

**EFFECT OF DECOMPOSING CROP RESIDUES ON SOIL
PROPERTIES AND CROP PRODUCTIVITY IN THE
SEMI-DECIDUOUS FOREST ZONE OF GHANA**

KNUST

**A thesis submitted to the Department of Crop and Soil Sciences, Faculty of
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the requirements for the award of degree of**

**DOCTOR OF PHILOSOPHY
IN
SOIL SCIENCE**

BY

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JULY, 2009

DEDICATION

This thesis is dedicated to my parents and siblings.



DECLARATION

I, the undersigned, hereby declare that this thesis is my own work, and that all the sources I have used or quoted have been indicated or acknowledged by means of completed references.

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Alfred Arthur
July, 2009

We declare that we have supervised the student in undertaking the study submitted herein and confirm that he has our permission to present it for assessment.

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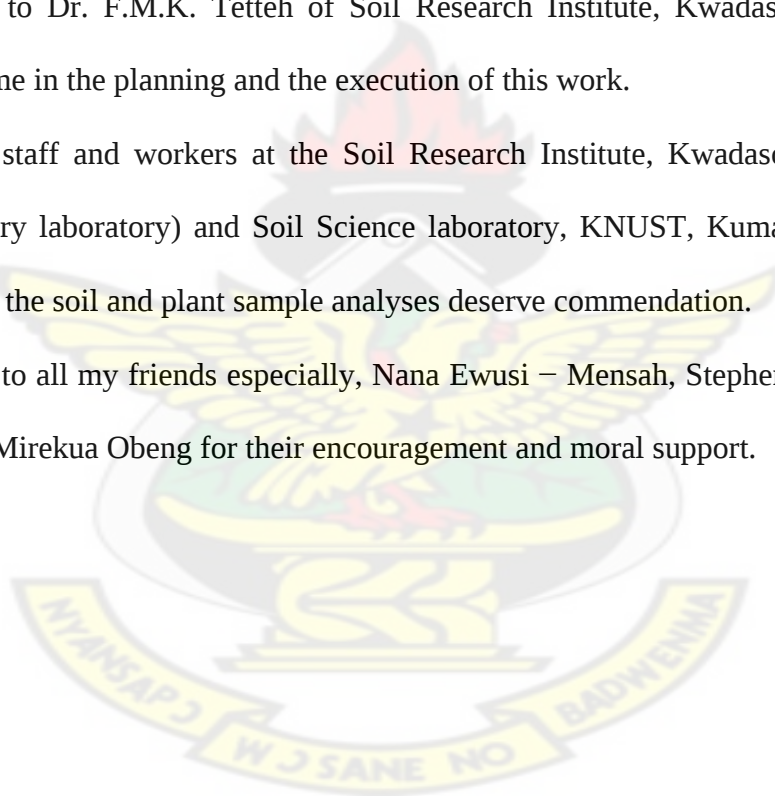


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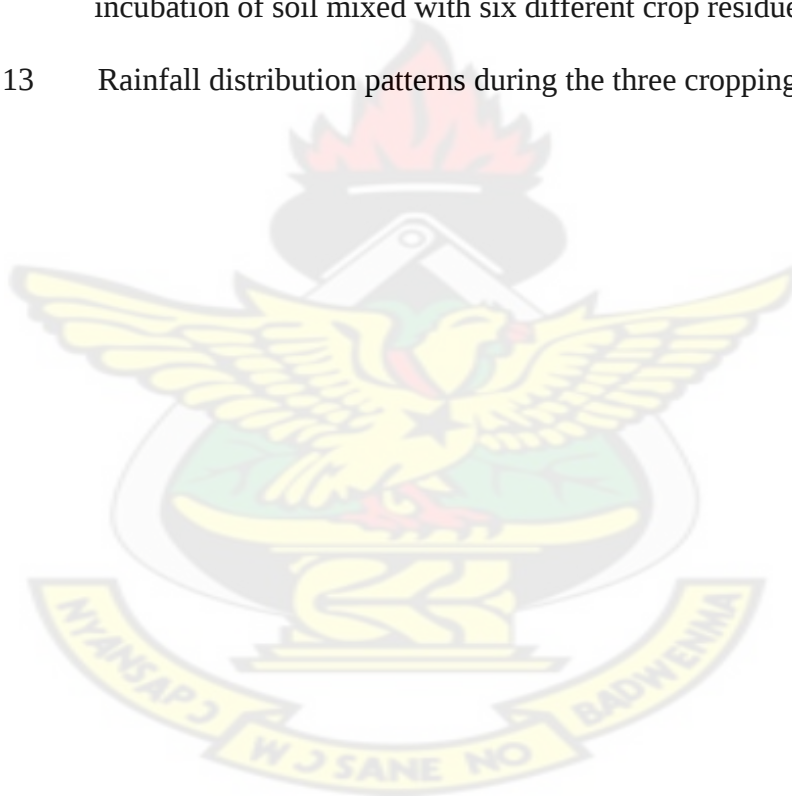
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ABSTRACT

A study was carried out to examine recycling of crop residues as a major component of integrated soil fertility management. The objectives of the study were to determine the quality, rates of decomposition and nutrient release patterns from residues of cassava leaves, cowpea haulm, groundnut haulm, maize stover, mucuna and soyabean haulm typical of cropping systems in Ghana as sources of plant nutrients. The study aimed at i). estimating the time course of nutrient release from crop residues to improve synchrony and increase maize yield, as well as ii). examining the changes in soil physico – chemical properties by applying some of the residues (maize stover and cowpea haulm) either alone or in combination with NPK (15–15–15) fertilizer. Laboratory and field experiments were conducted. The field experiments were conducted at the Central Agricultural Station, Kwadaso, Kumasi, in the semi – deciduous forest zone of Ghana. The laboratory experiments were conducted at the Soil Science laboratory, KNUST, Kumasi. The field studies were conducted on Asuansi soil series (Ferric Acrisol) in the minor season of year 2006 and repeated in the major and minor seasons of 2007. Total N content of the crop residues ranged from 0.74% in maize stover to 2.95% in cowpea haulm. Organic carbon ranged between 44.70% in groundnut haulm and 47.50% in maize stover. Total phosphorus ranged from 0.22% in groundnut haulm to 0.38% in maize stover. The C: N ratio of the residues ranged from 15.3 in mucuna to 65.1 in maize stover.

In the major season, the decomposition rate constant (k) was 0.224 and 0.305 week⁻¹ for surface – placed and buried maize stover respectively and 0.475 and 0.502 week⁻¹ for cassava leaves. In the minor season, the k values were 0.210 and 0.240 week⁻¹ for maize stover, 0.421 and 0.523 week⁻¹ for cowpea haulm and 0.541 and 0.659

week⁻¹ for cassava leaves. The values recorded in the dry season were 0.145 and 0.158 for maize stover, 0.206 and 0.258 for cowpea haulm and 0.233 and 0.290 for cassava leaves. Burying of the crop residues reduced the half – life (t_{50}) from 4.37 to 3.88 weeks for maize stover, 3.07 to 2.77 weeks for cowpea haulm and 2.62 to 2.34 weeks for cassava leaves.

Microbial biomass C and N were higher under the various treatments compared with microbial biomass P. Most of the microbial biomass P was locked up in the microbial cells. Combined application of the high quality cowpea haulm and low quality maize stover was able to increase the microbial biomass P.

Mean grain yield was highest (1.69 t ha⁻¹) under maize stover + ½ NPK treatment followed by cowpea haulm + ½ NPK treatment (1.62 t ha⁻¹) with the control treatment recording the lowest (0.83 t ha⁻¹). The results showed that all the treatments had significant effects on soil pH after cropping for three seasons. The level of organic matter increased under fertilizer treatment, while it decreased under the control treatment. Total N remained almost unchanged in all the plots after cropping. Available P decreased from initial value of 26.00 mg kg⁻¹ to 25.09 mg kg⁻¹ where no fertilizer was added but increased by 35 – 80% under fertilizer treatments. Exchangeable Ca, K and Na decreased in all the plots irrespective of the type of amendment. The combination of maize stover + ½ cowpea haulm increased the ECEC by 3%, remained unchanged under maize stover + ½ NPK treatment while it decreased in all other plots. Though maize grain yield increased under the combined application of crop residues and NPK fertilizer in this study, data on changes in soil properties after cropping suggest the need to increase the duration and the level of organic material added to sustain the fertility of the soil.

CHAPTER ONE

1.0 INTRODUCTION

Continuous soil fertility degradation is the most critical problem affecting Ghana's agricultural development. According to Syers *et al.* (1997), soil fertility decline is a key factor in soil degradation and is probably the major cause of declining crop yields. Annual rates of nutrient depletion from cultivated land have been estimated as 4.4, 0.5 and 3.0 million tonnes of N, P and K, respectively (Sanchez *et al.*, 1997).

Cropping intensification without fertilizers or with sub – optimal fertilizer rates has resulted in low crop yields, increased soil erosion and soil nutrient mining. Sanchez *et al.* (1997) reported annual losses of 660, 75 and 450 kg ha⁻¹ of nitrogen, phosphorus and potassium respectively in about 200 million hectares cultivated in thirty seven African countries. As noted by Henao and Baanante (1999), if nutrient depletion and land degradation continue at current rates, it is difficult to imagine how farmers in African countries will manage to grow enough food for the increasing populations in the next decade.

Reversal of soil fertility depletion is required to increase per – capita agricultural production (Sanchez and Leakey, 1997). In the past this was achieved by farmers through long fallow periods and opening of new lands. Increasing demand for land as a result of population increase has led to a break down of these soil fertility maintenance strategies (Kayuki and Wortmann, 2001). Soil fertility restoration could be achieved through the use of both inorganic and organic inputs. Use of inorganic fertilizers by resource – poor farmers is constrained by inadequate supply, unstable prices of agricultural produce, scarce financial resources, and lack of access to credit.

The removal of subsidies on mineral fertilizers in Ghana in 1994 led to a decline in mineral fertilizer consumption by 60% (Dreschel and Gyiele, 1999).

In agricultural systems in the tropics, there is an increasing interest in using crop residues for improving soil productivity which can reduce the use of external inputs of inorganic fertilizer (Tetteh, 2004; Fening *et al.*, 2005). The authors added that with the increasing concern on the need to abolish the slash and burn system of farming and the adoption of zero burning, the residues left in the field represent a significant resource in terms of organic matter and plant nutrients. The use of crop residues as a soil fertility amendment will enhance farmers' crop yields and reduce the need for large imports of mineral fertilizers. This, implicitly, will contribute to savings in Ghana's scarce financial resources which can be directed to other developmental programmes.

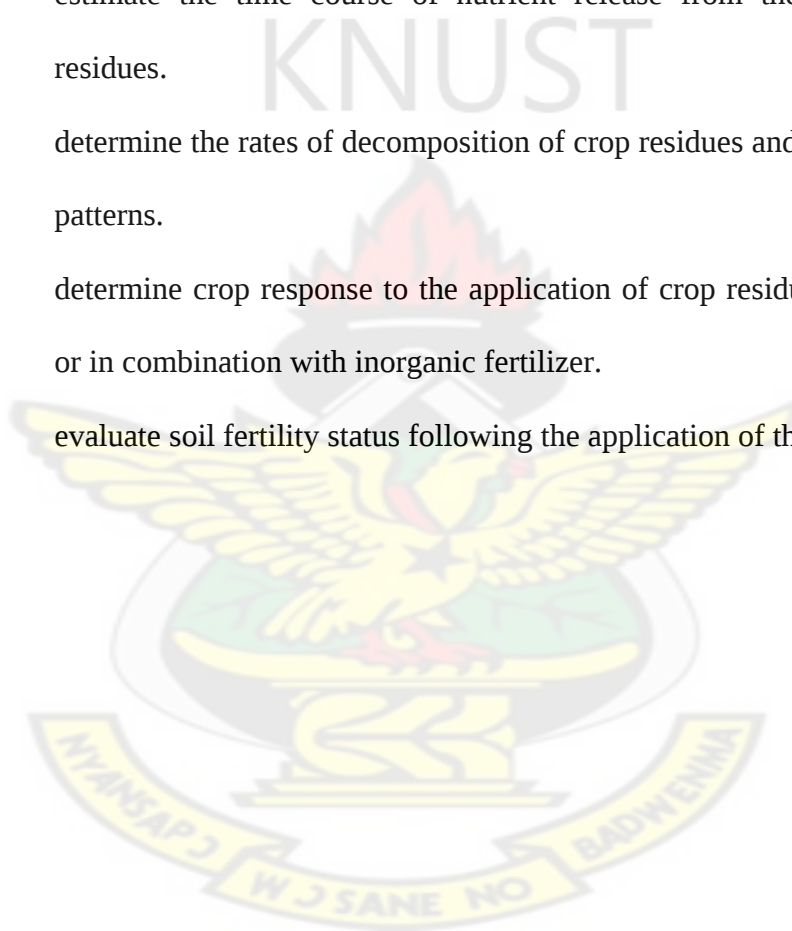
These crop residues are in sufficient abundance in farmers' fields at the end of a growing season and play an important role in soil fertility management through their short term effects on nutrient supply and longer term contribution to soil organic matter (Karanja *et al.*, 2006). However, they are often disposed off by removal (baling) or burning which is often criticized for accelerating losses of soil organic matter and nutrients, increasing carbon emissions and reducing soil microbial activity.

In Ghana, the use of crop residues has not been adopted by farmers, partly because they are not adequately informed about the nutrient values of these residues or because the method and time of application may be a problem. Understanding how crop residues decompose and how the nutrients released are recycled or lost is important for effective residue and fertilizer management practices.

The research was based on the hypothesis that, the biochemical composition of a crop residue will affect its rate of decomposition and nutrient release pattern.

The objectives of this study were therefore to:

- i. determine the biochemical composition of the residues and how they affect crop residue decomposition and nutrient release pattern.
- ii. estimate the time course of nutrient release from the different crop residues.
- iii. determine the rates of decomposition of crop residues and nutrient release patterns.
- iv. determine crop response to the application of crop residues, either alone or in combination with inorganic fertilizer.
- v. evaluate soil fertility status following the application of the amendments.



CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 What is crop residue decomposition?

Decomposition is the chemical breakdown of complex organic compounds into simpler inorganic compounds, often accomplished by microbial metabolism (Franzluebbers, 2004). According to Vigil and Spark (2004), decomposition of crop residue refers to the breakdown of visually recognizable organic material by microbial attack on the cellular structures of the material into unrecognizable soil organic matter. This breakdown is not like burning, in that there is a release of energy, carbon dioxide and water. The authors further stated that, some of the energy released and plant carbon is captured by the microorganisms in the soil and is used to carry out their daily activities for growth. After several breakdown cycles, the carbon that is left eventually forms stable soil organic matter called humus (Vigil and Spark, 2004).

Heal *et al.* (1997) reported that decomposition is the result of three component processes. Firstly, catabolism, a biochemical term which describes energy yielding enzymatic reactions usually involving the transformation of complex organic compounds to smaller and simpler molecules. Secondly, comminution, which is the physical process of reducing the particle size of organic material by the feeding activity of soil fauna. Finally, leaching which affects the access of substrates to microbial decomposition or even remove them from the system.

Decomposition processes play an important role in soil fertility in terms of nutrient cycling and formation of soil organic matter. Soil organic matter is central to soil functioning and the maintenance of soil quality. Its role in determining soil structural

processes, erosion control and nutrient supply is well established (Chan, 2008). Soil organic matter is also a significant pool of biospheric carbon, and changes in soil carbon content directly affect the atmospheric carbon dioxide (Rochette *et al.*, 1999). Application of crop residues is the major and often the only input of carbon in agricultural soils.

Decomposition of plant litter regulates recycling of nutrients in ecosystems, influences net ecosystem carbon storage, and is the first step in the formation of soil humus (Hobbie and Vitousek, 2000). Handayanto *et al.* (1997) reported that decomposition and nutrient release patterns are often cited as the most important characteristics for determining the potential of organic inputs in agroecosystems. Residue decomposition is often mathematically described by dividing the residue carbon into two, or more compartments that decompose at faster and slower rates (Saviozzi *et al.*, 1997). Although these compartments do not neatly correspond to chemically defined pools of carbon, many studies have shown that the fast or labile pool is comprised primarily of soluble carbon compounds (Trinsoutrot *et al.*, 2000). The slow pools are made up of structural, polymeric carbon compounds, such as hemicelluloses, cellulose, and lignin (Saviozzi *et al.*, 1997). Thus, as decomposition proceeds, the chemical composition of the residue changes (Horwath and Elliott, 1996).

2.2 Factors affecting the rate of crop residue decomposition

Several factors affect residue decomposition with the most important in agricultural systems being water and temperature (Schomberg and Steiner, 1999) and residue properties such as nitrogen, cellulose and lignin contents (Heal *et al.*, 1997). Under

tropical conditions, moisture is generally more important than temperature, as the latter remains rather constant except during the dry season (Vanlauwe *et al.*, 1997a). Vigil and Spark (2004) reported that soil organisms, physical characteristics of the residue, soil environment, and soil–crop–residue management play very significant roles in residue decomposition.

2.2.1 Soil environment

The physical properties of the soil such as temperature and moisture as well as its chemical condition such as pH and nutrient contents are among the factors which affect crop residue decomposition. Soil macrofauna such as earthworms, termites and ants also play very important roles (Vigil and Spark, 2004).

2.2.1.1 Soil temperature

The major requirement for crop residue decay is an active microbial population in contact with the residue. Soil microbes (bacteria, fungi, and actinomycetes) are most active and thrive under moist warm conditions (Vigil and Spark, 2004). Therefore residue decomposition proceeds rapidly during moist warm condition but slowly during wet periods. Microbial activity is generally predicted to increase rapidly up to a temperature of about 30°C. Vigil and Spark (2004) stated that maximum decomposition occurs in soils that are wet to near field capacity (wet but not muddy wet or glistening and about 55% water filled pore space) and at soil temperatures near 31– 33°C. The authors further indicated that decomposition proceeds slowly at soil temperatures below 14°C and above 35°C.

2.2.1.2 Soil moisture

Low soil water content affects the rate of decomposition. Work done by Vigil and Spark (2004) showed that decomposition is slow at soil water contents that are less than 40% water filled pore space (barely moist to the touch but not dusty dry) and stops in soils that are air dry (dusty, hard and crumbly to the touch, near a crop's permanent wilting point). Microbes need moisture to break down straw. When conditions are optimal, straw decays fastest when soil is at about 60% water holding capacity. A soil which is half or 2.5 times this wet delays the process. In saturated soil, air is excluded and decomposition occurs by the slower, anaerobic decay pathway (Brandon *et al.*, 1999).

2.2.1.3 Soil nutrient content

The inorganic nitrogen available in a soil is reported to influence crop residue decomposition. Recous *et al.* (1995) demonstrated that the decomposition of maize stover strongly depends on the availability of inorganic nitrogen. Their report showed that the inorganic nitrogen in soils with initial values of 10 ppm $\text{NO}_3^- - \text{N}$ was completely immobilized and there was a sharp decline in carbon mineralization after the initial flush. They added that further decomposition of maize stover was clearly limited by the lack of available nitrogen. According to Vigil and Spark (2004), decomposition is greater in soils that have high residual inorganic nitrogen and/or high potential for mineralization of inorganic nitrogen from native soil organic matter. Work done by Kabba and Aulakh (2004) clearly demonstrated that the initial phosphorus content influenced the mineralization of nitrogen and phosphorus, but not sulphur which was significantly higher in the soil with high

initial phosphorus content (18 mg P kg⁻¹ soil) than in the soil with low phosphorus status (8 mg P kg⁻¹ soil).

2.2.2 Crop residue characteristics

The quality or chemical composition such as nitrogen, polyphenol and lignin content, C: N ratio and physical characteristics of a crop residue affect how fast it will decompose. The quality or chemical composition of plant litter with respect to decomposition which can be defined as its relative ease of mineralization by decomposer organisms (Paustian *et al.*, 1997) is by far the most important factor used to predict crop residue decomposition.

2.2.2.1 Chemical composition

The decomposition of crop residues is the result of complex microbial processes controlled by numerous factors. Among these, the biochemical composition of the residues exerts an important influence (Trinsoutrot *et al.*, 2000). Biochemical properties such as hemicellulose, cellulose and lignin fractions or easily decomposable and recalcitrant fractions are often used to predict crop residue decomposition (Bending *et al.*, 1998). The criterion of quality used most often to predict mass loss or nitrogen mineralization during crop residue decomposition is the carbon: nitrogen (C: N) ratio of the plant material (Vanlauwe *et al.*, 1996). This ratio however, does not account for the availability of carbon and nitrogen, which is often essential to describe the decomposition kinetics (Seneviratne *et al.*, 1999). One explanation for this is that the total carbon content in itself is not closely related to decomposition while the presence of carbohydrates with differing decomposition rates is of greater importance (Gunnarsson, 2003).

Some studies have shown that the initial residue nitrogen content (Tian *et al.*, 1992a), polyphenols (Handayanto *et al.*, 1994; Tetteh, 2004), and soluble carbon concentrations (Kachaka *et al.*, 1993) are useful indicators of residue quality. Palm *et al.* (1997) introduced the soluble polyphenol content in organic resource quality – nitrogen – mineralization relationships, while Handayanto *et al.* (1994) showed that the content of soluble polyphenols that were actively binding proteins was better related to decomposition. The lignin+polyphenol: N and lignin: N ratios are also important parameters used for predicting crop residue decomposition (Mungai and Motavalli, 2006). Magid *et al.* (1997) suggested, however, that the lignin: N ratio is not a critical determinant of short to medium term decomposition rates, but it may be very important in governing long term decay.

According to Palm and Sanchez (1991), the threshold value for lignin is 15%, 3– 4% for polyphenol and 10 for the ratio L+PP: N. Plant materials above these thresholds are expected to decompose slowly and to immobilize N due to the formation of stable polymers between polyphenolics and amino groups and/or binding of lignin to cellulose (Dux *et al.*, 2006). Karanja *et al.* (2006) observed that the decomposition rate of Grevella prunings was slow and this could be attributed to its high lignin content (24%). The authors also stated that the release of nitrogen was influenced by L+PP: N ratio. Bean haulms having a ratio of 10 released nitrogen faster than either maize stover or Grevella prunings with ratios of 20 and 13 respectively.

Nitrogen availability may control the kinetics of decomposition of crop residues, particularly those with high C: N ratio such as cereals, when the nitrogen requirements of the soil decomposers are not fulfilled by the residue or soil nitrogen

contents (Recous *et al.*, 1995). According to Abiven *et al.* (2002), under such a situation the biochemical quality of the residue no longer controls the dynamics of carbon and the associated nitrogen dynamics, and residues containing various amounts of nitrogen are no longer comparable, whatever the nature of their constituents. It is therefore not surprising that in many studies the residue nitrogen content has been shown to be the main factor predicting the kinetics of decomposition (Schomberg and Steiner, 1999). Consequently, when nitrogen availability is a limiting factor of decomposition, the kinetics of decomposition or carbon mineralization observed do not allow the effect of biochemical quality to be assessed or distinguished from the effects of nitrogen availability on residue decomposition (Trinsoutrot *et al.*, 2000). Short term and long term net mineralization is correlated with different residue properties. Giller and Cadisch (1997) therefore concluded that no single index can characterize the quality of plant residues.

2.2.2.2 Physical characteristics

The relative particle size of a crop residue has an effect on rate of its decomposition (Burgess *et al.*, 2002) and may also influence the determination of recalcitrant substances, e.g. lignin using extraction procedures (Vanlauwe *et al.*, 1997b). Crop residues that are chopped and broken up by stalk choppers or tillage equipment have smaller particle sizes than residues that are left undisturbed (Vigil and Spark, 2004). Kennedy and Arceneaux (2006) found that additional shredding of residue would make the particle size smaller, increasing the surface area from which microbes could degrade the residue. Broken crop residues decompose faster than residues that are left intact. Dux *et al.* (2006) reported a slow decomposition rate for *Imperata* leaves compared to *Chromolaena* and *Phyllanthus* leaves. The authors ascribed this

to the fact that *Imperata* leaf material is very bulky and rigid compared to *Chromolaena* and *Phyllanthus* leaves. This led to poor contact between the residue and soil following application and may have delayed colonization by microorganisms and its subsequent decomposition.

2.2.3 Tillage, soil management and soil effects

Residue disturbance or incorporation caused by tillage operation influences residue decomposition rates. Vigil and Spark (2004) stated that the primary effect of tillage is to put the residue into intimate contact with soil microbes. By burying crop residues, tillage places the residues in a better environment for microbial activity.

The physical condition of a soil affects crop residue decay. Severe soil compaction caused by improper tillage or intense wheel traffic impedes both water and air movement into and out of the soil. If the soil is left in that condition for an extended period decomposition will be less (Vigil and Spark, 2004). The type of tillage equipment influences nitrogen mineralization, due to the effects of tillage on soil disturbance. Adoption of zero – tillage or minimum tillage, which usually maintains crop residues at or near the surface of the soil, accumulates nutrients at the soil surface (Hussain *et al.*, 1999).

Malpassi *et al.* (2000) reported a faster decomposition for shoots residue when incorporated into the soil by tillage. However, Abiven *et al.* (2002) made contrasting observation. In their work on the impact of residue quality and location in soil on the C and N mineralization of residues from cropping systems in Cerrados, Brazil, they found that residue location either on the soil surface or incorporation did not affect

the rate of decomposition. They attributed the decomposition of the residues to quality parameters and not location.

2.2.4 Herbicide and other added chemical effects

Very little quantitative information is available concerning the effect that herbicides and fertilizer nitrogen have on decomposition of crop residues (Vigil and Spark, 2004). The addition of nitrogen fertilizers to crop residues low in N to hasten decomposition has been reported extensively (Palm *et al.*, 1997). Research conducted by Sharma and Bali (1998) in India showed that faster decomposition and release of nitrogen from rice straw to soil is possible if it is treated with urea and applied during field preparation. Hobbie (2000) reported that the addition of N fertilizer to plant litter low in lignin content (12%) was faster compared to one with high lignin content (18%). This is because the added nitrogen enhanced microbial degradation of the recalcitrant lignin and hence decomposition was hastened. Lim and Zaharah (2000) indicated that the addition of inorganic N fertilizer in the form of ammonium sulphate significantly enhanced dry matter loss of oil palm empty fruit bunches. They stated that the inorganic N reduces the C: N ratio of the residue, due to enhanced microbial activity.

2.3 Management of crop residues

Crop residues, in general are parts of the plants left in the field after crops have been harvested and threshed. According to Hadas *et al.* (2004), plant residues are either of crops that remain in situ after harvest or residues from crop processing operations, such as tobacco residues, used for supplying available nitrogen, or rice hulls used as a soil amendment. These materials at times have been regarded as waste materials

that require disposal, but it has become increasingly realized that they are important natural resources and not wastes.

Mandal *et al.* (2004) reported that the recycling of crop residues has the advantage of converting the surplus farm waste into useful product for meeting nutrient requirement of crops. It also maintains the soil physical and chemical condition (Powel and Unger, 1997) and improves the overall ecological balance of the crop production system (Mandal *et al.*, 2004). The options available to farmers for the management of crop residues are burning, incorporation, surface retention and mulching, and baling and removing.

2.3.1 Residue burning

Most farmers' burn off crop residues at the beginning of a cropping season to facilitate ease of planting as these residues interfere with planting operations. Mandal *et al.* (2004) found that with the advent of mechanized harvesting, farmers in South Asia have been burning in – situ large quantities of crop residues left in the field as crop residues interfere with tillage and seeding operations for the subsequent crop, causing loss of nutrients and soil organic matter.

Burning of crop residues often leads to large losses of nutrients such as nitrogen, phosphorus, potassium and sulphur (Lefroy *et al.*, 1994). More than 70% of carbon and nitrogen are lost to the atmosphere when sugarcane trash is burnt (Mitchell *et al.*, 2000). It has also been reported that residue burning may adversely affect soil fertility due to the fact that it causes losses of some nutrients and organic matter over time (Hemwong *et al.*, 2008). Crop residues are about 50 percent carbon, and

carbon is volatile under most fire conditions, causing the loss of carbon to the air. Nearly all of the nitrogen and about half of the sulphur and phosphorus are also lost (Rosales *et al.*, 2004). The practice of crop residue burning also causes significant air pollution and killing of beneficial soil insects and also macroorganisms. Burning, however, also kills soil borne deleterious pests and pathogens. Mandal *et al.* (2004) found that one of the advantages of burning is that it clears the land quickly of residues before the next crop is established, thus facilitating seed germination and establishment. They however, added that when burnt, the residues instantly generate as much as 13 t of CO₂ ha⁻¹, contaminating the air and depriving soils of organic matter.

2.3.2 Residue incorporation

Incorporation of plant residues into agricultural soils is primarily a means to sustain soil organic matter content, and thereby enhance the biological activity, improve physical properties and increase nutrients availability. Crop residues may be incorporated partially or completely into the soil depending upon methods of cultivation (Dormaar and Carefoot, 1996). Unlike removal or burning, incorporation of straw increases soil organic matter and soil nitrogen, phosphorus and potassium contents (Mandal *et al.*, 2004). Thönnissen *et al.* (2000) showed that incorporated soybean green manure could be used to substitute N fertilizer as first side dressing to tomato, but after eight weeks N fertilizer was required to obtain high yields. Incorporation of residues before planting of the next crop generally decreases yields due to nitrogen immobilization (Yadvinder-Singh *et al.*, 2004). Effective mitigation of these effects depends on developing crop residue management strategies that enhance residue breakdown.

2.3.3 Surface retention and mulching

Maintaining a layer of crop residue over the soil surface helps to protect it from raindrop impact and cycles of drying – wetting (Wuest, 2007). Surface residues also trap windborne materials that are rich in nutrients (Schomberg and Steiner, 1999). Maintenance of surface residue cover is often recommended to reduce erosion by water and wind. Residues contribute to erosion control both through sheltering the soil with a non erodible material (cover) or through changing the surface conformation in ways that change the flow of water and wind across the surface (roughness or resistance). Both aspects are important for wind and water erosion (Steiner *et al.*, 2000). However, the large volume of residues remaining on the surface often leads to machinery failures, thus affecting sowing of seeds of the following crop. Surface retention of some or all of the residues may be the best option in many situations (Mandal *et al.*, 2004).

Leaving crop residues at the soil surface can reduce soil temperature and increase soil moisture, which in turn may restrict the decomposition of soil organic matter (Angers and Recous, 1997). As compared with incorporated straw, surface straw is often exposed to greater fluctuations in temperature and moisture and lower nutrient availability (Douglas *et al.*, 1980), all of which may reduce microbial activity and, hence, the rate of decomposition. However, Lal (2008) pointed out that any practice that involves removal of crop residues, leaving soil unprotected even for a short duration, would increase risks of accelerated erosion, depletion of soil organic carbon pool, disruption in cycling of nutrients, decline in activity and species diversity of soil fauna and flora, and decline in water retention capacity while jeopardizing the sustainable use of soil resources.

2.3.4 Baling and removing

According to Andrews (2006), residue removal can result in detrimental changes in many biological soil quality indicators including soil carbon, microbial activity, fungal biomass and earthworm populations, indicating reduced soil function. Residue removal leading to higher erosion and runoff rates would greatly decrease soil organic matter and nutrients. Residue harvest would also require increased fertilizer inputs to make up for nutrients removed in the plant material (Andrews, 2006). Research conducted by Bhat *et al.* (1991) show that, a continuous recycling of crop residues for seven years in rice – wheat markedly influenced the soil properties. They further stated that, the increase in nutrient status of soil may be ascribed to the average addition of $6 \text{ t ha}^{-1} \text{ yr}^{-1}$ of wheat straw and 12 t ha^{-1} of rice straw for seven years. In contrast, Beri *et al.* (1995) found that burning and residue removal resulted in greater grain yields of wheat and rice than residue incorporation. They propounded that by the addition of crop residues, nitrogen and phosphorus were converted to unavailable forms through immobilization and adsorption, respectively.

2.4 Effect of crop residues on some soil properties

2.4.1 Soil organic matter (SOM)

Soil organic matter is a complex and heterogeneous mixture of material which vary in their physical size, chemical composition, and degree of interaction with soil minerals and extent of decomposition (Baldock *et al.*, 2006). An increase in SOM could occur by plant mulch (Blanco–Canqui and Lal, 2007). Wood (1991) found an increase in soil organic C after mulching with $15 - 20 \text{ t ha}^{-1}$ of sugarcane trash for 5 years and mulching with $3.4 - 8.8 \text{ t ha}^{-1}$ of grain sorghum or wheat residues for 11

years. Giller and Cadisch (1995) reported that repeated use of lower quality residues may lead to a greater build up of soil organic matter and or a higher nitrogen conservation effect over the long term than is thought to be possible from higher quality residues. Long term benefits of wheat straw depend, however, on the quality (e.g. decomposition rates, C: N ratio) and amount of mulch application (Heal *et al.*, 1997).

2.4.2 Soil acidity

According to Mandal *et al.* (2004), soil acidity is one of the most important factors determining soil fertility for crop production. Crop production however, sometimes alters soil pH. Work done by Lal (1997) indicated that continuous cultivation over the long term usually leads to a decline in soil pH. This was confirmed by Kumar and Goh (2000), who reported that continuous cultivation in many parts of the world has led to a decline in soil pH. The authors attributed it among other things to the release of proton by roots of crop, which results in the accumulation of organic anions such as citrate, oxalate, and malate in plants. Research has shown that if these organic anions are returned to the soil, on decomposition by soil microorganisms, the pH of the soil can be increased due to the decarboxylation of organic anions (Mandal *et al.*, 2004). This presupposes that one possible way of protecting cultivated soils from becoming acidic is through returning crop residues to the soil.

2.4.3 Soil nutrients

Residue harvest removes more nutrients from the agroecosystem than crop harvest alone. Beri *et al.* (1995) compared residue removal, burning, and incorporation for rice and wheat on tilled soils in an experiment in India. They found that incorporated

residue treatment had the highest soil mineral nitrogen and phosphorus but the lowest yields for both crops. They attributed this result to immobilization of nitrogen and phosphorus during microbial decomposition of the incorporated residues, making the nutrients unavailable to support plant growth. After incorporating oilseed rape crop residues in soil, only the high – N content residues (leaves and roots) with N content of 1.6 and 1.7% respectively induced in a mineral N surplus in the soil, equivalent to 9 kg N ha⁻¹, by comparison to a control soil without application of residues (Trinsoutrot *et al.*, 1999).

A noticeable positive effect of surface plant mulch on exchangeable Ca has often been observed. Hussain *et al.* (1999) noticed a significantly greater exchangeable Ca content under no tillage compared with chisel plough and mouldboard plough in the top 0 – 5 cm layer. They attributed this to lack of tillage and concentration of crop residue at the soil surface under the no tillage system. Similar observation was made for soil phosphorus (Bray-P₁). They ascribed this to reduction in soil loss by erosion and increase in organic phosphorus due to residue on the soil surface. The long term application of corn residues may lead to increased levels of P and K in the soil (Dam *et al.*, 2005). On decomposition, organic P in crop residues could provide a relatively labile form of P to succeeding crops, thus providing a larger pool of mineralizable soil organic P to supplement soluble inorganic P pools (Cavigelli and Thien, 2003). Higher concentrations of exchangeable K and Mg (Geiger *et al.*, 1992) under crop residue mulch have also been reported. The appearance and extent of the effect of plant residue mulch on soil chemical properties are influenced not only by the amount and composition of crop residues used, but also by the initial concentrations

of the nutrients in soil as well as environmental conditions such as temperature and rainfall (Buerkert *et al.*, 2000).

2.5 Effect of crop residue on crop yield

The effect of retaining crop residues in farming systems is generally thought to be advantageous over burning and physical removal from the point of view of nutrient cycling. Power *et al.* (1986) found increased crop yields for corn and soybean when residues were left on the soil surface compared with yields under residue removal in Nebraska. This yield effect was most pronounced in drier years, leading them to attribute yield increases to residue-induced water conservation. They also cited benefits from reduced erosion and increased soil organic matter. Linden *et al.* (2000) found that corn yields in residue – returned treatments exceeded those of corn with no residue by approximately 22% in drier than average years. Differences were not significant in years with near average precipitation. Glab and Kulig (2008) detected that wheat yields obtained at reduced tillage system without mulch residues (5.54 t ha⁻¹) were significantly lower with respect to treatment when fodder radish mulch residue was applied 6.79 t ha⁻¹. The authors concluded that mulching can help to avoid yield reduction in wheat production when reduced tillage is used. Safwat *et al.* (2002) reported that peanut leaves supplied with 60 kg N ha⁻¹ resulted in high wheat yield compared with the treatment without added crop residues. They attributed this to the release of nutrients from the residue which had effect on soil properties and plant growth. Ruffo and Bollero (2003) however, stated that yield can be decreased by excessive biomass cover that reduces crop stands due to poor soil-seed contact and germination. They added that on the other hand, little residue may not be adequate for soil and water conservation goals.

