

**EFFECT OF ORGANIC AND INORGANIC FERTILIZERS  
AND THEIR COMBINATIONS ON THE GROWTH AND  
YIELD OF MAIZE IN THE SEMI-DECIDUOUS FOREST  
ZONE OF GHANA**

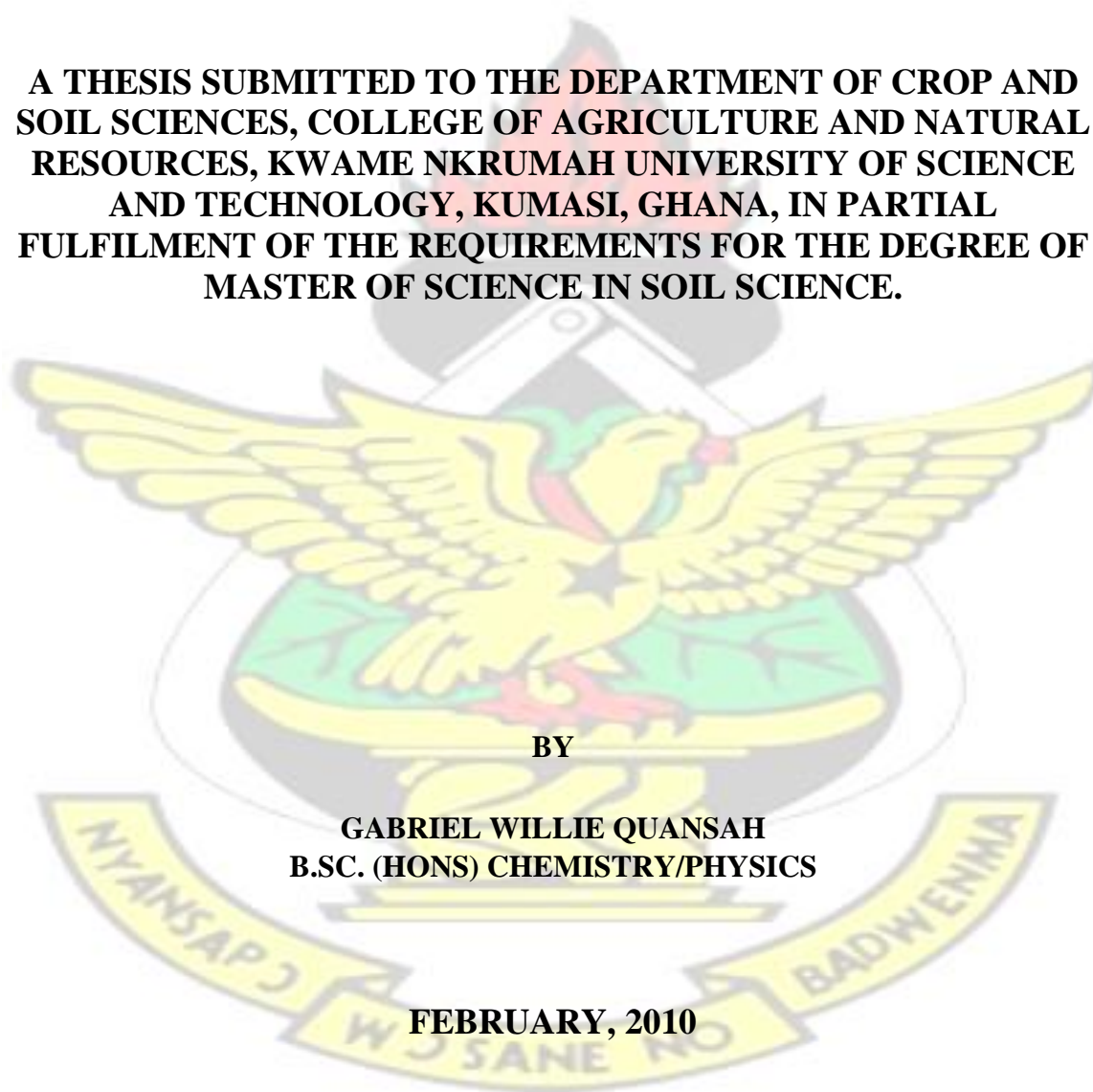
KNUST

**A THESIS SUBMITTED TO THE DEPARTMENT OF CROP AND  
SOIL SCIENCES, COLLEGE OF AGRICULTURE AND NATURAL  
RESOURCES, KWAME NKRUMAH UNIVERSITY OF SCIENCE  
AND TECHNOLOGY, KUMASI, GHANA, IN PARTIAL  
FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF SCIENCE IN SOIL SCIENCE.**

**BY**

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**FEBRUARY, 2010**



## DECLARATION

THIS THESIS IS AN ORIGINAL WORK AND HAS NOT BEEN SUBMITTED FOR A DEGREE IN ANY OTHER UNIVERSITY.

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## DEDICATION

TO GOD ALMIGHTY AND JESUS CHRIST HIS ONLY BEGOTTEN SON, FOR NOTHING IS IMPOSSIBLE WITH GOD AND TO MY DEAREST WIFE JOSEPHINE AND OUR WONDERFUL CHILDREN ASEDA, NHYIRA AND AYEYI. YOU ARE JUST COOL.

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## ABSTRACT

A study was conducted to characterize poultry manure and two composted materials (Household waste plus poultry manure and Market waste plus faecal sludge mixes in 3:1 ratio) based on their nutrient content and water holding capacity and to evaluate the influence of organic and inorganic fertilizers and their combination on the growth and yield of maize (*Zea mays*) in pot and field experiments at Soil Research Institute of CSIR, Kwadaso, Kumasi, Ghana.

The treatments were studied in a complete randomized design (CRD) in the pot experiment and in a randomized complete block design (RCBD) in the field experiment with three replications each. The results were analysed by ANOVA and the standard error of differences (SED) was used to separate the means. Regression analysis was used to establish relationships between measured parameters.

The experimental results showed that poultry manure was high in nutrients containing 2.06 % N, 0.52 % P and 0.73 % K whilst the composted materials were moderate in N and K but low in P. Percentage moisture of poultry manure at three stages; saturation, field capacity and 16 DAS were 119.51 %, 92.68 % and 63.41 % respectively which were higher than the values obtained under the composted materials.

Water use efficiency (WUE) increased significantly with increasing dry matter production in the pot experiment. The combined treatments had WUE values higher than the values obtained by the sole organic or inorganic treatments alone.

There were no significant differences ( $P > 0.05$ ) in the vegetative growth of maize for the various treatments; however, the combined treatments gave higher values of plant height, girth, leaf area and number of leaves than organic and inorganic fertilizers used separately.

Generally vegetative growth increased rapidly in all the treatments from 28 to 56 days after planting.

The field experiment showed trends that were similar to those observed in the pot experiment. The combined applications produced yields, which were significantly higher than organic or inorganic alone and the control. The highest grain and stover yields of 8.0 tons ha<sup>-1</sup> and 8.9 tons ha<sup>-1</sup> respectively was recorded by the combined treatment of poultry manure with mineral fertilizer at a rate of 60 kg ha<sup>-1</sup> N poultry manure and 60-4040 kg ha<sup>-1</sup> NPK mineral fertilizer, with the control recording the lowest grain and stover yields of 2.10 tons ha<sup>-1</sup> and 4.30 tons ha<sup>-1</sup> respectively.

The combined treatments had significantly higher nutrient uptake values than the sole organic and inorganic fertilizers alone. The highest nutrient uptake values of 142.09 kg ha<sup>-1</sup> N, 41.10 kg ha<sup>-1</sup> P and 50.87 kg ha<sup>-1</sup> K was recorded by the combined treatment of household waste and poultry manure mix compost with mineral fertilizer high rate.

Differences in soil nutrient concentrations after harvest were marginal for all the treatments. Soil pH and total N decreased in all the treatments while percentage C and available P and K increased generally.

Residual nutrients sustained maize plant growth and had yields, which were approximately 50% lower, with the sole application of mineral fertilizer as well as poultry manure high rate performing better than the combined applications contrary to what was observed in the major season.



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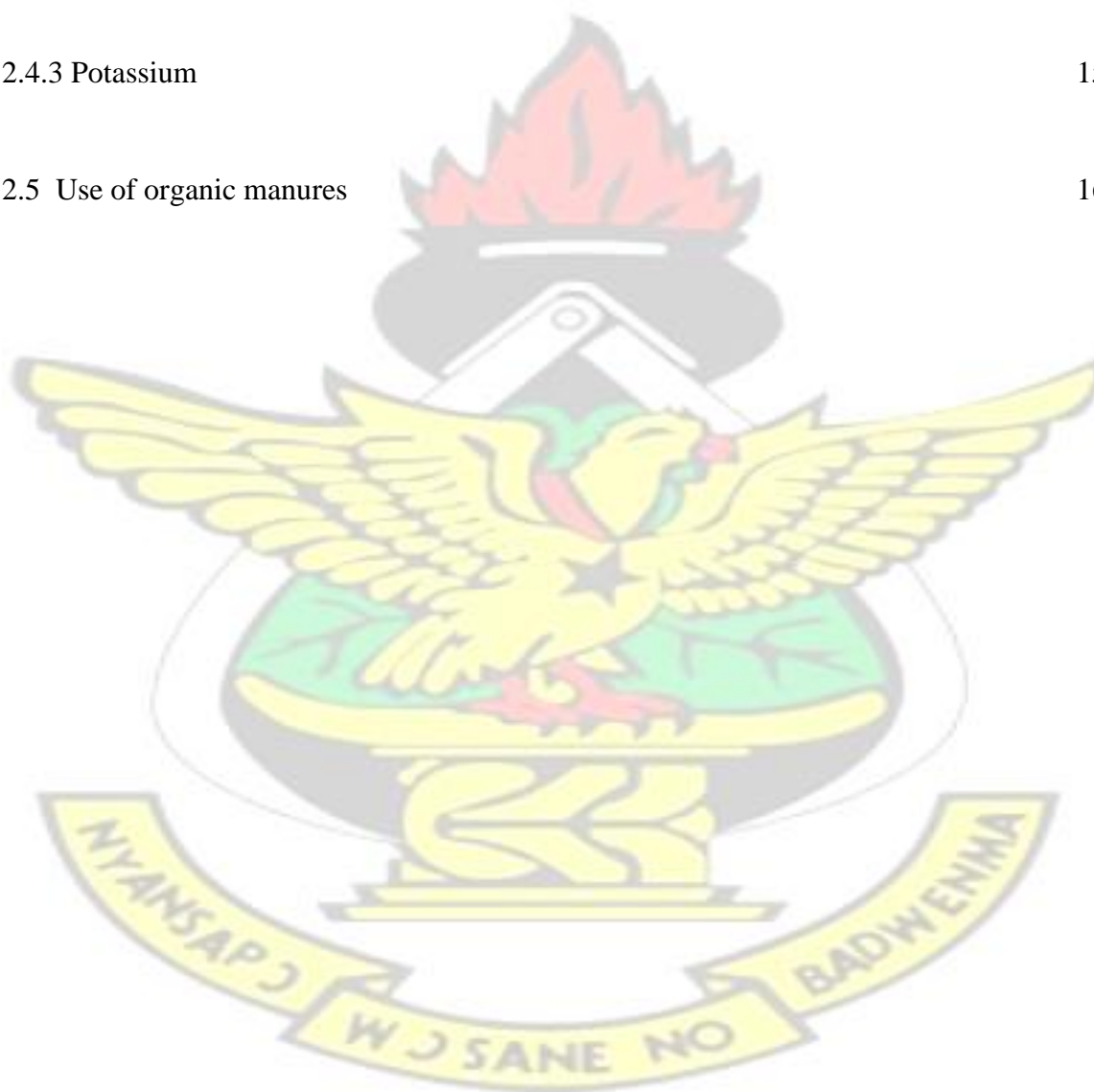
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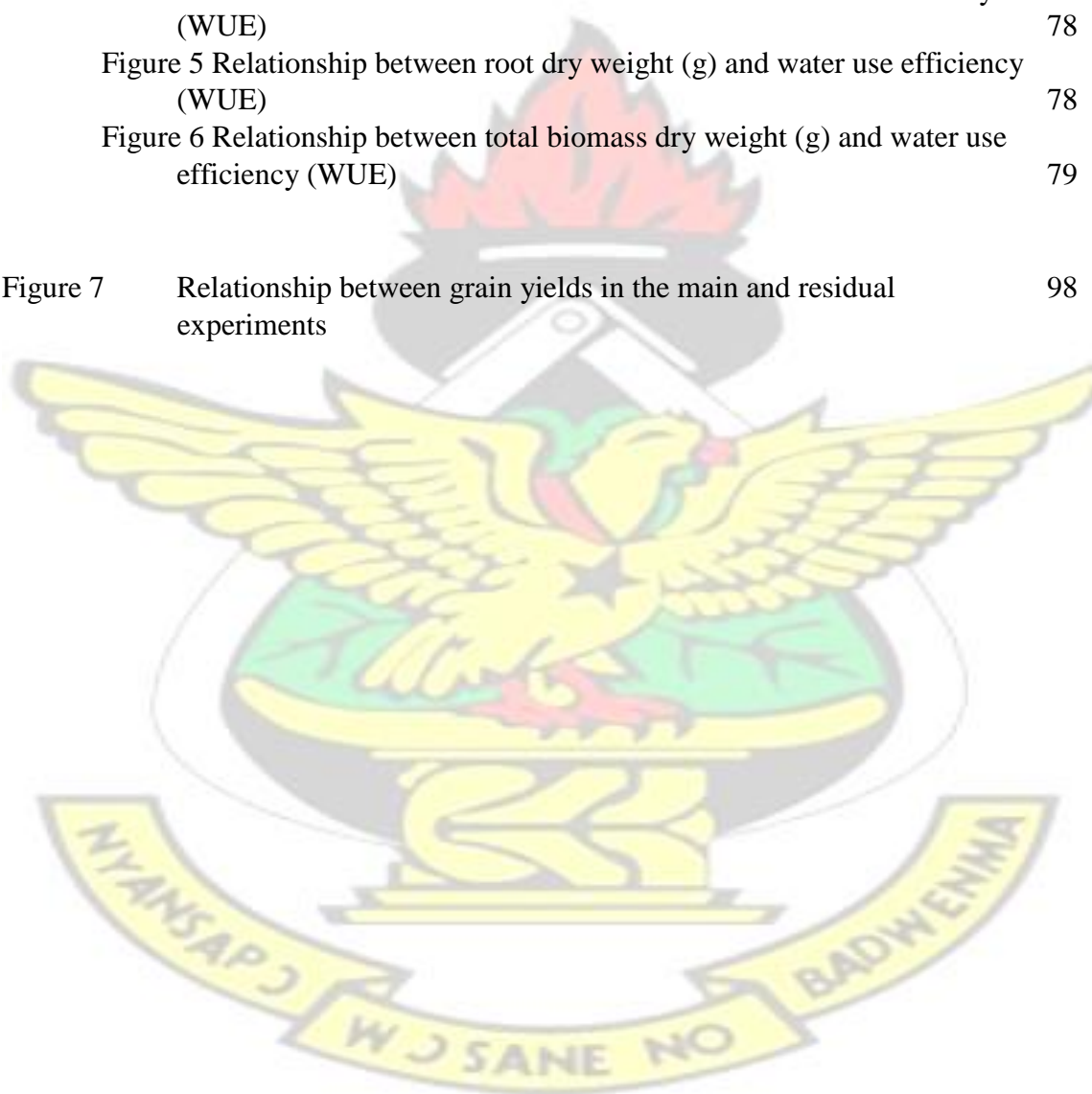


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## CHAPTER ONE

### 1.0 INTRODUCTION

Most food crops in Ghana are produced by subsistent farmers, who over the years, practised slash and burn and shifting cultivation to sustain yield even though at a low level. However, increasing human population has led to intensive cultivation without adequately replenishing soil nutrients. The result has been the decline in crop yields and depletion of the resource base. The soils become fragile, quickly lose organic matter and nutrients when exposed to harsh environmental conditions or intensive cultivation.

On smallholder farms, soil fertility decline has been recognised as one of the major biophysical constraints affecting agriculture, particularly nitrogen (N) and phosphorus (P) deficiencies (Mokwunye et al., 1996). However, soil fertility has seldom been considered a critical issue by the development community who, until very recently have focused primarily on other biophysical constraints, such as soil erosion, drought, and the need for improved crop germplasm, especially in Africa (Lele, 1981; Eicher, 1982; Davis and Schirmer, 1987). These authors concluded that soil fertility depletion in smallholder farms is the fundamental biophysical root cause of declining per capita food production in Africa, and that soil fertility replenishment should be considered as an investment in natural resource capital. They further observed that, no matter how effectively other conditions are remedied, per capita food production in Africa would continue to decrease unless the problem of soil fertility depletion is adequately addressed.

Generally, Ghanaian soils are of low inherent fertility and therefore require external inputs to improve fertility. The use of mineral fertilizers is the most effective and convenient way



to improve soil fertility. However, fertilizer use in Ghana has dropped to  $< 5\text{kg NPK ha}^{-1}$  (MOFA, 1998), due mainly to the high cost of mineral fertilizers (Bumb, 1994; Gerner et al., 1995). Consequently, there is presently a serious negative balance in nutrient budgets of soils in the country posing a major constraint to sustainable soil management for increased crop growth and yield. Ironically, there is a large amount of organic waste that can be turned into fertilizers for crop production at low cost. In Kumasi and its environs, for example, large quantities of poultry manure have given rise to disposal problems (Quansah, 2000). Also large quantities of urban waste are being generated each day in cities, which are facing disposal problems, notably in Accra and Kumasi. Complementary and supplementary to mineral fertilizer is the organic fertilizer, which contains large amounts of organic matter.

The use of organic inputs such as crop residues, manures and compost has great potential for improving soil productivity and crop yield through improvement of the physical, chemical and microbiological properties of the soil as well as nutrient supply (Tandon, 1992; Stone and Elioff, 1998). It follows that if a sustained productive agriculture is to be achieved, practices which maintain or increase soil organic matter reserves must be adopted. Young (1976) observed that the agricultural significance of organic matter in tropical soils is greater than that of any other property with the exception of moisture. However, the use of organic fertilizers has not been sufficiently explored. The extent to which organic fertilizers could increase the efficiency of applied mineral fertilizers in sustaining soil and crop productivity has not received much research attention. The little data available, however, indicate that integrated plant nutrition involving the combined use of organic and mineral fertilizers increases crop yields more than either used alone

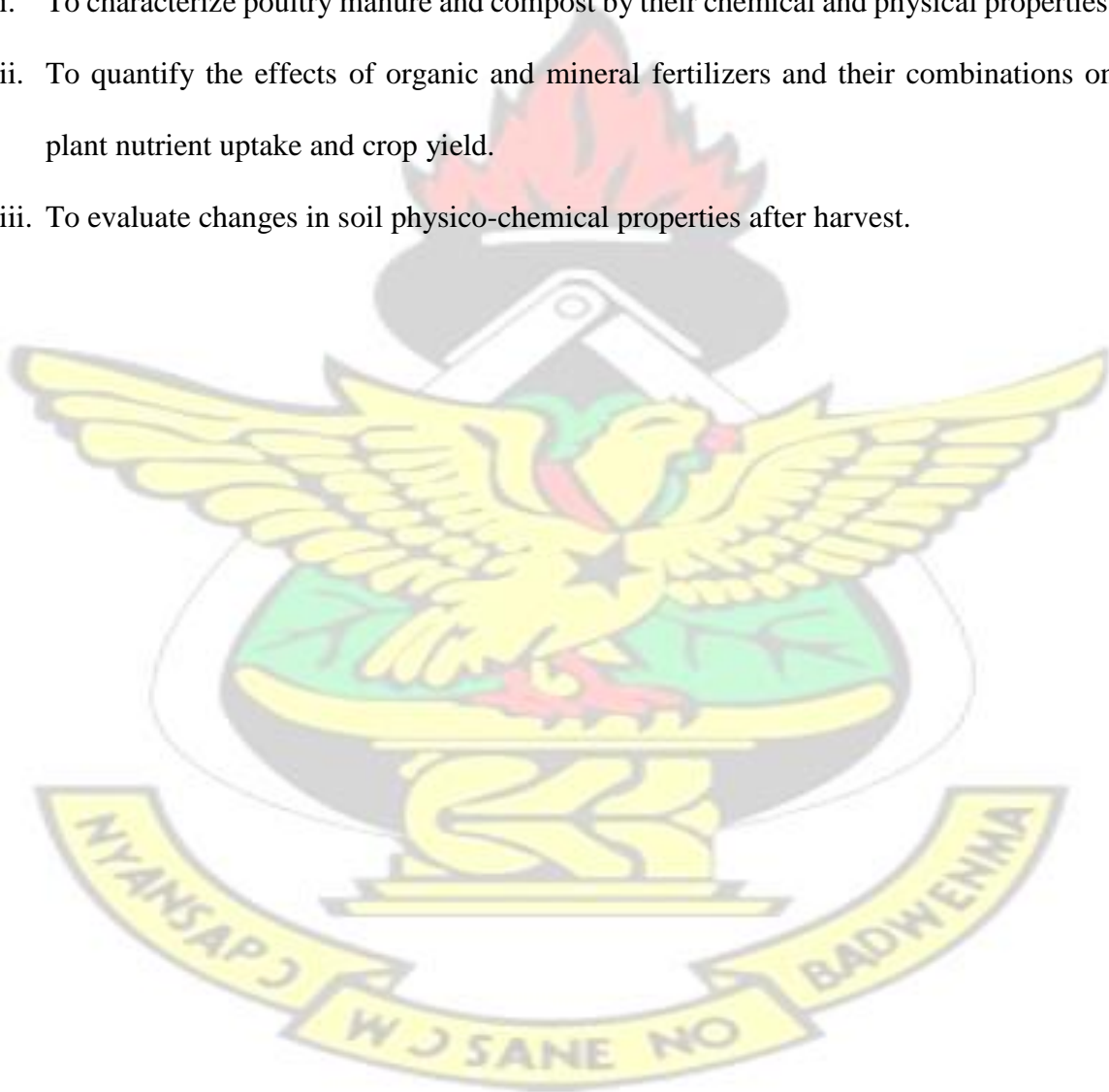


(Quansah, 2000). Soil fertility replenishment for sustaining crop productivity should use all possible sources of plant nutrients in an integrated manner (FAO, 1993).

It is within this context that this study was initiated to use organic and mineral fertilizers for maize production in the semi-deciduous forest zone of Ghana.

The objectives of the study were:

- i. To characterize poultry manure and compost by their chemical and physical properties.
- ii. To quantify the effects of organic and mineral fertilizers and their combinations on plant nutrient uptake and crop yield.
- iii. To evaluate changes in soil physico-chemical properties after harvest.



## CHAPTER TWO

### 2.0 LITERATURE REVIEW 2.1 INTRODUCTION

Everywhere in the world people settle first in areas with high potential fertile soils, adequate rainfall and mild temperatures. As populations grow, soilnutrient capital is gradually depleted when farmers are unable to sufficiently compensate losses by returning nutrients to the soil via crop residues, manures and mineral fertilizers.

Increasing pressures on agriculture result in much higher nutrient outflows and the subsequent breakdown of many traditional soil fertility maintenance strategies. These traditional fertility maintenance strategies such as fallowing, intercropping cereals with legume crops, manure producing mixed croplivestock farming and opening new lands have not been replaced by an effective fertilizer supply (Sanders et al., 1996). Several decades of nutrient depletion have transformed originally fertile lands that yielded about 2 to 4 t ha<sup>-1</sup> of cereal grain into infertile ones where cereal crops yield less than 1 t ha<sup>-1</sup>. For example, long-term trials in Kabete, Kenya indicated that a fertile soil lost about 1 t ha<sup>-1</sup> of soil organic N and 100 kg P ha<sup>-1</sup> of soil organic P during 18 years of continuous maize (*Zea mays*) – common beans (*Phaseolus vulgaris*) cultivation without nutrient inputs, with maize yields decreasing from 3 to 1 t ha<sup>-1</sup> during that period (Qureshi, 1991; Swift et al., 1994; Kapkiyai et al., 1997). The bulk of the food in Africa is produced on smallholder farms (Cleaver and Schreiber, 1994; Gladwin et al., 1997). One of the major problems affecting

food production in Africa is the rapid depletion of nutrients in smallholder farms (Badiane and Delgado, 1995). This is because the smallholder farmer is poorly resourced and unable to invest in soil fertility inputs, particularly mineral fertilizers. This is not surprising since about half of Africa's population is classified as "absolute poor" subsisting on per capita incomes of less than 1 US\$ per day (Badiane and Delgado, 1995). The situation is critical especially when the poor farmer has to bear the full cost of production owing to the removal of subsidies on mineral fertilizers.

The major effect of soil fertility decline is the observed reduced food production in most African countries, including Ghana. In order to sustain soil and crop productivity, it is necessary to explore alternative soil fertility replenishment strategies, which are effective and affordable to farmers, especially the smallholder farmer.

## **2.2 NUTRIENT DEPLETION**

The magnitude of nutrient depletion in Africa's agricultural land is enormous. Stoorvogel and Smaling (1990), indicated that an average of 660 kg N ha<sup>-1</sup>, 75 kg P ha<sup>-1</sup> and 450 kg K ha<sup>-1</sup> have been lost during the last 30 years from about 200 million hectares of cultivated lands in 37 countries of Sub-Saharan Africa, excluding South Africa. This is equivalent to 1.4 t of urea ha<sup>-1</sup>, 375 kg of triple superphosphate (TSP) ha<sup>-1</sup> or 0.9 t of phosphate rock (PR) ha<sup>-1</sup> of average composition and 896 kg of potassium chloride (KCl) ha<sup>-1</sup> during the said period. These figures represent the balance between nutrient inputs (in fertilizers,

manure, atmospheric deposition, biological nitrogen fixation (BNF) and sedimentation) and nutrient outputs (in harvested products, crop residue removals, leaching, gaseous losses, surface runoff and erosion (Stoorvogel and Smaling, 1990).

Food production has therefore depended on nutrient mining approach since very small amounts of nutrients are returned through fertilizer application (Ofori and Fianu, 1996). In a study commissioned by FAO, Stoorvogel and

Smaling (1990) found negative country N-P-K budgets in 1983 for all West African countries. Figures show that in Ghana there is a negative nutrient balance of approximately 27 kg N ha<sup>-1</sup>, 4 kg P ha<sup>-1</sup> and 21 kg K ha<sup>-1</sup> annually (FAO, 2004). Rhodes (1995) estimated the rates of total crop uptake in Ghana at 428,700 t of N, 73,100 t of P and 414,900 t of K over 10 years. Also production of the main food crops in Ghana removes almost 70,000 t of N and 25,000 t of P<sub>2</sub>O<sub>5</sub> from the soil annually (MOFA, 1998). To compensate for this nutrient uptake, a fertilizer consumption of about 400,000 t, assuming a use efficiency of 50 %, is required. Ghana's annual fertilizer consumption is approximately 35,000 t, about 10 times less than what is required in the circumstance stated above. The use of fertilizer N, P plus K has also been estimated to be 27 % of the quantity of nutrients removed by the grain/tuber food crops in Ghana (Rhodes, 1995). He also observed that as much as 44 % of N, 42 % of P and 56 % of K taken up were present in crop residues. The use of crop residues as sources of nutrients and soil organic matter amendment has long been a major component of many farming systems in Africa. In Ghana,



however, the use of plant residues is low. Presently, most of the crop residues are removed for uses with higher economic value such as animal feed, fuel and building materials (Bationo et al., 1993). Baanante et al. (1992) showed in a farm survey results that as much as 70 % of crop residue produced by farmers in the Ashanti region of Ghana served no useful agricultural purpose.

