OPTIMIZING MANURE QUALITY FOR INCREASED FOOD PRODUCTION ON SMALL HOLDER FARMS IN THE UPPER EAST REGION OF GHANA

BY

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B.Sc. (HONS) AGRICULTURE

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A Thesis submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, in partial fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY
IN
SOIL SCIENCE

BY
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DECLARATION

I declare that I have personally, under supervision, undertaken the study herein submitted.

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Nana Ewusi – Mensah

September, 2009

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

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Dr. J. V. K. Afun

Head of Department

DEDICATION

This dissertation is dedicated to the Omnipotent God, who knew me and my assignment even before I was conceived.

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I am not certain I can ever say how much I owe my dad, Dr. Ewusi – Mensah. For now I hope it is enough to say thank you. Your love, encouragement, financial and unflinching support have brought me this far. **Ayekoo dad!**

Lord God Almighty into your hands I finally commit this research work, may your name be glorified.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

The beneficial role of cattle manure to improving soil fertility has long been recognized. Its uses however have several drawbacks. One of such drawbacks is the nutrient content which is generally low and variable depending on the feed of the animal and manure management. This study focused on improving the quality of cattle manure for increased maize yields and consisted of five parts: 1. Assessment of the resource quality of cattle manure in seven districts of the Upper East region. 2. Composting of cattle manure. 3. Laboratory - incubation studies to determine nutrient release patterns of compost. 4. Field decomposition studies of buried compost in litter bags. 5. Assessment of the effects of compost, cowdung and NPK fertilizer on crop growth and yield.

A survey was conducted in seven districts of the Upper East region using structured questionnaires to seek information on management practices likely to influence manure quality such as storage and handling. The survey revealed that nitrogen losses up to 100% were sometimes obtained by the time the manure was incorporated into the soil.

An initial resource quality analysis of the manure sampled from the seven districts was conducted in the laboratory using standard protocols. The results indicated that N and P contents of the manure ranged from 0.27 to 1.14% and 0.28 to 0.76% respectively, which were all below the critical levels for net mineralization. Polyphenol levels on the other hand were lower than the critical value of 4%. Decomposition and nutrient release from the manure showed immobilization of total N during the first four weeks, suggesting the need to improve the quality by composting or by applying it in combination with mineral fertilizers.

In an attempt to improve the quality of the manure, composting with *Stylosanthes guinensis* using the aerated pile method was carried out. Two main compost types (1:1 and 2:1 ratios of cowdung to plant material) were prepared. Total N and P contents of the composts at the end of study period ranged from 1.10 to 1.46% and 0.28 to 0.31% respectively. Mineralization studies on the resultant composts were conducted under laboratory (leaching tube method) and field (litter bag technique) conditions. Under laboratory conditions, both compost types showed net N and P immobilizations during the first two weeks of incubation. However, under field conditions, net N and P mineralization rates were observed throughout the study period for both compost types. Half life values (time required for 50% of the initial mass to decompose) of 8 and 10 days respectively were recorded for the 1:1 and 2:1 compost types. Furthermore, the 1:1 compost had a higher decomposition rate constant ($k = 0.085$) than the 2:1 compost ($k = 0.056$). In all cases, negative correlations were observed between the mass of composts remaining and nutrient released.

The contribution of the composts to improving the fertility of the soil and hence crop growth was evaluated by comparing maize response to various rates of the composts with optimum mineral fertilizer combinations. The results showed that the 1:1 compost treatment at 3 t/ha, produced the highest maize grain yield (4.99 t/ha). Maize grain yields obtained from both compost types compared very well with NPK fertilizer suggesting that composting of cattle manure with *Stylosanthes guinensis* enhanced its quality and nutrient release potential for increased crop yield.

CHAPTER ONE

1.0 INTRODUCTION

Food insecurity and declining soil fertility across much of sub-Saharan Africa in recent decades have led to the pursuit of alternative nutrient management strategies for restoring degraded soils and improving crop yields (Sanchez, 2002). The application of inorganic fertilizer inputs is recognized as a convenient way for rapid correction of nutrient deficiencies in soils. However, the use of organic resources to build soil fertility and sustain crop yields will continue to be critical as smallholder farmers in the tropics are unable to access adequate quantities of mineral fertilizers due to high cost (Giller *et al*., 1997).

Organic inputs are often proposed as alternatives to mineral fertilizers. However, the benefits derivable from the use of organic materials have not been fully utilized in the humid tropics partly due to the low nutrient content of some of the materials and the huge quantities required in order to satisfy the nutritional needs of crops. Transportation as well as the handling costs also constitute major constraints (Ayoola, 2006). Given the high cost and uncertain accessibility of inorganic fertilizers in much of Africa, the combined use of inorganic and organic nutrient sources in particular has been put forth as a means both to improve both plant uptake and crop yields (Kramer *et al.,* 2002) and to reduce soil organic matter depletion (Bationo *et al.,* 2007). The success of this strategy however will depend on many factors such as the quality of the organic material used and the proportions of the nutrients applied from either source (Palm *et al*., 1997). This suggests that properties of these organic materials may have to be enhanced if maximum benefits are to be derived from their usage by the resource poor farmer, who has to increase productivity to adapt to increasing population and decreasing farm size. Unfortunately, for many trials there is lack of crucial information on nutrient content and quality of the organic inputs. Trials are needed that link the quality of the organic material to its fertilizer equivalency and its effect on the longer term composition of soil organic matter and crop yields.

Studies conducted by Fening *et al.* (2005) revealed the presence of substantial amounts of cattle manure in the Upper East region of Ghana that can be used by farmers for improving soil fertility. Despite this abundance, farmers experience appreciable decline in yield annually because the quality of the manure with regard to its nutrient release and crop uptake is poor. In many crop response trials on manure, rates and methods of application as well as effects on soil moisture dynamics have been considered (Dagg *et al*., 1965) and biological properties (Kapkiyai *et al*., 1999). However, these trials have seldom considered:

- the different factors that affect the quality of manure between time of excretion and application to fields
- mineralization and nutrient release patterns
- nutrient release and synchrony with crop demand and
- contribution of manure to amount of carbon sequestered.

Publications on organic matter transfer and utilization mainly deal with the livestock and soil-crop sub-systems and there is a distinct lack of information regarding manure handling and storage. When such studies have been carried out, research has concentrated on crop response to composted manure and invariably the origin of that manure is not specified (Rufino *et al*., 2006). This is very crucial since what happens to the manure between excretion and application to fields has a large impact on nutrient availability to crops. Furthermore, even though farmers may be fully aware of the fertilizing value of animal manure as well as the differences, for example, in nutrient release, most farmers do not display competence when it comes to the different factors that affect the quality of the manure (Kirchman, 1985; Kemppainnen, 1989; Muguira and Murwira, 1997). Neglect of issues relating to quality and decomposition may lead to immobilization of nutrients and reduction in crop yields.

The overall objective of this study therefore was to build on the wealth of research that has addressed the problems of sustainable soil fertility management practices in Ghana, taking into account factors that influence manure quality and also suggest credible options for optimizing manure. Working on the null hypothesis that the proper management of cattle manure increases its usefulness as fertilizer, the specific objectives of the study were to:

i. find out current manure management practices in the Upper East region of Ghana.

ii. evaluate management practices that can improve the quality of cattle manure. iii. determine the decomposition and nutrient release patterns of compost.

iv. assess the effects of organic and inorganic soil amendments on soil biological, chemical and physical properties indicative of soil quality.

v. determine the effects of complementary and sole applications of organic and inorganic fertilizers on the yield of maize.

CHAPTER TWO 2.0 LITERATURE REVIEW 2.1 Background

As human populations continue to grow towards an anticipated figure of over 8 billion by the year 2020, there is considerable anxiety that the food inequalities prevalent in the world today will worsen over the next 20 years (Pretty *et al*., 1996). Optimists calculate that, in absolute terms, the planet should be able to sustain this huge population through increases in crop production. It is also predicted that in developing countries, two-thirds of the increase in food output will in fact come from raising crop yields, the rest (20%) will be achieved through expansion of arable area into marginal and degraded lands, and from increased cropping intensity (13%) (Alexandrotos, 1995). However, these advances will have a disappointing impact upon mitigation of the impending crisis if disparity of access to food is not resolved for the poorest households.

Amongst strategies for improving access to food is ensuring that local capacity for staple food production is retained or, better still, enhanced (Pretty *et al*., 1996). This may seem an obvious suggestion but is becoming increasingly difficult to attain. Rising population densities in rural areas render the average size of agricultural landholdings too small even for subsistence crop production. The risk that rural families will lose access to viable land units providing a year-round food supply is real. This has led to a popular paradigm that rising rural populations place increasing pressure on land through increased cropping intensity and that this threatens the fundamental bio-physical factor underpinning food security – soil fertility (Donovan and Casey, 1998).

2.2 Soil fertility depletion

2.2.1 The magnitude of the problem

The magnitude of nutrient depletion in Africa's agricultural land is enormous (Smaling, 1993). Nutrient depletion from cultivated land in sub-Saharan Africa indicated annual rates of 4.4, 0.5 and 3 million tons of N, P and K respectively (Stoorvogel and Smaling, 1990; Sanchez *et al*., 1997). These rates are several times higher than Africa's annual fertilizer consumption excluding South Africa – of 0.8, 0.26 and 0.2 million tons of N, P and K respectively (FAO, 1995). Depletion rates also vary among countries. Intensive crop production without external inputs may even reveal higher localized depletion values. Assessing nutrient depletion through various output pathways would therefore form an important base for developing sound soil fertility management practices and replenishment strategies. Nutrient depletion rates vary, with soil properties being higher in sandy soils with initial lower levels of nutrient than clay soils with higher nutrient levels. This is largely because soil organic matter particles are less protected from microbial decomposition in sandier soils (Pieri, 1989; Swift *et al*., 1994).

2.2.2 Effects of soil fertility depletion

The removal of produce without replenishing nutrients exported by the crops causes a continued decline in soil fertility and the ability of the land to support any vegetation is impaired (Dudal and Bynes, 1993). The decline in soil fertility is almost associated with a reduction in soil organic matter which correlates with a loss of structure, lowered water infiltration, increasing erodibility, soil crusting, leaching and a decrease in nutrient depletion capacity (Greenland *et al*., 1994). These effects, in addition to less cover to protect the soil, increase runoff and erosion losses which may cause off-site siltation of reservoirs and in some cases eutrophication of rivers and lakes (Sanchez *et al*., 1997).

The major consequence of soil fertility depletion is a marked decline in crop yield and food security. Food shortages and famine become more acute during drought years. Low crop yields force more farmers to cultivate more land, usually forested areas and marginal lands which are more susceptible to erosion. The rippling effect is that rural-urban migration is engendered; a greater strain is put on the limited urban infrastructure which consequently leads to a rise in unemployment, crime and in some cases trigger off political unrest (Homer-Dixon *et al*., 1993; Bonsu and Quansah, 1992). Soil fertility replenishment could therefore contribute significantly to the resolution of most of the problems of depletion.

2.3 Soil fertility replenishment

A practical goal in the maintenance of soil fertility is to return to the soil most of the nutrients removed from it through harvests, runoff, erosion and other loss pathways (Aune, 1993; Quansah, 1996). The pathways for soil fertility replenishment include mineral fertilizer application, maintenance of soil organic matter (animal manure, plant residue, municipal waste, raw or processed into compost) and accompanying technologies (soil conservation and sound agronomic practices).

2.3.1 Fertilizer use

Mineral fertilizer application is the most obvious way to overcome soil fertility depletion. It has been responsible for a large part of the increases in food production that have occurred in the temperate regions, tropical Asia and Latin America and the commercial sector of Africa (Mokwunye and Hammond, 1992; Borlaug, 1996).

In spite of its benefits in food production, improper use may cause detrimental environmental effects (FAO, 1972). Within individual nutrient sources, their impact usually depends less on the fertilizer itself than on the amount and the way it is applied. Detrimental effects are usually due to application rates in excess of plant needs or to improper management practices (Dudal and Byrnes, 1993). The main negative effects of higher fertilizer applications are occurrences of serious nutrient imbalances and toxicities that affect yields or crop quality and off-site effects from leaching and erosion of nutrients particularly N and P. However, lack of adequate additions of externally derived nutrients severely limits the development of agricultural production on a sustainable basis (Ofori and Fianu, 1996). This situation may change if fertilizers are more widely used particularly where large doses are used in vegetable production in peri-urban areas and near streams.

2.3.2 Constraints to mineral fertilizer use

Generally, most smallholder farmers in Africa and those operating within the peri - urban areas in particular, appreciate the value of fertilizers but are seldom able to apply them at the recommended rates and at the appropriate time (Runge - Metzer, 1995). During the last three decades, a rapid increase in the application of fertilizer was witnessed in both developed and developing countries as a result of the favourable policies which were created by introducing fertilizer subsidies and crop price-support programme and investing in distribution systems (Stangel and Harris, 1987; Bumb, 1989). However, there has been a slow down in the use of fertilizer in both developed and developing countries due to economic, environmental and production policies (Williams, 1992; Putz, 1993; Bumb *et al*., 1998).

Fertilizer use is viewed as a recurring cost of production that must be financed by income from increased crop yields that fertilizer use itself causes. Attempts to introduce this approach to small-scale farming in Africa however have been met with limited success (Cleaver and Schreiber, 1994; Bumb and Baanante, 1996). Furthermore, the price of fertilizers in rural areas of Africa is usually at least twice the international price (Bumb and Baanante, 1996). This occurs in spite of the fact that during the past 25 years the real international price of fertilizers has decreased by about 38% for N and by more than 50% for P (Donovan, 1996). Coupled with all these constraints the poor small scale farmer has no other alternative but to lower the recommended application rates or to stop its usage entirely. Plant nutrient management should thus take advantage of a combined use of locally available and accessible sources of organic origin adapted to a specific farming system (FAO, 1995).

2.4 Sources and use of organic soil amendments

Organic soil amendments have two primary purposes: to contribute vital macro and micronutrients, and improve soil structure by introducing organic matter and providing a fertile environment for essential soil microbes. When applied as recommended, organic amendments improve drainage and provide ready access to root for moisture, plant nutrients and air. Barker (1996) observed that manure application rates to crop or grassland should not exceed the crop requirements, and timing of application, regular manure analysis and soil testing, liming and supplemental fertilizer needs should be considered.

2.4.1 Farmyard manure

The application of animal manure is an important tool for agriculture resulting in an increase in SOM levels and SOM mineralization potential. Farmyard manure often contains a significant supply of ammonium and nitrate - nitrogen that are readily available to crops.

The quality of manure, whether it is composted, fresh or aged, has a great impact on its ability to supply nutrients. For example, the bi - annual application of up to 10 t ha^{-1} of composted poultry manure for 10 years increased SOM by 8.6 t ha^{-1} (030 cm) compared to a conventionally managed system (Horwath *et al*., 2002). The use of a leguminous winter cover crop in the low-input system (cover crop and reduced synthetic fertilizer) alone resulted in a 5.5 t ha^{-1} increase in SOM compared to the conventionally fertilized no cover crop treatment. The difference of about 3 t ha^{-1} SOM between the organic and low-input systems was a result of the manure addition. The degree to which manure applications affect SOM levels is highly variable and depends on the quality and amount of the manure (Horwath *et al*., 2002).

Accoring to Horwath *et al*. (2002), the timing and method of manure application affect both SOM maintenance and nutrient availability. Hence application of manure should be done during periods of active decomposer activity and plant uptake, such as prior to planting. The application of manures during periods of low crop growth can result in significant amount of nutrients lost to leaching and erosion and gaseous N losses to the atmosphere. The quality of farmyard manure is a measure of its content of plant nutrients which depend on the way the manure was made up and how it was handled. Most of the plant nutrients in farmyard manure come from the feed given to the stock and only a small portion from the straw. Delve *et al*. (2001) found that adding fermentable carbohydrate to the diet of cattle increases the microbial requirement and promotes the utilization of excess ammonia. If much straw relative to excreta is used, the manure will be poorer. Nzuma and Murwira (2000) however found that the addition of straw to manure reduced ammonia losses by up to 85%. Nitrogen is lost as ammonia gas when heaps of manure are turned or spread over the land for any length of time before it is ploughed in. Both N and K are lost in the black liquor that oozes out. Heaps should not be turned but be kept as compact as possible and protected from rain to prevent leaching losses when applied to the land. Martins and Dewes (1992) found that turning manure heaps stimulated a loss of 49% of N as NH_3. It should be spread and ploughed in immediately.

2.4.2 Cattle manure

Metabolic materials excreted in faeces include endogenous substances (salts of fatty acids, bile salts, some sloughed off animal cells, mucus and keratinized tissue), microbial debris (bacterial cell walls from rumen bacteria and some whole cells from fermentation in the lower tract) (Rufino *et al.,* 2006) Microbial cell walls consist of substituted glucosamine (muramic acid) polymers with attached resistance to degradation (Van Soest, 1994). Faecal N is largely contained in indigestible microbial matter, which is produced approximately in proportion to dry matter intake. Undigested feed, microbial and endogenous N are estimated to account for 16, 55 and 29% of faecal N respectively in dairy cows supplemented with concentrates (Larsen *et al*., 2001).

The percentage of N composition in cattle manure is low (Anane Sakyi *et al*., 2005). Cattle manure comes fourth in terms of N composition after poultry, sheep and goat and pig manures. However, fertility value depends a lot on the type of animals, quality of diet, kind and amount of bedding and how the manure is applied or stored. Animals fed on high quality supplements produce high quality manures (Kimani and Lekasi, 2004).

2.4.3 Green manure

Green manures are plants grown for the expressed purpose of ploughing them under while green and often immature. Green manures may be used as a catch or cover crop and may prevent soil erosion and reduce nitrate leaching as well as weed infestation. Muller-Samann and Kotschi (1994) reported that green manure can increase plant nutrient supply in the soil especially nitrogen and improve crop yields. Green manuring with cowpea for 20 years decreased the organic matter content by 0.11% as compared to an increase of about 0.11% by adding 4 tons of farmyard manure. Green manure has a conserving influence on nutrients since it takes up soluble constituents that might otherwise be lost in drainage or by erosion. According to Lal *et al*. (1991), green manure legumes can provide good ground cover and minimize soil erosion through reduction of raindrop impact and runoff. Green manure has little or no real value in drier areas (Lal *et al*., 1991). This is because the available moisture which should go to the succeeding crop may be used by the green manure itself and the soil left light and open.

Jensen (1997) found that the addition of 30% of green manure to the soil raised the solubility of lime and phosphoric acid by 30 – 100%. When green manures are incorporated into a soil and have been thoroughly decomposed, there is an improvement in tilth of the finer-textured soils. This is brought about as a result of improved aggregation of the fine clay particles and in a lower bulk density. Green manure crops are good for soil and water conservation on account of their densely covering canopy and deep, well-developed root system.

2.4.4 Compost

Composting attempts to recreate the conditions, which would occur in an undisturbed ecosystem where organic matter builds up on the soil surface and is not regularly incorporated into the soil as in agricultural ecosystems (Lampkin, 1994). The nutrient content of composts, especially those derived from farmyard wastes, varies considerably depending on type of raw materials used, method of composting, and maturity. Compost applications can form the foundation of an effective nutrient and SOM management strategy. Nutrients in composts are generally less available compared to manures or leguminous cover crops. Composted manure for example, releases N at a considerably slower rate than unprocessed manure (Hadas *et al*., 1996). The primary reason for reduced nutrient availability in composts is the higher degree of decomposition leading to the production of humic substances resulting in a slower release of nutrients, especially N (Churchill *et al*., 1996).

The increase in stable SOM and favourable soil properties can be more effectively accomplished with compost than with fresh manure. The main reason for this is that compost is in an advanced state of decay. In the long term, however, the amount of organic matter applied is more important than the type of organic amendments used (Horwath *et al*., 2002). Increased SOM through compost additions often results in enhanced soil quality indicators. For example, Joyce *et al*. (2002) showed that organic management with composts improved porosity and water retention. Biological soil quality indicators, such as biomass C and N are also improved with compost applications (Horwath *et al*. 2002).

The application of composts and manures to soils on a consistent basis may impact soil fertility in numerous ways. There is increasing evidence that the use of animal manure and compost as a sole source of available nutrients can result in nutrient overloading of the soil (Clark *et al*., 1998). Excess P levels are created frequently by basing manure and compost application rates solely on the crop N need. The combination of low N to P ratios in many organic amendments and low crop P removal rates leave much of the applied P unused in the soil. Potential consequences of overloading the soil with nutrients include leaching of nitrate (Poudel *et al*., 2002) and the accumulation of P in the soil (Gartley and Sims, 1994). Arid regions with high evapotranspiration rates are particularly prone to buildup of excess salts found in manures and compost.

2.5 An overview of composting process

Composting is the deliberate biological decomposition of organic matter under controlled, aerobic conditions into a humus-like stable product (Epstein, 1997). The compost product is an organic matter source and adds humus to soil. It acts to improve soil conditions and plant growth, and reduce the potential for erosion, runoff, and nonsource pollution. The composting process is primarily concerned with the creation of a suitable environment in which aerobic micro-organisms that are responsible for breakdown of organic matter can be optimally active. Composting processes typically have three main stages:

a. A mesophilic growth stage, which is characterised by bacterial growth under temperatures of 25 – 40 ^{O}C;

b. A thermophilic stage, where bacteria, fungi and actinomycetes (first level consumers) functioning at temperatures of 50 – 60 ^{O}C, breakdown cellulose, lignin and other resistant materials (this thermophilic stage can go as high as 70 ^{O}C);

c. A maturation stage, where temperatures stabilise and some fermentation occurs, converting the organic materials to humus (this process commences when the temperature of the composting material reverts to the ambient temperature) (Coyne, 1999).

2.5.1 Output quality and rate determining factors in the composting process

2.5.1.1 Substrate

Organic material is the substrate or food for the decomposing community (bacteria and other organisms). Carbon and N are the two major elements contained in the organic matter and control the activities of the micro-organisms. Carbon is used as a source of energy by the organisms, which oxidize it, generating heat and CO_2. Nitrogen is the main source of protein needed for cell production and population growth (reproduction). Carbon and N vary with each organic material or feedstock. It is recommended that a blend of organic material be made in such a way that their C: N ratio is < 35 (FAO, 1987), with a range of 20 - 30 being ideal. When C:N ratio rises above this level, heat production drops and the rate of composting slows down due to the limitation of nitrogen, falling short of microbial demand. On the other hand, when the C: N ratio drops below 20, excess nitrogen is lost to the air as ammonia resulting in a rise in pH level. The rate of composting is dependent not only on the environmental factors but also on the nature of the input material (Stentiford, 1993). There is an order of decomposition rate for different fractions of the plant material: carbohydrates, sugars, proteins and fats decompose quickest, followed by hemicelluloses, cellulose and finally lignin. It is further indicated that composition of organic matter varies with source and consequently the organic constituents in compost also vary with their source (feedstock).