2.6 Soil fauna

Soil fauna consists of a large variety of organisms with different sizes and adaptive strategies. Verhoef and Brussaard (1990) reported that soil fauna can enhance the decomposition of soil organic matter and nutrient release, and hence ameliorate soil physical properties. Lavelle *et al.* (1994) argued that the abundance and composition of soil fauna impact on soil processes vary greatly depending on vegetation and land use practices. Parmelee *et al.* (1990) found that in temperate agroecosystems, earthworm biomass and densities were 70% greater under no-tillage systems than under conventional agriculture. Franzluebbers (2004) stated that soil mesofauna and macrofauna often fragment plant and animal residues, which increases the surface area and exposes internal constituents to soil microfauna and microflora for further attack. The author further added that larger soil organisms, therefore, stimulate soil microbial activity and also distribute smaller organisms within soil as a result of their generally greater range of mobility. In addition, larger soil organisms such as earthworms, ants, and beetles physically move organic substrates from the soil surface to within the soil, which can enhance decomposition by placement in a more favourable zone for microbial attack because of less extreme moisture and temperature variations (Franzluebbers, 2004).

Beare *et al.* (1997) pointed out that management practices such as continuous tillage can cause changes in the population structure, elimination or reduction of key species and in some cases extremely low abundance or biomass. They found that soil arthropods and earthworm densities were higher under no tillage than in conventional tillage practices, an expanded and beneficial involvement for this fauna in crop residue decomposition processes. Tian *et al.* (1997) reported that soil fauna

such as earthworms and arthropods enhance the biodegradation and humification of organic residues by comminuting and thereby decreasing residue particle size and changing their location in the soil. Njunie *et al.* (2004) in their study on residue decomposition and nutrient release dynamics from two tropical forage legumes in a Kenyan environment using the mesh bags technique, observed that across all placement dates and treatments, termites were present in about 11% of the bags. They further stated that the mesh bags attacked by termites had fewer residues, indicating that termites may be important contributors to the residue loss process.

Schroth *et al.* (1992) studied mulch decomposition under agroforestry conditions in a subhumid tropical savanna environment. Direct observations in the field and feeding marks on collected samples indicated that termites were an important factor of mass loss from the more lignified woody branches while bark and leaves were less affected. Gonzalez and Seastedt (2001) observed an enhanced annual decay rate for both high quality *Quercus gambelii* and low quality *Ceropia scheberiana* in control plots compared to the plots where soil fauna were excluded. Their result argues for recognition of soil fauna as a major regulating factor of decomposition other than the quality of the residue. Similar results were also reported by Liu and Zou (2002). They reported higher decay rates for residues in control plots compared to plots where earthworms were excluded by using electrical shocking devices.

2.7 Mineralization and Immobilization of Nitrogen and Phosphorus

Mineralization refers to the net release of mineral nutrient with the decay of organic matter, and immobilization refers to the transformation of inorganic compounds to the organic state. Both processes are mediated by soil microorganisms with

immobilization occurring when microorganisms assimilate inorganic nitrogen (ammonium and nitrate) in the synthesis of the organic constituents of their cells. A balance exists between these two concurrent processes (Grace and Merz, 2001). Soil nitrogen supply from organic amendments depends on both the initial availability of inorganic N in the amendments and also the long term rate of mineralization and subsequent immobilization of N (Flavel and Murphy, 2006). This means that organic amendments can either be a source of plant available N or compete with plants for it.

The C: N ratio of plant residues is most often used as an index to assess whether the residues will release or immobilize inorganic nitrogen. Different researchers quote different C: N ratios at which net mineralization and immobilization occur (Green and Blackmer, 1995). Vigil and Kissel (1991) integrated nitrogen immobilization data from several medium to long-term experiments with residues having a wide range of C: N ratios, and showed that the break – even point between net nitrogen immobilization and mineralization of residues was at a C: N ratio of 41. Chaves *et al.* (2004) reported a value of 36.6 as the break – even point between mineralization and immobilization. Green and Blackmer (1995) found that when plant residues with C: N ratios greater than approximately 20 parts C to one part N are added to the soil available N is immobilized during the first few weeks of decomposition. Green *et al.* (1995) observed that incorporation of corn stover into soil resulted in rapid immobilization of all available inorganic N during the rapid decomposition period. They attributed this to the fact that the microbial population decomposing the plant residue had increased exponentially in response to the carbon source, essentially needing the nitrogen much like cattle require protein in a balanced feed ration.

A review by Grace and Merz (2001) on nutrients mineralization and immobilization showed that when litter with a high C: N ratio (approximately 30:1 or higher) is added to soil, net immobilization may occur for a period of time (days to weeks) which is dependent on the prevailing soil moisture and temperature. After a proportion of carbon from the litter source has been consumed by organisms and respired, net mineralization may occur. Cabrera *et al.* (2005) concluded that the existence of a range instead of a single value for the break – even point is probably related to the variation in the C: N ratio of the decomposing microbial biomass as well as the existence of organic components with different susceptibility to decomposition.

Like nitrogen, organic phosphorus is converted to inorganic phosphate through the process of mineralization. Mineralization and immobilization of phosphorus occur simultaneously in the soil. Ultimately, the C: P ratio determines whether there is net phosphorus mineralization or immobilization (Silva and Uchida, 2000).

According to Silva and Uchida (2000), when the C: P ratio is less than 200:1, there is net mineralization. When the C: P ratio is between 200:1 and 300:1, immobilization and mineralization rates are fairly equal. However, when the C: P ratio is greater than 300:1, net immobilization occurs. During immobilization there is not enough P to sustain both plants and microorganisms; and so, microorganisms scavenge the soil for P.

2.8 Nitrogen mineralization

Most of the nitrogen in crop residues is usually in organic forms that are unavailable for plant uptake. According to Deenik (2006), in a process known as nitrogen

mineralization, the organic nitrogen contained in soil organic matter as well as freshly added crop residues is converted into plant – useable inorganic forms (ammonium, NH_4^+ , and nitrate, NO_3^-) as a result of the activities of soil microorganisms. The resulting NH_4^+ may be oxidized to NO_3^- through nitrification (Sierra, 2001). In contrast to mineralization of organic N, microorganisms use inorganic N to build up their bodies, resulting in N immobilization. Net N mineralization is the outcome of the two concurrent but opposite directed processes: gross N mineralization and gross N immobilization.

Grace and Merz (2001) noted that nitrogen mineralization from litter and soil organic pools represent the vast majority of nitrogen inputs into natural non-leguminous terrestrial ecosystems. In the case of managed crops, forests and grass pastures, an additional source of mineral nitrogen may be added in the form of fertilizers which is either taken up directly by plants or may be assimilated by microorganisms during an immobilization event and possibly mineralized at a later date (Grace and Merz, 2001). The transformations of organic and mineral nitrogen through the mineralization and immobilization processes as described is therefore the main driver of carbon and nitrogen change in soils as it involves a wide range of substrates from litter and soil.

2.8.1 Factors affecting nitrogen mineralization

Among the factors controlling net N mineralization are organic composition of the residue (Kumar and Goh, 2003), and soil environment (Seneviratne *et al.*, 1998). Chemical composition can, to a certain degree, be controlled to increase the synchronization of nitrogen (N) release with plant N demand, whereas climatic

factors cannot be controlled and so must be taken into account when planning management measures (Dahlin *et al.*, 2005).

2.8.1.1 Soil temperature and moisture

Work done by Deenik (2006) showed that soil temperature and moisture content have a strong effect on nitrogen mineralization reactions. Microbial activity is limited at soil temperature near freezing and increases with rising soil temperature. Maximum nitrogen mineralization occurs when the soil temperature reaches 30–35°C. In dry soils, N mineralization is low because soil microorganism activity is limited by water availability. In saturated soils, lack of oxygen limits N mineralization because only soil microorganisms that can survive under anaerobic conditions are active (Deenik, 2006).

MacDonald *et al.* (1995) studied the effect of temperature on microbial respiration and net N mineralization and found that accumulation of mineralized N increased with increasing temperature. It was suggested that because the microbial population is temperature sensitive, changes in soil temperature can affect which soil N pool, and thus the size of the soil N pool, that is accessed by microbes (MacDonald *et al.*, 1995).

2.8.1.2 Soil texture

Soil texture has been reported to influence nitrogen mineralization (Franzluebbers *et al.*, 1996) and this is primarily related to clay content and, to some degree, clay mineralogy (Scott *et al.*, 1996). The amount and type of clay in a soil affects N mineralization reactions. Deenik (2006) reported that mineralization tends to be greater in coarse – textured soils low in clay and less as the soil clay content

increases. Finely textured soils high in clay are abundant in micropores in which organic matter can find physical protection from microbial decomposition. Physical protection is limited in coarse – textured soils. This probably accounts for the high mineralization rate reported for these soils compared to finely textured soils. Deenik (2006) further stated that compared to soil texture, the effects of soil mineralogy on N mineralization are less clear.

Soils dominated by clay minerals that shrink and swell with fluctuations in soil moisture, such as montmorillonite, tend to have higher N mineralization rates than those containing clays that do not shrink and swell, such as kaolinite. Mineralizable carbon to nitrogen ratio decreases with increasing clay content (Franzluebbers *et al.*, 1996). Soil organic matter in coarse textured soils appears to be more labile, whereas in finer textured soils, the complex soil structure provides greater protection to the soil organic matter, thus reducing the turnover of organic nitrogen (Franzluebbers *et al.*, 1996).

2.8.1.3 Soil compaction

According to Breland and Hansen (1996), soil compaction reduces the proportion of large pore spaces and increases the relative proportion of small pore spaces. If it is accepted that organic material in the smaller pores is physically protected from microbial attack (Breland and Hansen, 1996), then the proportion of organic matter that is protected increases, and mineralization decreases as pore size decreases.

Breland and Hansen (1996) found that nitrogen mineralization was, in fact, negatively correlated with small soil pores. Scott *et al.* (1996) suggested that while small pore spaces protect organic matter from microbial attack, large pores will dry

too quickly to facilitate nitrogen mineralization and diffusion of mineral nitrogen products. Medium size pores allow microbes' access to organic matter and retain water under dryer conditions. Thus, medium size pores are the most important to mineralization and their loss under soil compaction is the most serious. Strong *et al.* (1999) agreed with this point of view and suggested that large pores appear to protect organic matter because they do not regularly fill with water; thus, these pores cannot be easily accessed by microbes and the biochemical process of mineralization and the transport of the products is severely limited.

2.8.1.4 Composition of the residue

Residue decomposition and subsequent release of N from the residue is dependent on the quality or chemical composition of the residue (Heal *et al.*, 1997). Van Veen *et al.* (1984) noted that residues typically are comprised of three fractions:

- (i) easily decomposable sugars and amino acids.
- (ii) slowly decomposable materials including cellulose and hemicelluloses.
- (iii) materials those are relatively resistant to decomposition, such as lignin.

Each of these different fractions is expected to have different decomposition rates. Differences in decomposition largely reflect the differences in the chemical composition of the materials and it is the N concentration in the plant material (Ruffo and Bollero, 2003), or more specifically the ratio of carbon to nitrogen (C: N) that is most frequently recognized as the best predictor of N mineralization rates. The relative amounts of C to N in the organic matter exert a considerable influence on the available N status of the soil. If insufficient N is present to meet microbial demands, inorganic N may be immobilized from the inorganic N pool and thus rendered unavailable for plant growth (Grace and Merz, 2001). Kirchmann *et al.*

(2002) found that straw residues frequently have a wide C: N ratio and when incorporated into soil can bind quite large amounts of nitrate. They stated that one tonne of straw containing 0.4% N will bind 9 kg of inorganic N when it decomposes for one year in the field.

2.9 Phosphorus mineralization

The main organic sources of P include manure and crop residues. The most significant P compound in soil in terms of bioavailability is the orthophosphate anions, which are associated with readily accessible short term availability for plants. For longer term availability, organic compounds can be degraded to release orthophosphate (Fuentes *et al.*, 2006).

2.9.1 Factors affecting phosphorus mineralization

For P from organic compounds to be available, it needs to be hydrolyzed and mineralized by the microbial biomass, which is a fundamental process for the release of orthophosphate ions to plants (Hayes *et al.*, 2000) and the maintenance of the P cycle in ecosystems. Through a mineralization process, organic compounds represent an important P source for plants and microorganisms (Thien and Myers, 1992), in soil with low levels of bioavailable P and in unfertilized cropping systems.

2.9.1.1 Soil physico-chemical properties

According to Hinsinger (2001), phosphorus in soil has a poor mobility due to the high reactivity of orthophosphate ions relative to the numerous soil constituents which condition this interaction and occur in the rhizosphere. The distribution of phosphorus in soil is determined primarily by the pH of the soil solution. At low pH,

soils have greater amounts of aluminium in the soil solution, which forms very strong bonds with phosphate.

In soil minerals, orthophosphate anions are specifically adsorbed and form inner sphere complexes by replacing coordinated surface –OH and –OH₂ groups with the orthophosphate ions (Jara *et al.*, 2005). Phosphorus fixation and retention also occur due to high amounts of soluble and exchangeable Ca²⁺ resulting from reaction of CaCO₃ with orthophosphate anions to form a precipitate. Organic matter also affects retention of P. Organic matter adsorption on clays occurs by ligand exchange with the surface hydroxyl groups, similar to phosphate. As the amount of clay increases in the soil, the P-sorption capacity increases as well. This is because clay particles have a tremendous amount of surface area for which phosphate sorption can take place.

According to Hundal *et al.* (1988), application of crop residues increase P availability due to mineralization, chelation of Ca in alkaline soil and Al in acid soils and accumulation of organic acids produced during decomposition. The organic acids produced during the decomposition complexed metal cations Ca, Al and Fe, thereby helping in solubilization of native P and reduction in P sorption.

2.9.1.2 Chemical composition of the residue

Much information exists on effect of plant quality on rates of decomposition and N mineralization (Heal *et al.*, 1997) but fewer studies have evaluated the relationship between litter quality and P release during decomposition (Kwabiah *et al.*, 2001).

The control of leaf quality on P mineralization has important implication for selection of organic materials as P sources in low input systems. Kwabiah *et al.*

(2001) studied the relationship between quality and the per cent of leaf mass, N and P remaining. They found out that, total P and C: P ratio showed more consistent relationships with the per cent of leaf mass, N, and P remaining compared to other quality parameters such as N: P and L + PP: P ratios.

2.10 Integrated nutrient management

Researchers provide various definitions and explanations for integrated nutrient management. Some researchers argue that it is a practice whereby both organic and inorganic nutrient resources are applied simultaneously to increase crop yields. Other scientists argue that in addition to organic and inorganic inputs, other agronomic practices of planting good seed, early planting, weed, pest and disease control, should be the components in the definition of integrated nutrient management. A third school of thought stresses that nutrient cycling is the centre of integrated nutrient management (Okalebo and Woomer, 2005).

According to Syers *et al.* (1997), nutrient depletion through harvested crop components and residue removal and by leaching and soil erosion accentuates the often very low inherent fertility of many soils in the tropics. Integrated soil fertility management recognizes that both mineral inputs and organic resources are required for sustainable tropical agriculture, partly because either of those usually is in short supply for sole application, but also because the combined application of mineral inputs and organic resources possibly generates added benefits, for example, in terms of extra crop yield or extra C build up (Vanlauwe *et al.*, 2001).

While nutrient deficiencies could be met largely through chemical fertilizers, desirable soil physical properties such as water holding capacity, congenial conditions for microbial activity and efficient use of applied fertilizers could be maintained by addition of organic manures. The use of inorganic fertilizers does not supply all the required nutrients, and the cost of purchasing is also unaffordable for poor smallholder farmer. Thus, farmers should be aware of the complementarities of the inorganic and organic fertilizers and one could not replace the other.

Some studies suggest that the use of organic matter inputs can completely replace the use of synthetic fertilizers in particular systems. Mugendi *et al.* (1999) found that *ex situ* prunings of the agroforestry tree species *Calliandra calothyrsus* and *Leucaena leucocephala*, applied to a maize cropping system in the subhumid highlands of Kenya, resulted in higher maize grain yield than both the fertilized and non-fertilized controls. Although these results are promising, they only provide one example in which the application of organic biomass was able to increase crop yields above the yields that were achieved in using inorganic resources. In most cases organic soil amendments need to be supplemented with small amounts of mineral fertilizer in order to obtain sufficient crop yields in tropical agroecosystems (Syers *et al.*, 1997; Palm *et al.*, 2001).

The goal of integrated nutrient management as reported by Gruhn *et al.* (2000) is to integrate the use of all natural and man – made sources of plant nutrients, so that crop productivity increases in an efficient and environmentally benign manner, without sacrificing soil productivity of future generations. Integrated nutrient management relies on a number of factors, including appropriate nutrient application

and conservation and the transfer of knowledge about integrated nutrient management practices to farmers and researchers (Gruhn *et al.*, 2000).

Decomposition is the process by which organic matter is transformed into inorganic chemical forms. The substrate for the decomposition process in agricultural soils is organic matter mainly derived from plant inputs in the form of crop residues. Understanding nutrient release patterns of plant materials is an important first step to better management of organic inputs that are applied in agroforestry and other related land use systems. The rate of decomposition of these residues and the subsequent release of nutrients depend on a range of factors such as the biochemical composition of the organic material, physical factors, decomposing organisms and the degree to which the organic matter is protected. Several management options are available for managing these residues each having its own advantages and disadvantages. To achieve synchrony, it is necessary to regulate N release from residues to suit the N demand of crops. Nitrogen release from residues can be regulated by altering or manipulating the factors that influence the mineralization of N from the residues, such as residue quality, environmental factors and management factors. Although the application of crop residues alone to the soil can supply nutrients to crops, increase soil organic matter and protect the soil from erosion, their value in terms of increasing crop yield could be enhanced by the addition of inorganic nutrient sources in an integrated nutrient management manner.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental sites

The research involved both field and laboratory studies. The field experiments were conducted at the Soil Research Institute experimental field, Kwadaso, which is about 8 km away from Kumasi, the Ashanti regional capital of Ghana. This area lies between latitudes 06° 39' and 06° 43' North and longitudes 01° 39' and 01° 42' West of the Greenwich meridian. The laboratory studies were conducted at the Soil Science Laboratory, Faculty of Agriculture, KNUST, Kumasi, Ghana.

3.2 Climate of the Soil Research Institute experimental site

The area falls within the moist semi – deciduous forest zone of Ghana that is characterized by two rainy seasons and two dry seasons in a year. The major rainy season starts from March to mid – July and the minor season starts from September to mid – November. There is a short dry spell 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 rainfall is about 1473 mm. Temperatures are uniformly high throughout the year, with low and high monthly average of about 25⁰ and 28⁰C recorded in August and February respectively. 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 in the dry season, it is low (about 40%).

3.3 Soil used for the study

The experiments were conducted at the Soil Research Institute experimental site. The soil is the Asuansi series classified by Adu (1992) as Ferric Acrisol according to FAO (1990). This soil occurs at the upper to middle slope sites of the Kumasi – Asuansi/Nta – Ofin Compound Association.

3.4 Soil sampling

Twelve different spots were dug to the depth of 0 – 20 cm and sampled. The samples were bulked in a bucket, mixed thoroughly and a sub – sample taken to the laboratory, for preparation and analysis. The sample was air – dried for five days and sieved through a 2 mm mesh sieve and stored for both chemical and physical analyses.

3.5 Soil chemical analyses

The following soil chemical properties were analyzed to determine the fertility status.

3.5.1 Determination of Soil pH

The pH of the soil was determined using a Suntex pH (mv) Sp meter (701) at soil: water ratio of 1:2.5 as described by McLean (1982). A 20 g soil sample was weighed into a 100 ml beaker. To this, 50 ml distilled water was added and the suspension was stirred continuously for 20 minutes and allowed to stand for 15 minutes. After calibrating the pH meter with buffer solutions of pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

3.5.2 Determination of soil organic carbon

Organic carbon was determined by a modified Walkley – Black wet oxidation method (Nelson and Sommers, 1982). Two grams of soil sample was weighed into 500 ml erlenmeyer flask. A blank sample was also included. Ten millilitres of 0.1667 M $K_2Cr_2O_7$ solution was added to the soil and the blank flask. To this, 20 ml of concentrated sulphuric acid was added and the mixture allowed to stand for 30 minutes on an asbestos sheet. Distilled water (200 ml) and 10 ml of concentrated orthophosphoric acid were added and allowed to cool. The excess dichromate ion ($Cr_2O_7^{2-}$) in the mixture was back titrated with 0.333 M ferrous sulphate solution using diphenylamine as indicator.

Calculation:

$$\% \text{Organic C} = \frac{(\text{m.e. } K_2Cr_2O_7 - \text{m.e. } FeSO_4) \times (1.32) \times 0.003}{\text{wt. of soil}} \times 100$$

where:

m.e. = molarity of solution x ml of solution used

0.003 = m.e. wt of C in grams (12/4000)

1.32 = correction factor

3.5.3 Organic matter

The organic matter of the soil sample was calculated by multiplying the per cent organic carbon by a Van Bemmelen factor of 1.724.

3.5.4 Determination of total nitrogen

The total nitrogen content of the soil was determined using the Kjeldahl digestion and distillation procedure as described by Bremner and Mulvaney (1982). A 10 g soil sample was put into a Kjeldahl digestion flask and 10 ml distilled water added to

it. Concentrated sulphuric acid and selenium mixture were added and mixed carefully. The sample was digested on a Kjeldahl apparatus for 3 hours until a clear and colourless digest was obtained. The volume of the solution was made to 100 ml with distilled water. A 10 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of NaOH solution was added followed by distillation. The distillate was collected in boric acid and titrated with 0.1M HCl solution with bromocresol green as indicator. Traces of nitrogen in the reagents and water used were taken care of by carrying out a blank distillation and titration.

Calculation:

$$\%N = \frac{14 \times (A - B) \times M \times 100}{1000 \times 1}$$

where:

M = concentration of HCl used in titration.

A = ml HCl used in sample titration

B = ml HCl used in blank titration

14 = atomic weight of nitrogen

1 = wt. of soil sample in gram

3.5.5 Determination of exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) content in the soil were determined in 1.0 M ammonium acetate (NH_4OAc) extract (Black, 1965) and the exchangeable acidity (hydrogen and aluminium) was determined in 1.0 M KCl extract (McLean, 1965).

3.5.5.1 Extraction of the exchangeable bases

A 10 g soil sample was weighed into an extraction bottle and 100 ml of 1.0 M ammonium acetate solution was added. The bottle with its contents was shaken for

one hour. At the end of the shaking, the supernatant solution was filtered through No. 42 Whatman filter paper.

3.5.5.2 Determination of exchangeable calcium

For the determination of calcium, a 10 ml portion of the extract was transferred into an erlenmeyer flask. To this, 10 ml of potassium hydroxide solution was added followed by 1 ml of triethanolamine. Few drops of potassium cyanide solution and few crystals of cal-red indicator were then added. The mixture was titrated with 0.02 *M* EDTA (ethylene diamine tetraacetic acid) solution from a red to a blue end point.

3.5.5.3 Determination of exchangeable calcium and magnesium

A 10 ml portion of the extract was transferred into an erlenmeyer flask and 5 ml of ammonium chloride – ammonium hydroxide buffer solution was added followed by 1 ml of triethanolamine. Few drops of potassium cyanide and Eriochrome Black T solutions were then added. The mixture was titrated with 0.02 *M* EDTA solution from a red to a blue end point.

Calculations:

$$\text{Ca} + \text{Mg (or Ca) (cmol/kg soil)} = \frac{0.02 \times V \times 1000}{W}$$

where:

W = weight in grams of soil extracted

V = ml of 0.02 *M* EDTA used in the titration

0.02 = concentration of EDTA used

3.5.5.4 Determination of exchangeable magnesium

This was calculated by subtracting the value obtained from calcium alone from the calcium + magnesium value.

3.5.5.5 Determination of exchangeable potassium and sodium

Potassium and sodium in the soil extract were determined by flame photometry. Standard solutions of 0, 2, 4, 6, 8 and 10 ppm K and Na were prepared by diluting appropriate volumes of 100 ppm K and Na solution to 100 ml in volumetric flask using distilled water. Flame photometer readings for the standard solutions were determined and a standard curve constructed. Potassium and sodium concentrations in the soil extract were read from the standard curve.

Calculations:

$$\text{Exchangeable K (cmol/kg soil)} = \frac{\text{Graph reading} \times 100}{39.1 \times w \times 10}$$

$$\text{Exchangeable Na (cmol/kg soil)} = \frac{\text{Graph reading} \times 100}{23 \times w \times 10}$$

where:

w = weight of air – dried sample soil in grams

39.1 = mole of potassium

23 = mole of sodium

3.5.5.6 Determination of exchangeable acidity

This consists of aluminium (Al^{3+}) and hydrogen (H^+). Five grams of soil sample was put into a shaking bottle and 100 ml of 1.0 M KCl solution added. The mixture was shaken for one hour and then filtered. Fifty millilitres portion of the filtrate was transferred into an erlenmeyer flask and 2 – 3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.05 M NaOH until the colour just turned permanently pink. The amount of base used was equivalent to total acidity ($\text{H}^+ + \text{Al}$). A few drops of 0.05 M HCl were added to the same mixture to bring the

solution back to colourless condition and 10 ml of 1.0 M sodium fluoride (NaF) solution added. The solution was then titrated with 0.05 M HCl until the colour disappeared. The milliequivalents of acid used are equal to the amounts of exchangeable Al. The amount of H was determined by difference (McLean, 1965).

Calculation:

$$\text{Exchangeable Al+H or Al (cmol/kg soil)} = \frac{0.05 \times v \times 200}{w}$$

where:

0.05 = molarity of NaOH or HCl used for titration

v = ml NaOH or HCl used for titration

w = weight of air – dried soil sample in grams

3.5.5.7 Calculation of effective cation exchange capacity (ECEC)

Effective cation exchange capacity was calculated by the sum of exchangeable bases (Ca, Mg, K, and Na) and exchangeable acidity (Al and H).

3.5.5.8 Percent base saturation

This was calculated from the sum of exchangeable bases as a percent of the ECEC of the soil.

3.5.5.9 Determination of available phosphorus

Available P was determined using the Bray P₁ method (Olsen and Sommers, 1982). The method is based on the production of a blue complex of molybdate and orthophosphate in an acid solution.

Standard series of 0, 0.8, 1.6, 2.4, 3.2 and 4.0 µg P/ml was prepared by diluting appropriate volumes of the 10 µg P/ml standard sub – stock solution. These standards were subjected to colour development and their respective transmittances read as specified above. A standard curve was constructed using the readings.

A 2.0 g soil sample was weighed into a 50 ml shaking bottle and 20 ml of Bray- 1 extracting solution was added. The sample was shaken for one minute and then filtered through No. 42 Whatman filter paper. Ten millilitres of the filtrate was pipetted into a 25 ml volumetric flask and 1 ml each of molybdate reagent and reducing agent were added for colour development. The percent transmission was measured at 520 nm wavelength on a spectronic 21 D spectrophotometer. The concentration of P in the extract was obtained by comparison of the results with a standard curve.

Calculations:

$$P \text{ (mg kg}^{-1}\text{)} = \frac{\text{Graph reading} \times 20 \times 25}{w \times 10}$$

where:

w = sample weight in grams

20 = ml extracting solution

25 = ml final sample solution

10 = ml initial sample solution

3.6 Soil physical analyses

3.6.1 Particle size analysis

The hydrometer method (Bouyoucos, 1963) was used for this analysis. A 51 g of air-dried soil sample was weighed into a ‘milkshake’ mix cup. To this, 50.0 ml of 10%

sodium hexametaphosphate along with 100 ml distilled water were added. The mixture was shaken for 15 minutes after which the suspension was transferred from the cup into a 1000 ml measuring cylinder. With a hydrometer in the suspension, distilled water was added to reach the 1000 ml mark. The mixture was inverted several times until all soil was in suspension. The cylinder was placed on a flat surface and the time noted. The first hydrometer and temperature readings were taken at 40 seconds. After the first readings the suspension was allowed to stand for 3 hours and the second hydrometer and temperature readings were taken. The first reading indicates the percentage of sand and the second reading percentage clay. The percentage of silt was determined by difference.

Calculations:

$$\% \text{ Sand} = 100 - [H_1 + 0.2 (T_1 - 20) - 2.0] \times 2$$

$$\% \text{ Clay} = [H_2 + 0.2 (T_2 - 20) - 2.0] \times 2$$

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

where:

H_1 = Hydrometer reading at 40 seconds

T_1 = Temperature at 40 seconds

H_2 = Hydrometer reading at 3 hours

T_2 = Temperature at 3 hours

$0.2 (T - 20)$ = Temperature correction to be added to hydrometer reading

$- 2.0$ = Salt correction to be added to hydrometer reading.

3.6.2 Determination of soil moisture content (θ_m)

This was determined by the gravimetric method (Marshall and Holmes, 1988). In this method, the loss in weight after oven – drying as a fraction of the oven – dried

soil represents the moisture content. A moisture can with its lid was dried in oven at 105°C to a constant weight, allowed to cool and its weight recorded. A 10 g soil was put into the can, covered and the weight taken. The lid was removed and placed under the can. The can with soil and the lid was placed in the oven and dried at 105°C for about 24 hours to a constant weight. The can was removed from the oven, covered with the lid, allowed to cool and the weight taken.

Calculation:

$$\% \text{ Soil moisture by weight (Mw)} = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

where:

W_1 = Weight of empty can + lid

W_2 = Weight of can + lid + fresh soil

W_3 = Weight of can + lid + oven – dried soil

3.6.3 Determination of soil bulk density (ℓ_b)

This was determined using the metal core sampler method (Blake and Harte, 1986). The core sampler was driven into the soil with the aid of a mallet. Soil at both ends of the tubes was trimmed and the end flushed with a straight-edged knife. The core sampler with its content was dried in the oven at 105°C to a constant weight, removed, allowed to cool and its weight taken. The weight of the core cylinder and its volume was determined.

Calculation:

$$\text{Dry bulk density } \ell_b \text{ (g cm}^{-3}\text{)} = \frac{W_2 - W_1}{V}$$

where:

W_2 = Weight of core cylinder + oven-dried soil

W_1 = Weight of empty core cylinder

V = Volume of core cylinder ($\pi r^2 h$), where:

$$\pi = 3.142$$

r = radius of the core cylinder

h = height of the core cylinder

3.6.4 Determination of volumetric moisture content (θ_v)

This was calculated by multiplying the moisture content by the bulk density.

$$\text{Volumetric moisture content } (\theta_v) = \theta_m \times \frac{\ell_b}{\ell_w}$$

where:

θ_m = gravimetric moisture content

ℓ_b = dry bulk density

ℓ_w = density of water

3.6.5 Porosity (f)

This was computed from the relation:

$$\text{Porosity } (f) = 1 - \frac{\ell_b}{\ell_s}$$

where:

ℓ_b = dry bulk density

ℓ_s = particle density, with a value of 2.65 g cm^{-3}

3.7 Characterization of the crop residues

The nutrient content, polyphenol, lignin, carbon/nitrogen, lignin/nitrogen and lignin + polyphenol/nitrogen ratios are some of the parameters usually used to express the quality of crop residues. Residues of the following crops were collected from the experimental fields of the Central Agricultural Station Kwadaso, and used for the study:

Cowpea [*Vigna unguiculata* (L.) Walp]

Groundnut [*Arachis hypogaea* (L.)]

Mucuna (*Mucuna pruriens* Bak)

Soyabean [*Glycine max* (L.) Merr]

Cassava (*Manihot esculenta* Crantz)

Maize (*Zea mays* L.)

These materials were dried in the oven at 70°C for 72 hours and milled to pass through a 2 mm sieve. Total nitrogen, phosphorus, potassium, calcium, magnesium, carbon, ash, polyphenol and lignin contents were determined and used to assess the quality of residues. All residues were fractionated into readily soluble fraction, lignin and ash.

3.7.1 Determination of organic carbon

Organic carbon content of residues was determined using the wet dichromate oxidation method. Milled residue (0.05 g) was weighed into an erlenmeyer flask. Ten millilitres concentrated sulphuric acid, 10 ml 0.1667 M K₂Cr₂O₇, and 10 ml of orthophosphoric acid were added. After the addition of water, the solution was allowed to stand for 30 minutes on an asbestos sheet and back titrated with 0.333 M FeSO₄ solutions with diphenylamine indicator.

Calculation:

$$\% \text{ Organic carbon} = \frac{(\text{m.e. K}_2\text{Cr}_2\text{O}_7 - \text{m.e. FeSO}_4) \times (1.32) \times 0.003 \times 100}{w}$$

where:

m.e. = molarity of solution x ml of solution used

w = weight of oven dried sample in grams

0.003 = milli-equivalent weight of carbon in grams (12/4000)

1.32 = correction factor

3.7.2 Determination of total nitrogen

Total nitrogen was determined by the Kjeldahl distillation and titration method. A 0.2 g of the milled residue was weighed into a Kjeldahl flask. Concentrated sulphuric acid and selenium mixture as a catalyst were then added. The mixture was digested for three hours until it became colourless. The clear digest obtained was transferred into a 50 ml conical flask and made to the mark with distilled water. Five millilitres each of a blank and sample were pippered separately into the Kjeldahl distillation apparatus. To this, 10 ml NaOH solution was added and distilled, collected in boric acid and titrated with 0.1 M HCl with bromocresol green – methyl red indicator (Okalebo *et al.*, 1993).

Calculation:

$$\% \text{ N} = \frac{14 \times (A - B) \times M}{1000 \times 0.02} \times 100$$

where:

A = ml 0.1 M HCl used for sample titration

B = ml 0.1 M HCl used for blank titration

M = mole of HCl

14 = atomic weight of nitrogen

0.02 = weight of sample in gram

3.7.3 Determination of total phosphorus, potassium, calcium, magnesium, zinc, copper, iron and manganese

A 0.5 g of the milled residue was ashed in a muffle furnace, at 550⁰C for 4 hours after which the ash was dissolved in 2.0 M HCl solution, heated and filtered. The filtrate was diluted to 100 ml with distilled water.

3.7.3.1 Determination of total phosphorus

A 5 ml aliquot of the filtrate above was taken into a 25 ml volumetric flask. Following this, few drops of molybdate solution and reducing agent were added and made to the 25 ml mark with distilled water. The solution was allowed to stand for 10 minutes for full colour development. A standard curve was also developed concurrently with phosphorus concentrations ranging from 0.0, 0.8, 1.6, 2.4, 3.2 and 4.0 µg/ml. The absorbance of the sample and standard solutions were read on a spectronic 21 D spectrophotometer at a wavelength of 520 nm. A standard curve was obtained by plotting the absorbance values of the standard solutions against their respective concentrations. Phosphorus concentration of the samples was determined from the standard curve.

Calculation:

$$\% P = \frac{\text{Graph reading} \times 25}{w \times 1000}$$

where:

w = weight of sample

25 = final volume of solution

3.7.3.2 Determination of total potassium

Potassium in the ash solution was determined using a flame photometer. Potassium standard solutions were prepared with the following concentrations: 0, 2, 4, 6, 8 and 10 µg/ml. The emission values were read on the flame photometer. A standard curve was obtained by plotting emission values against their respective concentrations.

Calculation:

$$\% K = \frac{\text{Graph reading}}{w \times 100}$$

where:

w = weight of sample

3.7.3.3 Determination of total calcium

A 10 ml aliquot of the ash solution was put in an erlenmeyer flask. Ten millilitres of 10% potassium hydroxide, 1 ml of triethanolamine and few drops of potassium cyanide solutions were added. The mixture was titrated with 0.02 M EDTA solution with cal red as an indicator.

3.7.3.4 Determination of total calcium and magnesium

Ten millilitres of the ash solution was put in an erlenmeyer flask. Potassium hydroxide, buffer solution, 1 ml of triethanolamine and few drops of potassium cyanide solutions were added. The mixture was titrated with 0.02 M EDTA solution with murexide as an indicator.

Calculation:

$$\%Ca = \frac{V \times 0.02 \times 20}{w}$$

where:

V = ml of EDTA required for titration

0.02 = molarity of EDTA

20 = equivalent weight of Ca (40/2)

w = weight of sample

3.7.3.5 Determination of total magnesium

The concentration of magnesium in the residue was calculated by subtracting the value obtained from calcium alone from the calcium + magnesium value.

Calculation:

$$\%Mg = \frac{V \times 0.02 \times 12}{w}$$

where:

V = ml of EDTA required for titration

0.02 = molarity of EDTA

12 = equivalent weight of Mg (24/2)

w = weight of sample

3.7.3.6 Determination of copper, zinc, iron and manganese

These were determined using the atomic absorption spectrophotometer (after dry ashing) by comparing the absorbances of Cu, Zn, Fe and Mn atoms with respect to a series of standard solutions. Graphs relating the absorbance to the amount of Cu, Zn, Fe and Mn in the plant tissues were plotted.

