higher economically viable VCR values than the $N_{90}P_{60}K_{60}$ recommended fertilizer rate. Across both soil types also, the VCR values increased with decrease in the rate of applied fertilizer nutrients under CMR but followed no definite trend with treatments under CMC system. Surprisingly, on the Plinthic Acrisol, the $N_{90}P_{60}K_{60}$ treatment under CMC gave VCR value of less than 1.

Compared to the micro-dose treatments, the highest NR was obtained with the recommended fertilizer rate treatments ($N_{90}P_{60}K_{60}$), except in the Plinthic Acrisol where $N_{20}P_{40}K_{20}$ treatment under CMC system produced the highest NR value. Among the

Table 4.21: Economic analysis of NPK fertilizer input on maize by value-cost ratio (VCR) and net return (NR)

Soil type	Cropping system	Treatment	VCR	NR (GH¢)
GPA	CMC	$N_0P_{20}K_{20}$	10.31	1563.71
		$N_0P_{40}K_{20}$	12.30	2852.75
		$N_{20}P_{40}K_{20}$	10.06	3275.71
		$N_{90}P_{60}K_{60}$	4.79	4410.44
	CMR	$N_0P_{20}K_{20}$	20.52	3131.71
		$N_0P_{40}K_{20}$	12.57	2916.75
		$N_{20}P_{40}K_{20}$	6.79	2203.71
		$N_{90}P_{60}K_{60}$	4.58	4234.44
PA	CMC	$N_0P_{20}K_{20}$	-4.48	-708.29
		$N_0P_{40}K_{20}$	6.32	1412.75
		$N_{20}P_{40}K_{20}$	11.09	3611.71
		$N_{90}P_{60}K_{60}$	0.47	474.43
	CMR	$N_0P_{20}K_{20}$	-2.08	-340.29
		$N_0P_{40}K_{20}$	11.44	2644.75
		$N_{20}P_{40}K_{20}$	6.25	2027.71
		$N_{90}P_{60}K_{60}$	4.19	3898.43

GPA = Gleyic Plinthic Acrisol; PA = Plinthic Acrisol; CMC = continuous maize cropping; CMR = cowpea-maize rotation micro-dose treatments, the highest NR was obtained with $N_{20}P_{40}K_{20}$ under CMC in both soil types, but with $N_0P_{20}K_{20}$ and $N_0P_{40}K_{20}$ treatments under CMR in the Gleyic Plinthic Acrisol and Plinthic Acrisol, respectively. Similar to the negative VCR obtained with $N_0P_{20}K_{20}$ treatment, negative NR values due to the treatment was also obtained under both cropping systems in the Plinthic Acrisol. Across cropping systems, both VCR and NR amongst the treatments were relatively higher in the Gleyic Plinthic Acrisol than in the Plinthic Acrisol.

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4.4.9.2 Discussion

To evaluate the financial incentives for a farmer to use fertilizer, value cost ratio **(**VCR) and/or net returns (NR) calculations are necessary before proposing any identified fertilizer treatment for adoption. The VCR values of > 4 obtained with all the treatments (except $N_{90}P_{60}K_{60}$ treatment under CMC and $N_0P_{20}K_{20}$ treatment under CMC and CMR of the Plinthic Acrisol) implies a positive return on fertilizer investment that is economically viable. Though fertilizer use is profitable with VCR of 2.7 (FAO, 2005b), VCR > 4 has been suggested to accommodate price and climatic risks and still provide an incentive to farmers (Guo *et al.*, 2009). Giving the higher VCR values, the application of the micro-dose treatments which suggests being more profitable than the recommended fertilizer rate ($N_{90}P_{60}K_{60}$), would be attractive to smallholder farmers. Low fertilizer application rates have been related to very high VCR owing to the small cost of the treatment and the associated high rate of response (Roy *et al.*, 2006). A VCR of > 8 has also been reported for maize (Guo *et al.*, 2009). The negative VCR and NR obtained with $N_0P_{20}K_{20}$ treatment under CMC and CMR of the Plinthic Acrisol resulted from the associated grain yield that was lower than the control. Also, the unexpected VCR < 1 obtained with $N_{90}P_{60}K_{60}$ treatment under CMC in the Plinthic Acrisol signifies negative return on fertilizer investment; hence this fertilizer recommendation is unlikely to be adopted by farmers.

In order to identify and recommend a fertilizer treatment for use by smallholder farmers, NR which is more understandable to farmers is thus considered. Such recommendation cannot be based on VCR alone because it is a poor tool for identifying the most profitable fertilizer dose and also for determining the likelihood of adoption when the VCR is greater than two (Kelly, 2006). Even though the recommended fertilizer rates gave the largest NR (except under CMC in the Plinthic Acrisol), the associated high fertilizer application rate is beyond the reach of smallholder farmers. With about GH¢1,000.00 NR difference from the recommended fertilizer rate, $N_{20}P_{40}K_{20}$ treatment under CMC in both soil types was more profitable than the other micro-dose fertilizer treatments. As such, the NR associated with the use of $N_{20}P_{40}K_{20}$ treatment is substantial and would also be attractive to smallholder farmers considering the low fertilizer application rate. Thus, $N_{20}P_{40}K_{20}$ treatment is recommended for use under CMC. On the other hand, though a relatively large NR is needed to convince smallholder farmers to adopt fertilizer, not all farmers aim for such when fertilizer cost and other production risks are taken into consideration. In view of that, the application of $N_0P_{40}K_{20}$ and $N_0P_{20}K_{20}$ treatments with reduced fertilizer cost and substantial NR is thus recommended for maize production under CMR in Plinthic Acrisol and Gleyic Plinthic Acrisol, respectively. Although there are presently no recommended standard of maize grain nutrient content, a farmer adopting this recommendation would however, be compromising the maize grain quality in terms of NPK concentrations.

.. Having identified promising micro-dose fertilizer treatments suitable for increased maize yields on the soils studied, it thus becomes necessary to assess fertilizer use and management practices of maize and cowpea smallholder farmers within the study locations. The information is necessary in determining the farmers' practices likely to influence the adoption of fertilizer micro-dose technology upon its demonstration and dissemination to the farmers. This will inform researchers and agricultural extension workers on whether to demonstrate and disseminate the proposed fertilizer micro-dosing technology to the farmers in the study area.

4.5 Survey of fertilizer use and management practices in maize and cowpea producing communities at Assin-Kushea and Twedie

4.5.1 Farmers' demographic characteristics

4.5.1.1 Results

The basic demographic information of the survey respondents is shown in Table 4.22. Out of the 200 farmers interviewed, 45 % were female, 72 % were married farmers and only 9 % were migrant settlers. The age of the farmers ranged from 18 to over 65 years, with 35 % of them within the age bracket of 45 to 54 years. Most of the farmers attended Junior High school (40 %), while 25 % had no formal education. High proportions of the respondents (89 %) had farming as their main occupation. Farm size of 0.2 to 1.0 ha predominate the area sown to maize and cowpea crops by 76 and 92 % respondents, respectively.