### **2.3 NUTRIENT REPLENISHMENT**

The major pathways of soil fertility decline on farmlands include the loss of nutrients through erosion, leaching, volatilization, crop uptake and harvest without the complementary replenishment. Soil nutrient replenishment is therefore a prerequisite for halting soil fertility decline. This may be accomplished through the application of mineral and organic fertilizers.

In Ghana, the most deficient nutrients in soils are nitrogen and phosphorus (Ofori and Fianu, 1996). Nitrogen inputs at the field scale mainly come from inorganic fertilizers, biological nitrogen fixation (BNF), biomass transfers, animal manures or composts produced outside the field and nitrate capture from subsoil depths beyond the reach of crop roots. The main issue in N replenishment is not the size of the capital N stocks, but the cycling rate (Giller et al., 1997). Therefore, appropriate strategies are those that will provide sufficient levels of N inputs while at the same time slowly rebuilding N stocks. Replenishing N stocks by these strategies would require very large inputs of organic N. For example, an increase in soil organic N concentration in the topsoil from 0.1 to 0.3 % is equivalent to an application of about 320 t ha<sup>-1</sup> of dry biomass. Such large applications are clearly impractical, so in the short to



medium term, increased soil N supply will depend on regular inputs of organic N sources (Sanchez, 1997).

Given the largely biological nature of N cycle, organic inputs (manure and plant biomass application) play a crucial role in N replenishment. Also, organic inputs have an important advantage over inorganic fertilizers with regard to fertility replenishment, in that they provide a source of carbon for microbial utilization. Soil microorganisms need a C substrate for growth and energy. They utilize the N from organic inputs, which results in the formation of soil organic N. Part of the N bound in the more recalcitrant forms in the organic inputs will also build up soil humic substance. Inorganic fertilizers do not contain such C sources, and therefore much of the fertilizer N not used by crops is subject to leaching and de-nitrification losses. Organic additions therefore apparently provide the C necessary to reduce the depletion of N in fertile soils (Sanchez, 1997). However, at high crop yield levels, e.g. above 6 t ha<sup>-1</sup> of maize grain, organic N inputs are likely to be insufficient and must be supplemented with inorganic fertilizers (Sanchez, 1994). The joint organicinorganic N replenishment strategy provides both N and C inputs that gradually increase soil N and C stocks (Buol and Stokes, 1997). Phosphorus replenishment is usually accompanied by nitrogen replenishment because most P-deficient soils are also deficient in N (Sanchez, 1997). Large applications of phosphorus can build the fertility of the soil either immediately or within a few years, and that the residual effect of such replenishment lasts for at least 10 years (Lopez, 1996). Application of superphosphate in the order of 150 to 500 kg P ha<sup>-1</sup> is probably the most direct way to replenish Pcapital and the effect lasts for several years

in high P-fixing soils (Goedert, 1987). The duration of the effects of P applications depends on several factors. However, the larger the application rate, the longer the residual effect.

The phosphorus content of plant residues and manures is normally insufficient to meet crop requirements. Plant materials applied as organic inputs (biomass transfer, manures and composts) contain 8 to 12 kg P ha<sup>-1</sup> when applied at the top realistic rate of 4 t dry matter ha<sup>-1</sup> (Palm, 1995). The decomposition of organic inputs produces organic acids that may dissolve (solubilize) phosphate rock. A combination of phosphate rock with compost has been shown to increase the availability of the phosphorus. Research has also shown that triple superphosphate (TSP) produces higher maize yields following the combined incorporation of P fertilizers with 1.8 t ha<sup>-1</sup> of *Tithonia diversifolia* dry biomass, rather than urea at an equivalent N rate. In intensive cropping, soil productivity can be sustained only through integrating mineral phosphorus application with organic inputs (manure, composts and plant residues) and this is the most effective means of replenishing soil phosphorus. Potassium deficiencies do occur in specific circumstances, but not to the same extent as N and P deficiencies. The level of K-mining (15 kg ha<sup>-1</sup> y<sup>-1</sup>) is six times that of P-mining, but crop responses to K fertilization, however, are rare in Africa except in sandy savanna soils (Ssali et al., 1986). This is probably due to the high K capital in many parts of Africa, even though it is rapidly being depleted.

#### **2.4. MAJOR NUTRIENTS AFFECTING PLANT GROWTH AND YIELD IN CROP PRODUCTION**

### 2.4.1. Nitrogen

The N-requirement of crops is comprehensively reviewed by Tisdale et al. (1993). Nitrogen is a vitally important plant nutrient, the supply of which can be controlled by man (Adediran and Banjoko, 1995; Shanti et al., 1997). In maize production it is a major yield-determining factor and its availability in sufficient quantity throughout the growing season is essential for optimum maize growth (Kogbe and Adediran, 2003).

In the soil, N found in decomposing organic matter may be converted into ammonium N ( $\text{NH}_4^+$ ) by soil microorganisms (bacteria and fungi) through mineralization (Pidwimy, 2002).

Nitrogen in the form of  $\text{NH}_4^+$  can then be adsorbed onto the surfaces of clay particles in the soil. The  $\text{NH}_4^+$  ion that has a positive charge may be held by soil colloids because they have a negative charge. This process is called micelle fixation (Pidwimy, 2002). As this fixation is reversible,  $\text{NH}_4^+$  may be released from the colloids by way of cation exchange. When released,  $\text{NH}_4^+$  may be chemically altered through bacteria action or processes resulting in the production of  $\text{NO}_3^-$ . Normally  $\text{NO}_3^-$  accumulates in the soil. This is because  $\text{NO}_3^-$  has a negative charge; it may not be adsorbed onto the soil colloids, so most  $\text{NO}_3^-$  stays in the soil solution. If  $\text{NO}_3^-$  is not taken up by the roots, it can be transported below the root zone and leached or denitrified. As  $\text{NO}_3^-$  is soluble in water, it is easily leached from the root zone by excessive rainfall or irrigation (Simonne and Hochmuth, 2003).

In plant nutrition, nitrogen is involved in the composition of all amino acids, proteins and many enzymes. Nitrogen is also part of the puric and pyrimidic bases, and therefore is a constituent of nucleic acids (Mills and Jones, 1996). Typically, N content in plants ranges between 1 and 6 % of the dry weight in leaf tissues. It is absorbed by plants in the form of nitrate and ammonium ions. In moist, warm, well-aerated soils the nitrate form is dominant. Once inside the plant, nitrate is reduced to  $\text{NH}_4^+$ -N using energy provided by photosynthesis. Glucose consumption for protein production is about 50 % higher when N is provided as  $\text{NO}_3^-$  rather than as  $\text{NH}_4^+$ . In addition to its role in the formation of proteins, nitrogen is an integral part of chlorophyll, which is the primary absorber of light energy needed for photosynthesis.

An adequate supply of N is associated with vigorous vegetative growth and a dark green colour and an imbalance of N or an excess of this nutrient in relation to other nutrients, such as P, K, and S can prolong the growing period and delay crop maturity (Marti and Mills, 1991). Stimulation of heavy vegetative growth early in the growing season can be a serious disadvantage in regions where soil moisture supplies are often low. Early-season depletion of soil moisture without adequate replenishment prior to the grain-filling period can depress yield. Application of up to 330 kg of N  $\text{ha}^{-1}$  lowered the percentage water in corn grain at harvest.

The supply of N is related to carbohydrate utilization. When N supply is insufficient, carbohydrates will be deposited in vegetative cells, which will cause them to thicken (Sasseville and Mills, 1979; Marti and Mills, 1991; Mills



and Jones, 1996). When N supplies are adequate, and conditions are favourable for growth, proteins are formed from the manufactured carbohydrates, less carbohydrate is thus deposited in the vegetative cells and more protein is formed, and because protoplasm is highly hydrated, a more succulent plant results. Excessive succulence in some crops may have a harmful effect. With grain crops, lodging may occur.

When plants are deficient in N, they become stunted and yellow in appearance. This yellowing, or chlorosis, usually appears first on the lower leaves; the upper leaves remaining green. In cases of severe N shortage the leaves will turn brown and die (Mills and Jones, 1996). The tendency of the young upper leaves to remain green as the lower leaves yellow or die is an indication of the mobility of N in the plant. When the roots are unable to absorb sufficient amounts of this element to meet the growing requirement, N compounds in the older plant parts will undergo lysis. This involves the conversion of protein N to a soluble form, which are translocated to the active meristematic regions and reused in the synthesis of new protoplasm.

#### **2.4.2. Phosphorus**

Phosphorus (P) is the most important nutrient element (after nitrogen) limiting agricultural production in most regions of the world (Holford, 1997; Kogbe and Adediran, 2003). It is a structural component of DNA and RNA, the two genetic entities that are essential for the growth and reproduction of living organisms. Living organisms whether plants or humans, also derive their internal energy from P-containing compounds, mainly adenosine diphosphate



(ADP) and adenosine triphosphate (ATP). This means that inadequate P supply will result in a decreased synthesis of RNA, the protein maker, leading to depressed growth (Hue, 1995).

Phosphorus-deficient plants, therefore, are stunted with a limited root system and thin stems. In many plants, seedlings look stunted and older leaves may turn purple because of the accumulation of anthocyanins or purple pigments. The plants may produce only one small ear containing fewer, smaller kernels than usual. Grain yield is often severely reduced (Jones et al., 2003). Plants concentrate phosphorus in the seed, which is usually harvested. The stem, leaves and roots of a mature crop tend to be lower in phosphorus and contribute only a small part of the next crop's phosphorus requirements.

Internally, most crops need 0.2 to 0.5 % P in the dry matter for normal growth. Plants extract P exclusively from the soil solution in either  $\text{H}_2\text{PO}_4^-$  or  $\text{HPO}_4^{2-}$  form. There is however a strong competition between plants and soils for P in the solution, and the winner usually being soils, especially highly weathered soils like those in the tropics. Most soils in the tropics contain large amounts of iron- and aluminium-oxides or amorphous alumino silicate clays, which tie up P firmly, making P virtually unavailable for plant uptake. It is estimated that as much as 90 % of added fertilizer phosphorus is fixed in these soils (Potash and Phosphate Institute, 2003). Generally, phosphorus in all its natural forms, including organic forms is very stable or insoluble and only a small proportion exists in the soil solution at any one time (Holford, 1997). This is simply known as “Phosphorus problem” based on a phenomenon where phosphorus in

fertilizer or manure is far in excess than what the crop actually takes up. Also this problem can be remedied when soil pH is maintained between 6 and 7. Soil phosphorus fixation is minimized. Amounts of P required vary, depending on how much P the soil has, to begin with. Addition of P to the soil year after year, builds up soil P to a point that it becomes detrimental to crops because of excess (Potash and Phosphate Institute, 2003). However, once P is built to a good level, that level would remain for many years without any additional P input. The reason is that unlike nitrogen, P is less soluble in water and leaching is minimal (Hue, 1995).

#### **2.4.3. Potassium**

Potassium is needed in large quantities by many crops as indicated by Hue (1995). It is required for maintaining the osmotic potential of cells and turgidity of plants. Since K regulates the osmotic potential of cells, and the closure or opening conditions of stomata, it plays an important role in water relations in the plant. Potassium is involved in water uptake from the soil, water retention in the plant tissue, and long distance transport of water in the xylem and of photosynthates in the phloem (Marschner, 1995).

Potassium affects cell extension. With adequate K, cell walls are thicker, thereby improving plant resistance to lodging, pests and diseases (Bergmann, 1992). Fruits and vegetables grown with adequate K seem to have a longer shelf life. Consequently, K-deficient plants show low resistance to diseases and

their seeds and fruits are small and shriveled (Martin-Prevel, 1989; Perrenoud, 1993). In maize, the maturity is delayed and ears are smaller when

K is deficient. The stalks are weak and lodging is common. The most visual K deficiency symptom is the scorching or firing along leaf tips and margins (Bergmann, 1992; Perrenoud, 1993; Singh and Trehan, 1998).

In soils, potassium is quite mobile as compared to phosphate. It exists as  $K^+$  in soil solution and is absorbed by roots in that form. Although  $K^+$  can be retained to some extent by negative charges on clay surface,  $Ca^{2+}$  or  $Mg^{2+}$  can displace it into the soil solution, when gypsum or dolomite is added. Thus if K is not taken up by plants, it might be lost by leaching (Bergmann, 1992;

Perrenoud, 1993; Singh and Trehan, 1998). One way to reduce K leaching is to add organic matter such as compost to the soil. Organic matter usually has large cation exchange capacity, which can retain K effectively.

## **2.5. USE OF ORGANIC MANURES**

Animal manures are valuable sources of nutrients and the yield-increasing effect of manure is well established. Apart from the nutrients in manure, its effects on the improvement of soil organic matter, soil structure and the biological life of the soil are well recognized particularly at high rates of application in on-station trials. There is also some evidence that it may contain other growth-promoting substances like natural hormones and B vitamins (Leonard, 1986). Plants can only use nutrients that are in an inorganic form. Manure N and P are present in organic and inorganic forms, and are not totally

available to plants. The organic forms must be mineralized or converted into inorganic forms over time before they can be used by plants. The availability of K in manure is considered similar to that in commercial fertilizer since the majority of K in manure is in the inorganic form (Motavalli et al., 1989). In general, 90 to 100 % of K in manure is available during the first year of application. Many studies have demonstrated that application of manure will produce crop yields equivalent or superior to those obtained with chemical fertilizers (Xie and MacKenzie, 1986; Motavalli et al., 1989). Crop quality has also been improved by manure application (Eck et al., 1990; Pimpini et al., 1992). When crop improvements with manure were greater than those attained with commercial fertilizer, response was usually attributed to manure supplied nutrients or to improved soil conditions not provided by commercial fertilizer (CAST, 1996). Zhang et al. (1998) found that 2 kg manure-N were equivalent to 1 kg of urea-N in terms of plant uptake and yield response during the first year following cattle feedlot manure application. Manure improves the physical condition of the soil and increases P and biological activity (Sommerfeldt and Chang, 1985; Chang et al., 1990; CAST, 1996). The organic matter, total N and micronutrient content of the surface soil are increased as a result of manure application. The manure requirements for most of the crops are high, ranging from 5 to 20 tons of fresh manure ha<sup>-1</sup>. A survey by Mclutire et al. (1992) revealed that in an on-station research applied quantities of manure were approximately 2.5 to 20 tons ha<sup>-1</sup>, whereas farmers' actual application levels ranged from 175 to 700 kg ha<sup>-1</sup>. William et al. (1995) indicated that there



was not enough manure to sustain yields at even the current levels found in farmers' fields.

Manure, when applied, will be mineralized gradually and nutrients become available. However, the nutrient content of manure varies, and the reason is that the fertilizer value of manure is greatly affected by diet, amount of bedding, storage and application method (Harris et al., 2001). Cross and Strauss (1985) quoted the following for municipal wastes, 0.4 – 3.6 % N, 0.3 – 3.5 %  $P_2O_5$ , and 0.5 – 1.8 %  $K_2O$ , while Gaur and Verma (1991) stated that Indian municipal wastes contain 0.5 % N, 0.3 % P and 0.3 % K. Also, Leonard (1986) quoted 1.1 % N, 1.1 %  $P_2O_5$  and 0.5 %  $K_2O$  for poultry manure at 70 % moisture content. In spite of the considerable variation, farmers in some cities favour organic manure (urban wastes) since their effect once applied might last for 2 or 3 years (Leonard, 1986). Boateng and Oppong (1995) reported improved soil physical properties by adding farmyard manure. In Kenya, the value of manure is approximately five times that of its chemical fertilizer equivalent value (Lekasi et al., 1998). This is presumably related to the effect of manure on the physical properties of soil as well as its role in plant nutrient supply. Bationo and Mokwunye (1992) also noted that the addition of organic materials either in the form of manures or crop residues has beneficial effects on the soils chemical and physical properties. It is also well known that the use of farmyard manure can reduce nutrient deficiency in soils. Koppen and Eich (1993) noted that K and P deficiencies were reduced when farmyard manure was applied, and with rising pH values, the Mn content of the soil declined. The potential of manure, especially poultry litter, to neutralize soil acidity and raise soil



pH is less well known. Long term field and greenhouse studies have demonstrated the liming effect of animal manure in acid and neutral soils.

Compost is also a slow-release fertilizer. Compared with fresh manure, its N is in a more stable form and not susceptible to loss as  $\text{NH}_3$  gas (Leonard, 1986). The nutrient value of compost varies a lot and depends on what it is made from. Aside from N, P and K, it supplies varying amounts of secondary nutrients and micronutrients. In addition some composts contain other growthpromoting substances such as B vitamins, natural hormones and organic acids. In the preparation of compost it is desirable to mix materials for composting in the proportions that give rapid, effective and complete decomposition to a stable product (Harris et al., 2001). Compost that has been made from a variety of materials is likely to provide the best spectrum of nutrients. Thus the range and supply of different materials may need to be considered in a waste management strategy for soil amelioration. Lopez-Real (1995) considered that the market wastes could be co-composted with sawdust waste. Leonard (1986) reported NPK ranges for composted materials as 0.75 – 1.5 % N, 0.25 – 0.5 %  $\text{P}_2\text{O}_5$  and 0.5 – 1.0 %  $\text{K}_2\text{O}$ .

## **2.6. USE OF INORGANIC FERTILIZERS**

Chemical fertilizers are used in modern agriculture to correct known plantnutrient deficiencies; to provide high levels of nutrition, which aid plants in withstanding stress conditions; to maintain optimum soil fertility conditions; and to improve crop quality. Adequate fertilization programmes supply the amounts of plant nutrients needed to sustain maximum net returns (Leonard,

1986). In essence, fertilizers are used to make certain that soil fertility is not a limiting factor in crop production.

## **2.7. INTEGRATED NUTRIENT MANAGEMENT**

Integrated nutrient management implies the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity on one hand and to minimize nutrient losses to the environment on the other hand. It is achieved through efficient management of all nutrient sources. Nutrient sources to a plant growing on a soil include soil minerals and decomposing soil organic matter, mineral and synthetic fertilizers, animal manures and composts, by-products and wastes, plant residue, and biological N-fixation (BNF) (Singh et al., 2002).

For sustainable crop production, integrated use of chemical and organic fertilizer has proved to be highly beneficial. Several researchers have demonstrated the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P and K fertilizers for a few years, without any micronutrient or organic fertilizer. A field experiment was conducted by Chand et al. (2006) for seven years continuously to evaluate the influence of combined applications and organic and chemical fertility buildup and nutrient uptake in a mint (*Mentha arvensis*) and mustard (*Brassica juncea*) cropping sequence. Results indicated that integrated supply of plant nutrients through FYM (farmyard manure) and fertilizer NPK, along with *Sesbania* green manuring, played a significant role in sustaining soil fertility and crop

productivity. Based on the evaluation of soil quality indicators, Dutta et al. (2003) reported that the use of organic fertilizers together with chemical fertilizers, compared to the addition of organic fertilizers alone, had a higher positive effect on microbial biomass and hence soil health. Application of organic manure in combination with chemical fertilizer has been reported to increase absorption of N, P and K in sugarcane leaf tissue in the plant and ratoon crop, compared to chemical fertilizer alone (Bokhtiar and Sakurai, 2005). Kaur et al. (2005) compared the change of chemical and biological properties in soils receiving FYM, poultry manure and sugarcane filter cake alone or in combination with chemical fertilizers for seven years under a cropping sequence of pearl millet and wheat. Results showed that all treatments except chemical fertilizer application improved the soil organic C, total N, P and K status. Increase in microbial biomass C and N was observed in soils receiving organic manures only or with the combined application of organic manures and chemical fertilizers compared to soils receiving chemical fertilizers. This study showed that balanced fertilization using both organic and chemical fertilizers is important for maintenance of soil organic matter (OM) content and long-term soil productivity in the tropics where soil OM content is low. Also in Burkina Faso, Pichot et al. (1981) found that manure in combination with small fertilizer applications improved the soil as opposed to heavy fertilizer doses alone or mere application of crop residues. Quansah et al. (1998) and Palm (1995) also obtained significant increase in crop yields when a combination of organic and mineral fertilizers was applied compared with sole application of organic or mineral fertilizer. Prasithikhet et al. (1993) used organic and mineral fertilizers

in farmers' rice fields and recommended that a low rate of compost manure should be used with mineral fertilizer over a long period in order to promote high rice yields and good soil fertility. Sutanto et al. (1993) in their studies on acid soils for sustainable food crop production noted that farmyard manure and mineral fertilizer produced excellent responses. Boateng and Oppong (1995) studied the effect of farmyard manure and method of land clearing on soil properties on maize yield and reported that plots treated with poultry manure and NPK (20-20-0) gave the best yield results.

The effects of organic fertilization and combined use of chemical and organic fertilizer on crop growth and soil fertility depends on the application rates and the nature of fertilizers used. In general, the application rates of organic fertilizer mostly are based on crop N need and estimated rates of organic fertilizer N supply, but do not consider the amount of P and K provided with organic fertilizer. However, the N/P ratio of organic fertilizer usually is significantly lower than the N/P uptake ratio of the crop. Therefore, basing organic fertilizer on N supply typically results in P addition in excess of the crop's need.

## **2.8. RESIDUAL EFFECTS**

The immediate short-term effects of applied fertilizers are often emphasized to the neglect of residual effects. Yet when farming is continued on the same site for several years, residual effects of fertilizer treatments may considerably affect the soil chemical properties and consequently crop yield (Gaur, 1982; Enwezor et al., 1989). Reviewing the residues of fertilizers on succeeding



crops, Cooke (1970) reported that past manuring with farmyard manure and fertilizers leaves residues of nitrogen, phosphorus and potassium in soil that benefit following crops. He further indicated that the residues of inorganic nitrogen fertilizers usually last only for a season, but the residual effects of continued manuring with phosphorus and potassium may last for many years.

Akande et al. (2003) also reported an increase in soil available P of between 112 and 115 % and 144 and 153 % respectively for a two year field trials, after applying rock phosphate with poultry manure on okra. Akande et al. (2005) further reviewing the effect of rock phosphate amended with poultry manure on the growth and yield of maize and cowpea reported that when rock phosphate application had continued over a period of several years a large pool of undissolved rock phosphate could accumulate.

Residual effects of manure or compost application can maintain crop yield level for several years after manure or compost application ceases since only a fraction of the N and other nutrients in manure or compost become plant available in the first year after application (Motavalli et al., 1989; Ramamurthy and Shivashankar, 1996; Eghball, 2002). Eghball and Power (1999) found that 40% of beef cattle feedlot manure N and 20% of compost N became plant available in the first year after application, indicating that about 60% of manure N and 80% of compost N became plant available in the succeeding years, assuming little or no loss of N due to  $\text{NO}_3^-$  - N leaching or denitrification. Residual effects of organic materials on soil properties can contribute to improvement in soil quality for several years after application ceases (Ginting et al., 2003).

Residual effect of organic matter added to the soil by the manure refers to the carry-over benefit of the application on the succeeding crop. Nutrients present in organic matter are not fully available to the crops in the season of its application (Ramamurthy and Shivashankar, 1996). In corn, the residual effect of organic matter improved the plant height, dry-matter production at different stages of crop growth and yield-attributing characters of corn like number of cobs plant<sup>-1</sup>, shelling (%), 100-grain weight, harvest index, protein contents of grain and protein yield ha<sup>-1</sup> (Raramurthy and Shivashankar, 1996).

However, residues of fertilizers left in the soil often raise yields in ways that are difficult to imitate with fresh fertilizer dressings, sometimes responses to fresh dressings are unaffected by residues of previous dressings, but usually residues lessen the size of the fresh dressing needed (Cooke, 1970).

Cooke (1970) found that 184.8 kg N ha<sup>-1</sup> given to potatoes raised yields of wheat the following year which received no fresh fertilizer nitrogen from 3463.8 to 4570.5 kg ha<sup>-1</sup>, but even where the wheat received a fresh dressing of 123.2 kg N ha<sup>-1</sup> residues from the dressing given to the previous potatoes still raised yields by 764.5 kg ha<sup>-1</sup>. Further results showed that when soil contains residues of inorganic nitrogen, larger maximum yields are possible than may be obtained from soil without residues. The results also showed that dressings of inorganic N fertilizers had large residual effects in the first year after the dressings stopped but much smaller effects in the second and third years.

The residual effect of a single dressing of phosphorus and potassium is usually much smaller than the direct effect the year before and may be too small to

measure accurately in experiments. But the cumulative residual effects of many annual dressings are large and may be sufficient for normal yields of crops with small additions of fertilizer (Cooke, 1970). Grewal and Treham (1979) noted that tuber size and yield of potato as well as uptake of P and K were significantly increased with application of P and K sources. They also realized that the direct and cumulative effects of P and K applications were significantly better than their residual effects.

## **2.9. ENVIRONMENTAL FACTORS AFFECTING THE GROWTH OF MAIZE**

Maize is grown in tropical, sub-tropical and temperate climates (FAOAGL, 2002). The highest production, however, occurs between 21 and 27 °C with annual precipitation of 250 to 5000 mm. Soil water availability is often the main factor limiting rainfed maize production. In these water-limited systems, efficient capture and retention of precipitation is essential to maximize crop growth. This is especially true for summer annual crops such as maize, which exhibit yield reductions in response to soil water deficits at any growth phase (Roygard et al., 2002). Many studies have shown maize grain yields to be especially sensitive to moisture stress at a period beginning approximately at tasseling and continuing through grain filling (Grant et al., 1989; NeSmith and Ritchie, 1992). Moisture stress at this stage commonly results in barrenness.

One of the main causes of this, though not the only one (Zinselmeier et al., 1995), is thought to be a reduction in the flux of assimilate to the developing ear below some threshold level necessary to sustain grain formation and growth

(Westgate and Bassetti, 1990; Schussler and Westgate, 1995). Drought which coincides with this growth period can cause serious yield instability at the farm level, as it allows no opportunities for farmers to replant or otherwise compensate for loss of yield. Moisture stress is thought to cause average annual yield losses in maize of about 17% per year in the tropics (Edmeades et al., 1992), but losses in individual seasons have approached 60% in regions such as southern Africa (Rosen and Scott, 1992).

The maize crop can tolerate a wide range of temperatures (from 5 to 45 °C), but very low or very high temperatures can have a negative effect on yield. Nielsen (2007) found that maximum temperatures greater than 32 °C around tasseling and pollination speeded up the differentiation process of the reproductive parts and resulted in higher rates of kernel abortion and yield reduction. A growth chamber study by Badu-Apraku et al. (1983) showed a more dramatic yield loss associated with high temperature during the period of grain filling. They observed a 42 % loss in grain weight per plant when day/night temperature from 18 days post-silking to maturity was increased from 25/15 to 35/15 °C, a 6 °C rise in average daily temperature.

Soil characteristics have an important bearing on the productivity of the maize crop. Olson and Sander (1988) described suitable soil environment for maize and observed that maize is grown across a wide range of soils from raw sands to clays, strongly acid to strongly alkaline soils, and shallow to deep soils, with large variations in crop productivity. Below pH 5, toxicity of Al, Mn and Fe may be encountered, though maize is relatively tolerant. At very low pH, soils



are likely to be deficient in P due to tying up with the active Al component. In addition, production of  $\text{NO}_3^-$  from  $\text{NH}_4^+$  is greatly retarded due to inactivity of the nitrobacter organism. At high pH levels, nutritional problems are often encountered with the elements P, Zn and Fe. For example, in calcareous soils with pH 7.5 to 8.4, P is deficient because virtually all phosphate ions are converted to low solubility tricalcium phosphate, forming carbonated apatite (Olson and Sander, 1988). They further noted that Zinc and Fe might also have low solubilities at high pH and be deficient to the crop. Hill (2007) noted that N, P and K are taken up slowly during the seedling growth, then rapidly during the active vegetative growth and grain filling stages. Nitrogen and phosphorus uptake continues until near maturity but potassium absorption is largely completed by silking time. The major portion of the nitrogen and phosphorus taken into the early shoot, stalk, leaves and tassel are translocated into grain, much less so with potassium. Two-thirds to three-fourths or more of potassium remains in the stover. Thus N and P tend to be depleted rapidly from soil with cash grain farming, but K is not.