Calculation:

$$\text{mg kg}^{-1} (\text{Cu, Zn, Fe and Mn/ DM}) = 100 \times (A - B)$$

where:

A = sample absorbance

B = absorbance of blank

100 = percentage

DM = dry matter

3.7.4 Determination of lignin

Lignin is an aromatic compound composed of repeating benzene rings that are branched and complex (Franzluebbers, 2004). It is defined as the residual organic fraction after chemical extraction which is resistant to microbial degradation (Anderson and Ingram, 1998). The acid detergent fibre method was used in determining the lignin content of the residues (Anderson and Ingram, 1998). Two grams of milled residue was weighed into a sealed pyrex tube. To this, 25 ml of 0.05 M sulphuric acid was added, heated at 100°C for 1 hour, cooled and centrifuged. The supernatant solution was saved in another container. This was repeated with distilled water to remove most of the sulphuric acid in the residue. The solution was transferred into a 100 ml erlenmeyer flask with 40 ml distilled water, boiled for 3 hours and filtered. The residue was washed with water, dried at 60°C for 48 hours, weighed and ashed in a muffle furnace at 550°C for 4 hours. The loss in weight on ignition is the lignin content of residue (Anderson and Ingram, 1998).

3.7.5 Determination of polyphenols

This was determined using the Folin – Denis method (Anderson and Ingram, 1998). A 0.2 g oven – dried and milled residue was weighed into a 50 ml beaker. Twenty millilitres of 50% methanol was added, covered and placed in a water bath at 80°C for 1 hour. The extract was filtered through No. 42 Whatman filter paper into a 50 ml volumetric flask using 50% aqueous methanol to rinse, and made up to the mark with distilled water. Standard solutions of tannic acid (0, 1, 2 and 4 ml) were prepared. The samples and tannic acid standards were subjected to colour development using Folin – Denis reagent. Values of absorbance of the standard and sample solutions were read on a spectronic 21 D spectrophotometer at 760 nm wavelength. A standard curve was obtained by plotting absorbance values against concentrations of the standard solutions, and used to determine the concentration of the sample solutions (Anderson and Ingram, 1998).

Calculation:

$$\text{Total extractable polyphenol (\%)} = \frac{\text{Graph reading} \times 50 \times 100}{w \times 1000}$$

where:

w = weight of sample in grams

3.8 Determination of residue moisture content

Twenty grams of fresh residues were put in clean paper bags and oven-dried at 70°C for 72 hours. At the end of the 72 hour period, the dry weights of the residues were taken and the percent moisture on fresh weight basis was calculated from the formula:

$$\% \text{ moisture} = \frac{W_2 - W_1}{W_2} \times 100$$

where:

W_1 = final weight of residue

W_2 = initial weight of residue

3.9 Laboratory experiments

The laboratory experiments carried out were the nutrient mineralization (leaching – incubation method) and soil microbial biomass analysis.

3.9.1 Leaching incubation experiment

The mineralization of crop residues in soil was studied by the leaching-incubation method as described by Handayanto *et al.* (1997). A 10 g soil sample was put into leaching tubes and a 100 mg each of milled residues were added to the soil in the tube.

The treatments were:

- i. Control (10 g soil with no residue)
- ii. Cassava (10 g soil + 100 mg cassava leaves)
- iii. Maize stover (10 g soil + 100 mg maize stover)
- iv. Cowpea haulm (10 g soil + 100 mg cowpea haulm)
- v. Groundnut haulm (10 g soil + 100 mg groundnut haulm)
- vi. Mucuna (10 g soil + 100 mg mucuna)
- vii. Soyabean (10 g soil + 100 mg soyabean)

Distilled water (6 ml) was added to the samples to raise the water content to 60% water holding capacity. The water holding capacity was determined by calculating 60% of the dry weight of the soil (10 g) + crop residue (0.1g). Thus, sixty percent of

the total weight represents the amount of water to be added to attain 60% water holding capacity.

The treatments were replicated three times in a completely randomized design. The experiment was conducted under the laboratory condition with maximum room temperature of about $30 \pm 1^{\circ}\text{C}$. The samples in the tubes were leached after 1, 2, 4, 6 and 8 weeks with 100 ml of 1.0 M KCl. Nitrate – N, ammonium – N, phosphorus, calcium and magnesium were determined in the leachate. Total mineral – N (NH_4^+ and NO_3^-) in 10.0 ml aliquot of the leachate was determined by the Kjeldahl distillation method. Sodium hydroxide (40%) and Devarda's Alloy which reduces NO_3^- to NH_4^+ were used for the distillation followed by the titration of the distillate trapped in boric acid solution with 0.02 M HCl (Keeney and Nelson, 1982).

The amount of nitrogen mineralized from the soil was estimated using a first – order rate equation:

$$N_{\text{rel}} = N_o [1 - \exp (-k_o t)] \quad (\text{Agehara and Warncke, 2005})$$

where:

N_{rel} = cumulative N released at time t.

N_o = size of potentially mineralizable N.

exp = the exponential constant with numerical value ≈ 2.718

k_o = the first – order rate constant.

t = time in weeks

Calcium and magnesium in the leachate were determined by EDTA titration. A solution of 0.02 M EDTA was titrated with 10.0 ml aliquot of the leachate using cal red and Eriochrome Black T indicators for calcium and magnesium determination. Potassium was not determined because of the extraction solution used (1.0 M KCl).

3.9.2 Soil microbial biomass analysis

Soil microbial biomass is an important component of soil quality assessment because of its important roles in nutrient dynamics, decomposition of organic amendments and physical stabilization of aggregates (Franzluebbers *et al.*, 1999). Microbial biomass as determined by the fumigation – extraction technique subjects a fresh soil to chloroform fumigation that results in cell wall lyses, allowing the cellular contents to become extractable in 0.5 M K₂SO₄. This is not a measure of soil microbial activity because no differentiation is made between quiescent and active organisms, or between different classes of micro-organisms (Okalebo *et al.*, 1993). Soil microbial carbon, nitrogen and phosphorus were studied following the application of both organic and inorganic amendments in a field experiment as described under section 3.10.2.

3.9.2.1 Determination of soil microbial carbon and nitrogen

Soil microbial C and N were monitored following the application of both organic and inorganic nutrient sources in a field experiment as described below. Ten grams field moist soil samples (Asuansi series), taken from plots treated with the amendments after passing through a 4 mm mesh, were each put in 50 ml beakers and placed in two desiccators. A shallow dish containing 30 ml chloroform was placed at the centre of one of the desiccators. The other desiccator containing the non-fumigated samples served as control. The desiccators were covered and allowed to stand at room temperature for five days. The soil samples were then transferred into 250 ml shaking bottles. A 50 ml 0.5 M K₂SO₄ solution was added and shaken for 30 minutes. The extract was filtered through No. 42 Whatman filter paper and the filtrate retained for analysis. An aliquot of 8 ml of the extract was used for organic C determination (Vance *et al.*, 1987). Microbial biomass carbon was calculated from

the difference in extractable organic C between the fumigated and non – fumigated soil samples as:

$$\text{Microbial biomass C } (\mu\text{g g}^{-1}) = 2.64E_C$$

where:

E_C refers to the difference in extractable organic carbon between fumigated and non–fumigated samples and 2.64 is the proportionality factor of microbial biomass carbon released by fumigation extraction (Vance *et al.*, 1987).

Total nitrogen in the extracts was measured by the Kjeldahl digestion. A 10 ml aliquot of extract was digested with sulphuric acid for three hours after addition of selenium mixture to promote organic matter breakdown. Microbial biomass nitrogen was calculated using the equation:

$$\text{Microbial biomass N } (\mu\text{g g}^{-1}) = 1.46 E_N \text{ (Brookes } et al., 1985).$$

where:

$$E_N = (\text{total N from fumigated soil}) - (\text{total N from non-fumigated soil})$$

1.46 = proportionality factor of microbial biomass nitrogen released by extraction.

3.9.2.2 Determination of soil microbial phosphorus

Microbial P was determined using the fumigation – sorption method of Morel *et al.* (1996) and modified for use with tropical soils by Oberson *et al.* (1997). Five grams of soil samples were fumigated with chloroform. Another soil sample without chloroform served as control. Following fumigation, samples were extracted with 35 ml of Bray solution (0.03 M NH_4F and 0.025 M HCl) using a solution to soil ratio of

7:1 (Bray and Kurtz, 1945) for 1 minute, filtered, and stored for analysis. Concurrently, parallel soil samples were spiked with different amounts of P (0, 5, 10, 15 and 20 mg/kg) and extracted to determine the effect of sorption reactions over the course of the experiment. Solutions were analyzed for P by the ammonium molybdate ascorbic acid method (Olsen and Sommers, 1982). Microbial biomass estimates were obtained using the relationships described by Morel *et al.* (1996).

$$\text{Ext}_p = \text{Ext}_0 + b_1 P_{ad}^{b_2} \dots\dots\dots (1)$$

where:

Ext_p = Pi concentration (mg/l) extracted after equilibration with
different amounts of P added,

Ext_0 = Pi concentration extracted without P addition,

b_1, b_2 = coefficients estimated by non-linear regression of mean
values of Ext_p against P_{ad} .

P_{ad} = amount of P added (0 – 20 mg kg⁻¹).

Chloroform released P corresponds to a P addition and is calculated from the equation:

$$P_{chl.} = [(\text{Ext}_{chl.} - \text{Ext}_0)/b_1]^{1/b_2} \dots\dots\dots (2)$$

where:

$P_{chl.}$ = chloroform released P (mg kg⁻¹),

$\text{Ext}_{chl.}$ = Pi concentration in extracts of fumigated samples.

Microbial biomass P (µg g⁻¹) = (b – a) × 2.65 × (c – a)

where:

a = non – fumigated soil

b = from fumigated soil

c = from spiked soil

2.65 = proportionality factor (Brookes *et al.*, 1982).

3.10 Field experiments

3.10.1 Decomposition of crop residues

Crop residue decomposition rate in the field was measured by the loss of weight of residue with time, and expressed as a negative exponential function as described by Anderson and Ingram (1998) using both the confined (litterbag) and unconfined methods.

3.10.1.1 Litter decomposition experiment (unconfined)

Measurement of mass losses from unconfined litter under natural conditions is only possible in the initial phases of decomposition before materials start to disintegrate (Anderson and Ingram, 1998). A 200 g of shredded fresh crop residue (cowpea haulm, cassava leaves and maize stover) was spread on an open field with plot size, 0.25 m² in three replications on a Ferric Acrisol in the semi – deciduous forest zone. Three samples per treatment were retrieved from the field after 1, 2, 4, 6, and 8 weeks. A graph of percentage residual mass remaining against time was plotted and the rate constant determined from the slope of the graph.

3.10.1.2 Litter decomposition (in litter bags)

Decomposition in terrestrial ecosystem is commonly studied using the litter bag method (Wieder and Lang, 1982) which consists of enclosing plant material of

known mass and chemical composition in a screened container. Initially, a large number of bags were placed in the field and, at each subsequent sampling, a random set of bags was retrieved and analyzed for loss of mass and/or changes in the chemical composition of residues. The use of the litter bag makes it possible to recover the residual experimental material even after the material has undergone some decomposition (Anderson and Ingram, 1998). This experiment was carried out in the major and minor rainy seasons and repeated in the dry season to compare the effect of moisture availability (season) on rate of decomposition.

Litter bags (20 x 30 cm) were made from nylon mosquito nets with 1.0 mm mesh size (Palm and Sanchez, 1990; Tetteh, 2004). A 20 g sample each of cassava leaves and maize stover, during the major rainy season (9th June – 4th August, 2006) and cassava leaves, cowpea haulm and maize stover during the minor rainy season (12th September – 7th November, 2006) and dry season (2nd December 2006 – 27th January, 2007) were put in litter bags. One set of samples was buried into the soil at a depth of 10 cm and at an angle of 45° in a relatively uniform area of Asuansi series, a Ferric Acrisol (FAO, 1990) at Kwadaso in two parallel lines between rows of maize. The other set was placed on the surface with the same arrangement as above to study placement effect on the rate of decomposition. Three litter bags for each crop residue and method of placement were taken from the field after 1, 2, 4, 6 and 8 weeks (Anderson and Ingram, 1998). The soil attached to the residue was carefully removed and fresh weight of the residue left undecomposed determined. The sample material was transferred into paper bags and oven-dried at 70°C for dry weight determination. These samples were milled to pass through a 2 mm mesh sieve and analysed for total nitrogen, phosphorus, potassium, calcium, magnesium and organic carbon in the laboratory.

The percentage of initial mass of residue remaining was calculated by the formula

$$\% \text{ dry weight remaining} = \frac{DW_t}{DW_i} \times 100$$

where:

DW_t = mean oven dry weight at time t

DW_i = initial oven dry weight

The rate of decomposition was expressed by the single exponential equation:

$$Y = e^{-kt} \text{ (Hartemink and O'Sullivan, 2001; Kayuki and Wortmann, 2001).}$$

where:

Y = proportion of initial mass remaining

t = time in weeks

k = decomposition factor

To calculate the decomposition factor (k), the formula was rewritten as:

$$\ln Y = -kt$$

Hence the gradient of the line, calculated by linear regression, was the decomposition factor, k .

This single exponential model assumes that decomposition rates are constant over time, though there is an initial fast phase due to leaching of water soluble materials (labile organic material) followed by a slower phase dominated by the breakdown of the recalcitrant organic materials like lignin, cellulose, hemicellulose and waxes (Weider and Lang, 1982). The two phases of decomposition can be expressed as:

$$Y = \Phi_0 e^{-k_1 t} + \Phi_1 e^{-k_2 t} \text{ (Isaac *et al.*, 2000)}$$

where:

Y = the amount of crop residue remaining at time t

Φ_0 = easily decomposable fraction

Φ_1 = the difference $(100 - \Phi_0)$

k_1 and k_2 = decomposition rate constants

t = time in weeks

The percentage initial mass and percentage $\log_n$ initial mass remaining was plotted against time (weeks). Curves were fitted with the single negative exponential model to derive the decomposition rate constant, k . The half-life, t_{50} (in weeks), the time required for 50% of the initial mass to decompose was estimated from the graph. The t_{50} value could also be estimated from the equation:

$$t_{50} = \frac{0.693}{k} \quad (\text{Crohn, 2004}).$$

3.10.2 Maize response trial

This field experiment was carried out to study the fertilizing effect of two crop residues (maize stover and cowpea haulms) on maize yield. The two residues were either applied alone or in combination with inorganic fertilizer. This was done to find out the complementary effects of both organic and inorganic nutrient sources.

At the Kwadaso Central Agricultural Station, maize variety (Obatanpa) which is medium maturing was planted on the Asuansi soil (Ferric Acrisol, FAO, 1990) with plot size 3.0 m x 4.0 m at a planting distance of 80 cm x 40 cm. Three seeds were planted per hill and thinned to two plants per hill four weeks after planting.

The treatments were as follows:

- i. Control (no residue applied)
- ii. Maize stover (10 t ha^{-1})
- iii. Maize stover (5 t ha^{-1}) + cowpea haulm (5 t ha^{-1})
- iv. Maize stover (5 t ha^{-1}) + $\frac{1}{2}$ NPK
- v. Cowpea haulm (10 t ha^{-1})
- vi. Cowpea haulm (5 t ha^{-1}) + $\frac{1}{2}$ NPK
- vii. NPK (15–15–15) + 30 kg N ha^{-1} using urea ($90\text{--}60\text{--}60 \text{ kg ha}^{-1}$) full rate.

The organic amendments were applied one week after planting. Crop residue at the soil surface tends to reduce germination, which could be due to barrier effect. This could obstruct the emergence of tender seedlings. Application of residue mulch soon after emergence could overcome this phenomenon. The inorganic fertilizer was applied in two splits: first application of NPK (15–15–15) at $60\text{--}60\text{--}60 \text{ kg ha}^{-1}$ two weeks after planting and the second application of urea at 30 kg N ha^{-1} after six weeks. The treatments were arranged in a randomized complete block design with three replications.

Soil samples were taken before imposing the treatments and after harvest and analyzed for both physical and chemical properties. Stover weight, grain yield, nitrogen uptake, harvest index and 100 seed weight were determined. The field trial was established in the minor rainy season of year 2006 and repeated in the major and minor seasons of year 2007. The harvest index was calculated using the relation as described by (Bange *et al.*, 1998).

$$\text{Harvest index (HI)} = \frac{\text{economic yield}}{\text{biomass yield}}$$

The nitrogen recovery (NR) of applied fertilizer, organic inputs or fertilizer + organic input was calculated with the difference method (Vanlauwe *et al.*, 2001) as:

$$\%N \text{ recovery} = \frac{(\text{total N uptake in treated soil} - \text{total N uptake in control})}{\text{total N applied}} \times 100$$

3.10.3 Soil macrofauna assessment

Soil fauna are well known for increasing soil fertility. For example earthworms, in the process of burrowing, hasten litter decomposition, change pore structure, increase aeration and water infiltration, and accelerate carbon and nitrogen mineralization (Savin *et al.*, 2004). This study was conducted to find out how the populations and biomass of soil fauna could be manipulated in order to enhance nutrient cycling, improve soil physical and chemical properties and regulate the processes of decomposition. Sampling was done on plots with organic and inorganic inputs at three different periods: week 4, 8 and at harvest using maize as the test crop.

The treatments were as follows:

- i. Control
- ii. Maize stover (10 t ha⁻¹)
- iii. Cowpea haulm (10 t ha⁻¹)
- iv. Maize stover (5 t ha⁻¹) + cowpea haulm (5 t ha⁻¹)
- v. NPK (15–15–15) + 30 kg N ha⁻¹ using urea (90–60–60 kg ha⁻¹)

The treatments were arranged in a randomized complete block design with three replications. Using monolith samplers of 25 cm x 25 cm x 30 cm, samples were taken at three periods: week 4, 8 and at harvest. At each sample period, two samples were taken randomly from each plot. The monolith sampler was placed over a randomly selected spot and driven into the soil with the aid of a mallet. The soil from

the monolith was removed by hand depthwise (0 – 10, 10 – 20 and 20 – 30 cm) into plastic trays (20 cm x 30 cm) and gently sorted out to locate the living organisms (earthworms and termites) and counted (Anderson and Ingram, 1998). Numbers of organisms counted were transformed using the square root method ($\sqrt{(x + 0.5)}$). Under such conditions, the data fit the Poisson distribution in which the variance is equal to the mean. This transformation makes the variances independent of the mean. When the data include zero values, 0.5 must be added to all values before the square root is determined.

3.10.4 Data analyses

All data on initial laboratory analyses were done in duplicate and presented as means of duplicate samples. Data on treatments and times of sampling of decomposing crop residues, nutrient release pattern, decomposition and mineralization rate constants, changes in soil chemical and physical properties as well as maize grain and biomass yield were subjected to separate analysis of variance (ANOVA). Repeated measurements were also performed to find out the differences at the same level of treatments due to the seasons for some of the data (grain and biomass yield as well as that of the soil). Regression analyses such as simple linear, multiple linear and non linear models were also carried out. Spearman's rank correlation coefficient was used to find out correlations between some of the parameters estimated. All statistics were performed using the GenStat (2007) statistical package. Treatment means were compared using the Fisher's least significant difference (LSD) method.

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

4.1 CHEMICAL COMPOSITION OF THE CROP RESIDUES

4.1.1 RESULTS

The chemical composition of the crop residues evaluated in this study are presented in Tables 1, 2 and 3.

Table 1: Chemical composition of the crop residues used for the study

Crop residues	Org. Carbon	N	P	K	Ca	Mg	Polyphenols	Lignin
			%					
Cassava leaves	46.75 (0.35)	2.88 (0.52)	0.33 (0.03)	0.75 (0.04)	0.97 (0.33)	0.45 (0.18)	2.24 (0.27)	35.72 (0.50)
Maize stover	47.50 (0.71)	0.74 (0.09)	0.38 (0.06)	0.45 (0.18)	0.55 (0.32)	0.74 (0.05)	1.12 (0.23)	4.46 (0.13)
Cowpea haulm	45.50 (0.71)	2.95 (0.19)	0.27 (0.04)	0.88 (0.03)	1.54 (0.13)	0.49 (0.13)	0.74 (0.13)	3.87 (0.33)
Groundnut haulm	44.70 (0.35)	2.66 (0.49)	0.22 (0.04)	0.69 (0.03)	1.41 (0.13)	0.69 (0.01)	1.49 (0.06)	14.10 (0.28)
Mucuna	46.75 (0.35)	2.66 (0.05)	0.33 (0.09)	0.90 (0.14)	0.54 (0.04)	0.51 (0.02)	0.75 (0.00)	4.00 (0.00)
Soyabean	46.00 (0.00)	2.41 (0.18)	0.23 (0.04)	0.83 (0.06)	1.00 (0.14)	0.75 (0.04)	1.51 (0.26)	16.09 (0.38)

Values are the means of duplicate samples

Values in brackets represent standard deviations

The N content of the crop residues ranged from 0.74 to 2.95%. Cowpea haulm had the highest N content (2.95%) and maize stover had the lowest (0.74%). The N content of the crop residues was in the order cowpea haulm > cassava leaves > groundnut = mucuna > soyabean > maize stover. The highest P content was recorded by maize stover (0.38%) with the lowest in groundnut haulm (0.22%). Calcium content of the residues ranged from a high value of 1.54% in cowpea haulm to a low value of 0.54% in mucuna. For magnesium, soyabean had the highest value of 0.75% followed by maize stover (0.74%) with cassava leaves having the lowest value

(0.45%). Polyphenols content was high in cassava leaves (2.24%) with cowpea haulm having the lowest (0.74%). The lignin content of the residues followed the same trend as that of the polyphenol. Carbon content was high in maize stover (47.50%) and low in groundnut haulm (44.70%).

Table 2: Chemical ratios of the crop residues used for the study

Crop residues	C: N	C: P	PP: N	L+PP: N	L: N	N: P
Cassava leaves	16.5 (2.9)	142.2 (13.3)	0.8 (0.2)	13.4 (2.8)	12.6 (2.5)	8.8 (2.3)
Maize stover	65.1 (7.2)	126.5 (20.7)	1.6 (0.5)	7.7 (1.5)	6.1 (0.9)	2.0 (0.5)
Cowpea haulm	15.5 (0.8)	173.4 (25.8)	0.3 (0.1)	1.6 (0.1)	1.3 (0.0)	11.3 (2.2)
Groundnut haulm	17.2 (3.3)	207.4 (41.6)	0.6 (0.1)	6.0 (0.9)	5.39 (0.9)	12.1 (0.1)
Mucuna	15.3 (3.5)	150.0 (43.5)	0.3 (0.0)	1.8 (0.0)	1.5 (0.0)	8.5 (2.6)
Soyabean	19.2 (1.5)	203.5 (37.5)	0.6 (0.1)	7.3 (0.3)	6.7 (0.4)	10.6 (1.2)

Values are the means of duplicate samples
Values in brackets represent standard deviation

Maize stover had the highest carbon: nitrogen (C: N) ratio (65.1) followed by soyabean, groundnut haulm and cassava leaves in that order (Table 2). The lowest values (15.3 and 15.5) were recorded by mucuna and cowpea haulm respectively. The carbon: phosphorus (C: P) ratio was highest in groundnut haulm (207.4) and soyabean (203.5) with the lowest value recorded by maize stover (126.5). The polyphenol: nitrogen (PP: N) was highest in maize stover (1.6) followed by cassava leaves (0.8), soyabean (0.6) and groundnut haulm (0.6). The lowest value (0.3) was found in mucuna and cowpea haulm respectively. Cassava leaves had the highest

lignin + polyphenol: nitrogen (L+PP: N) ratio followed by maize stover, soybean and groundnut haulm with cowpea haulm and mucuna having the lowest. The same trend was observed for the lignin: nitrogen (L: N) ratio. The nitrogen: phosphorus (N: P) ratio of the crop residues was highest in groundnut haulm (12.1) followed by cowpea haulm (11.3) and soyabean (10.6). Cassava leaves had (8.8), mucuna (8.5) with maize stover having the lowest value (2.0) (Table 2).

Table 3: Micronutrients content of the crop residues used for the study

Crop residues	Cu	Fe	Mn	Zn
	-----mg kg ⁻¹ -----			
Cassava leaves	80.0 (0.0)	291.0 (7.1)	174.0 (0.0)	75.0 (4.2)
Maize stover	130.0 (14.1)	351.0 (4.2)	114.0 (0.0)	112.0 (0.0)
Cowpea haulm	135.0 (7.1)	303.0 (4.2)	36.0 (0.0)	81.0 (1.4)
Groundnut haulm	120.0 (0.0)	352.0 (2.8)	43.0 (1.4)	80.0 (0.0)
Mucuna	125.0 (7.1)	282.0 (2.8)	34.0 (2.8)	156.0 (2.8)
Soyabean	100.0 (0.0)	142.0 (0.0)	28.0 (0.0)	159.0 (1.4)

Values are the means of duplicate samples
Values in parentheses represent standard deviation

Cowpea haulm had the highest amount of copper (135.0 mg kg⁻¹) followed by maize stover (130.0 mg kg⁻¹) with cassava leaves having the lowest (80.0 mg kg⁻¹). The values obtained for mucuna, groundnut haulm and soyabean were between the lowest and highest values. In terms of iron (Fe) content, groundnut haulm had the highest value (352.0 mg kg⁻¹) and the lowest value of 142.0 mg kg⁻¹ was obtained in

soyabean. However, soyabean had the highest content of zinc (159.0 mg kg⁻¹). The manganese content of the residues was in the range 28.0 – 174.0 mg kg⁻¹ (Table 3).

Table 4: Moisture content of the crop residues used for the study

Crop residue	Moisture content (%)
Cassava leaves	65.0 (0.4)
Maize stover	5.2 (0.2)
Cowpea haulm	64.0 (1.3)
Groundnut haulm	50.7 (0.5)
Mucuna	81.3 (1.8)
Soyabean	43.2 (0.4)
Values are the means of duplicate samples	
Values in brackets represent standard deviation	

The moisture content of the crop residues on fresh weight basis (Table 4) was highest in mucuna (81.3%) followed by cassava leaves (65.0%) and cowpea haulm (64.0%) with maize stover having the lowest value (5.2%). The values recorded by groundnut haulm and soyabean were 50.7 and 43.2% respectively.

4.1.2 DISCUSSION

The quality or chemical composition of plant litter with respect to decomposition can be defined as its relative ease of mineralization by decomposer organisms (Paustian *et al.*, 1997). Quality of residue is largely determined by the organic constituents and nutrient contents. Large differences in the quality of the residues were observed. The N concentrations of all residues apart from maize stover contained values > 2.0 to 2.5% below which net N immobilization from the soil would be expected when these residues are applied as soil amendment as established by Palm and Sanchez (1991).

Maize stover with the lowest N content, when applied to the soil as an organic amendment, will lead to N immobilization of the soil. Low N content of maize stover is commonly found in cereals. Palm *et al.* (2001) gave a range of N content in maize stover as 0.4 to 0.8%. Tetteh (2004) however, reported a value of 0.85% as the N content of maize stover. Such differences in the N content of maize stover, is possibly related to differences in germplasm, the time of sampling and the environmental condition under which the crop is grown. Thus fast decomposition and N mineralization would be expected in cowpea haulm with the highest N concentration and slowest in maize stover. The expected decomposition and N mineralization from the residues would be in the order: cowpea haulm > cassava leaves > groundnut = mucuna > soyabean > maize stover.

According to Blair and Boland (1978), 0.25% is the critical value below which net P immobilization would be expected. From this study phosphorus immobilization would be expected when residues of groundnut haulm and soyabean with concentrations of 0.22 and 0.23% are applied. The P concentrations of the other residues were above the critical value of 0.25%. The K concentration was lowest in maize stover and highest in mucuna. Potassium release would be in the order: mucuna > cowpea haulm > soyabean > cassava leaves > groundnut haulm > maize stover. Calcium was low in mucuna and high in cowpea haulm. For magnesium, soyabean haulm recorded the lowest value while cassava leaves recorded the highest.

All the residues had low polyphenol contents which were below the threshold value of 3 to 4% above which N immobilization would be expected according to Palm and

Sanchez (1991). Lignin concentrations of soyabean and cassava leaves were above the threshold value of 15% as established by Palm and Sanchez (1991). Such materials with higher lignin concentrations ($> 15\%$) lead to slow decomposition and N immobilization. Because lignin is an aromatic, branched and complex compound, it will require a longer time before being broken down by soil microorganisms. Lignin contributes to the recalcitrance of plant litter to decomposition by occluding more easily decomposable polysaccharides (Melillo *et al.*, 1982). Hence the higher the lignin concentration, the slower the decomposition and N mineralization rate of the residue. All the residues had very high concentrations of carbon. The bulk of litter or residue comprises structural components of plant cell walls (cellulose, lignin and hemicelluloses) and hence carbon is always in much larger concentration than other nutrients (Johansson, 1995).

The C: N ratio of maize stover was very high (65.1) which was above the critical value of 20 to 25. Materials with C: N ratio greater than 25 have been reported to lead initially to immobilization whereas those with C: N ratio less than 25 releases N (Burgess *et al.*, 2002). The high C: N ratio of maize stover was as a result of its low N concentration. The entire crop residues had almost the same carbon concentration. Thus with the exception of maize stover, the other crop residues would release mineral N faster as their C: N ratios were below 25.

The C: P ratio of all the residues was above the critical value of 123:1. Net mineralization of P from plant residues would not occur unless the C: P ratio of the residue was low (123: 1) as observed by White and Ayoub (1983). Other studies have reported the C: P ratio at which net mineralization occurs to be variable,

ranging from 100 to 300 (Myers *et al.*, 1994). This may therefore not be a good index of quality.

The N: P ratio has been suggested as a better indicator with P mineralization at N: P ratio of 10 to 15 (Vogt *et al.*, 1986). Maize stover, because of its low N concentration, had the highest PP: N ratio (1.55) and would immobilize mineral N when applied to the soil. With the exception of cassava leaves, all the other crop residues had L+PP: N ratios which were below the threshold value of 10 above which immobilization of N would be expected as reported by Palm and Sanchez (1991). Cowpea, groundnut and soyabean haulms even though had high N concentrations, their N: P ratios were high due to their low P concentrations.

The low moisture content of maize stover would make it a better mulch material as it could remain on the soil surface for a longer time compared with the residues with moisture content > 43%.

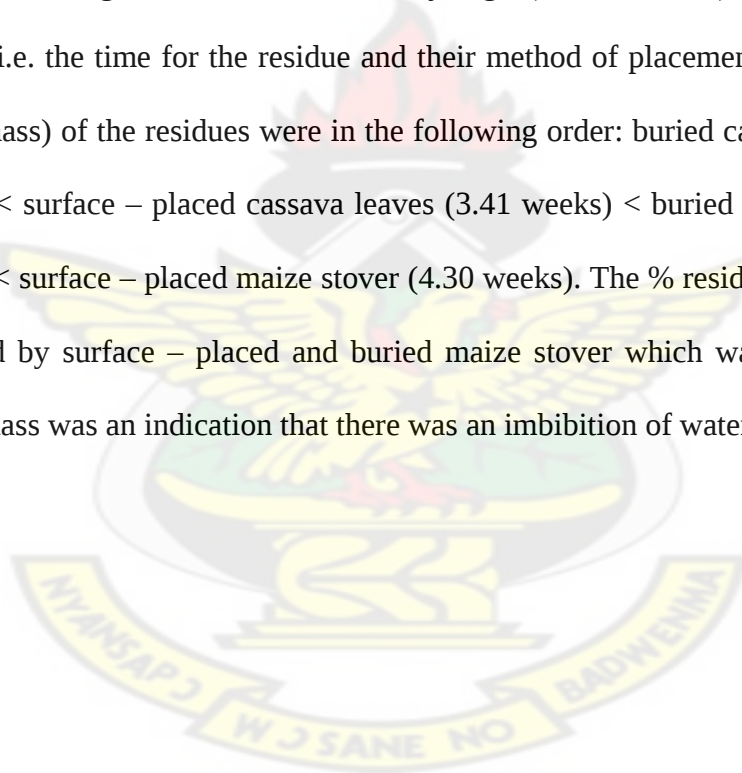
4.2 DECOMPOSITION PATTERN OF THE RESIDUES

4.2.1 RESULTS

4.2.1.1 Decomposition Pattern of Residues in Litter Bag (2006 major season)

The decomposition patterns of maize stover and cassava leaves during the major season are in Figs. 1a and 1b, whereby the mass remaining is expressed as percentage of the initial oven dry weight of the residues. During the first week of decomposition, buried crop residue decomposed faster than surface – placed. Loss in mass was rapid for buried cassava leaves (30%) and 20% for buried maize stover. By the fourth week of decomposition, almost all the residues had lost more than 50% of their initial mass. The loss of mass at the end of the study period was of the order:

buried cassava leaves (97.33%) > surface placed cassava leaves (96.96%) > buried maize stover (92.47%) > surface placed maize stover (80.53%). The decomposition rate constant ($k \text{ wk}^{-1}$) of the crop residues also showed statistical difference ($P < 0.05$) (Table 5a). Buried cassava leaves had the highest k value (0.502 wk^{-1}) and surface – placed maize stover the lowest (0.224 wk^{-1}). Intermediate values were recorded by surface placed cassava leaves (0.475 wk^{-1}) and buried maize stover (0.305 wk^{-1}). This means decomposition was fastest for buried cassava leaves and slowest for surface – placed maize stover. The coefficients of determination (r^2) which indicate goodness of fit were very high (91.5 – 95.3%). The half life (t_{50}) values (i.e. the time for the residue and their method of placement to lose half their initial mass) of the residues were in the following order: buried cassava leaves (2.82 weeks) < surface – placed cassava leaves (3.41 weeks) < buried maize stover (3.90 weeks) < surface – placed maize stover (4.30 weeks). The % residue mass remaining recorded by surface – placed and buried maize stover which was greater than the initial mass was an indication that there was an imbibition of water (Fig. 1a).



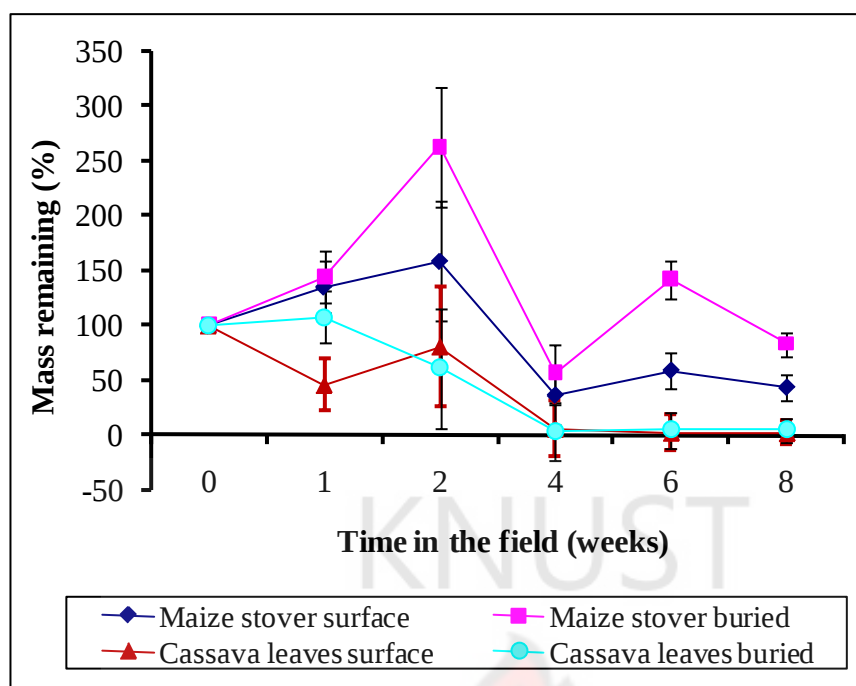


Fig.1a: Decomposition of surface – placed and buried crop residues (confined fresh weight) on a Ferric Acrisol in the 2006 major season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

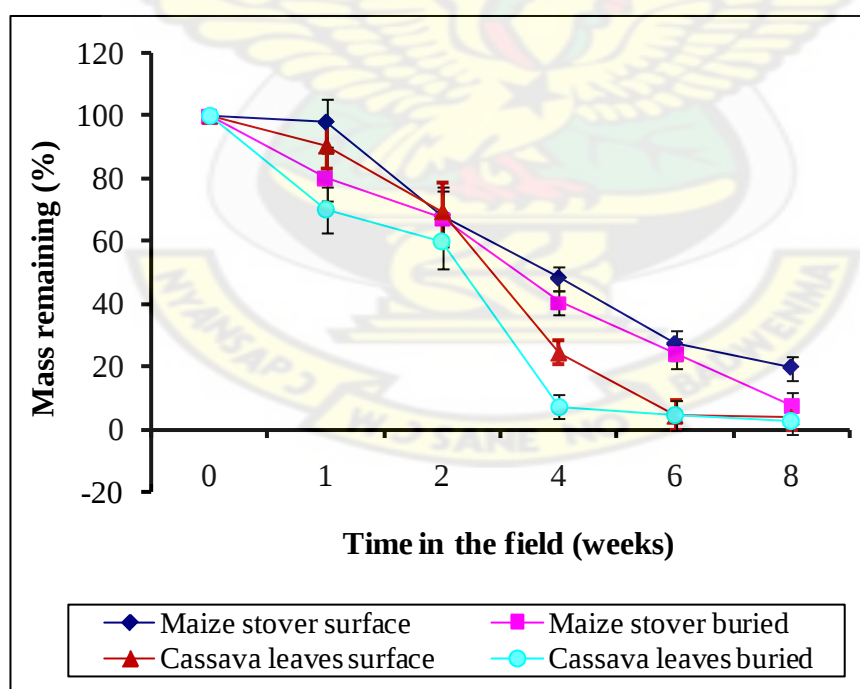


Fig.1b: Decomposition of surface – placed and buried crop residues (confined dry weight) on a Ferric Acrisol in the 2006 major season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

Table 5a: Decomposition rate constant (k), coefficient of determination (r^2), correlation coefficient (r) and half life (t_{50}) of the crop residues (2006 major season: confined)

Residue and placement	k (wk ⁻¹)	r^2	r	Half life	
				Observed	*Calculated
Maize stover (surface)	0.224	0.953	-0.962	4.30	3.09
Cassava leaves (surface)	0.475	0.943	-0.978	3.41	1.46
Maize stover (buried)	0.305	0.934	-0.968	3.90	2.27
Cassava leaves (buried)	0.502	0.915	-0.963	2.82	1.38
LSD (5 %)	0.05	0.06	0.03		
CV (%)	6.40	3.20	1.60		

* t_{50} was calculated from the equation: $t_{50} = \frac{0.693}{k}$ (Crohn, 2004).