Table 4.22: Demographic characteristics of survey respondents at Assin-Kushea and Twedie

Demography	Number of respondents	Male respondents (%)	Female respondents (%)
Gender	200	55	45
Age (years)			
18-24	3	67	33
25-34	24	71	29
35-44	42	45	55
45-54	70	50	50
55-64	41	63	37
Over 65	20	50	50
Marital status			
Single	8	100	-
Married	144	63	37
Separated	10	20	80
Divorced	17	35	65
Widowed	21	14	86
Level of education			
None	50	28	72
Primary	25	44	56
Junior High	80	61	39
Senior High	22	82	18
Apprenticeship/vocational training	20	75	25
Undergraduate	2	50	50
Postgraduate	1	100	-
Main occupation			
Farming	178	54	46
Trading	15	40	60
Formally employed	7	86	14
Residence status			
Native	183	55	45
Migrant	17	53	47
Farm size (ha)			
Maize			
0.2-1.0	144	53	47
1.1-2.0	41	51	49
2.1-3.0	2	50	50
3.1-6.0	2	-	100
Cowpea			
0.2-1.0	47	64	36
1.1-2.0	4	75	25

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4.5.1.2 Discussion

Considering the farm size, the result indicated that the respondents are mostly smallholder maize and cowpea farmers. The area sown to maize and cowpea are generally small. Agriculture is predominantly on a smallholder basis in Ghana with about 90 % cultivating less than 2 ha of farm size (MoFA, 2011). Noteworthy among the data is the number of female respondents. The relatively high female respondents suggest that the same number of women as men were maize/cowpea farmers. However, this high proportion of women farmers probably stems from the fact that these crops are short season crops which are used to meet the immediate needs of the family both for consumption and income generation. With high native residence status of the respondents, it is expected that the farmers would farm sustainably unlike migrant farmers who over work the land to deplete the soil nutrients and abandon it. As such, high adoption of fertilizer micro-dosing is anticipated. More so, the educational level of the farmers will facilitate easy training and enhance the understanding and applicability of micro-dosing technology when disseminated. Nonetheless, the age characteristics of the farmers indicated that those who are actively involved in crop production are advanced. It thus implies that more youth are involved in other jobs than agriculture. Therefore, government policies on youth in agriculture should be promoted and extended across Ghana.

4.5.2 Agricultural activities

4.5.2.1 Results

Among the interviewed farmers, 75 % cultivated only maize while 21 % cultivated both maize and cowpea with 4 % engaging themselves in cowpea cultivation (Table 4.23). The semi- deciduous forest zone of Ghana which covers an area of 8,400 km^2 (MoFA, 2011) is among the leading maize producing areas. Under the various cropping systems, less farmers were engaged in sole cowpea cropping (1%), cowpea intercropped with maize (2 %) and in maize/cowpea rotation (5 %).

Table 4.23: Agricultural activities of the respondents at Assin-Kushea and Twedie

Activity	Number of respondents	Male (%)	Female (%)
Crop cultivated			
Maize	150	53	47
Cowpea	8	75	25
Both maize and cowpea	42	55	45
Cropping system			
Continuous sole maize	39	77	23
Continuous sole cowpea	1	100	-
Maize/cowpea intercrop	3	-	100
Maize/cowpea rotation	9	67	33
Mixed cropping	135	47	53
Strip cropping	13	62	38

4.5.2.2 Discussion

The survey results demonstrated that maize is an important crop for the majority of smallholder farmers in the surveyed area. Though cowpea constitutes the major legume grown in the semi-deciduous forest zone (Gerken *et al*., 2001), it is mainly grown in the savanna and forest-savanna transitional agro-ecological zones of Ghana (CRI, 2006). Even in the surveyed communities, cowpea is cultivated mostly in the minor season in rotation with maize grown in the major cropping season. Mixed cropping involving cassava, maize, okra, garden egg, and cowpea crops predominates among the respondents. This result affirms the report of Fosu and Tetteh (2008) that mixed cropping is typical to farmers in the semi-deciduous forest zone of Ghana. Moreover, maize and cowpea are important components of mixed cropping systems in many countries (Okigbo, 1982).

4.5.3 Gender and fertilizer adoption for maize and cowpea crops

4.5.3.1 Results

The data in Tables 4.24 provides clear evidence of low smallholder fertilizer adoption for maize (32 %) and cowpea (19 %) crops. This implies that 68 and 81 % maze and cowpea smallholder farmers, respectively, have been farming without inorganic fertilizer replenishment. The data further indicated the low participation of females (33 %) than males (67 %) in fertilizer utilization for cropping maize. In contrast, more females used fertilizer for growing cowpea (62 %) as compared to the males (38 %). Unfortunately, not all fertilizer adopters could access subsidized fertilizer. Only 48 % benefited from fertilizer subsidy while about half of the fertilizer adopters (49 %) got fertilizer input (unsubsidized) from the open market (Figure 4.4).

Table 4.24: Gender and fertilizer adoption for maize and cowpea crops

Crop	Response	Number of respondents	Male (%)	Female (%)
Maize				
	Yes	63	67	33
	No	131	47	53
Cowpea				
	Yes	8	38	62
	No	34	71	29

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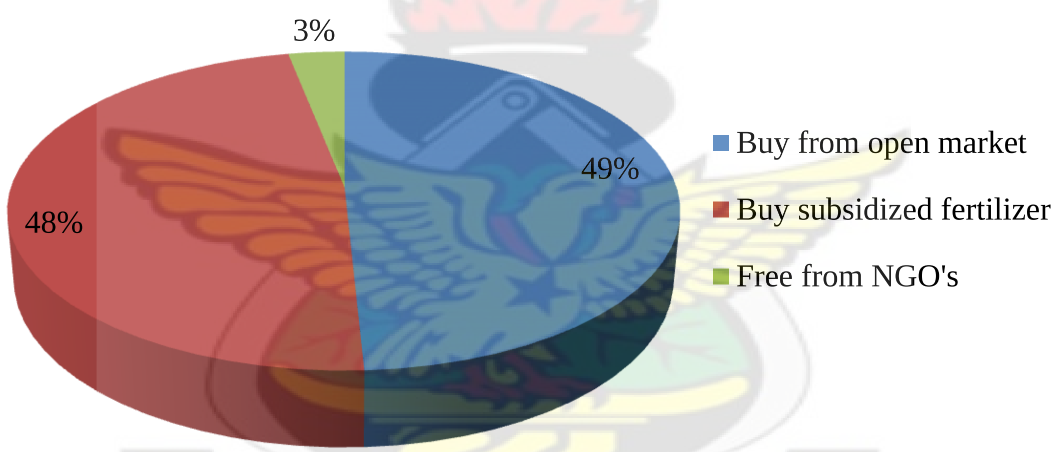

Figure 4.4: Source of fertilizer input

4.5.3.2 Discussion

Low fertilizer use in Ghana has been a general problem over the years. The low adoption of mineral fertilizer contributes to the large difference between farmer's yields and potential yield (Bationo *et al*., 2006). Considering the poor nutrient status of the soils and the mixed cropping system that predominate the surveyed locations, the soil may become impoverished and unable to sustain crop production if farming without amendment is not halted and reversed. The findings agree with GOG (2010) study that reported even lower level of fertilizer adoption (10 %) by smallholders with less than 1.0 ha of farm land. Quinones and Diao (2011) reported of 15 % fertilizer users in the forest agro-ecological zone of Ghana. The data raise the question as why the rate of fertilizer adoption by smallholder maize and cowpea farmers has been low even with the introduction of fertilizer subsidy. Of all the inputs used in crop production, none has received government intervention as fertilizer input that is clearly highlighted in national development plans. If farmers can access subsidized fertilizer and use it appropriately, it will ameliorate soil nutrient deficiencies while having a positive effect on crop productivity.

The low fertilizer use for cowpea could also be attributed to farmers' common knowledge that cowpea improves soil fertility. Chiezey *et al*. (1990) however, reported that cowpea scarcely satisfies its N requirements in poor soils, and that the crop performance is improved with fertilizer addition. Though Azarpour *et al*. (2011) has also shown the significance of applied fertilizer N to growth and yield of cowpea, urea fertilizer however, was not used for growing cowpea. The use of correct type of fertilizer is of paramount importance as nutrients supplied through fertilizer must match crop needs for their efficient utilization (Sanginga and Woomer, 2009). Inclusion of P fertilizer is needed for adequate growth of both maize and cowpea crops. In addition, knowledge of soil characteristics in relation to nutrient availability to crops is essential to raise production per unit of applied fertilizer nutrient. Considering the soil structure of the study sites, application of NPK fertilizer to maize would have greater chance of being utilized by the crops as compared to ammonium sulphate fertilizer which is extremely soluble in water and more prone to leaching losses due to high rainfall regime of the area. In addition, ammonium sulphate fertilizer contributes low N content per kg relative to NPK 15:15:15 fertilizers, hence it is not economical.