During the composting process, the C:N ratio of the initial feedstock typically declines because the C is oxidised and the N mineralized by the micro-organisms. A number of researchers have observed a significant reduction in C: N ratios when different sources of organic materials have been composted. For example, Thambirajah *et al*. (1995) observed a substantial reduction in C: N ratio when they composted empty fruit branches (with a relatively high lignin content) with manure added to the substrate. It is clear that C: N ratio is an indicator that the substrate has gone through the biochemical changes of composting, but more importantly is an indicator of compost maturity. A stable product that can be applied to a soil without significant immobilisation of soil mineral nitrogen is indicated by the final C: N of the product; for example, mature compost is indicated by a C: N ratio of 10:1 to 15:1 when the original material was 30:1 to 50:1 (Thambirajah *et al*., 1995)

2.5.1.2 Air

The metabolic process used by bacteria to produce energy requires a terminal electron acceptor to enzymatically oxidize the carbon source to carbon dioxide. Different classes of micro-organisms exist based on the carbon and terminal electron acceptor sources they use in metabolic processes. Bacteria that use reduced organic compounds (e.g. naturally occurring organics) as their source of carbon are termed heterotrophic; those that use inorganic carbon compounds (e.g. carbon dioxide) are autotrophic. Bacteria that use free oxygen as their terminal electron acceptor are aerobic; those that use a compound other than free oxygen (e.g. nitrate, sulfate) are anaerobic; and those that can utilize both oxygen and other compounds as terminal electron acceptor are described as facultative (Epstein, 1997).

An aerobic process is the most efficient form of metabolic activity. Hence, oxygen is required for respiration by all aerobic organisms within the composting heap, making proper aeration a crucial factor in aerobic composting. Having sufficient oxygen, aerobic micro-organisms such as bacteria will be active and grow rapidly, consuming more organic material and in the process making nutrients available for plant growth. In the absence of oxygen, aerobic bacteria cannot thrive and anaerobic bacteria take over. These break down the organic material very slowly and often produce volatile compounds with unpleasant odours. This odour comes from sulphur compounds (hydrogen sulphide, dimethyl sulphide, dimethyl disulfide), ammonia and volatile fatty acids (Epstein, 1997).

2.5.1.3 Temperature

Biological systems typically operate over a limited range of temperature. At low temperatures microbes revert to resting state and at very high temperatures, essential proteins are denatured, killing them (Winkler *et al*., 1996). Microbes can be classified based on their temperature tolerance. These include psychrophiles that grow at temperatures of less than $20^{O}C$, mesophiles growing best between 15 and $45^{O}C$, and thermophiles growing at temperatures greater than $45^{O}C$. The compost heap temperature is a function of the accumulation of heat from metabolic processes and at the same time the temperature is a determinant of metabolic activity. The interaction between heat output and temperature determine the succession of microbial communities and metabolic rates during composting (MacGregor *et al.,* 1981).

The temperature phases or composting phases are therefore a result of the amount of heat being produced by microorganisms, balanced by how much is being lost through conduction, convection, and radiation (MacGregor *et al.,* 1981). In heat loss by conduction, energy is transferred from atom to atom by direct contact; at the edges of a compost pile, conduction causes heat loss to the surrounding air molecules. Loss by convection indicates transfer of heat by movement of a fluid such as air or water. The warm air within compost system rises, creating convective currents which cause a steady but slow movement of heated air upwards through the compost and out the top. During this process, the energy is transferred in the form of latent heat, the energy required to evaporate water. Finally, heat is also lost from the compost heap through radiation. The heat generated in the compost pile radiates out into the cooler surrounding air. The smaller the bioreactor or compost pile, the greater is the surface area-to-volume ratio, and therefore the larger the degree of heat loss to conduction and radiation (Richard, 2005; Themelis, 2002). Insulation of small compost piles helps to reduce excess heat losses.

The maintenance and residence of the high temperatures within the compost heap as compared to the outside, is controlled by the composting system, the nature of the feedstock, rate of microbial activity and external conditions (temperature and wind). Since there are interactions between the metabolic heat output and temperature, outside temperature plays a role in controlling the rate of composting. The warmer external temperatures in the warmer regions stimulate microbial activities and speed composting while colder temperatures of the colder regions slow down the composting process. In general, the optimum temperature range for fast decomposition is between 50 and $60^{O}C$, but Epstein, (1997) gave a range of 65-70^{O}C as the temperature where maximum decomposition takes place for municipal solid wastes. This thermophilic stage is also important for destroying thermo-sensitive pathogens, fly larvae, and weed seeds. In outdoor systems, compost invertebrates survive the thermophilic stage by moving to the periphery of the pile or becoming dormant (Coyne, 1999). To achieve a significant reduction of pathogens during composting, the compost should be maintained at a minimum operating temperature of 40°C for five days, and with temperatures exceeding 55°C for at least four hours of this period. Most species of micro-organisms cannot survive at temperatures above 60 - 65°C, demanding cooling of the compost systems when temperatures get too high.

2.5.1.4 Surface area and particle size

Microbial activity mostly occurs on the surface of the organic particles. Smaller particles of organic material provide more surface area for microbes to attack and speed up composting (Haug, 1993). This is achieved by shredding and breaking down the organic materials into smaller pieces in order to expose a greater area for the microbes to work on and allowing ample air spaces thereby increasing the rate of decomposition. Apart from increasing surface area, the cutting of the feedstock also destroys the cell wall protective cover. The absence of the cell wall exposes the organic matrix for microbial attack. On the other hand, very small and compact particles hinder air circulation through the pile. Consequently, this reduces O_2 available to microorganisms within the pile and the microbial activities decreases (Haug, 1993).

2.5.1.5 Volume

Volume is the factor aimed at retaining heat of the compost. The more the compost volume the more self-insulating it becomes in retaining the heat generated by the microbes (Richard, 2005). Smaller compost piles are associated with greater surface areato-volume ratios. This exposes the pile to a greater degree of heat loss (Themelis, 2002).

2.6 Improving manure effectiveness by combining with mineral fertilizers

Integrated plant nutrient management is increasingly becoming an important subject of research. A combination of organic-inorganic nutrient sources is thought to improve synchronization of nutrient release and subsequent uptake by crop (Kimani *et al*., 2001). For example, the synchrony between N release and uptake is thought to be best achieved under a combined application of manures and inorganic fertilizers. This is particularly so when the manures are available on-farm, where only modest quantities of inorganic fertilizer are applied. According to Kimani *et al*. (2001), the concept of organic-inorganic combinations has been demonstrated in Central Kenya where combinations resulted in higher maize grain yields. However, the success of this strategy will depend on many factors such as the quality of the organic material used and the proportions of nutrient applied from either source (Palm *et al*., 1997). Most trials on integrated plant nutrient management have failed to provide conclusive guidelines of the interaction of the effects of nutrients supplied by the various sources in combination because nutrients were not balanced (Gachengo *et al*., 1999).

2.7 Effects of manure on soil physical properties

Soil physical indicators refer to water storage and movement, soil structure and soil aggregate stability. Many physical indicators are related such as the effect of soil structure on water - soil relations. Farm waste has been found to improve soil structure and fertility (Obi and Ebo, 1994). Barker (1996) had indicated that land application of cattle manure can beneficially alter the soil properties. Thus the overall soil tilth is improved by the addition of organic matter and the soil infiltration rate particularly in fine textured soil is increased. Cattle manure also stimulated plant growth by increasing soil water holding capacity and on sandy soils organic matter reduced leaching and increased crop yields by helping plants better utilize water and nutrients (Baker, 1996).

Gibbs and Chambers (2003) reported that the addition of compost increased soil density and strength making soil easier to cultivate but less trafficable. Manure further increased plant available water supply; soil porosity and drainage status (Ogedengbe and Fashina, 2001). Lampkin (1994) composting manure with unmanured soils confirmed the concept that soil physical environment as related to soil and crop management system is a primary determinant of microbial population.

2.8 Effects of manure on soil chemical properties

Important chemical indicators include the presence and amount of essential nutrients and other possible growth inhibiting compounds. Indicators such as the effects of pH and cation exchange capacity (CEC) on nutrient availability are often related. Marginal micronutrient deficiencies, which may occur after repeated cropping with chemical fertilizers, can be prevented with supplementary applications of manure (Barker, 1996). According to Barker (1996), significant amounts of N, P and K and micronutrients are present in cattle manure and decomposition and mineralization of manure in the soil releases nutrients for crop growth. Applying too little manure can lead to inadequate crop growth because of lack of nutrients, while applying too much may reduce crop quality or increase risk of plant diseases (Barker, 1996; Bary *et al*., 2004).

Gibbs and Chambers (2003) observed that compost additions increased the chemical fertility of the soil; in contrast there was an inverse relationship between soil pH (Moore, 1994) and topsoil organic matter levels, although the size of the increase was relatively small even at the highest compost addition rate. Soil nutrients such as N, P, K and Ca were enhanced in a sandy soil by the application of poultry, cattle and combined poultry and cattle manures due to higher nutrient contents of the organic waste amended soil (Ogedengbe and Fashina, 2001). Farm wastes have been found to increase crop yield (Lungu *et al*., 1993) as well as nutrient uptake by crops (Olayinka, 1990).

2.9 Effects of manure on soil biological properties

Soil biological indicators often refer to the amounts, types and activities of soil organisms. A large, diverse and active population of soil organisms may be the most important indicators of healthy, high quality soil (Kleinhenz and Bierman, 2001). Gibbs and Chambers (2003) and Obi and Ebo (1994) reported that compost additions increased the size and activity of the soil microbial community and long-term organic N release. There is good evidence that earthworm greatly increase overall microbial activity in the organic waste primarily providing fragmented organic materials for microbial growth of soil bacteria and fungi. Edwards (1998) noted that soils treated with inorganic fertilizers only had much less organic matter available for microbial growth compared with those in the vermi compost-treated soils.

2.10 Effects of manure on soil fertility

About 40% of farmers of the world depend wholly or in part on animal waste to enhance soil fertility (McDowell, 1992). No national figures are available for Ghana but dependence on animal manure wholly or in part may not exceed 10%. Manure provides the most benefits in soils with deficient to adequate levels of nutrients and as such soils with a high to excessive level of nutrients are not a good choice for manure use because the nutrients in the manure are less likely to benefit the crops (Bary *et al*., 2004) and application above agronomic rate depress growth and yield (Dewiet *et al*., 1994).

2.11 Effects of manure on plant diseases

Composts are biologically active and contain a complex mix of micro-organisms which have been shown to suppress a range of plant pathogenic species including *Pythium, Phythophthera* and *Rhizoctonia* which cause a variety of symptoms including wilting, root rots and tissue necrosis (WRAP, 2005). However, Alhison (1973) was of the view that there is no fixed pattern by which organic residue exerts its effect on the different kinds of pathogens present. If it serves as direct food sources for disease causing organisms, it may increase disease intensity; if it acts as a source of nutrients for its host, it may build up a resistance to the disease organism; and if it increases the growth of the composting organisms, it may suppress the disease.

2.12 Manure quality

Manure quality may simply be defined as the value of manure in improving soil properties and enhancing crop yields. Scientists have used laboratory analysis for nutrient contents as a measure of manure quality (Kimani and Lekasi, 2004). The perception has been that the higher the nutrient levels, the better the manure quality. According to Kimani and Lekasi (2004), the use of nutrient release patterns, using laboratory incubations of manures, and how the nutrient release can be synchronized with crop uptake has been considered a better measure of manure quality. Mugwira and Murwira (1997), in a review of cattle manure use in improving soil fertility in Zimbabwe, report on quality in terms of the nitrogen content, an aspect that farmers may not comprehend by mere visual observation of the physical appearance of the manure heap. On the other hand farmers have traditionally used their own yardsticks to determine what the quality of manure is.

The evidence that farmers can accurately assess the quality of manure and use this knowledge strategically is gradually building up. Motavalli *et al.* (1994) in a survey conducted in the semi - arid tropics of India reported that farmers judge the quality of manure from its physical composition, which determines its workability and its effect on crop development and edaphic and biotic factors. Others may not judge the quality until the results are seen in the final crop yield obtained after application of such manures. The farmers of central Kenya use texture, longevity of composting, homogeneity, presence of fungi spores/hyphae, as some of the quality characteristics (Lekasi *et al.*, 1998; Wanjekechie *et al.*, 1999). It can thus be said that whilst farmers are aware of the "ingredients" and methods involved in making good manures, they do not display competence in assessing the quality of manures or appreciate when home-made manure is ready for application. The challenge is therefore to match the scientist and farmer perceptions to come up with simple decision tools for defining quality manure without expensive laboratory analysis.

2.13 Nitrogen mineralization and immobilization from organic materials

Mineralization can be defined as the process whereby soil organic N is converted into inorganic (NH_4^+, NO_3^-) forms. Several authors, for example, Kai *et al*. (1973) and Marumoto *et al.* (1982) have observed that sudden changes in environmental conditions, such as drying and wetting, fluctuating temperatures, can cause the death of a large proportion of the microbial biomass resulting in large flushes of N mineralization. Environmental conditions (like increasing temperature) can also stimulate mineralization by increasing microbial activity.

Immobilization is the process whereby inorganic N is converted to organic N in microbial biomass (Haynes, 1986). Thus immobilization results in the temporary reduction of available N. This usually happens during the decomposition of material with a wide C: N ratio (usually greater than 30:1) when micro-organisms utilize some of the N present in the soil for their body building and energy requirements. This N can later be mineralized after the death of the microbial population. Thus, rapid microbial immobilization of added fertilizer N may be followed by a slow demineralization over a number of years (Campbell, 1978). Rosswall (1976) estimated that in the global plant-soil system, immobilization was responsible for the fate of slightly more than half of the annual gross mineralization of N.

Thus, N availability for plant uptake depends on the excess of mineralization over immobilization, which is referred to as net mineralization (Haynes, 1986).

Accurate predictions of N mineralization from organic materials in soil remain elusive, since interactions between the differentially labile carbon (C) and N pools are complex and strongly influenced by environmental conditions (Rufino *et al*., 2006). However, an understanding of the main factors has developed, notably for plant materials applied directly to soil (Palm *et al*., 2001). The release of N is governed by the N demand of microorganisms, which is a function of the availability of C sources for microbial growth. Rufino *et al*. (2006) reported that the presence of labile C increases the demand for labile N, and therefore suppresses N release. Plant materials also often contain lignin, which is recalcitrant for decomposition and soluble polyphenols, which bind to proteins and this retard N mineralization.

According to Rufino *et al*. (2006) mineralization of N is essential to release N for plant uptake, but if N concentrations rise because of a large release of N from labile pools when there is little plant demand for N, large losses can occur. Ammonia losses are greatly reduced if manure is incorporated into the soil. Recalcitrant C and N pools also create and satisfy microbial demand for N, respectively, but at a slower rate, and so these pools change size more slowly and have less influence over soluble N concentrations (Rufino *et al*., 2006). They may, however, be important for soil structure and for longer term nutrient cycling.

The release of N from manures is also governed by microbial demand, but the starting composition of manures differs from that of plant materials in several important ways. Soluble polyphenols are unlikely to be present in manures and the stable fraction includes large amounts of glucosamine polymers derived from microbial cell walls (Rufino *et al*., 2006). This may explain the limited success that has been achieved from applying plant quality indices to the prediction of manure mineralization. The mineralization rate of manure N tends to be higher for manure with narrow C: N ratios, but the influence of other chemical quality factors remains uncertain. Quality parameters could not explain N mineralization / immobilization in incubations in soil of fresh manure (Delve *et al*., 2001). All manure types released N in the first week of the incubation, but then immobilized N for 17 – 28 weeks, resulting in a lack of response in maize (*Zea mays* (L)) growth to any of the manures in both pot and field experiments.

Kyvsgaard *et al*. (2000) found that N mineralization from manure was significantly negatively correlated with Neutral Detergent Fibre residue (NDF), Acid Detergent Fibre residue (ADF), crude fibre and apparent digestibility of the feed. Apparent digestibility was correlated to faecal N concentration and it was proposed that faecal N could be predicted from dietary N and digestibility of the feed, which ignored N recycling in the animal and excess N excreted as urine. Because N mineralization was correlated with faecal N, the authors concluded that N mineralization could be predicted from feed quality. Nyamangara *et al*. (1999) observed that aerobically decomposed manure with a C: N ratio of 9:1 immobilized added fertilizer N, whereas manures with a C: N ratio of 18:1 did not. They concluded that C: N ratio of the manures is not a suitable parameter to predict N mineralization of manures.

2.14 Factors influencing rate of mineralization in Organic materials

Decomposition of OM and the release of mineral N from either native OM or fresh plant residue is affected by several factors. These include the type and quality of substrate, environmental factors and soil type.

2.14.1 Substrate type and quality

The type and chemical composition or 'quality' of the decomposing material has long been recognized as critical factors determining the rate of nutrient release. In a study involving alfalfa and maize stovers, Pare *et al*. (2000) observed that during 140-day incubation at 25°C, 50% of the alfalfa and only 8% of the maize residues were mineralized. Rubaduka *et al*. (1993) noted marked differences between species assessed in terms of N release from the leaves of various tree legumes they studied.

Several workers have shown the importance of N in controlling decomposition rates and net mineralization (Aber and Melillo, 1980; Palm *et al*., 1997). The C: N ratio of the decomposing material has been described as probably the most robust index when all plant materials are considered (Constantinides and Fownes, 1994). Heal *et al*. (1997) described N as a very important factor that affects plant litter decomposition because it determines the growth and turnover of the microbial biomass mineralizing the organic carbon. Heal *et* *al*. (1997) reported that the theoretical optimum ratio of C: N of plant residue that can be decomposed by soil microbes is about 25, although fungi and bacteria can decompose resources with far higher ratios. Generally, it has been well documented that residues with low C: N ratios (below 20:1) facilitate N mineralization by encouraging high rate of decomposition, whilst those with high ratios (above 30:1) are not readily decomposable and often lead to N immobilization.

The lignin content of plant residues can exert great influence on their composition (Melillo *et al*., 1982; Hammel, 1997). Hammel (1997) described lignin as probably the most recalcitrant naturally produced organic chemical, which is consistent with its function of ensuring the rigidity of plants to stand upright and to protect their structural polysaccharides from attack by other organisms. The polyphenol content of litter also affects decomposition (Harbone, 1997). Palm and Sanchez (1991) in a decomposition experiment with 10 tropical legumes and rice straw indicated that polyphenolic content may play a more important role in influencing mineralization patterns for leguminous leaves than percent nitrogen or lignin: nitrogen ratio. In another study, Fox *et al*. (1990) suggested that lignin + polyphenol: N ratio appeared to be a good predictor for N mineralization rates from incorporated legumes. Evaluating several substrate quality factors affecting decomposition and mineralization of certain woody species, Kachaka *et al*. (1993) observed that lignin: N and lignin + polyphenol: N ratios accounted for the observed differences in decomposition and N mineralization of some tree species. Northrup *et al*. (1995) also reported that the polyphenol concentration of decomposing *inus muricata* litter controlled the proportion of N released in dissolved organic forms relative to mineral forms.

2.14.2 Soil moisture and aeration

Generally, decomposition rate increases with increasing soil moisture between permanent wilting point and field capacity, whilst above and below these limits, the rate declines. Soil moisture can influence the mineralization of N in two ways. Coyne (1999) reported that microbial growth and activity require enough moisture to keep water films on solid surfaces for movement and metabolism and for the diffusion of soluble compounds. Moisture stress inhibits microbial growth, thereby reducing their ability to decompose. Secondly, as soil moisture content increases, aeration decreases and microbial growth is inhibited. Although the decomposer organisms differ in their response to the moisture content of their environment, it is generally believed that the catabolic activities of the total biomass may be limited at moisture potentials below -1000 to -5000 kPa (Moore, 1986; Donnelly *et al*., 1990). At very high moisture contents, the rates of biological activity and decomposition are decreased through reduced oxygen availability. Since the majority of fungi and actinomycetes are aerobes, decomposition rates are affected by moisture content (Patrick, 1982).

2.14.3 Temperature

Temperature is a major factor influencing the decomposition of organic materials. The decomposer organisms have different temperature optima and growth ranges (Donnelly *et al*., 1990). It is known that the populations of mesophilic bacteria, actinomycetes and fungi (temperature range optima from 0 to 45°C) are high in most soils. On the other hand, populations of thermophilic bacteria and actinomycetes (range 45 to 60°C) are low in most soils, except in arid and desert environments (Alexander, 1977). However, it is widely accepted that the combined effects of high moisture and temperature generally favour microbial growth. Generally the Q_{10} (rate of a chemical reaction with every 10°C rise in temperature) of decomposition by soil microbes between 10 and 30°C is considered to be two ie. microbial activity doubles for every 10^{0}C rise in temperature (Coyne, 1999).

2.14.4 Soil pH

Decomposition proceeds more readily in neutral than in acid or strongly alkaline soils. The optimum pH for maximum decomposition by micro-organisms is 6 – 7.5 (Haynes, 1986). Decomposition in acid soils can be improved by treatment with lime (Alexander, 1977). Changes are known to occur to soil microbial populations and activities as soil pH changes. Alexander (1980) observed population shifts from bacteria to actinomycetes to fungi as soil pH declined although the acid tolerance of individual species varied widely.

2.14.5 Priming effect

The addition of fresh organic residue or inorganic fertilizer N can either stimulate or retard the decomposition of the native soil OM, and hence its mineralization. This is referred to as the priming effect (Haynes, 1986), and can be either negative or positive. Several workers have observed a positive priming effect on soil OM decomposition following additions of fresh organic materials (Jenkinson, 1971; Dalenberg and Jager, 1981). Broadbent and Nakashima (1974) observed a positive priming effect following addition of ^{15}N-labelled barley tops to a soil on the release of native soil organic N. In this study, they reported that net release of soil organic N was greater in the barleyamended treatments than in the treatments without the amendment. Although the exact mechanisms by which such a priming effect occurs are not clearly understood, it has been proposed that the addition of fresh residues or inorganic N provides a source of energy for rapid microbial growth, resulting in a larger and more active microbial biomass. Under this condition enzyme activity could be enhanced resulting in a faster breakdown of native soil OM as well as of the added materials (Haynes, 1986). Another likely explanation may be that fresh organic residues could cause modifications in the microbial environment, especially in terms of soil pH, aeration, or nutrient availability, either one or more of which could hasten or retard the decomposition process (Handayanto *et al*., 1997).

2.15 Summary of literature review

Africa's declining food production phenomenon is no longer news. The main threat to this scenario is the diminishing capacity of the soils in the region to support increased crop production coupled with low use of soil fertility enhancing technologies. This has opened a new wave of research in an attempt to find low-cost solutions to improve soil fertility and achieve the ultimate goal of food security. Although nutrient deficiencies can be effectively addressed with mineral fertilizers, economic and policy constraints limit their use by smallholder farmers. Thus, the use of organic resources to sustain crop yields and build soil fertility will continue to be critical in the tropics. As a key component of agricultural sustainability, there has been a shift in paradigm towards the combined use of organic and mineral inputs. In order to effectively manage the short term and long term nutrient availability of this strategy, there is the need to understand how the quality of organic materials affects nutrient release pattern during decomposition and mineralization.