## **2.10. GROWTH AND YIELD INDICES**

### **2.10.1. Root to shoot ratio**

The nutrient supply and demand of root and shoot are inter-dependent due to their different functions and local environment (Siddique et al., 1990; Li et al., 2001). The ratio of root to shoot (R/S) is an index that reflects growth and dry matter accumulation between root and shoot (Lioert et al., 1999). The R/S is

affected both by genetic (O'Toole and Bland, 1987) and environmental factors, such as water status (Miao et al., 1998; Grant, 1998; Hebert et al., 2001), nutrient availability (Liang, 1996; Marsh and Pierzynski, 1998; Maranov et al., 1998), and soil texture (Vos et al., 1998). Root growth is closely related to physiological metabolism and dry matter accumulation in shoot (Siddique et al., 1990). An excessively low R/S indicates poor root growth, resulting in insufficient water and nutrients for shoot growth. An extremely high R/S may lead to root redundancy, which reduces shoot growth, yield, and water and nutrient use efficiencies (Zhang, 1995). Therefore, it is important to coordinate root and shoot relations and maximize dry matter accumulation and water and nutrient use efficiencies (Tomar et al., 1997; Kahn and Schroeder, 1999). Cultivars with a greater R/S usually have a relatively greater water and nutrient uptake capacity, higher yield stability, and greater drought resistance (Passioura, 1983). The R/S of early maturity varieties is smaller than that of late maturity. The root density increased in soil profile under irrigation, while the root penetrating capacity increased under drought conditions (Tomar et al., 1997). Root and shoot growth is significantly correlated with WUE, and an increase in both root and shoot could increase WUE (Shangguan et al., 2004). Because of the high interdependence between root and shoot, the stronger the root system, the better the foundation for the robust shoot growth and more efficient water use (Feng and Liu, 1996). It was also found that WUE decreased with increasing R/S. However, if the root system is deeply extended, the shallow stored water is limited, and then the significance of the great ratio of

root/shoot loses importance. The root-shoot ratio increases if water is withheld from the rooting medium (Sharp and Davies, 1979).

### **2.10.2. Harvest Index**

Plant harvest index, the ratio of grain weight to total plant weight, is an important trait associated with the increases in crop yields. Here total plant weight takes into account grain weight as well as vegetative parts of crop plants above the soil surface. Thus, plant harvest index is the economic yield / total plant yield (Hay, 1995). Harvest index reflects the partitioning of photosynthate between the grain and the vegetative plant and improvements in harvest index emphasize the importance of carbon allocation in grain production. The values for modern varieties of most intensively-cultivated grain crops fall within the range 0.4 to 0.6 (Hay, 1995). In most cases, the improvement in harvest index has been a consequence of increased grain population density coupled with stable individual grain weight. However, without improving harvest index, increase in yield could not be materialized. It is clear that directing maximum dry matter produced in the season to the harvesting portion would help to improve yield. It is important to mention that reduction in stem and leaf sheath dry matter to half current average values and a reallocation of this dry matter to the ear could raise the harvest index from about 0.5 to 0.62 (Hay, 1995).

### 2.10.3 Water use efficiency

Water supply is often the most critical factor limiting crop growth and yield in rainfed areas and the most expensive input of irrigated crops. Therefore, crop production usually requires maximizing yields on limited available water resources. One of the key components of crop production is to achieve greater water-use efficiency (WUE). WUE is defined as the ratio of grain yield to water consumed expressed as either evapotranspiration (ET) or total water input to the system in a defined season (Cooper et al., 1988). WUE is strongly influenced by weather conditions affecting evapotranspiration and assimilation by leaves, plants and crop differently (Tanner and Sinclair, 1983). Also differences in plant architecture might be expected to influence the ability of the crop canopy to use available soil moisture and thus affect water use efficiency (Khan et al., 2001).

If we hold the conventional view that plant biomass production is linearly coupled with the amount of water used, it is not a surprise that higher WUE is a trade-off for lower biomass production. This means that high biomass production, supported by high water supply will not lead to high WUE. In agriculture, many ways of conserving water have been investigated and techniques such as partial irrigation, deficit irrigation or drip irrigation have shown that WUE can be enhanced. Grain yield can be improved while reducing the amount of water applied to the crop (Zhang et al. 1999; Yang et al. 2000; 2001; 2002), mainly via improved harvest index which has been shown as a key component to improve WUE of yield (*e.g.* Ehdaie and Waines, 1993).



Aggarwal et al. (1986) reporting on the relationship between WUE and evapotranspiration indicated that WUE decreased with increasing evapotranspiration, whereas Musick et al. (1994) found that WUE did not change with seasonal evapotranspiration.

#### **2.10.4 Evapotranspiration**

Crop water use, also known as evapotranspiration (ET), represents soil evaporation and the water used by a crop for growth and cooling purposes. This water is extracted from the soil root zone by the root system, which represents transpiration and is no longer available as stored water in the soil. Consequently, ET is used interchangeably with crop water use (ICM, 2000).

Prevailing weather conditions, available water in the soil, crop species, and growth stage influence crop water use. At full cover, a crop is at the maximum ET rate if soil water is not limited, namely, if the soil root zone is at field capacity (CropWatch, 2008). When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. Thus, at sowing nearly 100% of ET comes from evaporation, while at full cover more than 90% of ET comes from transpiration (FAO, 1998). Crop evapotranspiration during a significant proportion of the growing cycle depends on stored soil water and on the capacity of the root system to absorb it (Hall et al., 1992). In soil profiles without physical constraints, root systems penetrate rapidly. Their ability to

grow into compacted layers, however, could limit water absorption (Passioura, 1982). Topsoil compaction imposed experimentally affected root growth and distribution resulting in reduced ET (de Willigen and Van Noordwijk, 1987; Tardieu et al., 1992). Studies on the effects of limited irrigation (Li 1982; Shan 1983; Fapohunda et al. 1984; Sharma et al. 1986; Singh et al. 1991; Zhang et al. 1999) show that the relationship between crop yield and seasonal evapotranspiration can take different forms and that the empirical coefficients vary with climate, crop type and variety, irrigation, soil texture, fertiliser and tillage methods. For example, Otegui et al. (1995) reported a reduction of 4.7 kernels m<sup>-2</sup> in maize for each mm reduction in ET around silking. Thus, crop yield according to Otegui et al. (1995) has a positive correlation with evapotranspiration.

The above review points out the beneficial effects of the combined use of organic and inorganic fertilizers in sustaining soil fertility and crop productivity. However, it does not provide enough data on the moisture retention and nutrient build-up attribute of the organic inputs. There is the need to fill this knowledge gap using the results of this study.

## **CHAPTER THREE 3.0. MATERIALS AND METHODS**

### **3.1. Location of the study area**

The study was conducted at the Soil Research Institute of CSIR, Kwadaso, Kumasi, which is about 8 km away from the city center and at the south western part of Kumasi. The area lies between latitudes  $06^{\circ}.39'$  and  $06^{\circ}.43'$  North and longitudes  $01^{\circ}.39'$  and  $01^{\circ}.42'$  West of the Greenwich meridian.

### **3.2. Climate of the study area**

The area falls within the semi-deciduous forest zone of Ghana (Taylor, 1952). This zone is characterized by two rainy seasons and two dry seasons in a year (Walker, 1957). The major rainy season starts from March to July and the minor season starts from September to November. There is a short dry period in August. The major dry season occurs between the end of the minor wet season and the next major wet season (November to March). Rainfall distribution is bimodal with peaks in June and October. The mean annual precipitation is about 1500 mm.

Temperatures are generally high and uniform throughout the year. The mean monthly temperatures range from  $24 - 28^{\circ}\text{C}$ .

Relative humidity is generally high in the mornings being about 90 % at 0600 hours and falling to between 60 and 70 % in the afternoon (1500 hours). Generally, in the wet season relative humidity is high (about 95 %) while it is low (about 40 %) in the dry season.

### **3.3. Soils of the study area**

The experiments were carried out on Kumasi series classified by Adu (1992) as Ferric Acrisol following the guidelines of FAO (1990). Kumasi series occurs at the upper toposite of the Kumasi-Asuansi/Nta-Ofin Compound Association. The same soil was sampled for the pot experiments in the green house.

### **3.4. Soil sampling and Preparation**

In order to characterize the soil of the experimental field, samples were taken across the field to a depth of 30 cm and bulked for laboratory analysis. In the laboratory, the soil samples were air-dried, crushed using a wooden mortar and pestle and then sieved through a 2 mm mesh. The sieved samples were stored in polythene bags for laboratory chemical and physical analyses at the Soil Research Institute, Kwadaso-Kumasi.

### **3.5. Soil Chemical Analysis**

#### **3.5.1. Soil pH**

Soil pH was measured in a 1:1 soil-water ratio using a glass electrode (H19017 Microprocessor) pH meter. Approximately 25 g of soil were weighed into a 50 ml polythene beaker and 25 ml of distilled water was added to the soil. The soil-water solution was stirred thoroughly and allowed to stand for 30 minutes. After calibrating the pH meter with buffers of pH 4.01 and 7.00, the pH was read by immersing the electrode into the upper part of the soil solution and the pH value recorded.



### 3.5.2. Soil organic carbon

Soil organic carbon was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). The procedure involves a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid. After the reaction, the excess dichromate is titrated against ferrous sulphate. Approximately 1.0 g of air-dried soil was weighed into a clean and dry 250 ml Erlenmeyer flask. A reference sample and a blank were included. Ten ml 0.1667M potassium dichromate ( $K_2Cr_2O_7$ ) solution was accurately dispensed into the flask using the custom laboratory dispenser. The flask was swirled gently so that the sample was made wet. Then using an automatic pipette, 20 ml of concentrated sulphuric acid ( $H_2SO_4$ ) was dispensed rapidly into the soil suspension and swirled vigorously for 1 minute and allowed to stand on a porcelain sheet for about 30 minutes, after which 100 ml of distilled water was added and mixed well. Ten ml of ortho-phosphoric acid and 1 ml of diphenylamine indicator was added and titrated by adding 1.0M ferrous sulphate from a burette until the solution turned dark green at end-point from an initial purple colour. About 0.5 ml 0.1667M  $K_2Cr_2O_7$  was added to restore excess  $K_2Cr_2O_7$  and the titration completed by adding  $FeSO_4$  drop-wise to attain a stable end-point. The volume of  $FeSO_4$  solution used was recorded and % C calculated.

Calculation:

The organic carbon content of soil was calculated as:

$$\% \text{ O.C} = \frac{M \times 0.39 \times mcf \times (V_1 - V_2)}{s}$$

where

M = molarity of ferrous sulphate solution.

$V_1$  = ml of ferrous sulphate solution required for blank.

$V_2$  = ml of ferrous sulphate solution required for sample.

s = weight of air – dry sample in grams.

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

$0.39 = 3 \times 0.001 \times 100 \% \times 1.3$  (3 = equivalent weight of carbon).

1.3 = a compensation factor for the incomplete combustion of the organic carbon.

### 3.5.3. Total nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984). Approximately 0.2 g of soil was weighed into a Kjeldahl digestion flask and 5 ml distilled water added. After 30 minutes a tablet of selenium and 5 ml of concentrated  $\text{H}_2\text{SO}_4$  were added to the soil and the flask placed on a Kjeldahl digestion apparatus and heated initially gently and later vigorously for at least 3 hours. The flask was removed after a clear mixture was obtained and then allowed to cool. About 40 ml of distilled water was added to the digested material and transferred into 100ml distillation tube. 20 ml of 40 % NaOH was also added to the solution and then distilled using the Tecator Kjeltec distiller. The digested material was distilled for 4 minutes and the distillate received into a flask containing 20 ml of 4 % boric acid ( $\text{H}_3\text{BO}_3$ ) prepared with PT5 (bromocresol green) indicator producing approximately 75 ml of the distillate. The colour change was from pink to green after distillation, after which the content of the flask was titrated with 0.02M HCl from a burette. At the endpoint when the

solution changed from weak green to pink the volume of 0.02M HCl used was recorded and % N calculated. A blank distillation and titration was also carried out to take care of traces of nitrogen in the reagents as well as the water used.

Calculation:

The percentage nitrogen in the sample was expressed as:

$$\% N = \frac{(M \times (a - b) \times 1.4 \times mcf)}{s}$$

where

M = concentration of hydrochloric acid used in titration.

a = volume of hydrochloric acid used in sample titration.

b = volume of hydrochloric acid used in the blank titration.

s = weight of air – dry sample in grams.

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

#### 3.5.4. Bray's No. 1 Phosphorus (available phosphorus)

The readily acid-soluble forms of phosphorus were extracted with a HCl:NH<sub>4</sub>F mixture called the Bray's no.1 extract as described by Bray and Kurtz (1945) and Olsen and Sommers (1982). Phosphorus in the extract was determined on a spectrophotometer by the blue ammonium molybdate method with ascorbic acid as reducing agent. Approximately 5 g of soil was weighed into 100 ml extraction bottle and 35 ml of extracting solution of Bray's no. 1 (0.03M NH<sub>4</sub>F in 0.025M HCl) was added. The bottle was placed in a reciprocal

shaker and shaken for 10 minutes after which the content was filtered through Whatman no.42 filter paper. The resulting clear solution was collected into a 100 ml volumetric flask. An aliquot of about 5 ml of the clear supernatant solution was pipetted into 25 ml test tube and 10ml colouring reagent (ammonium paramolybdate) was added as well as a pinch of ascorbic acid and then mixed very well. The mixture was allowed to stand for 15 minutes to develop a blue colour to its maximum. The colour was measured photometrically using a spectronic 21D spectrophotometer at 660 nm wavelength. Available phosphorus was extrapolated from the absorbance read.

A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6 mg P/l was prepared from a 12 mg/l stock solution by diluting 0, 10, 20, 30, 40 and 50 ml of 12 mg P/l in 100 ml volumetric flask and made to volume with distilled water. Aliquots of 0, 1, 2, 4, 5 and 6 ml of the 100 mg P/l of the standard solution were put in 100 ml volumetric flasks and made to the 100 ml mark with distilled water.

Calculation:

$$P \text{ (mgkg}^{-1}\text{)} = \frac{(a - b) \times 35 \times 15 \times \text{mcf}}{s}$$

where

a = mg/l P in sample extract.

b = mg/l P in blank.

s = weight of air – dry sample in gram.

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

35 = volume of extracting solution.

15 = final volume of sample solution.



### 3.5.5. Determination of available Potassium

Available potassium extracted using the Bray's no. 1 solution was determined directly using the Gallenkamp flame analyzer. Available potassium concentration was determined from the standard curve. Potassium standard solutions were prepared with the following concentrations: 0, 10, 20, 30, and 50  $\mu\text{g K / ml}$  of solution. The emission values were read on the flame analyser. A standard curve was obtained by plotting emission values against their respective concentrations.

Calculation:

$$\text{K (mg kg}^{-1}\text{)} = \frac{(a - b) \times 35 \times \text{mcf}}{s}$$

where

$a = \mu\text{gK/ml}$  in sample.

$b = \mu\text{gK/ml}$  in blank.

$s = \text{weight of air - dry sample in gram.}$

$35 = \text{volume of extracting solution.}$

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

### 3.5.6. Exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0N ammonium acetate ( $\text{NH}_4\text{OAc}$ ) extract.

### 3.5.6.1. Extraction of the exchangeable bases

A 5 g soil sample was transferred into a leaching tube and leached with 100 ml of buffered 1.0*N* ammonium acetate (NH<sub>4</sub>OAc) solution at pH 7.

### 3.5.6.2. Determination of calcium

A 25 ml portion of the extract was transferred to an Erlenmeyer flask. Hydroxylamine hydrochloride (1.0 ml), potassium cyanide (1.0 ml of 2 % solution) and potassium ferrocyanide (1.0 ml of 2 %) were added. After a few minutes, 4 ml of 8*M* potassium hydroxide and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01*N* EDTA solution to a pure blue colour. The titre value was again recorded.

### 3.5.6.3. Determination of calcium and magnesium

For the determination of the calcium plus magnesium, a 25 ml of the extract was transferred into an Erlenmeyer flask. A 1.0 ml portion of hydroxylamine hydrochloride, 1.0 ml of 2.0 per cent potassium cyanide buffer (from a burette), 1.0 ml of 2.0 per cent potassium ferrocyanide, 10.0 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution were added. The solution was titrated with 0.01*N* EDTA (ethylene diamine tetraacetic acid) to a pure turquoise blue colour. The titre value was recorded.

The titre value for calcium was subtracted from this value to get the titre value for magnesium. Calculation:

Exchangeable Calcium (cmol of Ca (+) kg<sup>-1</sup>soil) =

$$\left[ \frac{V_1 - V_2}{V_3} \times V_4 \times N \times \frac{100}{w} \right] \times \text{mfc}$$

where

$V_1$  = volume of EDTA required for sample aliquot titration, ml

$V_2$  = volume of EDTA required for blank titration, ml

$V_3$  = volume of aliquot taken, ml

$V_4$  = total volume of original  $\text{NH}_4\text{OAc}$  extracts, ml

$N$  = normality of EDTA

$w$  = weight of sample taken in g

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

Exchangeable Calcium plus Magnesium (cmol of Ca + Mg  $\text{kg}^{-1}$  soil)

$$= \left[ \frac{V_5 - V_6}{V_7} \times V_4 \times N \times \frac{100}{w} \right] \times \text{mfc}$$

where

$V_5$  = volume of EDTA required for sample aliquot titration, ml

$V_6$  = volume of EDTA required for blank aliquot titration, ml

$V_7$  = volume of aliquot taken, ml  $V_4$  = total volume of original  $\text{NH}_4\text{OAc}$  extracts, ml

$N$  = normality of EDTA

$w$  = weight of sample taken in g

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

$$1\text{ml } 0.01 \text{ N EDTA} = 0.2004 \text{ mg Ca}^{2+} = 0.1216 \text{ Mg}^{2+}$$

#### 3.5.6.4. Exchangeable potassium and sodium determination

Potassium and sodium in the percolate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg/l potassium and sodium solutions to 100 mg/l. This was done by taking a 25 ml portion of each into one 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks respectively. One hundred milliliters of 1.0N  $\text{NH}_4\text{OAc}$  solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg/l for potassium and sodium. Potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively.

Calculations:

$$\text{Exchangeable K (cmolkg}^{-1}\text{soil)} = \frac{(a - b) \times 250 \times \text{mcf}}{10 \times 39.1 \times s}$$

$$\text{Exchangeable Na (cmolkg}^{-1}\text{soil)} = \frac{(a - b) \times 250 \times \text{mcf}}{10 \times 23 \times s}$$

where

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

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

s = weight of air – dry sample in gram.

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



### 3.5.6.5. Exchangeable acidity

Exchangeable acidity is defined as the sum of Al + H and this was determined in 1.0M KCl extract as described by Page et al. (1982). The soil sample was extracted with unbuffered 1.0M KCl, and the sum of Al + H was determined by titration. Ten grams of soil sample was put in a 100 ml bottle and 50 ml of 1.0M KCl solution added. The bottle was capped and shaken for 1.0 hour and the filtered. Twenty five milliliters portion of the filtrate was taken with a pipette into a 250 ml Erlenmeyer flask and 2 – 3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1M NaOH until the colour just turned permanently pink. A blank was included in the titration.

Calculation:

$$\text{Exchangeable acidity (cmolkg}^{-1}\text{soil)} = \frac{(a - b) \times M \times 2 \times 100 \times \text{mcf}}{s}$$

where

a = ml NaOH used to titrate sample.

b = ml NaOH used to titrate blank.

M = molarity of NaOH solution.

s = weight of air – dry sample in gram.

2 = 50/25 (filtrate/pipetted volume)

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

#### **3.5.6.6. Effective cation exchange capacity (ECEC)**

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

### **3.6. Soil Physical Analysis**

#### **3.6.1. Soil texture**

The soil texture was determined by the Hydrometer method. Approximately 40 g of soil was weighed into 250 ml beaker and oven dried at  $105^{\circ}\text{C}$  over night. The sample was removed from the oven and then placed in a desiccator to cool, after, which it was weighed and the oven dry weight taken. A 100 ml of dispersing agent commonly known as Calgon (Sodium Bicarbonate and Sodium Hexa-metaphosphate) was measured and added to the soil. It was then placed on a hot plate and heated until the first sign of boiling was observed. The content in the beaker was washed completely into a shaking cup and then fitted to a shaking machine and shaken for 5 minutes. The sample was sieved through a 50 microns sieve mesh into a 1.0 L cylinder. The sand portion was separated by this method while the silt and clay went through the sieve into the cylinder. The sand portion was dried and further separated using graded sieves of varying sizes into coarse, medium and fine sand. These were weighed and their weights taken.

The 1.0 L cylinder containing the dispersed sample was placed on a vibrationless bench and then filled to the mark. It was covered with a watch glass and allowed to stand over night. The Hydrometer method was used to determine the silt and the clay contents. The cylinder with its content was agitated to allow the particles to be in suspension, it was then placed on the bench and hydrometer readings taken at 30 seconds, 4 minutes, 1 hour, 4 hours and 24 hours intervals. At each hydrometer reading the temperature was also taken.

Coarse silt, medium silt, fine silt and clay portions were then calculated graphically. The various portions were expressed in percentage and using the textural triangle the texture was determined.

### 3.6.2. Bulk density

Bulk density in the field at 0 – 15 cm and 15 – 30 cm depth was determined by the core method described by Blake and Hartge (1986). A cylindrical metal sampler of 5 cm diameter and 15 cm long was used to sample undisturbed soil. The core was driven to the desired depth (0 – 15 cm and 15 – 30 cm) and the soil sample was carefully removed to preserve the known soil volume as existed in situ. The soil was then weighed, dried at 105 °C for two days and reweighed. Bulk density was computed as:

$$\rho_b = \frac{M_s}{V_t}$$

where

$\rho_b$  = soil bulk density ( $\text{gcm}^{-3}$ ).

$M_s$  = mass of the oven dry soil (g).

$V_t$  = total volume of soil ( $\text{cm}^3$ )

## 3.7. Characterization of soil and organic materials used in the experiments

### 3.7.1. Chemical analysis

The soil and organic materials used in the experiment were characterized by pH, organic carbon, and N, P, K following the procedures described in section 3.4.

### 3.7.2. Physical analysis

The physical analyses comprised particle size distribution (soil only) bulk density and field capacity (soil and organic materials).

Particle size analysis was by the hydrometer method as described in section 3.5.1.

Bulk density of the soil in all the pots was kept at  $1.14 \text{ g cm}^{-3}$  being the average  $\rho_b$  of the 30 cm depth at the field experimental site. This was obtained by packing 5.4 kg of oven-dry soil ( $105^\circ\text{C}$ ) into the  $4710 \text{ cm}^3$  pots.

The same procedure was used to determine the bulk density of the organic materials by weighing 3000 and 4000 g of poultry manure and composts (Household waste and poultry manure, and Market waste and Faecal sludge) oven-dried at  $105^\circ\text{C}$  into pots of volume  $4710 \text{ cm}^3$  to obtain a bulk density of 0.64 and  $0.85 \text{ g cm}^{-3}$  respectively.

The field capacity of the soil and organic materials was determined by placing the pots with the samples in a tank containing water and saturated through the bottom. Pots were removed from the tank after saturation and covered with transparent polythene sheet to prevent evaporation. They were allowed to drain freely for 48 hours to achieve field capacity status. The amount of water at field capacity was calculated as the difference in the amount of water used for saturation less the amount freely drained after 48 hours. The percentage saturation and field capacity were calculated as:

$$\% \text{ Saturation} = \left[ \frac{A - B}{B} \right] \times 100$$

where

A = weight of saturated sample (g)

B = weight of dry sample at  $105^\circ\text{C}$  (g)



$$\% \text{ F.C} = \frac{(a - b)}{b} \times 100$$

where

a = weight of moist sample (g).

b = weight of dry sample at 105 °C (g).

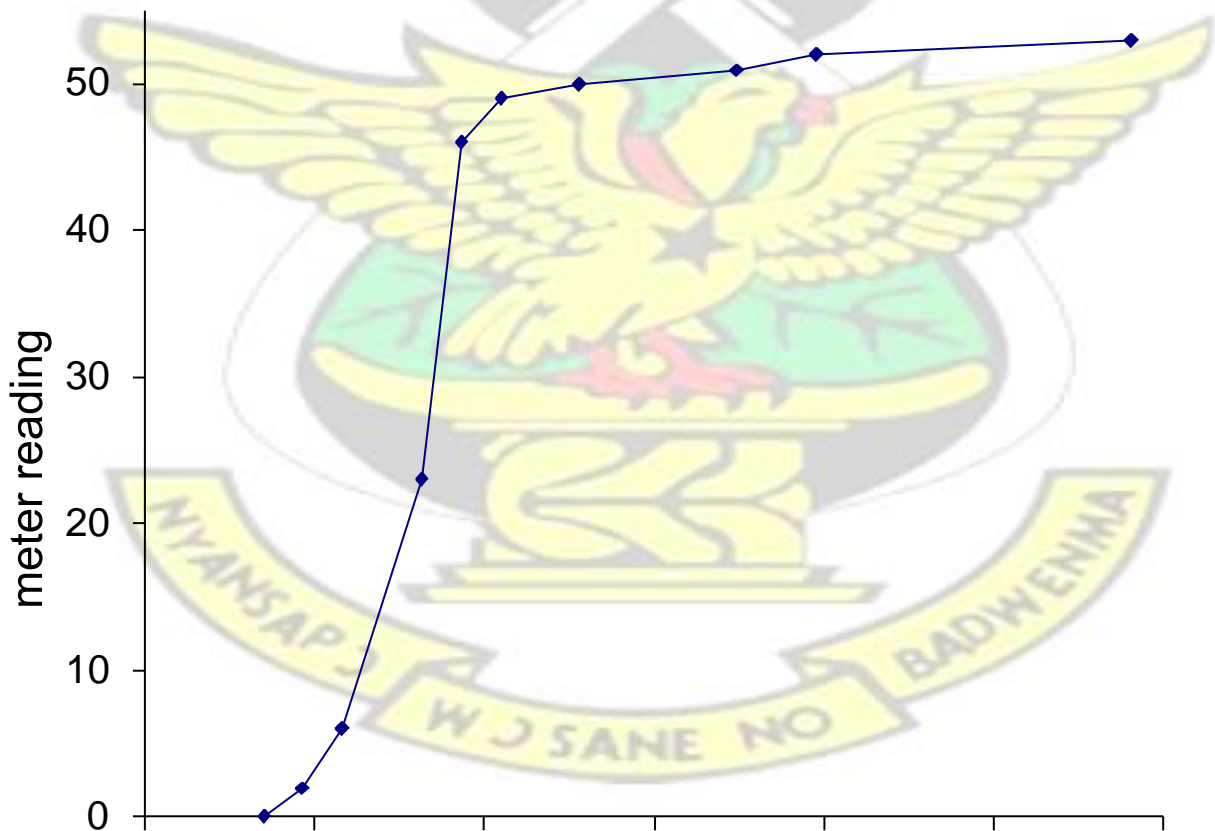
The experiment was duplicated.