4.5.4 Types of fertilizer applied to crops

4.5.4.1 Results

Table 4.25 presents the different types of fertilizer the interviewed farmers apply. Majority of the farmers used more than one type of fertilizer. Generally, NPK 15:15:15 was mostly used by 61 % farmers while 35 % used ammonium sulphate. Other fertilizer types such as TSP, MOP and urea received low patronage by the maize smallholder farmers. Similarly, NPK 15:15:15 dominated cowpea farms with 50 % users, followed by MOP with 25 % users.

Table 4.25: Percentage of farmers applying different fertilizer types on maize and cowpea

Crops	NPK 15:15:15	Ammonium sulphate	TSP	MOP	Urea
Maize	61	35	1	2	1
Cowpea	50	12.5	12.5	25	0

TSP = triple superphosphate, MOP = muriate of potash

Figure 4.5a shows that preference of a fertilizer type was mainly determined by fertilizer availability and fertilizer accessibility as reported by 33 and 28 % farmers, respectively. The choice of fertilizer quantity (Figure 4.5b) used by the smallholder farmers was mostly attributed to their purchasing power (40 %) whereas 20 % were guided by their personal decision. Strikingly, 33 % farmers claimed recommended rate as reason for choice of fertilizer quantity.

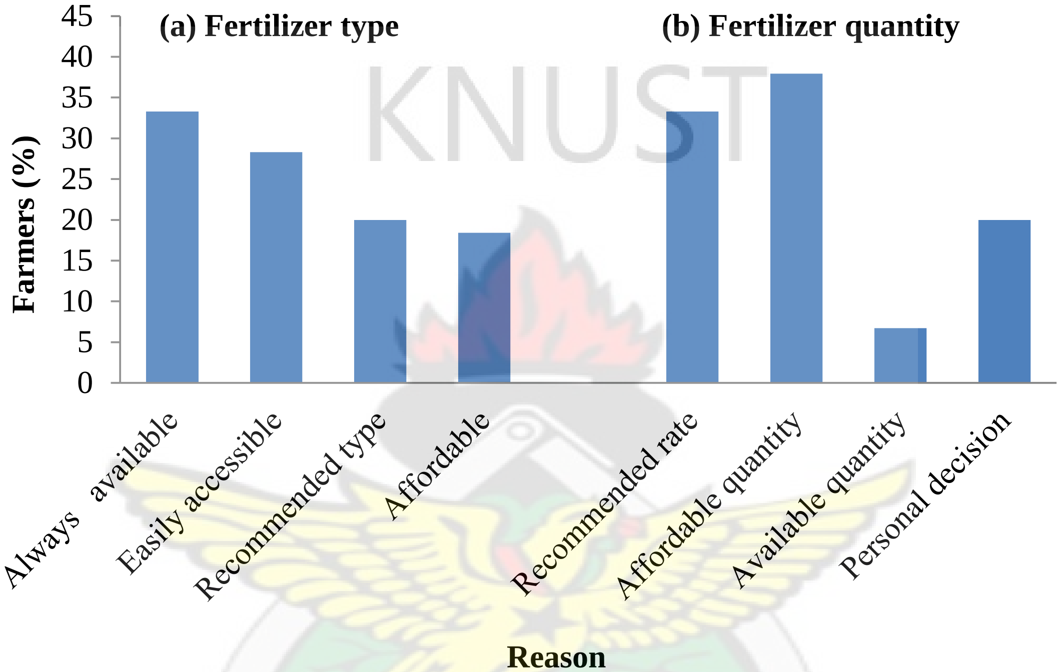

Figure 4.5: Reasons for choice of fertilizer type and fertilizer quantity

4.5.4.2 Discussion

Combining the data in Figure 4.4 and Table 4.25, it infers that NPK 15:15:15, ammonium sulphate and urea which are among the subsidized fertilizer types could not be accessed by over 50 % of targeted smallholder farmers for whom the subsidy programme was introduced. Inadequate access to the above mentioned subsidized fertilizer types were a challenge for most of the respondents. Even though NPK 15:15:15 is the most widely used fertilizer in Ghana (Banful, 2009), the prevailing fertilizer supply chain and its distribution thus become doubtful as whether large percentage of smallholder farmers does benefit from subsidized fertilizer. Hence, the preference of a fertilizer type by the farmers was highly dependent on its availability and accessibility. These two reasons though important are quite different from using the recommended fertilizer type which is by far more imperative to augmenting the nutrient needs of crop for increased productivity. For the farmers whose choice of fertilizer quantity was based on recommended rate, available information (FAO, 2005) shows that the fertilizer quantity applied by the farmers is actually not the recommended fertilizer rate. Fertilizer affordability did not inform the choice of fertilizer type; rather it informed the choice of fertilizer quantity used by majority of the respondents. This attributes fertilizer cost (affordability) as the major constraint to fertilizer quantity used by smallholder farmers while fertilizer type is dependent on availability and accessibility. Among the recommended basic fertilizer types (NPK 15:15:15, ammonium sulphate and urea) (GAL, 2009), NPK 15:15:15 proved to be always available and accessible for use by over 50 % of both maize and cowpea farmers. Therefore, the effectiveness and efficiency of fertilizer distribution to peasant farmers needs to be addressed. This will give an insight as to rate and time of fertilizer delivery to local agro- dealers for easy accessibility by smallholder farmers.

4.5.5 Quantity of fertilizer applied to crops

4.5.5.1 Results

Table 4.26 compares the quantity of fertilizer applied to maize and cowpea crops. The fertilizer quantity reported here was calculated based on the commonly used type which is NPK 15:15:15. Generally, fertilizer application rate was within the range of 0.83 and 37.50 kg ha^{-1}. On the average, the smallholder farmers applied 18.45 kg ha^{-1} and 9.05 kg ha^{-1} of NPK 15:15:15 fertilizer for the cultivation of maize and cowpea, respectively. While 51 % farmers used 25 kg ha^{-1} NPK 15:15:15 fertilizer, 19 % farmers used approximately 8 kg ha^{-1} NPK 15:15:15 fertilizer for maize. The result also showed higher association of males to higher fertilizer utilization rate of 16.67 to 37.50 kg ha^{-1}, while more females were associated with the utilization of lower fertilizer rates (0.83 to 8.33 kg ha^{-1}). On the other hand, majority of the cowpea farmer respondents (57 %) applied only 8 kg ha^{-1} fertilizer.

Table 4.26: Amount of fertilizer applied to maize and cowpea crops

Fertilizer quantity (kg ha^{-1})	Maize			Cowpea		
	Frequency	Male (%)	Female (%)	Frequency	Male (%)	Female (%)
0.83	3	33	67	1	-	100
4.17	1	-	100	1	-	100
8.33	12	33	67	4	50	50
12.50	4	100	-	-	-	-
16.67	9	78	22	-	-	-
25.00	32	75	25	1	-	100
37.50	1	100	-	-	-	-

4.5.5.2 Discussion

In Ghana, fertilizer consumption rate of about 7.2 kg ha^{-1} has been reported (IFDC, 2012). Compared to other African countries, fertilizer application rates were 22 and 32 kg ha^{-1} in Malawi and Kenya, respectively (Fuentes *et al.*, 2012). The low fertilizer application rates for maize and cowpea crops suggests that Ghana is still far from attaining to the targeted 50 kg ha^{-1} average fertilizer consumption by 2015 (African Fertilizer Summit, 2006). Though the results showed that the choice of fertilizer quantity applied by the farmers was due to their purchasing power; women's poorer access to fertilizer, capital and credit may have contributed to the lower fertilizer utilization quantity for maize in particular.