CHAPTER THREE 3.0 MATERIALS AND METHODS

3.1 Survey of manure management practices in the Upper East region of Ghana

3.1.1 The survey area

The Upper East region of Ghana stretches approximately from longitudes 0.50^{o} W to 0.05^{o} E and latitudes 10.60 ^{o} N to 11.2 ^{o} N in the east. It covers a total land area of 8,842 km^2 with a population of 917,251 (Macmillan, 2001), which is 87 % rural (MOFA, 2001). The mainstay of livelihood for sustaining the ever increasing population is agriculture. The major districts in the region include: Garu-Tempane, Bawku Municipal, Bawku West, Bongo, Talensi-Nabdam, Bolgatanga, Kessena-Nankana, and Bulsa.

3.1.2 Climate of the survey area

The zone is characterized by relatively longer dry season of about 6 – 7 months. Average annual rainfall ranges between 892 mm in the East and 973 mm in the West (Table 1). The area is warm throughout the year. Mean monthly temperature ranges from 26 – 32 ^{o}C. Day maximum temperatures in the range of 39 – 42 ^{o}C in the dry season are high (Table 1). Relative humidity is generally high (80 – 90%) in the wet season (from May to Mid-October) and low (10 – 11%) in the dry season especially in the harmathan period from November to February.

Table 1. Mean monthly rainfall and temperature of selected stations within or close to the Sudan savanna

	Mean monthly rainfall (mm)		Mean monthly temperature (^{O}C)
Month	**Navrongo**	**Manga**	**Navrongo**

Jan	0.9	0.2	27.3 29.9
Feb	3.1	0.9	32.1 32.2
Mar	17.8 55.0	12.7	30.5 28.3
Apr	93.2	33.8	26.9 26.4
May	123.3	92.1	26.7 28.2
Jun	190.1	121.7	28.2
Jul	267.5	175.0	27.1
Aug	165.0	226.5	
Sept	50.3	164.6	
Oct	4.2	55.5	
Nov	2.9	5.4	
Dec	973.3	3.6	
Total (rainfall)		892.3	

Source: Ghana Meteorological Services Department (1961 – 1995)

3.1.3 Soils of the survey area

The dominant geology in the zone is granite, which are either rich in biotite or hornblende. The upland soils of areas underlain by biotitic granites are red, sandy clay, variably gravely and concretionary soils (Varempere series) on summits, yellowish brown sandy loam to sandy clay loam, non-concretionary soils (Tafali series) on middle slopes and greyish gritty sandy clays (Pu series) on lower slopes. Occasionally, Pusiga series, which is shallow and 'brashy' to hard rock and Gulo series, which is shallow to incipient pan are found on upper and lower slopes respectively. Eroded summits and upper slopes have Hilun series with many to abundant concretions overlying ironpan boulders at shallow depths. Valley areas have soils ranging from sandy loams to silty clays. According to FAO (1990) the soils are classified as Plinthosols, Planosols, Lixisols, Leptosols, Regosols and Gleysols.

3.1.4 Vegetation of the survey area

The natural vegetation is that of the savannah woodland characterized by short scattered drought-resistant trees and grass that gets burnt by bushfire or scorched by the sun during the long dry season. Human interference with ecology is significant, resulting in near semi-arid conditions. The most common economic trees are the *Vitellaria paradoxa* (sheanut), *Parkia filicoidea* (dawadawa), *Adansonia digitata* (baobab) and *Acacia spp* (acacia).

3.1.5 Survey methodology

In May 2006, a preliminary survey of manure management practices and quality was carried out in the Upper East region of Ghana. Three hundred farmers who owned cattle were interviewed using structured questionnaires. The survey sought information on practices likely to influence (i) cattle management practices, including: type of animal enclosure, roofing, floor type, use of bedding, (ii) manure management including: quantity, collection, handling, storage, treatment prior to utilization, (iii) manure application. In addition to the questionnaire, personal field observations and interviews with key informants such as extension officers and local leaders were conducted using a check list. A draft questionnaire was pre-tested on 30 farm households in the study area.

The results of the pre-testing helped in the final restructuring of the questionnaire by incorporating missing variables or information, omitting irrelevant questions and paraphrasing questions that appeared ambiguous to the respondents.

3.1.5.1 Manure sampling from the survey area

From each farm, approximately 5 kg of fresh manure was obtained from the surface of the manure heap from different kraals and stored in plastic bags. The manure sampled from the various districts was taken to the Soil Research Institute laboratory, Kwadaso, which is about 8 km away from the city centre of Kumasi where it was heaped under a shade to dry before use. During the drying it was mixed thoroughly and sub-samples were taken for chemical analysis to determine plant nutrient content.

3.1.5.2 Questionnaire administration in the survey area

A multi-stage approach was used during the questionnaire administration. A number of communities were purposefully selected as clusters. The cluster sampling was followed by quota sampling. The quota given to the selected communities were based on the concentration of households who owned cattle. A random household sampling technique was adopted in each community. Enumerators were recruited and trained to help the author in the questionnaire administration.

3.1.5.3 Data collection

Primary and secondary data (qualitative and quantitative) were used as the main sources of information. Primary data was collected through direct interviews by the use of structured questionnaire. Secondary data from past research works, books and journals and articles were sources of valuable inputs in the preparation of the questionnaire for the study.

3.1.5.4 Limitations of the survey

Due to lack of record keeping, households interviewed had difficulties in recalling how much manure was applied per cropping season and the exact quantities of yields obtained. The enumerators had to interpret the questions in the local languages since most of the respondents were illiterate and also due to the technical nature of some questions in the questionnaire. Periodic checks were made on the enumerators to ensure that they followed proper interview procedure.

3.2 Laboratory soil analyses

3.2.1 Soil sampling and sample preparation

The experiments were carried out on soils of *Kumasi series* (Ferric Acrisol, FAO, 1990; Adu, 1992). Soil samples were randomly taken using auger from a depth of 0–15 cm. The soil samples were air dried, crushed and passed through a 2 mm mesh sieve. The sieved soil was thoroughly mixed and stored in polythene bags for laboratory analyses. Fresh soil samples were stored in a refrigerator for microbial biomass nitrogen, phosphorus and carbon determination. Except where otherwise stated, all laboratory analyses reported in the following sections were carried out in duplicates.

3.2.2 Determination of soil chemical properties

3.2.2.1 Soil pH

This was determined using the glass electrode HT 9017 pH meter in a 1: 2.5 soil to distilled water (soil: water) ratio. A 20 g soil sample was weighed into a 100 ml plastic beaker. To this 50 ml distilled water was added from a measuring cylinder, stirred thoroughly and allowed to stand for 30 minutes. After calibrating the pH meter with buffer solutions at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

3.2.2.2 Soil organic carbon

The modified Walkley and Black procedure as described by Nelson and Sommers (1982) was used to determine organic carbon. The procedure involved a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid after which the excess dichromate was titrated against ferrous sulphate. One gram soil was weighed into a conical flask. A reference sample and a blank were included. Ten millilitres of 0.166 *M* (1.0 *N)* potassium dichromate solution was added to the soil and the blank flask. To this, 20 ml of concentrated sulphuric acid was carefully added from a measuring cylinder, swirled and allowed to stand for 30 minutes on an asbestos mat. Distilled water (250 ml) and 10 ml concentrated orthophosphoric acid were added and allowed to cool. One millilitre of diphenylamine indicator was added and titrated with 1.0 *M* ferrous sulphate solution.

Calculation:

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

where:

M = molarity of ferrous sulphate solution

V_1 = ml ferrous sulphate solution required for blank titration

V_2 = ml ferrous sulphate solution required for sample titration s

= weight of air-dry sample in gram

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

0.39 = 3 x 0.001 x 100% x 1.3 (3 = equivalent weight of C)

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

3.2.2.3 Total nitrogen

The macro Kjeldahl method involving digestion and distillation as described by Soil Laboratory Staff (1984) was used in the determination of total nitrogen. A 0.5 g soil sample was weighed and put into a Kjeldahl digestion flask and 5 ml distilled water added to it. After 30 minutes, 5 ml concentrated sulphuric acid and selenium mixture were added, mixed carefully and digested for 3 hours. The digest was diluted with 50 ml distilled water and allowed to cool. The digest was made to 100 ml with distilled water and mixed well. A 25 ml aliquot of the digest was transferred to the reaction chamber and 10 ml of 40% NaOH solution was added followed by distillation. The distillate was collected in 2% boric acid. Using bromocresol green as an indicator, the distillate was titrated with 0.02 *N* HCl solution. A blank distillation and titration was also carried out to take care of traces of nitrogen in the reagents as well as the water used.

Calculation:

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

where:

M = concentration of HCl used in titration.

a = ml HCl used in sample titration b

= ml HCl used in blank titration s

= weight of air-dried sample in grams

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

1.4 = 14 x 0.001 x 100% (14 = atomic weight of nitrogen) v

= total volume of digest

t = volume of aliquot taken for distillation

3.2.2.4 Available phosphorus

The readily acid – soluble forms of phosphorus were extracted with Bray No. 1 solution (HCl : NH_4F mixture) (Bray and Kurtz, 1945; Olsen and Sommers, 1982). Phosphorus in the sample was determined on a spectrophotometer by the blue ammonium molybdate with ascorbic acid as a reducing agent. A 5 g soil was weighed into 100 ml extraction bottle and 35 ml of Bray's no. 1 solution (0.03*M* NH_4F and 0.025*M* HCl) was added. The bottle was placed in a reciprocal shaker and shaken for about 10 minutes and filtered through Whatman No. 42 filter paper. An aliquot of 5 ml of the filterate was pipetted into 25 ml flask and 10 ml colouring reagent (ammonium paramolybdate) was added followed by a pinch of ascorbic acid. After mixing well, the mixture was allowed to stand for 15 minutes to develop a blue colour. The colour was measured using a 21D spectrophotometer at 660 nm wavelength. The available phosphorus was extrapolated from a standard curve.

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

Calculation:

$$P(mg/kg) = \frac{(a-b)\times 35\times 15\times mcf}{s}$$

where:

a = mg P/l in the sample extract

b = mg P/l in the blank s =

sample weight in gram mcf =

moisture correction factor 35 =

volume of extracting solution

15 = final volume of sample solution.

3.2.2.5 Extraction of exchangeable cations

Calcium, magnesium, potassium and sodium in the soil were determined in 1.0 *M* ammonium acetate (NH_4OAc) extract (Black, 1986). A 10 g sample was transferred into a leaching tube and leached with a 250 ml of buffered 1.0 *M* ammonium acetate (NH_4OAc)

solution at pH 7. Hydrogen plus aluminum were determined in 1.0 *M* KCl extract as described by Page *et al*. (1982).

3.2.2.5.1 Determination of exchangeable calcium and magnesium

A 25 ml portion of the extract was transferred into a conical flask and the volume made to 50 ml with distilled water. Potassium ferrocyanide (1 ml) at 2%, hydroxylamine hydrochloride (1 ml), potassium cyanide (1 ml) at 2% (from a burette), ethanolamine buffer (10 ml) and 0.2 ml Eriochrome Black T solutions were added. The mixture was titrated with 0.01 *M* ethylene diamine tetraacetic acid (EDTA) to a pure turquoise blue colour. A 20 ml 0.01 *M* EDTA in the presence of 25 ml of 1.0 *M* ammonium acetate solution was added to provide a standard blue colour for titration. The titre value again was recorded. The titre value of calcium was subtracted from this value to get the titre value for magnesium.

Calculation:

$$\text{Ca + Mg (cmol(+)/kg} = \frac{0.01\times(V_a - V_b)\times 1000\ 0.1\times}{W}$$

where:

W = weight in grams of air - dry soil extraction.

V_a = ml of 0.01 *M* EDTA used in the sample titration.

V_b = ml of 0.01 *M* EDTA used in the blank titration.

0.01 = concentration of EDTA used

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3.2.2.5.2 Determination of calcium only

A 25 ml portion of the extract was transferred to a 250 ml conical flask and the volume made to 50 ml with distilled water. Hydroxylamine hydrochloride (1 ml), potassium cyanide (1 ml of 2% solution) and potassium ferro cyanide (1 ml of 2%) were added. After a few minutes, 4 ml of 8 *M* potassium hydroxide and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01 *M* EDTA solution to a pure blue colour. Twenty milliliters of 0.01 *M* calcium chloride solution was titrated with 0.01 *M* EDTA in the presence of 25 ml 1.0 *M* ammonium acetate solution to provide a standard pure blue colour. The titre value of calcium was recorded.

3.2.2.5.3 Determination of exchangeable potassium and sodium

Potassium and sodium in the percolate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg/l potassium and sodium solutions to 100 mg/l. This was done by taking a 25 mg portion of each into one 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks respectively. 100 milliliters of 1.0 *M* NH_4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg/l for potassium and sodium. Potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively.

Calculations:

$$\text{Exchangeable K (cmol/kg soil)} = (a - b) \times 250 \times mcf$$

$10 \times 39.1 \times s$

Exhangeable Na (cmol/kg soil) = $\frac{(a - b) \times 250 \times mcf}{10 \times 23 \times s}$

where:

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

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

s = air-dried sample weight of soil in grams.

mcf = moisture correcting factor

3.2.2.5.4 Determination of exchangeable acidity

Exchangeable acidity (defined as the sum of Al and H) was determined by titration method after extraction with 1.0 *M* potassium chloride (Page *et al*., 1982). A 50 g soil sample was put in 200 ml plastic bottle and 100 ml of 1.0 *M* KCl solution added. The bottle was capped and shaken for 1 hour on a mechanical-electric shaker and then filtered. A 50ml portion of the filtrate was taken with a pipette into a 250ml conical flask and 2 – 3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1 *M* NaOH until the colour just turned permanently pink. A blank was included in the titration.

Calculation:

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

where a = ml NaOH used to titrate with sample.

b = ml NaOH used to titrate with blank.

M = molarity of NaOH solution s

= air-dried soil sample weight in gram

2 = aliquot factor (100/50)

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

3.2.2.5.5 Effective Cation Exchange Capacity (ECEC)

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

3.2.3 Soil microbial biomass analysis

3.2.3.1 Soil microbial nitrogen

The fumigation - extraction method of Jenkinson and Ladd (1981) was used to determine the microbial biomass. Moist soil samples (15 g) were put in 50 ml beakers and placed in a dessicator containing 30 ml alcohol-free chloroform (Plate 1). The dessicator was then covered and kept for 72 hours at room temperature. Determination of biomass N was done immediately after fumigation by extracting the soil samples with 0.5 *M* K_2SO_4. Similarly, the non-fumigated sub-samples were also extracted. The extract was analyzed for total N after Kjeldahl digestion. Biomass N was determined as the difference between the extracted N in the fumigated and non-fumigated soils.

Calculation:

Microbial biomass N = (Extracted N_{t1} – Extracted N_{to}) (Brookes *et al*., 1985).
where

Nt_1 = Extracted N produced following fumigation

Nt_0 = Extracted N in unfumigated sample

3.2.3.2 Soil microbial phosphorus

For exractable P, a moist sub-sample was shaken with Bray No. 1 solution (HCl : NH_4F mixture) for 5 minutes and then filtered through a Whatman No. 42 paper using Bray - 1 method. The extracted P was then determined by the ammonium molybdate - ascorbic acid method. Biomass P was determined as the difference between the extracted P in the fumigated and non-fumigated soils.

Calculation:

Microbial biomass P = (Extracted P_{t1} – Extracted P_{to})

where:

P_{t1} = Extracted P produced following fumigation

P_{t0} = Extracted P in unfumigated sample

3.2.3.3 Soil microbial carbon

The amount of microbial carbon in 0.5 *M* K_2SO_4 solution was determined after an aliquot of the extracted carbon had been evaporated to dryness. The dichromate oxidation method was used.

Calculation:

Microbial biomass C = (Extracted C_{t1} – Extracted C_{to}) (Vance *et al*., 1988).

where

C_{t1} = Extracted C produced following fumigation

C_{t0} = Extracted C in unfumigated sample

Plate 1. Experimental apparatus and sample arrangement under fumigation as described by Jenkinson and Ladd (1981).

3.2.4 Determination of soil physical properties

3.2.4.1 Particle size distribution

This was determined by the Bouyoucos hydrometer method (Bouyoucos, 1936). A 40 g soil was weighed into 250 ml beaker and oven dried at 105^0 C over night. The sample was removed from the oven and placed in a desiccator to cool, after which the oven dry weight was taken. A 100 ml of dispersing agent sodium hexa-metaphosphate was added to the soil. It was then placed on a hot plate and heated until the first sign of boiling was observed. The content of the beaker was weighed into a shaking cap and fitted to a shaking machine and shaken for 5 minutes. The sample was sieved through a 50 µm sieve mesh into a 1.0 L cylinder. The sand portion was dried and further separated using graded sieves of varying sizes into coarse, medium, and fine sand. These were weighed and their weights taken. The 1.0 L cylinder containing the dispersed sample were placed on a vibration - less bench and then filled to the mark. It was covered with a watch glass and allowed to stand overnight. The hydrometer method was used to determine the silt and the clay contents. The cylinder with its content was agitated to allow the particles to be in suspension. It was then placed on the bench and hydrometer readings taken at 40 seconds and 6 hours interval. At each hydrometer reading, the temperature was also taken. The percent sand, silt and clay were calculated as follows:

% Clay = corrected hydrometer reading at 6 hours x 100/weight of sample

% Silt = corrected hydrometer reading at 40 seconds x100/weight of sample - % clay.

% Sand = 100 %- % silt - % clay

The various portions were expressed in percentage and using the textural triangle, the texture was determined.

3.2.4.2 Determination of bulk density

About 1 – 2 cm surface soil was removed from the sampling spot and the spot levelled. A 5 cm diameter thin-sheet metal tube of known weight (W_1) and volume V was driven 5 cm into the soil surface. The soil around the tube was excavated and excess soil trimmed from the tube ends. The soil was put in an oven at 105ºC for 2 days and its weight (W_2) recorded.

Calculation:

$$\text{Bulk density (gcm}^{-3}\text{)} = \frac{W_2 - W_1}{V}$$

3.2.4.3 Soil physical fractionation by wet - sieving

Following the method described by Six *et al*. (1998) and Puget *et al*. (2000), a 100 g subsample from an air-dried whole soil was weighed on a digital weighing balance. A white basin (30 cm diameter, 8 cm deep) was filled with water until water level was approximately 1 cm above a 2000 µm sieve mesh. The soil sample was evenly spread on the sieve and allowed to stand for 5 minutes to allow slaking. After 5 minutes, the soil was sieved for two minutes by moving sieve 50 times up and down with a slight angle to ensure that water and small particles go through the mesh (Plate 2). The insides of the sieve were then rinsed with water in order to have all particles in suspension. Using preweighed small drying pans, >2000 µm (i.e. large macroaggregates) was backwashed with sufficient water after which all floating litter was discarded. Drying pans containing the large macroaggregates was put in an oven at 60 ^{0}C overnight. Water and particles that went through the 2000 µm and remained in the white basin was poured onto a 250 µm which was held above a second basin and the sieving procedure repeated as described above. The 250 – 2000 µm (i.e. small aggregates) was also backwashed into preweighed drying pans and oven dried at 60 ^{0}C overnight. Water and particles that went through the 250 µm sieve into the basin was poured through a 53 µm sieve held above a third basin and sieving procedure repeated as described above. Microaggregates (i.e. 53 – 250 µm) were backwashed into preweighed drying pans and oven dried for 24 hours. Four hundred milliliters of water and particles; < 53 µm (i.e. silt + clay) remaining in the basin was pipetted into a large drying pan and oven dried till all the water was evaporated from the pan. The weights of the four main soil aggregates were recorded and expressed as percentages of the initial soil weight taken.

Plate 2. Wet - sieving of whole soil as described by Six *et al*. (1998).

3.2.5 Determination of soil biological properties

3.2.5.1 Isolation and characterization of soil fungi and bacteria

Five different compost and fertilizer treatments (1:1 compost at 5 t/ha, 2:1 compost at 5 t/ha, cowdung, 100% NPK and control) were evaluated to assess their effects on soil total viable bacteria and fungi after three cropping seasons. Soil samples were collected after harvest and enumerated for total bacteria and fungi populations.

Using a sterile spatula, 1 g each of the soil samples collected were aseptically transferred into 10 ml distilled water and thoroughly mixed by inverting and shaking the sample bottle several times. Several dilutions were then made as follows: 1 ml aliquot from each solution was taken with an automatic pipette from an inch below the surface and added to 9 ml sterile Ringers solution (diluent) in a test tube ensuring that the pipette did not touch the surface of the diluent but held against the inside of the test tube. This is the 10^{-1} dilution. A 1 ml sample of the 10^{-1} solution was pipetted into another tube containing 9 ml sterile Ringers solution. This is the 10^{-2} dilution. Solutions were prepared down to 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6} by repeating the above procedure further four times.

Using a fresh sterile pipette for each dilution, 1 ml each of the dilutions was poured onto sterilized petri dishes. To this, molten plate count agar at 45 ºC was aseptically poured (Plate 3) onto it and swirled and allowed to solidify. The dishes were labeled, cellotaped and incubated in inverted positions at 37 ºC for 24 hours for growth to occur. The same procedure was repeated using cassava dextrose agar as a medium for fungi. After the incubation period (24 hours), the colony forming units were counted using a Quebec colony counter.

Using a sterile inoculation loop, a little each of bacteria colony from each plate was taken and spread on a slide containing a drop of distilled water, allowed to dry and fixed by passing over a Bunsen flame (Plate 4) two or three times. Each slide of bacterial smear was stained with 0.5% crystal violet for 2 minutes, washed with water and stained with dilute iodine for another 2 minutes. Absolute alcohol was carefully dripped onto the smear and allowed to run off. This was repeated 3 times and washed off with water. Counterstaining with 1% safranin for 2 minutes and washing finally with water was undertaken. After staining, the slides were examined without a coverslip under a light microscope at X100.

Plate 3. Aseptic pouring of medium into petri dishes.

Plate 4. Bacteria culture being fixed onto a glass microscope slide prior to staining.

3.2.6 Resource quality analyses of manure

Manure samples collected were air-dried at room temperature to a constant weight. Sub - samples were taken, milled and passed through a 2mm mesh sieve and analysed.

3.2.6.1 Determination of total nitrogen in manure

Kjeldahl's method involving oxidation by sulphuric acid and hydrogen peroxide with selenium as catalyst was used in the determination of total nitrogen in manure samples. The nitrogen present is converted into NH_4^+. The ammonium ion, which reacts with the excess of sulphuric acid to form ammonium sulphate, is distilled off in an alkaline medium into boric acid :

$NH_3 + H_3BO_3 \rightarrow NH_{4+} + H_2 BO_{3-}$.