Table 5b: Exponential function describing the decomposition pattern of the crop residues and their corresponding correlation coefficient (r) values (2006 major season: confined)

Residue and placement		r
Maize stover (surface)	$Y = 114.5e^{-0.224t}$	0.827**
Cassava leaves (surface)	$Y = 141.0e^{-0.475t}$	0.828**
Maize stover (buried)	$Y = 173.6e^{-0.305t}$	0.913***
Cassava leaves buried	$Y = 113.0e^{-0.502t}$	0.722**

** significant at $P < 0.01$ level

*** significant at $P < 0.001$ level

4.2.1.2 Decomposition Pattern of Residues in Litter Bag (2006 minor season)

Figures 2a and 2b show the decomposition patterns of the crop residues during the minor season. Decomposition was rapid during the second week for both surface – placed and buried cassava leaves and cowpea haulm. Buried cassava leaves lost almost 60% while surface – placed lost 53%. Cowpea haulm lost 57 and 51% for buried and surface – placed respectively. All the residues except surface – placed maize stover lost more than 50% of their initial mass by the fourth week. The time taken for the residues to lose 50% of their initial mass (t_{50}) were: buried cassava leaves 1.36 weeks, buried cowpea haulm 1.63 weeks, surface cassava leaves 1.79

weeks, surface- placed cowpea haulm 1.92 weeks, buried maize stover 2.98 weeks and surface- placed maize stover 3.53 weeks (Table 6a). Buried cassava leaves lost all its mass by the sixth week with surface – placed retaining about 6%. Cassava leaves lost 100% and 98% respectively for both methods of placement. Buried and surface – placed cowpea haulm lost 98 and 96% respectively, whilst buried and surface – placed maize stover lost 87 and 80% respectively. Decomposition rates constant ($k \text{ wk}^{-1}$) of the residues showed significant differences ($P < 0.05$). Buried cassava leaves had the highest k value (0.659 wk^{-1}) and surface- placed maize stover, the lowest (0.210 wk^{-1}) (Table 6a). High r^2 (94.2 – 99.4%) and r (-0.975 to -0.997) values were obtained for the decomposition patterns of the crop residues.

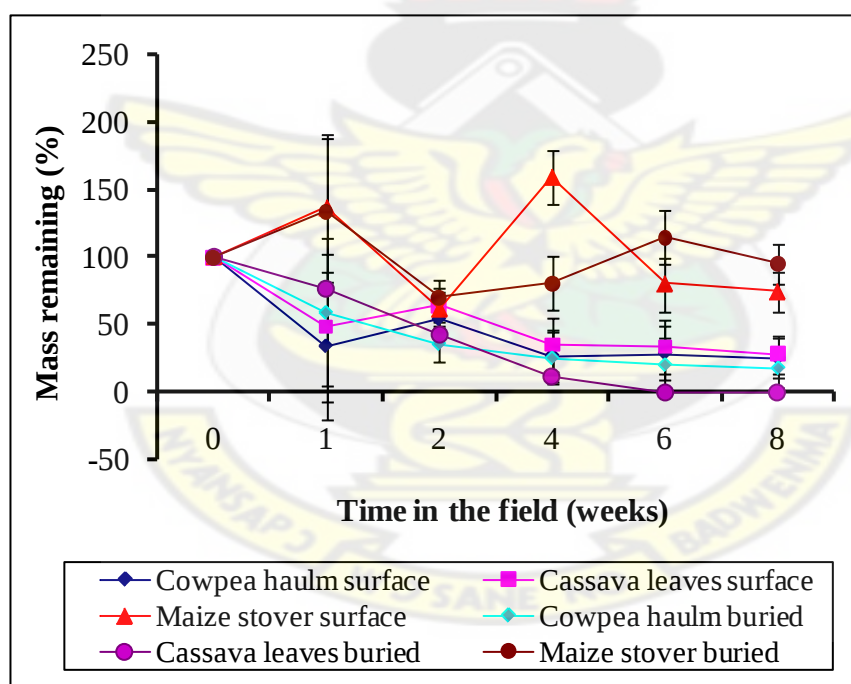


Fig. 2a: Decomposition of surface – placed and buried crop residues (confined: fresh weight) on a Ferric Acrisol in the 2006 minor season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

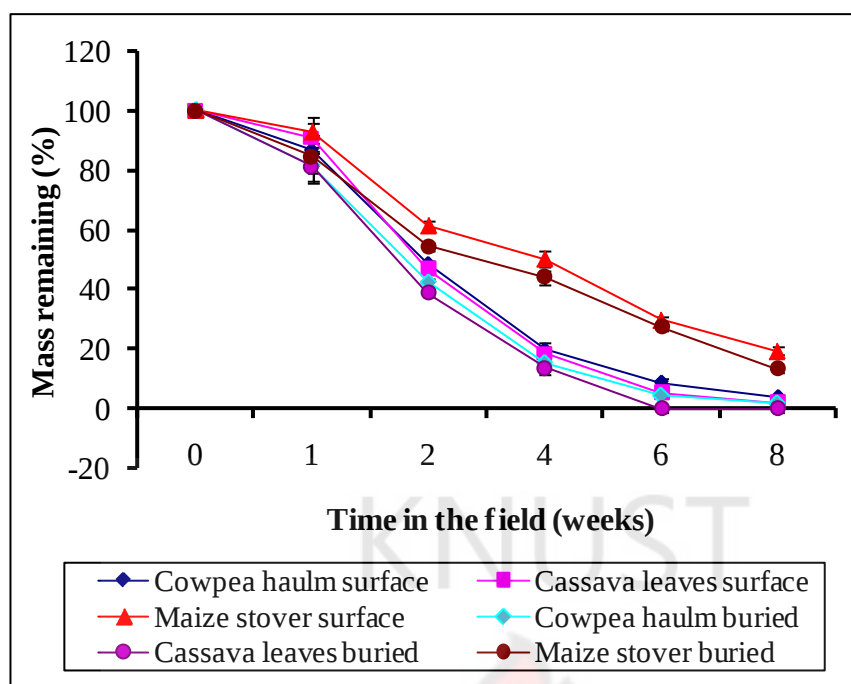


Fig. 2b: Decomposition of surface – placed and buried crop residues (confined: dry weight) on a Ferric Acrisol in the 2006 minor season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

Table 6a: Decomposition rate constant (k), coefficient of determination (r^2), correlation coefficient (r) and half life (t_{50}) of the crop residues (2006 minor season: confined).

Residue and placement	k	r^2	r	Half life	
				Observed	*Calculated
Cowpea haulm (surface)	0.421	0.994	-0.997	1.92	1.65
Cassava leaves (surface)	0.541	0.989	-0.996	1.79	1.28
Maize stover (surface)	0.210	0.974	-0.992	3.53	3.30
Cowpea haulm (buried)	0.523	0.994	-0.989	1.63	1.33
Cassava leaves (buried)	0.659	0.942	-0.975	1.36	1.05
Maize stover (buried)	0.240	0.976	-0.987	2.98	2.89
LSD (5%)	0.04	0.01	0.01		
CV (%)	4.70	0.40	0.70		

* t_{50} was calculated from the equation: $t_{50} = \frac{0.693}{k}$ (Crohn, 2004).

Table 6b: Exponential function describing the decomposition pattern of the crop residues and their corresponding correlation coefficient (r) values (2006 minor season: confined)

Residue and placement		r
Cowpea haulm (surface)	$Y = 119.3e^{-0.421t}$	0.742 *
Cassava (surface)	$Y = 113.7e^{-0.541t}$	0.735*
Maize stover (surface)	$Y = 110.2e^{-0.210t}$	0.840**
Cowpea haulm (buried)	$Y = 111.9e^{-0.523t}$	0.699*
Cassava leaves (buried)	$Y = 114.7e^{-0.659t}$	0.693*
Maize stover (buried)	$Y = 100.4e^{-0.240t}$	0.745*

* significant at $P < 0.05$ level

** significant at $P < 0.01$ level

4.2.1.3 Decomposition Pattern of Residue in Litter Bag (2006–2007 dry season)

The patterns of mass loss during the dry season are shown in Figs. 3a and 3b. There was less rapid loss of mass especially during the first week of decomposition. Loss of mass was rapid for buried residues than surface – placed. The same pattern was observed for the residues during the second week. Only buried cassava leaves had lost about 50% of its initial mass by week four. Significant differences ($P < 0.05$) were detected among the treatments. The half lives (t_{50}) value of the residues were in the following order; cassava leaves buried 3.60 weeks, surface – placed cassava leaves 4.26 weeks, surface – placed cowpea haulm 4.46 weeks, buried maize stover 5.38 weeks and surface- placed maize stover 6.34 weeks (Table 7a). Cassava leaves retained 8 and 16% for buried and surface – placed respectively. Whiles buried and surface – placed cowpea haulm retained 11 and 20% respectively. For maize stover the amount retained at the eighth week were 24 and 31% respectively. These values were statistically different ($P < 0.05$). The rate constant ($k \text{ wk}^{-1}$) value was high for

buried cassava leaves (0.290 wk^{-1}) and lowest for surface – placed maize stover (0.145 wk^{-1}) (Table 7a).

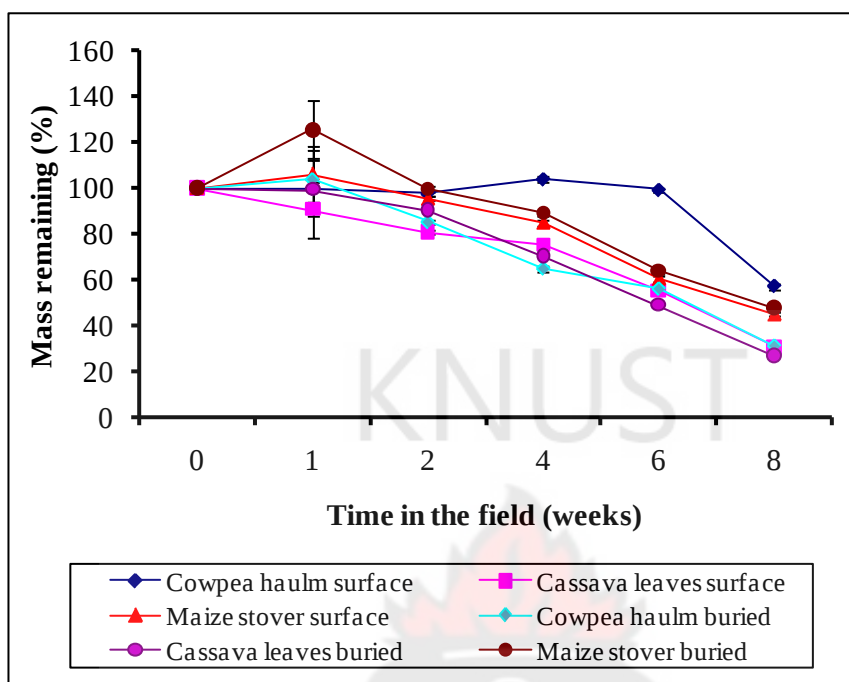


Fig. 3a: Decomposition of surface – placed and buried crop residues (confined: fresh weight) on a Ferric Acrisol in the 2006–2007 dry season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

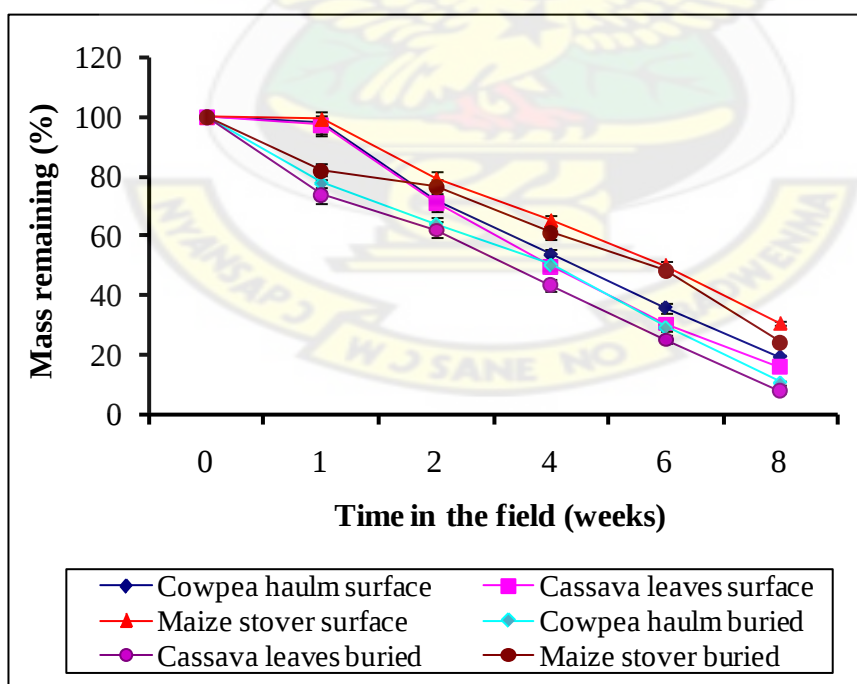


Fig. 3b: Decomposition of surface – placed and buried crop residues (confined: dry weight) on a Ferric Acrisol in the 2006–2007 dry season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

Table 7a: Decomposition rate constant (k), coefficient of determination (r^2), correlation coefficient (r) and half life (t_{50}) of the crop residues (2006–2007 dry season: confined).

Residue and placement	k (wk ⁻¹)	r^2	r	Half life	
				Observed	*Calculated
Cowpea haulm (surface)	0.206	0.976	-0.988	4.46	3.36
Cassava leaves (surface)	0.233	0.981	-0.991	4.24	2.97
Maize stover (surface)	0.145	0.962	-0.984	6.34	4.78
Cowpea haulm (buried)	0.258	0.948	-0.970	4.03	2.69
Cassava leaves (buried)	0.290	0.944	-0.973	3.60	2.39
Maize stover (buried)	0.158	0.918	-0.958	5.38	4.39
LSD (5%)	0.01	0.02	0.13		
CV (%)	1.40	1.20	1.30		

* t_{50} was calculated from the equation: $t_{50} = \frac{0.693}{k}$ (Crohn, 2004).

Table 7b: Exponential function describing the decomposition pattern of the crop residues and their corresponding correlation coefficient (r) values (2006–2007 dry season: confined)

Residue and placement		r
Cowpea haulm (surface)	$Y = 172.0e^{-0.206t}$	0.919*
Cassava leaves (surface)	$Y = 162.2e^{-0.223t}$	0.905*
Maize stover (surface)	$Y = 229.0e^{-0.145t}$	0.955*
Cowpea haulm (buried)	$Y = 144.0e^{-0.258t}$	0.898*
Cassava leaves (buried)	$Y = 119.6e^{-0.290t}$	0.853**
Maize stover (buried)	$Y = 176.0e^{-0.158t}$	0.942*

* Significant at $P < 0.05$ level

** Significant at $P < 0.01$ level

4.2.1.4 Decomposition Pattern of Unconfined crop residues (2006 major season)

Figures 4a and 4b depict the decomposition pattern during the major season. There was slow loss of mass for maize stover (4%) and 12% for cassava leaves during the first week. Statistical differences ($P < 0.05$) were however, detected in these loss of mass. The time taken for cassava leaves to lose half its original mass was 3.21 weeks and that of maize stover was 4.72 weeks (Table 8a). There was significant difference ($P < 0.05$) between the decomposition rate constant (k wk⁻¹) of the residues. The k values were 0.304 wk⁻¹ for cassava leaves and 0.162 wk⁻¹ for maize stover (Table 8a).

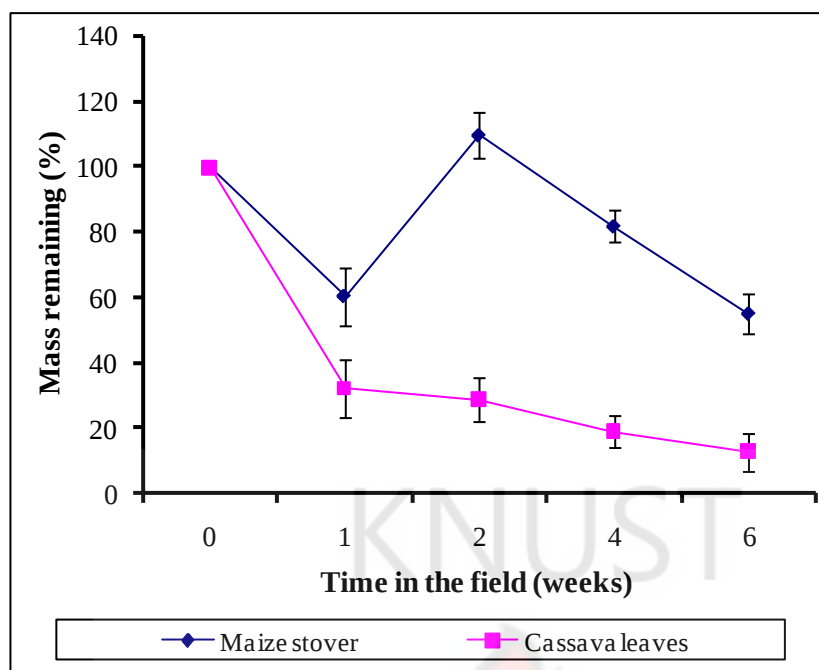


Fig. 4a: Decomposition of crop residues (unconfined: fresh weight) on a Ferric Acrisol in the 2006 major season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana.
Bars indicate LSD (5%).

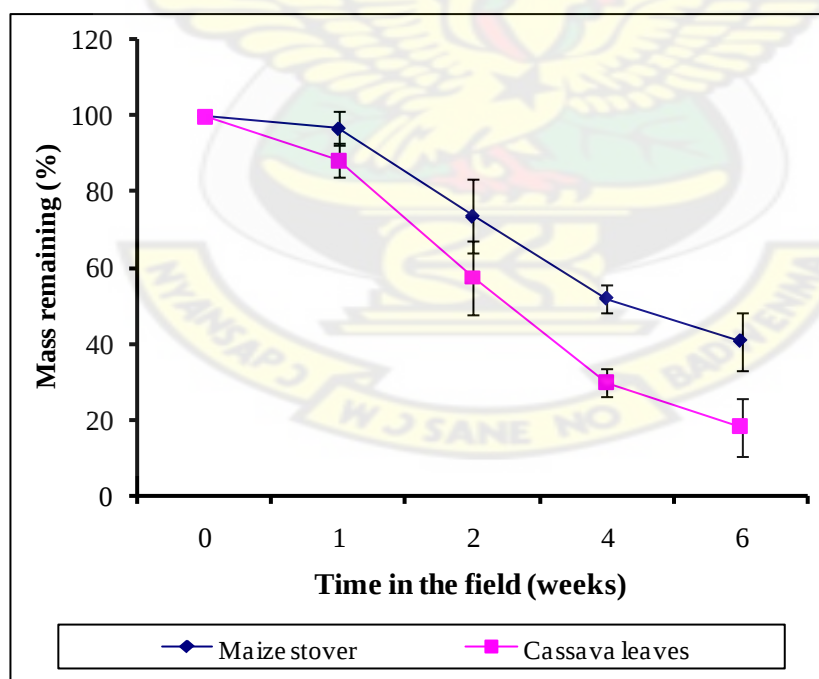


Fig. 4b: Decomposition of crop residues (unconfined: dry weight) on a Ferric Acrisol in the 2006 major season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana.
Bars indicate LSD (5%).

Table 8a: Decomposition rate constant (k), coefficient of determination (r^2), correlation coefficient (r) and half life (t_{50}) of the crop residues (2006 major season: unconfined)

Residue	k (wk ⁻¹)	r^2	r	Half life	
				Observed	*Calculated
Maize stover	0.162	0.969	-0.985	4.72	4.23
Cassava leaves	0.304	0.986	-0.992	3.21	2.28
LSD (%)	0.05	0.01	0.01		
CV(%)	9.80	1.70	1.00		

* t_{50} was calculated from the equation: $t_{50} = \frac{0.693}{k}$ (Crohn, 2004).

Table 8b: Exponential function describing the decomposition pattern of the crop residues and their corresponding correlation coefficient (r) values (2006 major season: unconfined).

Residue		r
Maize stover	$Y = 117.5e^{-0.162t}$	0.875*
Cassava leaves	$Y = 119.2e^{-0.304t}$	0.800*

* Significant at $P < 0.05$ level

4.2.1.5 Decomposition Pattern of Unconfined crop residues (2006 minor season)

Decomposition patterns of unconfined residues in the minor season are presented in Figs. 5a and 5b. Cassava leaves lost about 10% of its initial mass while's cowpea haulm and maize stover lost 13 and 5% respectively during the first week. There was rapid loss of mass during the second week which was statistically significant ($P < 0.05$). Both cassava leaves and cowpea haulm significantly ($P < 0.05$) lost more than 50% of their initial mass by the fourth week with maize stover retaining approximately 51% of its initial mass. The half life values were 2.99 weeks for cassava leaves, 3.08 weeks for cowpea haulm and 4.62 weeks for maize stover (Table 9a). High k value was recorded for cassava leaves (0.404 wk⁻¹) with maize stover recording the lowest (0.164 wk⁻¹) (Table 9a).

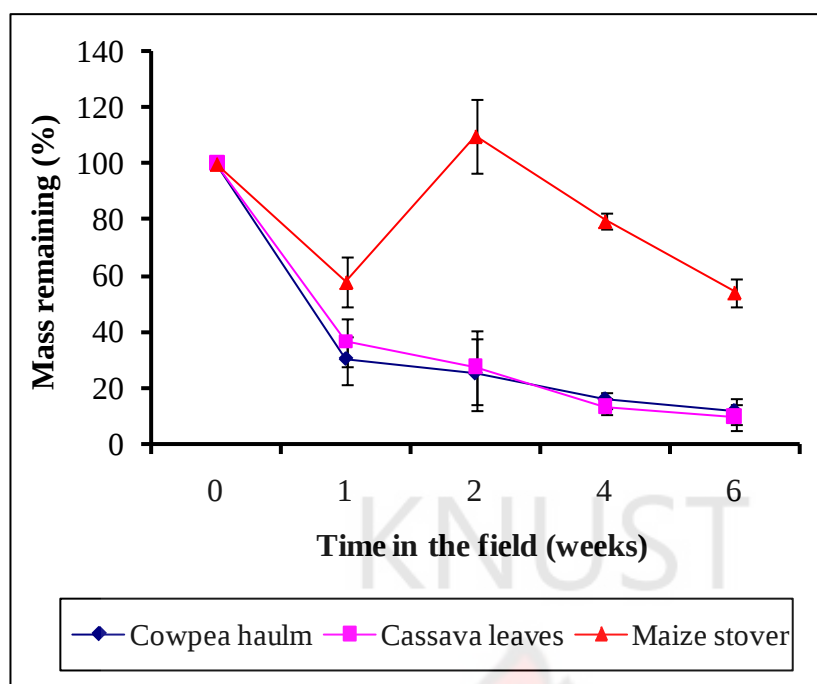


Fig. 5a: Decomposition of crop residues (unconfined: fresh weight) on a Ferric Acrisol in the 2006 minor season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana.
Bars indicate LSD (5%).

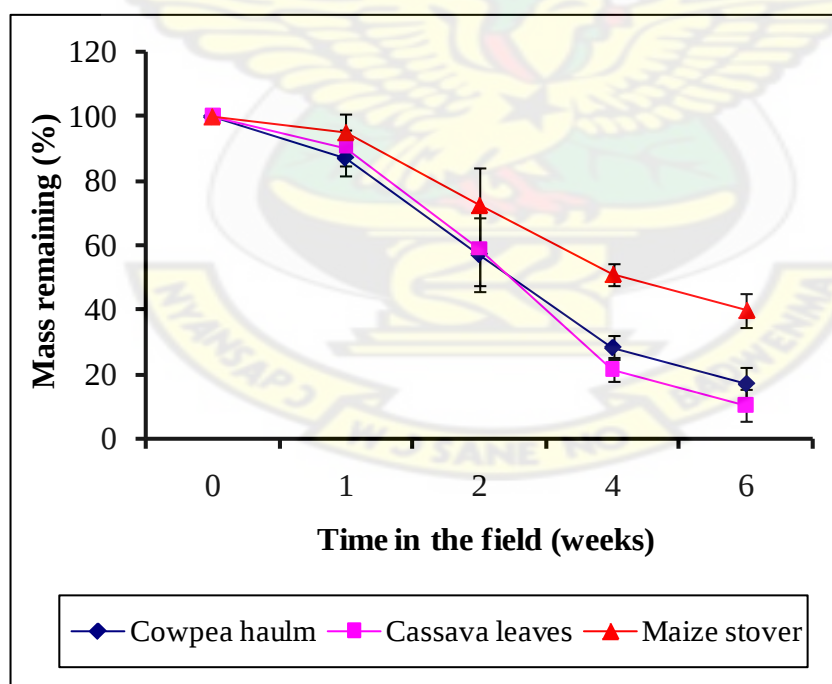


Fig. 5b: Decomposition of crop residues (unconfined: dry weight) on a Ferric Acrisol in the 2006 minor season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana.
Bars indicate LSD (5%).

Table 9a: Decomposition rate constant (k), coefficient of determination (r^2), correlation coefficient (r) and half life (t_{50}) of the crop residues (2006 minor season: unconfined)

Residue	k	r^2	r	Half life	
				Observed	*Calculated
Cassava leaves	0.404	0.978	-0.988	2.99	1.72
Cowpea haulm	0.313	0.988	-0.991	3.08	2.21
Maize stover	0.164	0.972	-0.958	4.62	4.23
LSD (5 %)	0.05	0.02	0.01		
CV (%)	7.80	1.00	0.40		

* t_{50} was calculated from the equation: $t_{50} = \frac{0.693}{k}$ (Crohn, 2004).

Table 9b: Exponential function describing the decomposition pattern of the crop residues and their corresponding correlation coefficient (r) values (2006 minor season: unconfined)

Residue		r
Cowpea haulm	$Y = 119.3e^{-0.313t}$	0.798*
Cassava leaves	$Y = 149.0e^{-0.404t}$	0.837*
Maize stover	$Y = 110.2e^{-0.164t}$	0.863*

* Significant at $P < 0.05$ level

4.2.1.6 Decomposition Pattern of Unconfined crop residues (2006–2007 dry season)

Figs. 6a and 6b show the decomposition pattern of the crop residues during the dry season. Mass loss during the first week was slow especially for maize stover which lost less than 1% of its initial mass. Both cassava leaves and cowpea haulm significantly ($P < 0.05$) lost more than 50% of their initial mass by the sixth week with maize stover retaining more than 50% of its original mass. Thus the half life (t_{50}) of the crop residues were 4.62 weeks for cassava leaves, 4.81 weeks for cowpea haulm and 6.56 weeks for maize stover (Table 10a). The k values of the residues were 0.164, 0.149 and 0.109 wk^{-1} for cassava leaves, cowpea haulm and maize stover respectively which were different ($P < 0.05$) (Table 10a).

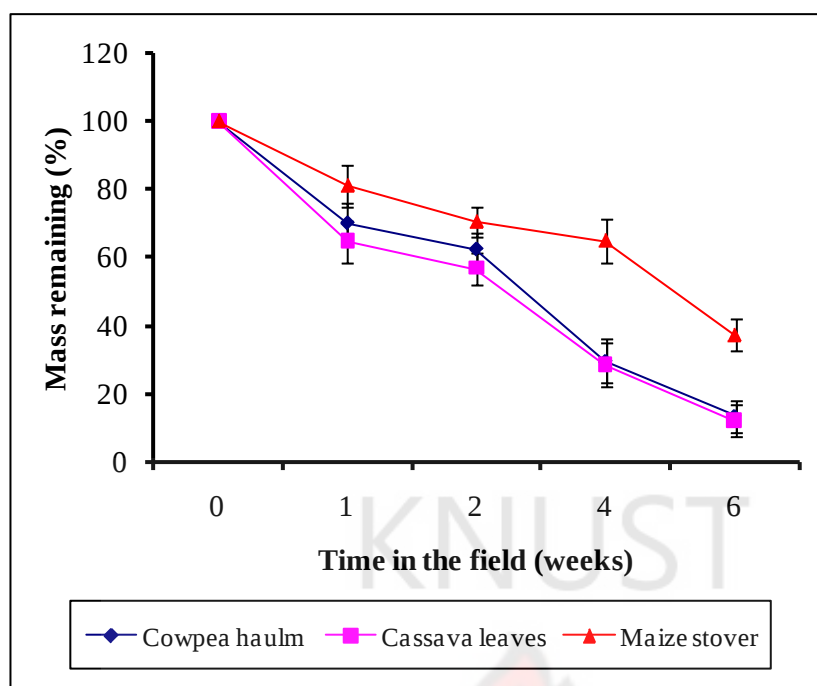


Fig. 6a: Decomposition of crop residues (unconfined: fresh weight) on a Ferric Acrisol in the 2006–2007 dry season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana.
Bars indicate LSD (5%).

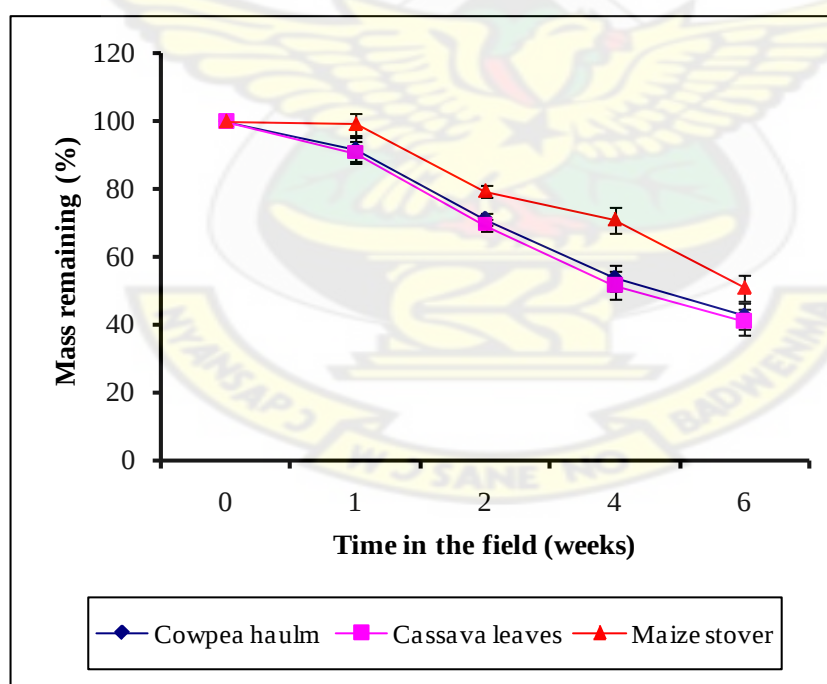


Fig. 6b: Decomposition of crop residues (unconfined: dry weight) on a Ferric Acrisol in the 2006–2007 dry season of the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana.
Bars indicate LSD (5%).

Table 10a: Decomposition rate constant (k), coefficient of determination (r^2), correlation coefficient (r) and half life (t_{50}) of the crop residues (2006-2007 dry season: unconfined)

Residue	k (wk ⁻¹)	r^2	r	Half life	
				Observed	*Calculated
Cassava leaves	0.161	0.961	-0.992	4.62	4.30
Cowpea haulm	0.149	0.985	-0.993	4.81	4.65
Maize stover	0.108	0.966	-0.977	6.56	6.42
LSD (5 %)	0.02	0.02	0.01		
CV (%)	6.30	1.20	1.00		

* t_{50} was calculated from the equation: $t_{50} = \frac{0.693}{k}$ (Crohn, 2004).

Table 10b: Exponential function describing the decomposition pattern of the crop residues and their corresponding correlation coefficient (r) values (2006-2007 dry season: unconfined)

Residue		r
Cowpea haulm	$Y = 88.4e^{0.149t}$	0.826*
Cassava leaves	$Y = 86.8e^{0.161t}$	0.811*
Maize stover	$Y = 84e^{0.108t}$	0.807*

* Significant at $P < 0.05$ level

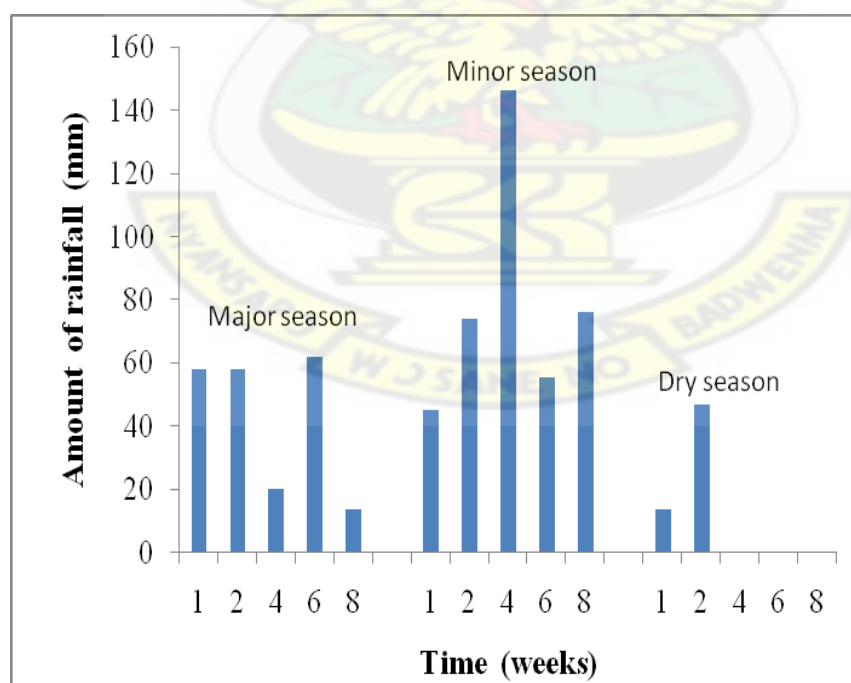


Fig. 7: Weekly rainfall (mm) received during three seasons of crop residue decomposition on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana.

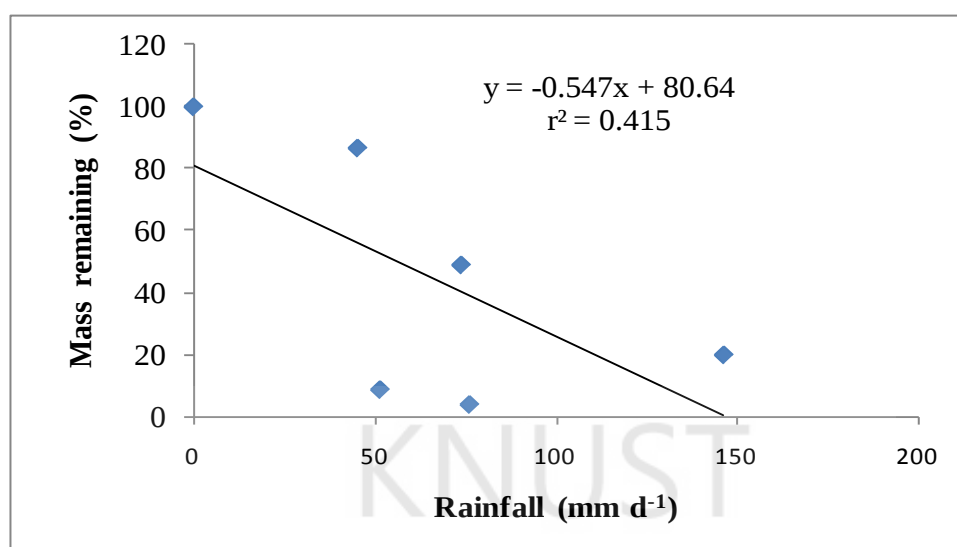


Fig. 8: Relationship between % mass remaining and amount of rainfall received during decomposition of crop residues in the 2006 minor season.