4.5.6 Methods of fertilizer application

4.5.6.1 Results

The different methods of fertilizer application used by the farmers varied between the maize and cowpea crops (Figure 4.6). In general, prevalence of point/side fertilizer placement was higher (79 %) than band placement (3 %), ring (9 %), foliar (6 %) and broadcast (3 %) application methods for maize crop. For cowpea, the use of ring application method by 40 % of the farmers was higher than methods such as foliar, broadcast and point/side fertilizer placement methods (with 20 % users each).

4.5.6.2 Discussion

The predominance of farmers practicing point/side placement and ring methods could be attributed to the economics of the smallholder farmers and for efficient utilization of applied fertilizer. These methods involve the application of relatively small but equal amount of fertilizer to each individual crop. Fertilizer precision placement is often exercised in order to reduce input cost, while enhancing nutrient use efficiency. Interestingly, these two methods are part of the strategic fertilizer application methods (Tabo *et al*., 2006) which are also similar to fertilizer micro-dosing technology.

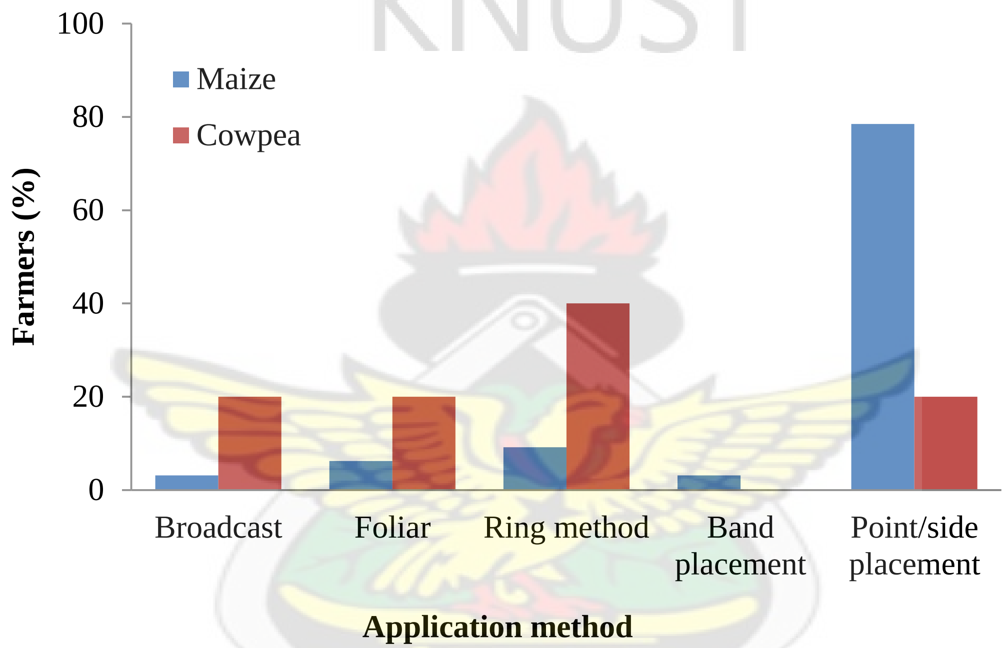

Figure 4.6: Methods of fertilizer application on maize and cowpea crops

4.5.7 Time of fertilizer application

4.5.7.1 Results

Fertilizer application time varied from 2 to 8 weeks after planting (WAP) for maize and from 1 to 4 WAP for cowpea crop (Table 4.27). In general, fertilization at 2 WAP was commonly practiced as affirmed by 77 % maize and 50 % cowpea farmers.

Higher percentage of farmers (82 %) got information on fertilizer application time (Figure 4.7) from the agricultural extension agents. Few farmers were informed from mass media (5 %), 3 % from other farmers/friends, and 10 % were guided by their personal decision.

Table 4.27: Time (week after planting) of fertilizer application by the farmers

	Maize		Cowpea	
Time	Frequency	Percent	Frequency	Percent
1 WAP	-	-	1	10
2 WAP	47	77	5	50
3 WAP	7	11.5	1	10
4 WAP	4	6.6	3	30
8 WAP	3	4.9	-	-
% CV	1.34		10.7	
SD	0.82		1.07	

WAP = week after planting.

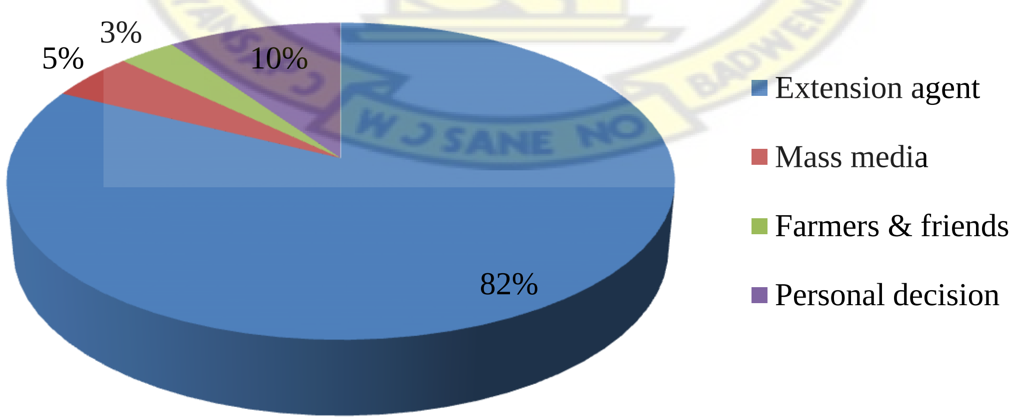

Figure 4.7: Farmers' sources of information on fertilizer application time

4.5.7.2 Discussion

Fertilizer application at 2 WAP as practiced by majority of the maize and cowpea farmers is viewed as appropriate and in accordance with GAL (2009) recommendations. On the contrary, "basal dressing" at planting and "top dressing" at 4 to 6 WAP are recommended fertilizer application times across Ghana (Kombiok, 2008). However, depending on fertilizer type, sub-surface application is recommended for cowpea at 2 WAP. This will facilitate nutrient uptake and hence enhance the nutrient use efficiency. Be that as it may, information on fertilizer application time was mostly disseminated to the farmers by agricultural extension agents. This finding affirms the indispensible role extension officers play in the dissemination of agricultural innovations to smallholder farmers including bridging the link between researchers and farmers. This implies that the dissemination of fertilizer micro-dosing in the study area would be more effective with the intervention of agricultural extension agents.

4.5.8 Factors constraining fertilizer use

4.5.8.1 Results

Table 4.28 indicated that high fertilizer cost accounted for the non-fertilizer utilization by 74 % smallholder farmers, while few farmers attributed non-fertilizer utilization to the other issues listed in the Table. It is noteworthy that only about 4 % of farmers claimed to have no knowledge on fertilizer. The issued enumerated under the "other factors" by the 7 % interviewed non-fertilizer users included difficulty in accessing credit and low market price for surplus output.

Table 4.28: Constraints for non-fertilizers input by smallholder farmers

Issues raised	No of respondents	Percentage of respondents
High fertilizer cost	83	74.1
Unavailability of fertilizer to purchase	2	1.8
Inaccessibility of subsidized fertilizer	8	7.1
High recommended rate of application	2	1.8
Insufficient fertilizer recommendation	3	2.7
No knowledge about fertilizer	4	3.6
Labourious to apply	2	1.8
Others	8	7.1
CV (%)	15.57	
SD	2.18	

SD = standard deviation

4.5.8.2 Discussion

Although fertilizer use is generally profitable, there are several constraints that limit its usage by most smallholder farmers. This finding agrees with the report of Sanchez (2002) that the use of external inputs by resource-poor farmers is constrained by high costs. Other reported major problems for effective utilization of fertilizers are availability of fertilizer (Thomas *et al*., 2004), inappropriate fertilizer recommendations (Bationo *et al*., 2006), and the distance from the farm to the nearest agro-dealer selling fertilizer (IFDC, 2012). Although the NPK 15:15:15 fertilizer commonly used by smallholder farmers is subsidized, the cost of procuring it from the sales outlet to the farm will in the long run increase its total cost. Hence, forming co-operative group among smallholder farmers could help in bulk fertilizer purchase and transport in order to minimize cost. According to Bationo *et al*. (2006), warrantage or inventory credit has helped to resolve the farmers' capital constraint. The claim of having no knowledge about fertilizer by very few farmers implies that majority of the smallholder farmers are well aware of the use of fertilizer to boost crop yield. Nonetheless, effort in helping smallholder farmers to understand the economics of fertilizer use through micro-dosing technology is vital for promoting fertilizer utilization. Moreover, adoption of micro-dosing techniques that utilizes small quantity of fertilizer entails minimizing the cost of fertilizer input needed to enhance crop yield.