The $H_2BO_3^-$ that is formed is titrated with standard hydrochloric acid back to H_3BO_3. A 20 g oven dried manure sample was ground in a stainless mill and sieved through 1 mm mesh and mixed well to ensure homogeneity. Approximately 0.2 g of the manure was weighed into a Kjeldahl flask, a tablet of selenium catalyst was added and 5 ml of concentrated H_2SO_4 was also added to the mixture. This was digested on the electro thermal Kjeldahl apparatus for three hours. After the clear digest had cooled, 20 ml of distilled water was added to the Kjeldahl flask containing the digested material before it was transferred into a 100 ml distillation tube. Additional 20 ml of distilled water was added plus 20 ml of 40% NaOH. It was then distilled for 45 minutes. The distillate was received in a conical flask containing 20 ml of 4 % boric acid with bromocresol green and methyl red (PT5) indicator. The received greenish solution was titrated against 0.1 *M* HCl solution.

Calculation:

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

where:

a = ml 0.1 *M* HCl used for sample titration b

= ml 0.1 *M* HCl used for blank titration

M = Molarity of HCl

1.4 = 14 x 0.001 x 100% (14 = atomic weight of nitrogen) s

= weight of sample in mg

3.2.6.2 Determination of phosphorus and potassium in manure

Phosphorus and potassium in the manure were determined after ashing 0.5 g sample in a muffle furnace at a temperature of 450 – 500º C for 4 hours and then allowed to cool. The ashed sample was removed from the oven and made wet with 1 - 2 drops of distilled water and dissolved in a 10 ml 1:2 dilute HNO_3 solution. The crucible was heated on a hot metal plate until the first sign of boiling was observed. The crucible was removed and allowed to cool. The content was filtered into a 100 ml volumetric flask using a Whatman No. 42 filter paper. The crucible was washed two times with about 20 ml distilled water. For phosphorus determination, 10 ml each of ammonium vanadate and ammonium molybdate solutions were added and shaken thoroughly. The solution was allowed to stand for 10 minutes for full colour development and filled to the 100 ml mark. The absorbance of the sample and standard solutions was read on the 21D spectrophotometer at a wavelength of 470 mm. A standard curve was obtained by plotting the absorbance values of the standard solutions against their concentrations. Phosphorus concentration of the sample was determined from the standard curve.

Potassium in the ash was determined using the Gallenkamp flame analyser. Potassium standard solutions were prepared with the following concentrations: 0, 10, 20, 40, 60, and 100 μg K per litre of solution. The emission values were read on the flame analyser. A standard curve was obtained by plotting emission values against their respective concentrations.

3.2.6.3 Determination of calcium and magnesium in manure

Calcium and magnesium were estimated using the procedure of Anderson and Ingram (1993). A 25 ml aliquot of the ash solution was put in a conical flask. Potassium ferrocyanide and potassium cyanide solutions were added to eliminate interfering cations such as Fe and Cu. The solution was titrated with 0.02 *M* EDTA solution using Eroichrome Black T indicator. To determine calcium content, potassium hydroxide was added to raise the pH to about 12. At this pH, magnesium is precipitated leaving calcium in solution. The solution was titrated again with EDTA using murexide as indicator. The difference in values between the first and second titres represents magnesium concentration in the solution.

3.2.6.4 Determination of copper, zinc, iron and manganese in manure

The atomic adsorption spectrophotometer was used in the determination of Cu, Zn, Fe and Mn in the ash solution by comparing the abosrbances of Cu, Zn, Fe and Mn atoms with respect to a series of standard solutions. Micronutrients content of the manure were measured directly from the digest. Graphs relating the absorbance to the amount of Cu, Zn, Fe and Mn in the manure were plotted.

Calculation:

mg/kg (Cu, Zn, Fe and Mn/DM) = 100 x (a – b) x mcf where:

a = sample absorbance b

= absorbance of blank 100

= percentage mcf =

moisture correcting factor

DM = dry matter

3.2.6.5 Determination of polyphenol content in manure

This was determined using the Folin – Denis method (Constantinides and Fownes, 1994). One gram oven-dried and milled manure was weighed into a 50 ml beaker. Twenty milliliters of ethanol was added, covered and placed in a water bath at 80^0C for 1 hour. The extract was filtered through No. 42 Whatman filter paper into a 50 ml volumetric flask and made up to the mark with distilled water. Standard solutions of tannic acid (0, 10, 20, 50 and 100 mg/l) 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 the 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.

Calculation:

mg/kg polyphenol = graph reading x sample dilution x aliquot dilution

= graph reading x 4 where

Sample dilution = final volume / weight of sample = 50/1

Aliquot dilution = 50/1 (1.0 ml of initial 50 ml extract was put in a 50 ml flask and made to the 50 ml mark with ethanol (ie. 50/1).

3.2.6.6 Ash and organic carbon content in manure

One gram of a well mixed air dry (<2 mm) sample of known moisture content was weighed into a dry porcelain crucible of known weight and heated for 4 hours at a temperature of 450°C in a muffle furnace. After 4 hours, the crucible containing a grayish white ash was allowed to cool in a dessicator and weighed.

Calculations:

$$\%Ash = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100$$

% organic matter = 100 - % ash where

W_1 = weight of empty dry crucible

W_2 = weight of dry crucible containing manure

W_3 = Weight of dry crucible containing manure following ignition.

Organic carbon of manure was then calculated by dividing organic matter values by the van Bemmelen factor of 1.724.

3.2.6.7 Moisture content of manure

A 1.0 g air-dry sample of manure was put into an already dried and weighed porcelain crucible and oven-dried at 105°C over-night. The sample was removed from the oven, covered with an aluminium foil and allowed to cool in a dessicator for at least 30 minutes and weighed.

Calculation:

$$\% \text{ Moisture} = \frac{\text{loss of weight}}{\text{weight of sample}}$$

$$\text{Moisture correction factor} = \frac{100}{100 - \%\text{moisture}}$$

3.3 Composting experiment

3.3.1 Materials used for composting

- *Stylosanthes guinensis* (biomass)
- Maize stover
- Cowdung

3.3.2 Compost preparation

Two main compost types were prepared according to the following ratio combinations:

- 1:1 compost (1 part of plant material i.e. *Stylosanthes;* 1 kg + maize stover; 1 kg: 1 part of cowdung; 2kg)
- 2:1 compost (2 parts of plant material i.e.*Stylosanthes;* 1 kg + maize stover; 1kg: 1 part of cowdung; 1 kg)

Weights of cowdung and plant materials used were taken on dry weight basis. Plant materials were reduced to lengths of 5 – 10 mm, weighed and mixed prior to composting. The source of cowdung used was from some districts of Upper East region of Ghana (Appendix 6). Compost piles measuring 1.2 m x 1.2 m x 1.5 m were constructed on perforated bamboo pipes (aerated pile method). The piles were covered with soil to minimize water loss. The soil also acted as a bio – filter to minimize odor emission. The moisture content of each pile was maintained at 50 – 60% throughout the composting process. Temperature and pH of the compost were taken at 0, 1, 2, 4, 6, 8, 10 and 12 weeks of maturation using a mercury thermometer graduated in degree celsius and a glass electrode pH meter respectively. Composting was done under a shade at Soil Research Institute and harvested after 100 days of maturation.

At the end of the composting process, samples were collected using a spatula sterilized in 70% alcohol. The spatula was used to mix the compost slightly and to transfer compost samples into sterile containers and sealed tightly before being taken for laboratory analysis. Compost samples were analyzed physically, chemically and biologically.

The physical analyses included:

i. colour (based on the Munsel Colour Chart)
ii. moisture holding capacity.

Chemical analyses included the determination of:

i. Total macro-nutrients (N, P, K, Ca and Mg)
ii. Total organic carbon

Biological analyses involved mainly identification of the following microbes:

i. Fungi ii.

Bacteria.

3.3.3 Compost maturity test

A 20 g compost sample was weighed into a 100 ml plastic beaker. To this, 50 ml distilled water was added from a measuring cylinder, stirred by hand for 5 minutes, allowed to stand for 30 minutes and filtered into a 250 ml conical flask. A 10 ml portion of the compost filtrate was poured into petri dishes lined with filter papers. Petri dishes containing 10 mls distilled water without filtrate was included as a control treatment. Cowpea seeds (20) were put in each petri dish, covered, labeled and kept in a dark place at room temperature for seven days. Germination index as proposed by Zucconi *et al.*

(1981) was calculated as follows:

$$\text{Germination index} = \frac{\%\ \text{Compost emergence}}{\%\ \text{Emergence in control}} \div \frac{\%\ \text{Root length in compost}}{\%\ \text{Root length in control}}$$

3.4 Compost decomposition and nutrient release studies

3.4.1 Nutrient release patterns of compost under laboratory conditions

Nutrient release patterns of the composts were determined using the leaching tube incubation procedures (Stanford and Smith, 1972) (Plate 5). The leaching tube incubation method gives an estimate of potential nutrient release under optimal conditions of moisture and temperature. Glass tubes of 200 mm length with a diameter of 20 mm were used. Ten grams soil sample collected from the experimental site was put into leaching tubes of 2 cm diameter and 20 cm long and 100 mg each of compost were added to the soil in the tube.

Each compost type was replicated three times in a completely randomized design. Control treatments (0% compost) were also included in the set up. The experiment was conducted under laboratory conditions with maximum room temperature of about 27 ^{0}C.

The samples in the tubes were leached at 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 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). Phosphorus in 5 ml aliquot of the leachate was determined on a spectrophotometer by the blue ammonium molybdate with ascorbic acid as a reducing agent. 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. After each leaching event the tubes were subjected to mild suction to bring the water content of each tube to 60 – 70% water holding capacity.

Plate 5. Aerobic leaching tube method as described by Stanford and Smith (1972).

3.4.2 Nutrient release patterns of compost under field conditions

This study was carried out during the major rainy season of 2008 at Kwadaso over a period of eight weeks. The objective was to study the rates of breakdown of the two compost types and their nutrient release patterns under actual field conditions. Litter bags measuring (20 x 30 cm) were made from nylon mosquito nets (1 mm mesh size). The design of the experiment was a randomized complete block with three replicates. A 100 g each of the compost types were put in the litter bags and buried in a predetermined randomized sequence, 20 cm apart, at a depth of 10 cm in two parallel lines between rows of maize. A safety pin attached to a stainless steel nail anchored each bag to the soil. Each treatment had four samples. One sample each of each treatment was oven dried, ground and analyzed for total N, P, K, Ca and Mg contents.

Dry matter disappearance from the decomposition bags was monitored at 1, 2, 4, 6 and 8 weeks (Anderson and Ingram, 1993) after incubation. At each sampling time, the remaining composts from the bags were dried at 65 ^{o}C to a constant weight and their dry weights recorded. The materials were then ground to less than 1 mm particle size and analyzed for total nitrogen, phosphorus, potassium, calcium, magnesium and organic carbon. The amounts of nutrients remaining in the litter bags at each sampling time were determined by multiplying the masses of the nutrients remaining by their respective concentrations as described by Giashuddin *et al.* (1993).

% nutrient released = 100 - % of the original nutrient content remaining

For each treatment, decomposition rate and nutrient release constants were determined from which time to 50% decomposition and nutrient released were estimated. The decomposition and nutrient release constants, k, were determined by the negative exponential model,

$$m_t / m_o = m_o e^{-kt}$$

where m_t = mass of material remaining at time 't' in days

m_o = initial mass of material or nutrient

Half life (t_{50}) was calculated as

$$t_{50} = \underline{\hspace{2cm}}^{-}\ Ink(0.5)$$

3.5 Maize response to compost application

3.5.1 The study site

The study was conducted at the Soil Research Institute experimental site, Kwadaso, during the major and minor cropping seasons of 2007 and major cropping season of 2008. The area lies between latitudes $06^0.39'$ and $06^0.39'$ and longitudes $01^0.39'$ and $01^0.42'$ West of the Greenwich meridian in the semi-deciduous forest zone of Ghana. The area receives bimodal rainfall of 1500 mm per year with peaks in June and September. Temperatures are generally high and uniform throughout the year. Mean monthly temperatures range from 24 – 28^0C. Relative humidity is generally high in the mornings (90%) and falls (60 – 70%) in the afternoon. The farm site for the experiment had been previously cropped to cowpea with no mineral fertilizer application coupled with inconsistent fallow periods.

3.5.2 Field preparations, compost application and planting of maize

The experimental field was manually cleared with cutlass and hoe after which the field layout was done. Plot sizes measuring 3 m x 4 m were demarcated. Compost and mineral fertilizer treatments were applied by the method of hill placement two weeks after planting. The inorganic fertilizer was applied in two splits: first application of NPK, 1515-15 at 60-60-60 kg/ha and top dressed with 30 kg N/ha applied as urea six weeks after planting. Control plots did not receive compost or chemical fertilizer applications. Maize (Obaatanpa) with a germination percentage of 85% was planted at three seeds per hole of about 5 – 7 cm deep at a spacing of 80 cm x 40 cm. These were thinned to two seedlings per hill 14 days after planting.

3.5.3 Experimental design

A field experiment was carried out to study the fertilizing effect of the two main compost types and all possible combinations with mineral fertilizer on maize yield. The soil amendments were as follows:

T_o = Control

T_1 = 1:1 compost at 3 t/ha

T_2 = 1:1 compost at 5 t/ha

T_3 = 1:1 compost at 3 t/ha + 100% NPK

T_4 = 1:1 compost at 5 t/ha + 100% NPK

T_5 = 1:1 compost at 3 t/ha + 50% NPK

T_6 = 1:1 compost at 5 t/ha + 50% NPK

T_7 = 2:1 compost at 3 t/ha

T_8 = 2:1 compost at 5 t/ha

T_9 = 2:1 compost at 3 t/ha + 100% NPK

T_{10} = 2:1 compost at 5 t/ha + 100% NPK

T_{11} = 2:1 compost at 3 t/ha + 50% NPK T_{12}

= 2:1 compost at 5 t/ha + 50% NPK

T_{13} = cowdung at 5 t/ha

T_{14} = 50% NPK (45:30:30 kg/ha)

T_{15} = 100% NPK (90:60:60 kg/ha)

There were three replications of each treatment arranged in a randomized complete block design.

3.5.4 Data collection

3.5.4.1 Plant parameters

At 50% flowering stage, the following plant parameters were determined:

i. Leaf area ii. Plant height

Plant height and leaf area were measured using a measuring tape. The plant height was taken from the soil surface to the apical tip of the plant. The leaf length and breadth were measured to obtain the leaf area. The leaf area was estimated as its length multiplied by its maximum width multiplied by 0.75 (maize leaf calibration factor) (Ellings, 2000).

Three measurements of each of the parameters were taken and then averaged.

At harvest, a sub-sample of eight plants was randomly taken from each plot and the rest discarded. The plants were separated into ears (cob + grains) and stovers (stem, leaves and husks) and oven-dried at 80ºC to a constant weight. The following were measured as yield parameters:

i. Stover yield (kg/ha) = TDM (stover) x 833.3 where

TDM = total dry matter

833.3 = conversion factor, i.e. $\frac{10,000\ m_2}{12\ m_2}$ to

yield/ha ii. Grain yield (kg/ha) = TDM (grain) x 833.3

where

TDM = total dry matter

833.3 = conversion factor, i.e. $\frac{10,000\ m_2}{12\ m_2}$ to yield/ha

iii. 100 seed weight

3.5.4.2 Plant tissue analysis

Laboratory analysis of plant tissues (stems and leaves) at the end of each cropping season were carried out to determine total N, P, K, Ca and Mg contents as described according to procedures in sections 3.2.4.1 – 3.2.4.3.

3.5.4.3 Soil analysis

Representative soil samples from the top 0 – 15 cm of each plot were collected after harvest from the hills where treatments were applied and analyzed to determine the following: particle size, pH (H_2O), organic carbon (OC), total nitrogen (N), Bray available phosphorus (Bray P), exchangeable cations, effective cation exchange capacity (ECEC), base saturation, total microbial load, soil microbial biomass C and N as described according to procedures in the earlier sections.

3.5.5 Nitrogen recovery

Total nitrogen recovery by maize was determined by the difference method as:

$$\%\ \text{N recovery} = \frac{(\text{Total maize N})^{f} - (\text{Total maize N})^{c}\ x100}{\text{Amout of N added}}$$

where

f = fertilized plot

c = control plot

3.5.6 Data analyses

Data obtained from the survey were analyzed using Statistical Package for Social Scientist (SPSS 10.0). Frequency distribution tables were used to describe, organize and summarize the responses received. Laboratory analyses of cowdung and soil samples were done in duplicates and presented as means of duplicate samples. Plant, soil and all data measured during composting, mineralization and maize establishment experiments were analyzed using Genstat Windows Software Package. The significance of the tests run in this study was done at $p = 0.05$ (5% level). Analysis of variance (ANOVA) (Gomez and Gomez, 1984) was used in these tests and the separation of treatment means was done by looking at Standard Error of Difference (SED) of the means at $p = 0.05$. To equalize variances, densities of bacteria and fungi counts and total microbial loads were transformed logarithmically before calculation of means and standard deviations and comparisons of means to determine the statistical significance of differences.

CHAPTER FOUR 4.0 RESULTS 4.1 Survey of manure management practices

4.1.1 Demographic features of respondents

This survey was conducted to assess farmers' perceptions on manure and its management, manure quality and its use and challenges or concerns of farmers regarding manure use in Upper East region of Ghana. The results indicate that all age groups are involved in agriculture (Fig. 1) with the majority (86%) being male farmers (Fig. 2). The relatively higher male proportion may be attributed to males being predominantly owners of land and heads of the family in the region. The data further revealed that 74% of the farmers had between 5 – 10 children. The higher numbers of children in the family may be due to the polygamous nature of the family structure and the need for labour on farms. The literacy status of the respondents varied from highly educated (tertiary) (15%) to illiterates (78%) (Appendix 2). In all, about 13 tribes were encountered during the survey. The largest of the tribes was the Frafra (25%), followed by the Kasena (20%), and the Kusasi (17%) and Fulani (13%) respectively. The least was the Sisala (less than 1%). The survey showed that 94% of the respondents did farming as their main occupation. Most of the respondents (89%) had reared cattle for between 5 - 15 years. Respondents cited manure production (84%) and labour (7%) as the main purposes for rearing cattle. Surprisingly only (4%) of the total respondents reared cattle for meat. Out of the total respondents interviewed, 76% and 20% respectively were Moslems and Christians.

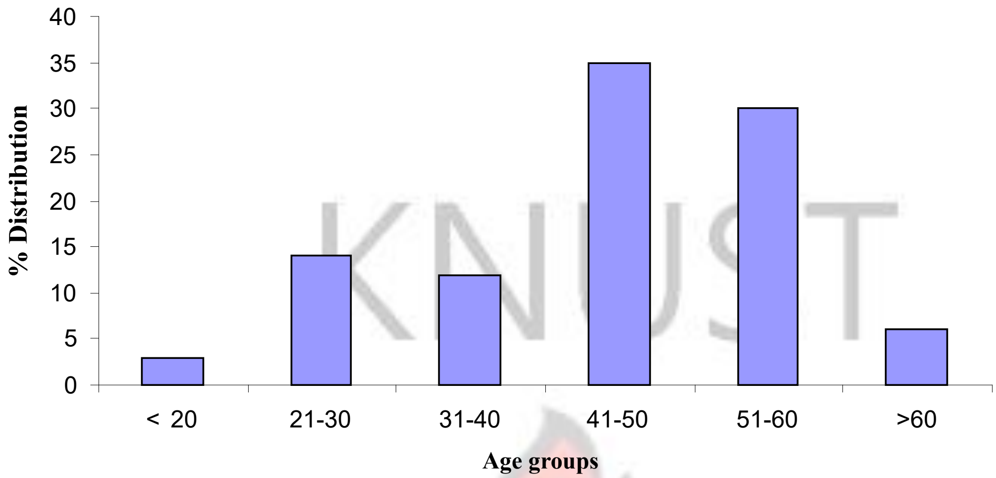


Fig. 1. Age distribution of respondents. Source: Field survey, 2006.

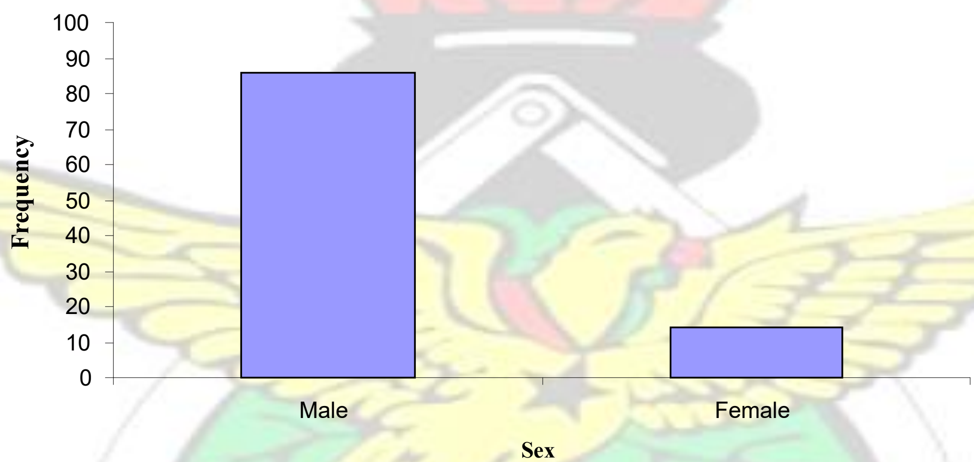


Fig. 2. Sex distribution of respondents. Source: Field survey, 2006.

4.1.2 Housing structure for cattle

Two main types of housing structures were encountered during the survey:

(i) the dynamic kraaling system in which animals are tethered to logs near the household compound (this system allows cattle to be tethered after their return from grazing) (Plate 6) (ii) a kraaling system in which thorny trees are used to temporary build the kraal and their location within the field shifted accordingly at certain time intervals. After a certain period (usually 5 – 14 days) of tethering at a spot, the animals are moved to another part of the field. During the rainy season, animals are usually moved at every 2 – 3 days intervals. This process is repeated until large quantities of cowdung have been deposited all over the cropping field. The accumulated cowdung is then ploughed into the soil at the beginning of the cropping season. It was further observed that some farmers especially the Fulanis were so skillful in the use of the latter that they no longer purchased mineral fertilizer for their maize farms.

Plate 6. Compound 'mud' system of housing cattle in the Upper East region.