### 3.7.3. Calibration of Gypsum Blocks and Tensiometer

a. Gypsum blocks, also known as electrical resistance blocks were used to measure water content of the soil and organic materials used in the experiment. To monitor water content gypsum blocks were first calibrated using a test soil sample and a moisture characterization curve plotted. The curve was used to convert meter readings to percent soil water content on dry weight basis. The soil samples were air dried and weighed into pots. In order to get a range of soil moisture contents for the calibration curve, the field capacity (the upper limit of soil moisture availability) of the soil sample was determined to serve as the basis for soil moisture gradation. The soil samples were saturated and covered with polythene sheet to prevent evaporation and allowed to drain freely for 48 hours. Soil moisture content at 48 hours of drainage represented the field capacity of the soil. The moisture content of the soil at field capacity was taken as 100 % moisture and this was varied through a percentage moisture range of 10 – 100 %. Ten pots were used in the experiment. The test soil sample in each of the pots was moistened to give the requisite range of the soil moisture content. Gypsum blocks were first soaked in water over-night and inserted in a smear of slurry in the centre of the soil in each of the pots. They were allowed to stand to attain moisture equilibration between the soil, slurry and the gypsum

block. Readings from the moisture meter were taken at 6-hour intervals until constant readings were achieved. A plot of meter readings with their corresponding moisture content gave a calibration curve which was used to convert meter readings in both the pot and field experiments to moisture content on dry basis (Fig. 1).

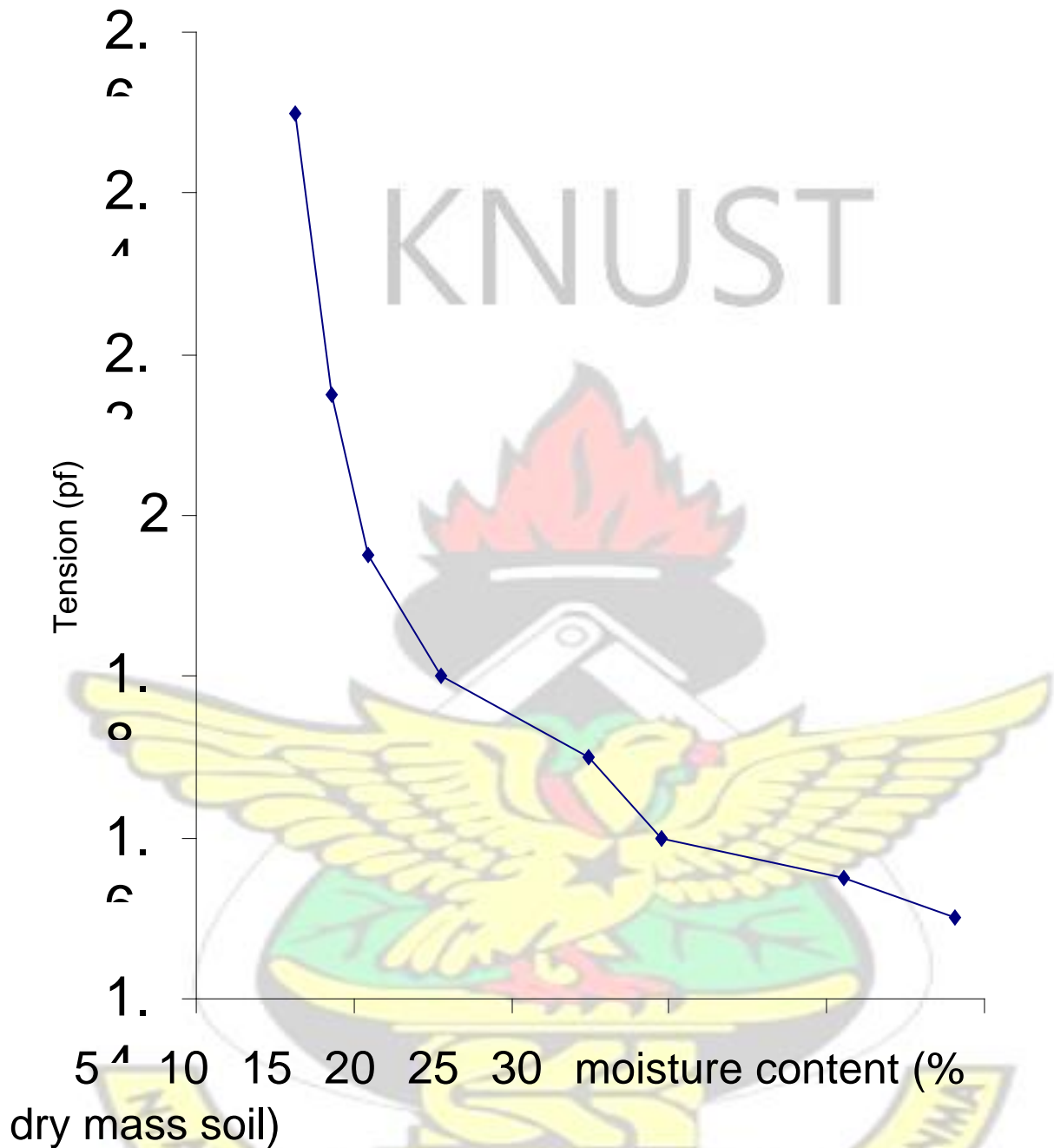
**b.** Soil water tension was measured using a Tensiometer. The calibration of the Tensiometer was done along side with the gypsum blocks. In each of the varied moistened pots within the range of 10 – 100 % FC of the test soil sample Tensiometer readings were taken and their corresponding moisture content gave a calibration curve (Fig. 2).



0                      5                      10                      15                      20                      25                      30  
moisture content (% dry mass soil)      Fig.1.

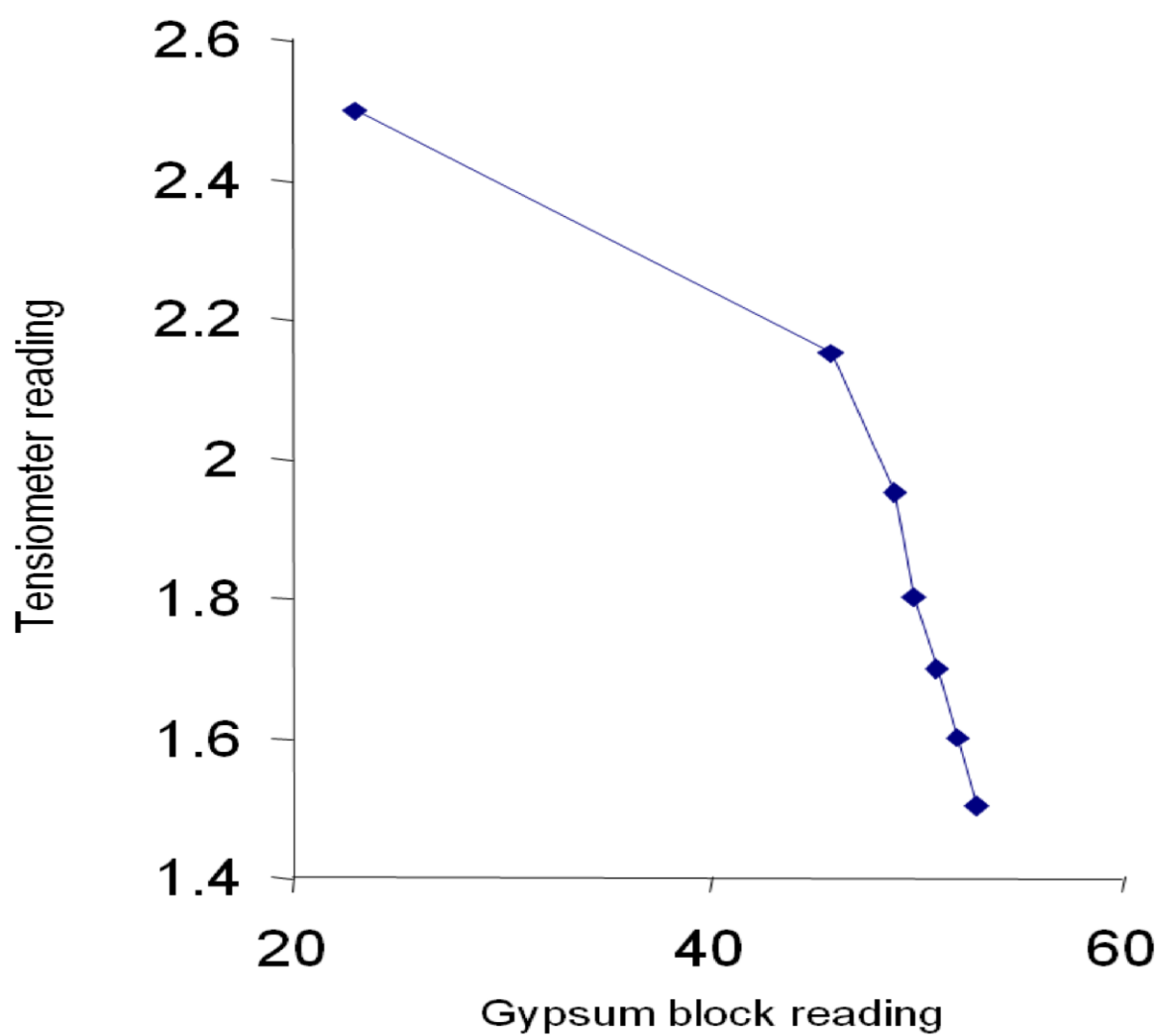
Calibration of gypsum block with the soil used in the experiment





**Fig. 2. Calibration of Tensiometer with the soil used in the experiment**





**Fig. 3 Tensiometer versus gypsum block readings**

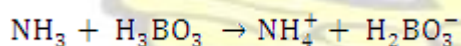
### 3.8. Plant analysis

#### 3.8.1. Plant sampling and preparation

Maize grain and stover parts sampled at harvest were kept in paper envelopes and oven-dried at 60 °C for 48 hours after which they were milled to pass through 20 mesh sieve.

#### 3.8.2. Nitrogen

Total nitrogen was determined by the Kjeldahl method in which plant material was digested with concentrated sulphuric acid and hydrogen per-oxide with selenium as catalyst. The organic N present was converted into  $\text{NH}_4^+$ . The ammonium ion, which reacted with the excess of sulphuric acid to form ammonium sulphate, was distilled off in an alkaline medium into boric acid.



The  $\text{H}_2\text{BO}_3^-$  that was formed was titrated with standard hydrochloric acid back to  $\text{H}_3\text{BO}_3$ . About 20.0 g oven-dried plant materials was ground in a stainless steel hammer mill with a sieve mesh of 1 mm, and mixed well to ensure homogeneity. Approximately 0.2 g of the plant material was weighed into a Kjeldahl flask, a tablet of selenium catalyst was added and 5 ml of concentrated  $\text{H}_2\text{SO}_4$  was also added to the mixture. This was digested on the Electrothermal Kjeldahl apparatus for three hours. After the clear digest has cooled, about 20 ml of distilled water was poured into the Kjeldahl flask containing the digested material before it was transferred into a 100 ml distillation tube. In the distillation tube another 20 ml distilled water was added plus 20 ml 40 % NaOH then distilled for 4 minutes. The distillate was received in a conical flask containing 20 ml of 4 % boric acid with PT5

indicator (methyl red and bromocresol green indicators). The received greenish solution was titrated against 0.1 M HCl dispensed from a burette. % N was calculated from the volume of HCl used to attain end-point (Soil Laboratory Staff, 1984).

Calculation:

$$\% \text{ N DM}^{-1} = \frac{(a - b) \times M \times 1.4 \times \text{mcf}}{s}$$

where

a = volume of 0.1 M HCl used for sample titration.

b = volume of 0.1 M HCl used for the blank titration.

M = molarity of HCl.

1.4 =  $14 \times 0.001 \times 100\%$  (14 = atomic weight of N)

s = weight of sample in gram.

### 3.8.3. Organic carbon

Organic carbon content of organic material was determined using the dichromate-acid oxidation method. To 0.5 g of organic material in an Erlenmeyer flask was added 10ml concentrated sulphuric acid, 10 ml 0.1667M  $\text{K}_2\text{Cr}_2\text{O}_7$  and 10 ml of concentrated orthophosphoric acid. After the addition of water, the solution was allowed to stand for 30 minutes and back titrated with 1.0M  $\text{FeSO}_4$  solutions with diphenylamine indicator.

The organic carbon content was calculated from the following equation:

$$\% \text{ C} = \frac{M \times 0.39 \times 10^{-3} \times (a - b)}{s}$$

where

M = Molarity of  $\text{FeSO}_4$ .

a = volume of  $\text{FeSO}_4$  solution required for blank titration.

b = volume of  $\text{FeSO}_4$  solution required for sample titration.

s = weight of oven – dried sample in grams.

$0.39 = 3 \times 0.001 \times 100\% \times 1.3$  (3 = equivalent weight of carbon).

1.3 = compensation factor allowing for incomplete combustion.

#### 3.8.4. Determination of phosphorus and potassium

Phosphorus and potassium were determined in plant ash using the Vanado-Molybdenum method. Approximately 0.5 g of the plant material was weighed into a porcelain crucible and ashed in a muffle oven at a temperature of  $450 - 500^\circ\text{C}$ . The ashed sample was removed from the oven after cooling then made wet with 1–2 drops of distilled water and 10 ml of 1:2 dilute  $\text{HNO}_3$  added. The crucible was then heated on a water bath until the first sign of boiling was observed. The crucible was removed and allowed to cool. The content was filtered into a 100 ml volumetric flask using a no. 540 filter paper. The crucible was washed two times with about 5 ml distilled water followed by the filter which was also washed two times with about 20 ml distilled water. After 10 ml each of ammonium vanadate and ammonium molybdate solutions were added and shaken thoroughly. The solution was allowed to stand for 10 minutes for full colour development and then filled to the 100 ml mark. A standard curve was also developed concurrently with P concentrations ranging from 0, 1, 2, 5, 10, and 15 to 20  $\mu\text{g P}$  per millilitre of solution. The absorbance of the sample and standard solutions were read on the spectrophotometer (spectronic 21D) at a wavelength of 470 nm. A standard curve was obtained by plotting the absorbance values of the standard solutions against their concentrations. Phosphorus concentration of the



samples was determined from the standard curve. Potassium in the ash solution was determined using a Gallenkamp flame analyser. Potassium standard solutions were prepared with the following concentration: 0, 10, 20, 40, 60 and 100  $\mu\text{g K}$  per millilitre of solution. The emission values were read on the flame analyser. A standard curve was obtained by plotting emission values against their respective concentrations.

### 3.9. Pot experiments

Soil for the experiments was taken from the Soil Research Institute experimental field. The soil, a Kumasi series, (Ferric Acrisol: FAO, 1990) was air-dried and 5.4 kg sample weighed into pots of volume 4710  $\text{cm}^3$ . Forty-five pots were used comprising 15 treatments and 3 replications. The pot experiments were carried out in a Greenhouse using a CRD. The treatments used are as indicated in Table 1.

**Table 1 Treatments used in the experiments**

No.	Treatment	Code
-----	-----------	------

1.	Control	Cont.
2.	Mineral fertilizer – NPK (60-40-40 kg ha <sup>-1</sup> ) High rate	NPK (H)
3.	Mineral fertilizer – NPK (30-20-20 kg ha <sup>-1</sup> ) Low rate	NPK (L)
4.	Poultry manure (60 kg N ha <sup>-1</sup> ) High rate	Pm (H)
5.	Poultry manure (30 kg N ha <sup>-1</sup> ) Low rate	Pm (L)
6.	Household waste and Poultry manure Compost (60 kg N ha <sup>-1</sup> ) High rate	Hw:Pm (H)
7.	Household waste and Poultry manure Compost (30 kg N ha <sup>-1</sup> ) Low rate	Hw:Pm (L)
8.	Market waste and faecal sludge Compost (60 kg N ha <sup>-1</sup> ) High rate	Mw:Fs (H)
9.	Market waste and faecal sludge Compost (30 kg N ha <sup>-1</sup> ) Low rate	Mw:Fs (L)
10.	Poultry manure and mineral fertilizer (60 N Pm + 60-40-40 NPK kg ha <sup>-1</sup> )	Pm + NPK (H)
	High rate	
11.	Poultry manure and mineral fertilizer (30 N Pm + 30-20-20 NPK kg ha <sup>-1</sup> )	Pm +NPK (L)
	Low rate	
12.	Household waste and Poultry manure Compost + Mineral fertilizer	Hw:Pm + NPK (H)
	(60 N Hw:Pm + 60-40-40 NPK kg ha <sup>-1</sup> ) High rate	
13.	Household waste and Poultry manure Compost + mineral fertilizer	Hw:Pm + NPK (L)
	(30 N Hw:Pm + 30-20-20 NPK kg ha <sup>-1</sup> ) Low rate	
14.	Market waste and Faecal sludge Compost + mineral fertilizer	Mw:Fs + NPK (H)
	(60 N Mw:Fs + 60-40-40 NPK kg ha <sup>-1</sup> ) High rate	
15.	Market waste and Faecal sludge Compost + mineral fertilizer	Mw:Fs + NPK (L)
	(30 N Mw:Fs 30-20-20 NPK kg ha <sup>-1</sup> ) Low rate	

### 3.9.1. Fertilizing materials

The fertilizing materials used were:

- i. Straight fertilizers of urea, triple super phosphate and muriate of potash.
- ii. Poultry manure, Household waste + poultry manure compost and Market waste + faecal sludge compost.

The calculations of rates of mineral and organic fertilizers are presented in Appendices A1 to A3.

### **3.9.2. Planting and fertilizer application**

Planting was done on the 21<sup>st</sup> October 2004. The maize (*Zea mays*) variety used was Obatanpa. Four seeds per pot were planted and then thinned to two plants per pot three days after germination. Before planting, the treatments were imposed by working the various organic and mineral fertilizers into the top 2 – 3 cm depth of the soil. During the [9period of growth, soil water content was kept as close to FC as possible by weighing the pots every other day and water added to maintain the weight of the soil at FC.

### **3.9.3. Data collection**

The following data were collected: **a.**

#### **Water content**

Water content was assessed by weighing the pots on a top-loading balance and the loss of water determined by difference in weight. Fresh weights of the plants, which added extra weight to the pot, were determined from dummy plants on weekly basis and these were used to adjust watering. Readings from the gypsum blocks buried in pots were also taken every other day. The corresponding water content of the gypsum block readings were obtained from the calibration curve. Water use efficiency (WUE) based on g of root, shoot and total dry matter production of the various treatments was computed as:

$$\text{WUE for root production} = \frac{\text{root weight (g/pot)}}{\text{water used}}$$

$$\text{WUE for shoot production} = \frac{\text{shoot weight (g/pot)}}{\text{water used}}$$

$$\text{WUE for total dry matter production} = \frac{\text{total dry matter weight(g/pot)}}{\text{water used}}$$

### **b. Evapotranspiration**

In order to measure evapotranspiration (ET) the pots with plants at 4 weeks after planting were placed on a top-load balance and weighed at field capacity, then after 4 days the pots were weighed again and the difference in weight was evaluated as evapotranspiration. The transpirable soil water (TSW) was also evaluated directly by weighing the pots with the plant at field capacity and then, the pots were covered at the soil surface with a transparent plastic sheet for 48 hours to prevent evaporation from the soil surface. The transparent plastic sheets were removed after 4 days and the pots were re-weighed. The difference in weight was evaluated as transpirable soil water.

### **c. Relative humidity**

Relative humidity was measured indirectly with dry and wet-bulb thermometers. The air temperature was measured using an ordinary mercury-in-glass thermometer (dry-bulb thermometer). A second thermometer was covered by a wick in water to keep the bulb moist (wet-bulb thermometer). The readings from the two thermometers were taken 3 times daily i.e. 07, 12 and 15 hours GMT and the values used to calculate the relative humidity quantities. Readings from the wet bulb thermometer were lower than the drybulb because of the cooling effect of the water evaporating from the wick.



The relative humidity was calculated using the formula below:

$$\text{Relative humidity} = \frac{e}{e_s} \times 100$$

where

$$e \text{ (actual vapour pressure)} = 6.11 \times 10^{\frac{7.5 \times T_d}{237.7 + T_d}}$$

The factor 6.11 is the pressure coefficient for standard atmosphere and

$T_d$  = dewpoint temperature in degrees celsius

$$e_s \text{ (saturated vapour pressure)} = 6.11 \times 10^{\frac{7.5 \times T}{237.7 + T}}$$

and  $T$  = air temperature in degrees Celsius. The relative humidity equation formula is as stated by Wanielista et al. (1997).

Greenhouse air temperature ranged between 25 °C and 36 °C while the dewpoint temperature also ranged between 24 °C and 29 °C with estimated relative humidity ranging between 60.1 % and 94.2 %. Relative humidity and temperature records are provided at the appendix.

#### **d. Growth parameters**

The following growth data were collected:

i. Plant height ii.

Plant girth iii.

Number of leaves iv.

Leaf area

Plant height and leaf area were measured using a measuring tape. The plant height was taken from the soil surface to the apical tip of the plant. The leaf length and breadth were measured to obtain the leaf area. The leaf area was estimated as its length multiplied by its

maximum width multiplied by 0.75 (maize leaf calibration factor), Elings (2000). Plant girth was measured using vernier calipers. Three measurements of each of the parameters were taken and then averaged. The number of leaves was also recorded. Data were collected weekly for six weeks after planting.

#### **e. Yield**

The whole plants in the pots were harvested after six weeks. Each pot contained two maize plants which were harvested by soaking the pots over-night and the plants together with the soil were taken and washed in a tank filled with water. The supernatant suspension and the root were transferred onto a 0.5 mm sieve to trap all broken roots. Washing continued until all soil particles were removed. The yield components harvested were the root and the shoot of the maize plant. They were oven-dried at a temperature of 60 °C for 48 hours and their weights recorded as total dry matter per pot.

### **3.10. Field experiment**

#### **3.10.1. Field layout**

The experiments were sited at Soil Research Institute experimental field. Plot size was 4 m x 3 m (12 m<sup>2</sup>). Plots were pegged and separated from each other by 0.50 m. In all, 45 plots consisting of 15 treatments and 3 replications were laid out as RCBD. The treatments are as described in page 58.

#### **3.10.2. Planting and fertilization**

Maize variety, Obatanpa was used as the test crop. The planting was done on 6<sup>th</sup> May 2004 at 40 cm within rows and 80 cm between rows with 4 seeds per hole. Filling was done on 14<sup>th</sup> May 2004. On 20<sup>th</sup> May 2004 the plants were thinned to two plants per hill to give a

plant population of about 58,331 per hectare and the various treatments imposed. The mode of application was broadcast. Nitrogen in the form of urea was split applied. Two-thirds at the first application and 1/3 applied 5 weeks later.

### 3.10.3 Growth measurements

The growth data collected during the field experiment were height, leaf area, leaf number and girth. This was done at 4 weeks interval starting on 6<sup>th</sup> May and ending on 2<sup>nd</sup> July 2004. Six maize plants were selected at random from each plot and tagged for growth measurements.

### 3.10.4. Yield

Harvesting was done on 28<sup>th</sup> August 2004. The entire plants on the plots were harvested except for the border rows by cutting at the ground level and weighed to represent the total fresh weight. A sub-sample of 6 plants were randomly selected and weighed. The plants were then separated into ears (cob + grains) and stovers (stem, leaves and husks). The plant parts i.e. ears and stovers were weighed and their weights recorded as fresh weights. The ears were further separated into cobs and grains by shelled. The various plant parts were put in brown paper envelopes and then oven dried at 60 °C for 48 hours to estimate their dry matter.

Dry matter of the various plant parts were calculated as follows:

$$\text{TDM (stover) in } 12 \text{ m}^2 = \frac{\text{DM}_s \times \text{TFW}}{\text{FW}_s}$$

$$\text{TDM (grain) in } 12 \text{ m}^2 = \frac{\text{DM}_s \times \text{TFW}}{\text{FW}_s}$$

where

TDM = total dry matter weight

DM<sub>s</sub> = sub-sample dry matter weight

TFW = total fresh weight

FW<sub>s</sub> = sub-sample fresh weight

Maize stover and grains were milled and sieved through a 20 mesh for plant nutrient analysis. All nutrients estimated were reported on elemental percentage basis. Grain and stover yields were also estimated per hectare as well as hundred grain weights at grain moisture content of 15 %.

Stover yield (kg/ha) = TDM (stover) × harvested area.

and

Grain yield (kg/ha) = TDM (grain) × harvested area

Harvest Index (HI) was computed as:

HI = Dry grain weight for the 6 ears / (Dry weight of 6 ear + dry weight of stover)

### 3.10.5. Water content

Water content of the various treatments was monitored by burying gypsum blocks at 15 cm depth on each plot. Water content values were obtained from a gypsum block calibration curve. Soil water content expressed in mm was calculated as follows:

$$\theta_m = \theta_m \times \frac{\rho_b}{\rho_w} \times 10 \times z$$

where

$\theta_m$  = soil moisture content (mm)  $\theta_m$  =

gravimetric moisture content (%)  $\rho_b$  =



bulk density ( $\text{g cm}^{-3}$ )  $\rho_w$  = density of

water ( $\text{g cm}^{-3}$ )

Z = depth of soil in cm

Factor 10 = conversion of cm to mm

### **3.10.6. Nutrient uptake**

Nutrient uptake was determined for maize stover and grain. This was calculated from the nutrient concentrations obtained from the tissue analysis and oven-dry matter weight expressed in kg/ha.

### **3.10.7. Residual experiment**

Residual experiment was carried out during the minor season to determine the residual effect of the treatments.

### **3.10.8. Statistical analysis**

All data were subjected to statistical analysis. The statistical package used was GenStat. Standard error of difference was used as mean separates. Regression analyses were carried out to establish the relationships between parameters measured for predictive purposes.

## **CHAPTER FOUR 4.0 RESULTS AND DISCUSSION**

**4.1 Characterization of the soil and organic materials used in the experiment.** The application of soil amendments as the major treatment of the study necessitated the chemical and physical characterization of the soil and organic materials used.

Table 2: Chemical properties of the soil and organic materials used in the study

Sample	pH (H <sub>2</sub> O)	% O.C	% N	% P	% K
Pm	7.67(1:5)	29.40	2.06	0.52	0.73
Hw:Pm	7.51(1:1)	9.94	1.49	0.48	0.56
Mw:F <sub>s</sub>	7.41(1:1)	9.94	0.92	0.35	0.58
Soil	6.14 (1:1)	1.34	0.15	0.02	0.01

Values are the means of duplicate samples; Pm = Poultry manure, Hw = Household waste Mw = Market waste, F<sub>s</sub> = Faecal sludge. Values in parenthesis are sample to water ratio.

The results of selected chemical properties (Table 2) showed the pH of the top 30 cm bulk soil sample to be slightly acidic whilst that of the organic materials was slightly alkaline to moderately alkaline. The soil recorded the least content of all the selected chemical constituents which ranked as Pm > Hw:Pm > Mw:F<sub>s</sub> > soil (Table 2). The values indicated that all the organic materials could be used to potentially enhance the fertility status of the soil with the poultry manure being the best. A similar conclusion has been made by several authors (Lombin et al., 1992; Kindness, 1999; Quansah et al., 1998).

Table 3: Bulk density and percentage moisture content of the soil and organic materials

Sample	Bulk density(gcm <sup>-3</sup> )	Saturation %	Field capacity %	16 DAS %
Pm	0.64	119.51	92.68	63.41
Hw:Pm	0.85	45.00	41.67	28.33
Mw:F <sub>s</sub>	0.85	46.67	40.00	22.67
Soil	1.14	29.07	25.58	3.49

Values are the means of duplicate samples

Whilst the chemical properties of the soil are often considered the major constituents of soil fertility, the physical properties (Table 3) are equally important. The mean bulk density ( $1.14 \text{ g cm}^{-3}$ ) of the top soil (0 – 30 cm) was, as expected, relatively higher than that of the organic materials which ranged from 0.64 to  $0.85 \text{ g cm}^{-3}$ . The bulk density of the soil was, however, in the range generally considered suitable for the normal growth of crops.