4.5.9 Knowledge of fertilizer micro-dosing technology

4.5.9.1 Results

The data on micro-dosing awareness (Table 4.29) proved that out of the total respondents, only 8 % was aware of the technology. The source of information was mainly from MoFA/extension officers (44 %). Other information sources were from researchers, mass media and friends/family/other farmers by 6, 19 and 31 % respondents, respectively. Remarkably, only one maize farmer had tested the performance of this technology with about 8 g of NPK 15:15:15 per hill applied at one WAP. Though the trial was successful, the farmer however was not practising it.

Table 4.29: Knowledge of fertilizer micro-dose technology among farmers at the survey areas

Micro-dose technology	Number of respondents	Male (%)	Female (%)
Awareness			
Yes	16	56	44
No	184	54	46
Source of information			
Researchers	1	-	100
MOFA/Extension officers	7	71	29
Friends/family/other farmers	5	60	40
Mass media	3	33	67
Micro-dosing trial			
Yes	1	100	-
No	15	53	47

4.5.9.2 Discussion

The result suggest that majority of the farmers are not aware of fertilizer micro-dosing technology. For this reason, awareness creation of fertilizer micro-dosing is needed in the study areas. Indeed, both agricultural extension agents and MoFA field workers have a significant role to play in the dissemination of micro-dosing technology to the farmers in the two surveyed communities. It is also promising to note that majority of the interviewed fertilizer users practised similar fertilizer application method as micro-dosing. More so, the quantity of fertilizer utilized by the respondent farmers is comparable to micro-dose rate. Since, there will be no fundamental change in the farming system of the respondents, high adoption of micro-dosing technology is anticipated when demonstrated to the farmers in the study communities. It must however be emphatically stated that understanding the techniques and profitability associated with micro-dosing is required to accentuate its adoption. With reference to the identified major constraint to fertilizer use (high cost), smallholder farmers will be much inclined to adopt micro-dosing since it involves using lower rates of fertilizer in more efficient ways that deliver high economic returns.

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CHAPTER FIVE

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Maize growth and performance was better in the Gleyic Plinthic Acrisol than in the Plinthic Acrisol. The application of $N_{120}P_{90}$ and N_0P_{90} treatments enhanced maize growth than $N_{120}P_0$ treatment. Maize grain yield increased by 10, 77 and 95 % with the application of $N_{120}P_{0,}$ N_0P_{90} and $N_{120}P_{90}$ treatments, respectively. The $N_{120}P_{90}$ treatment which gave significantly higher stover yield showed a synergistic effect of P on maize use of N. The over 50 % NUE of N_0P_{90} treatment, in addition to the low apparent recovery of P compared to that of N due to the application of $N_{120}P_{90}$ treatment indicated that P rather than N was the most limiting nutrient for maize production in the Gleyic Plinthic Acrisol. Above all, application of N_0P_{90} gave higher HI, AE and proved to be economically more viable than the other treatments.

Maize showed differential yield response to the application of N and P fertilizers at varying rates; while P response was quadratic in function, N response showed no trend in both soil types. Even so, NUE of applied N decreased with increasing N levels. Maize yield response between applied N and P fertilizers differed within blocks and not between soil types. The application of P fertilizer was agronomically more efficient than N fertilizer, with lower rates of P being agronomically more efficient than the higher rates**.** Nonetheless, the application of N_0P_{60} and N_0P_{90} treatments marked the plateau where P no longer determined maize yield in the Plinthic Acrisol and the Gleyic Plinthic Acrisol, respectively.

The application of $N_{20}P_{40}$ and $N_{90}P_{60}$ treatments significantly influenced maize yields (stover and grain) in both soil types. The Plinthic Acrisol produced more maize stover and grain yields than the Gleyic Plinthic Acrisol. Relative to the control, the application of $N_{20}P_{40}$ (micro-dose) and $N_{90}P_{60}$ (recommended) treatments increased maize grain yield by 47 and 86 %, respectively, in the Plinthic Acrisol and by 52 and 62 %, respectively, in the Gleyic Plinthic Acrisol. With averages of 0.70 and 1.03 t $ha^{-1}$for the Gleyic Plinthic Acrisol and the Plinthic Acrisol, respectively, the application of micro-dose N_0P_{20} to cowpea gave significantly higher stover yield than the control but had no significant effect on grain yield in both soil types. The weight of effective cowpea nodule response with N_0P_{20} treatment was twice in the Plinthic Acrisol than under N_0P_0 treatment in the Gleyic Plinthic Acrisol.

The $N_{20}P_{40}K_{20}$ micro-dose treatment was comparable to the recommended fertilizer rate of $N_{90}P_{60}K_{60}$ in producing similar stover yield across both cropping systems and soil types. The $N_{90}P_{60}K_{60}$ and $N_{20}P_{40}K_{20}$ treatments produced significantly higher maize grain and stover than the other treatments across cropping systems and soil types. The application of the NPK micro-dose fertilizer treatments increased maize yields by 33 to 99 % across cropping systems and soil types. Grain yield increase with micro-dose fertilizer treatments was generally higher in the Gleyic Plinthic Acrisol than in the Plinthic Acrisol. The $N_{20}P_{40}K_{20}$ micro-dose treatment under CMC gave the highest grain yield increase of 76 and 99 % in the Plinthic Acrisol and the Gleyic Plinthic Acrisol, respectively; while under CMR, maize yield increase of 46 % with $N_0P_{40}K_{20}$ treatment and 74 % with $N_0P_{20}K_{20}$ treatment were obtained in the Plinthic Acrisol and the Gleyic Plinthic Acrisol, respectively.

The NUE and AE generally decreased significantly from the lowest fertilizer micro-dose treatment combination ($N_0P_{20}K_{20}$) to the highest fertilizer treatment combination ($N_{90}P_{60}K_{60}$). Among the treatments, NUE was significantly higher under CMR than that obtained under CMC in both soil types. The grain N, P and K uptake among the treatments were significantly higher under CMC than CMR system in both soil types. In addition, grain N, P and K uptake under CMC system generally increased significantly with increase in the fertilizer nutrient treatment combination rates. With few exceptions, application of the micro-dose fertilizer treatments generally gave higher economically viable VCR values than the recommended fertilizer rate. Though the highest NR was obtained with the recommended fertilizer rate treatments; among the micro-dose treatments however, highest NR was obtained with $N_{20}P_{40}K_{20}$ under CMC in both soil types, but with $N_0P_{20}K_{20}$ and $N_0P_{40}K_{20}$ treatments under CMR in the Gleyic Plinthic Acrisol and the Plinthic Acrisol, respectively.

The socio-economic survey conducted at Assin-Kushea and Twedie communities showed that about 65 and 80 % of maize and cowpea farmers respectively, identified high cost of fertilizer as a major constraint to fertilizer utilization. Consequently, only 32 % maize farmers and 19 % cowpea farmers were fertilizer users. The average application rate of the mostly used fertilizer type for maize and cowpea crops were 18.45 kg $ha^{-1}$and 9.05 kg ha^{-1} NPK 15:15:15, respectively. The prevalent fertilizer application method on maize was mostly by point/side placement while ring application was largely used for cowpea. Awareness of fertilizer micro-dosing among the farmers was very poor (10 %).