Sixty four percent of the respondents had no bedding, whiles 34%, 7% and 7% used straw, grass and sawdust respectively as forms of bedding materials (Appendix 3). Fifty seven percent of the respondents used the floor of the kraal for cowdung storage, 41% heaped the cowdung close to the kraal during storage whiles 2% composted cowdung prior to application. Thirty two percent of the respondents had received some form of training from

NGO's and MOFA with regards to cowdung collection and storage, use of bedding and composting. Despite the alternative uses of cowdung in the region, 84% of the respondents ranked its application to crop fields as the main objective for rearing cattle. About 44% of the respondents used other types of manure apart from cowdung (manure from small ruminants, poultry and crop residues) whiles 36% applied mineral fertilizers in addition to cowdung on their fields.

4.2 Respondents' knowledge of composting

Forty nine percent of the respondents had no idea about composting whiles 2% cited scarcity of composting materials as major drawbacks for not composting cowdung (Appendix 4). Ninety percent of the total respondents who used compost on their farms prepared it during the rainy season whiles 8% began compost preparation at the tail end of the rainy season which sometimes overlaps into the dry season. Some respondents (2%) however prepared compost at any time of the year.

Two main methods of compost preparation were encountered during the survey: heap and pit. Only 2% of the total respondents built compartments with mud (Appendix 4). Eventhough this mud compartment method of preparing compost according to farmers gives best quality compost, a lot of labour was required for its construction and turning. About 40% of the compost users used the pit method which was mostly constructed around the homestead. To them, although this method is labour intensive, the effort made in its construction is worthwhile as the same pits can be used over and over again.

Furthermore, water was available for watering the compost heaps unlike constructing the pits in the field where they sometimes reduced farmland areas as well. Fifty eight percent of the respondents stored matured compost in heaps in the open air (Appendix 4). The main indicator used by farmers to check the 'richness' of their compost was how 'dark' it appeared. Wheelbarrows and donkey carts were mainly used for the transport of compost to fields. However, over long distances, farmers preferred to use bicycles although the volume they could cart on the carriers was little.

Two main types of compost application methods were encountered: spot and broadcast. About 22% of the compost users used the spot method of application, whiles 74% broadcasted and ploughed the compost into the soil (Appendix 4). Farmers generally perceived compost as a good material for soil amelioration and crop growth due to its long term effects on the soil relative to inorganic fertilizer. Appendix 5 shows that less than 10% of the total respondents were unwilling to use compost. The results further revealed that this fraction considered compost preparation and application labour intensive. On the other hand, 84% of the total respondents were willing to use compost as long as returns after application were worthwhile (Appendix 5).

4.3 Characterization of cowdung in the Upper East region

Appendix 6 shows results of the resource quality of cowdung sampled from the various districts in the Upper East region. The results point out that the average N content of cowdung in the region is 0.75% (Table 2). The frequency of distribution was negatively skewed with the majority of cowdung samples having N contents ranging between 0.27

and 1.14%. On the other hand, phosphorus and potassium contents of cowdung ranged from 0.28 – 0.76% and 0.22 – 0.46% respectively (Table 2). On the average, ash content values ranged from 22.37 – 99.85% (Appendix 6). Calcium, magnesium and carbon contents ranged from 0.37 – 0.69%, 0.59 – 1.12% and 19.0 – 30.5% respectively (Table 2).

Table 2. Selected chemical properties of cowdung sampled from the Upper East region

Property	Number of samples	Min.	Max.	Mean	Std. dev.
Org. C (%)	7	19.0	30.50	26.88	4.10
Total N (%)	7	0.27	1.14	0.75	0.34
Total P (%)	7	0.28	0.76	0.43	0.16
Total K (%)	7	0.22	0.46	0.35	0.09
Total Ca (%)	7	0.37	0.69	0.53	0.11
Total Mg (%)	7	0.59	1.12	0.86	0.18

Chemical analyses of cowdung under various management systems were also assessed during the survey (Table 3). The general trend of nitrogen concentration of cowdung under the various management systems followed the order: compound > kraal > intensive > free range. Phosphorus contents of cowdung varied from 0.21% (intensive) – 0.38% (compound). Potassium content varied from 0.18% under free range to 0.57% under compound. Calcium content was highest (1.35%) and lowest (0.28%) under compound and intensive systems respectively. Magnesium content was highest under kraal (0.70%) and lowest under intensive (0.51%). Organic carbon content ranged between 22.0% under free range to 43.0% under intensive system. The polyphenol content ranged from 0.16% under free range to 0.81% under kraal. The C: N ratio of the cowdung samples collected under the various management systems ranged from 20.2 for compound to 64.2 for intensive.

Table 3. Chemical properties of cowdung under different management systems

Management	**N**	**P**	**K**	**Ca**	**Mg**	**Ash**	**Org. C**	**PP**	**C:N**
Ratio System						**%**			
Free range	0.42	0.28	0.18	0.83	0.53	56.0	22.0	0.16	46.81
Kraal	1.23	0.28	0.29	0.80	0.70	50.0	25.0	0.81	20.16
Compound	1.24	0.38	0.57	1.35	0.56	47.0	26.5	0.47	21.37
Intensive	0.67	0.21	0.24	0.28	0.51	14.0	43.0	0.48	64.18

- PP – polyphenols
- Values are means of duplicate samples

4.4 Chemical properties of composted cowdung

The chemical characteristics of cowdung used for composting is presented in Table 4. Quality analyses of the two compost types showed total levels of nitrogen, potassium, phosphorus, calcium and magnesium contents of 1.46, 1.26, 0.31, 0.45 and 0.36% respectively for 1:1 compost type and 1.10, 0.68, 0.28, 0.62 and 0.32% respectively for 2:1 compost type (Table 5). The pH values for the various compost mixtures declined (approximately 27 and 19% respectively for 1:1 and 2:1 compost) from day one up to the end of the composting period. Three months of gradual decomposition lowered the organic carbon content of the 1:1 and 2:1 compost mixtures from 46.50 - 34.20% and 46.70 - 32.58% respectively. Aqueous compost extracts had germination indexes of 71.1 and 83.8% respectively for 1:1 and 2:1 composts (Table 5).

Table 4. Chemical properties of cowdung used for composting

Parameter	Value
pH (1: 5)	9.04
Total nitrogen (%)	0.72
Total phosphorus (%)	0.26
Total potassium (%)	0.39
Total calcium (%)	0.51
Total magnesium (%)	0.38
Organic carbon (%)	20.12
C/N ratio	27.9

Table 5. Characteristics of composted cowdung after 90 days maturity

Property	1:1 composted manure	2:1 composted manure
pH (1: 5)	6.58 (8.40) 1.46	7.23 (8.60) 1.10
Total nitrogen N (%)	(1.90)	(1.89)
Org. C (%)	34.20 (46.50)	32.58 (46.70)
Total phosphorus (%)	0.31 1.26	0.28
Total potassium (%)	0.45 0.36	0.68
Total calcium (%)	23.4	0.62
Total magnesium (%)	71.10	0.32
C:N ratio	Dark brown	29.6
Germination index	Coarse	83.80
Colour	Slightly 'earthy'	Dark brown
Texture		Coarse
Smell		Slightly 'earthy'

- Values represent means of duplicate samples.
- Initial values for pH, C and N are presented in brackets.

4.5 Microbial properties of composted cowdung

Reasonable amounts of microorganisms were present in both compost types at maturity.

The main bacteria identified were *Bacillus* spp. and *Streptococuss* spp. as shown in Plates 7 and 8 respectively. *Escherica coli* and *Staphylococcus* species were also isolated. The main fungi identified were *Trichoderma* spp., *Fusarium* spp., *Aspergillus* spp., and *Penicillim* spp. as shown in Plates 9, 10,11and 12 respectively.

Mean helminthes numbers per 10 g of the compost ranged from 4 – 6. Microscopy results indicated the presence of two main species of helminthes namely *Ascaris lumbricoides* and *Schistosoma* spp. Mean MPN faecal coliform per 100 g compost was 2.3 x 10^3.

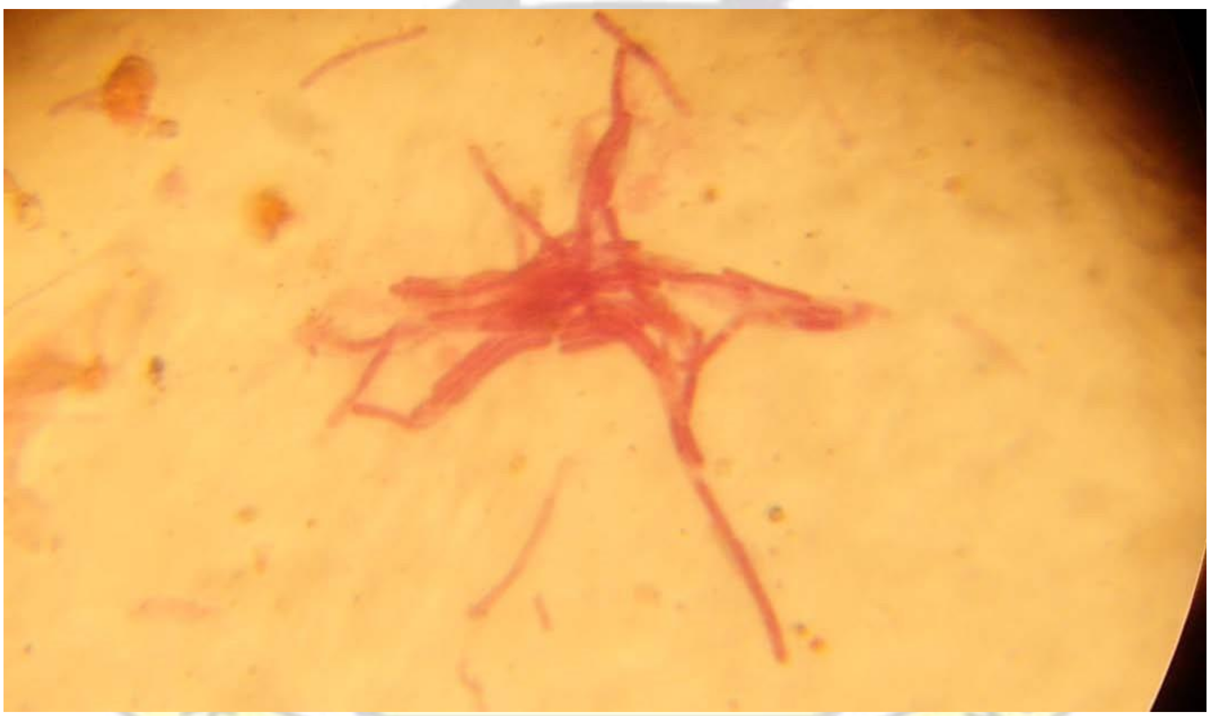


Plate 7. *Bacillus* spp. x100

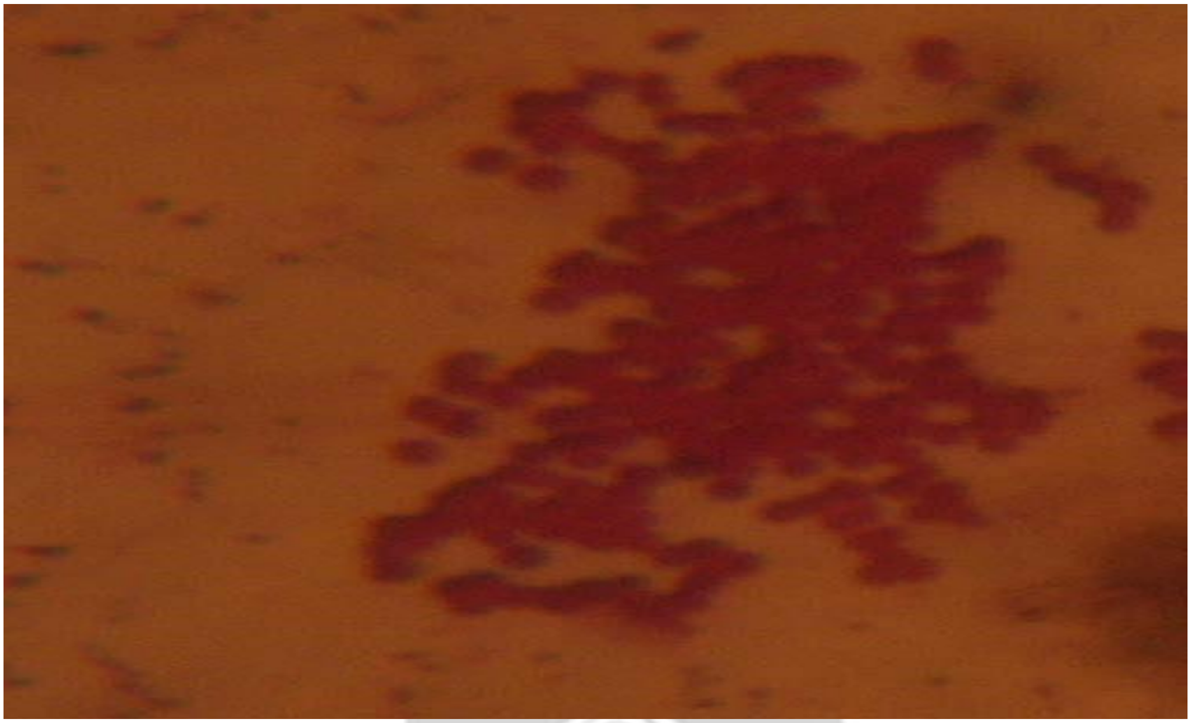


Plate 8. ***Streptococcus*** **spp. x100.**

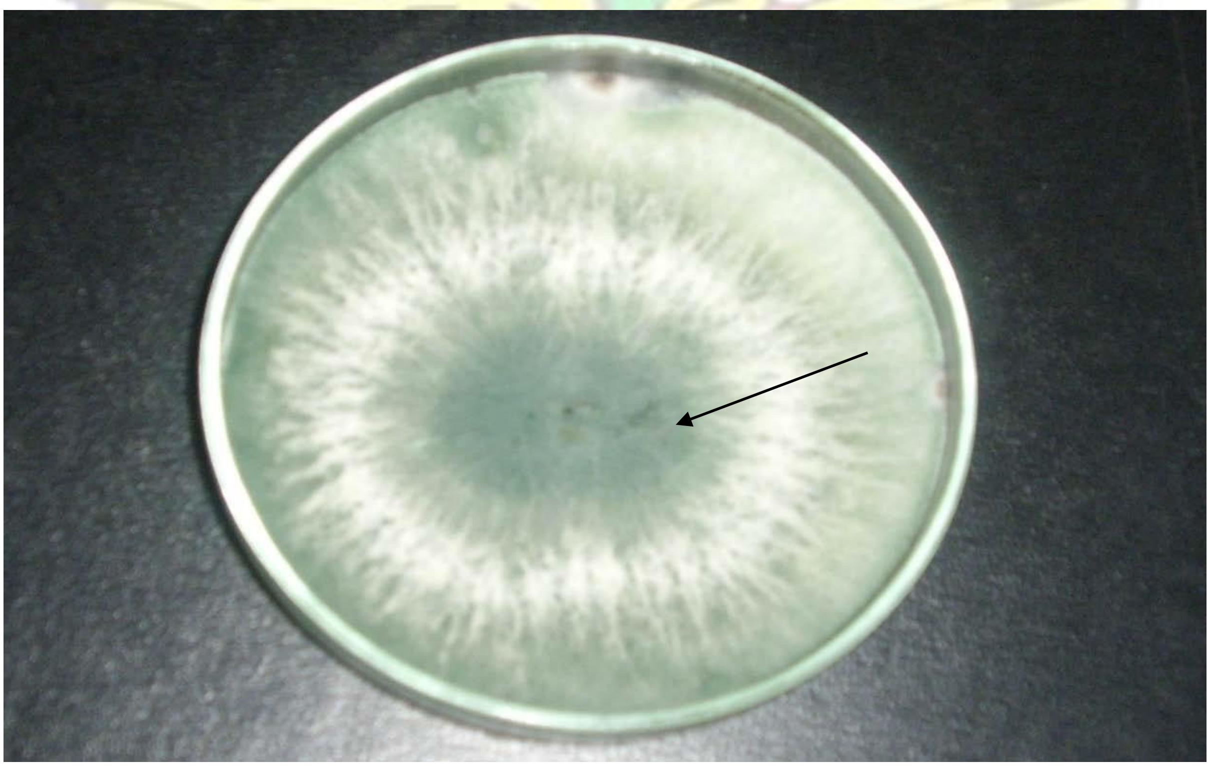


Plate 9. ***Trichoderma*** **species growing on agar plate.**

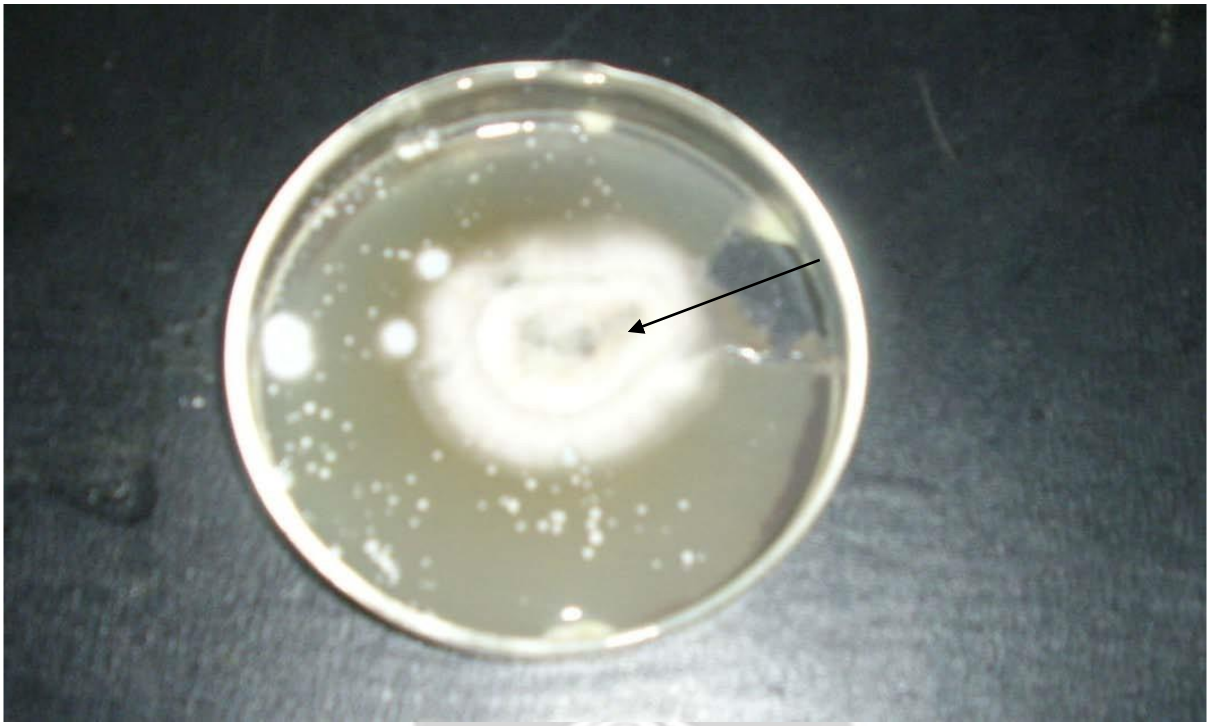


Plate 10. ***Fusarium*** **species growing on agar plate.**

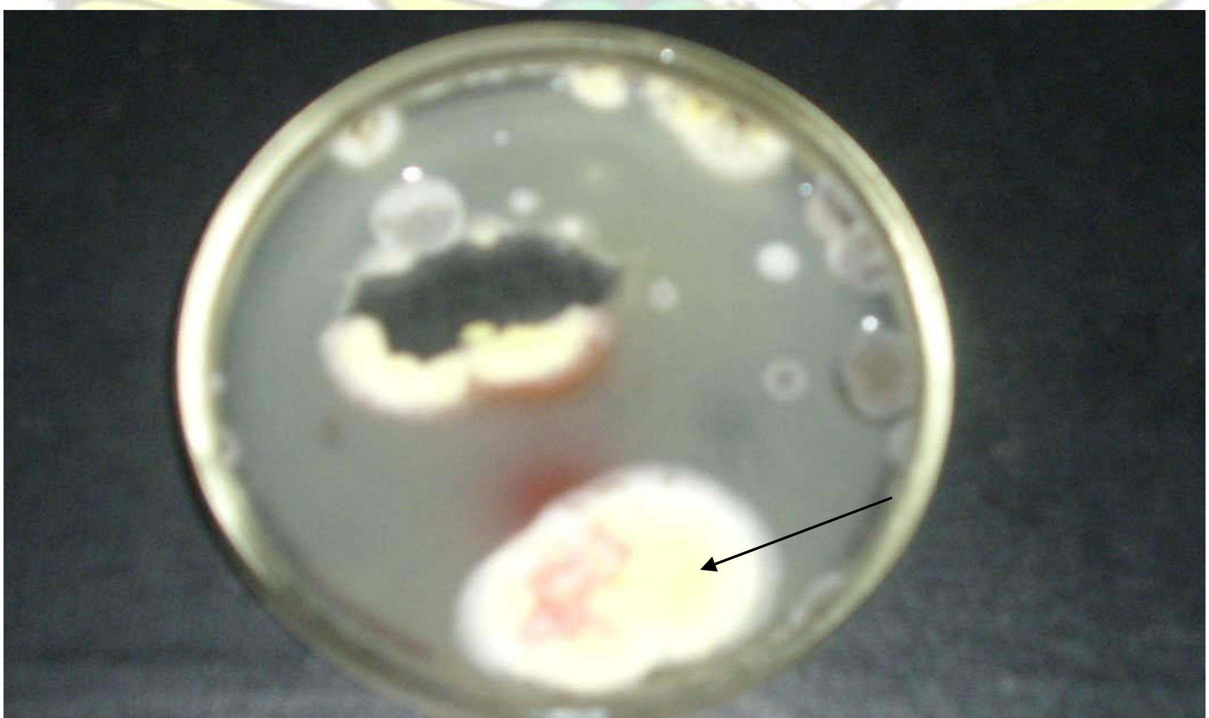


Plate 11. ***Aspergillus*** **species growing on agar plate.**

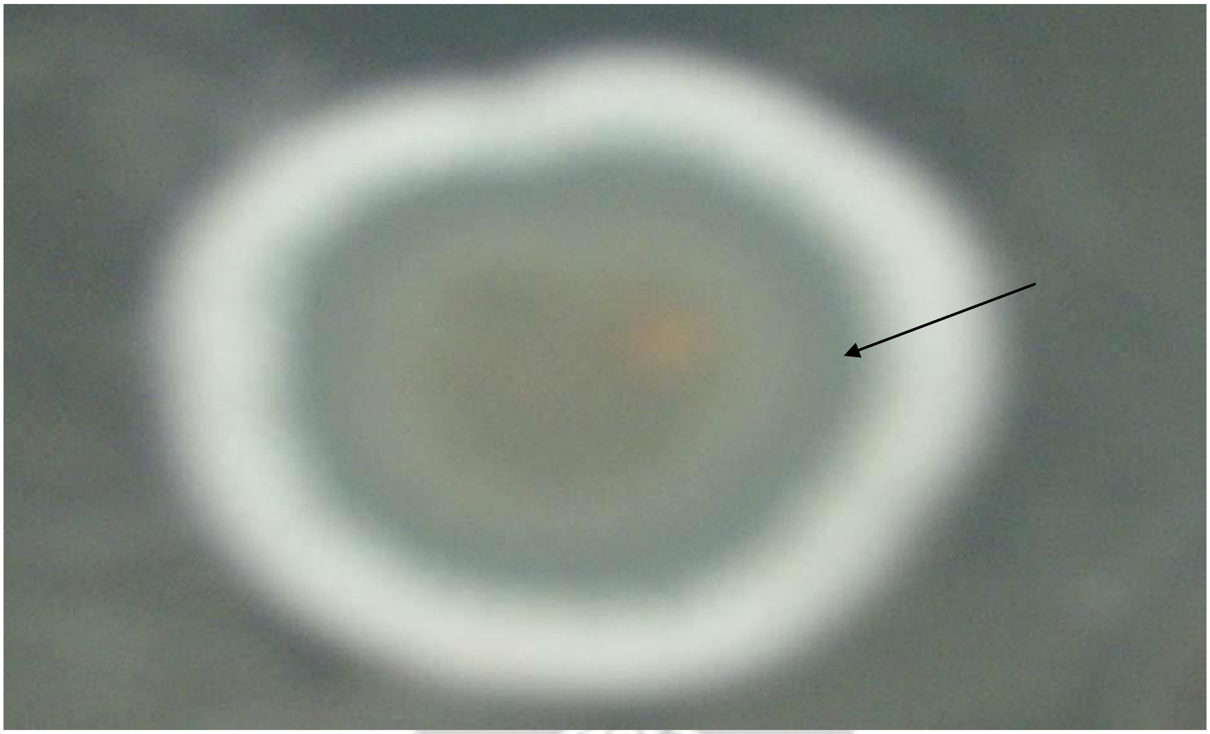


Plate 12. ***Penicillium*** **species growing on agar plate.**

4.6 Temperature regime of the composts

Temperature changes of both compost mixtures measured over a three month period is shown in Fig. 3. Temperature was monitored consecutively over the initial 14 days of composting because this phase is considered most intensive. The highest temperature recorded during the study period was 44 ºC and this was observed in the 1:1 compost after 2 days of composting. The lowest temperature (25 ºC) was however observed in the 2:1 compost after 98 days of maturation. Generally, temperatures for both compost types were relatively higher than the ambient temperatures till after 42 days of compost maturity. However, after 77 days of compost maturation, ambient temperatures exceeded temperatures of both compost types up to the end of the study. The lowest and highest ambient temperatures recorded over the study period were 26 and 36 ºC respectively.