4.2.2 DISCUSSION

4.2.2.1 Effect of environmental condition on decomposition

The physico – chemical environment, quality of litter, and the composition of the decomposer community are the three main factors controlling litter decomposition (Cadisch and Giller, 1997). Large differences were found in the decomposition pattern of the residues. Relative to maize stover (Tetteh, 2004; Nhamo *et al.*, 2007) and cowpea haulm (Palm *et al.*, 2001), little information is available in the literature on the chemical composition and decomposition of cassava leaves (Udealor and Asiegbu, 2007). The remaining mass of crop residues decreased with increasing decomposition time.

The decomposition pattern was biphasic with an initial rapid phase followed by a slower phase. A similar pattern was observed by Tetteh (2004) and Nhamo *et al.* (2007). The initial rapid phase could be due to congenial environmental conditions associated with the presence of readily digestible water soluble compounds in the

residue (Wang *et al.*, 2004). This might have triggered the activity of soil fauna and soil microbes, which are responsible for the decomposition. In addition, the high leaching losses of water-soluble fractions from the decomposing materials during the rainy periods (major and minor rainy seasons) might have resulted in a heavy loss of mass during the initial phase. The rapid rate of decomposition of crop residue from June to November (i.e. major and minor seasons) indicated its significant role in crop production. Rapid rate of decomposition meant less organic matter addition to the soil. It is an established fact that the yield of crops especially maize is at its peak both quantitatively and qualitatively during these periods in the tropical climatic condition such as the semi – deciduous forest zone (Tetteh, 2004).

4.2.2.2 Effect of chemical composition of residue on decomposition

The chemical composition of plant residue affects how fast it will decompose. Generally, high levels of nutrients, notably nitrogen, are expected to be able to accelerate the decomposition process (Alhamd *et al.*, 2004). Several studies have shown a positive correlation between initial N concentration and the decomposition rate constant (Melillo *et al.*, 1982). In this study, cowpea haulm and cassava leaves, which had the highest initial N concentration of 2.95 and 2.88% respectively, showed fast decomposition rate. The carbon: nitrogen (C: N) ratio is often used to predict decomposition rate (Jensen *et al.*, 2005). Cassava leaves and cowpea haulm with narrow C: N ratios (15.5 and 16.5) decomposed faster than maize stover which had a wide C: N ratio (65.1) for both method of residue placement. Similar observation was made by Nhamo *et al.* (2007) who reported slow decomposition rate for maize litter with a C: N ratio of 52. Polyphenol as well as lignin content of residue also affect how fast it decomposes. Polyphenol appear to influence rates of

decomposition as they bind to nitrogen in crop residues forming compounds resistant to decomposition (Palm and Sanchez, 1990).

The mineralization of N is controlled more by soluble polyphenol (PP) than lignin (L) or N content (Oglesby and Fownes, 1992). Palm and Sanchez (1990) were among the first to combine these three parameters to predict rate of decomposition using the ratio L+PP: N. This ratio has been found to be a useful indicator in successive decomposition studies. From this study, it was found that the rate of decomposition of maize stover was slow inspite of its low L+PP: N ratio compared to cassava leaves and cowpea haulm. Lignin contents in maize stover and cowpea haulm were also low compared to that in cassava leaves. Heal *et al.* (1997) pointed out that cereal and legume straws and litter from annual crops usually contain less than 10 to 15% of lignin. The initial lignin content has been suggested as a reasonable predictor of the rate of decomposition (Wieder and Lang, 1982), because it physically protects cellulose and other carbohydrates from degradation (Chesson, 1997). Based on the initial high lignin content of cassava leaves, slow rate of decomposition was expected to occur. The result from this study however, showed otherwise.

Oven drying of litter may alter the polyphenol and lignin content (Mafongoya *et al.*, 1997). However, all residues were dried at the same temperature, which may be sufficient for comparative analysis as conducted in this study. Koenig and Cochran (1994) suggested that decomposition may be more strongly influenced by N, cellulose and C: N ratio than by lignin. Many studies have examined the relationship between total N and C: N ratio to litter decomposition, especially for crop residues (Mungai and Motavalli, 2006). Decomposer organisms use N to breakdown C

substrates, therefore, litters with high total N and narrow C: N ratio decomposes more rapidly. These facts corroborate the findings of this research. Cassava leaves and cowpea haulm showed similar rate of mass loss and this could be attributed to their high N content and narrow C: N ratios. The decomposition rate of the residues cannot also be explained by polyphenol and the L+PP: N ratio because both were low for maize stover, yet its decomposition rate was slow. The slow decomposition is mainly caused by the very high C: N and PP: N ratios and low N concentration. Therefore the rate of decomposition for the crop residues in the prevailing environmental condition is attributed to their C: N and PP: N ratios and N concentrations.

4.2.2.3 Effect of residue placement on decomposition

The method of placement (surface vrs. buried) as well as the season of the study also affected the rates of the decomposition of the residues with buried residues exhibiting rapid rate of decomposition than surface – placed. Rate of decomposition was rapid during the minor season when the highest amount of rainfall was received especially by the fourth week. Possible explanations for this observation was the leaching of soluble carbon compounds and enhanced microbial activity which enhanced faster rate of decomposition during period of higher rainfall. This finding was in agreement with the report of Tetteh (2004) at the same site that the rate of decomposition of residues was faster during the major season compared to the slow rate in the dry season. Rapid mass loss of decomposing litter in the rainy season has also been reported in northeastern India (Pandey *et al.*, 2007). The authors ascribed the enhanced litter decomposition rates in the rainy season to a combined effect of higher rainfall, air temperature and relative humidity. Similar findings were made in

the present study especially during the fourth week of major and minor season decompositions. This could be seen from the half life values of the residues for the different seasons. The half life values were in the order dry season > major season > minor season. Rapid loss of tissue by the third to fourth week was consistent with the findings of other researchers (Tetteh, 2004; Coppens *et al.*, 2007).

Greater mass loss rates for buried residues than surface residues have been reported by other researchers (Beare *et al.*, 2002; Tetteh, 2004). Differences in rates of mass loss can be partly attributed to differences in environmental conditions between the soil surface and 10 cm beneath the surface. Surface residues are more exposed to extremes of wetting and drying that can modify the kinetics of decomposition (Franzuebbers *et al.*, 1994; Coppens *et al.*, 2007). Seneviratne and Wild (1985) found that mild wet/dry cycles could enhance carbon dioxide emission from soil, suggesting that variation in environmental conditions affect rates of decomposition. Generally, surface – placed residues retained more mass at the end of week eight compared to buried residues in this study. This supports the conclusions of Douglas *et al.* (1980) that surface residues decompose less rapidly than buried residues.

4.2.2.4 Effect of residue physical characteristics on decomposition

Morphology and tissue structure are important factors governing the colonization of plant tissues by soil microbes and consequently the decomposition of residues in soil (Chesson, 1997). The thickness of maize stover compared to cassava leaves and cowpea haulm may have slowed its colonization by soil biota, and allowed the microenvironment within the residues to differ to a greater extent from that in the soil, possibly impeding some degradational activities of the biota.

The contact between residue and soil influences the rate of decomposition and the effect of residues on processes of N – cycle, especially during the initial stages of decomposition (Angers and Recous, 1997). Since litterbags often reduce that contact, they can affect experimental results. Tian *et al.* (1992a) reported that rates of nutrient release were proportional to mesh size of the litterbag used. The chemical quality of residues strongly affects mass loss, with more readily degraded substrates being less affected by reduced soil contact (Breland, 1994). Poor soil contact was also found to slow straw decomposition (Christensen, 1986). Use of litterbags compared to unconfined in the current study undoubtedly affected the rates of decomposition, but was considered a fixed effect for treatment comparisons. Finally, the use of the single exponential function accurately described the decomposition pattern of the residues considering the high r^2 values recorded for the residues and their method of placement. Also, fitting the decomposition data to the non – linear model revealed a strong correlation indicating that decomposition of crop residues was a non linear process.

4.3 NUTRIENT RELEASE PATTERN FROM THE CROP RESIDUES

4.3.1 RESULTS

4.3.1.1 2006 major rainy season

4.3.1.1.1 Nitrogen

Fig. 9a shows the N release pattern from the crop residues during the major season. There was an initial rapid release of N from buried cassava leaves which was significantly higher than ($P < 0.05$) from the same leaves and also maize stover. The pattern of N release was however, irregular especially for both residues. There was slow N release in the second week. At the sixth week almost all the treatments have released more than 50% of their initial N contents. At the end of the eighth week,

buried cassava leaves retained 17% N and the surface – placed, 29% while maize stover retained 49% N when buried compared to 33% N when placed on the surface. The N mineralization rate constant ($k \text{ wk}^{-1}$) for the residues and their method of placement is presented in Table 11a with buried cassava leaves having the highest value indicating fast mineralization.

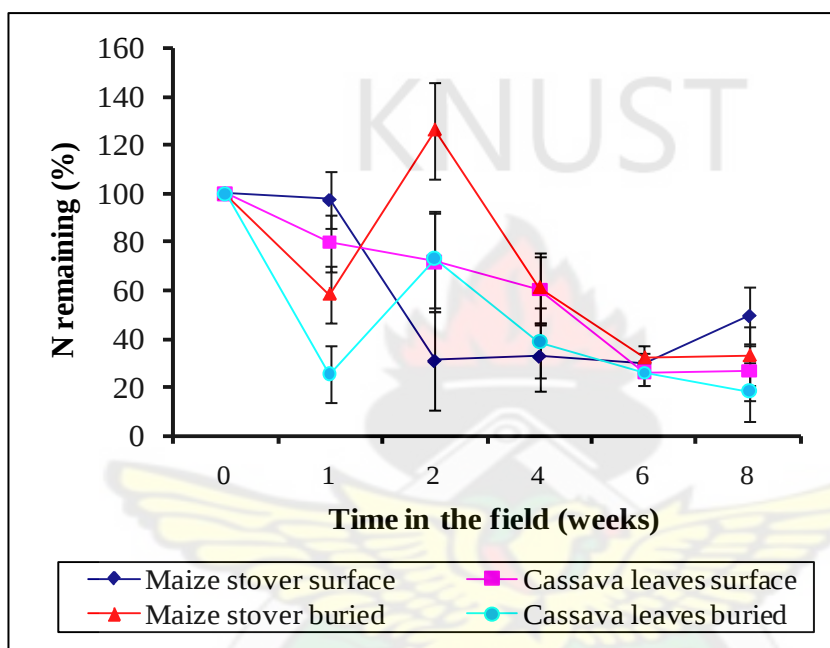


Fig. 9a: Nitrogen released from buried and surface – placed decomposing crop residues (2006 major rainy season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

4.3.1.1.2 Phosphorus

Release of P during the first week was slow compared to that of nitrogen for both residues and the method of placement (Fig. 9b). Almost all the residues with the exception of surface – placed maize stover released more than 50% of their initial P content by the second week. At week eight, the amount of P remaining was 12 – 30% for both residues and their placement method. Buried maize stover had the highest k value (0.227 wk^{-1}) with buried cassava the lowest value (0.122 wk^{-1}) (Table 11b) indicating that the former released P faster than the latter.

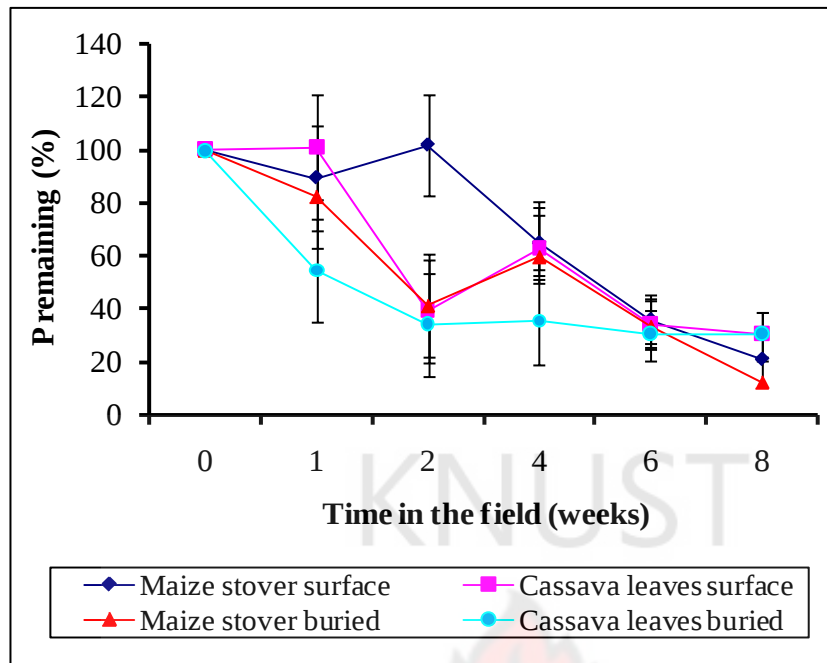


Fig. 9b: Phosphorus released from buried and surface – placed decomposing crop residues (2006 major rainy season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

Table 11a: Nitrogen release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006 major rainy season)

Residue and placement	k (wk ⁻¹)	r^2	r
Maize stover (surface)	0.105	0.320	-0.570
Cassava leaves (surface)	0.108	0.133	-0.343
Maize stover (buried)	0.151	0.647	-0.803
Cassava leaves (buried)	0.153	0.520	-0.723
LSD (5%)	0.03	0.09	0.62
CV (%)	12.40	12.40	9.00

Table 11b: Phosphorus release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006 major rainy season)

Residue and placement	k (wk ⁻¹)	r^2	r
Maize stover (surface)	0.203	0.907	-0.953
Cassava leaves (surface)	0.146	0.687	-0.833
Maize stover (buried)	0.227	0.817	-0.903
Cassava leaves (buried)	0.122	0.613	-0.773
LSD (5%)	0.04	0.08	0.06
CV (%)	12.80	5.30	3.60

4.3.1.1.3 Potassium

Potassium release pattern from the crop residues is shown in Fig. 9c. Both residues and their placement method except buried cassava leaves showed initial slow release of K. The pattern of release was however, irregular from week one until the eighth week. At the eighth week, both residues had released more than 50% of their initial K content. More K was released from buried cassava leaves as indicated by the high rate constant value of 0.265 wk^{-1} (Table 11c). The K content remaining at week eight ranged from 9 – 19% for both residues and their method of placement.

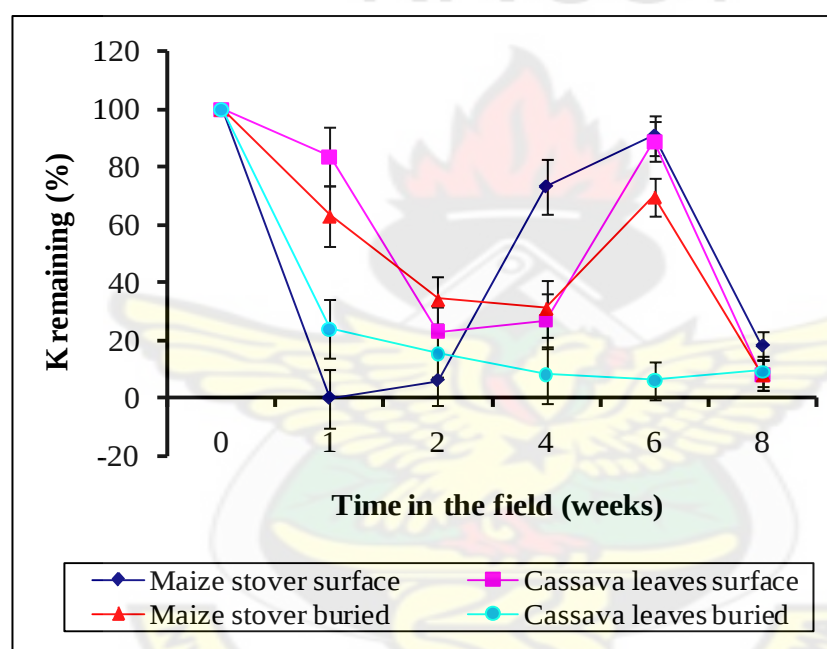


Fig. 9c: Potassium released from buried and surface – placed decomposing crop residues (2006 major rainy season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana.

Bars indicate LSD (5 %).

Table 11c: Potassium release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006 major rainy season)

Residue and placement	$k \text{ (wk}^{-1}\text{)}$	r^2	r
Maize stover (surface)	0.160	0.567	-0.757
Cassava leaves (surface)	0.205	0.390	-0.623
Maize stover (buried)	0.208	0.520	-0.723
Cassava leaves (buried)	0.265	0.630	-0.797
LSD (5%)	0.04	0.08	0.05
CV (%)	9.20	8.60	3.80

4.3.1.1.4 Calcium

Surface – placed maize stover released more than 50% of its initial Ca content during the second week (Fig. 9d). By the fourth week both residues and their method of placement had released more than 50% of their Ca content. The Ca content remaining at week eight were significantly different ($P < 0.05$). The amount remaining ranged between 13 and 44% for both residues.

4.3.1.1.5 Magnesium

Fig. 9e shows the magnesium release pattern of the residues. There was significantly ($P < 0.05$) initial rapid release of Mg from maize stover for both methods of placement. At week six, both residues had released more than 50% of their Mg content. The amount of Mg remaining was 13% for surface – placed cassava leaves, 24% for surface – placed maize stover, 41 and 44% for buried maize stover and cassava leaves respectively.

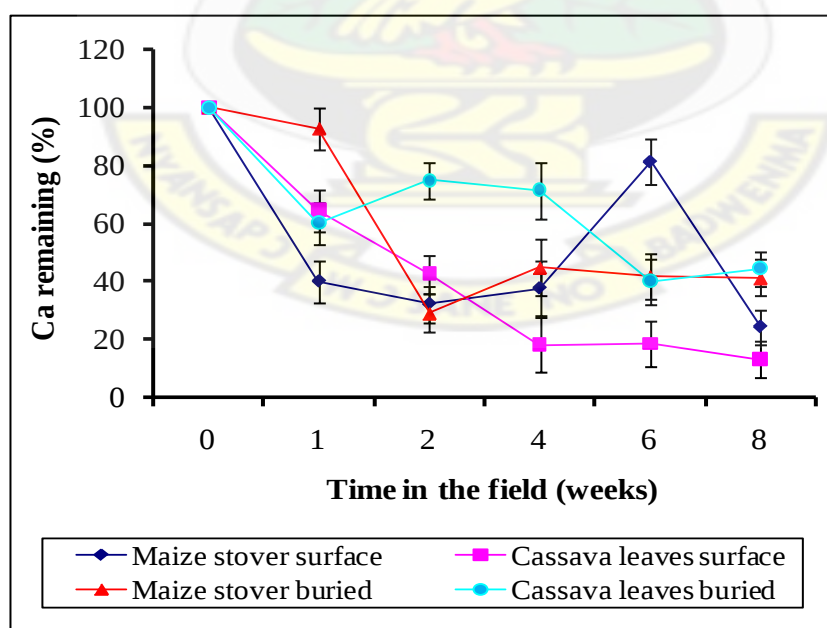


Fig. 9d: Calcium released from buried and surface – placed decomposing crop residues (2006 major rainy season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5 %).

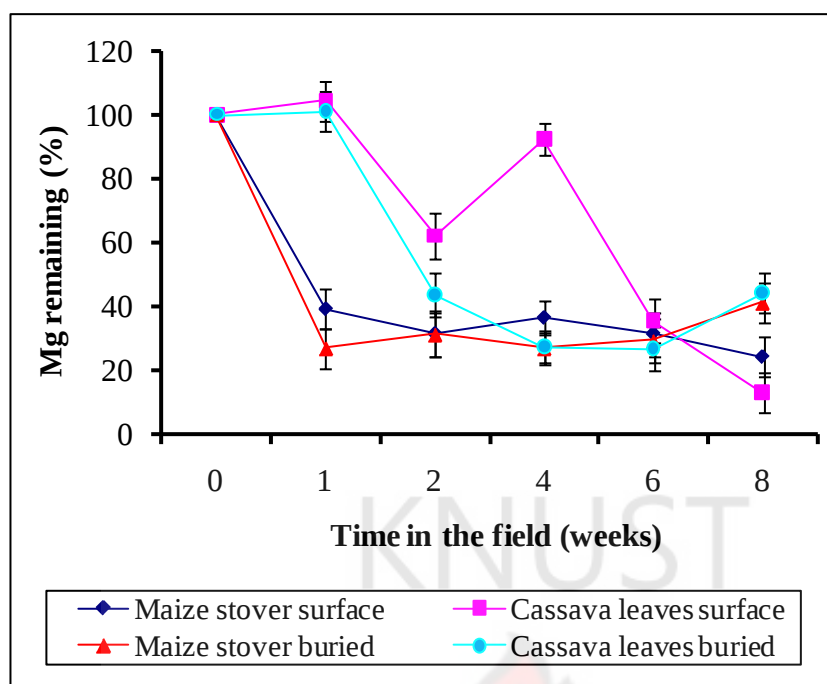


Fig. 9e: Magnesium released from buried and surface – placed decomposing crop residues (2006 major rainy season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5 %).

Table 11d: Calcium release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006 major rainy season)

Residue and placement	k (wk ⁻¹)	r^2	r
Maize stover (surface)	0.071	0.167	-0.400
Cassava leaves (surface)	0.251	0.883	-0.947
Maize stover (buried)	0.097	0.353	-0.590
Cassava leaves (buried)	0.094	0.700	-0.833
LSD (5 %)	0.03	0.13	0.12
CV (%)	10.80	13.30	9.60

Table 11e: Magnesium release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006 major rainy season)

Residue and placement	k (wk ⁻¹)	r^2	r
Maize stover (surface)	0.120	0.560	-0.750
Cassava leaves (surface)	0.072	0.300	-0.547
Maize stover (buried)	0.127	0.437	-0.657
Cassava leaves (buried)	0.133	0.467	-0.683
LSD (5 %)	0.03	0.14	0.11
CV (%)	13.90	17.20	9.00

4.3.1.2 2006 minor rainy season

4.3.1.2.1 Nitrogen

Fig. 10a shows the N release patterns of the residues during the minor season. There was initial rapid N release for both buried cassava leaves and cowpea haulm. All residues released more than 50% of their initial N content during the second week. Release patterns were however, irregular for all the residues during the fourth and sixth weeks respectively. Significant ($P < 0.05$) amount of N remained at the eighth week (0 – 47%) with surface – placed maize stover retaining more N (47%). This can be seen from its low rate constant (k) value of 0.061 wk^{-1} (Table 12a).

4.3.1.2.2 Phosphorus

There was rapid P release during the first week with all the residues releasing more than 50% of their initial P content (Fig. 10b). Buried cowpea haulm released the highest amount (86%). The patterns of P release were rapid throughout the study period (i.e. 1 – 8 weeks). At week eight the amount of P remaining were 0% for buried cassava leaves, surface – placed maize stover (9%), buried maize stover (11%), buried cowpea haulm (16%), surface- placed cassava leaves (18%) and surface – placed cowpea haulm (23%).

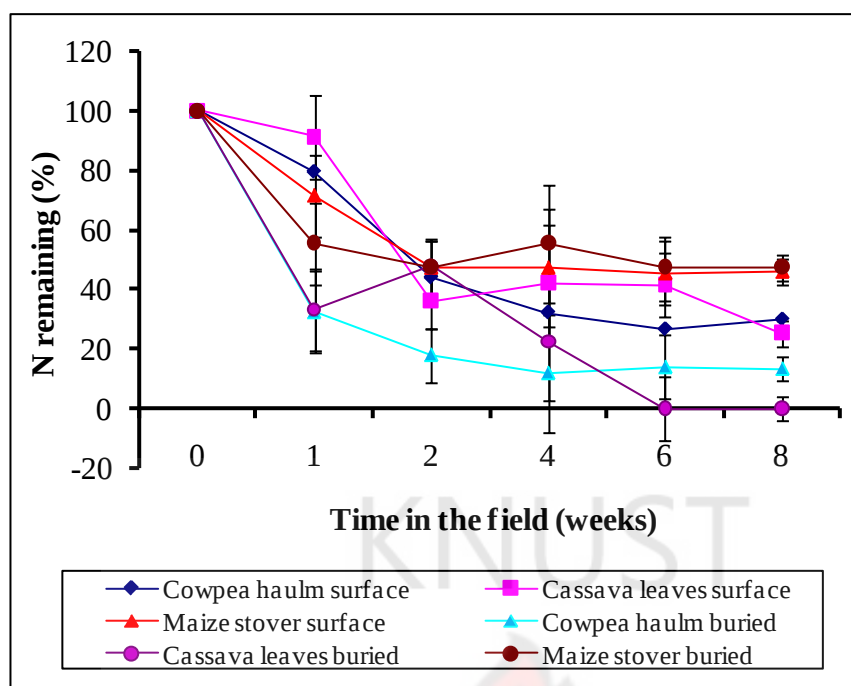


Fig. 10a: Nitrogen released from buried and surface – placed decomposing crop residues (2006 minor rainy season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

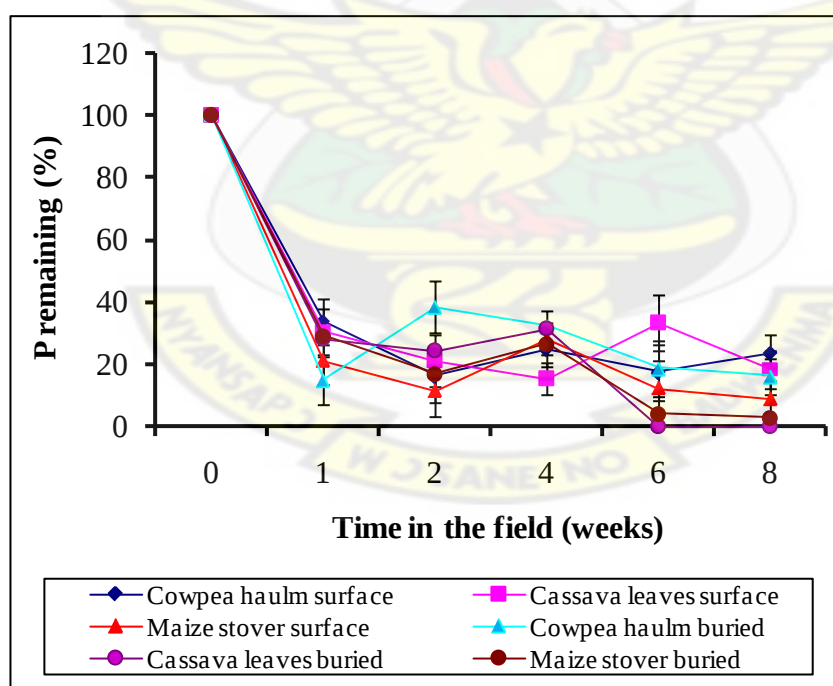


Fig. 10b: Phosphorus released from buried and surface – placed decomposing crop residues (2006 minor rainy season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

Table 12a: Nitrogen release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006 minor rainy season)

Residue and placement	k (wk ⁻¹)	r^2	r
Cowpea haulm (surface)	0.158	0.773	-0.880
Cassava leaves (surface)	0.150	0.653	-0.810
Maize stover (surface)	0.061	0.367	-0.690
Cowpea haulm (buried)	0.208	0.587	-0.767
Cassava leaves (buried)	0.612	0.883	-0.940
Maize stover (buried)	0.072	0.493	-0.597
LSD (5 %)	0.03	0.19	0.14
CV (%)	7.00	17.30	10.30

Table 12b: Phosphorus release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006 minor rainy season)

Residue and placement	k (wk ⁻¹)	r^2	r
Cowpea haulm (surface)	0.133	0.343	-0.580
Cassava leaves (surface)	0.127	0.337	-0.577
Maize stover (surface)	0.206	0.497	-0.700
Cowpea haulm (buried)	0.144	0.363	-0.593
Cassava leaves (buried)	0.580	0.840	-0.917
Maize stover (buried)	0.285	0.567	-0.753
LSD (5 %)	0.04	0.15	0.12
CV (%)	8.60	16.90	9.80

4.3.1.2.3 Potassium

There was slow release of K from all the residues during the first week (Fig. 10c). All the residues and their placement methods showed regular K release patterns throughout the period. At the sixth week all the residues had lost more than 50% of their initial K content. These release patterns except between surface – placed cassava leaves and cowpea haulm were significantly different ($P < 0.05$). This could also be seen from the rate constants of the residues (Table 12c). The amount of K that remained at week eight was in the range 0 – 16%.

4.3.1.2.4 Calcium

Slow Ca release pattern was observed during the first week for all the residues and their methods of placement (Fig. 10d). Buried cowpea haulm released more than 50% of its initial Ca content at the second week which was significantly different ($P < 0.05$) from the other treatments. The release pattern for buried cassava leaves showed the slowest rate of release from the first to the fourth week. However, at week six it showed the most significant ($P < 0.05$) rapid rate of release. Surface – placed cassava leaves retained more amount of Ca at week eight (78%) compared to 0% for buried cassava leaves. Only buried cowpea haulm and cassava leaves released more than 50% of their initial Ca content at the end of the study period.

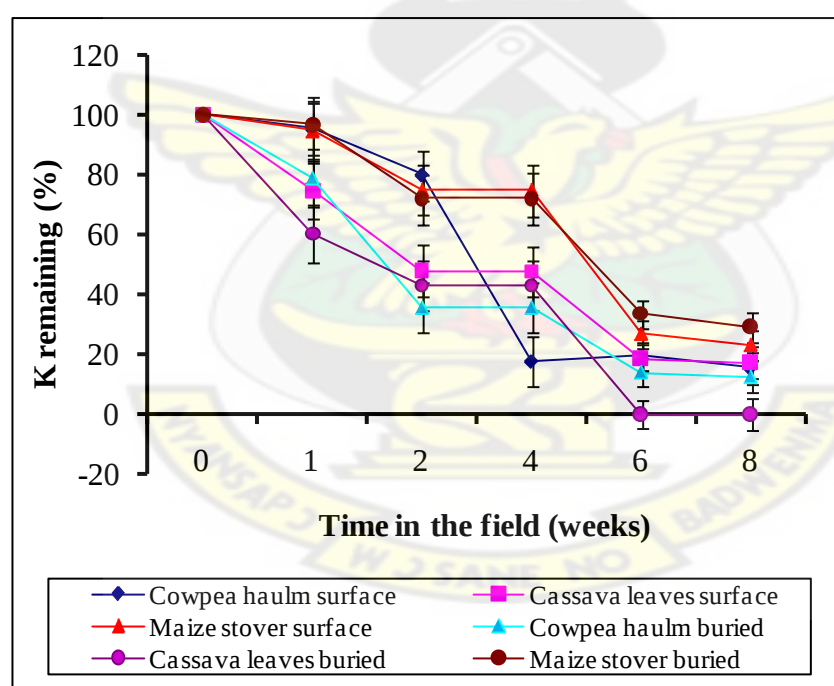


Fig. 10c: Potassium released from buried and surface – placed decomposing crop residues (2006 minor rainy season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

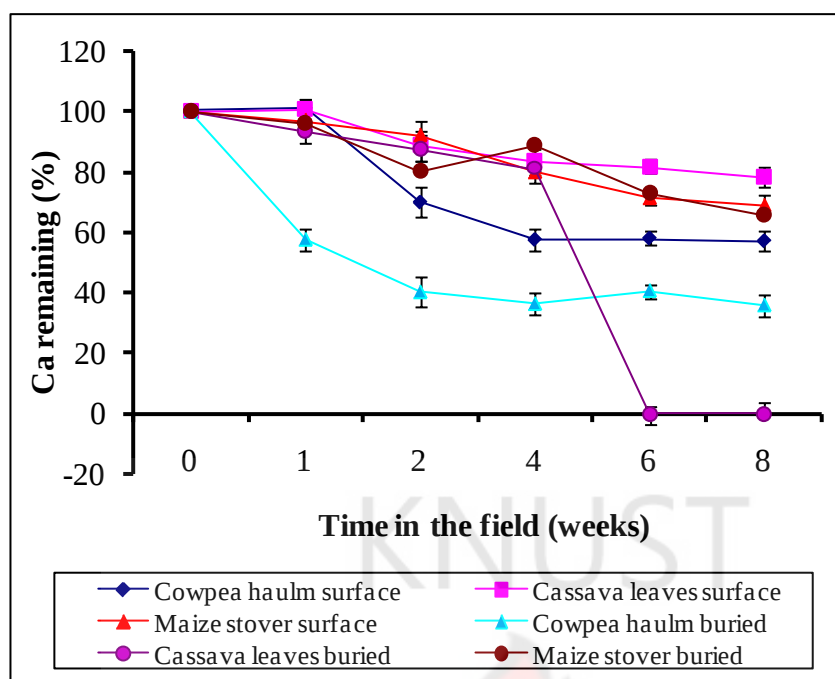


Fig 10d: Calcium released from buried and surface – placed decomposing crop residues (2006 minor rainy season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

Table 12c: Potassium release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006 minor rainy season)

Residue and placement	k (wk ⁻¹)	r^2	r
Cowpea haulm (surface)	0.268	0.843	-0.920
Cassava leaves (surface)	0.225	0.923	-0.960
Maize stover (surface)	0.169	0.883	-0.940
Cowpea haulm (buried)	0.272	0.917	-0.963
Cassava leaves (buried)	0.635	0.853	-0.923
Maize stover (buried)	0.201	0.883	-0.940
LSD (5 %)	0.03	0.05	0.03
CV (%)	4.80	2.90	1.50

Table 12d: Calcium release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006 minor rainy season)

Residue and placement	k (wk ⁻¹)	r^2	r
Cowpea haulm (surface)	0.074	0.683	-0.823
Cassava leaves (surface)	0.033	0.867	-0.930
Maize stover (surface)	0.051	0.963	-0.980
Cowpea haulm (buried)	0.098	0.560	-0.750
Cassava leaves (buried)	0.673	0.800	-0.890
Maize stover (buried)	0.049	0.837	-0.917
LSD (5 %)	0.04	0.09	0.05
CV (%)	2.80	6.30	3.40

4.3.1.2.5 Magnesium

There was initial rapid release of Mg from buried maize stover (Fig. 10e) which was significantly different ($P < 0.05$) from the others. All the residues except buried cassava leaves showed increases in concentration of Mg during the second week. At the sixth week surface – placed maize stover and both buried cassava and maize stover had released more than 50% of their initial Mg concentration. Surface – placed cowpea haulm retained the highest amount of Mg concentration (87%).

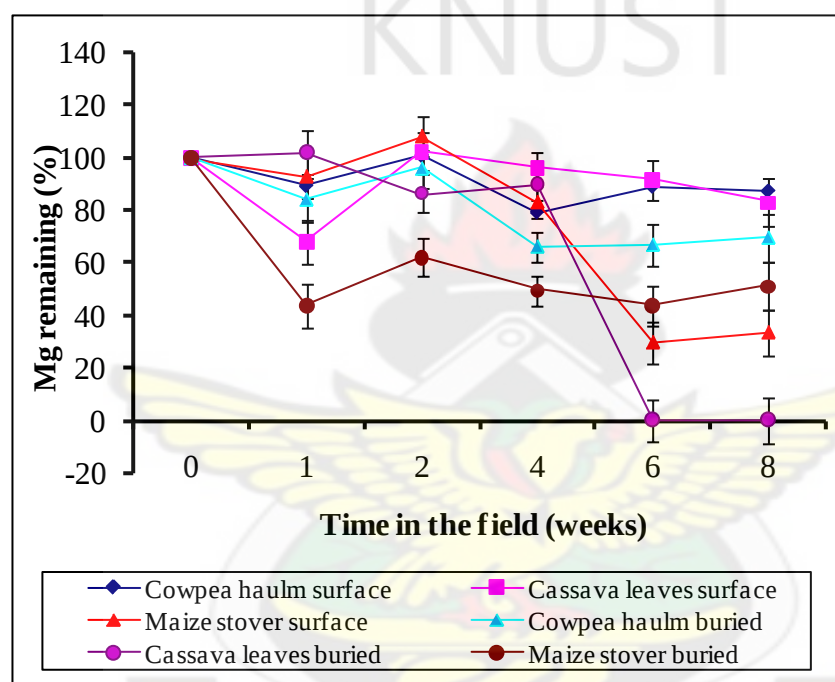


Fig 10e: Magnesium released from buried and surface – placed decomposing crop residues (2006 minor rainy season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

Table 12e: Magnesium release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006 minor rainy season)

Residue and placement	k (wk ⁻¹)	r^2	r
Cowpea haulm (surface)	0.016	0.267	-0.513
Cassava leaves (surface)	0.007	0.030	-0.150
Maize stover (surface)	0.064	0.787	-0.887
Cowpea haulm (buried)	0.061	0.640	-0.793
Cassava leaves (buried)	0.677	0.787	-0.887
Maize stover (buried)	0.053	0.260	-0.500
LSD (5 %)	0.06	0.19	0.15
CV (%)	23.50	23.00	13.90

4.3.1.3 2006 – 2007 dry season

4.3.1.3.1 Nitrogen

Fig. 11a depicts the N release pattern of the crop residues during the dry season. Release patterns were slow for both surface – placed and buried maize stover during the first week. This is evident from the low k values of the residues (Table 13a). The amount of N however, released from the other residues (36 and 48%) for buried cassava leaves and cowpea haulm respectively over release from surface maize stover only. All the residues except maize stover released more than 50% of their initial N content at week four. Slow release pattern was observed in maize stover for both method of placement throughout the study period. The amount of N that remained at week eight were 59, 64 and 79% for surface – placed cowpea haulm, cassava leaves and maize stover respectively and 72, 42 and 37% for buried maize stover, cowpea haulm and cassava leaves respectively.