5.2 Conclusions

The following conclusions are drawn based on the results of the study:

The Plinthic Acrisol and Gleyic Plinthic Acrisol of the semi-deciduous forest soils of Ghana have low to moderate soil fertility status with unequal crop production potential. The impact of sole application of N-based fertilizers on maize growth and yield are not evident on these soil types, until when complemented with P-based fertilizer. This study therefore established that P is the major nutrient limiting maize growth and yield in the Gleyic Plinthic Acrisols and the Plinthic Acrisols of the semi-deciduous forest zone of Ghana. Hence, P should be externally supplied for increased and sustainable maize production on these soils.

Maize yield response varied with N and P fertilizers in both soil types. However, the two soil types exhibited similar maize grain and stover yields response to the individual application of N and P fertilizers at varying rates. Even though N_0P_{30} treatment was superior to other P fertilizer rates in terms of better NUE and AE in both soil types, the study has demonstrated that the critical level of P appropriate for optimum maize yield was at N_0P_{60} and N_0P_{90} in Plinthic Acrisol and Gleyic Plinthic Acrisol, respectively. Therefore, fertilizer P application should not exceed the critical level suitable to the maize crop-soil system for these soils.

The NPK fertilizer micro-dose experiment under CMC and CMR systems has proven that fertilizer micro-dosing technology can substantially increase maize yields on the Gleyic Plinthic Acrisols and Plinthic Acrisols of the semi-deciduous forest zone of Ghana. This study has also demonstrated that the two soil types studied have different capacity in producing maize stover and grain yield due to fertilizer treatments but not under CMR or CMC systems. Nonetheless, maize grain yield over the control was generally higher on the Gleyic Plinthic Acrisol than on the Plinthic Acrisol and under CMC than CMR. The study has confirmed that the micro-dose fertilizer treatments which had higher NUE were also more agronomically efficient than the recommended fertilizer rate. More importantly, the present study provides unique information on the following:

- The $N_{20}P_{40}K_{20}$ micro-dose treatment under CMC which gave the highest maize grain yield and net returns than the other micro-dose treatments tested was thus the proposed fertilizer micro-dose treatment appropriate for increased maize yield in the Plinthic Acrisol and the Gleyic Plinthic Acrisol.
- Since there was no adverse effect due to fertilizer treatment on the soil chemical properties after harvest, fertilizer application of $N_{20}P_{40}K_{20}$ under CMC which has the highest N, P and K concentrations in maize grain should be adopted in maize production.
- Adopting this technology will increase maize yield and production of the smallholder farmers in the study area, and hence increase their income generation and subsequently improve their livelihood.

The socioeconomic survey has established that fertilizer usage by maize and cowpea smallholder farmers at the study areas was low, and was mainly due to high fertilizer cost. The quantity of fertilizer used by the smallholder farmers and the fertilizer application methods were comparable to fertilizer micro-dosing. Hence, introduction of the technology will not require any fundamental change in the farming system at the study areas. Moreover, considering the depleted nutrient status of the soils, the current farmers' practices are inefficient in sustaining the soil characteristics for increased maize and cowpea production at the study sites. The proposed fertilizer micro-dose option identified in this study is therefore, appropriate and better than the prevailing farmer's practices in the surveyed areas.

5.3 Recommendations

From this research study, the following recommendations are formulated: Since P is critical to increased maize production in both soil types, modeling of this result will be necessary in determining when response to P will peak and its long term effect in terms of sustainability.

The proposed micro-dose fertilizer option identified for both soil types increased maize yields considerably. To increase fertilizer adoption by the smallholder farmers, subsidizing fertilizer input costs, particularly, P fertilizers (TSP or SSP) will be needed for augmenting the widely used NPK 15:15:15 application to these soils with critical P limitations. Applying the recommended fertilizer type is by far more imperative to augmenting the nutrient needs of crop for increased productivity. Government policies should ensure that the prevailing subsidized fertilizer supply chain and its distribution benefit large percentage of smallholder farmers for better soil management and increased crop production.

In view of the non significant cowpea grain yield response to the applied P fertilizer in the two soil types, further studies should aim at identifying optimum micro-dose fertilizer options for N in combination with varying doses of P and K, which can give higher yield that is economically viable than the sole application of N_0P_{20} to cowpea crop. Furthermore, it is necessary to assess the long term impact of the fertilizer micro-dose technology on the fertility status of the soils and implications for crop yield in terms of sustainability.

Considering the little prevailing fertilizer micro-dosing awareness and the poor soil nutrient status, awareness creation and dissemination of fertilizer micro-dose technology are needed to sustain the soils chemical characteristics for efficient crop production. However, on-farm experimentation is first recommended before transferring this promising technology to demonstration trials. Furthermore, it is recommended that extension agents and MoFA field workers are actively involved in the education on micro-dosing technology to smallholder farmers at Twedie and Assin-Kushea communities. This will facilitate adoption rate and hence, promote fertilizer use among smallholder farmers for sustained maize and cowpea production.

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APPENDICES

Appendix 1: Survey of Current Fertilizer use in Maize and Cowpea Producing Communities in the Assin-Kushea and Twedie Locations of Ghana

Name of interviewer: ……………………………..…………………………

Name of respondent: ………………………………………………………….

Location: ………………………………..

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1. Gender: Male [ ] Female [ ]
2. Age: (i) 18 – 24 [ ] (ii) 25 – 34 [ ] (iii) 35 – 44 [ ]

   (vi) 45 – 54 [ ] (v) 55 – 64 [ ] (vi) Over 65 [ ]
3. Level of education:
   - i. None [ ]
   - ii. Primary [ ]
   - iii. Junior High school [ ]
   - iv. Senior High school [ ]
   - v. Apprenticeship/vocational training [ ]
   - vi. Undergraduate University [ ]
   - vii. Postgraduate University [ ]

4. Marital Status: (i) Single [ ] (ii) Married [ ] (iii) Separated [ ]

   (vi) Divorced [ ] (v) Widowed [ ]

5. Family Size: ……………………………………………………
6. Main occupation: ……………………………………..………
7. Secondary occupation: ………………………………………
8. Migrant or native of the community: (i) Native [ ] (ii) Migrant [ ]

9. Which crop(s) do you cultivate?

i. Maize [ ]

ii. Cowpea [ ]

iii. Both [ ]

iv. Other(s), specify ……………………………………

10. What crop variety do you commonly cultivate?

i. Maize ………………………………………………

ii. Cowpea ……………………………………………

11. What planting distance do you adopt?

i. Maize ………………………………………………

ii. Cowpea …………………………………………….

12. What size of farm do you cultivate?

i. Maize ……………………………….…………......

ii. Cowpea ……………………………………………

13. What is (are) the major/key purpose(s)/reason(s) for cultivating the crop(s)?

		Maize	Cowpea
i.	For sale/income	[ ]	[ ]
ii.	For household use	[ ]	[ ]
iii.	For sale/household use	[ ]	[ ]
iv.	Low labour required	[ ]	[ ]
v.	Fixes soil nutrient (N)	[ ]	[ ]

vi. Other(s), specify ……………………………………….

14. What system of cropping do you practice?

i.	Continuous sole maize	[ ]
ii.	Continuous sole cowpea	[ ]
iii.	Maize/cowpea intercrop	[ ]
iv.	Cowpea/maize rotation	[ ]
v.	Mixed cropping (specify crops)	[ ] ………………………
vi.	Strip cropping (specify crops)	[ ] ………………………
vii.	Other(s), specify ……………………………………………..…….	