Soil moisture at saturation and field capacity was in the order of  $P_m > M_w:F_s > H_w:P_m >$  soil. The values showed that organic materials take and hold more water at saturation and field capacity respectively than the soil. Soil moisture retention is of major significance to sustain crop growth. The results (Table 3) showed that after 16 days of moisture depletion, the organic materials retained more moisture than the soil. Soil moisture, as a percentage of field capacity moisture content, was 68.4 for  $P_m$ ; 68 for  $H_w:P_m$ ; 56.7 for  $M_w:F_s$ ; and 13.6 for soil. This moisture retention attribute of the organic materials underscores the higher moisture content often recorded for soils with greater contents of organic matter and sustained growth of crops grown on them during periods of moisture stress.

## **4.2 Pot experiments**

### **4.2.1. Effect of mineral fertilizers and organic amendments on the growth parameters of maize.**

The temporal effects of the soil amendments studied on the growth parameters of maize are presented in Appendices B to E. Maize plant height (Appendix B) under all the treatments increased with time with a peak height at 6 weeks after planting (WAP) ranging from 54.10 to 78.83 cm for the low level of  $M_w:F_s$  compost and the high level of  $H_w:P_m + \text{NPK}$

combination respectively (Table 4). Plant height at all the sampling periods did not vary significantly amongst the treatments. The comparison of the means using SED showed no significant differences ( $P > 0.05$ ). The rate of growth progressively increased with time during the vegetative growth up to 4 WAP after which growth slowed down. This trend follows the normal growth curve of cereals which exhibit rapid growth during the vegetative phase followed by a slow growth rate as the reproductive phase is initiated. The top five treatments that recorded high plant height at 6 WAP were in the order of Hw:Pm+NPK(H) > Mw:Fs+NPK(H) > Mw:Fs+NPK(L) > Hw:Pm(L) > Control (Table 4). Whilst the high levels of the soil amendments generally recorded greater plant height than the low levels, the reverse was true with NPK, Pm and Hw:Pm. Thus, higher rates of application appeared to have a positive effect on plant growth especially in the case of the organic inputs plus mineral fertilizers. This demonstrates the beneficial effects of combined application of organic inputs with inorganic fertilizers – the integrated soil fertility management (ISFM) technology for tropical soil fertility restoration.

Leaf area also increased with time with a peak at 6 WAP (Appendix C). Leaf area at 6 WAP (Table 4) ranged between 215.70 cm<sup>2</sup> and 340.55 cm<sup>2</sup> for the low level of Mw:Fs and the high level of NPK respectively. Leaf area did not differ amongst the treatments at all sampling periods except at 4 WAP where there were significant differences among the treatments ( $P < 0.05$ ). Leaf area for the top five treatments at 6 WAP were ranked as NPK(H) > Mw:Fs+NPK(H) > Mw:Fs+NPK(L) > NPK(L) > Hw:Pm+NPK(H). Apart from Mw:Fs (L) which recorded the least leaf area, all the other soil amendments recorded higher leaf area than the control. In the case when soil moisture is not limiting a larger leaf surface area is preferred to optimize photosynthate production for the enhancement of crop yield.



Plant girth increased with time, peaking at 4 WAP for all the treatments (Appendix D).

At 6 WAP (Table 4) the mean plant girth ranged between 0.79 cm and 1.01 cm for Mw:F<sub>s</sub>(L) and Mw:F<sub>s</sub>+NPK(L) respectively. Generally, the high levels of the treatments recorded greater girth than the low levels, except for NPK and Mw:F<sub>s</sub>+NPK where the reverse was true. This shows that a high rate of application has a positive effect on the maize stem girth. As was observed in the leaf area, treatments recorded greater girth than the control, except for Mw:F<sub>s</sub>(L). The girth also showed no significant differences ( $P > 0.05$ ) among the means of all the treatments except at 4 WAP where significant differences were observed. The decline of plant girth 4 WAP could be due to translocation of photosynthates to grain formation i.e. the reproductive phase of the maize growth.

Leaf number increased with time and peaked around 3<sup>rd</sup> and 4<sup>th</sup> WAP (Appendix E). In most cases, the peak number of leaves was maintained up to the 6 WAP. Mean leaf number per plant ranged from 6 to 8 for Pm+NPK(L) and NPK(H) respectively. The differences among the treatments were not significant ( $P > 0.05$ ). An increase in the number of leaves could positively affect the photosynthetic activity of the plant since leaf number is a growth index that could enhance crop yields.

**4.2.2. The effect of mineral fertilizers and organic amendments on maize biomass** In the pot experiment, total biomass, being the sum of the shoot and root dry matter weights was used as an index of yield. The mean shoot and root biomass over a six-week period and the amount of water used for the production are presented in Table 5. The results showed that the application of mineral and organic fertilizers had a positive effect on both shoot and root dry matter production.

#### 4.2.2.1. Shoot dry matter

The results (Table 5) showed that all the soil amendments significantly increased shoot yield over that of the control except for Mw:Fs(L) where the differences were not significant. The mean shoot yield per plant varied from 7.98 to 19.19g for the control and NPK(H) respectively. The yields obtained by the high rate of the combined fertilizer application (Pm+NPK(H), Hw:Pm+NPK(H), and Mw:Fs+NPK(H)) were significantly ( $P < 0.05$ ) higher than the sole application of the organic amendments. The sole application of NPK(H), on the other hand, produced higher shoot yield than its combination with Hw:Pm, Mw:Fs and Pm.

Table 4: Effect of soil amendments on mean growth parameters of the maize plant at 6 weeks after planting (WAP)

Treatment	Leaf Number	Leaf area (cm )	Plant height (cm)	Plant girth (cm)
Control	6.67	255.70	67.80	0.80
NPK(H)	7.67	340.50	63.30	0.87
NPK(L)	7.33	299.10	66.10	0.92
Pm(H)	6.67	296.10	62.00	0.90
Pm(L)	7.33	264.30	66.80	0.80
Hw:Pm(H)	7.00	289.70	57.80	0.87
Hw:Pm(L)	6.33	273.10	68.50	0.82
Mw:Fs(H)	6.33	263.60	64.30	0.86
Mw:Fs(L)	6.33	215.70	54.10	0.79
Pm+NPK(H)	7.00	284.10	65.80	0.92

Pm+NPK(L)	6.00	272.90	57.50	0.81
Hw:Pm+NKP(H)	6.67	296.50	78.80	0.87
Hw:Pm+NPK(L)	6.33	275.30	59.50	0.85
Mw:F <sub>s</sub> +NPK(H)	7.00	338.90	71.20	0.87
Mw:F <sub>s</sub> +NPK(L)	7.33	334.20	68.80	1.01

SED	0.53	33.24	7.41	0.08
CV	9.50	14.20	14.00	11.40

The differences in yield between sole NPK(H) and its combination with Pm were however, not significant. Whilst other researchers (Swift, 1997; Gitari and Friesen, 2001; Makinde,

2007) have observed that the combined use of organic and mineral fertilizers results in higher yields than either source used alone, the results of this study have shown an enrichment of the organic sources by the mineral fertilizers. This accounts for the observed significantly higher yield of the combined fertilizers than the sole organic sources.

The enrichment of the organic amendments is also evident in the higher (but not significant) yield of the low rate of the combined fertilizer application than the sole organic sources.

#### **4.2.2.2. Root dry matter**

The results (Table 5) showed that root biomass per plant varied from 2.56g for the control to 8.93g for Hw:Pm+NPK(L). All the soil amendments significantly ( $P < 0.05$ ) increased root biomass yield over that of the control. The higher nutrient content and possibly availability in the soil amendments may have accounted for the observed increases in root dry matter yield. For the same reasons, the application of the combined mineral and organic fertilizers significantly had yielded their sole counterparts.

With the exception of Hw:Pm(L), the low rates of all the soil amendments produced significantly greater root biomass than the high rates. Mineral nutrient supply can strongly affect root growth, morphology and distribution of the root systems in the soil. This effect, according to Marschner (1995) is particularly marked with nitrogen, less distinct with phosphorus, and usually absent with other nutrients, except for magnesium.

It was, therefore expected that the higher rates of soil amendments would produce greater root biomass. However, Marschner (1995) indicated that, in the responsive zone (i.e. concentration range where nutrients limit plant growth), increasing nitrogen supply enhances both shoot and root growth, but usually the shoot growth is more than the root growth. This, according to Marschner (1995) reduces the root/shoot ratio. Over the range



of the applied soil amendments, and relative to the shoot and root yield of the control, the higher rates averaged 45 and 47 per cent increase in the shoot and root dry matter yield respectively. The corresponding values for the low rates were 27 and 53 per cent. This observation, as shown in the next section, has implications for the magnitude of the root/shoot ratios recorded under the various soil amendments.

#### **4.2.2.3. Root/Shoot ratio**

The results (Table 5) showed the root/shoot ratios to ranged between 0.28 and 0.68 for NPK(H) and Hw:Pm+NPK(H) respectively. These values imply that the amount of dry matter incorporated into the roots per plant varies from 28 to 68 per cent. The low rates of soil amendments recorded significantly higher root/shoot ratios than the high rates. This is due to the observed higher increases in root than shoot growth under the low rates of soil amendments. This accords with Marschner's (1995) observation and underscores Kramer's (1975) conclusion that root/shoot dry matter ratio is lower in fertile than in infertile soil. The results further support the observation by Zhang (1995) that high root/shoot ratio may lead to root redundancy, which reduces shoot growth and yield.

#### **4.2.3. Water use and water use efficiency**

Crops take up water from the soil for dry matter production. The amount of water required for optimum production is about equal to the amount of evapotranspiration ( $ET_{crop}$ ) from the crop-soil unit under non-restricting soil conditions including soil water and fertility. In this study, the amount of water applied for total dry matter production is presented in Table 6. The amount of water applied ranged between  $2.88 \times 10^{-3}m^3$  and  $3.91 \times 10^{-3}m^3$  in the

control and NPK(H) treatments for the respective production of  $1.05 \times 10^{-2}$ kg and  $2.45 \times 10^{-2}$ kg of maize dry matter.

The efficiency with which crops use available water for dry matter production is very important for sustainable use of water for crop production. The water use efficiency (WUE), defined as the ratio of quantity of dry matter produced to the total depth of water consumed during the entire crop growth season, is expressed as  $\text{kg}/\text{cm}^3$  or  $\text{kg}/\text{m}^3$  water used. The results of the mean WUE is presented in Table 6. The WUE ranged from 7.62 to  $3.64 \text{ kg}/\text{m}^3$  for the Pm+NPK(H) and Mw:Fs(L) respectively. With the exception of Hw:Pm and Hw:Pm+NPK, the high rates of soil amendments recorded higher WUE. The examination of the data collected in the study gave an indication of a consistent trend between WUE and maize dry matter production. Consequently regression analysis was carried out to establish the relationship between WUE and dry matter production. The results, presented in Figures 1 to 3, showed WUE to be positively correlated with maize dry matter production. WUE therefore increased with increasing dry matter production. This accord with the observations of Kramer (1975) and Marschner (1995) that the higher the yield of dry matter, the higher the efficiency of water use because dry matter production increases more rapidly than water loss.

Table 5: Mean shoot and root dry matter yields of the various soil amendments 6 weeks after planting

Control	7.98	2.56	10.54	0.32
NPK (H)	19.19	5.28	24.47	0.28

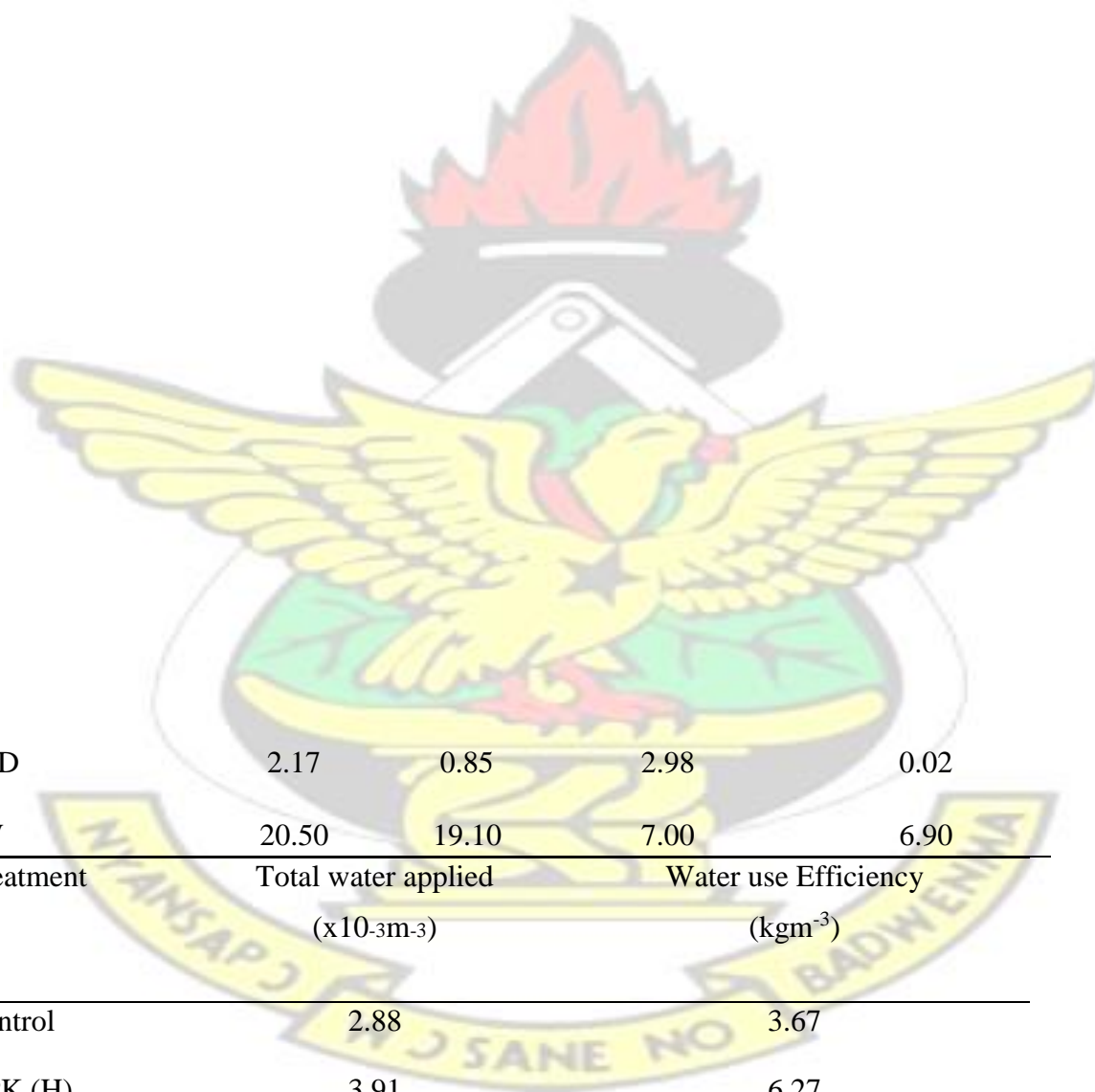
NPK (L)	12.45	6.36	18.81	0.51
Pm (H)	14.84	4.75	19.59	0.32
Pm (L)	11.15	5.66	16.81	0.50
Hw:Pm (H)	12.72	4.06	16.78	0.32
Hw:Pm (L)	11.82	3.71	15.53	0.32
Mw:F <sub>s</sub> (H)	10.14	3.17	13.31	0.31
Mw:F <sub>s</sub> (L)	8.93	4.05	12.98	0.46
Pm+NPK (H)	18.52	7.16	25.68	0.39
Pm+NPK (L)	11.61	6.01	17.62	0.52
Hw:Pm+NPK(H)	15.16	6.76	21.92	0.45
Hw:Pm+NPK(L)	13.23	8.93	22.16	0.68
Mw:F <sub>s</sub> +NPK(H)	15.62	6.53	22.15	0.42
MwF <sub>s</sub> +NPK(L)	11.06	6.86	17.92	0.62
Dry matter (g) / plant			Root to Shoot	
total biomass				
Treatment				

Shoot

Root

Ratio

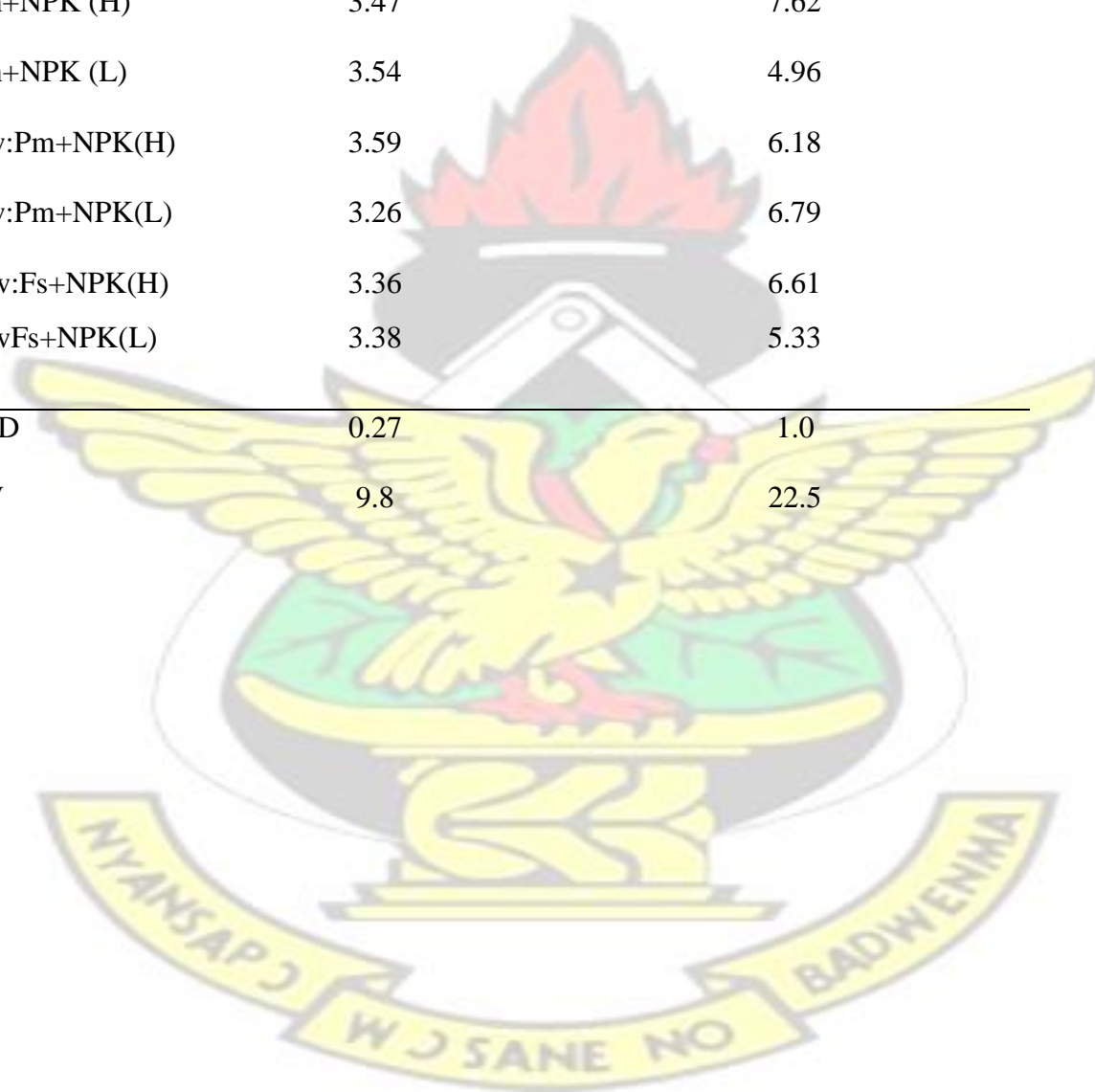
Table 6: Water use of the various soil amendments 6 weeks after planting



SED	2.17	0.85	2.98	0.02
CV	20.50	19.10	7.00	6.90
Treatment	Total water applied ( $\times 10^{-3} \text{m}^3$ )		Water use Efficiency ( $\text{kgm}^{-3}$ )	
Control	2.88		3.67	
NPK (H)	3.91		6.27	
NPK (L)	3.65		5.15	
Pm (H)	3.47		5.64	



Pm (L)	3.29	5.10
Hw:Pm (H)	3.48	4.80
Hw:Pm (L)	2.98	5.30
Mw:F <sub>s</sub> (H)	2.96	4.52
Mw:F <sub>s</sub> (L)	3.58	3.64
Pm+NPK (H)	3.47	7.62
Pm+NPK (L)	3.54	4.96
Hw:Pm+NPK(H)	3.59	6.18
Hw:Pm+NPK(L)	3.26	6.79
Mw:F <sub>s</sub> +NPK(H)	3.36	6.61
MwF <sub>s</sub> +NPK(L)	3.38	5.33
SED	0.27	1.0
CV	9.8	22.5



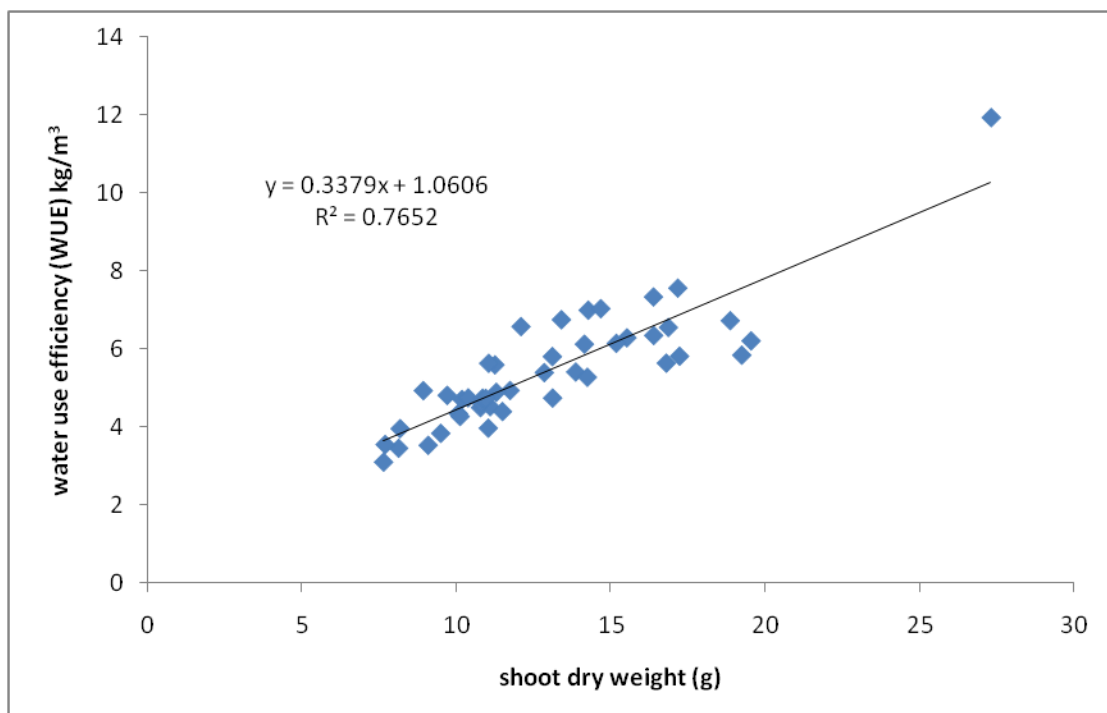


Figure 4 Relationship between shoot dry weight (g) and water use efficiency (WUE)

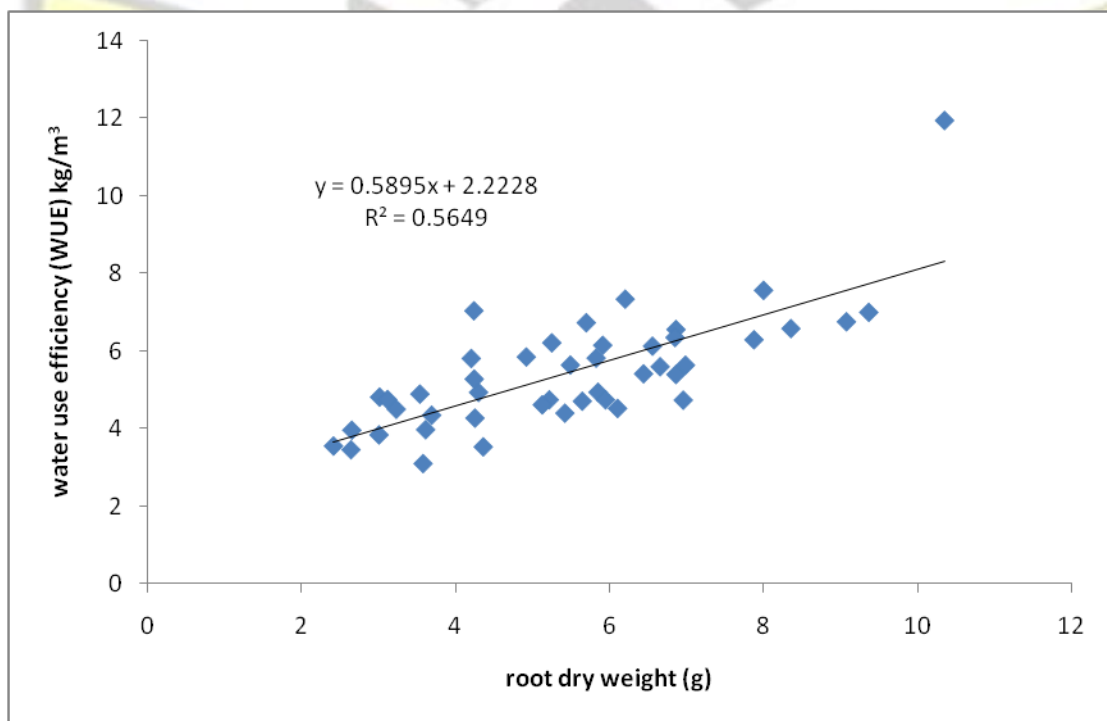


Figure 5. Relationship between root dry weight (g) and water use efficiency (WUE)

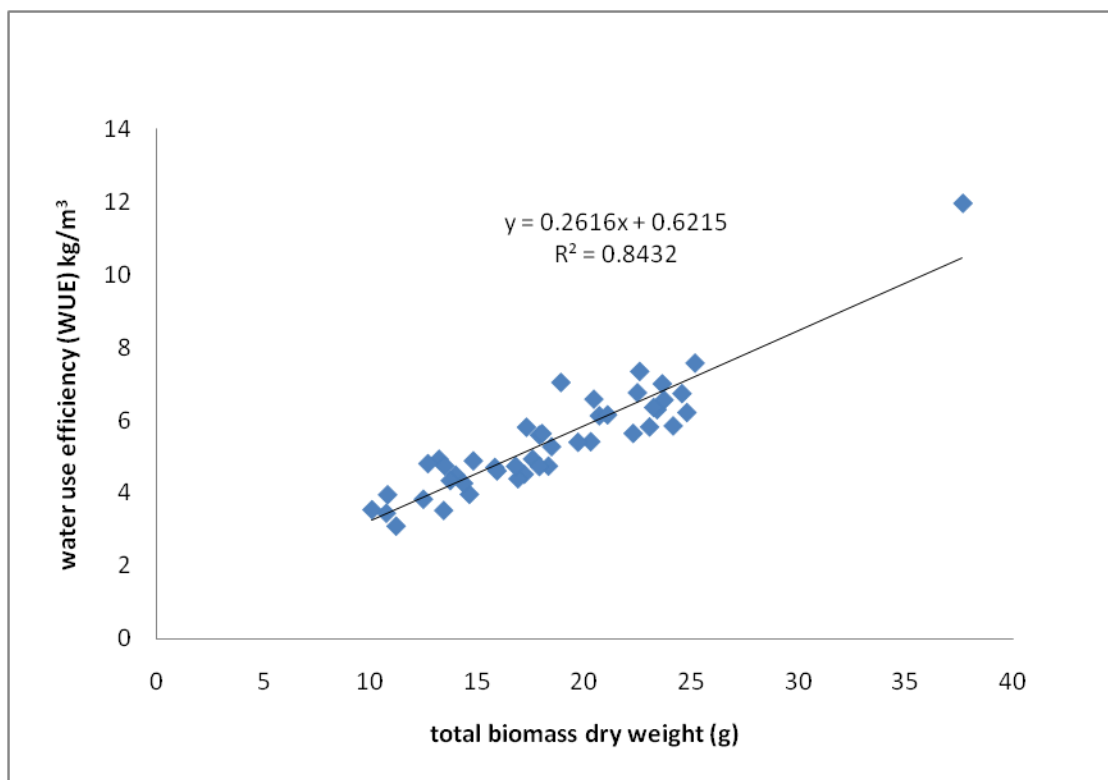


Figure 6. Relationship between total biomass dry weight and water use efficiency (WUE)

Kramer (1975) therefore concluded that WUE is increased by use of high-yielding deep rooted varieties of crops grown at optimum density with adequate fertilization. However, even under optimum conditions, 200 – 500 units of water are used to produce one unit of dry matter in  $C_4$  plants, such as maize, compared with usually more than 500 units in  $C_3$  plants such as trees (Kramer, 1975; Marschner, 1995). This is because efficient photosynthetic structures permitting entrance of large amounts of  $CO_2$  permit the exit of large amounts of water vapour, pineapple being the only exception. In this study, the grams of water used to produce a gram of maize dry matter ranged from 135 to 277 for Pm+NPK(H) and Mw:Fs(L) respectively.