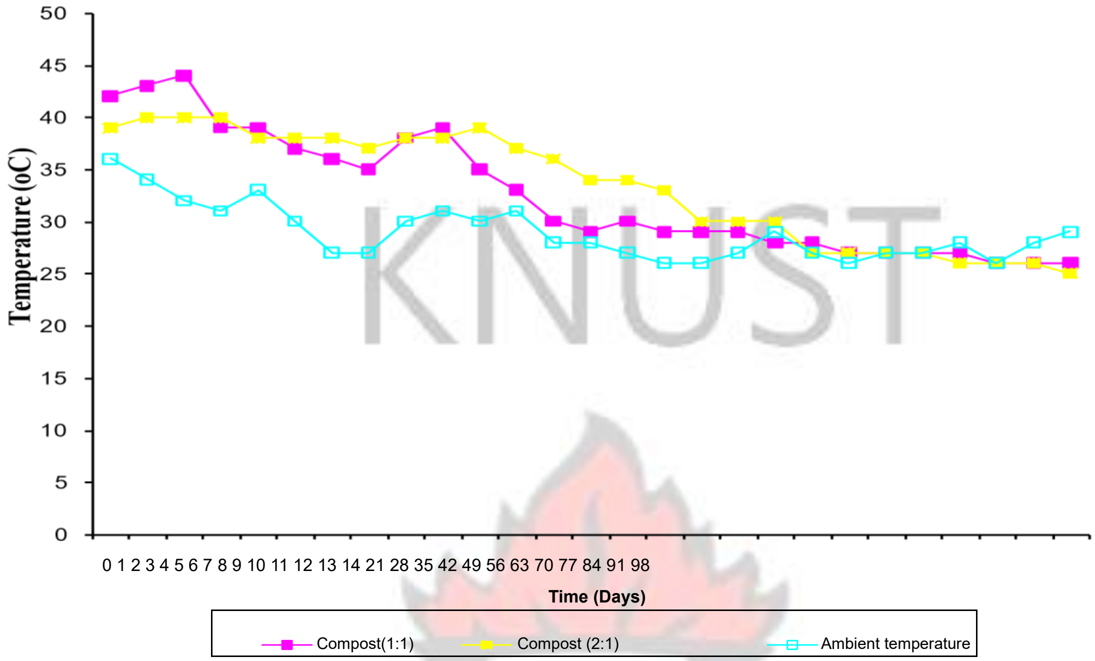


Fig. 3. Changes in temperature during composting.

4.7 Decomposition and nutrient release patterns of compost under laboratory conditions

This study was conducted to assess the mineralization patterns of the two compost types under laboratory conditions. The 1:1 compost showed net N immobilization of -57 mg/kg soil during the first and second weeks of incubation while the 2:1 compost showed net immobilizations of -56 mg/kg soil and -9 mg/kg soil over the same period (Fig. 4). This was followed by a net N mineralization for both compost types till the end of the study except on the 28th day of incubation when 1:1 compost immobilized N.

Ammonium - N was mineralized from both compost types throughout the study period except for the 1:1 compost on days 7 and 14 and on the 28th day for 2:1 compost (Fig. 5). Nitrate - N from both treatments were immobilized throughout the incubation period except for 2:1 compost on the 28th and 56th days of composting (Fig. 6) when mineralization occurred. The highest immobilized nitrate - N (-56 mg/kg soil) was observed in the 1:1 compost on the 7th and 14th days of composting.

Phosphorus was immobilized in both compost mixtures throughout the incubation period except on the 28th and 42nd days of composting when net mineralization of less than 1 mg/kg soil was observed (Fig. 7). Calcium was mineralized from both compost types during the first 14 days of incubation and thereafter immobilized till the end of incubation except the 1:1 compost which mineralized 0.1 mg/kg soil (Fig. 8). Magnesium release patterns for both compost types followed similar release trends except on the 28th day of incubation when the 1:1 compost immobilized whiles 2:1 compost mineralized (Fig. 9).

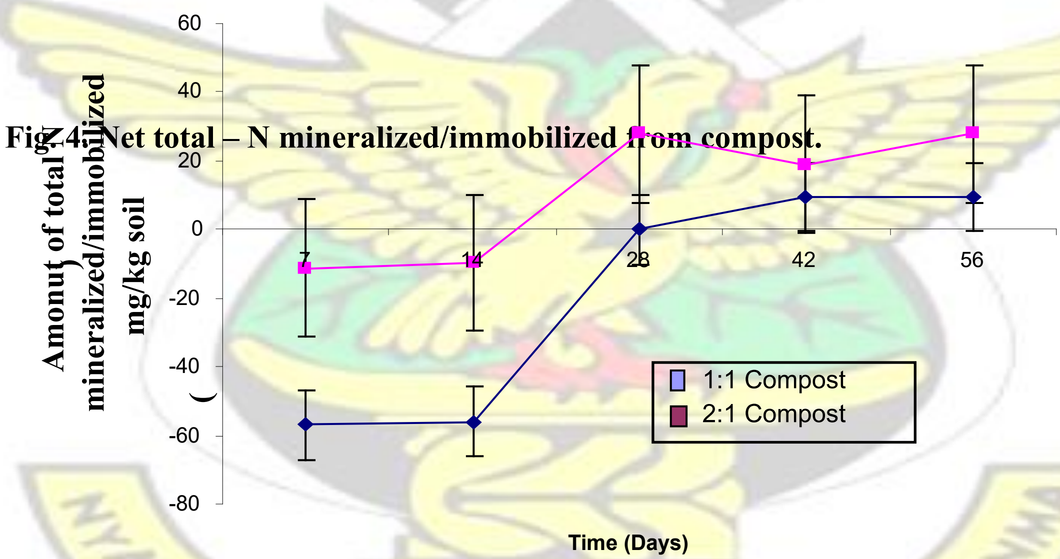


Fig. 4. Net total – N mineralized / immobilized from compost. Bars denote SED at 5%.

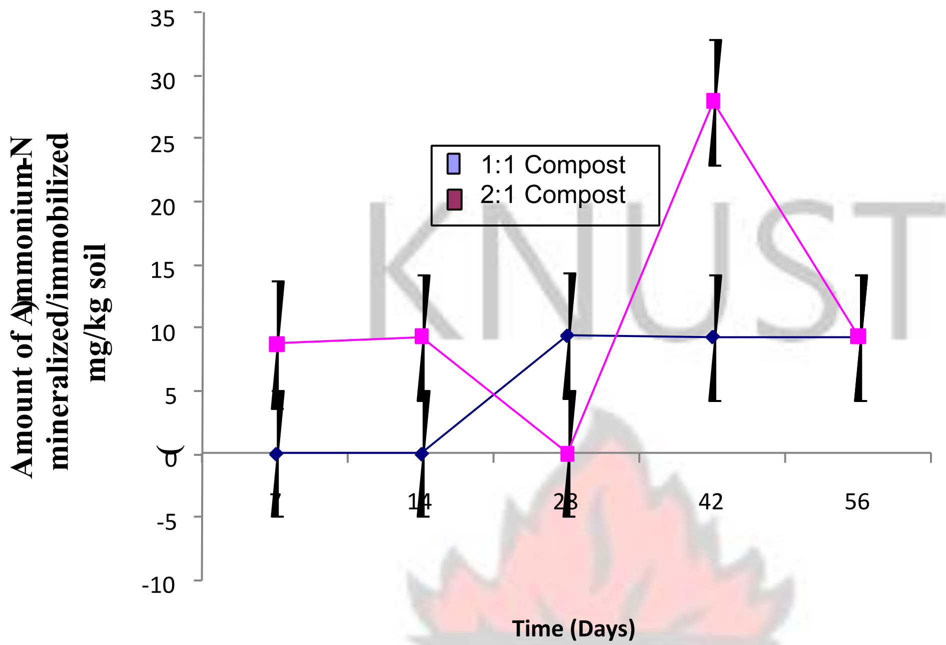


Fig. 5. Net ammonium - N mineralized/immobilized from compost. Bars denote SED at 5%.

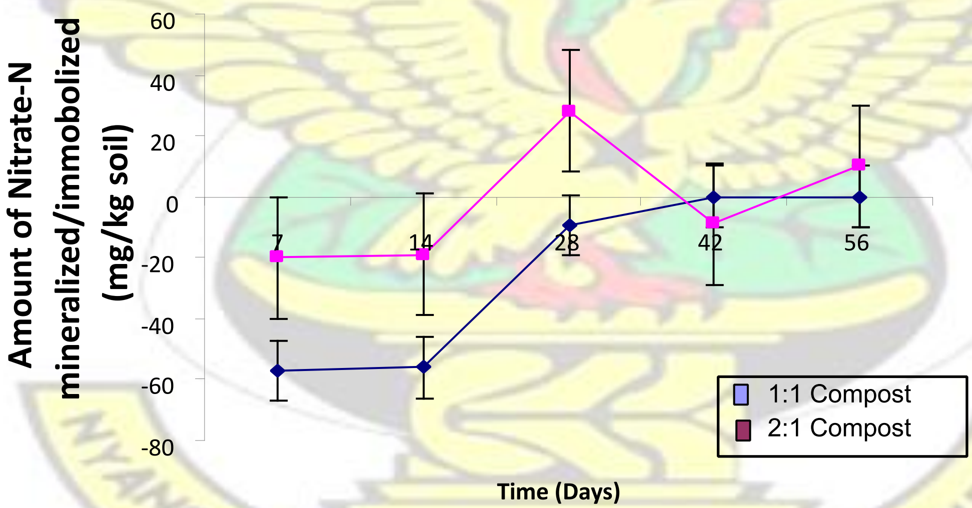


Fig. 6. Nitrate - N mineralized / immobilized from compost. Bars denote SED at 5%.

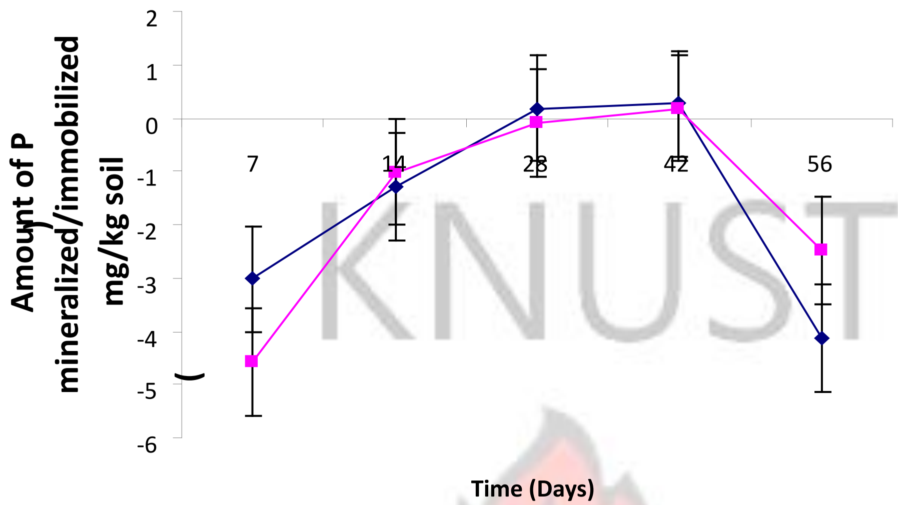


Fig. 7. Net phosphorus mineralized/immobilized from compost. Bars denote SED at 5%.

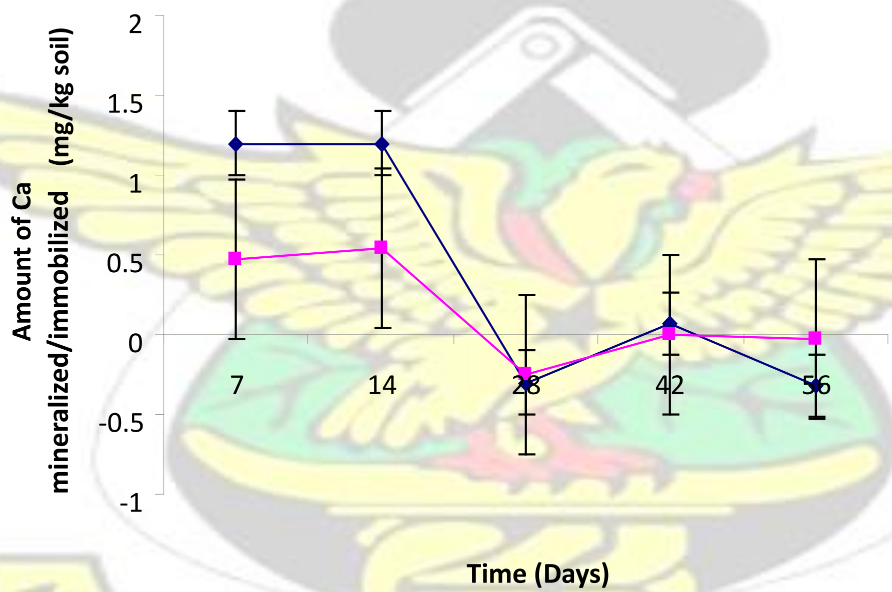


Fig. 8. Net calcium mineralized/immobilized from compost. Bars denote SED at 5%.

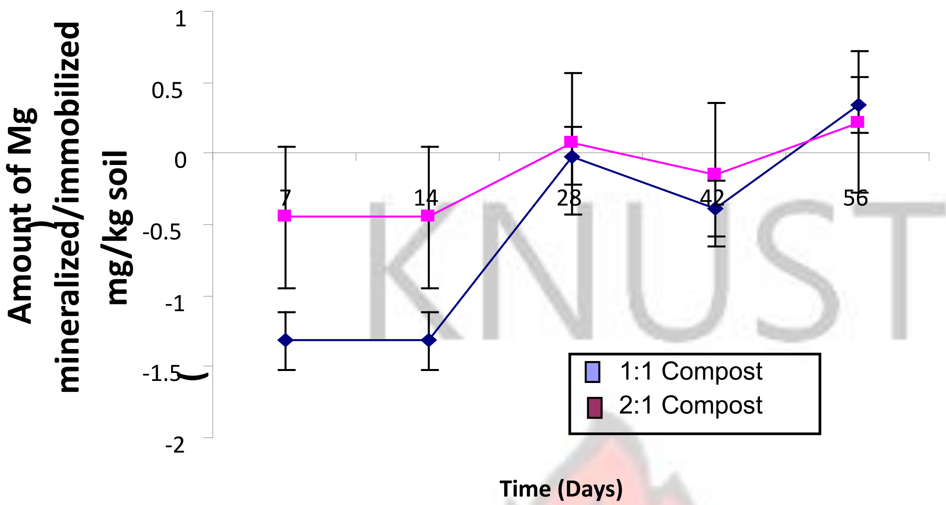


Fig. 9. Net magnesium mineralized/immobilized from compost. Bars denote SED at 5%.

4.8 Decomposition and nutrient release patterns of compost under field conditions

This study was conducted to investigate the nutrient release patterns of the two compost types under field conditions. The results indicated that nitrogen release pattern of the 2:1 compost was always above that of the 1:1 compost except on the 12th week of incubation (Fig. 10). The results further indicated that phosphorus release patterns in the 2:1 compost was always above that of the 1:1 compost type except on the 2nd week of incubation (Fig. 11). Both nitrogen and phosphorus were however mineralized throughout the incubation study.

Carbon release patterns for both compost types followed similar patterns throughout the incubation period. Both compost types immobilized C during the first two weeks of incubation followed by continuous mineralization up to the end of the incubation period (Fig. 12). The C: N ratio of the 2:1 compost declined up to the 6th week of incubation and then assumed a linear trend up to the 8th week (Fig. 13). However, C: N ratio of the 1:1

compost declined from the start of incubation up to the 4th week, rose up again by the end of the 6th week and finally declined up to the end of incubation.

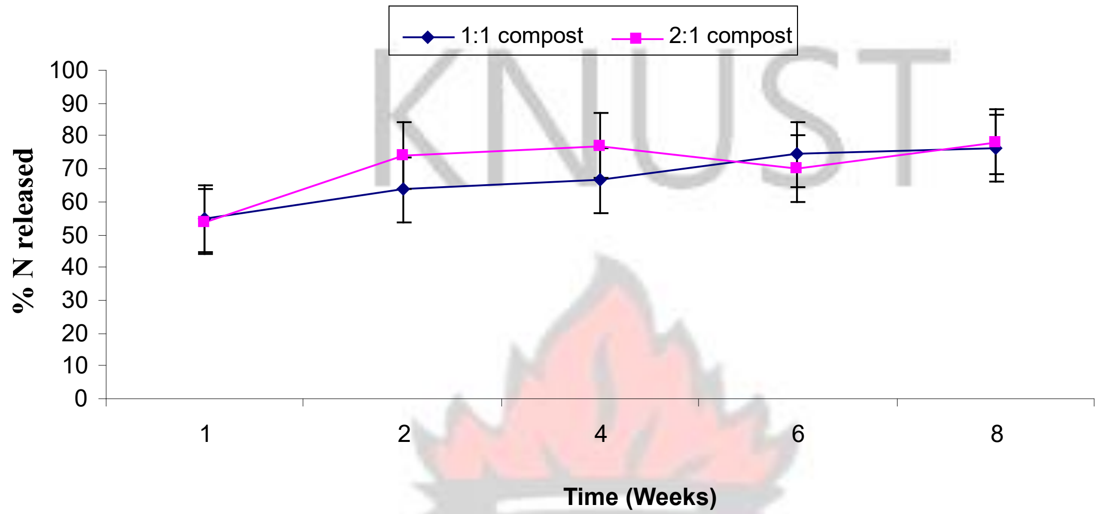


Fig. 10. Nitrogen release patterns of decomposing compost in-situ. Bars denote SED at 5%.

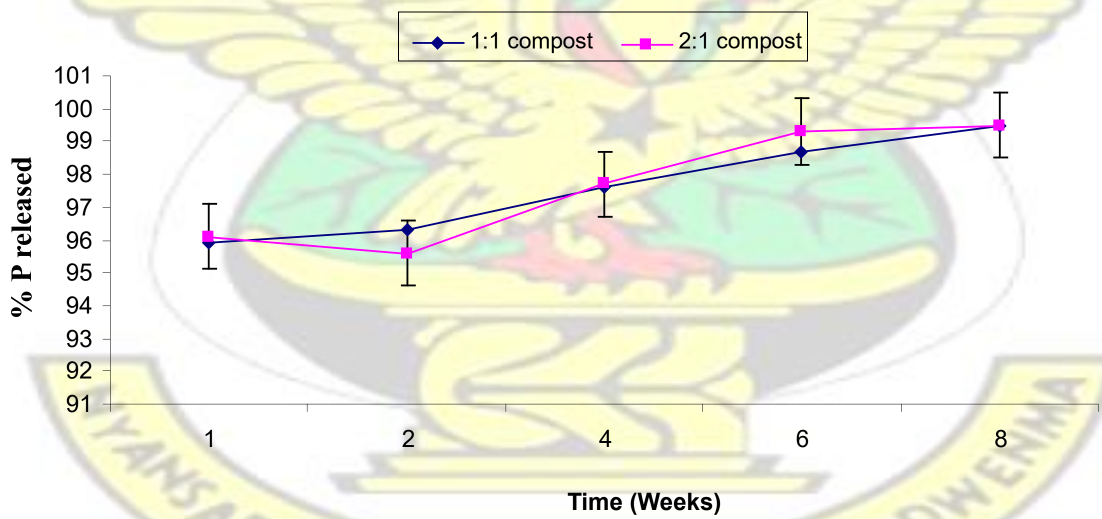
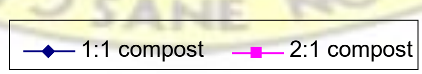


Fig. 11. Phosphorus release patterns of decomposing compost in-situ. Bars denote SED at 5%.