15. How long have you practised the chosen system above? ……………………

16. What is the main purpose for practising the chosen system?

		Maize	Cowpea
i.	Dual harvest per year	[ ]	[ ]
ii.	Easy to manage	[ ]	[ ]
iii.	High market demand	[ ]	[ ]
iv.	Soil fertility maintenance	[ ]	[ ]
v.	Short season crop	[ ]	[ ]
vi.	Higher income	[ ]	[ ]
vii.	Other(s), specify …………………………………………..….…		

17. Do you apply inorganic fertilizer?

i.	Maize	Yes [ ]	No [ ]
ii.	Cowpea	Yes [ ]	No [ ]

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18. If yes, what are the problems you have encountered with applying inorganic fertilizer?

		Maize	Cowpea
i.	Low yield response	[ ]	[ ]
ii.	Labourious to apply	[ ]	[ ]
iii.	Leaching/runoff	[ ]	[ ]
iv.	Erosion	[ ]	[ ]

v. Other(s), specify …………………………………..……………….

19. If no, why?

		Maize	Cowpea
i.	High fertilizer cost	[ ]	[ ]
ii.	Unavailability of fertilizer to purchase	[ ]	[ ]
iii.	Inaccessibility of subsidized fertilizer	[ ]	[ ]
iv.	High recommended rate of application	[ ]	[ ]
v.	Insufficient fertilizer recommendation/advice	[ ]	[ ]
vi.	No knowledge about fertilizer	[ ]	[ ]
vii.	Labourious to apply	[ ]	[ ]

viii. Other(s), specify ………………………………………………….

20. How do you obtain the inorganic fertilizer?

i. Buy from the open Market [ ]

ii. Buy subsidized fertilizer [ ]

iii. Free from NGO's [ ]

21. Are you benefiting from the fertilizer subsidy?

i.	For maize	Yes [ ]	No [ ]
ii.	For cowpea	Yes [ ]	No [ ]

22. What type(s) of inorganic fertilizer do you apply?

		Maize	Cowpea
i.	Compound fertilizer e.g NPK 15:15:15	[ ]	[ ]
ii.	Ammonium sulphate	[ ]	[ ]
iii.	Triple superphosphate (TSP)	[ ]	[ ]
iv.	Muriate of Potash (MOP)	[ ]	[ ]
v.	Urea	[ ]	[ ]
vi.	Other(s), Specify ……………………………….………………		

23. Why do you prefer the selected inorganic fertilizer(s) above?

i.	Always available	[ ]
ii.	Easily accessible	[ ]
iii.	Cheaper	[ ]
iv.	Recommended type	[ ]
v.	Subsidized fertilizer	[ ]
vi.	Other(s), specify …………………………………………	

24. How many bags of inorganic fertilizer do you apply? (specify bags/acre or bags/hectare)

i. Maize ……………………………………..……..

ii. Cowpea …………………………………………….

25. Why do you apply the quantity above? Specify crop.

i. Recommended rate [ ] …………………………

ii. Affordable quantity [ ] …………………………

iii. Available quantity [ ] …………………………

iv. Other farmers do so [ ] …………………………

v. Personal decision [ ] …………………………

vi. Other(s), specify ……………………………………………………

26. What method of fertilizer application do you practice? Specify crop.

i. Broadcast [ ] ………………………..

ii. Foliar [ ] ………………………..

iii. Ring method [ ] ………………………..

iv. Band placement [ ] ………………………..

v. Point/side placement [ ] ………………………..

vi. Other(s), specify ………………………………………………

27. At what time or stage of crop development do you apply inorganic fertilizer?

i. Maize ……………………………………………………..

ii. Cowpea …………………………………………………...

28. Who advised you on the application time?

i. Extension agents/MOFA officers [ ]

ii. Researchers [ ]

iii. From media (TV, radio, newspaper etc) [ ]

iv. Other farmers/friends [ ]

v. Personal decision [ ]

29. What maximum yield (bags/money) do you obtain per acre or hectare?

i. Maize ……………………………………………………………..

ii. Cowpea ……………………………….……………………...

30. Have you heard about fertilizer micro-dosing technology? Yes [ ] No [ ]

31. If yes, from what source?

i. Researchers [ ]

ii. Extension agents/MOFA officers [ ]

iii. Friends/family/other farmers [ ]

iv. Mass media (internet/television/newspapers/film/radio) [ ]

v. Other(s), specify …………………………………………………..

32. Are you practising fertilizer micro-dosing technology? Yes [ ] No [ ]

33. What crop(s) do you apply micro-doses of inorganic fertilizer?

………………………………………………………………………………

34. What type(s) of inorganic fertilizer do you apply in micro-doses?

……………………………………………………………………………..

35. What micro-dose (quantity) of inorganic fertilizer do you apply per plant?

………………………………………………………………………………

36. At what stage/time of crop cultivation do you apply the micro-dose fertilizer?

………………………………………………………………………………

37. What problems have you encountered with fertilizer micro-dosing technology?

………………………………………………………………………………

Thank you.

Appendix 2: Physico-chemical characteristics of Gleyic Plinthic Acrisols at Assin-Kushea and of Plinthic Acrisols at Twedie during the major season of 2012

Soil type	Horizon depth (cm)	Exch Ca	Exch Mg	Exch Na	Exch K	Exch Al	Exch H	ECEC	BS	OC	Sand	Silt	Clay	Total porosity	Bulk Density	OC pool
		cmol₊ kg⁻¹							%						(g cm⁻³)	(Mg ha⁻¹)
GPA	0-12	1.0	0.6	0.09	0.06	0.4	0.8	3.0	59	1.05	81	14	5	0.46	1.43	18.02
	12-20	1.6	0.4	0.09	0.06	0.6	1.6	4.4	49	0.51	83	12	5	0.39	1.61	16.55
	20-28	1.4	0.4	0.09	0.08	0.6	1.2	3.8	53	0.20	81	12	7	0.38	1.66	9.18
	28-45	1.2	0.8	0.10	0.10	0.8	1.6	4.6	48	0.30	79	10	11	0.41	1.58	21.07
	45-65	1.2	0.4	0.08	0.04	1.4	1.8	4.9	35	0.32	75	6	19	0.39	1.61	33.07
	65-82	1.0	0.6	0.09	0.09	1.6	1.8	5.2	34	0.30	71	6	23	0.44	1.50	36.44
	82-105	1.0	0.2	0.24	0.11	2.2	2.0	5.8	27	0.36	63	6	31	0.44	1.50	56.00
	105-128	1.2	0.6	0.27	0.11	2.0	2.0	6.2	35	0.36	65	4	31	0.42	1.55	70.58
	128-148	1.0	0.4	0.11	0.06	2.2	1.8	5.6	28	0.32	65	4	31	0.39	1.61	75.46
	148-160	1.4	0.2	0.08	0.05	1.8	2.0	5.5	31	0.26	61	6	33	ND	ND	ND
PA	0-10	0.8	2.8	0.18	0.25	0.8	0.6	9.4	85	1.96	67	22	11	0.56	1.17	22. 89
	10-20	1.8	2.2	0.14	0.10	0.6	0.8	5.6	75	0.89	63	20	17	0.45	1.46	26.00
	20-30	1.2	1.4	0.12	0.06	1.2	0.8	4.8	58	0.59	49	14	37	0.35	1.72	30.65
	30-40	1.0	1.2	0.14	0.09	1.8	0.2	4.4	55	0.50	47	10	43	0.43	1.50	29.79
	40-50	0.8	1.2	0.12	0.07	2.2	0.8	5.2	42	0.44	47	14	39	0.40	1.59	34.66
	50-60	0.8	1.0	0.11	0.06	2.2	0.4	4.6	43	0.24	55	16	29	0.40	1.60	22.76
	60-70	0.6	1.2	0.13	0.10	2.6	0.2	4.8	42	0.18	55	14	31	0.39	1.61	20.04
	70-80	0.4	1.2	0.15	0.05	2.8	0.2	4.8	38	0.22	49	18	33	ND	ND	ND
	80-90	1.0	0.8	0.16	0.07	3	0.2	5.2	39	0.22	37	26	37	ND	ND	ND
	90-100	0.8	0.8	0.13	0.06	3.2	0.2	5.2	35	0.16	47	20	33	ND	ND	ND
	100-110	0.4	1.0	0.14	0.07	3.2	0.6	5.4	30	0.18	41	22	37	ND	ND	ND