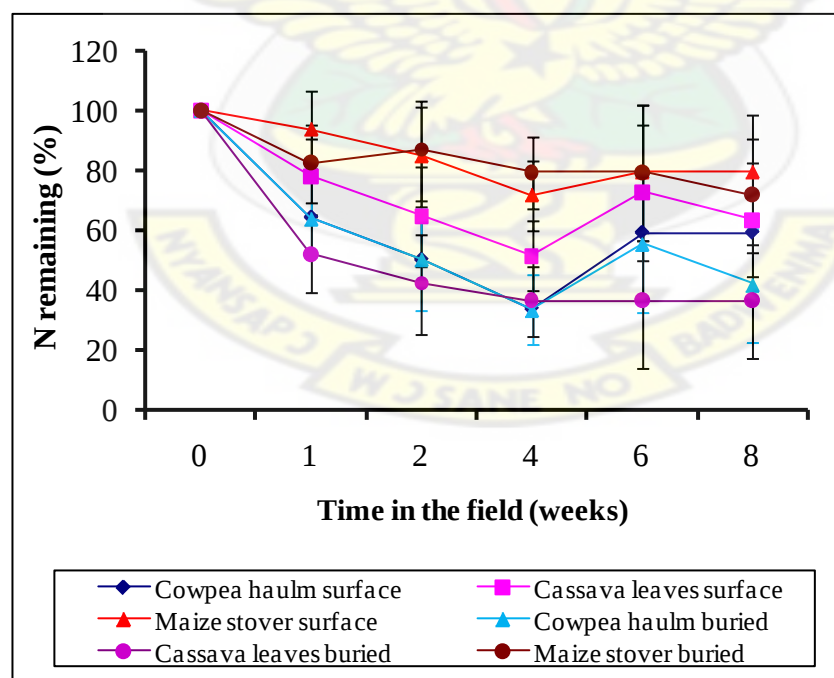


Fig 11a: Nitrogen released from buried and surface – placed decomposing crop residues (2006–2007 dry season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

4.3.1.3.2 Phosphorus

Release of P from the crop residues was very rapid and regular for all the residues during the first week (Fig. 11b). Maize stover released more than 50% of its initial P content during the same period. All the residues released more than 50% of their initial P content after the second week. Surface – placed cowpea haulm retained more P than the other treatments, about 10% more than surface – placed and 20% for buried at the end of the eighth week. This could be seen from its low k value of 0.041 wk^{-1} (Table 13b). The amount of P released ranged from 45 – 82%.

4.3.1.3.3 Potassium

The release pattern of K is shown in Fig. 11c. The pattern of K release was very slow during the first week for all the residues. Rapid K release was observed in cowpea haulm and buried cassava leaves during the fourth week both releasing significant amount of K ($P < 0.05$) than from all other residues. At week six all the residues had released more than 50% of their initial K content. The amount of K released during this period range from 53 to 80%. Buried cowpea haulm retained the least amount of K at week eight (19%) with buried maize stover retaining the highest (34%). The nutrient release constant (k) was highest for buried cowpea haulm (0.214 wk^{-1}) and lowest for buried maize stover (0.144 wk^{-1}) (Table 13c).

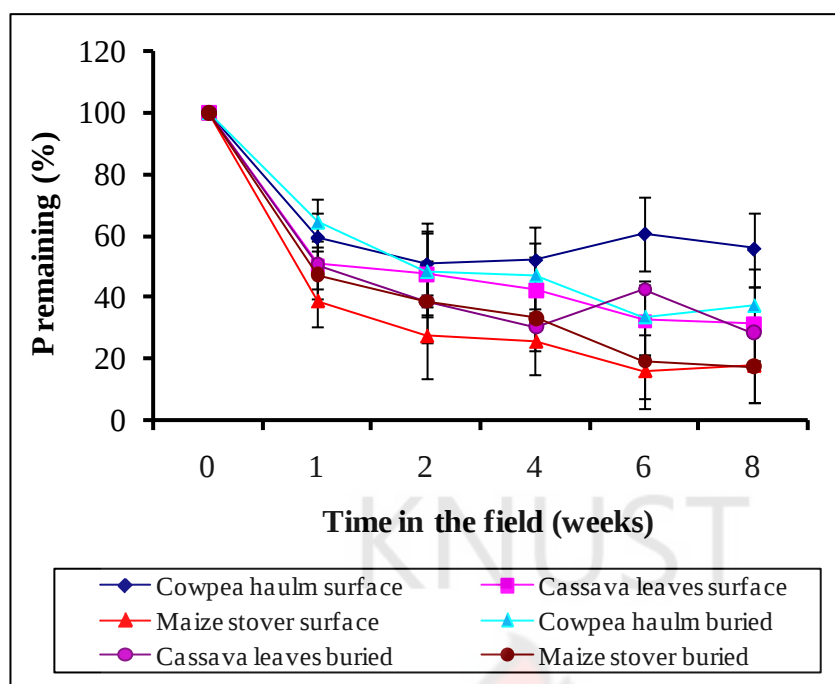


Fig 11b: Phosphorus released from buried and surface – placed decomposing crop residues (2006–2007 dry season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

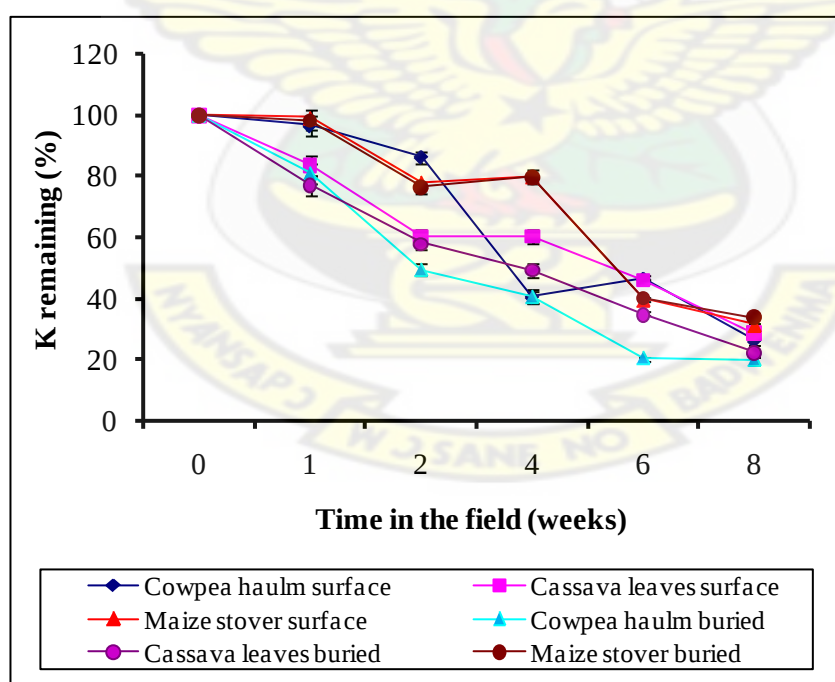


Fig 11c: Potassium released from buried and surface – placed decomposing crop residues (2006–2007 dry season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

Table 13a: Nitrogen release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006–2007 dry season)

Residue and placement	k (wk ⁻¹)	r^2	r
Cowpea haulm (surface)	0.045	0.163	-0.390
Cassava leaves (surface)	0.043	0.320	-0.527
Maize stover (surface)	0.030	0.387	-0.597
Cowpea haulm (buried)	0.083	0.400	-0.633
Cassava leaves (buried)	0.097	0.557	-0.747
Maize stover (buried)	0.032	0.407	-0.630
LSD (5 %)	0.02	0.28	0.27
CV (%)	23.10	42.70	25.90

Table 13b: Phosphorus release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006–2007 dry season)

Residue and placement	k (wk ⁻¹)	r^2	r
Cowpea haulm (surface)	0.041	0.250	-0.477
Cassava leaves (surface)	0.122	0.687	-0.827
Maize stover (surface)	0.186	0.707	-0.840
Cowpea haulm (buried)	0.117	0.667	-0.800
Cassava leaves (buried)	0.117	0.533	-0.717
Maize stover (buried)	0.195	0.847	-0.917
LSD (5 %)	0.06	0.30	0.22
CV (%)	25.50	27.70	15.90

Table 13c: Potassium release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006–2007 dry season)

Residue and placement	k (wk ⁻¹)	r^2	r
Cowpea haulm (surface)	0.170	0.900	-0.953
Cassava leaves (surface)	0.140	0.938	-0.967
Maize stover (surface)	0.156	0.910	-0.953
Cowpea haulm (buried)	0.214	0.940	-0.970
Cassava leaves (buried)	0.172	0.979	-0.987
Maize stover (buried)	0.144	0.918	-0.937
LSD (5 %)	0.01	0.02	0.02
CV (%)	2.50	17.30	1.20

4.3.1.3.4 Calcium

All the residues except buried cowpea haulm showed increase in Ca concentration during the initial stage (Fig. 11d). Ca release was however, observed from all the

residues during the second week. Only surface – placed cowpea haulm showed regular pattern of Ca release from the second to the eighth week with the rest showing mineralization and increase in concentration of Ca. At week eight none of the residues was able to release 50% of its initial Ca content. Release of Ca from the residues was slow considering their low k values which ranged from 0.037 to 0.089 wk^{-1} (Table 13d). The amount that remained ranged from 57 to 86% with surface – placed cassava leaves retaining the highest amount (87%).

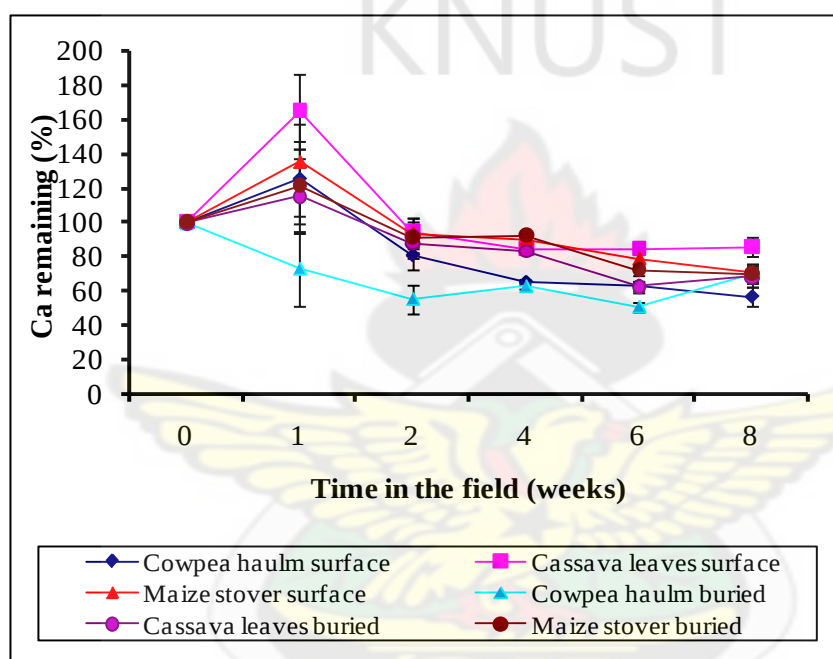


Fig 11d: Calcium released from buried and surface – placed decomposing crop residues (2006–2007 dry season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

Table 13d: Calcium release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006–2007 dry season)

Residue and placement	k (wk^{-1})	r^2	r
Cowpea haulm (surface)	0.089	0.780	-0.883
Cassava leaves (surface)	0.050	0.427	-0.580
Maize stover (surface)	0.060	0.697	-0.833
Cowpea haulm (buried)	0.037	0.237	-0.477
Cassava leaves (buried)	0.067	0.760	-0.870
Maize stover (buried)	0.059	0.783	-0.887
LSD (5 %)	0.02	0.18	0.11
CV (%)	16.30	17.30	8.30

4.3.1.3.5 Magnesium

The pattern of Mg release was slow during the first week (Fig. 11e). The release of Mg showed irregular pattern for all the residues except buried cassava leaves throughout the study period. Buried maize stover exhibited fast rate of Mg release as indicated by its high k value of 0.100 wk^{-1} (Table 13e). Multiple linear regression analysis (Table 14) showed that mass loss of surface – placed residues were influenced more by Ca content whiles P and K influenced buried residues. Again correlation analysis (Tables 15a, 15b and 15c) indicated a strong relationship between mass loss and Ca content of residue.

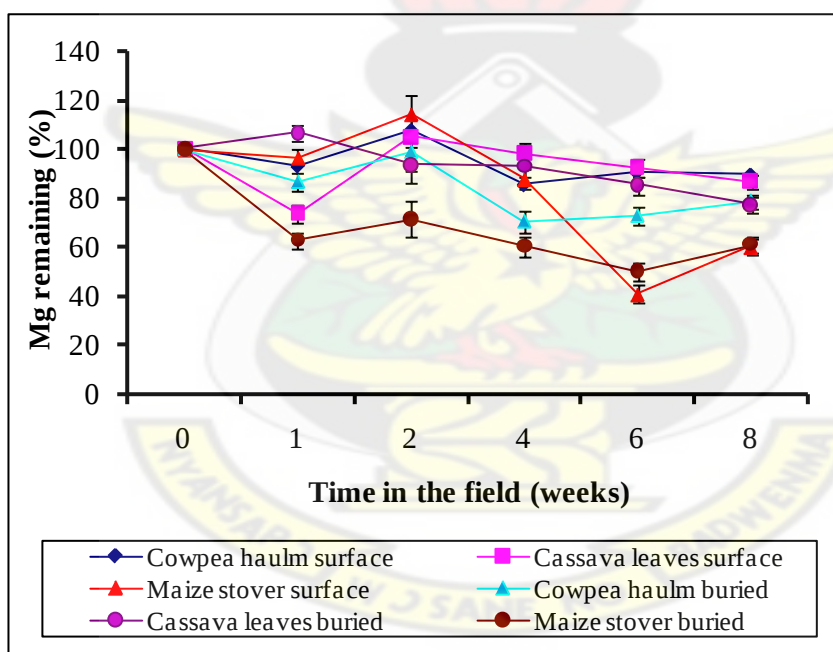


Fig 11e: Magnesium released from buried and surface – placed decomposing crop residues (2006–2007 dry season) on a Ferric Acrisol in the semi – deciduous forest zone, Kwadaso, Kumasi, Ghana. Bars indicate LSD (5%).

Table 13e: Magnesium release rate constant (k), coefficient of determination (r^2) and correlation coefficient (r) of the crop residues (2006–2007 dry season)

Residue and placement	k (wk ⁻¹)	r^2	r
Cowpea haulm (surface)	0.017	0.773	-0.988
Cassava leaves (surface)	0.005	0.653	-0.991
Maize stover (surface)	0.100	0.493	-0.984
Cowpea haulm (buried)	0.030	0.587	-0.970
Cassava leaves (buried)	0.035	0.883	-0.973
Maize stover (buried)	0.050	0.367	-0.958
LSD (5 %)	0.01	0.19	0.13
CV (%)	14.30	17.30	10.30

Table 14: Multiple linear regressions describing the relationship between % mass and % nutrients remaining of surface applied and buried crop residues

Residue and placement	equation	r^2
Cowpea haulm (surface)	$Y = 22 - 1.28Ca + 2.34N + 0.28K - 0.56P$	95.9
Cassava leaves (surface)	$Y = -379 + 4.85Ca + 0.18K - 0.42N + 0.18P$	97.1
Maize stover (surface)	$Y = -116.72 + 1.98Ca + 0.66K - 0.51Mg + 0.04N$	99.9
Cowpea haulm (buried)	$Y = -28.2 + 0.61P + 0.42K + 0.49Ca - 0.25N$	99.8
Cassava leaves (buried)	$Y = -4.61 + 4.02K + 0.62N - 2.44P - 1.20Ca$	99.9
Maize stover (buried)	$Y = 131 + 1.08K - 0.62Ca + 2.09P - 2.86N$	89.9

Table 15a: Spearman rank correlation coefficients between %mass and nutrient remaining of cassava leaves

	Mass	Ca	K	P	N
Mass	1.000				
Ca	0.991***	1.000			
K	0.955***	0.945**	1.000		
N	0.929***	0.936**	0.914**	1.000	
P	0.679	0.634	0.741*	0.756*	1.000

* correlation is significant at $P < 0.05$

** correlation is significant at $P < 0.01$

*** correlation is significant at $P < 0.001$

Table 15b: Spearman rank correlation coefficients between %mass and nutrient_remaining of cowpea haulm

	Mass	Ca	N	K	P
Mass	1.000				
Ca	0.976***	1.000			
N	0.973***	0.971***	1.000		
K	0.956**	0.920**	0.889**	1.000	
P	0.734	0.703	0.848*	0.589	1.000

* correlation is significant at $P < 0.05$

** correlation is significant at $P < 0.01$

*** correlation is significant at $P < 0.001$

Table 15c: Spearman rank correlation coefficients between %mass and nutrient_remaining of maize stover

	Mass	Ca	K	Mg	N
Mass	1.000				
Ca	0.973***	1.000			
K	0.951**	0.943**	1.000		
Mg	0.822*	0.904**	0.928**	1.000	
N	0.807*	0.707	0.638	0.405	1.000

* correlation is significant at $P < 0.05$

** correlation is significant at $P < 0.01$

*** correlation is significant at $P < 0.001$

4.4.2 DISCUSSION

4.4.2.1 Nitrogen

Nitrogen release from the crop residues followed different patterns from that of the mass loss. All treatments showed mineralization and increases in N concentration throughout the study period. Similar pattern of N dynamics have been reported by other researchers (e.g. Schomberg *et al.*, 1994). In decomposition studies, increases in concentration have been reported to be the result of one or more of the following reasons: nutrient input from atmospheric precipitation and N_2 fixation (Berg, 2000).

Cassava leaves and cowpea haulm released N rapidly than maize stover especially during the first two weeks. This could be attributed to their high N content and low C: N ratios compared to low N content and high C: N ratio in maize stover.

Organic residues which have a high ratio of C: N, tend to mineralize much slower under the same conditions than materials that have a lower ratio (cassava leaves and cowpea haulm). The high C: N ratio may be beneficial under certain soil conditions. The slow decomposition of the maize stover was expected to result in net N immobilization during the short term. While the very slow turnover of a large fraction of the organic matter of the maize stover material leads to the accumulation of carbon in the soil, the immobilization of available soil mineral N caused by the decomposing maize stover, as well as the actual N sequestered in the non-degradable fraction of this organic matter, can result in extremely small concentrations of plant-available N in the long term. High quality organic materials decompose very fast releasing N initially in excess of plant needs (Handayanto *et al.*, 1994). The excess N will be lost through leaching and other natural processes, resulting in N deficits a few weeks after peak mineralization. Therefore, reduction of such losses would greatly improve N use efficiency by the crops. Synchrony between N release from high organic materials with the crop's N demand can be achieved by optimizing timing of the application of organic materials, and by combining high and low quality organic materials (Handayanto *et al.*, 1997).

Improved synchronization between N net mineralization (N release) from organic materials and plant N demand has been advocated as a means of improving N use efficiency (Myers *et al.*, 1994), especially in tropical cropping systems. Correct timing of application of organic materials relative to planting the crop is difficult in

the tropics because of unpredictable rainfall patterns (Makumba *et al.*, 2007). Dry season period at the experimental site typically lack the heavy leaching rains that are common during major and minor rainy seasons. This may allow considerable time before significant leaching of nitrate occurs at the onset of the rains (Dahlin *et al.*, 2005).

4.4.2.2 Phosphorus

Release of P from the residues followed similar pattern to that of N. That is there were periods of mineralization and increases in P concentration. This pattern of P release has been reported by other researchers (e.g. Lupwayi *et al.*, 2007). The increase in concentration of P in the crop residues during the sixth week can be explained by dry weight loss being greater than P loss. However, unlike nitrogen, P release from the residues was rapid during the initial stages in the low quality material (maize stover) compared to the high quality materials (cassava leaves and cowpea haulm). Kwabiah *et al.* (2003) and Lupwayi *et al.* (2007) observed that phosphorus release during decomposition of crop residues was positively correlated with P concentration of residue and negatively correlated with C: P and lignin: P ratios. Fast release of P from maize stover could be attributed to its initial high P content.

4.4.2.3 Potassium

Potassium release pattern was very rapid when compared with other nutrients. The initial rapid loss of K, from the residues, is commonly found in litterbag studies (Tian *et al.*, 1992b). It may have been slightly increased by oven-drying of the residues, as cell disruption makes K more accessible to leaching. However, rapid

loss of K is expected from dead material, as this element is not chemically bound to the substrate and also its high water solubility.

4.4.2.4 Calcium

The mineralization of Ca proceeded much slowly than N, P and K throughout the study period. The rate of release was related to concentration of Ca in the residue and it was highest for cowpea haulm. Generally speaking, the tendency is for the mineralization of Ca to follow the pattern of disappearance of organic material, since it is used in the building of the cell walls of plants. Thus, the usual delay in the mineralization of Ca allows time for the breakdown of shielding substances such as lignins and tannins (Songwe *et al.*, 1995). Hartemink and O'Sullivan (2001) stated that the divalent cations were bound more strongly by the cation exchange properties of the organic substrate and released only in proportion to the biomass lost. Correlation analysis indicated that variation in mass loss was accurately explained by its association with the release of Ca.

4.4.2.5 Magnesium

The release of Mg follows similar pattern as Ca and its release is related to the initial Mg content of the residues. Maize stover with the highest concentration of Mg released more Mg than the other residues throughout the study periods.

4.5 NUTRIENTS RELEASE PATTERN FROM DECOMPOSING CROP RESIDUES (LEACHING INCUBATION METHOD)

4.5.1 RESULTS

4.5.1.1 Nitrate nitrogen (NO_3^- – N)

Fig. 12a summarizes the dynamics of nitrate in soil amended with six crop residues. All the crop residues released significant ($P < 0.05$) amount of nitrate during the first

week of incubation. Groundnut haulm released more nitrate ($3659 \text{ mg kg}^{-1} \text{ soil}$) with soyabean releasing the least amount ($121 \text{ mg kg}^{-1} \text{ soil}$). With the exception of cowpea and soyabean haulms, all the other residues exhibited nitrate immobilization during the second and fourth weeks respectively. However, nitrate immobilization was observed for all the residues during week six. At the end of the incubation period nitrate mineralization was observed for all the crop residues. Cowpea haulm released the highest amount of nitrate ($1680 \text{ mg kg}^{-1} \text{ soil}$) with maize stover releasing the lowest ($140 \text{ mg kg}^{-1} \text{ soil}$).

4.5.1.2 Ammonium nitrogen ($\text{NH}_4^+ - \text{N}$)

Apart from cowpea haulm and maize stover all the other crop residues showed initial NH_4^+ mineralization (Fig. 12b). Groundnut haulm, mucuna and soyabean did not release any amount of NH_4^+ during the second week. However, cassava leaves, cowpea haulm and maize stover released significant ($P < 0.05$) NH_4^+ . All the residues released significant NH_4^+ ($P < 0.05$) with soyabean releasing the highest amount ($102 \text{ mg kg}^{-1} \text{ soil}$) and groundnut haulm the lowest ($8.7 \text{ mg kg}^{-1} \text{ soil}$) during the fourth week. Soyabean immobilized NH_4^+ at the end of the incubation period whiles the other crop residues mineralized significant ($P < 0.05$) NH_4^+ . The values recorded were soyabean ($-19 \text{ mg kg}^{-1} \text{ soil}$) and groundnut haulm ($121 \text{ mg kg}^{-1} \text{ soil}$) (Fig. 12b).

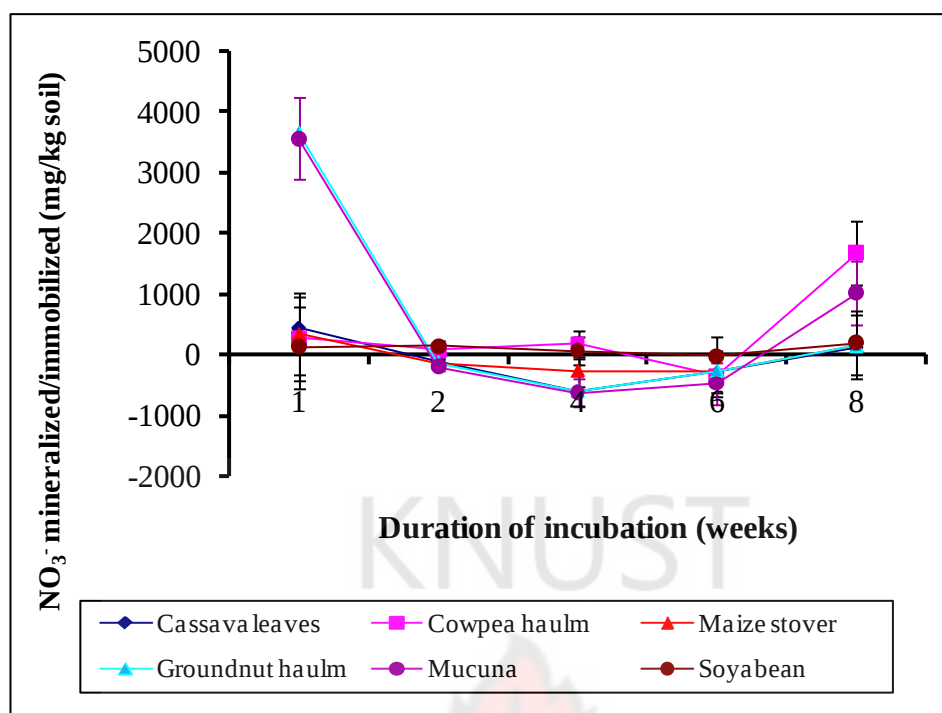


Fig. 12a: NO_3^- – N mineralized or immobilized during eight weeks of incubation of soil mixed with six different crop residues. Bars indicate LSD (5%).

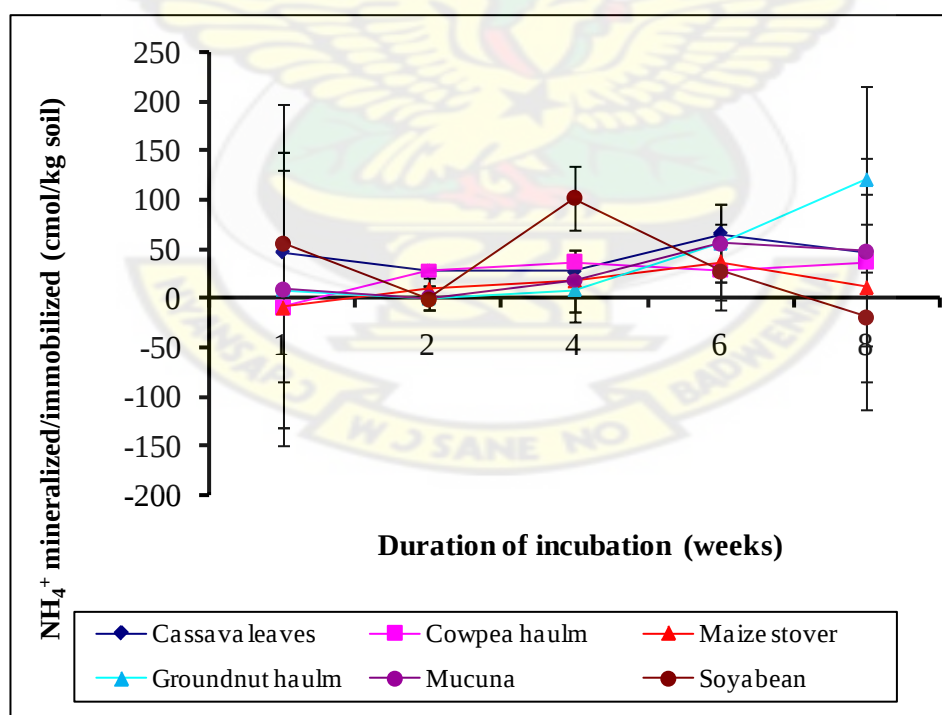


Fig. 12b: NH_4^+ – N mineralized or immobilized during eight weeks of incubation of soil mixed with six different crop residues. Bars indicate LSD (5%).

4.5.1.3 Total nitrogen ($\text{NO}_3^- - \text{N} + \text{NH}_4^+ - \text{N}$)

The dynamics of total N released is depicted in Fig. 12c. The amounts of N which were released during the first week ranged from 177 to 3668 mg kg^{-1} soil. All the residues immobilized N at week six except soyabean. At week eight, the amounts of N in the range 157 – 1717 mg kg^{-1} soil were released.

4.5.1.4 Phosphorus

There was significant ($P < 0.05$) initial mineralization of P from the residues during the first week with soyabean releasing the highest amount (11.39 mg kg^{-1} soil) and groundnut haulm the lowest (2.81 mg kg^{-1} soil) (Fig. 12d). The trend in mineralization of P continued in the second week. However, all the residues immobilized P during the fourth week. Cowpea haulm and maize stover did not release any amount of P during the sixth week. In contrast, the other four residues released significant ($P < 0.05$) amount of P during the same period. The amount released were 4.48 mg kg^{-1} soil for groundnut haulm, 4.87 mg kg^{-1} soil for cassava leaves, 6.14 mg kg^{-1} soil for mucuna and 13.53 mg kg^{-1} soil for soyabean. At the end of the incubation period cowpea haulm, maize stover and soyabean immobilized P while cassava leaves released 0.76 mg, groundnut haulm, 1.18 mg and mucuna 1.52 mg P kg^{-1} soil.

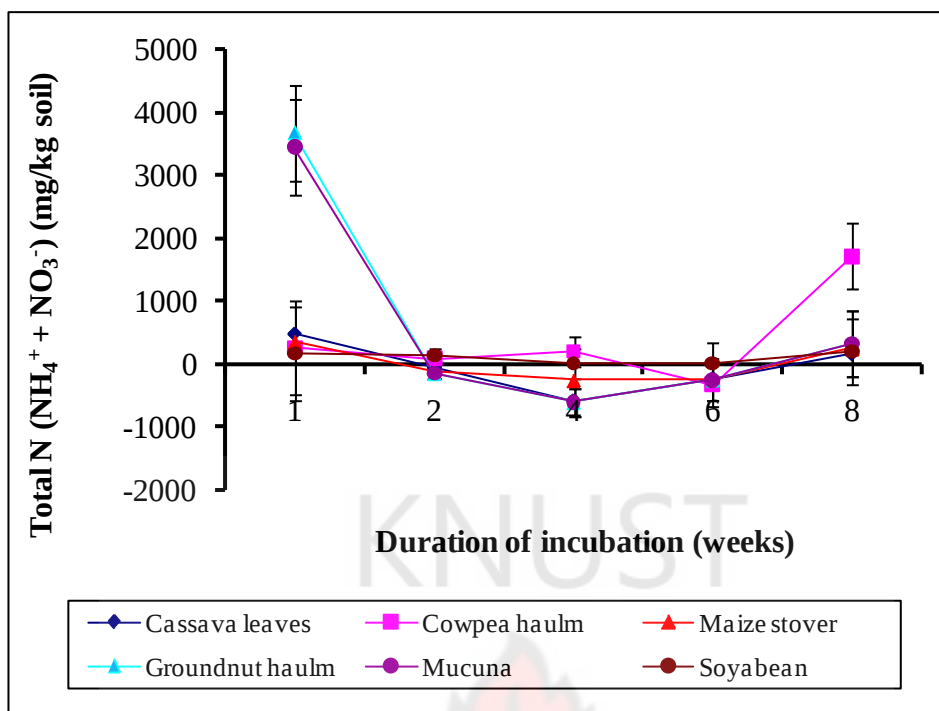


Fig. 12c: Total N mineralized or immobilized during eight weeks of incubation of soil mixed with six different crop residues. Bars indicate LSD (5%).

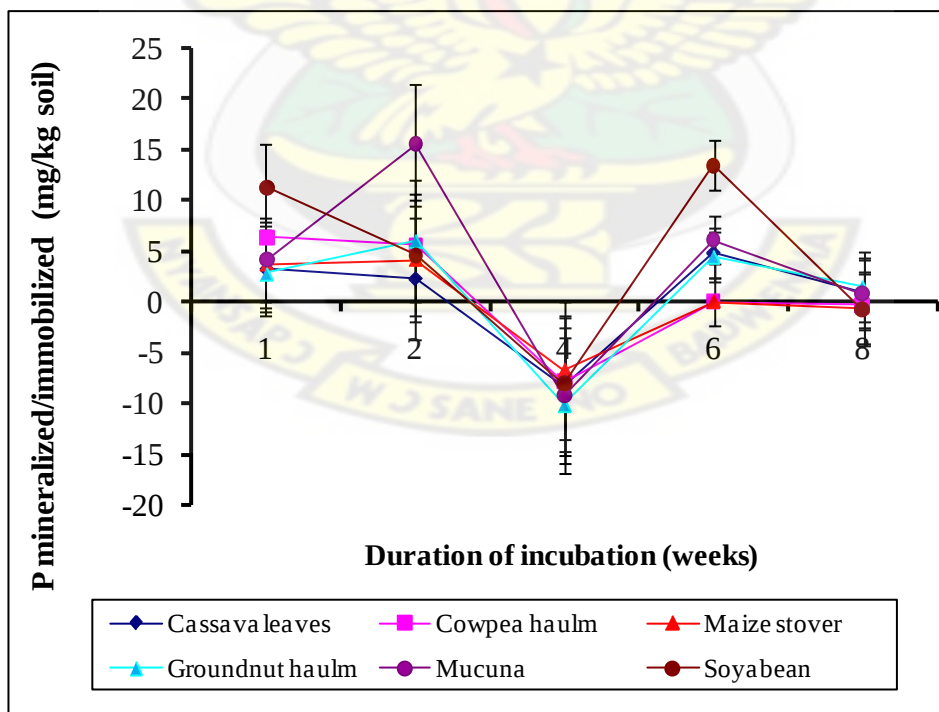


Fig. 12d: Phosphorus mineralized or immobilized during eight weeks of incubation of soil mixed with six different crop residues. Bars indicate LSD (5%).

4.5.1.5 Exchangeable calcium

With the exception of mucuna, the other residues released significant ($P < 0.05$) amount of exchangeable Ca during the first week (Fig. 12e). During the second week only cowpea haulm immobilized Ca. Cowpea haulm and maize stover released significant ($P < 0.05$) amount of Ca while the other four residues immobilized Ca at week four. Only cowpea haulm released significant ($P < 0.05$) amount of $0.13 \text{ cmol kg}^{-1}$ soil at the end of the incubation period.

4.5.1.6 Exchangeable magnesium

Magnesium released during the first week ranged between 1.53 and $2.73 \text{ cmol kg}^{-1}$ soil (Fig. 12f). Mineralization of Mg was slow from the second week to the end of the incubation period. The amounts of Mg released at the end of the incubation ranged from $0.20 - 0.53 \text{ cmol kg}^{-1}$ soil.

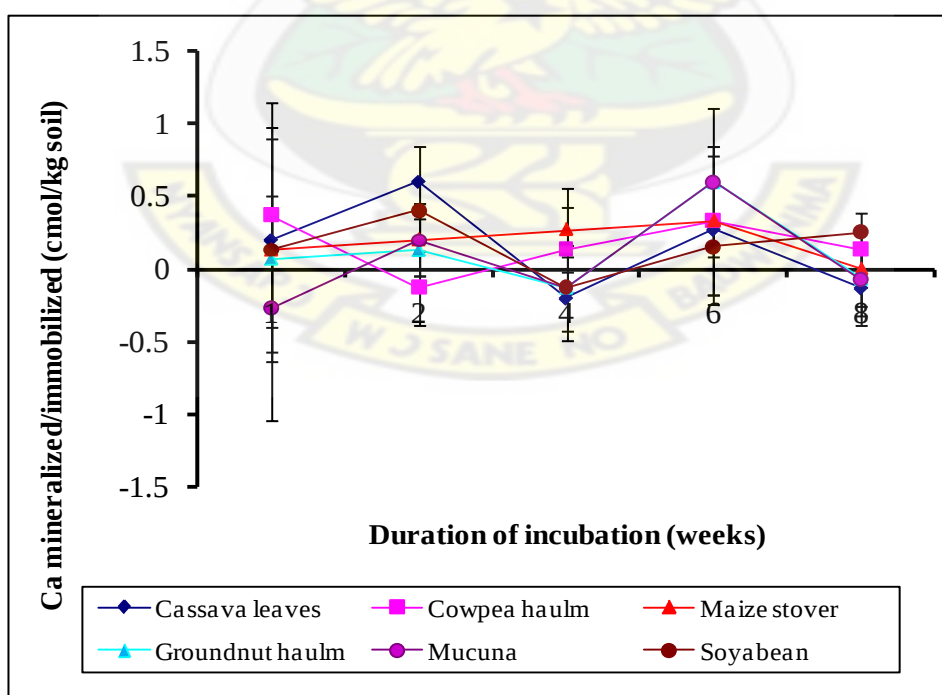


Fig. 12e: Calcium mineralized or immobilized during eight weeks of incubation of soil mixed with six different crop residues. Bars indicate LSD (5%).