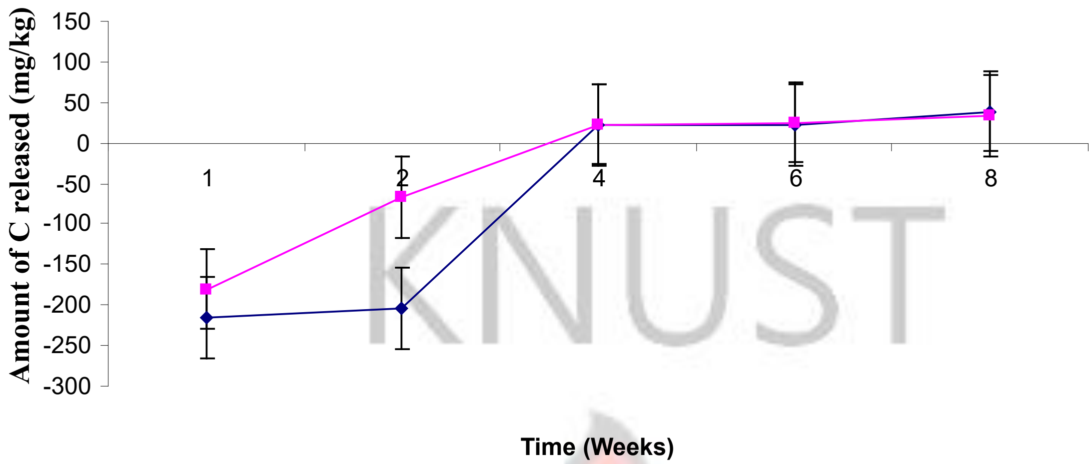


Fig. 12. Carbon release patterns of decomposing compost in-situ. Bars denote SED at 5%.

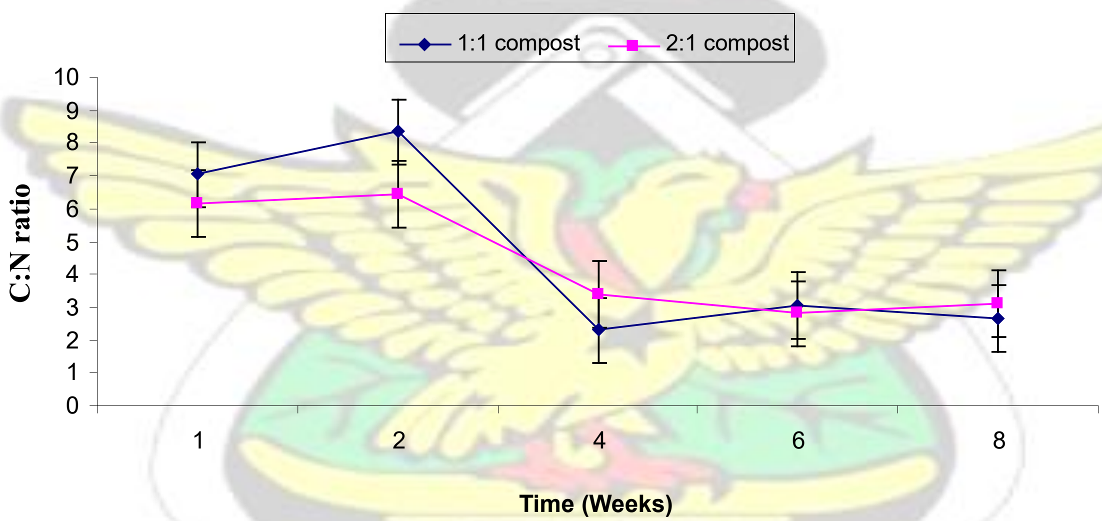


Fig. 13. C: N ratio of decomposing compost in-situ. Bars denote SED at 5%.

Table 6 shows the decomposition rate constants and half-life of the two compost types after 56 days of decomposition. Half-life values of 8 and 12 days were recorded for 1:1 and 2:1 composts respectively. The results further indicated that the 1:1 compost had a higher decomposition rate (k = 0.085) than the 2:1 compost (k = 0.056).

Table 6. Decomposition rate constants (k) and half-life (t_{50}) values for two compost types

Parameter	1:1 compost	2:1 compost
k ($week^{-1}$)	0.085 6	0.056 7
Half-life (observed)		
Half-life (calculated)*	8	12
R^2	0.927	0.836

Values are the means of duplicate samples. $* \; Half-life = \frac{-In(0.5)}{k}$

Figures 14 - 17 illustrate the effects of C: N ratio on nitrogen and phosphorus release of the two compost types. Positive correlations were observed between the C: N ratio and nitrogen release from both compost types. R^2 values of 0.33 and 0.35 were recorded for 1:1 and 2:1 compost types respectively. Positive correlations were also observed between the C: N ratio and phosphorus release from both compost types (Figs. 16 – 17). R^2 values of 0.70 and 0.74 were recorded for 1:1 and 2:1 compost types respectively.

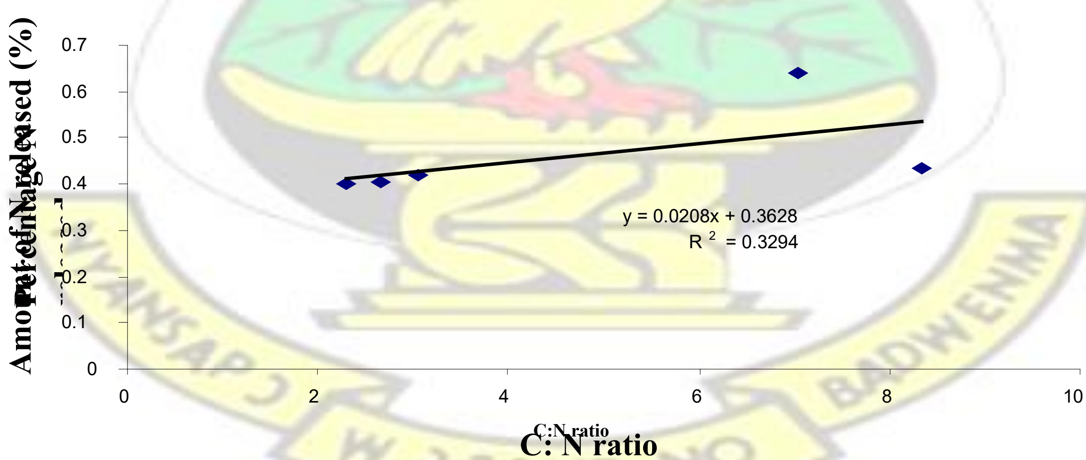


Fig. 14. Relationship between C: N ratio of 1:1 compost and amount of nitrogen released.

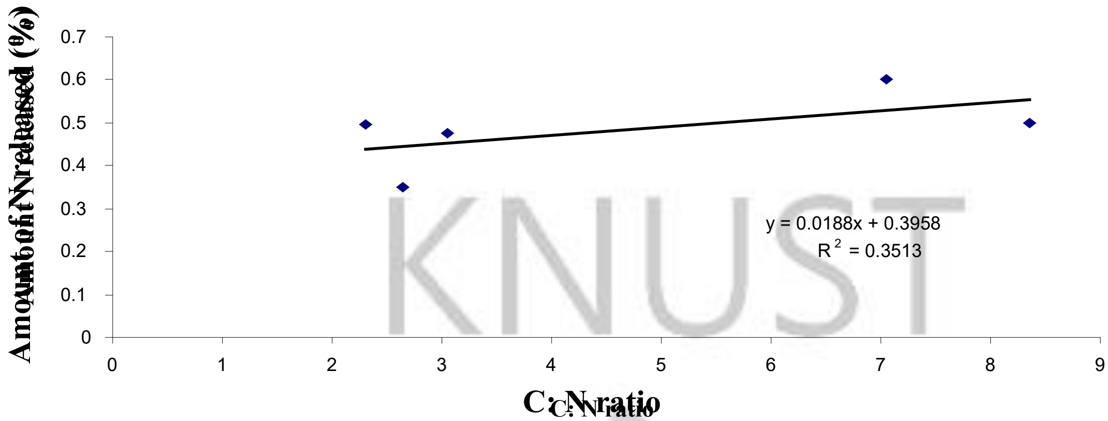


Fig. 15.Relationship between C: N ratio of 2:1 compost and amount of nitrogen released.

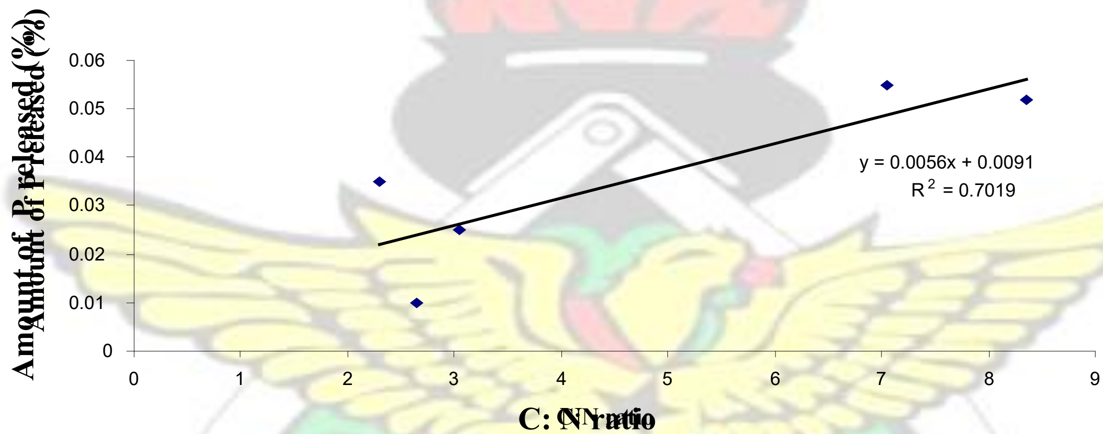


Fig. 16. Relationship between C: N ratio of 1:1 compost and amount of phosphorus released.

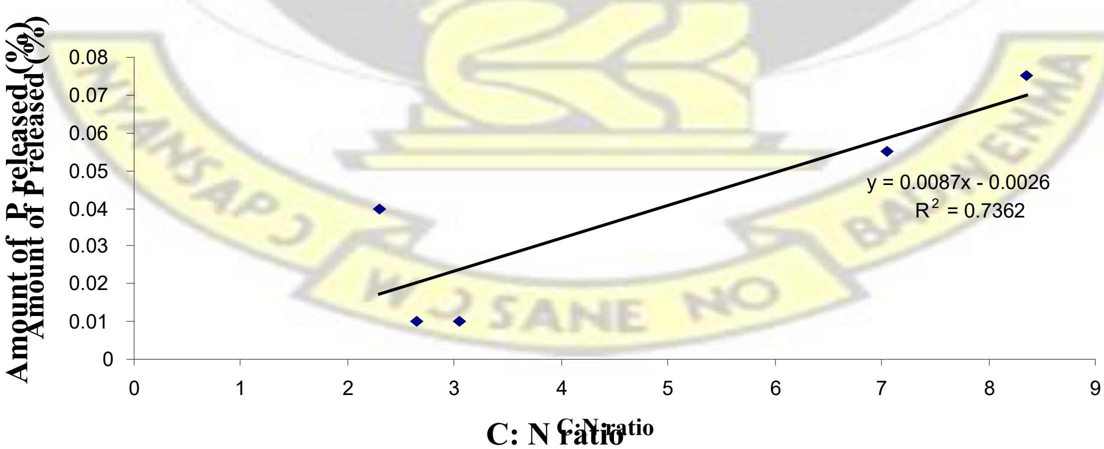


Fig. 17. Relationship between C: N ratio of 2:1 compost and amount of phosphorus released.

Figures 18 - 21 show the relationships between mass of composts remaining and the amounts of nutrient released. In all cases, negative correlations were observed between the mass of composts remaining and nutrient released. The association between mass of compost remaining and nitrogen released gave R^2 values of 0.63 and 0.85 for 1:1 and 2:1 compost types respectively. The association between mass of compost remaining and phosphorus released gave R^2 values of 0.57 and 0.67 for 1:1 and 2:1 compost types respectively.

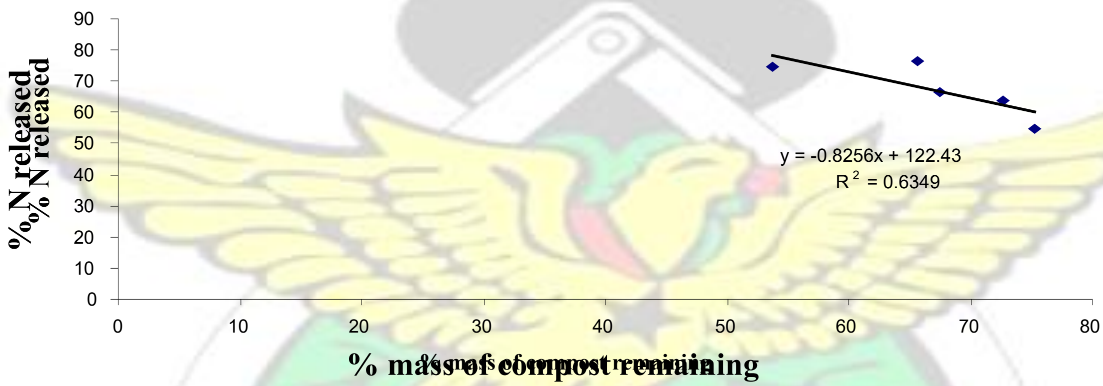


Fig. 18. Relationship between percent mass of 1:1 compost remaining and amount of nitrogen released.

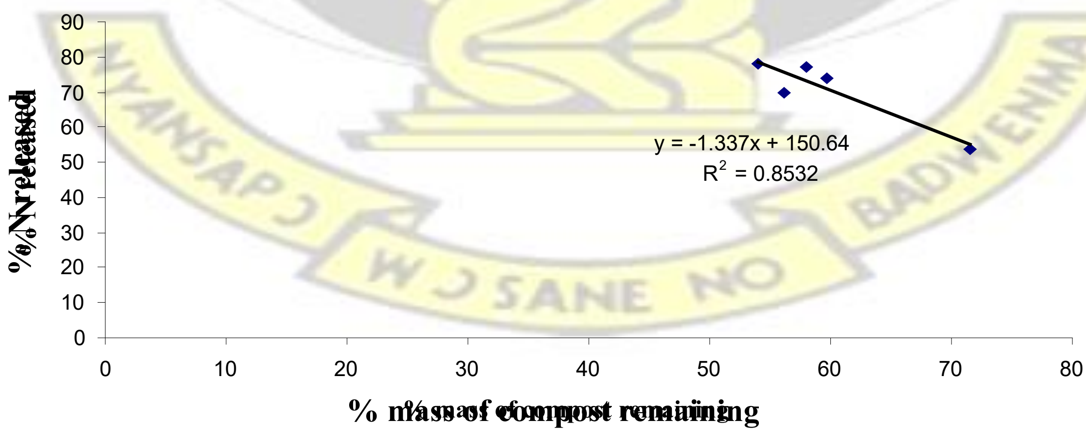


Fig. 19. Relationship between percent mass of 2:1 compost remaining and amount of nitrogen released.

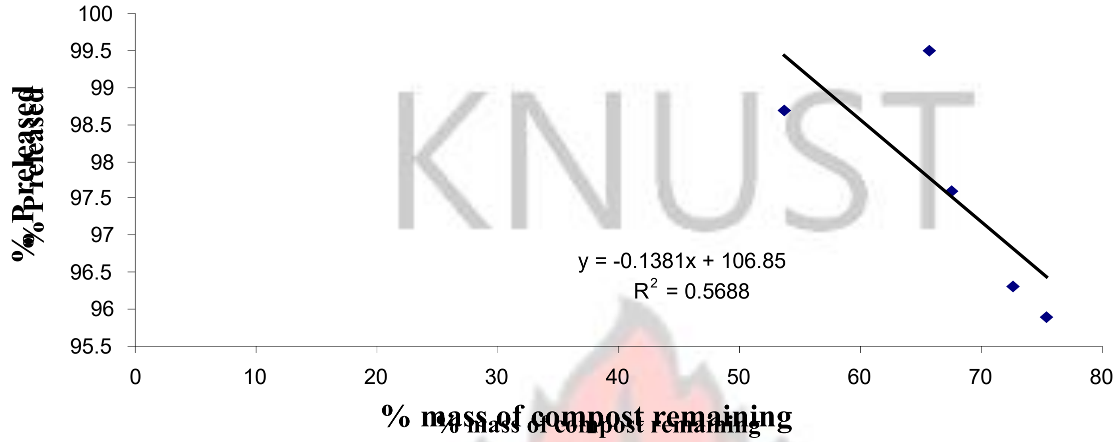


Fig. 20. Relationship between percent mass of 1:1 compost remaining and amount of phosphorus released.

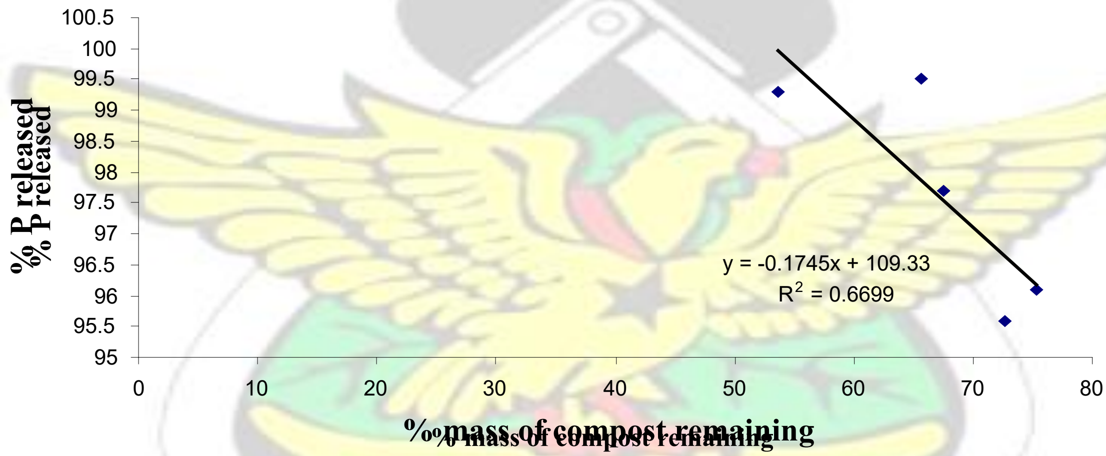


Fig. 21. Relationship between percent mass of 2:1 compost remaining and amount of phosphorus released.

4.9 Changes in microbial populations of decomposing compost in situ

The mean number of bacteria colonies per 1 g of the 1: 1 compost varied from 4.9 (log_{10}) - 5.4 (log_{10}) (Fig. 22). Furthermore, the mean number of bacteria colonies per 1 g of the 2: 1 compost varied from 5.3 (log_{10}) - 5.7 (log_{10}). The results of this study further indicated that the highest bacteria populations were recorded in weeks two and four respectively for 1:1 and 2:1 composts.

The mean number of fungal colonies per 1 g of the 1: 1 compost varied from 4.6 (log_{10}) 5.3 (log_{10}) (Fig. 23). However, the mean number of fungal colonies per 1 g of the 2:1 compost varied from 4.5 (log_{10}) - 5.2 (log_{10}). It was observed that, the highest fungal population over the period of this study was attained in weeks four and two respectively for 1:1 and 2:1 composts. However, unlike bacterial populations, increases in fungal populations were still observed even at the eighth week of sampling.

Total microbial loads over the incubation period for 1:1 and 2:1 compost types were highest on weeks four and two respectively (Fig. 24). The relationship between moisture content and total microbial load are expressed as correlation coefficients in Figs. 25 - 26. The results indicated negative correlations for both compost types with moisture becoming a limiting factor for microbial loads beyond a certain limit. R-squared values of

0.71 and 0.32 respectively were obtained for 1:1 and 2:1 compost types.

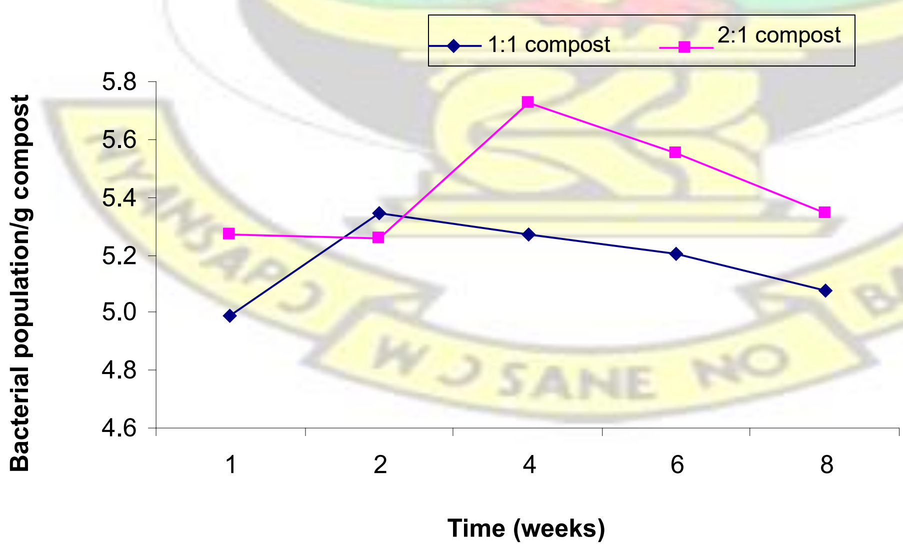


Fig. 22. Changes in bacterial populations from decomposing compost in-situ.

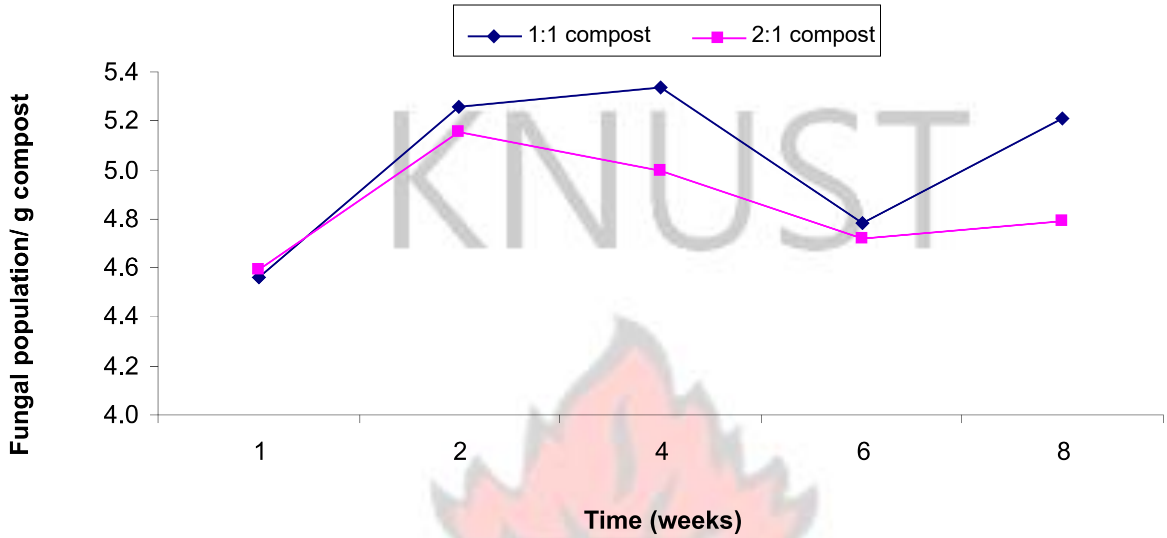


Fig. 23. Changes in fungal populations from decomposing compost in-situ.