#### **4.2.4. Effect of mineral fertilizers and organic amendments on evapotranspiration and transpiration**

Data on evapotranspiration are required not only for water balance analysis but for irrigation scheduling and maintaining soil moisture at a constant value, e.g. Field capacity, where water application is not a variable. The design of the experiment facilitated the determination of evapotranspiration, transpiration and evaporation. The results of the evapotranspiration studies in the pot experiments are presented in Table 7. The evapotranspiration values ranged between 136.67 and 250.00  $\text{cm}^3 \text{ day}^{-1} \text{ pot}^{-1}$  in Hw: Pm+NPK(H) and Pm+NPK(H) respectively. Significant differences ( $P < 0.05$ ) in evapotranspiration were observed among the treatments. The transpiration values also showed significant differences ( $P < 0.05$ ) among the treatments. The values ranged from 90.00 to 166.67  $\text{cm}^3 \text{ day}^{-1} \text{ pot}^{-1}$  in NPK(L) and Mw:Fs+NPK(H) respectively. As indicated in the previous section of WUE, evapotranspiration tended to increase with increasing dry matter production under the limiting moisture conditions of the experiment. Kang et al. (2002) reported similar results indicating that evapotranspiration was high under continuous high soil moisture conditions, as well as above ground biomass. The authors observed that water is lost by transpiration in amounts far greater than those found within the plant and that both dry matter yield and evapotranspiration increased with the supply of water in the soil (Black, 1960; Kang et al., 2002). Evaporation values were lower compared with the transpiration values. This was because the transpiration experiment was conducted at 4 WAP when the maize was well developed and completely covered the soil. Under such conditions transpiration was the main process in evapotranspiration. However, evaporation also showed significant differences ( $P < 0.05$ ) among the treatments, with NPK(L) recording the highest (126.70  $\text{cm}^3 \text{ day}^{-1} \text{ pot}^{-1}$ , followed by Pm(L) and Hw:Pm(H) in that order, while the lowest value of 16.70  $\text{cm}^3 \text{ day}^{-1} \text{ pot}^{-1}$  was obtained by Hw:Pm+NPK(H).



Table 7: Mean Evapotranspiration, Transpiration and Evaporation values for the various soil amendments

Treatment	Evapotranspiration	Transpiration	Evaporation
	(cm <sup>3</sup> day <sup>-1</sup> pot <sup>-1</sup> )		
Control	166.70	93.30	73.40
NPK(H)	246.70	146.70	100.00
NPK(L)	216.70	90.00	126.70
Pm(H)	220.00	116.70	103.30
Pm(L)	213.30	100.00	113.30
Hw:Pm(H)	216.70	110.00	106.70
Hw:Pm(L)	176.70	116.70	60.00
Mw:F <sub>s</sub> (H)	176.70	150.00	26.70
Mw:F <sub>s</sub> (L)	183.30	100.00	83.30
Pm + NPK(H)	250.00	150.00	100.00
Pm + NPK(L)	216.70	133.30	83.40
Hw:Pm + NPK(H)	216.70	126.70	90.00
Hw:Pm + NPK(L)	136.70	120.00	16.70
Mw:F <sub>s</sub> + NPK(H)	216.70	166.70	50.00
Mw:F <sub>s</sub> + NPK(L)	183.30	126.70	56.60
SED	19.46	14.90	23.98
CV	11.80	14.80	37.00

### 4.3. Field experiment

#### 4.3.1. Effect of mineral fertilizers and organic amendments on growth parameters of maize

Two field experiments were carried out in the major and minor seasons of 2004 to study the effect of the soil amendments on the growth and yield of maize. The selected soil amendments were applied during the major season experiment. The mean plant height of maize under all the treatments increased with time peaking at 12 WAP (Appendix H). At 50 % flowering stage there were no significant differences ( $P > 0.05$ ) in plant height among the treatments (Table 8). The maximum plant height of 178.10 cm was recorded under (Mw:Fs + NPK(H)) while the minimum plant height of 105.80 cm was recorded in Hw:Pm(H). The results (Table 8) further showed that the combined mineral and organic amendments had values relatively higher than the sole applications. The top five treatments that recorded high plant height at 50 % flowering stage were in the order of Mw:Fs+NPK(H) > NPK(H) > Pm+NPK(H) > Pm+NPK(L) > Pm.

The rate of growth was rapid during the vegetative phase of the maize plant up to 8<sup>th</sup> week after which growth slowed down as the reproductive phase was initiated. This trend follows the normal growth curve of the maize plant and this could be attributed to the remobilization of restored carbohydrates in filling the cob/ear (Osafo and Milbourn, 1975; Palta et al., 1994; Riccardi and Stelluti, 1995). The mean leaf area of the maize at the 50 % flowering stage (Table 8) showed no significant differences ( $P > 0.05$ ) among the treatments, however, the combined treatments, for example Pm + NPK(H) produced larger leaf area than the sole treatments, except for NPK(H) which obtained comparable values.

Table 8: Effect of soil amendments on maize plant growth at 50 % flowering stage

Treatment	Mean Values			
	Leaf Number	Leaf area (cm <sup>2</sup> )	Plant height (cm)	Plant girth (cm)
Control	8.00	570.00	147.60	1.99
NPK(H)	8.33	718.00	168.10	2.23
NPK(L)	8.00	686.00	153.70	2.01
Pm(H)	8.00	647.00	165.30	2.07
Pm(L)	8.00	576.00	136.30	1.78
Hw:Pm(H)	8.33	477.00	105.80	1.69
Hw:Pm(L)	8.33	623.00	150.70	1.98
Mw:Fs(H)	7.67	631.00	160.10	1.99
Mw:Fs(L)	7.33	559.00	121.20	1.91
Pm+NPK(H)	8.00	751.00	166.80	2.29
Pm+NPK(L)	7.33	684.00	166.20	2.04
Hw:Pm+NPK(H)	8.33	636.00	147.70	2.05
Hw:Pm+NPK(L)	7.33	652.00	144.60	2.17
Mw:Fs+NPK(H)	8.00	617.00	178.10	2.02
Mw:Fs+NPK(L)	6.67	581.00	150.40	1.87
SED	0.62	84.10	23.19	0.17
CV	9.70	16.40	18.80	10.60

The highest and lowest values were obtained by Pm + NPK(H) and Hw:Pm(H) respectively and the top five treatments recorded were in the order of Pm+NPK(H) > NPK(H) > NPK(L) >

Pm+NPK(L) > Hw:Pm+NPK(L). Leaf area generally increased with time, peaking at a point and then either kept a constant growth or declined (Appendix I). The higher rates of application tended to favour larger leaf area growth.

There were no significant differences ( $P > 0.05$ ) in plant girth among the treatments at 50 % flowering stage. The trend in plant girth was similar to that of the leaf area. The top five treatments recorded were in the order of Pm+NPK(H) > NPK(H) > Hw:Pm+NPK(L) > Pm(H) > Hw:Pm+NPK(H). Generally, there was an increase in the plant girth up to the 4<sup>th</sup> week after which a decrease was observed (Appendix J). The number of leaves of the various treatments generally increased with time peaking at the 12<sup>th</sup> week (Appendix K). At the 50 % flowering stage there were no significant differences ( $P > 0.05$ ) among the treatments and the mean leaf number per plant ranged from 7 to 8. The higher rates of the combined soil amendments produced more leaves per plant as similarly reported by Qasim et al. (2001).

**4.3.2. Effect of mineral fertilizers and organic amendments on maize yield indices** The results showed that grain and stover yields were influenced significantly ( $P < 0.05$ ) by the application of organic and/or inorganic fertilizers (Table 9). The combined treatments produced yields which were significantly higher than those produced by organic and inorganic fertilizers separately. Pm+NPK(H) and Hw:Pm+NPK(H) treatments produced 8.0 and 7.5 tons ha<sup>-1</sup> of maize grain respectively. This observation is in agreement with the finding of Swift (1997) who observed that the combined use of organic and inorganic inputs results in higher yields than either source used alone. Boateng and Oppong (1995) also confirmed the superiority of the combined organic and inorganic inputs over the organic or inorganic inputs in their studies on the effect of farmyard manure and method of land clearing on soil properties and maize yield. They reported that the plots treated with poultry manure and NPK (20-20-0) gave the best yield. The control recorded



the lowest grain and stover yields of 2.10 and 4.30 tons ha<sup>-1</sup> respectively among the treatments. The highest and lowest stover yields of 9.40 and 2.7 tons ha<sup>-1</sup> were produced by Hw:Pm + NPK(H) and Mw:F<sub>s</sub>(L) respectively (Table 9). This may be due to an increase in the number of leaves as well as increase in the leaf area, which may have promoted photosynthate production to enhance high stover yield in the combined treatments. There were no significant differences ( $P > 0.05$ ) among the 100 seed weight of all the treatments (Table 9). However, the highest and lowest 100 seed weight of 31.30 and 26.10 g were obtained by Hw:Pm(H) and Mw:F<sub>s</sub> + NPK(L) respectively. The Mw:F<sub>s</sub> (H) treatment obtained the highest estimated harvest index (HI) of 0.48 which was significantly higher ( $P < 0.05$ ) than the other treatments. Harvest index obtained were in the acceptable range of 0.4 - 0.6 for maize. Grain yield was highest at a combined application of 30 kg ha<sup>-1</sup> N of poultry manure and 30-20-20 kg ha<sup>-1</sup> NPK which produced 8.0 t ha<sup>-1</sup> of maize grain (Obatanpa maize variety). This may be attributed to the supply of enough nutrients which prolonged the leaf area duration after flowering (LADF) to facilitate more photosynthate partitioning into the grain (Lafitte, 1988).

Table: 9 Effect of soil amendments on yield and yield components

Treatment	100 seed Grain	Yield (t ha <sup>-1</sup> )		Harvest index	dry wt.(g)
		Grain	Stover		
Control	28.41	2.10	4.30	0.33	
NPK(H)	27.29	5.97	6.70	0.47	
NPK(L)	27.30	4.70	7.10	0.40	
Pm(H)	28.53	4.70	6.30	0.43	
Pm(L)	27.69	3.27	4.00	0.45	
Hw:Pm(H)	31.30	2.40	3.10	0.44	
Hw:Pm(L)	31.03	5.57	7.80	0.42	
Mw:F <sub>s</sub> (H)	27.61	3.70	4.07	0.48	
Mw:F <sub>s</sub> (L)	28.63	2.30	2.67	0.46	
Pm+NPK(H)	28.42	8.00	8.90	0.47	
Pm+NPK(L)	29.57	5.10	8.60	0.37	
Hw:Pm+NPK(H)	28.67	7.50	9.40	0.45	
Hw:Pm+NPK(L)	29.33	3.67	5.80	0.39	
Mw:F <sub>s</sub> +NPK(H)	30.85	3.27	4.80	0.40	
Mw:F <sub>s</sub> +NPK(L)	26.10	3.10	5.37	0.37	
SED	2.51	0.59	0.71	0.02	
CV	10.70	16.60	14.60	7.00	

#### 4.3.3. Chemical composition of maize grain and stover

The mean nutrient concentrations in maize grain and stover are presented in Table 10.

Table: 10 Some nutrient composition of Maize grain and stover.

Treatment	Nutrient Concentration (%)
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	Grain			Stover		
	N	P	K	N	P	K
Control	0.61	0.17	0.43	0.72	0.08	0.59
NPK(H)	0.80	0.18	0.34	0.72	0.10	0.59
NPK(L)	0.87	0.17	0.31	0.51	0.07	0.56
Pm(H)	0.94	0.24	0.37	0.53	0.10	0.52
PM(L)	0.94	0.19	0.32	0.74	0.16	0.52
Hw:Pm(H)	1.29	0.24	0.36	0.52	0.12	0.53
Hw:Pm(L)	0.73	0.21	0.36	0.86	0.09	0.62
Mw:F <sub>s</sub> (H)	1.04	0.28	0.45	0.88	0.19	0.55
Mw:F <sub>s</sub> (L)	0.91	0.25	0.39	0.76	0.25	0.78
Pm+NPK(H)	0.72	0.21	0.32	0.62	0.14	0.60
Pm+NPK(L)	0.87	0.21	0.35	0.45	0.10	0.51
Hw:Pm+NPK(H)	1.03	0.22	0.33	0.62	0.22	0.32
Hw:Pm+NPK(L)	1.17	0.22	0.39	0.62	0.14	0.64
Mw:F <sub>s</sub> +NPK(H)	1.24	0.22	0.39	0.69	0.22	0.61
Mw:F <sub>s</sub> +NPK(L)	0.69	0.18	0.35	0.68	0.13	0.59
SED	0.27	0.02	0.05	0.18	0.09	0.11
	16.40	33.90	74.30	24.20	35.80	11.10

The results (Table 10) showed that even though the values obtained for N, P and K in the maize grain were not significantly different ( $P > 0.05$ ), the combined treatments contained higher nutrient values than the sole organic and inorganic treatments. A similar trend was observed in the maize stover. Nitrogen content of the maize grain ranged from 0.61 to 1.29 % for control and Hw:Pm(H) respectively. The nitrogen content of the maize stover ranged from 0.45 to 0.88 %. The highest and lowest N were obtained by Mw:F<sub>s</sub>(H) and Pm + NPK(L) respectively. Phosphorus content of the maize grain ranged from 0.17 to 0.28 %. The highest and lowest P values were recorded under Mw:F<sub>s</sub>(H) and control respectively. Phosphorus content of the maize stover ranged from 0.07 to 0.25 %. Comparing the values, they were lower than the amounts found in the maize grain. The highest and lowest P content were obtained by Mw:F<sub>s</sub>(L) and NPK(L) respectively.

Potassium content of the maize grain ranged from 0.31 to 0.45 %. Mw:F<sub>s</sub>(H) and NPK(L) contained the highest and lowest K values respectively. Potassium content of the maize stover ranged from 0.51 to 0.78 %. The highest and lowest K content were obtained by Mw:F<sub>s</sub>(L) and Pm+NPK(L) respectively. The higher values observed in the combined treatments could be attributed to the fact that the combined treatments improved the soil environment for nutrient uptake. However, more N and P were found in the grain than in the stover, whilst more K was found in the stover than the grain. According to Marschner (1995) mineral nutrition and sink-source relationship indicate that as much as 80% of the total amount of N or P is located in the grains of matured cereals, compared with less than 20% of total potassium. Olson and Sander (1988) observed that K is used in about the same magnitude as P for grain production but much greater amount is contained in the stover (about two-thirds to three-fourths). On the other hand substantial amounts of P are taken up in the grain (IITA, 1982), hence the high amount of P observed in the grain as compared to the stover.



#### 4.3.4. Plant macronutrient uptake by maize under the different soil amendments

Nutrient uptake under the various treatments was significantly different ( $P < 0.05$ ) from one another, except for N uptake in the grain and P uptake in the stover (Table 10). Nutrient uptake ranged from 12.8 to 82.9 kg N ha<sup>-1</sup>, 3.6 to 16.8 kg P ha<sup>-1</sup> and 8.7 to 26.4 kg K ha<sup>-1</sup> in the maize grain and 20.1 to 66.3 kg N ha<sup>-1</sup>, 3.4 to 24.6 kg P ha<sup>-1</sup> and 16.4 to 54.7 kg K ha<sup>-1</sup> in the stover. N uptake values in both the grain and stover were higher than P and K uptake values. Generally nitrogen is required in the largest amounts, followed by potassium and phosphorus in that order but with much variation between crops (Rowell, 1993). The combined treatments of Pm+NPK(H) and Hw:Pm+NPK(H) promoted significantly ( $P < 0.05$ ) higher nutrient uptake in both the grain and stover than the sole organic or inorganic treatments. This may be due to the fact that the combined treatments improved the soil environment which was efficiently exploited by the maize plants as compared to the sole organic or inorganic treatments.

Table: 11 Effect of soil amendments on nutrient uptake of maize grain and stover.

Nutrient Uptake (kg/ha)
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Treatment	N	Grain			Stover	
		P	K	N	P	K
Control	12.80	3.57	9.17	30.80	3.44	25.50
NPK(H)	47.60	10.75	20.21	47.90	6.40	39.50
NPK(L)	41.10	7.99	14.53	36.30	4.80	39.60
Pm(H)	43.60	11.28	17.31	33.70	6.30	32.80
PM(L)	30.10	6.21	10.36	29.60	6.30	20.90
Hw:Pm(H)	30.50	5.76	8.71	16.10	3.80	16.40
Hw:Pm(L)	39.70	11.70	20.10	66.30	6.68	47.70
Mw:F <sub>s</sub> (H)	38.80	10.36	16.50	37.10	7.80	22.80
Mw:F <sub>s</sub> (L)	20.30	5.75	8.89	20.10	5.75	20.80
Pm+NPK(H)	58.30	15.20	26.44	53.30	11.40	54.70
Pm+NPK(L)	44.20	10.71	18.03	38.70	8.70	44.10
Hw:Pm+NPK(H)	82.90	16.50	24.77	59.20	24.60	26.10
Hw:Pm+NPK(L)	43.20	8.07	14.67	36.40	8.20	37.30
Mw:F <sub>s</sub> +NPK(H)	41.30	7.19	13.05	33.40	10.70	28.90
Mw:F <sub>s</sub> +NPK(L)	21.50	5.58	10.82	35.90	6.20	32.00
SED	16.81	2.79	3.50	10.41	6.96	8.38
CV	51.60	21.60	27.60	33.30	96.00	31.50

#### 4.3.5. Soil analysis before and after harvest

Tables 12 and 13 show some selected physico-chemical properties of the soil from the experimental field. Table 2 also shows the initial characterization of soil sampled for the pot experiment. The soil pH before the application of treatments ranged from 5.34 to 6.95 (acidic to neutral). The lowest pH value was recorded by plot Hw:Pm(H) while plot Pm+NPK(H) had the highest pH value (Table 12). The soil pH range after harvest was 4.64 – 5.95 (very acidic to moderately acidic). Similarly, Hw:Pm(H) and Pm+NPK(H) plots recorded the lowest and highest pH values respectively (Table 13). Generally, there was a drop in the pH of all the treatments after harvest indicating an increase in soil acidity, with NPK(H) and Pm+NPK(H) values decreasing by about one pH unit (Table 12 & 13).

Soil organic carbon contents ranged from low to medium (0.62 to 1.02 %) before the experiment. Plots Mw:F<sub>s</sub>(H) and NPK(L) recorded the highest O.C. value while Mw:F<sub>s</sub>+NPK(L) showed the lowest. The organic carbon levels after harvest ranged from 0.77 to 1.35 % (low to medium).

Total nitrogen content before the experiment ranged from 0.12 to 0.22 % (medium to high). After harvest the soil total nitrogen ranged from 0.07 to 0.12 % (low to medium). Generally, as a result of nutrient uptake by the maize, soil total nitrogen content decreased in all the treatments after harvest (Table 12 & 13). Hanway (1971) observed that N tends to be depleted rapidly from the soil with cash grain farming such as maize.

Soil available phosphorus was low to high, both before (8.98 to 26.40 mg kg<sup>-1</sup>) and after (11.68 to 29.87 mg kg<sup>-1</sup>) the experiment, though, there was a slight increase after harvest on most of the plots (Table 12 & 13). Soil available potassium was moderate (58.78 to

95.22 mgkg<sup>-1</sup>) on all the plots before the experiment. The levels of available potassium after harvest however, ranged from low to high (42.79 to 103.13 mgkg<sup>-1</sup>) with most of the plots having moderate to high available K.

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Table: 12 Selected physical and chemical properties of the soil before the experiment.

Treatment	pH (H <sub>2</sub> O)	N %	Carbon %	Av. P mgkg <sup>-1</sup>	Av. K mgkg <sup>-1</sup>	Sand %	Silt %	Clay %
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Cont.	5.82	0.13	0.82	8.98	78.76	72.27	10.53	17.20	SED 0.61 0.06 0.17
NPK(H)	6.09	0.14	0.88	16.89	95.22	71.87	11.73	16.40	
NPK(L)	5.53	0.14	1.02	14.02	88.16	69.60	11.20	19.20	
Pm(H)	5.68	0.16	0.85	22.31	61.52	74.00	6.53	19.47	
Pm(L)	6.08	0.12	0.71	20.52	77.40	75.33	7.20	17.47	
Hw:Pm(H)	5.34	0.15	0.69	13.14	93.25	71.33	7.87	20.80	
Hw:Pm(L)	5.92	0.15	0.71	17.94	74.45	72.93	9.74	17.33	
Mw:Fs(H)	5.89	0.18	1.02	24.23	58.78	74.93	9.87	15.20	
Mw:Fs(L)	6.75	0.22	0.87	25.33	90.91	70.93	11.87	17.20	
Pm+NPK(H)	6.95	0.18	0.96	22.42	93.26	72.93	12.54	14.53	
Pm+NPK(L)	5.38	0.15	0.74	26.40	64.69	73.33	7.87	18.80	
Hw:Pm+NPK(H)	6.15	0.18	0.74	16.39	85.16	69.27	10.53	20.20	
Hw:Pm+NPK(L)	6.39	0.14	0.69	16.28	64.65	70.27	11.07	18.67	
Mw:Fs+NPK(H)	6.48	0.15	0.83	25.40	69.75	75.60	10.40	14.00	
Mw:Fs+NPK(L)	5.70	0.13	0.62	19.52	83.85	73.33	7.87	18.80	
	10.30	17.66	2.82	2.14	2.45				
CV	12.30	44.9	25.80	43.70	27.50	4.80	26.80	17.00	

Table: 13 Selected physical and chemical properties of the soil after harvest.

Treatment	pH H <sub>2</sub> O	N %	Carbon %	Av. P mgkg <sup>-1</sup>	Av. K mgkg <sup>-1</sup>	Sand %	Silt %	Clay %
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Cont.	5.35	0.09	1.02	11.68	42.79	68.40	11.87	19.73	
NPK(H)	5.03	0.07	0.83	18.43	98.24	70.40	12.40	17.20	
NPK(L)	4.80	0.08	0.93	15.91	103.13	71.07	11.20	17.73	
Pm(H)	4.88	0.08	0.99	27.49	51.57	68.00	13.20	18.80	SED
Pm(L)	5.35	0.08	0.94	24.51	59.25	72.00	11.87	16.13	0.47
Hw:Pm(H)	4.64	0.09	1.01	18.60	98.30	70.93	11.87	17.20	0.02
Hw:Pm(L)	5.42	0.07	0.80	19.28	85.58	70.67	13.33	16.00	0.18
Mw:Fs(H)	5.32	0.08	0.96	29.87	71.78	72.67	11.86	15.47	
Mw:Fs(L)	5.76	0.09	1.07	23.40	85.58	72.00	13.07	14.93	
Pm+NPK(H)	5.95	0.12	1.35	20.57	84.48	71.33	14.54	14.13	
Pm+NPK(L)	5.04	0.08	0.92	27.18	82.42	72.00	11.87	16.13	
Hw:Pm+NPK(H)	5.26	0.10	0.95	19.45	94.35	68.67	13.20	18.13	
Hw:Pm+NPK(L)	5.31	0.09	1.09	13.02	72.30	66.00	15.20	18.80	
Mw:Fs+NPK(H)	5.89	0.08	0.94	27.96	63.63	73.07	12.66	14.27	
Mw:Fs+NPK(L)	4.93	0.07	0.77	17.29	90.94	72.00	12.00	16.00	
	11.85	21.53	2.46	2.02	2.12				
CV	10.80	31.10	22.20	45.50	33.40	4.30	19.50	15.60	

Generally, there was an increase in  $\text{mg kg}^{-1}$  K in most of the treatments except the Mw:Fs(L), Pm+NPK(H), Hw:Pm+NPK(L) and Mw:Fs+NPK(L). This is contrary to reports by several authors of high K leaching losses in tropical humid soils.

Percentage sand, silt and clay ranged from 66.00 to 75.60, 6.53 to 15.20 and 14.00 to 21.20 respectively.

#### 4.4. Residual effect

**4.4.1. The effect of Residual soil amendments on growth parameters of maize** The experiment in the major season was repeated in the minor season to assess the residual effects of the applied soil amendments. There were no significant differences ( $P > 0.05$ ) in the growth parameters among the various treatments (Table 14). Generally, plant height increased with time peaking at 12 WAP (Appendix M). At the 50 % flowering stage NPK(L) and Mw:Fs+NPK(L) recorded the highest and the lowest plant height of 148.17 cm and 101.00 cm respectively (Table 14). Plant leaf area also increased with time peaking at 8 WAP (Appendix N) and ranged from 524.34 cm<sup>2</sup> and 378.71 cm<sup>2</sup> for Pm+NKP(L) and Hw:Pm+NPK(H) respectively. Plant girth ranged from 1.81 cm and 1.53 cm for Mw:Fs+NPK(H) and Mw:Fs+NPK(L) respectively. Generally, a similar trend of results was observed in the vegetative growth of maize during the major season. However, the values were comparatively lower in the residual experiment (Tables 7 & 14). This could be due to the fact that the residual plant nutrients were not adequate for the growth of the succeeding maize crop.

Table: 14 Effect of treatments on mean maize plant growth at 50% flowering stage during the residual experiment.