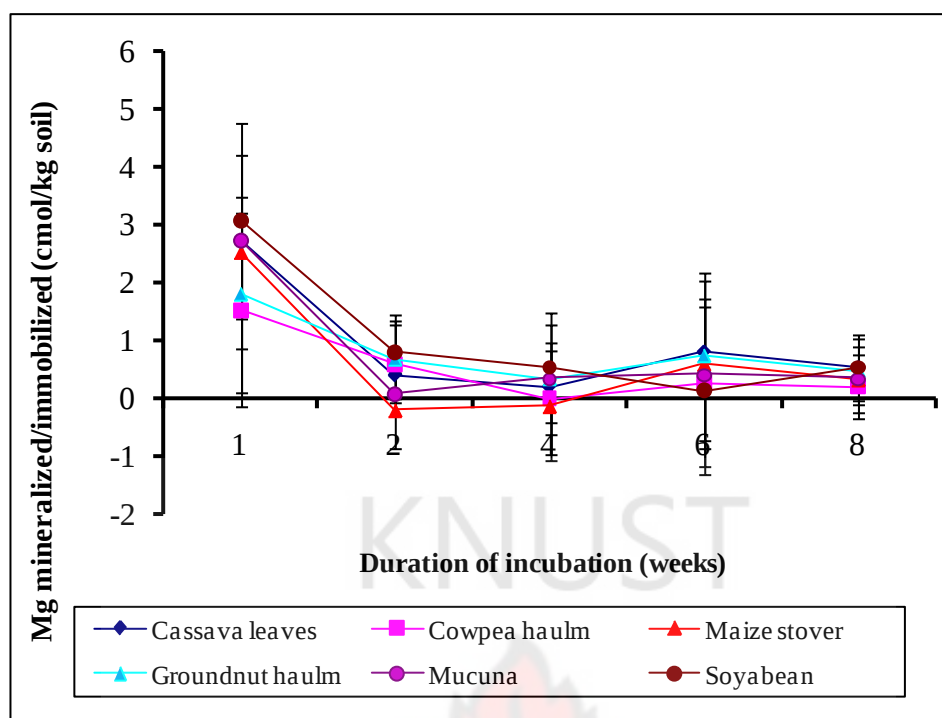


Fig. 12f: Magnesium mineralized or immobilized during eight weeks of incubation of soil mixed with six different crop residues. Bars indicate LSD (5%).

4.5.2 DISCUSSION

4.5.2.1 Total N ($\text{NO}_3^- + \text{NH}_4^+$)

The net effect of applying crop residues on the dynamics of soil mineral N and the maximum quantities of N immobilized is related mainly to the concentrations of organic N and C: N ratios of the residues. Tian *et al.* (1992a) suggested that the initial concentration of N is a better index than the C: N ratio, perhaps because the C: N ratio can be distorted by the presence of appreciable quantities of mineral N (mainly NO_3^-) in the plant tissues, which are thus immediately available.

Some authors (e.g. Palm *et al.*, 1997) have suggested that net mineralization of N occurs when C: N ratios of residues are < 25 . However, results of the present study contradict this assertion. All the residues showed rapid initial N release irrespective of their N or C: N ratios. Maize stover with a C: N ratio (65: 1) released more N than

cowpea haulm and mucuna both of which have low C: N ratios (< 25) during the first week of incubation. The rapid initial release of N could be attributed to the polyphenol concentration of the residues. During the early stages of decomposition, it appears that N and polyphenol contents are the main quality parameters that determine mineralization of nitrogen (Gachengo *et al.*, 2004). Polyphenols may control the short – term release of N in residues because they are thought to bind to organic-N and render it unavailable for uptake by microbes. The polyphenol concentrations were below the critical value (3 – 4%) at which N immobilization occurs (Palm and Sanchez, 1991) and might have accounted for the release of N from the residues at the initial stage of the incubation period.

Considering the net effect of the residues after eight weeks of incubation, all of them induced net mineralization of N, with cassava leaves releasing the least amount of N. This could probably be due its initial high lignin concentration (35.72%) which was above the critical value (15%) (Palm and Sanchez, 1991). Lignin concentration appears to be the primary influence on the mineralization rate at later stages of the process (Mueller *et al.*, 1998).

Nitrate is the dominant form of soil N under most conditions. However, if there is adequate soil aeration, moisture and temperature ammonium released by mineralization is quickly nitrified. As a result most N is taken up as nitrate. The findings of this research are in agreement with this fact because the total N mineralized from all the residues was dominated by nitrate. However, a low concentration of $\text{NH}_4^+ - \text{N}$ is not necessary an indication of low ammonification,

because it can also indicate rapid nitrification or immobilization (Quemada and Cabrera, 1995).

4.5.2.2 Phosphorus

Release of P from the residues followed similar pattern as N. There was initial rapid release of P followed by immobilization. Concentrations of P in crop residues were within the commonly reported 0.20 to 0.30 per cent net P mineralization threshold level (Yadvinder-Singh *et al.*, 1992). The initial P released from the crop residues could be due to their initial high P concentrations which were above the threshold levels. Decomposition processes, which are stimulated when crop residues are incorporated into the soil, can increase availability of P by releasing CO₂, which forms H₂CO₃ in the soil solution, resulting in the dissolution of primary P-containing minerals. In soils with high P – fixing capacities, organic compounds released during decomposition processes may increase P availability by blocking P-adsorption sites (Easterwood and Sartain, 1990).

4.5.2.3 Calcium

Little is known about the mineralization of Ca from crop residues under laboratory condition using the leaching incubation method (Tetteh, 2004). All the residues exhibited mineralization and immobilization of Ca throughout the study period. This finding was in contrast to the observation made by Tetteh (2004) who reported mineralization of Ca throughout his study period. It appears that not all the calcium in plant residues was released into soil and/or they were partly adsorbed in soil matrix. In this study, concentrations of this cation decreased with time of incubation, indicating that soil adsorption occurred during the incubation.

4.5.2.4 Magnesium

The release of Mg from all the residues showed net mineralization of Mg except maize stover. The immobilization of Mg exhibited by maize stover is unexplained because it contains the highest amount of Mg and was expected to have mineralized Mg throughout the incubation period.

4.6 EFFECT OF ORGANIC AND INORGANIC NUTRIENT SOURCES ON SOIL MICROBIAL BIOMASS CARBON, NITROGEN AND PHOSPHORUS

4.6.1 RESULTS

4.6.1.1 Microbial biomass carbon

Soil microbial biomass was significantly ($P < 0.05$) higher under the 10 t ha^{-1} maize stover treatment ($1150.12 \mu\text{g g}^{-1}$) at week four which was about 135 and 191% over the control and NPK fertilizer treatments respectively. The next best treatments were the combined application of maize stover + cowpea haulm ($1050.10 \mu\text{g g}^{-1}$) and 10 t ha^{-1} cowpea haulm ($1028.23 \mu\text{g g}^{-1}$) respectively. The inorganic fertilizer (NPK) treatment recorded the lowest value ($395.40 \mu\text{g g}^{-1}$). The soil microbial biomass carbon declined significantly ($P < 0.05$) irrespective of treatment over the sampling periods (Table 16a).

Table 16a: Effect of organic and inorganic nutrient sources on soil microbial biomass carbon (MBC) in a Ferric Acrisol at different periods during 2007 major season.

Amendments	sampling periods			
	4 weeks	8 weeks	16 weeks	mean
	MBC ($\mu\text{g g}^{-1}$)			
Control	490.17	276.70	126.00	297.60
10 t ha^{-1} Cowpea haulm	1028.23	386.30	227.70	547.40
10 t ha^{-1} Maize stover	1150.12	515.00	373.00	679.30
5 t ha^{-1} Maize + 5 t ha^{-1} Cowpea	1050.10	471.70	278.70	600.10
NPK (90–60–60 kg ha^{-1})	395.40	225.70	107.00	242.60
LSD (5 %)	83.78	49.56	19.57	46.53
CV (%)	15.40	13.40	10.30	13.30

LSD (%) for comparing means at the same level(s) of treatments = 148.74.

4.6.1.2 Microbial biomass nitrogen

Table 16b summarizes the soil microbial N content following different soil amendments sampled at three different periods during 2007 major rainy season.

Table 16b: Effect of organic and inorganic nutrient sources on soil microbial biomass nitrogen (MBN) in a Ferric Acrisol at different periods during 2007 major season.

Amendments	sampling periods			
	4 weeks	8 weeks	16 weeks	mean
	MBN ($\mu\text{g g}^{-1}$)			
Control	35.57	29.86	19.92	28.45
10 t ha ⁻¹ Cowpea haulm	76.03	42.13	31.32	49.83
10 t ha ⁻¹ Maize stover	115.43	63.30	41.24	73.32
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ Cowpea	97.60	58.10	37.70	62.47
NPK (90–60–60 kg ha ⁻¹)	25.33	22.85	16.81	21.66
LSD (5%)	5.71	4.39	5.00	2.69
CV (%)	4.30	9.20	9.40	3.00

LSD (5%) for comparing means at the same level(s) of treatments = 5.63.

The trend observed for microbial biomass N was similar to that of microbial biomass carbon. Sole application of 10 t ha⁻¹ maize stover recorded the highest value (115.43 $\mu\text{g g}^{-1}$) during the first sampling (at 4 weeks) followed by the combined maize stover + cowpea haulm treatment (97.60 $\mu\text{g g}^{-1}$). The lowest value of 25.33 $\mu\text{g g}^{-1}$ was recorded by the NPK fertilizer treatment. Significant ($P < 0.05$) decreases in soil microbial N was found among the treatments over the sampling periods. The mean values recorded for the three sampling periods ranged from 21.66 – 73.32 $\mu\text{g g}^{-1}$ (Table 16b).

4.6.1.3 Microbial biomass phosphorus

Application of the different treatments significantly ($P < 0.05$) affected the microbial biomass P content of the soil throughout the sampling periods (Table 16c). Combined maize stover + cowpea haulm treatment recorded the highest value (50.09 $\mu\text{g g}^{-1}$) at week four followed by the 10 t ha⁻¹ maize stover treatment (36.32 $\mu\text{g g}^{-1}$).

The lowest values (8.17 and 13.82 $\mu\text{g g}^{-1}$) were recorded by the NPK fertilizer and control treatments respectively. However, the values declined with time. At the end of the study period the mean values recorded ranged between 6.80 and 34.21 $\mu\text{g g}^{-1}$.

Table 16c: Effect of organic and inorganic nutrient sources on soil microbial biomass phosphorus (MBP) in a Ferric Acrisol at different periods during 2007 major season.

Amendments	sampling periods			
	4 weeks	8 weeks	16 weeks	mean
	MBP ($\mu\text{g g}^{-1}$)			
Control	13.82	9.68	7.26	10.22
10 t ha ⁻¹ Cowpea haulm	23.17	17.79	12.81	17.92
10 t ha ⁻¹ Maize stover	36.32	24.27	17.81	26.18
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ Cowpea	50.09	32.44	20.11	34.21
NPK (90–60–60 kg ha ⁻¹)	8.17	7.47	4.77	6.80
LSD (5%)	4.63	5.46	3.61	3.30
CV (%)	9.30	15.80	15.20	9.20

LSD (5%) for comparing means at the same level(s) of treatments = 3.75.

4.6.2 DISCUSSION

4.6.2.1 Microbial biomass carbon

High level of microbial biomass C was recorded in plots treated with crop residues. According to Schnurer *et al.* (1985), the decomposition rate of organic input is responsible for the variation in the level of microbial biomass. Although the quantity of microbial biomass is mainly related to C inputs, other mitigating factors such as temperature and moisture can regulate the growth and activity of the native microflora.

4.6.2.2 Microbial biomass nitrogen

Microbial biomass nitrogen undergoes changes in the soil. This is confirmed by the differences between the data recorded in the fourth week and at harvest following the application of the residues. At the time of sampling, the readily soluble plant materials had decomposed and were left with the recalcitrant materials such as lignin

on the soil surface. As shown by the evaluation of the particular treatments, the highest content of microbial biomass nitrogen was determined for residue application. In the treatments with mineral fertilizer, microbial biomass nitrogen was lower than in the control. Lovell and Jarvis (1998) reported that regular and long term applications of nitrogen led to a decrease in the content of soil microbial biomass.

4.6.2.3 Microbial biomass phosphorus

Microbial biomass P recorded was low when compared with MBC and MBN. Many soils chemically fix P on soil surfaces, where it is then removed from plant – available pool (Brookes, 2001). However, MBP was higher in plots treated with crop residues compared with the NPK fertilizer and the control plots. Organic matter additions (crop residues) may decrease P fixation by masking sites which would otherwise fix P. The microbial biomass which decomposes the residue will also have large demand for P as it grows. Thus P will be immobilized within the microbial cells and so protected from fixation by the soil colloids. As the biomass declines, following the exhaustion of the residue, the microbial biomass P will be mineralized to inorganic P, which plants can use again (Brookes, 2001).

4.7 EFFECT OF ORGANIC AND INORGANIC NUTRIENT SOURCES ON SOIL MACROFAUNA

4.7.1 RESULTS

4.7.1.1 Earthworm

The population counts of earthworms in soil treated with maize stover, cowpea haulm and NPK fertilizer sampled at three different periods are presented in the Table 17a.

Table 17a: Population counts of earthworms in a Ferric Acrisol amended with crop residues compared with fertilized and unfertilized control at different periods during 2007major season.

Amendments	sampling periods			
	4 weeks	8 weeks	16 weeks	mean
	m ⁻²			
Control	3.33	2.76	1.56	2.55
10 t ha ⁻¹ Cowpea haulm	4.43	3.70	3.68	3.94
10 t ha ⁻¹ Maize stover	5.68	4.62	4.63	4.98
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ Cowpea	5.19	4.57	4.41	4.66
NPK (90–60–60 kg ha ⁻¹)	2.72	2.00	1.29	2.03
LSD (5 %)	0.89	0.39	0.71	0.61
CV (%)	11.10	10.70	12.21	8.90

LSD (5%) for comparing means at the same level(s) of treatments = 0.39.

Statistical analysis of the population counts of earthworm indicated significant differences due to treatments and also across sampling periods. The average earthworm numbers were low for both fertilizer and no input control, but addition of maize stover, cowpea haulm and their combination recorded higher number of earthworms. The combined maize stover + cowpea haulm and the sole maize stover treatments did not differ in their effect on earthworm population. Earthworm population was initially higher after four weeks and it decreased considerably in the course of the season irrespective of treatment.

4.7.1.2 Termites

Addition of crop residues resulted in significantly ($P < 0.05$) higher number of termites compared with the fertilizer and the no input control. Termite population was higher under the 10 t ha⁻¹ maize stover and was over 200 and 186% over the fertilizer and no input control respectively four weeks after treatments application. However, the population declined thereafter for all the treatments in the course of the season (Table 17b).

Table 17b: Population counts of termites in a Ferric Acrisol amended with crop residues compared with fertilized and unfertilized control at different periods during 2007 major season.

Amendments	sampling periods			
	4 weeks	8 weeks	16 weeks	mean
	m ⁻²			
Control	19.90	11.79	7.94	13.21
10 t ha ⁻¹ Cowpea haulm	31.77	15.52	10.85	19.38
10 t ha ⁻¹ Maize stover	57.01	30.38	16.38	34.59
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ Cowpea	42.48	29.19	12.57	28.08
NPK (90–60–60 kg ha ⁻¹)	17.89	10.50	6.72	11.70
LSD (5 %)	2.54	0.38	0.86	0.68
CV (%)	4.00	2.00	4.20	3.00

LSD (5%) for comparing means at the same level(s) of treatments = 1.69.

4.7.2 DISCUSSION

In arable land use systems, the change in habitat structure where vegetation is removed, reduced range and abundance of food resources and extreme climatic conditions at the soil surface combine to create an environment beyond tolerance limits of most soil fauna groups. The small number of fauna observed particularly in the control plot typically represents the status of soil fauna in the fields of resource poor farmers. This could be attributed to the lack of inputs of organic residues resulting in a lack of food so that arable soils characteristically support a small community of fauna with narrow species diversity as observed by Haynes *et al.* (2003).

Organic inputs such as crop residues provide food to soil organisms. High population of soil fauna observed in residue applied treatments may be the result of a greater accumulation of organic matter. Accumulation of organic matter from the crop residues (maize stover and cowpea haulm) may have provided resource base for the soil organisms. Beare *et al.* (1997) found that soil organisms are strongly limited by available energy sources and are in a state of starvation much of the time. The

increased supply of organic matter may possibly eliminate this state, in turn allowing their consumers (earthworm and termites) to subsequently increase in numbers. Surface applied residues preserve soil water from evaporation, reduce soil temperature and provide conducive niche for certain faunal groups (Robertson *et al.*, 1994).

The population of termite was higher under maize stover compared with cowpea haulm possibly due to preference for the former to the latter. Termite populations have been reported to increase with mulching and termite consumption is higher on plant residues with low nutritional quality (Tian *et al.*, 1993). Application of mulch and decomposition and of green manure in alley cropping and agroforestry studies has also been attributed to differences in termite activity with quality of plant matter (Lehmann *et al.*, 1995).

4.8 PHYSICO – CHEMICAL PROPERTIES OF THE SOIL AT THE STUDY SITE

4.8.1 RESULTS AND DISCUSSION

The initial physico – chemical properties of the soil used for this study are presented in Table 18.

4.8.1.1 Soil pH

The pH of the soil measured in water recorded a value of 5.07 (Table 18). According to Landon (1996), soil with pH value > 8.5 is rated very high, 7.0 – 8.5 high, 5.5 – 7.0 medium and < 5.5 low. Based on these ratings, the pH of the soil could be rated as low. The low pH value recorded at the experimental site could be attributed to leaching of basic cations and also the amount of acidic cations present.

Table 18: Initial physico–chemical properties of the Asuansi soil series (Ferric Acrisol) at the study site

Soil property	Mean (0- 20 cm)
pH (soil: water, 1:2.5)	5.07 (0.05)
Organic carbon (%)	1.21 (0.19)
Organic matter (%)	2.09 (0.33)
Total N (%)	0.10 (0.01)
Available P (mg kg ⁻¹)	26.00 (0.02)
Exchangeable cations (cmolkg⁻¹ soil)	
Ca	5.52 (0.68)
Mg	0.64 (0.00)
K	0.42 (0.08)
Na	0.27 (0.04)
Al	0.90 (0.14)
H	2.70 (0.42)
ECEC (cmolkg ⁻¹)	10.45 (0.08)
Base saturation (%)	65.55 (5.57)
Physical analyses	
Sand (%)	64.78 (2.06)
Silt (%)	22.97 (2.11)
Clay (%)	12.25 (0.05)
Textural class	Sandy loam
Bulk density (g cm ⁻³)	1.51 (0.02)
Moisture content (%)	11.50 (0.71)
Volumetric moisture content (%)	17.37 (0.82)
Porosity (%)	43.02 (0.00)

Values are the means of duplicate samples

Values in parentheses represent standard deviation

4.8.1.2 Soil organic matter

The percent organic carbon content of the soil was 1.21 and that obtained for organic matter was 2.09. Landon (1996) rated soil containing organic carbon > 20% as very high, 10 – 20% high, 4 – 10% medium, 2 – 4% low and < 2% very low. With reference to these ratings, the percent organic carbon could be described as low. This could be ascribed to lack of addition of organic materials in the form of crop residues and farm yard manure. These materials have been reported to increase the content of organic carbon and for that matter soil organic matter (Giller and Cadisch, 1995).

4.8.1.3 Total N

The value recorded for total N (0.10%) was low. Per cent total N content in soil > 1.0 is rated as very high, 0.5 – 1.0 high, 0.2 – 0.5 medium, 0.1 – 0.2 low and < 0.1 very low (Landon, 1996). Nitrogen is an essential component of organic matter. Consequent upon decomposition of organic matter, some nutrients including nitrogen are released for plant uptake. The low amount of total N obtained was as result of the low organic matter content of the soil.

4.8.1.4 Available P

The available P content of the soil (26.00 mg kg⁻¹) could be rated as high. Page *et al.* (1982) in referring to concentration of P soluble in dilute acid fluoride gave the following ratings: < 3 mg kg⁻¹ very low, 3 – 7 mg kg⁻¹ low, 7 – 20 mg kg⁻¹ medium and > 20 mg kg⁻¹ high. Landon (1996) reported that low phosphorus values certainly indicate deficiencies. However, high laboratory values can result from soils with low or even deficient phosphorus levels.

4.8.1.5 Exchangeable bases

The soil recorded a medium amount of calcium (5.52 cmolkg⁻¹). Landon (1996) rated soils having Ca > 10 cmolkg⁻¹ as high and < 4 cmolkg⁻¹ as low. The Mg content of the soil was 0.64 cmolkg⁻¹ (Table 18). Magnesium content < 0.2 cmolkg⁻¹ is rated low, 0.2 – 0.5 cmolkg⁻¹ medium and > 0.5 cmolkg⁻¹ high (Landon, 1996). Based on these ratings the soil could be rated as having a high Mg content. Magnesium content in the soil is closely related to the presence of other cations, particularly Ca and K. Increasing Ca: Mg ratio above 5: 1 makes magnesium to become less available to plants though soils can remain fertile over a wide range of

Ca: Mg ratios (Landon, 1996). The exchangeable K concentration of the soil sample recorded was 0.42 cmolkg^{-1} . Very sandy soils with low cation exchange capacity such as the one under consideration are poorly buffered with respect to potassium. In them the potassium ion concentration may be quite high at the initial stages of the growing season just after fertilizer application but the soils have little capacity to maintain the K concentration as plants remove the dissolved K from the soil solution. The exchangeable Na concentration of the soil recorded was 0.27 cmolkg^{-1} . When the estimated exchangeable Na exceeds 1.0 cmolkg^{-1} the soil is considered “sodic.”

4.8.1.6 Exchangeable acidity

The concentrations of the acidic cations (Al^{3+} and H^{+}) were 0.90 and 2.70 cmolkg^{-1} respectively (Table 18). Aluminium ion (Al^{3+}) is much less common than hydrogen ion (H^{+}) at pH values > 5 but becomes the dominant ion in extremely acid soils: pH < 4.5 .

4.8.1.7 Effective cation exchange capacity (ECEC)

The soil recorded a low ECEC value of $10.45 \text{ cmolkg}^{-1}$ soil according to the rating given by Landon (1996) (i.e. in cmolkg^{-1}) > 40 very high, $25 - 40$ high, $15 - 25$ medium, $5 - 15$ low. Cation exchange capacity is generally low at low pH values (Landon, 1996). The low ECEC value ($10.45 \text{ cmolkg}^{-1}$ soil) recorded could be due to the low pH value (5.07).

4.8.1.8 Percent base saturation

The calculated percent base saturation was (65.55%) (Table 18). Under most conditions, a relatively high base saturation ($> 60\%$) is desirable (Espinoza *et al.*,

2007). Based on this fact, the percent base saturation value of the soil could be said to be desirable.

4.8.1.9 Physical properties

A value of 1.51 g cm^{-3} was recorded as the bulk density of the soil (Table 18). Many studies have reported that soil compaction increases bulk density and soil strength, resulting in poor hydraulic and physical soil properties (Arvidsson, 1998). If bulk density becomes too high, it can limit plant root growth. The soil used for the study recorded a porosity value of 43.02% (Table 18). The porosity can be further improved by addition of crop residues. Volumetric moisture content of the soil recorded was 17.32% (Table 18). Adequate soil moisture content is effective for enhanced plant growth. Low soil water content could have moisture stress on crops at the early stages of growth. However, this will depend on the rainfall distribution pattern during the cropping season.

4.9 CHANGES IN SOIL PHYSICO – CHEMICAL PROPERTIES FOLLOWING THE APPLICATION OF CROP RESIDUES, NPK FERTILIZER AND THEIR COMBINATIONS

4.9.1 RESULTS

4.9.1.1 Soil pH

Application of 10 t ha^{-1} maize stover recorded a significantly ($P < 0.05$) high pH value (5.44) and the control treatment the lowest value (5.06) during the first cropping season (2006 minor). In the second cropping season (2007 major) a significant ($P < 0.05$) increase in pH values occurred irrespective of treatment applied. The increase was more pronounced in the 10 t ha^{-1} maize stover treatment (6.01). There was further increase during the third cropping season (2007 minor).

The change in soil pH after cropping for three seasons ranged from 11 to 18% (Table 19a).

4.9.1.2 Soil organic matter (SOM)

Changes in soil organic matter content following the application of different amendments revealed that the 10 t ha⁻¹ maize stover treatment recorded significantly ($P < 0.05$) high value relative to the others in the first cropping season (2006 minor). Soil organic matter content increased during the second cropping season (2007 major). There was a reduction in SOM content during the third cropping season (2007 minor). After cropping for three seasons, 10 t ha⁻¹ maize stover treatment recorded the highest value (2.35%) which was 12% above the initial value (2.09%). The control plot caused about 11% reduction in the amount of SOM.

Table 19a: Effect of crop residues, NPK fertilizer and their combinations on soil pH and soil organic matter (SOM) during three cropping seasons (2006-2007).

Amendments	pH				SOM (%)			
	2006 (minor)	2007 (major)	2007 (minor)	Mean	2006 (minor)	2007 (major)	2007 (minor)	Mean
Control	5.06	5.55	6.27	5.63	1.22	2.93	1.44	1.86
10 t ha ⁻¹ Maize stover	5.44	6.01	6.44	5.96	2.15	3.00	1.90	2.35
5 t ha ⁻¹ Maize stover + ½ NPK	5.26	5.78	6.46	5.83	1.88	2.96	1.66	2.17
NPK (90–60–60 kg ha ⁻¹)	5.09	5.77	6.27	5.71	1.38	2.94	1.62	1.98
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ cowpea	5.27	5.88	6.69	5.95	1.72	3.00	1.72	2.15
10 t ha ⁻¹ Cowpea haulm	5.35	5.98	6.61	5.98	1.50	3.00	1.55	2.02
5 t ha ⁻¹ Cowpea haulm + ½ NPK	5.37	5.94	6.27	5.86	1.82	2.95	1.72	2.16
LSD (5 %)	0.17	0.43	0.45	0.23	0.66	0.35	0.32	0.26
CV (%)	3.80	4.20	4.00	3.90	22.70	6.60	10.70	4.50

LSD (5 %) for comparing means (pH) at the same level(s) of treatments = 0.34.

LSD (5 %) for comparing means (SOM) at the same level(s) of treatments = 0.50.

4.9.1.3 Total N

There were no significant ($P > 0.05$) differences in soil total N among the treatments in the first season. Application of 10 t ha^{-1} maize stover recorded the highest value (0.09%) while the lowest values were recorded by the maize stover + cowpea haulm and 10 t ha^{-1} cowpea haulm treatments respectively (0.07%). Only the 10 t ha^{-1} maize stover treatment was able to increase the soil N content during the second cropping season (0.12%). The mean value obtained at the end of the study period range from 0.09 to 0.11% (Table 19b).

Table 19b: Effect of crop residues, NPK fertilizer and their combinations on total N and available P during three cropping seasons (2006-2007).

Amendments	Total N (%)				Avail. P (mg kg^{-1})			
	2006 (minor)	2007 (major)	2007 (minor)	Mean	2006 (minor)	2007 (major)	2007 (minor)	Mean
Control	0.08	0.08	0.10	0.09	23.18	26.70	25.40	25.09
10 t ha^{-1} Maize stover	0.09	0.12	0.11	0.11	44.41	54.20	42.10	46.90
5 t ha^{-1} Maize stover + $\frac{1}{2}$ NPK	0.08	0.10	0.12	0.10	32.77	44.30	38.80	38.46
(90–60–60 kg ha^{-1})	0.08	0.10	0.10	0.09	30.55	41.60	34.80	35.65
5 t ha^{-1} Maize + 5 t ha^{-1} cowpea	0.07	0.10	0.12	0.10	24.71	57.20	49.20	43.70
10 t ha^{-1} Cowpea haulm	0.07	0.10	0.11	0.09	30.29	45.80	36.40	37.50
5 t ha^{-1} Cowpea haulm + $\frac{1}{2}$ NPK	0.08	0.10	0.10	0.09	26.41	42.00	37.20	35.20
LSD (5%)	0.03	0.02	0.03	0.01	5.17	7.59	6.02	4.10
CV (%)	19.80	12.20	12.80	5.30	11.60	18.80	13.90	3.90
LSD (5%) for comparing means (Total N) at the same level(s) of treatments = 0.02								
LSD (5%) for comparing means (Avail. P) at the same level(s) of treatments = 6.40								

4.9.1.4 Available P

Available soil P content under the 10 t ha^{-1} maize stover treatment recorded a significantly ($P < 0.05$) high value (44.41 mg kg^{-1}) with the control recording the lowest 23.18 mg kg^{-1} (Table 19b). Significant ($P < 0.05$) increases were recorded by all the treatments during the second cropping season. The highest value was recorded

by the maize stover + cowpea haulm (57.20 mg kg^{-1}) followed by the 10 t ha^{-1} maize stover treatment (54.20 mg kg^{-1}) while the control recorded the lowest value (25.40 mg kg^{-1}). All the treatments except the control were able to increase the available P content of the soil with values ranging between 35 – 80% above the initial value of 26 mg kg^{-1} (Table 18).

4.9.1.5 Exchangeable bases

Changes in the content of exchangeable bases of the soil following the application of the different amendments are presented in Tables 19c(i) and 19c(ii) respectively. Exchangeable Ca content was lowest ($3.00 \text{ cmol kg}^{-1}$) under the 5 t ha^{-1} maize stover + $\frac{1}{2}$ NPK fertilizer treatment while the 10 t ha^{-1} maize stover and maize stover + cowpea haulm treatments recorded the highest values ($3.93 \text{ cmol kg}^{-1}$) in the first cropping season. There was an increase in the calcium content irrespective of the treatment applied in the second cropping season. The values further increased in the third cropping season (Table 19c(i)). Exchangeable Ca content decreased in all the plots after the three seasons cropping when compared to the initial value ($5.52 \text{ cmol kg}^{-1}$).

During the first cropping season, exchangeable Mg contents under maize stover + cowpea haulm treatment recorded the highest value ($2.07 \text{ cmol kg}^{-1}$) while the lowest value ($1.30 \text{ cmol kg}^{-1}$) was recorded by the control treatment. High values were obtained in the second cropping season. There was a significant ($P < 0.05$) decline in the exchangeable Mg content during the third cropping season for all the treatments except the 10 t ha^{-1} cowpea haulm and cowpea haulm + $\frac{1}{2}$ NPK treatments (Table 19c(ii)).

Table 19c(i): Effect of crop residues, NPK fertilizer and their combinations on exchangeable Ca and Mg during three cropping seasons (2006-2007).

Amendments	Ca (cmolkg ⁻¹)				Mg (cmolkg ⁻¹)			
	2006 (minor)	2007 (major)	2007 (minor)	Mean	2006 (minor)	2007 (major)	2007 (minor)	Mean
Control	3.40	4.87	5.38	4.55	1.30	2.33	1.20	1.92
10 t ha ⁻¹ Maize stover	3.93	5.27	5.40	4.87	1.87	3.27	2.33	2.20
5 t ha ⁻¹ Maize stover + ½ NPK	3.00	4.07	4.87	3.98	2.00	3.27	3.00	2.76
NPK (90–60–60 kg ha ⁻¹)	3.40	3.53	6.00	4.31	1.60	2.00	1.67	1.76
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ cowpea	3.93	5.27	6.13	5.11	2.07	2.33	1.53	1.98
10 t ha ⁻¹ Cowpea haulm	3.67	5.13	5.20	4.67	1.67	2.53	2.93	2.38
5 t ha ⁻¹ Cowpea haulm + ½ NPK	3.60	4.27	5.60	4.49	1.80	2.53	2.60	2.31
LSD (5%)	0.97	1.64	1.39	0.62	0.67	1.09	0.73	0.84
CV (%)	15.30	20.20	14.20	4.00	21.60	16.50	18.70	11.60
LSD (5%) for comparing means (Ca) at the same level(s) of treatments = 1.39.								
LSD (5%) for comparing means (Mg) at the same level(s) of treatments =1.36.								

Combined application of maize stover + cowpea haulm recorded the highest K value (0.36 cmolkg⁻¹) with 10 t ha⁻¹ cowpea haulm being the next best treatment recording a value of 0.35 cmolkg⁻¹. Potassium content decreased in the second cropping season in the plots treated with the various amendments. But there was a significant ($P < 0.05$) increase in all the plots except the unamended control. The mean values recorded after the three cropping seasons were lower than the initial content of 0.42 cmolkg⁻¹ (Table 19c(ii)).

The exchangeable Na content recorded in the first cropping season (2006 minor) ranged between 0.16 and 0.20 cmolkg⁻¹ (Table 19c(ii)). The second cropping season (2007 major) recorded increases in the exchangeable Na content. However, these increases were not statistically different ($P > 0.05$) from each other. This trend was again observed in the third cropping season (2007 minor).

Table 19c(ii): Effect of crop residues, NPK fertilizer and their combinations on exchangeable K and Na during three cropping seasons (2006-2007).

Amendments	K (cmolkg ⁻¹)				Na (cmolkg ⁻¹)			
	2006 (minor)	2007 (major)	2007 (minor)	Mean	2006 (minor)	2007 (major)	2007 (minor)	Mean
Control	0.28	0.14	0.13	0.18	0.17	0.26	0.33	0.25
10 t ha ⁻¹ Maize stover	0.32	0.15	0.16	0.21	0.17	0.26	0.33	0.25
5 t ha ⁻¹ Maize stover + ½ NPK	0.26	0.13	0.19	0.19	0.20	0.25	0.32	0.26
NPK (90–60–60 kg ha ⁻¹)	0.29	0.18	0.20	0.22	0.20	0.27	0.34	0.27
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ cowpea	0.36	0.13	0.22	0.24	0.16	0.28	0.34	0.26
10 t ha ⁻¹ Cowpea haulm	0.35	0.16	0.21	0.24	0.19	0.27	0.32	0.26
5 t ha ⁻¹ Cowpea haulm + ½ NPK	0.28	0.17	0.19	0.21	0.18	0.27	0.33	0.26
LSD (5%)	0.13	0.08	0.04	0.06	0.06	0.04	0.04	0.03
CV (%)	23.50	30.50	11.20	6.40	17.90	9.30	6.30	3.30
LSD (5%) for comparing means (K) at the same level(s) of treatments = 0.08								
LSD (5%) for comparing means (Na) at the same level(s) of treatments = 0.04								

4.9.1.6 Exchangeable acidity (Al and H)

The control treatment recorded the highest value of exchangeable H (4.33 cmolkg⁻¹) with 10 t ha⁻¹ treatment recording the lowest value (3.07 cmolkg⁻¹) during the first season. The exchangeable H concentration declined during the second cropping season. The values further declined in the third cropping season. With the exception of the control and NPK amended plots, all the other treatments reduced the exchangeable H content by about 15 – 18% when compared to the initial value of 2.70 cmolkg⁻¹ at the end of the three cropping seasons (Table 19d). Exchangeable Al content during the first cropping season varied significantly ($P < 0.05$) with the plot treated with NPK fertilizer recording the highest value (1.21 cmolkg⁻¹) and the 10 t ha⁻¹ maize stover treatment recording the lowest value (0.57 cmolkg⁻¹). With the exception of the 10 t ha⁻¹ maize stover treatment, all the other treatments showed a decline in the exchangeable Al content in the second cropping season. The values

obtained at the end of study period ranged between 0.61 and 0.78 cmolkg⁻¹ which were about 13 – 32% below the initial value (0.90 cmolkg⁻¹) (Table 19d).

Table 19d: Effect of crop residues, NPK fertilizer and their combinations on exchangeable acidity (Al and H) during three cropping seasons (2006-2007).

Amendments	Al (cmolkg ⁻¹)				H (cmolkg ⁻¹)			
	2006 (minor)	2007 (major)	2007 (minor)	Mean	2006 (minor)	2007 (major)	2007 (minor)	Mean
Control	0.80	0.53	0.70	0.68	4.33	3.47	0.47	2.76
10 t ha ⁻¹ Maize stover	0.57	0.87	0.60	0.68	3.27	3.20	0.40	2.29
5 t ha ⁻¹ Maize stover + ½ NPK	0.93	0.47	0.70	0.70	3.40	3.27	0.20	2.29
NPK (90–60–60 kg ha ⁻¹)	1.20	0.53	0.60	0.78	4.27	3.60	0.33	2.73
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ cowpea	1.07	0.47	0.50	0.68	3.87	2.60	0.40	2.29
10 t ha ⁻¹ Cowpea haulm	0.87	0.47	0.50	0.61	3.30	3.07	0.40	2.26
5 t ha ⁻¹ Cowpea haulm + ½ NPK	0.87	0.47	0.50	0.61	3.33	2.93	0.40	2.22
LSD (5%)	0.52	0.20	0.10	0.07	1.17	0.84	0.12	0.89
CV (%)	33.00	13.90	21.10	12.80	18.30	15.20	22.90	6.40
LSD (5%) for comparing means (Al ³⁺) at the same level(s) of treatments = 0.20.								
LSD (5%) for comparing means (H ⁺) at the same level(s) of treatments = 0.89								

4.9.1.7 Effective cation exchange capacity (ECEC)

The ECEC of the soil recorded during the first cropping season ranged between 9.79 and 11.46 cmolkg⁻¹. The ECEC values increased during the second cropping season under all the treatments except the NPK fertilizer and maize stover + cowpea haulm treatments. During the third cropping season there was a significant ($P < 0.05$) increase under all treatments. The control recorded the lowest value (8.21 cmolkg⁻¹) whiles cowpea haulm + ½ NPK treatment recorded the highest value (9.62 cmolkg⁻¹) during the third cropping season (Table 19e).