Appendix 3: Horizon description of Gleyic Plinthic Acrisol at Assin-Kushea (27/07/12)

Horizon no	Depth (cm)	Symbol	Description
1	0 – 12	A	Dark greyish brown (10YR 4/2); loamy fine sand; moderate medium granular; friable non-sticky non-plastic; many fine interstitial pores; many very fine and fine few medium roots, presence of termites, earthworms and millipedes; gradual smooth boundary.
2	12 – 20	AE	Dark brown (10YR 3/3); loamy fine sand; moderate medium granular; friable, non-sticky non-plastic; many fine interstitial pores few fine channels; common very fine and fine roots, presence of termites, earthworms and millipedes; clear smooth boundary.
3	12 – 20	E_1	Brown (10YR 4.5/3); loamy fine sand; weak fine and medium granular; friable non-sticky non-plastic; many fine interstitial pores; few fine channels; few very fine and fine roots; presence of termites, earthworms and millipedes; gradual smooth boundary.
4	28 – 45	E_2	Yellowish brown (10YR 5/4); fine sandy loam; weak medium sub-angular blocky; very few (< 2 %) coarse gravel; friable slightly sticky slightly plastic; few faint clay coatings in pores; very few fine, hard iron nodules; many fine interstitial pores; few medium channels; few very fine and fine roots; presence of termites, earthworms and millipedes; gradual smooth boundary.
5	45 – 65	Bt_1	Dark yellowish brown (10YR 4/4); sandy clay loam; moderate medium sub-angular blocky friable, sticky plastic; common faint clay and iron in pores; very few fine hard and soft iron nodules; many fine interstitial pores; common channels and vughs; few every fine and fine roots; presence of termites, earthworms and millipedes; diffuse smooth boundary.
6	65 – 82	Bt_2	Dark yellowish brown (10YR 4/5); sandy clay loam; moderate medium sub-angular blocky; friable sticky plastic; common faint clay coatings

Appendix 3 continued:

Horizon no	depth (cm)	Symbol	Description
			in pores; very few (< 1 %) soft and hard iron nodules; many fine interstitial pores; common channels and vughs; few very fine and fine roots; presence of termites, earthworm and millipedes; clear smooth boundary.
7	82 – 105	$Btcs_1$	Yellowish brown (10YR 5/4); common distinct five yellowish red (5YR 4/6) mottles; sandy clay; moderate medium sub angular blocky; friable, sticky plastic; common district clay coatings in pores; few (3 %) fine soft-iron nodules; many fine interstitial pores; common channels and vughs; few very fine and fine roots; presence of termites, earthworms and millipedes; gradual smooth boundary.
8	105 – 128	$Btcs_2$	Yellowish brown (10YR 5/6); common district yellowish red (5YR 5/4) and dark red (10R 3/6) mottles; sandy clay; moderate medium sub angular blocky; friable, sticky plastic; common district clay coatings in pores; few (3 %) medium soft iron nodules; many fine interstitial pores; common medium channels and course vughs; clear smooth boundary.
9	128 – 148	$Btcs_3$	Brownish yellow (10YR 6/6); common district medium yellowish red (5YR 4/6) and dark red (10R 3/6) mottles; sandy clay loam; moderate medium sub-angular blocky; friable, sticky plastic; common distinct clay and iron coatings in pores; common (15 %) medium soft iron nodules; many fine interstitial pores; common medium channels and coarse vughs; gradual smooth boundary.
10	148 – 162	Btv	Reddish brown (5YR 4/4); mixed colour; many district medium pale yellow (5Y 8/2), dark red (7.5R 3/6) and yellow (10YR 7/6) mottles, moderate medium sub-angular blocky; friable, sticky plastic; common distinct clay and iron coatings in pores; abundant (50 %) soft medium iron nodules.

Appendix 4: Horizon description of Plinthic Acrisol at Twedie (28/04/2012)

Horizon no	Depth (cm)	Symbol	Description
1	0 – 12	Ap	Dark brown (7.5 YR 3/4) moist; silty clay loam; moderate fine granular; very few medium and coarse quartz gravel; very friable slightly sticky slightly plastic; very few hard rounded iron concretions; many fine interstitial pores; many very fine and fine roots; few termites; clear smooth boundary.
2	12 – 26	BAcs	Dark red (2.5 YR 3/6) moist: silty clay; moderate fine sub-angular blocky; few (5 %) fine and medium gravels, very few stones; friable, sticky plastic; common (10 %) hard iron concretions; many fine interstitial pores; very few vughs; common very fine and fine few medium roots; few ants; gradual smooth boundary.
3	26 – 42	$Btcs_1$	Dark brown (7.5 YR 3/4) moist; silty clay loam; moderate fine sub-angular blocky; common fine (10 %), few coarse quartz gravels; friable sticky plastic; common (10 %) hard iron concretions; many fine interstitial pores; few medium vughs; very few fine roots; clear smooth boundary.
4	42 – 63	$Btcs_2$	Red (2.5 YR 4/6) moist, very few distinct fine red (10 R 4/6) and bright yellow (10 YR 6/6) mottles; silty clay moderate medium sub-angular blocky; few fine quartz gravels; common distinct clay and iron cutans along pores; common soft and hard iron nodules; many fine interstitial pores; very few fine roots; gradual smooth boundary.
5	63 – 82	Btv_1	Red (2.5 YR 4/6) moist, common distinct red (10 YR 4/6) moist and bright yellow (10 YR 6/6) moist mottles; silty clay loam; weak fine sub-angular blocky; very few (< 1 %) fine quartz gravels; common distinct clay and iron cutans along pores and bridging grains; firm sticky plastic; many (20 %) soft iron nodules; common fine interstitial; few fine planar voids; very few fine roots; diffuse smooth boundary.

Appendix 4 continued:

Horizon no	Depth (cm)	Symbol	Description
6	82 – 105	Btv_2	Red (2.5 YR 4/6) moist; common distinct medium red (10 R 4/6) moist and bright yellow (10 YR 6/6) mottles; silty clay loam; weak fine sub-angular blocky; common distinct clay and iron cutans along pores; firm sticky plastic abundant (50 %) soft iron nodules; common fine interstitial pore, few coarse vughs; very few fine roots; diffuse boundary.
7	105 – 130	Btv_3	Red (2.5 YR) moist, common distinct red (2.5 YR 4/6) moist and bright yellow (10 YR 6/6) mottles; silty clay loam; weak fine sub-angular blocky; common distinct clay and iron nodules.

Appendix 5: Analysis of variance (ANOVA) of levels of N and P fertilizer treatments on maize grain and stover yields

		Grain yield (t ha^{-1})		Stover yield (t ha^{-1})	
Source of variation	df	ms	F pr.	ms	F pr.
Soil type	1	2.23	-	0.60	-
Block within location	4	2.83	-	2.81	-
Treatment	8	1.30	0.24	1.46	0.21
N linear	1	0.06	0.81	0.03	0.86
N quadratic	1	0.10	0.75	0.17	0.69
N cubic	1	0.03	0.86	0.43	0.52
N quartic	1	0.22	0.64	0.12	0.74
P linear	1	0.78	0.37	3.22	0.08
P quadratic	1	3.04	0.08	3.73	0.06
P cubic	1	0.01	0.93	0.93	0.34
P quartic	1	0.52	0.46	0.15	0.70
N versus P	1	7.95	0.01**	5.45	0.03*
Residual	40	0.94	-	1.01	-

df = degree of freedom; ms = mean square; F pr. = Fisher's probability

Appendix 6: Regression analysis of effective cowpea nodules in both soils (n = 30)

Source of variation	d.f	Mean deviance	F probability
Regression	3	32.71	< 0.001***
Residual	26	16.73	
Total	29	18.38	

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