Treatment	Leaf area (cm <sup>2</sup> )	Plant height (cm)	Plant girth (cm)
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Control	461.00	125.10	1.63
NPK(H)	437.00	144.70	1.66
NPK(L)	415.00	148.20	1.59
Pm(H)	415.00	119.30	1.65
Pm(L)	460.00	108.30	1.63
Hw:Pm(H)	394.00	113.80	1.61
Hw:Pm(L)	487.00	142.10	1.79
Mw:F <sub>s</sub> (H)	413.00	118.90	1.66
Mw:F <sub>s</sub> (L)	436.00	125.90	1.65
Pm+NPK(H)	498.00	141.50	1.69
Pm+NPK(L)	524.00	128.60	1.69
Hw:Pm+NPK(H)	379.00	123.90	1.61
Hw:Pm+NPK(L)	454.00	130.20	1.70
Mw:F <sub>s</sub> +NPK(H)	429.00	122.30	1.81
Mw:F <sub>s</sub> +NPK(L)	388.00	101.00	1.53
SED	63.60	20.15	0.16
CV	17.70	19.50	11.50

#### 4.4.2. Residual effect of nutrients on maize yield

Yield

indices

measured

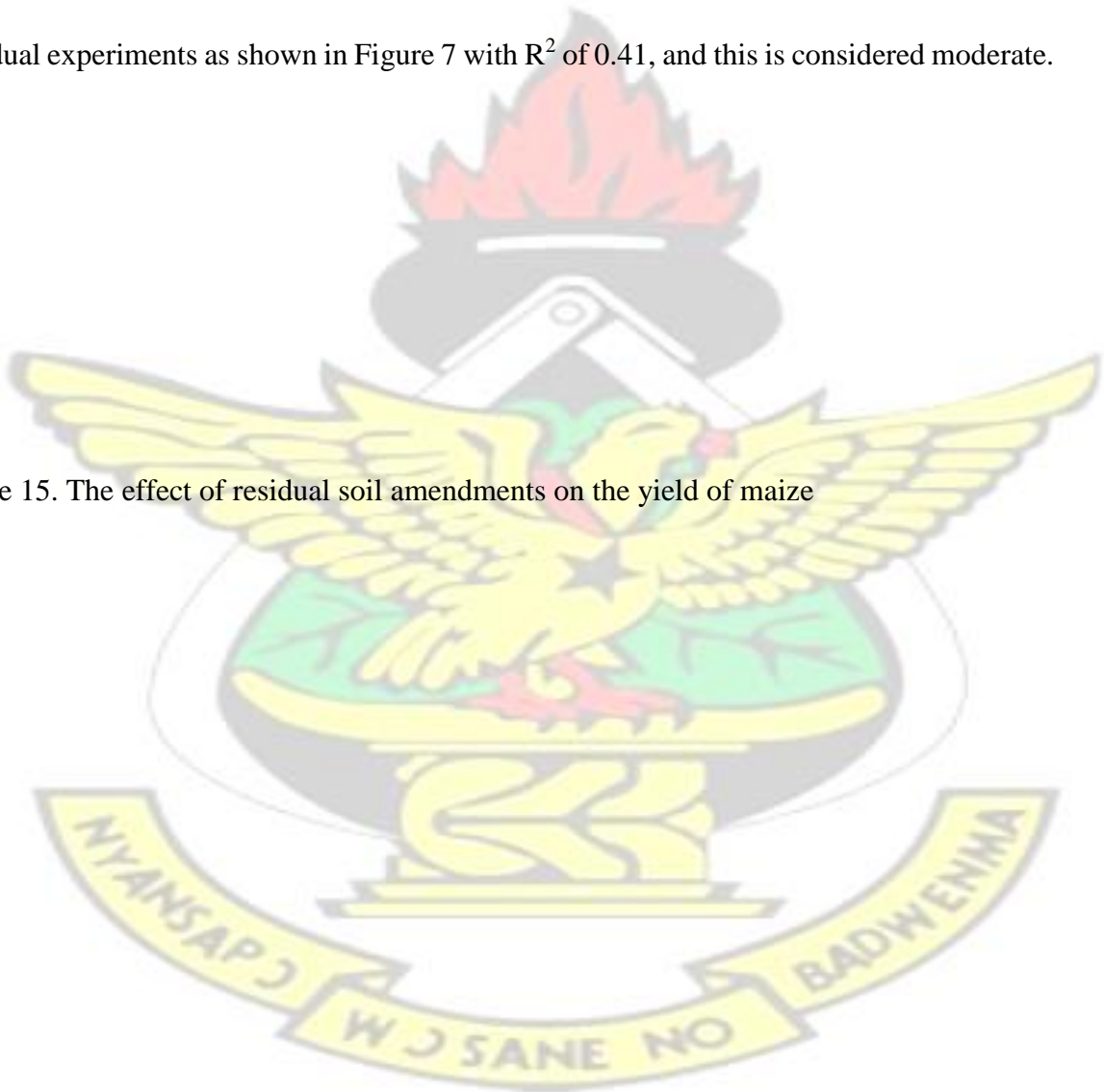
were

significantly different ( $P < 0.05$ ) from one another (Table 15) except for the 100 seed weight. The NPK(H) ( $3.60 \text{ tons ha}^{-1}$ ) and Pm(H) ( $3.10 \text{ tons ha}^{-1}$ ) however, performed better (Table 15) than Pm+NPK(H) ( $2.80 \text{ tons ha}^{-1}$ ) and Hw:Pm+NPK(H) ( $2.70 \text{ tons ha}^{-1}$ ) which gave the best yields in the major season (Table 8). The highest and lowest 100 seed weight values of 23.75 g and 18.00 g were recorded by NPK(H) and Hw:Pm(H) respectively. There were significant differences ( $P < 0.05$ ) in the stover yield among the treatments (Table 15). The control recorded a yield of  $5.20 \text{ t ha}^{-1}$  which was higher than all the treatments except Mw:F<sub>s</sub>+NPK(H) and Hw:Pm(L) with yields 6.0 and  $5.50 \text{ t ha}^{-1}$ . However, Hw:Pm(H) produced the lowest yield of  $2.20 \text{ t ha}^{-1}$ . Stover yields were significantly lower than those recorded in the major season. The results generally showed



that yields recorded by the treatments were about 50 % lower compared to yields in the major season. However, NPK(H) and Pm(H) produced yields which were significantly higher compared to the other treatments. Although the residual yields were lower, the results showed that both organic manure and mineral fertilizer especially N fertilizer dressings, leave residues that benefit the following crop as observed by Sharma et al. (1986). There was therefore a positive correlation between the grain yield in the major and residual experiments as shown in Figure 7 with  $R^2$  of 0.41, and this is considered moderate.

Table 15. The effect of residual soil amendments on the yield of maize



Treatment	100 seed Yield (t/ha)	Harvest index	dry wt. (g)	Grain	Stover
Control	19.76	1.00	5.20	0.16	
NPK(H)	23.75	3.60	2.70	0.56	
NPK(L)	20.60	2.10	3.30	0.39	
Pm(H)	21.11	3.10	3.60	0.46	
Pm(L)	20.77	2.40	3.10	0.44	
Hw:Pm(H)	18.00	1.20	2.20	0.35	
Hw:Pm(L)	22.87	3.40	5.50	0.38	
Mw:F <sub>s</sub> (H)	22.00	2.40	3.00	0.44	
Mw:F <sub>s</sub> (L)	21.79	2.20	6.00	0.27	
Pm+NPK(H)	22.72	2.80	4.50	0.38	
Pm+NPK(L)	18.84	1.80	3.60	0.32	
Hw:Pm+NPK(H)	20.72	2.70	4.10	0.39	
Hw:Pm+NPK(L)	20.57	2.70	4.40	0.38	
Mw:F <sub>s</sub> +NPK(H)	20.82	2.20	6.00	0.27	
Mw:F <sub>s</sub> +NPK(L)	21.44	1.20	3.60	0.25	
SED	2.11	0.46	0.32	0.04	
CV	12.30	24.70	9.80	14.50	

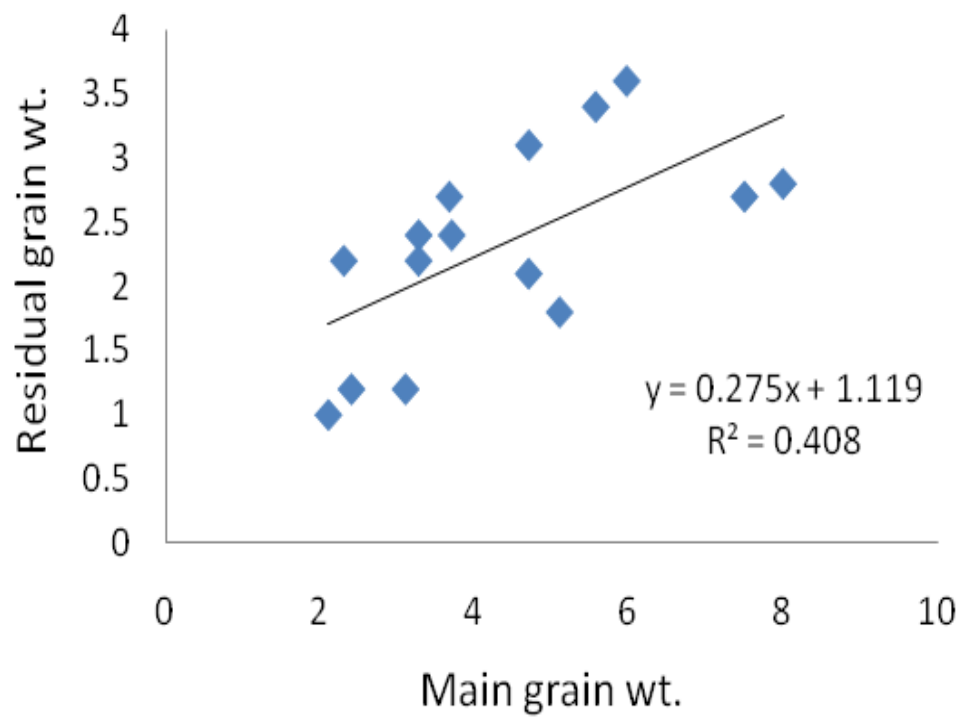
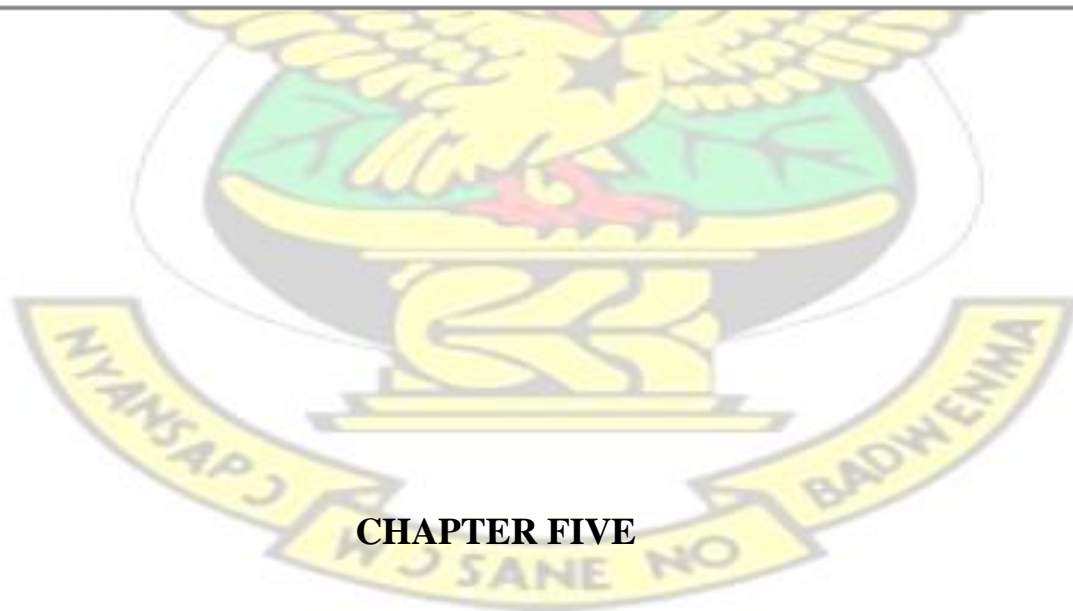


Figure 7. Relationship between grain yields in the main and residual experiment



## 5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS 5.1. SUMMARY

- ❖ Poultry manure has higher nutrient content and water holding capacity than composted materials (Hw:Pm and Mw:F<sub>s</sub> composts). The nutrient content was 2.06 % N, 0.52 % P and 0.73 % K, in poultry manure whilst the (Hw:Pm) and (Mw:F<sub>s</sub>) composts were moderate in N and K but low in P with 1.49 and 0.92 % N, 0.56 and 0.58 % K and 0.48 and 0.35 % P respectively.
- ❖ The moisture content of poultry manure at saturation, field capacity and 16 DAS were higher (119.51 %, 92.68 % and 63.41 %) than in (Hw:Pm) and (Mw:F<sub>s</sub>) composts and therefore has higher water holding capacity.
- ❖ Results obtained from the Greenhouse experiment showed that the growth parameters (plant leaf area, height, girth and the number of leaves) measured were not significantly different among the various treatments.
- ❖ The use of fertilizers (organic and/or inorganic) increased maize biomass production. However, the yields obtained by the combined treatments were significantly higher than their sole treatments except for NPK(H) which produced a yield value equal to that of the combined treatments.
- ❖ Water use efficiency (WUE) increased significantly with increasing maize dry matter production. The treatments which produced higher biomass (Pm + NPK(H), Hw:Pm +NPK(H) and Mw:F<sub>s</sub> +NPK(H)) used smaller quantities of water than those which produced lower biomass. The implication is that the former treatments created conditions for a more efficient use of water by the plants.
- ❖ The results obtained from the field experiment showed that there were no significant differences among the treatments in relation to the growth parameters measured as was observed in the Greenhouse experiment.



- ❖ The combined treatments produced yields which were significantly higher than the values obtained by organic or inorganic fertilizers separately. The highest grain and stover yields of 8.0 and 8.9 tons ha<sup>-1</sup> were obtained by Pm+NPK at a combined application of 60 N kg ha<sup>-1</sup> poultry manure plus 60-40-40 kg ha<sup>-1</sup> NPK. The control obtained the lowest grain and stover yields of 2.1 and 4.3 tons ha<sup>-1</sup> respectively.
- ❖ The combined treatments of Pm+NPK(H) and Hw:Pm+NPK(H) had significantly higher nutrient uptake values than the control. The highest nutrient uptake of 142.066 kg N ha<sup>-1</sup>, 55.737 kg P ha<sup>-1</sup> and 50.870 kg K ha<sup>-1</sup> was obtained under the combined application of compost and fertilizer (Hw:Pm+NPK(H)).
- ❖ The soil pH at the end of the experiment decreased in all the treatments with NPK(H) and Pm+NPK(H) decreasing by 1.06 and 1.00 units respectively. Soil total N decreased in all the treatments while percentage C and available P and K increased. However, differences in soil nutrient concentrations were marginal or low.
- ❖ Residual nutrients sustained maize plant growth and had yields, which were 50 % lower than what was obtained from the nutrient applied plots. Grain yields from the sole organic or inorganic treatments, for example Pm (H) and NPK(H) were higher compared to yields obtained by the combined treatments, even though the reverse was the case when the soil amendments were applied in the major season.

## 5.2. CONCLUSION

- ❖ Poultry manure and household waste plus poultry manure compost improved nutrient availability to crops and moisture retention in the soil.

- ❖ Combined application of organic and inorganic fertilizers results in a high water use efficiency implying a judicious use of water in the combined applications.
- ❖ Combined application of the organic and inorganic fertilizers results in yields higher than sole application of each nutrient source.
- ❖ Nutrient uptake values were higher in the combined application than the sole application.

## **RECOMMENDATION**

- ❖ The combined application of organic and inorganic fertilizers at 60 kg N organic manure plus 60-40-40 NPK ha<sup>-1</sup> mineral fertilizer is thus recommended for smallholder farmers.
- ❖ Long term studies of the treatments used in this study should be carried out to further ascertain their effects on the physico-chemical properties of the soil.

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## APPENDIX A1

### FERTILIZER CALCULATIONS

Quantity of fertilizer applied in the pot experiment:

$$\frac{R \times W \times 100}{2,000,000 \times C}$$

$$2,000,000 \times C$$

where

R = rate of fertilizer to be applied (kg / ha).

W = weight of soil used (kg).

C = concentration of element in fertilizer (%).

2,000,000 = assumed weight of soil per ha per (0 – 15 cm) depth (kg).

#### a. Inorganic

Straight fertilizer of N, P and K sources were urea (46% N), triple super phosphate (46% P<sub>2</sub>O<sub>5</sub>) and muriate of potash (60% K<sub>2</sub>O) respectively at rates of 60:40:40 NPK (high) and 30:20:20 NPK (low).

$$\begin{aligned} \text{i. Quantity of Urea applied (high rate)} &= (60 \times 5.4 \times 100) / (2,000,000 \times 46) \\ &= 3.50 \times 10^{-4} \text{ kg} \\ &= 0.35 \text{ g} \end{aligned}$$

$$\text{ii. Quantity of urea applied (low rate)} = 0.35 / 2 = 0.18 \text{ g}$$

## APPENDIX A2

iii. Quantity of triple super phosphate applied (high rate) =  $(40 \times 5.4 \times 100) / (2,000,000 \times 46)$

$$= 2.35 \times 10^{-4} \text{ kg}$$

$$= 0.24 \text{ g}$$

iv. Quantity of triple super phosphate applied (low rate) =  $0.24 / 2 = 0.12 \text{ g}$

v. Quantity of muriate of potash applied (high rate) =  $(40 \times 5.4 \times 100) / (2,000,000 \times 60)$

$$= 1.83 \times 10^{-4} \text{ kg}$$

$$= 0.18 \text{ g}$$

vi. Quantity of muriate of potash applied (low rate) =  $0.18 / 2 = 0.09 \text{ g}$

### b. Organic

Poultry manure (Pm), Household waste and poultry manure composted material (Hw:Pm) in 3:1 ratio i.e. 3 parts of household waste to 1 part of poultry manure and market waste and faecal sludge composted material (Mw:F<sub>s</sub>) in 3:1 ratio i.e. 3 parts of market waste to 1 part of faecal sludge based on 60% N and 30% N representing high and low rates respectively.

i. Quantity of poultry manure applied (high rate) =  $(60 \times 5.4 \times 100) / (2,000,000 \times 2.06)$

$$= 0.00786 \text{ kg (7.86 g)}$$

ii. Quantity of poultry manure applied (low rate) =  $7.86 / 2 = 3.93 \text{ g}$

iii. Quantity of Hw:Pm compost applied (high rate) =  $(60 \times 5.4 \times 100) / (2,000,000 \times 1.49)$

$$= 0.01087 \text{ kg (10.87 g)}$$

## APPENDIX A3

- iv. Quantity of Hw:Pm compost applied (low rate) =  $10.87 / 2 = 5.44$  g
- v. Quantity of Mw:F<sub>s</sub> compost applied (high rate) =  $(60 \times 5 \times 100) / (2,000,000 \times 0.92)$   
= 0.01761 kg (17.61 g)
- vi. Quantity of Mw:F<sub>s</sub> compost applied (low rate) =  $17.61 / 2 = 8.81$  g

Quantity of fertilizer applied in the field experiment:

$$\frac{R \times A \times 100}{10,000 \times C}$$

where

R = rate of fertilizer to be applied (kg / ha).

A = area of plot (m<sup>2</sup>).

C = concentration of element in fertilizer (%).

10,000 = area per ha (m<sup>2</sup>).

### a. Inorganic

- i. Quantity of urea applied (high rate) =  $(60 \times 12 \times 100) / (10,000 \times 46)$   
= 0.1565 kg (156.50 g)
- ii. Quantity of urea applied (low rate) =  $156.50 / 2 = 78.25$  g
- iii. Quantity of triple super phosphate applied (high rate) =  $(40 \times 12 \times 100) / (10,000 \times 46)$   
= 0.1043 kg (104.30 g)

## APPENDIX A4

- iv. Quantity of triple super phosphate applied (low rate) =  $104.30 / 2 = 52.15$  g
- v. Quantity of muriate of potash applied (high rate) =  $(40 \times 12 \times 100) / (10,000 \times 60)$

$$= 0.08 \text{ kg (80.00 g)}$$

vi. Quantity of muriate of potash applied (low rate) =  $80.00 / 2 = 40.00 \text{ g}$

## **b. Organic**

i. Quantity of poultry manure applied (high rate) =  $(60 \times 12 \times 100) / (10,000 \times 2.06)$

$$= 3.50 \text{ kg (3500 g)}$$

ii. Quantity of poultry manure applied (low rate) =  $3500 / 2 = 1750 \text{ g}$

iii. Quantity of Hw:Pm compost applied (high rate) =  $(60 \times 12 \times 100) / (10,000 \times 1.49)$

$$= 4.80 \text{ kg (4800 g)}$$

iv. Quantity of Hw:Pm compost applied (low rate) =  $4800 / 2 = 2400 \text{ g}$

v. Quantity of Mw:Fz compost applied (high rate) =  $(60 \times 12 \times 100) / (10,000 \times 0.92)$

$$= 7.80 \text{ kg (7800 g)}$$

vi. Quantity of Mw:Fz compost applied (low rate) =  $7800 / 2 = 3900 \text{ g}$

## **APPENDIX B**

### **Plant height (cm) growth data in pot experiment**

Control	6.43	14.67	23.83	40.67	56.60	67.83
NPK(H)	5.93	15.53	24.70	38.20	54.33	63.27

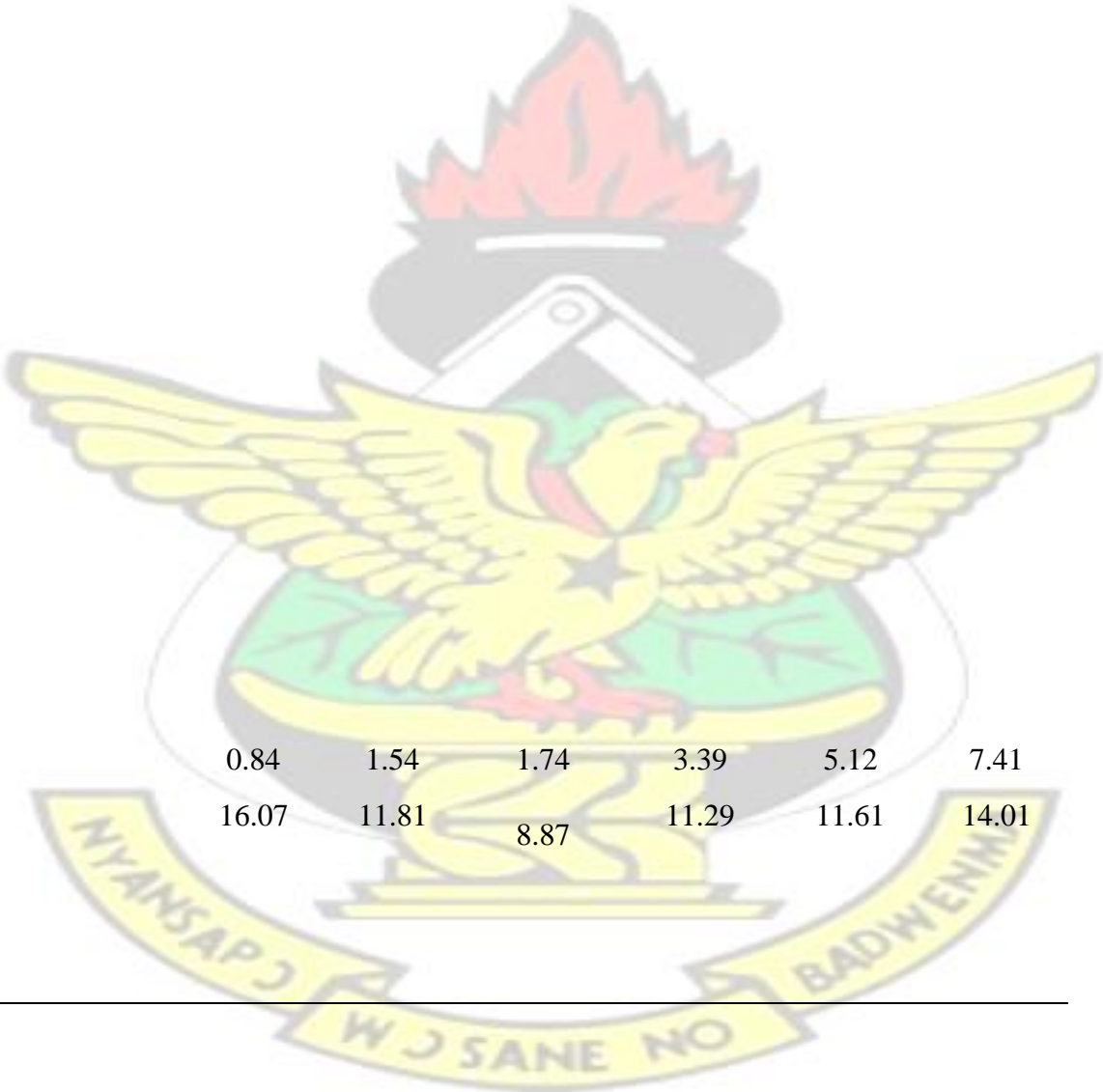


NPK(L)	6.83	17.77	24.27	37.53	54.00	66.10
Pm(H)	5.50	15.27	23.10	32.10	51.03	62.00
Pm(L)	8.03	17.43	24.67	39.17	57.17	66.83
Hw:Pm(H)	6.20	15.33	24.13	35.50	50.10	57.77
Hw:Pm(L)	5.40	16.43	25.30	38.53	57.10	68.50
Mw:Fs(H)	5.93	14.83	23.50	37.53	54.20	64.33
Mw:Fs(L)	7.27	15.53	21.60	33.03	45.83	54.10
Pm+NPK(H)	7.10	17.10	23.53	36.93	54.27	65.77
Pm+NPK(L)	5.87	14.93	23.10	32.17	48.33	57.50
Hw:Pm+NPK(H)	6.43	16.43	25.07	36.67	60.93	78.83
Hw:Pm+NPK(L)	6.47	15.37	23.27	34.50	49.83	59.50
Mw:Fs+NPK(H)	5.67	16.87	26.77	40.77	58.67	71.17
Mw:Fs+NPK(L)	6.50	15.37	23.43	38.43	57.00	68.77
	1	2	3	4	5	6

Week						
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Treatment

# KNUST



The logo of the Kenya National University of Science and Technology (KNUST) is centered in the background. It features a yellow eagle with its wings spread, perched on a green shield. Above the eagle is a black mortar and pestle with a red flame. Below the eagle is a yellow banner with the text 'NYANSAPU' on the left and 'BADWENNI' on the right. At the bottom, another yellow banner contains the text 'WU SANE NO'.