Table 19e: Effect of crop residues, NPK fertilizer and their combinations on ECEC and percent base saturation during three cropping seasons (2006-2007).

Amendments	ECEC (cmolkg ⁻¹)				BS (%)			
	2006 (minor)	2007 (major)	2007 (minor)	Mean	2006 (minor)	2007 (major)	2007 (minor)	Mean
Control	10.28	11.60	8.21	10.03	50.10	65.52	85.75	67.12
10 t ha ⁻¹ Maize stover	10.13	13.02	9.22	10.79	62.09	68.74	89.15	73.33
5 t ha ⁻¹ Maize stover + ½ NPK	9.79	11.46	9.28	10.18	55.77	67.36	90.30	71.14
NPK (90–60–60 kg ha ⁻¹)	10.96	10.11	9.14	10.07	50.09	58.89	89.82	66.02
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ cowpea	11.46	11.08	9.12	10.55	56.89	72.29	90.13	73.10
10 t ha ⁻¹ Cowpea haulm	10.05	11.63	9.56	10.41	58.51	69.56	90.59	72.89
5 t ha ⁻¹ Cowpea haulm + ½ NPK	10.06	10.64	9.62	10.10	58.25	66.60	90.64	72.31
LSD (5%)	1.80	2.41	1.26	1.40	8.67	6.27	2.23	4.72
CV (%)	10.10	11.80	7.70	6.30	5.40	7.40	4.40	8.20
LSD (5%) for comparing means (ECEC) at the same level(s) of treatments = 2.10.								
LSD (5%) for comparing means (% BS) at the same level(s) of treatments = 15.24.								

4.9.1.8 Percent base saturation

High percent base saturation was recorded under the 10 t ha⁻¹ maize stover treatment (62.09%) while the NPK fertilizer treatment recorded the lowest value (50.10%) in the first cropping season (2006 minor). The values increased in the second season (2007 major). The percent base saturation value of the soil further increased significantly ($P < 0.05$) during the third cropping season (2007 minor). The mean values obtained for three cropping seasons ranged between 66.02 and 73.33% (Table 19e).

4.9.1.9 Physical properties

The effect of the different amendments on soil physical properties are presented in Tables 19f(i) and 19f(ii). Soil bulk density was significantly ($P < 0.05$) higher under the unamended plot (1.55 g cm⁻³) and lower in the plot treated with 10 t ha⁻¹ maize

stover (1.40 g cm^{-3}) in the first cropping season. The values decreased during the second cropping season and increased again in the third cropping season. The mean values recorded for the three cropping seasons were 1.52 g cm^{-3} in the control plot and 1.39 g cm^{-3} in the plot treated with 10 t ha^{-1} maize stover (Table 19f(i)). Porosity was low (41.51%) under the control plot and high (47.17%) in the plot treated with 10 t ha^{-1} maize stover during the first cropping season. There was a significant ($P < 0.05$) increase during the second cropping season. The values decreased slightly in the third cropping season. The mean values recorded after cropping for three seasons ranged from 42.51 to 47.42% (Table 19f(i)).

Table 19f(i): Effect of crop residues, NPK fertilizer and their combinations on soil bulk density and porosity during three cropping seasons (2006-2007).

Amendments	Bulk density (gcm^{-3})				Porosity (%)			
	2006 (minor)	2007 (major)	2007 (minor)	Mean	2006 (minor)	2007 (major)	2007 (minor)	Mean
Control	1.55	1.50	1.52	1.52	41.51	43.40	42.64	42.51
10 t ha^{-1} Maize stover	1.40	1.38	1.40	1.39	47.17	47.92	47.17	47.42
5 t ha^{-1} Maize stover + $\frac{1}{2}$ NPK	1.47	1.46	1.48	1.47	44.50	44.91	44.15	44.52
NPK (90–60–60 kg ha^{-1})	1.49	1.49	1.51	1.50	43.77	43.77	43.02	43.52
5 t ha^{-1} Maize + 5 t ha^{-1} cowpea	1.43	1.41	1.45	1.43	46.03	46.79	45.28	45.91
10 t ha^{-1} Cowpea haulm	1.43	1.42	1.46	1.44	46.03	46.42	44.91	45.79
5 t ha^{-1} Cowpea haulm + $\frac{1}{2}$ NPK	1.43	1.43	1.45	1.44	46.03	45.28	45.28	45.53
LSD (5%)	0.04	0.03	0.05	0.07	2.00	3.15	2.10	1.50
CV (%)	1.70	1.00	3.30	2.30	2.40	1.50	3.00	2.00
LSD (5%) for comparing means (bulk density) at the same level of treatments = 0.10								
LSD (5%) for comparing means (Porosity) at the same level of treatments = 1.00								

Volumetric moisture content was significantly ($P < 0.05$) higher under the maize stover + cowpea haulm treatment and low in the control plot during the first cropping season (Table 19f(ii)). The same pattern was observed in the second and third cropping seasons. Application of 10 t ha^{-1} maize stover, 10 t ha^{-1} cowpea

haulm and their combination increased the volumetric moisture content after cropping for three seasons. The values obtained were 17, 9 and 6% respectively above the initial content.

Table 19f(ii): Effect of crop residues, NPK fertilizer and their combinations on soil volumetric moisture content during three cropping seasons (2006-2007).

Amendments	Volumetric moisture (%)			Mean
	2006 (minor)	2007 (major)	2007 (minor)	
Control	12.91	15.00	12.69	13.53
10 t ha ⁻¹ Maize stover	19.14	22.08	19.60	20.27
5 t ha ⁻¹ Maize stover + ½ NPK	16.17	19.46	15.99	17.21
NPK (90–60–60 kg ha ⁻¹)	14.41	14.11	14.18	14.23
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ cowpea	18.59	20.21	17.88	18.89
10 t ha ⁻¹ Cowpea haulm	17.16	19.41	18.72	18.43
5 t ha ⁻¹ Cowpea haulm + ½ NPK	15.16	18.12	15.73	16.34
LSD (5%)	2.76	2.33	3.00	2.15
CV (%)	9.60	7.10	12.15	10.14
LSD (5%) for comparing means at the same level(s) of treatments= 2.25				

Table 20: Spearman rank correlation coefficients between bulk density, volumetric moisture content, SOM and porosity

	Porosity	ρ_b	Θ_v	SOM
Porosity	1.000			
ρ_b	-1.000**	1.000		
Θ_v	0.989*	- 0.984**	1.000	
SOM	0.976*	-0.976	0.934	1.000

* correlation is significant at $P < 0.05$

** correlation is significant at $P < 0.01$

4.9.2 DISCUSSION

4.9.2.1 Soil pH

The residue amended plots were able to increase the pH level of the soil at the end of the study period. Residue on the soil surface protects it from raindrop impact that can lead to erosion and leaching of basic cations (Schomberg and Steiner, 1999). The NPK fertilizer treatment and the control plots at the end of the study period recorded the lowest values. The low pH recorded under the NPK fertilizer treatment might be due to acidification of the soil by the urea N fertilizer applied. Bouman *et al.* (1995) also observed that long term use of ammonium nitrate and urea led to soil acidification in silty loam soils.

4.9.2.2 Soil organic matter (SOM)

Soil organic matter contents were relatively higher in plots treated with crop residues compared with the control and NPK fertilizer treated plots. It must be emphasized that the values recorded at the end of study period especially in the residue amended plots were low when compared to the ratings given by Landon (1996). Low organic matter content may have been as a result of crop residues blown out of the plots by wind before decomposition. Other factors such as soil texture and mineralogy and the amount of annual crop residue can affect the rate of C accumulation in soils (Bayer *et al.*, 2006).

An improvement of SOM level due to 15 – 20 t ha⁻¹ mulch for 5 years was reported in Queensland, which is cooler than the semi – deciduous forest zone of Ghana (Wood, 1991). The amount of residue mulch applied in this study was 10 t ha⁻¹ for three cropping seasons (2006–2007). Thus the rates of application of crop residue

mulch and the duration in the present study were relatively lower and shorter to result in an apparent SOM increase in the semi – deciduous environment in Ghana, although there were relative increases during the second cropping season. This could be attributed to adequate or favourable condition for plant growth which indirectly add organic matter through or from the root and also biomass production. The decrease in 2007 minor is possibly related to unfavourable condition for decomposition (especially moisture) as well as residues been blown out from the plot before decomposition.

4.9.2.3 Total N

Soil total N content decreased in all plots irrespective of the type of amendment applied in the first cropping season. This is possibly due to immobilization especially in the residue amended plots. There was a significant improvement in total N in the maize stover amended plots relative to the others (Table 19b) in the second cropping season. Combined application of crop residues and residue + $\frac{1}{2}$ NPK fertilizer increased the N content in the third season. Thompson (1992) recorded a similar interaction on a Vertisol in southern Queensland, where highest total N was recorded with combination of no – tillage, stubble retention and N fertilizer application.

4.9.2.4 Available P

Changes in available P were generally high in all the amended plots when compared with the initial value. The increases were highest in plots treated with crop residues and residue + $\frac{1}{2}$ NPK fertilizer. This could be due to the relative increase in organic matter content in these plots. The incorporation of crop residues has been shown to increase the amount of soluble organic matter which are mainly organic acids that

increase the rate of desorption of phosphate and thus improves the available P content in the soil (Nziguheba *et al.*, 1998). The decrease in P values in 2007 minor season could be attributed to the decline in SOM content during that period.

4.9.2.5 Exchangeable bases

The exchangeable Ca content of the soil decreased in all plots at the end of the study period by 7 and 28%. The decrease was more pronounced in the plot treated with the 10 t ha⁻¹ maize stover. The various amendments increased exchangeable Mg content. The sole maize stover treated plot recorded the highest value. The high Mg values recorded could be ascribed to the low Ca content. High Ca content tends to affect the availability of Mg according to Landon (1996). Exchangeable K decreased in all the plots irrespective of treatment and the changes ranged between 43% under organic fertilizer, 55% under combined organic and inorganic treatments and 57% under control and inorganic fertilizer treatments (Table 19c(ii)). Application of the different amendments decreased the exchangeable Na content of the soil. The decrease was higher in plots treated with crop residues.

4.9.2.6 Exchangeable acidity (Al and H)

Application of crop residues alone and residue + inorganic fertilizer decreased the exchangeable Al and H content of the soil. Residues on soil surface protect it from leaching of basic cations and thus prevent the soil from becoming acidic.

4.9.2.7 Effective cation exchange capacity (ECEC)

Only the maize stover + ½ NPK and maize stover + cowpea treatments were able to increase the ECEC content of the soil at the end of the study of period.

4.9.2.8 Percent base saturation

The percent base saturation of the soil increased throughout the study period. Application of crop residues (cowpea haulm and maize stover) recorded the highest values while the control and NPK fertilizer amended plots recorded the lowest.

4.9.2.9 Physical properties

The application of crop residues especially 10 t ha^{-1} maize stover was able to decrease the bulk density of the soil. The significant decrease in bulk density by the maize stover residue was in contrast to the report by Borresen (1999) who observed that 4 – year wheat straw application at 4.3 t ha^{-1} in Norway did not affect the bulk density. This discrepancy may be attributed to the type of residue (maize stover) and the quantity (10 t ha^{-1}) applied in this study. The porosity of the soil at the end of the study period was higher in plot treated with 10 t ha^{-1} maize stover. Addition of mulch increased the total porosity in more compacted soil under reduced tillage where crop residues are retained (Ghuman and Sur, 2001).

The 10 t ha^{-1} maize stover increased the initial volumetric moisture content by 17%. This may be due to the low bulk density value recorded under this treatment. The negative correlation ($r = -0.984$) found between volumetric moisture content and bulk density meant that, a high soil bulk density (due to compaction) would impede both water and air movement into the soil and hence low amount of water would be stored in the soil.

4.10: MAIZE GRAIN AND STOVER YIELDS AS AFFECTED BY THE APPLICATION OF CROP RESIDUES, NPK FERTILIZER AND THEIR COMBINATIONS

4.10.1 RESULTS

4.10.1.1 Grain yield

Maize grain yield following the application of maize stover, cowpea haulm, NPK fertilizer and their combinations during three cropping seasons (2006 – 2007) are presented in Table 21a. The NPK fertilizer treatment recorded the highest yield (1.17 t ha^{-1}) followed by the 5 t ha^{-1} cowpea haulm + $\frac{1}{2}$ NPK fertilizer treatment (1.11 t ha^{-1}) which were $0.40 - 0.46 \text{ t ha}^{-1}$ (56.3 – 64.8%) over the control (Table 21a). In the second cropping season (2007 major), the effect of the amendments on maize grain yield deviated from those observed in the first season (2006 minor). The 5 t ha^{-1} maize stover + $\frac{1}{2}$ NPK treatment recorded the highest yield (2.78 t ha^{-1}) followed by the 5 t ha^{-1} cowpea haulm + $\frac{1}{2}$ NPK treatment (2.72 t ha^{-1}) while the control recorded the lowest yield (1.35 t ha^{-1}). The yield increases over the control ranged from $1.37 - 1.43 \text{ t ha}^{-1}$ (101.5 – 105.9%). Yield significantly ($P < 0.05$) declined in the third cropping season (2007 minor). However, all the amendments performed better than the control. Yield increments over the control ranged between $0.14 - 0.80 \text{ t ha}^{-1}$ (16.9 – 96.4%). Mean grain yield over the three cropping seasons were highest in the 5 t ha^{-1} maize stover + $\frac{1}{2}$ NPK (1.69 t ha^{-1}) and 5 t ha^{-1} cowpea haulm + $\frac{1}{2}$ NPK (1.62 t ha^{-1}) treatments and lowest in the control (0.83 t ha^{-1}).

Table 21a: Effect of crop residues, NPK fertilizer and their combinations on maize grain and stover yields during three cropping seasons (2006-2007).

Amendments	Grain yield (t ha ⁻¹)				Stover yield (t ha ⁻¹)			
	2006	2007	2007	Mean	2006	2007	2007	Mean
	(minor)	(major)	(minor)		(minor)	(major)	(minor)	
Control	0.71	1.35	0.42	0.83	1.72	2.67	1.04	1.83
10 t ha ⁻¹ Maize stover	0.74	1.56	0.62	0.97	1.72	2.88	1.36	1.98
5 t ha ⁻¹ Maize stover + ½ NPK	1.05	2.78	1.25	1.69	2.09	4.10	2.45	2.88
NPK (90–60–60 kg ha ⁻¹)	1.17	2.47	1.01	1.55	2.20	3.83	2.13	2.72
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ cowpea	0.85	1.88	0.74	1.15	1.74	3.10	1.75	2.21
10 t ha ⁻¹ Cowpea haulm	1.01	2.07	0.82	1.30	2.09	3.50	1.85	2.48
5 t ha ⁻¹ Cowpea haulm + ½ NPK	1.11	2.72	1.07	1.62	2.16	4.04	2.16	2.79
LSD (5%)	0.10	0.12	0.16	0.10	0.24	0.33	0.37	0.24
CV (%)	6.00	3.30	11.00	3.10	7.10	5.50	12.00	5.60
LSD (5%) for comparing means (grain) at the same level(s) of treatments = 0.14								
LSD (5%) for comparing means (stover) at the same level(s) of treatments = 0.25								

4.10.1.2 Stover yield

The stover yield during three cropping seasons (2006 – 2007) following the application of maize stover, cowpea haulm, NPK fertilizer and their combinations are presented in Table 21a. In the first cropping season (2006 minor) significantly high ($P < 0.05$) biomass yield of 2.18 t ha⁻¹ was recorded by the 5 t ha⁻¹ cowpea haulm + ½ NPK treatment while the control treatment recorded the lowest yield of 1.70 t ha⁻¹. The yield obtained during the second cropping season (2007 major) ranged between 2.67 – 4.10 t ha⁻¹. The control treatment recorded the lowest stover yield and the 5 t ha⁻¹ maize stover + ½ NPK treatment the highest. In the third cropping season (2007 minor) stover yield declined in all the treatments with yield values ranging between 1.04 and 2.45 t ha⁻¹. The mean stover yield for the three cropping seasons indicated that the unamended treatment recorded the lowest yield (1.80 t ha⁻¹) and again the maize stover + ½ NPK treatment produced the highest yield (2.88 t ha⁻¹).

4.10.1.3 Harvest index

Table 21b shows the effects of the various amendments on harvest index. Treatments significantly influenced ($P < 0.05$) harvest index. In the first cropping season (2006 minor) the inorganic fertilizer treatment recorded the highest harvest index (53.2%) followed by the 5 t ha^{-1} cowpea haulm + $\frac{1}{2}$ NPK treatment (51.4%) with the control recording the lowest value (38.3%). Significantly high ($P < 0.05$) harvest indices were recorded for all the treatments during the second cropping season (2007 major). The highest value was recorded by the 5 t ha^{-1} + $\frac{1}{2}$ NPK treatment (67.8%) and the lowest value (50.6%) by the control. The values significantly declined ($P < 0.05$) in the third cropping season (2007 minor) for all the treatments with values ranging from 40.4 – 51.0% (Table 21b).

Table 21b: Effect of maize stover, cowpea haulm, NPK fertilizer and their combinations on harvest index during three cropping seasons (2006-2007).

Amendments	Harvest index (%)			
	2006 (minor)	2007 (major)	2007 (minor)	Mean
Control	38.27	50.56	40.38	44.07
10 t ha^{-1} Maize stover	43.02	54.16	45.59	47.59
5 t ha^{-1} Maize stover + $\frac{1}{2}$ NPK	50.24	67.80	51.02	55.19
NPK (90–60–60 kg ha^{-1})	53.18	64.49	47.42	56.23
5 t ha^{-1} Maize + 5 t ha^{-1} cowpea haulm	48.02	60.32	42.29	50.21
10 t ha^{-1} Cowpea haulm	48.33	59.10	44.32	50.58
5 t ha^{-1} Cowpea haulm + $\frac{1}{2}$ NPK	51.39	67.33	48.15	55.62
LSD (5%)	4.02	4.47	3.54	2.06
CV (%)	4.50	4.10	4.40	2.20

LSD (5%) for comparing means at the same level(s) of treatments = 4.71

4.10.1.4 Hundred seed weight

Table 21c summarizes the effect of the various treatments on hundred seed weight.

The hundred seed weight followed a similar trend as the maize grain yield (Table 21c). There were significant differences ($P < 0.05$) among the treatments in the first

cropping season (2006 minor). The 5 t ha⁻¹ Maize stover + ½ NPK treatment recorded the highest weight (42.37 g) and the control the lowest weight (36.37 g) in the first cropping season (2006 minor). Significantly high (P < 0.05) values were recorded during the second cropping season (2007 major) compared to the first season. The values obtained were in the range 38.72 – 44.97 g. The hundred seed weight values obtained in the third season (2007 minor) were the lowest compared with the first two seasons. The control treatment recorded the lowest value (22.64 g) while the 5 t ha⁻¹ maize stover + ½ NPK treatment had the highest (27.50 g).

Table 21c: Effect of maize stover, cowpea haulm, NPK fertilizer and their combinations on hundred seed weight during three cropping seasons (2006 – 2007).

Amendments	seed weight (g)			Mean
	2006 (minor)	2007 (major)	2007 (minor)	
Control	36.37	38.72	22.64	32.58
10 t ha ⁻¹ Maize stover	38.32	39.72	24.58	34.28
5 t ha ⁻¹ Maize stover + ½ NPK	42.37	44.97	27.50	38.28
NPK (90–60–60 kg ha ⁻¹)	40.35	44.34	25.73	36.81
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ cowpea haulm	40.60	45.07	24.66	36.78
10 t ha ⁻¹ Cowpea haulm	40.13	41.46	25.19	35.59
5 t ha ⁻¹ Cowpea haulm + ½ NPK	39.75	43.10	25.03	35.76
LSD (5%)	2.86	3.70	3.25	2.71
CV (%)	4.00	4.90	7.30	4.30

LSD (5%) for comparing means at the same level(s) of treatments = 2.09

4.10.1.5 Nitrogen uptake

Amount of N taken up by grain and stover following the application of different treatments are presented in Table 21d. More N was taken up by both grain and stover from combined application of cowpea haulm + ½ NPK fertilizer followed by 10 t ha⁻¹ cowpea haulm in the first cropping season. In the second season application of crop residues + ½ NPK recorded the highest N uptake with the control the lowest. This pattern was again observed after the three cropping seasons (Table 21d).

Table 21d: Effect of crop residues, NPK fertilizer and their combinations on N uptake by grain and stover during three cropping seasons (2006-2007).

Amendments	Grain (kg ha ⁻¹)				Stover (kg ha ⁻¹)			
	2006 (minor)	2007 (major)	2007 (minor)	Mean	2006 (minor)	2007 (major)	2007 (minor)	Mean
Control	4.95	12.08	4.18	7.07	8.50	13.33	6.17	9.34
10 t ha ⁻¹ Maize stover	8.04	15.52	6.69	10.08	12.94	25.16	12.49	16.86
5 t ha ⁻¹ Maize stover + ½ NPK	9.04	28.07	15.00	17.37	14.23	31.69	17.31	21.08
NPK (90–60–60 kg ha ⁻¹)	9.84	23.41	12.60	15.28	11.76	24.41	21.23	19.13
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ cowpea	9.09	18.89	9.22	12.40	13.39	25.12	18.89	19.13
10 t ha ⁻¹ Cowpea haulm	11.76	23.84	7.13	14.24	18.24	26.90	10.07	18.40
5 t ha ⁻¹ Cowpea haulm +½ NPK	12.88	33.66	11.71	19.24	19.97	37.59	19.85	25.81
LSD (5%)	1.07	1.53	1.93	0.88	1.92	2.43	3.86	0.97
CV (%)	6.40	3.90	11.40	3.60	7.60	5.20	14.30	5.60
LSD (5%) for comparing means (grain) at the same level(s) of treatments = 1.46								
LSD (5%) for comparing means (stover) at the same level(s) of treatments = 1.07								

4.10.1.6 Nitrogen recovery

Nitrogen recovered by the maize grain and stover after the application of organic and inorganic nutrient sources and their combinations are presented in Table 21e.

Table 21e: Effect of maize stover, cowpea haulm, NPK fertilizer and their combinations on N recovery during three cropping seasons (2006-2007).

Amendments	Grain (%)				Stover (%)			
	2006 (minor)	2007 (major)	2007 (minor)	Mean	2006 (minor)	2007 (major)	2007 (minor)	Mean
10 t ha ⁻¹ Maize stover	3.97	3.88	3.27	3.71	7.86	14.34	9.14	10.45
5 t ha ⁻¹ Maize stover + ½ NPK	4.79	19.27	12.99	12.35	7.28	23.14	13.51	14.64
NPK (90–60–60 kg ha ⁻¹)	5.02	11.60	8.90	8.24	2.12	11.02	10.39	7.85
5 t ha ⁻¹ Maize + 5 t ha ⁻¹ cowpea	2.58	3.90	2.80	3.12	3.24	6.54	8.08	5.96
10 t ha ⁻¹ Cowpea haulm	2.50	3.80	1.33	2.54	3.05	3.87	1.13	2.69
5 t ha ⁻¹ Cowpea haulm +½ NPK	4.38	10.88	3.91	6.39	6.61	11.24	6.91	8.25
LSD (5%)	0.33	0.78	0.18	0.21	0.36	1.28	0.08	0.52
CV (%)	4.70	4.80	1.80	5.00	3.90	6.00	1.20	5.40
LSD (5%) for comparing means (grain) at the same level(s) of treatments = 0.58								
LSD (5%) for comparing means (stover) at the same level(s) of treatments = 0.88								

In the first cropping season (2006 minor) the NPK fertilizer treatment significantly recovered ($P < 0.05$) the highest amount of N (5.02%) in the grain, while the lowest (2.50%) was recorded by the 10 t ha⁻¹ cowpea haulm treatment. However, with respect to the stover in the same cropping season, the NPK fertilizer treatment recovered the lowest value (2.12%) while the 10 t ha⁻¹ maize stover the highest (7.86%). Significantly high ($P < 0.05$) N was recovered in the maize grain following the application of maize stover + ½ NPK fertilizer in the second and the third cropping seasons (2007 major and minor) respectively. Similar trend was observed for the stover. The mean amount of N recovered at the end of the three cropping seasons in the grain ranged between 2.54 and 12.35% and that of the stover was 2.69 and 14.64% (Table 21e).

Table 22a: Spearman rank correlation coefficients between grain yield and porosity, volumetric moisture content and SOM

	Yield	Porosity	Øv	SOM
Yield	1.000			
Porosity	0.994**	1.000		
Øv	0.989*	0.999**	1.000	
SOM	0.948*	0.976	0.985*	1.000

* correlation is significant at $P < 0.05$

** correlation is significant at $P < 0.01$

Table 22b: Spearman rank correlation coefficients between grain yield and stover yield, N uptake, N recovery and harvest index

	Yield	Stover	N uptake	N recovery	Harvest index
Yield	1.000				
Stover	0.998**	1.000			
N uptake	0.979*	0.990*	1.000		
N recovery	0.880*	0.908	0.959	1.000	
Harvest index	0.853*	0.884	0.942*	0.999*	1.000

* correlation is significant at $P < 0.05$

** correlation is significant at $P < 0.01$

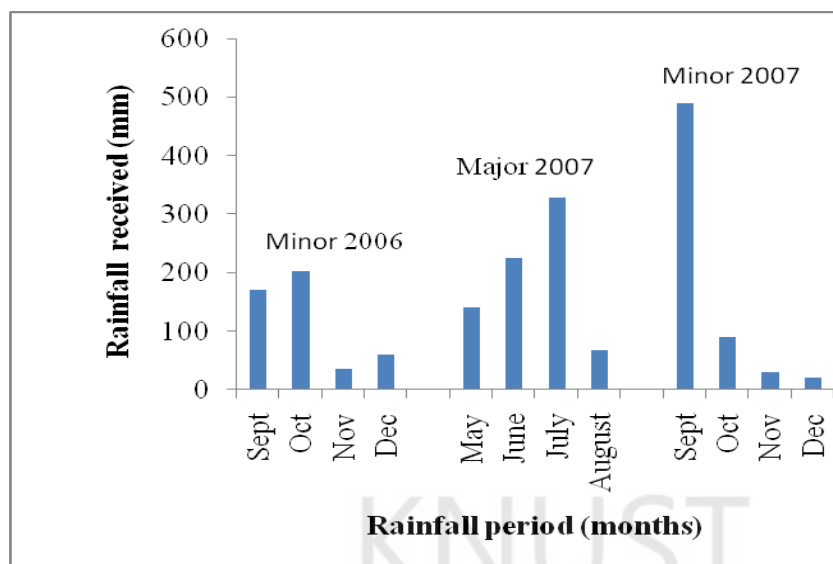


Fig. 13: Rainfall distribution patterns during the three cropping seasons.

4.10.2 DISCUSSION

4.10.2.1 Grain yield

The different amendments influenced grain yield throughout the study period. The NPK fertilizer recorded the highest yield during the first cropping season followed by the combined application of cowpea haulm and $\frac{1}{2}$ NPK fertilizer. All the treatments were significantly superior over the control. The high grain yield recorded by the NPK fertilizer in the first cropping season could be attributed to the readily available nutrients which could be utilized by the plant for growth. The low yield recorded by the sole application of the organic amendments (especially 10 t ha^{-1} maize stover) could be attributed to the slow release of nutrients for crop uptake. This slow nutrients release pattern of organic nutrient sources is attributed to the microbial decomposition and subsequent mineralization of N, a process largely affected by climate and residue quality (Palm and Sanchez, 1990).

The combined application of organic and NPK fertilizer recorded the highest grain yield during the second cropping season. Other workers have demonstrated identical results with combined use of organic and inorganic sources of nutrients (Gitari and

Friesen, 2001; Ayoola and Makinde, 2007). This might be due to addition of crop residues, which add organic matter and nitrogen to the soil and also the readily available nutrients in the inorganic fertilizer. Nutrient availability increases due to production of carbon dioxide and organic acids during decomposition of crop residues, which help in good growth of the plant.

An integrated nutrient management with combination of maize stover or cowpea haulm and fertilizer could help to reduce 50% fertilizer dose. Palm *et al.* (1997) also reported the possibility of saving 50% dose of fertilizers through integrated use of fertilizers and crop residues. Application of 50% of fertilizer through 5 t ha⁻¹ cowpea haulm and maize stover significantly increased the grain yield of maize compared with the control. These results provided evidence to the belief that about 50% fertilizers could be saved with the combined use of inorganic and organic fertilizers. Similar beneficial effect of integrated nutrient management has been reported by (Negassa *et al.*, 2007). The amount of rainfall received during the season could also possibly account for the high yield obtained for all the treatments compared with the other seasons (minor rainy seasons of 2006 and 2007) (Fig. 13).

Low yield in the third season could be attributed to low rainfall received during the period. Similar observations have been reported by (Tetteh, 2004) and Tanimu *et al.* (2007). The overall mean grain yield after three cropping seasons indicated that the unamended plots recorded the lowest yield. This was because the crops had to use the limited nutrients supplied by the soil without any external inputs. While the combined maize stover + ½ NPK fertilizer recorded the highest yield. Correlation analysis also showed that soil physical properties (porosity and volumetric moisture content) and SOM significantly affected maize grain yield.

4.10.2.2 Stover yield

The trend in stover yield was similar to that of the grain yield. Combined maize stover + $\frac{1}{2}$ NPK treatment recorded the highest yield. The pooled analysis of three season's data indicated that all the treatments were significantly superior to that of the control. Similar results were also reported by Vanlauwe *et al.* (2001) and Tanimu *et al.* (2007). Nitrogen uptake and grain yield correlated well with stover yield indicating the significant role of nitrogen in the final stover yield of crop.

4.10.2.3 Hundred seed weight

The hundred seed weight recorded by the various treatments followed similar trend as that of the grain yield. The grain yield greatly influenced the seed weight with the treatment recording the highest grain yield also producing the highest hundred seed weight.

4.10.2.4 Harvest index

Harvest index is the ratio of economic yield to biological yield and is used to describe the accumulation and redistribution of assimilates to achieve final yield (Bange *et al.*, 1998). This value and its stability are key determinants of crop yield (Echarte and Andrade, 2003). Harvest index of maize grain has been reported to be 0.50 (50 %) for most tropical maize (Hay and Gilbert, 2001). Most of the treatments recorded low harvest index values during the first cropping season (2006 minor) when compared to the value reported by Hay and Gilbert (2001). The mean harvest index obtained for the three cropping seasons showed that the control and application of 10 t ha⁻¹maize stover recorded values which were below the critical value of 0.5 (50%). Low grain crop harvest index could be attributed to late sowing,

imperfect sowing methods, low plant population, poor plant protection, and non-availability of water for irrigation at critical crop growth stages (Ahmad *et al.*, 2007).

Adequate rainfall at critical crop growth stage is essential for its growth and development. Non – availability of irrigation at critical growth stage significantly reduces crop harvest index (Ahmad *et al.*, 2007). Extremely low harvest index during the first and third cropping seasons (2006 minor and 2007 minor) was due to low rainfall received during the periods. Tropical maize varieties are generally tall and have a substantial capacity to store photosynthate as simple sugars in the stem. The consequence is that photosynthate is preferentially partitioned to structural components and sugar stores in the stem and to the tassel rather than the ear. To the intensive grain farmer, this represents a serious loss, but the subsistence farmer can benefit from improved digestibility of the maize stover, and superior materials for fencing and thatching. Low harvest index may not, therefore, be perceived as such a serious problem (Hay and Gilbert, 2001).

4.10.2.5 Nitrogen uptake

Studies on nitrogen uptake further supported the superiority of combined application of organic and inorganic nutrient sources over application of sole organic or inorganic fertilizer. Application of NPK fertilizer + cowpea haulm noted maximum nitrogen uptake followed by application of sole cowpea haulm. The overall N uptake following the various treatments application showed that combined use of organic and inorganic nutrient sources was better utilized by the maize plant. All the treatments were significantly superior to the control. These results are in conformity with Vanlauwe *et al.* (2001) that application of mineral inputs could have directly

improved uptake of residue – N by maize by enhancing the residue decomposition–mineralization process through the supply of N to the soil decomposer community.

This might be due to slow and continuous supply of nutrients to maize plant as required by the plants due to influence of chemical fertilizer on organic fertilizer as noted by Palm *et al.* (1997). Kramer *et al.* (2002) also indicated that the inorganic nitrogen source applied in combination with organic sources is better utilized than inorganic source of nutrient alone. The nitrogen uptake by maize is governed by its concentration in plants and dry matter accumulation. Correlation analysis between maize grain yield and N uptake indicated a strong relationship ($r = 0.979$) (Table 22a). It was evident that higher uptake of the nutrients especially N by the crop has contributed towards the increased grain yield, which was not seen in the unamended treatment (no crop residue or fertilizer).

4.10.2.6 Nitrogen recovery

The mean N recovery values also indicate that combined maize stover + $\frac{1}{2}$ NPK fertilizer treatments recorded the highest value. The values calculated for the sole organic amendment in this experiment support the hypothesis that crop residue decomposition rates influence nutrient availability. The lowest N recovery was always associated with the crop residue with the fastest decomposition rates, namely cowpea haulm. However, high nutrient recovery was found on the sole maize stover treatment, the residue with the slowest decomposition rate. Whitbread *et al.* (2003) found that the use of plant residues with slower decomposition rates due to factors such as lignin, secondary metabolites and leaf structure, was shown to increase soil C and to decrease C leached from a drained pot.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Application of crop residues to the soil supply nutrients and also help build soil organic matter over the long term. Knowledge of the nutrient contents, mineralization and decomposition patterns of crop residues, and their effects on crop productivity and soil properties, is important to planning their use in fertility management. Farming systems in Ghana produce substantial crop residues of different qualities with varying nutrient contents.

Decomposition was faster in the rainy seasons than in the dry season. Incorporation (burying) of the residues in the rainy season resulted in increased rate of decomposition thus reducing the half – life (t_{50}) of the residues by about 50%. Decomposition in the dry season was, however, not consistent due to variable moisture and temperature conditions. The organic material with higher C: N ratio (maize stover) had greater impacts on soil microbial biomass carbon and nitrogen than the high quality organic material (cowpea haulm).

5.2 Conclusions

It is essential to consider the properties and constitution of organic materials, and their effect on soil microbial biomass carbon, nitrogen and phosphorus. In the presence of soil fauna, the mulching effect of low quality organic material such as maize stover can improve soil physical properties but may reduce crop nitrogen use efficiency due to increased nitrogen immobilization. Since the maintenance of soil nutrient status is an important aspect of sustainability, the management of crop

residues and fertilizer to maintain soil fertility is necessary. The assessment of nutrient status, following the application of these amendments in an agricultural system, is an important step in understanding efficient nutrient management in agro-ecosystems.

Sole application of crop residues under the field experiment, did not improve maize grain yield. Application of slow decomposing maize stover could help build SOM in the long term and also help prevent leaching of nitrate. Combined application of organic and inorganic nutrient sources in an integrated nutrient management promised to be the option farmers could adopt to ensure higher yields. Whilst the return of crop residues is being advocated in Ghana, large improvements in soil fertility would require balanced fertilizer applications. In the long term, nutrient balances could be used to predict the likely fertilizer requirements. This study has added to knowledge on the quality, decomposition and nutrient release patterns of common crop residues in farming systems in Ghana. The study has also confirmed findings of other researchers that residues are diverse in quality, with rates of decomposition and nutrient release patterns depending on the chemical composition, climatic condition and placement method (i.e. burying or surface – placed).

5.3 Recommendations

Considering the high N content of cassava leaves and its fast decomposability which is comparable to leguminous plants usually used as source of nutrients, especially N, cassava leaves could be a good source of N in arable crop production. The changes in soil nutrient status after cropping for three seasons showed that there might be the need to increase the level of organic materials added and the duration of their

application to sustain the fertility of the soil. It is also recommended that maize stover should be applied two weeks before planting, whilst cowpea haulm should be applied at planting to ensure proper synchrony of nutrient release.

Further research on microbial biomass especially biomass P should be conducted by combining high and low quality residues to help make available this nutrient locked in the microbial biomass. There is also the need for further study on complementary application of organic and inorganic fertilizers under monocropping system to improve both the physical and chemical properties of soil.



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