SED	0.84	1.54	1.74	3.39	5.12	7.41
CV	16.07	11.81	8.87	11.29	11.61	14.01

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## APPENDIX C

### Leaf area (cm<sup>2</sup>) growth data in pot experiment

Week						
Treatment						
Control	24.49	64.83	143.53	167.90	262.68	255.68
NPK(H)	23.56	69.78	177.49	264.22	299.69	340.55
NPK(L)	29.1	88.25	141.93	224.91	252.79	299.13
Pm(H)	24.35	60.44	157.00	245.75	271.26	296.05
Pm(L)	25.73	71.66	145.79	228.71	241.16	264.34
Hw:Pm(H)	23.58	59.46	137.02	230.01	283.64	289.73
Hw:Pm(L)	24.44	73.41	155.74	234.26	273.71	273.10
Mw:F <sub>s</sub> (H)	28.01	78.68	171.17	204.56	242.05	263.59
Mw:F <sub>s</sub> (L)	24.20	61.98	124.37	163.79	192.55	215.70
Pm+NPK(H)	27.29	83.54	145.88	244.74	261.49	284.06
Pm+NPK(L)	16.32	62.73	134.81	190.09	241.91	272.85
Hw:Pm+NPK(H)	20.99	56.51	136.86	198.91	274.09	296.53
Hw:Pm+NPK(L)	26.06	73.36	120.84	173.60	268.08	275.32
Mw:F <sub>s</sub> +NPK(H)	23.02	72.89	158.00	242.80	299.76	338.86
Mw:F <sub>s</sub> +NPK(L)	19.02	70.21	143.46	242.48	286.99	334.16
	1	2	3	4	5	6
SED	3.46	14.82	22.77	26.35	28.93	33.24
CV	17.63	25.98	19.07	14.86	13.45	14.20

## APPENDIX D

### Plant girth (cm) growth data in pot experiment

Week						
Treatment						
Control	0.35	0.61	0.81	0.96	0.83	0.80
NPK(H)	0.38	0.68	1.05	1.13	0.95	0.87
NPK(L)	0.43	0.69	0.93	1.07	0.98	0.92
Pm(H)	0.33	0.72	1.00	1.09	0.95	0.90
Pm(L)	0.35	0.71	0.94	0.92	0.84	0.80
Hw:Pm(H)	0.33	0.65	0.95	1.02	0.92	0.87
Hw:Pm(L)	0.33	0.64	0.89	0.92	0.86	0.82
Mw:F <sub>s</sub> (H)	0.38	0.70	0.91	0.92	0.88	0.86
Mw:F <sub>s</sub> (L)	0.38	0.64	0.88	0.88	0.83	0.79
Pm+NPK(H)	0.35	0.74	0.97	1.07	0.95	0.92
Pm+NPK(L)	0.33	0.59	0.86	0.92	0.85	0.81
Hw:Pm+NPK(H)	0.34	0.65	0.87	1.04	0.94	0.87
Hw:Pm+NPK(L)	0.39	0.67	0.93	0.96	0.89	0.85
Mw:F <sub>s</sub> +NPK(H)	0.35	0.66	0.96	1.07	0.90	0.87
Mw:F <sub>s</sub> +NPK(L)	0.32	0.64	0.97	1.16	1.05	1.01
	1	2	3	4	5	6
SED	0.04	0.07	0.06	0.09	0.10	0.08
CV	12.54	13.03	8.38	10.33	12.81	11.43



## APPENDIX E

### Number of leaves of the maize plant in pot experiment

Week						
Treatment						
Control	3.67	5.67	7.33	7.33	7.33	6.67
NPK(H)	3.33	5.67	7.33	7.67	7.33	7.67
NPK(L)	3.33	5.67	6.33	7.00	6.67	7.33
Pm(H)	3.33	5.67	7.67	6.67	6.67	6.67
Pm(L)	4.00	6.00	7.00	7.00	6.33	7.33
Hw:Pm(H)	4.00	5.67	7.33	7.00	6.67	7.00
Hw:Pm(L)	3.33	5.00	6.33	6.33	6.00	6.33
Mw:Fs(H)	3.33	6.00	7.00	6.33	6.00	6.33
Mw:Fs(L)	4.00	6.00	6.67	6.67	6.33	6.33
Pm+NPK(H)	3.67	5.67	7.33	7.00	6.67	7.00
Pm+NPK(L)	3.33	5.67	7.00	7.33	6.33	6.00
Hw:Pm+NPK(H)	3.67	5.67	7.33	7.33	6.67	6.67
Hw:Pm+NPK(L)	4.00	5.67	7.33	6.33	6.00	6.33
Mw:Fs+NPK(H)	3.33	5.67	8.00	7.67	6.67	7.00
Mw:Fs+NPK(L)	3.67	6.00	7.33	7.67	7.00	7.33
	1	2	3	4	5	6
SED	0.41	0.42	0.45	0.61	0.46	0.52
CV	14.09	8.93	7.69	10.66	8.63	9.47

## APPENDIX F

### Soil moisture data (%) in the pot experiment

Week					
Treatment					
Control	8.90	9.17	9.20	9.13	11.73
NPK(H)	14.40	11.07	9.90	8.87	8.43
NPK(L)	8.53	8.30	9.00	8.53	8.53
Pm(H)	8.87	8.43	9.03	8.43	8.30
Pm(L)	8.73	9.23	9.23	9.03	11.83
Hw:Pm(H)	9.13	9.37	9.43	9.17	12.80
Hw:Pm(L)	9.43	8.90	9.17	9.17	12.00
Mw:F <sub>s</sub> (H)	8.90	8.63	9.40	9.43	16.37
Mw:F <sub>s</sub> (L)	9.03	9.73	10.03	10.07	19.07
Pm+NPK(H)	9.73	8.67	8.87	7.87	7.73
Pm+NPK(L)	9.70	9.80	9.90	9.10	11.23
Hw:Pm+NPK(H)	10.90	9.23	9.43	9.27	16.20
Hw:Pm+NPK(L)	8.07	7.90	8.67	8.10	8.10
Mw:F <sub>s</sub> +NPK(H)	9.77	9.47	9.43	9.13	11.67
Mw:F <sub>s</sub> +NPK(L)	9.90	9.23	9.27	9.13	10.17
	1	2	3	4	5
SED	1.24	0.50	0.22	0.64	2.91
CV	15.77	6.70	2.90	8.72	30.74

### APPENDIX G1

**Relative humidity data**

Date	Time	Dry temp.	Wet temp.	Vapour pressure	Sat. vap. Pressure	Relative humidity
	GMT	°C	°C			
05/11/04	6:00	28	25	37.71	31.61	83.83
05/11/04	15:00	36	29	59.23	39.95	67.46
06/11/04	15:00	36	28	59.23	37.71	63.66
07/11/04	6:00	28	25	37.71	31.61	83.83
07/11/04	12:00	35	28	56.06	37.71	67.26
11/11/04	12:00	35	28	56.06	37.71	67.26
12/11/04	12:00	31	26	44.80	33.54	74.85
13/11/04	6:00	28	25	37.71	31.61	83.83
13/11/04	12:00	36	27	59.23	35.57	60.05
14/11/04	12:00	35	28	56.06	37.71	67.26
15/11/04	6:00	27	25	35.57	31.61	88.86
15/11/04	12:00	31	27	44.80	35.57	79.39
16/11/04	6:00	25	24	31.61	29.77	94.20
16/11/04	12:00	34	28	53.04	37.71	71.09
16/11/04	15:00	33	28	50.16	37.71	75.17
17/11/04	6:00	26	24	33.54	29.77	88.78
17/11/04	12:00	35	28	56.06	37.71	67.26
18/11/04	6:00	26	24	33.54	29.77	88.78
18/11/04	12:00	35	28	56.06	37.71	67.26

**APPENDIX G2**

Date	Time	Dry temp.	Wet temp.	Vapour	Sat. vap.	Relative
------	------	-----------	-----------	--------	-----------	----------

	GMT	°C	°C	pressure	Pressure	humidity
18/11/04	15:00	32	27	47.42	35.57	75.01
19/11/04	12:00	34	27	53.04	35.57	67.06
20/11/04	6:00	28	25	37.71	31.61	83.83
20/11/04	12:00	35	28	56.06	37.71	67.26
21/11/04	15:00	28	24	37.71	29.77	78.97
22/11/04	6:00	27	24	35.57	29.77	83.71
22/11/04	15:00	36	29	59.23	39.95	67.46
23/11/04	12:00	29	25	39.95	31.61	79.11
23/11/04	15:00	36	28	59.23	37.71	63.66
24/11/04	6:00	26	24	33.54	29.77	88.78
24/11/04	12:00	35	28	56.06	37.71	67.26
25/11/04	6:00	26	24	33.54	29.77	88.78
26/11/04	12:00	28	25	37.71	31.61	83.83
26/11/04	15:00	34	28	53.04	37.71	71.09
27/11/04	12:00	33	28	50.16	37.71	75.17
28/11/04	12:00	32	27	47.42	35.57	75.01
29/11/04	6:00	28	25	37.71	31.61	83.83
30/11/04	6:00	28	25	37.71	31.61	83.83
31/11/04	6:00	29	24	39.95	29.77	74.52
01/12/04	12:00	34	27	53.04	35.57	67.06

### APPENDIX G3

Date	Time	Dry temp.	Wet temp.	Vapour pressure	Sat. vap.	Relative humidity
	GMT	°C	°C		Pressure	



02/12/04	12:00	36	28	59.23	37.71	63.66
03/12/04	12:00	35	28	56.06	37.71	67.26
05/12/04	12:00	33	28	50.16	37.71	75.17
09/12/04	12:00	29	25	39.95	31.61	79.11
10/12/04	6:00	27	25	35.57	31.61	88.86
10/12/04	12:00	32	26	47.42	33.54	70.73
11/12/04	12:00	31	26	44.80	33.54	74.85
13/12/04	6:00	27	24	35.57	29.77	83.71
14/12/04	6:00	27	25	35.57	31.61	88.86
14/12/04	12:00	34	28	53.04	37.71	71.09
15/12/04	15:00	35	27	56.06	35.57	63.45
16/12/04	15:00	35	27	56.06	35.57	63.45
17/12/04	6:00	27	25	35.57	31.61	88.86
18/12/04	12:00	35	28	56.06	37.71	67.26
18/12/04	6:00	28	25	37.71	31.61	83.83

## APPENDIX H

### Plant height (cm) data in the field experiment

	4	8	
Control	62.35	147.57	172.27
NPK(H)	81.60	168.10	196.60
NPK(L)	73.75	153.73	169.87
Pm(H)	78.74	165.28	191.40
Pm(L)	62.13	136.28	166.60
Hw:Pm(H)	40.71	105.81	136.40
Hw:Pm(L)	69.85	150.69	176.60
Mw:F <sub>s</sub> (H)	65.62	160.07	187.20
Mw:F <sub>s</sub> (L)	62.13	121.16	165.13
Pm+NPK(H)	86.06	166.79	188.00
Pm+NPK(L)	68.65	166.17	191.00
Hw:Pm+NPK(H)	67.11	147.66	180.60
Hw:Pm+NPK(L)	60.73	144.57	174.53
Mw:F <sub>s</sub> +NPK(H)	90.52	178.07	200.13
Mw:F <sub>s</sub> +NPK(L)	54.22	150.37	170.80
Week			

Treatment			
SED	19.07	23.19	19.53
CV	34.20	18.84	13.45

## APPENDIX I

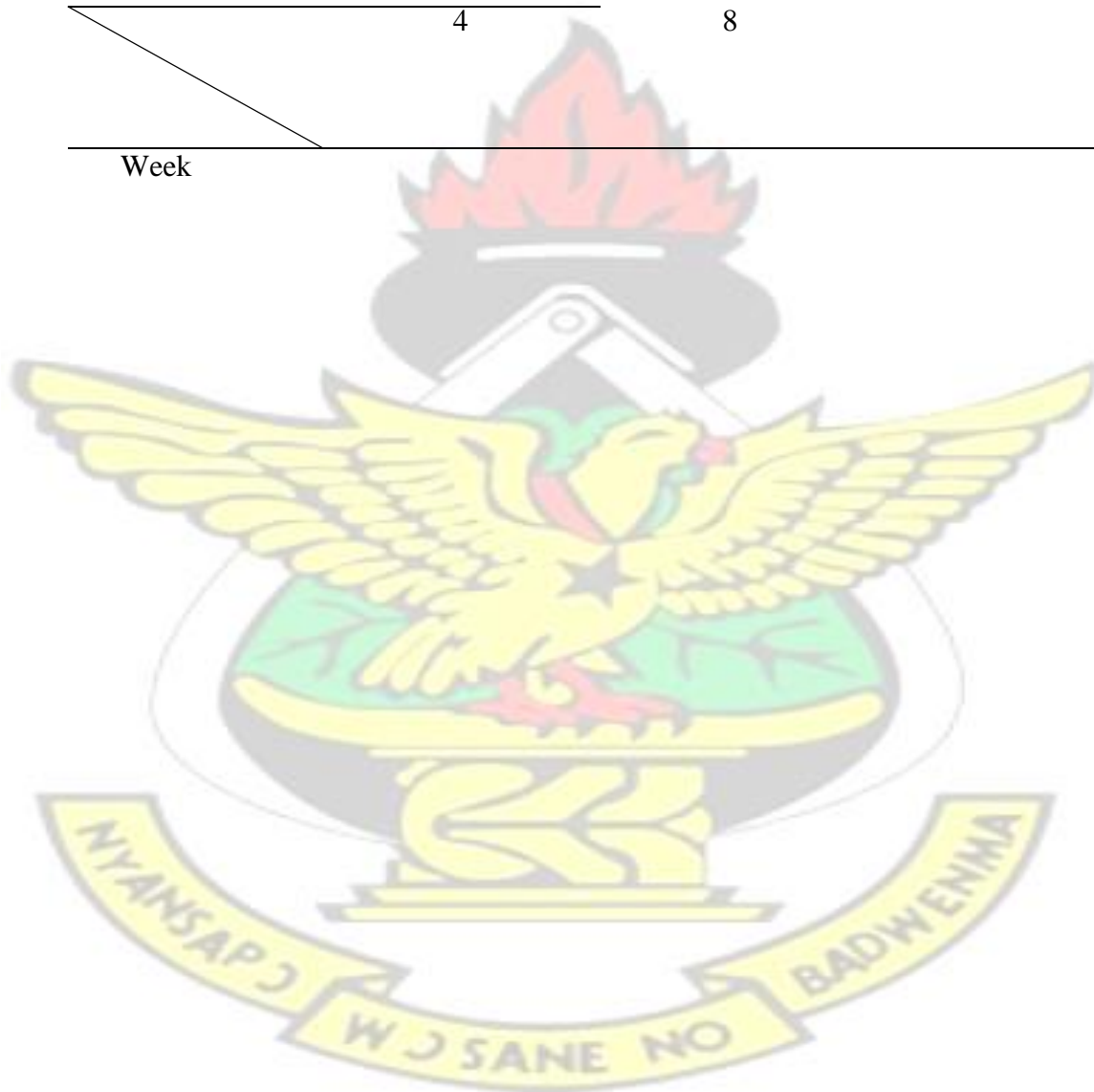
### Leaf area (cm<sup>2</sup>) data in the field experiment

Control	466.03	570.49	569.74
NPK(H)	592.36	718.45	660.22
NPK(L)	496.93	686.37	635.63
Pm(H)	524.66	647.19	591.75
Pm(L)	436.02	576.05	567.37
Hw:Pm(H)	353.21	476.97	445.67
Hw:Pm(L)	496.01	623.24	597.96
Mw:F <sub>s</sub> (H)	470.42	631.03	592.06
Mw:F <sub>s</sub> (L)	360.04	559.12	506.94
Pm+NPK(H)	505.75	750.90	695.52
Pm+NPK(L)	478.39	684.46	599.78

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Hw:Pm+NPK(H)	475.00	636.49	571.93
Hw:Pm+NPK(L)	527.97	652.30	626.47
Mw:F <sub>s</sub> +NPK(H)	522.26	617.32	609.52
Mw:F <sub>s</sub> +NPK(L)	420.25	581.11	564.12
	4	8	

Week

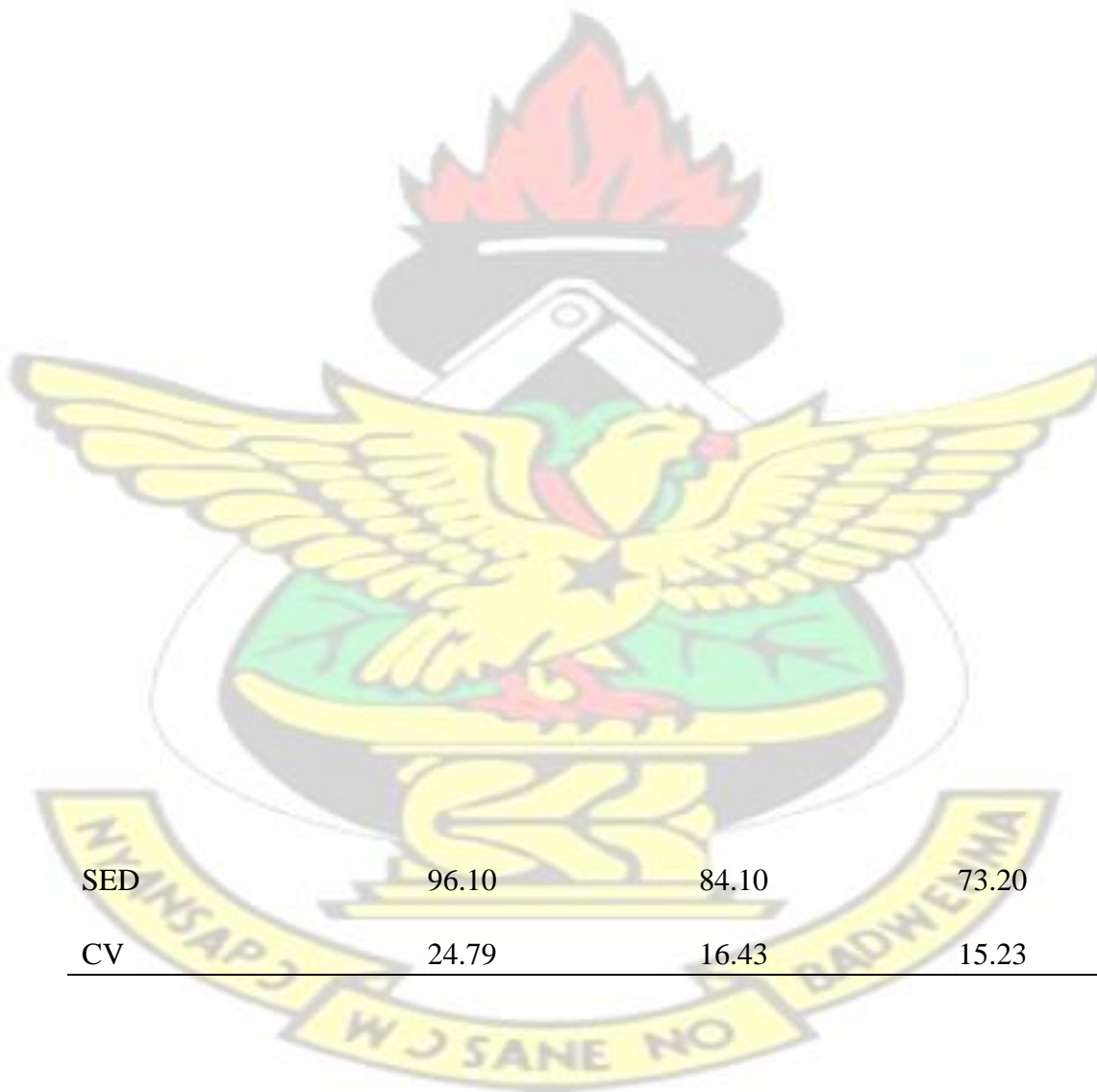




Treatment

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## APPENDIX J



SED	96.10	84.10	73.20
CV	24.79	16.43	15.23

### Plant girth (cm) data in the field experiment

SED	0.21	0.17	0.16
CV	12.79	10.60	10.35
Control	1.99	1.99	1.90
NPK(H)	2.28	2.23	2.13
NPK(L)	2.06	2.01	1.98
Pm(H)	2.15	2.07	2.03
Pm(L)	1.87	1.78	1.78
Hw:Pm(H)	1.68	1.69	1.69
Hw:Pm(L)	2.07	1.98	1.85
Mw:F <sub>s</sub> (H)	2.08	1.99	1.90
Mw:F <sub>s</sub> (L)	1.74	1.91	1.75
Pm+NPK(H)	2.35	2.29	2.15
Pm+NPK(L)	2.08	2.04	2.02
Hw:Pm+NPK(H)	2.19	2.05	2.05
Hw:Pm+NPK(L)	2.20	2.17	2.01
Mw:F <sub>s</sub> +NPK(H)	2.06	2.02	1.93
Mw:F <sub>s</sub> +NPK(L)	1.91	1.87	1.87
	4	8	
Week			

Treatment

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0.65 0.62 1.00

### Number of leaves of the maize plant in the field experiment

SED	0.65	0.62	1.00	Week
CV	11.25	9.66	12.51	
Control	7.00	8.00	10.00	
NPK(H)	8.33	8.33	10.67	
NPK(L)	7.33	8.00	10.00	
Pm(H)	6.33	8.00	9.33	
Pm(L)	7.00	8.00	9.33	
Hw:Pm(H)	8.33	8.33	9.33	
Hw:Pm(L)	7.33	8.33	10.00	
Mw:F <sub>s</sub> (H)	6.67	7.67	8.67	
Mw:F <sub>s</sub> (L)	6.00	7.33	9.33	
Pm+NPK(H)	7.33	8.00	10.67	
Pm+NPK(L)	7.00	7.33	10.33	
Hw:Pm+NPK(H)	7.33	8.33	10.67	
Hw:Pm+NPK(L)	7.00	7.33	10.33	
Mw:F <sub>s</sub> +NPK(H)	6.67	8.00	9.33	
Mw:F <sub>s</sub> +NPK(L)	6.67	6.67	8.33	
	4	8	12	
Treatment				



## APPENDIX L

### Soil moisture data (mm) in the field experiment

Week									
Treatment									
Control	29.98	32.49	32.49	33.86	32.49	23.26	21.89	14.42	8.95
NPK(H)	49.93	49.93	15.62	16.47	16.93	10.37	13.34	8.04	6.33
NPK(L)	17.67	17.21	14.08	15.73	15.79	12.31	9.69	8.84	8.04
Pm(H)	49.93	49.93	16.30	16.19	17.21	16.70	14.82	10.66	8.61
Pm(L)	15.90	16.47	17.21	16.19	15.85	14.14	10.72	9.01	8.04
Hw:Pm(H)	49.93	49.93	26.73	49.93	49.93	22.52	13.62	9.80	8.44
Hw:Pm(L)	17.44	17.44	19.15	17.67	17.44	15.90	12.03	8.95	8.04
Mw:F <sub>s</sub> (H)	44.57	32.49	15.16	16.76	14.54	12.31	15.39	8.84	8.04
Mw:F <sub>s</sub> (L)	49.93	49.93	33.86	29.75	29.75	25.42	13.51	10.43	8.84
Pm+NPK(H)	49.93	38.87	16.30	16.76	17.44	15.28	11.97	9.41	8.38
Pm+NPK(L)	49.93	49.93	16.07	17.44	18.13	17.21	14.42	10.09	8.61
Hw:Pm+NPK(H)	17.44	16.19	13.57	15.62	15.73	15.22	10.43	8.61	8.04
Hw:Pm+NPK(L)	33.86	32.49	15.28	16.47	17.21	15.73	14.02	9.58	8.61
Mw:F <sub>s</sub> +NPK(H)	29.75	25.02	14.36	17.21	16.87	11.23	9.12	8.04	6.90
Mw:F <sub>s</sub> +NPK(L)	43.21	27.13	15.50	15.73	15.68	13.05	10.89	9.98	8.61
	1	2	3	4	5	6	7	8	9
SED	3.19	4.27	5.39	0.24	0.73	2.45	0.68	0.41	0.23

CV 10.66 15.53 35.18 1.43 4.31 18.67 6.41 5.17 3.51

## APPENDIX M

### Plant height (cm) data in the residual experiment

Week					
Treatment					
Control	19.10	38.63	125.10	161.17	149.33
NPK(H)	21.53	53.37	144.67	161.83	154.58
NPK(L)	16.87	47.37	148.17	147.50	149.67
Pm(H)	15.27	36.97	119.27	159.50	150.17
Pm(L)	15.10	40.10	108.33	156.10	161.83
Hw:Pm(H)	18.57	50.00	113.83	129.17	156.17
Hw:Pm(L)	17.27	46.93	142.10	164.00	157.17
Mw:F <sub>s</sub> (H)	16.00	38.93	118.93	145.83	151.00
Mw:F <sub>s</sub> (L)	16.27	35.27	125.93	153.33	151.67
Pm+NPK(H)	17.63	42.93	141.50	160.67	178.00
Pm+NPK(L)	18.90	42.00	128.60	151.50	165.83
Hw:Pm+NPK(H)	17.60	40.27	123.87	141.50	137.43
Hw:Pm+NPK(L)	16.60	37.52	130.25	159.17	168.83
Mw:F <sub>s</sub> +NPK(H)	15.67	42.53	122.33	165.83	173.67
Mw:F <sub>s</sub> +NPK(L)	16.73	33.03	101.00	148.83	152.67
	4	6	8		
SED	3.40	10.06	20.15	15.83	16.57

CV

24.16

29.53

19.54

12.61

12.91

# KNUST



## APPENDIX N

### Leaf area (cm<sup>2</sup>) data in the residual experiment

Week					
Treatment					
Control	115.76	336.04	460.91	457.52	476.69
NPK(H)	188.21	336.39	436.68	423.36	419.64
NPK(L)	127.26	356.98	414.51	391.09	443.30
Pm(H)	115.06	261.23	414.66	428.56	414.88
Pm(L)	103.46	282.59	459.54	413.23	462.23
Hw:Pm(H)	136.26	326.10	393.59	383.97	412.68
Hw:Pm(L)	137.43	377.52	487.21	467.93	452.10
Mw:F <sub>s</sub> (H)	88.26	302.69	413.34	397.59	424.73
Mw:F <sub>s</sub> (L)	84.98	258.14	435.81	418.39	378.59
Pm+NPK(H)	130.20	377.80	497.88	441.38	501.20
Pm+NPK(L)	118.33	375.93	524.34	502.76	490.89
Hw:Pm+NPK(H)	153.11	314.30	378.71	370.75	332.21
Hw:Pm+NPK(L)	100.34	348.23	453.93	443.00	490.34
Mw:F <sub>s</sub> +NPK(H)	81.56	337.18	429.16	452.64	469.68
Mw:F <sub>s</sub> +NPK(L)	80.36	277.88	387.93	421.93	404.00
	4	6	8		
SED	40.36	53.19	63.60	67.60	70.20
CV	42.12	20.07	17.74	19.37	19.61



## APPENDIX O

### The growth of plant girth (cm) in the residual experiment

Week					
Treatment					
Control	0.91	1.53	1.63	1.50	1.52
NPK(H)	1.16	1.63	1.66	1.51	1.46
NPK(L)	0.92	1.55	1.59	1.46	1.55
Pm(H)	0.75	1.43	1.65	1.52	1.38
Pm(L)	0.86	1.54	1.63	1.50	1.62
Hw:Pm(H)	1.02	1.57	1.61	1.45	1.55
Hw:Pm(L)	0.90	1.64	1.79	1.57	1.45
Mw:F <sub>s</sub> (H)	0.82	1.51	1.66	1.53	1.51
Mw:F <sub>s</sub> (L)	0.75	1.44	1.65	1.38	1.37
Pm+NPK(H)	0.96	1.69	1.69	1.61	1.53
Pm+NPK(L)	0.88	1.54	1.69	1.57	1.55
Hw:Pm+NPK(H)	1.03	1.56	1.61	1.48	1.41
Hw:Pm+NPK(L)	0.84	1.51	1.70	1.53	1.57
Mw:F <sub>s</sub> +NPK(H)	0.82	1.56	1.81	1.61	1.55
Mw:F <sub>s</sub> +NPK(L)	0.80	1.36	1.53	1.38	1.38
	4	6	8		
SED	0.17	0.15	0.16	0.17	0.15

CV	22.69	12.15	11.47	14.16	12.04
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## APPENDIX P1

### Soil nutrient (mineral) content

Nutrient	Rank / Grade
Soil pH (Distilled Water Method)	
<5.0	Very Acidic
5.0 – 5.5	Acidic
5.6 – 6.0	Moderately Acidic
6.1 – 6.5	Slightly Acidic
6.6 – 7.0	Neutral
7.1 – 7.5	Slightly Alkaline
7.6 – 8.5	Alkaline
> 8.5	Very Alkaline
Organic Matter (%)	
< 1.5	Low
1.6 – 3.0	Moderate
> 3.0	High
Nitrogen (%)	
< 0.1	Low
0.1 – 0.2	Moderate
> 0.2	High

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## APPENDIX P2

Nutrient	Rank / Grade
Phosphorus, P (ppm) – Bray's No.1	
< 10	Low
10 – 20	Moderate
> 20	High
Potassium, K (ppm)	
< 50	Low
50 – 100	Moderate
> 100	High
Calcium, Ca (cmol (+) kg <sup>-1</sup> ) / Mg = 0.25 Ca	
< 5	Low
5 – 10	Moderate
> 10	High
Exchangeable Potassium (cmol (+) kg <sup>-1</sup> )	
< 0.2	Low
0.2 – 0.4	Moderate
> 0.4	High
ECEC (cmol (+) kg <sup>-1</sup> )	
< 10	Low
10 – 20	Moderate
> 20	High

From Soil Research Institute (CSIR)

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