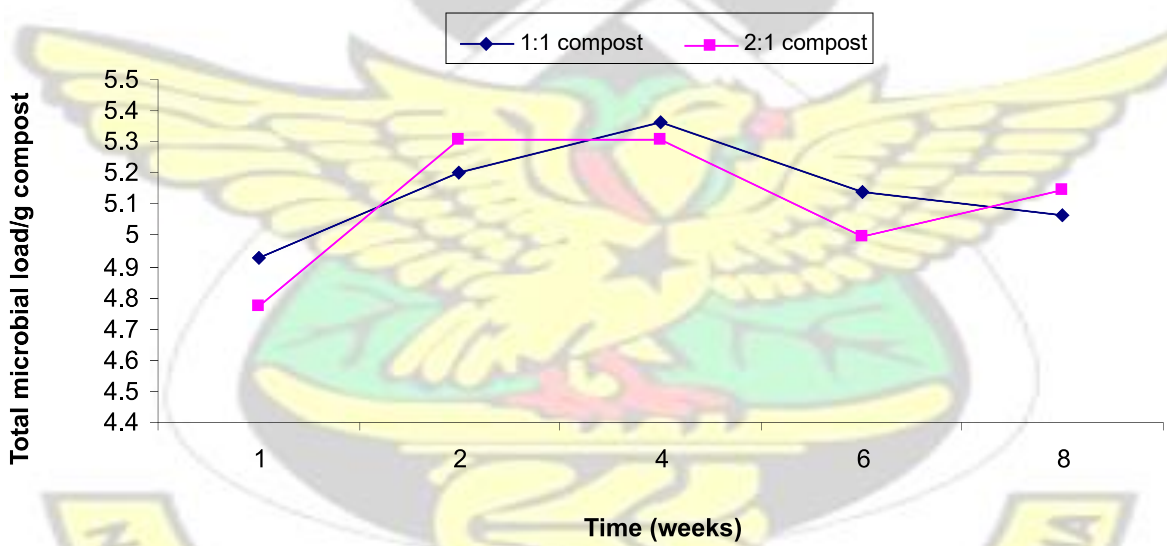


Fig. 24. Changes in total microbial load from decomposing compost in-situ.

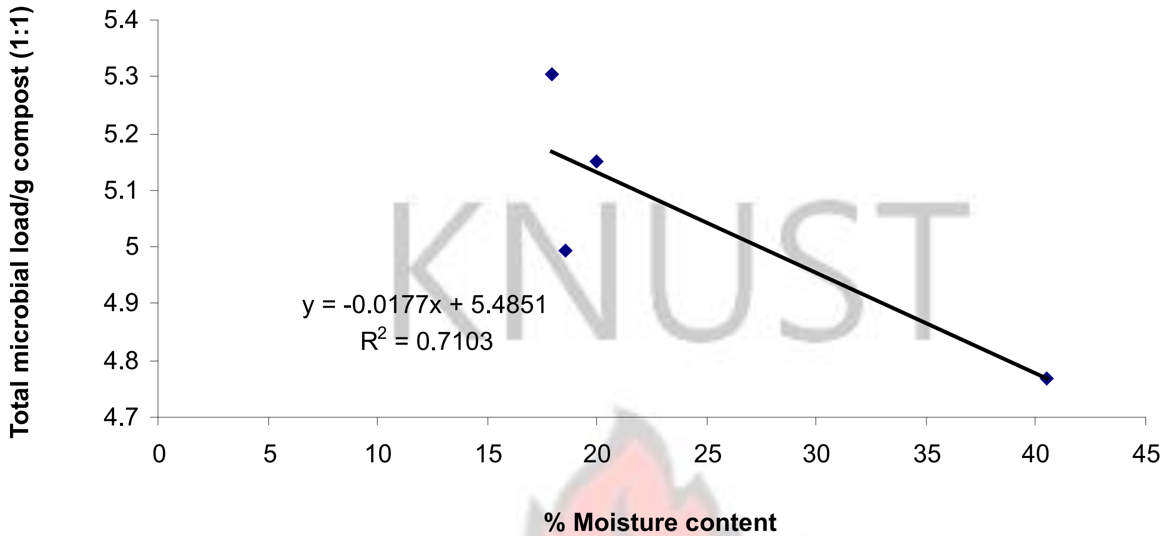


Fig. 25. Relationship between moisture content and total microbial load of 1:1 compost.

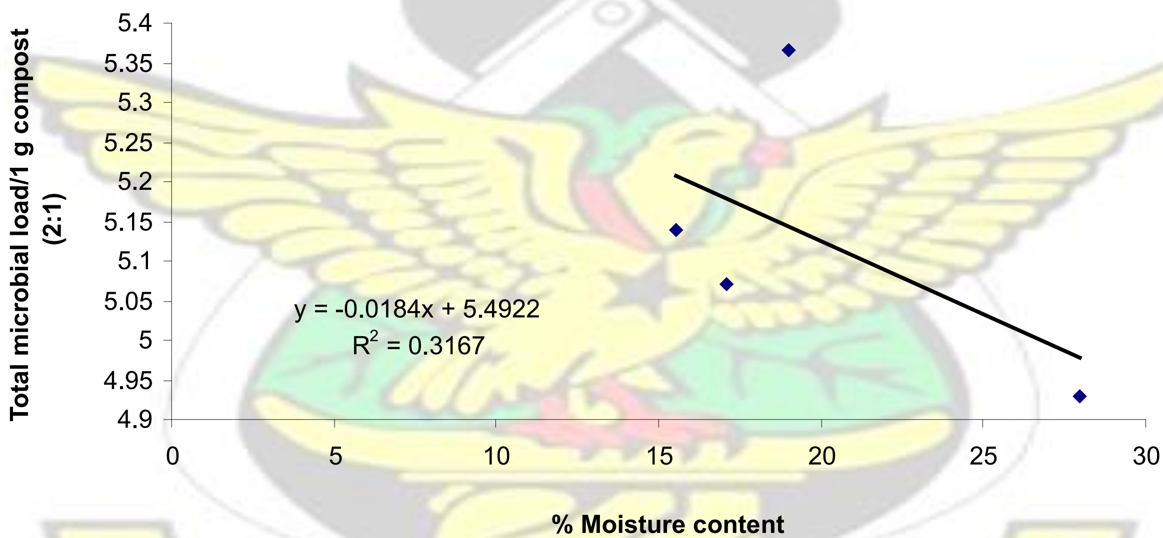


Fig. 26. Relationship between moisture content and total microbial load of 2:1 compost.

4.10 Studies on the effect of compost on maize yield

4.10.1 Selected physico - chemical properties of soil of the experimental field Data on the physico - chemical properties of the experimental field is presented in Table

7. The results indicated that the soil was moderate in phosphorus (Bray P) but low in total nitrogen, effective cation exchange capacity and base saturation (Source: CSIR – Soil Research Institute, 1980). Exchangeable potassium, calcium and magnesium of the soil were adequate for maize production. The soil was moderately acidic and predominantly sandy loam.

Table 7. Selected physico - chemical properties of Kumasi soil series (Ferric Acrisol) before trial establishment (0 – 15 cm depth)

Soil parameter	Value
pH (1: 2.5 H_20) Organic	5.79 ± 0.32 1.32
C (%)	± 0.30
Total N (%)	0.10 ± 0.02
Bray's P1 ($mgkg^{-1}$)	12.50 ± 11.60
Exchangeable bases ($cmolkg^{-1}$)	
Ca	4.79 ± 1.40 2.43
Mg	± 0.92 0.44 ±
K	0.13 0.15 ± 0.03
Na	7.80 ± 2.27 0.19
Total exchangeable bases ($cmolkg^{-1}$)	± 0.04 7.98 ±
Exchangeable (Al+H) ($cmolkg^{-1}$)	2.25
ECEC ($cmolkg^{-1}$)	97.46 ± 0.94
Base saturation (%)	60.76 25.17
Sand (%)	14.07
Silt (%)	Sandy Loam
Clay (%)	
Texture	

- Means represent triplicate samples ± standard deviation

4.10.2 Data of major rainy season, 2007

4.10.2.1 Plant height

Plant heights of all treatments were significantly greater than the control. The tallest and shortest plants at 50% flowering were recorded by 1:1 compost at 5 tons + 100% NPK and the control respectively (Table 8). Plant heights obtained from both compost types at 3 and 5 t/ha application rates were significantly different from each other. A similar trend was observed when both compost types were combined with 100% NPK. Significant differences in height were observed between the compost types at the different application rates as: 1:1 compost at 3 t/ha > 1:1 compost at 5 t/ha and 2:1 compost at 3 t/ha < 2:1 compost at 5 t/ha.

4.10.2.2 Leaf area

At 50% flowering stage, significant differences in leaf area were observed among the following: 1:1 compost at 3 t/ha and 1:1 compost at 5 tons, 2:1 compost at 3 tons + 50% NPK, 1:1 compost at 5 tons and 2:1 compost at 5 tons + 100% NPK treatments (Table 8). In all cases, leaf area of all treatments was significantly greater than the control. The largest leaf area was obtained by 2:1 compost at 3 tons + 100% NPK and least in 1:1 compost at 5 t/ha.

Table 8. Effect of compost and inorganic fertilizer and their combinations on plant height and leaf area at 50% flowering in a Ferric Acrisol, Kwadaso (major season, 2007)

Treatment	Plant height (cm)	Leaf area (cm^2)
1:1compost at 3 t/ha	207.4	239.4
1:1 compost at5 t/ha	183.6	191.0
1:1 compost at 3t/ha+100% NPK	174.0	208.7
1:1 compost at 5 t/ha+100% NPK	190.3	225.1
1:1 compost at 3t/ha+50% NPK	151.0	198.0
1:1 compost 5t/ha+50% NPK	195.8	193.6
100% NPK	199.8	204.0
50% NPK	174.8	196.9
2:1compost at 3 t/ha	193.0	214.1
2:1 compost at5 t/ha	200.0	210.8
2:1 compost at 3t/ha+100% NPK	190.2	222.8
2:1 compost at 5 t/ha+100% NPK	214.4	240.3
2:1 compost at 3t/ha+50% NPK	195.8	215.8
2:1 compost 5t/ha+50% NPK	195.2	196.9
Cowdung	187.3	195.9
Control	148.7	174.8
SED	18.58	26.89
CV (%)	5.10	6.40

4.10.2.3 Maize grain yield

The results of this study indicated that total grain yields of all the treatments were significantly higher than the control except 2:1 compost at 3 t/ha (Table 9). The highest grain yield was recorded by the 2:1 compost applied at 5 tons + 100% NPK, which was 100% more than the control. A lower application rate of the 1:1 compost at 3 t/ha was capable of increasing maize yields 33% more than a higher rate of 5 t/ha of the same compost type. A higher application rate of 5 t/ha of 2:1 compost produced grain yields (4.1 tons) relatively higher than a lower rate of 3 t/ha (3.1 tons). Comparing 3 t/ha application rates of both compost types, it was observed that grain yields were significantly higher in 1:1 compost and lower in the 2:1 compost. On the other hand, at 5 t/ha rate, there were no significant differences between the two compost types. Statistical analysis of the data showed that maize yields obtained from both compost types were higher than that obtained from sole cowdung amended plots.

Maize grain yield was increased further by 2% when 1:1 compost at 3 t/ha was combined with 100% NPK (Table 9). However, grain yields declined by 39% when the same treatment was combined with 50% NPK. A similar trend was observed in the 2:1 compost type. The addition of 100% NPK to 2:1 compost type at 3 t/ha rate increased yields by 40% but declined by 17% when 50% NPK was added. No significant differences were observed between 2:1compost at 3 tons + 100% NPK and 2:1 compost at 3 tons + 50% NPK. Grain yield from the 2:1 compost at 5 tons + 100% NPK was significantly higher than 2:1 compost at 5 tons + 50% NPK. Unlike the 2:1 compost type, 1:1 compost at 3 tons + 100% NPK produced significantly higher yields than the 2:1 compost at 3 tons + 50% NPK.

4.10.2.4 Hundred seed weight

Whereas 2:1 compost at 5 tons + 100% NPK produced the highest maize grain yield, 1:1 compost at 3 tons + 100% NPK gave the highest hundred seed weight (Table 9). Significant differences were obtained between the 1:1 compost at 3 tons + 100% NPK and the 1:1 compost at 5 tons + 100% NPK treatments. On the whole, hundred seed weights of the 1:1 compost treated plots were significantly higher than sole NPK amended plots.

Table 9. Effect of compost and inorganic fertilizer and their combinations on maize grain yield in a Ferric Acrisol, Kwadaso (major season, 2007)

Treatments	Grain yield (t/ha)	Increase over control (%)	100 seed weight (g)
1:1compost at 3 t/ha	4.99	88.30	35.88
1:1 compost at5 t/ha	3.76	41.89	36.47
1:1 compost at 3t/ha+100% NPK	5.08	91.70	36.60
1:1 compost at 5 t/ha+100% NPK	5.25	98.11	34.08
1:1 compost at 3t/ha+50% NPK	3.60	35.85	32.44
1:1 compost 5t/ha+50% NPK	4.10	54.72	32.36
100% NPK	3.65	37.74	33.75
50% NPK	3.51	32.45	32.36
2:1compost at 3 t/ha	3.08	16.23	31.71
2:1 compost at5 t/ha	4.08	53.96	32.70
2:1 compost at 3t/ha+100% NPK	4.31	62.64	31.82
2:1 compost at 5 t/ha+100% NPK	5.77	117.74	36.21
2:1 compost at 3t/ha+50% NPK	3.50	32.08	33.22
2:1 compost 5t/ha+50% NPK	4.70	77.36	34.65
Cowdung	2.80	-16.98	26.52
Control	2.65	-	31.17
SED	0.84		2.14
CV (%)	13.40		2.90

4.10.2.3 Maize biomass yield

Table 10 shows maize biomass yields (aerial parts excluding seed) of the treatments obtained after harvest. The highest and lowest biomass yields were obtained by the 2:1 compost at 5 tons + 100% NPK and the 1:1 compost at 3 tons + 50% NPK treatments respectively. A lower application rate of the 1:1 compost at 3 t/ha gave biomass yields which were significantly higher than a higher rate of 5 t/ha of the same compost type. Generally, it was observed that biomass yields from both compost types were not significantly different even when they were supplemented with 100% NPK fertilizer.

Table 10. Effect of compost and inorganic fertilizer and their combinations on maize biomass yields in a Ferric Acrisol, Kwadaso (major season, 2007)

Treatment	Biomass yield (t/ha)	Increase over control (%)
1:1compost at 3 t/ha	9.90	32.53
1:1 compost at5 t/ha	7.47	-
1:1 compost at 3t/ha+100% NPK	9.72	30.12
1:1 compost at 5 t/ha+100% NPK	8.16	9.24
1:1 compost at 3t/ha+50% NPK	6.77	-9.37
1:1 compost 5t/ha+50% NPK	8.51	13.92
100% NPK	8.85	14.85
50% NPK	8.68	16.20
2:1compost at 3 t/ha	9.55	27.84
2:1 compost at5 t/ha	9.20	23.16 6.96
2:1 compost at 3t/ha+100% NPK	7.99	51.00
2:1 compost at 5 t/ha+100% NPK	11.28	25.44
2:1 compost at 3t/ha+50% NPK	9.37	18.47
2:1 compost 5t/ha+50% NPK	8.85	- -
Cowdung	7.47	
Control	7.47	
SED	2.09	
CV (%)	18.80	

4.10.2.6 N, P and K uptake by maize grain and stover

Tables 11 and 12 summarize nitrogen, phosphorus and potassium uptake by maize grain and stover after harvest respectively. It was observed that plants treated with 2:1 compost at 5 tons + 100% NPK recorded the highest grain nitrogen uptake whiles the least was observed in the control (Table 11). Furthermore, the uptake of grain phosphorus was highest in the 2:1 compost at 5 tons + 100% NPK treatment whiles the least was in 2:1 compost applied at 3 tons. Percentage potassium partitioned into maize grain ranged from 1.17 – 7.73 kg/ha. Plants treated with 2:1 compost at 5 tons + 100% NPK recorded the highest stover N uptake whiles the least was observed in the control (Table 12). Total phosphorus and potassium partitioned into stover ranged from 2.12 - 7.52 kg/ha and 3.88 – 14.36 kg/ha respectively.

Table 11. N, P and K uptake by maize grain in a Ferric Acrisol, Kwadaso (major season, 2007)

Treatments	N	P	K	
		kg / ha		
1:1compost at 3 t/ha				35.28
1:1 compost at5 t/ha				19.66
1:1compost at 3t/ha+100% NPK				40.28
1:1 compost at 5 t/ha+100% NPK				37.59
1:1 compost at 3t/ha+50% NPK				19.19
1:1 compost 5t/ha+50% NPK				20.62
100% NPK				20.11
50% NPK				18.04
2:1compost at 3 t/ha				13.24
2:1 compost at5 t/ha				23.75
2:1 compost at 3t/ha+100% NPK				26.94
2:1 compost at 5 t/ha+100% NPK				50.72
2:1 compost at 3t/ha+50% NPK				16.80
2:1 compost 5t/ha+50% NPK				31.54
Cowdung				18.50
Control				9.08

Table 12. N, P and K uptake by stover in a Ferric Acrisol, Kwadaso (major season, 2007)

Treatments	N	P	K
		kg / ha	
1:1compost at 3 t/ha	45.24	7.52	14.36
1:1 compost at5 t/ha	15.84	4.11	3.88
1:1 compost at 3t/ha+100% NPK	41.80	4.57	11.66
1:1 compost at 5 t/ha+100% NPK	32.64	2.69	10.69
1:1 compost at 3t/ha+50% NPK	16.86	2.30	6.63
1:1 compost 5t/ha+50% NPK	22.04	2.81	8.08
100% NPK	25.84	4.51	11.15
50% NPK	26.60	4.25	8.51
2:1compost at 3 t/ha	23.49	3.06	4.30
2:1 compost at 5 t/ha	25.48	3.22	7.08
2:1 compost at 3t/ha+100% NPK	27.57	2.88	10.63
2:1 compost at 5 t/ha+100% NPK	59.11	5.98	13.20
2:1 compost at 3t/ha+50% NPK	21.36	3.09	8.90
2:1 compost 5t/ha+50% NPK	32.39	3.54	10.18
Cowdung	24.49	2.12	5.69
Control	15.24	2.47	4.63

Total nutrient uptake positively correlated with maize grain and stover yields (Figs. 27 – 32).

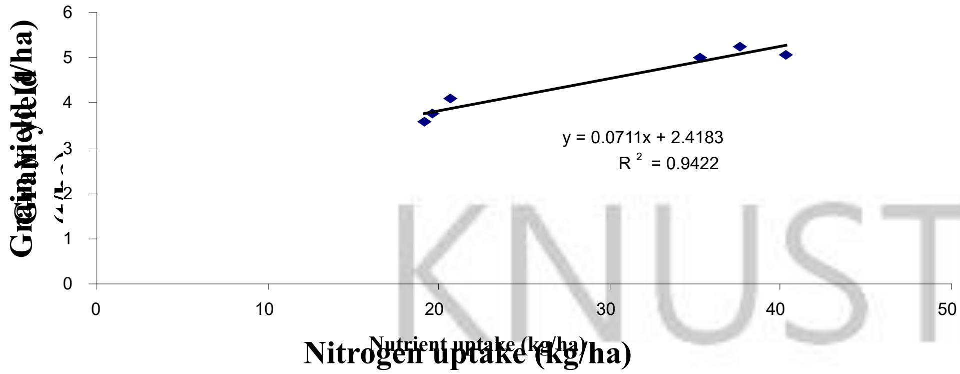


Fig. 27. Relationship between total N uptake from 1:1 compost and maize grain yield.

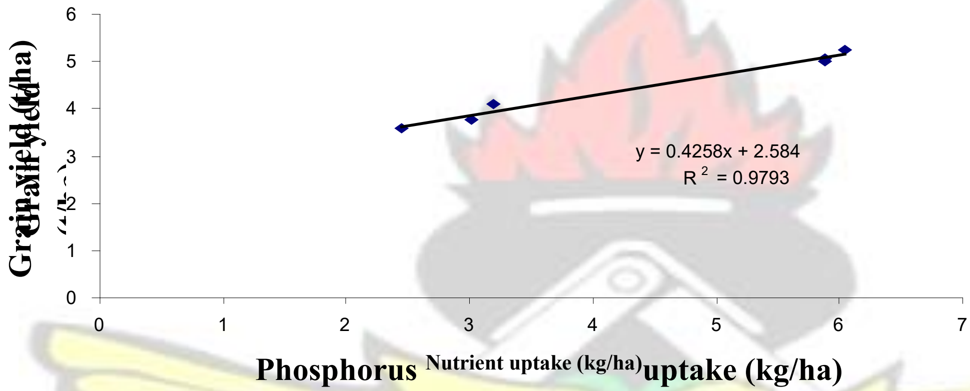


Fig. 28. Relationship between total P uptake from 1:1 compost and maize grain yield.

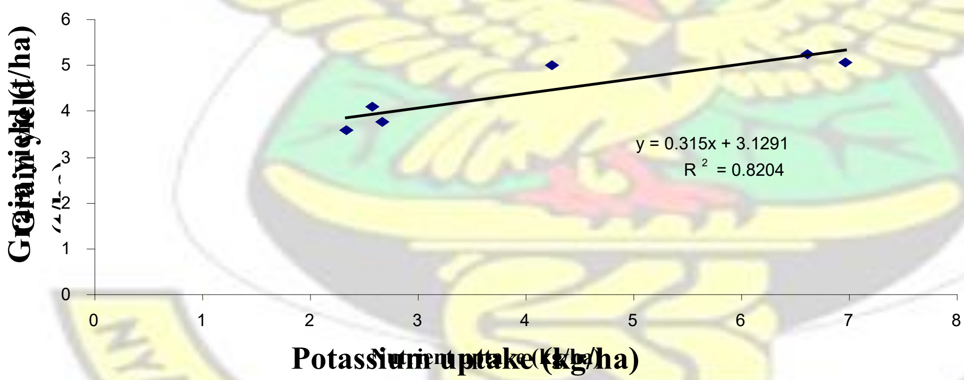


Fig. 29. Relationship between total K uptake from 1:1 compost and maize grain yield.

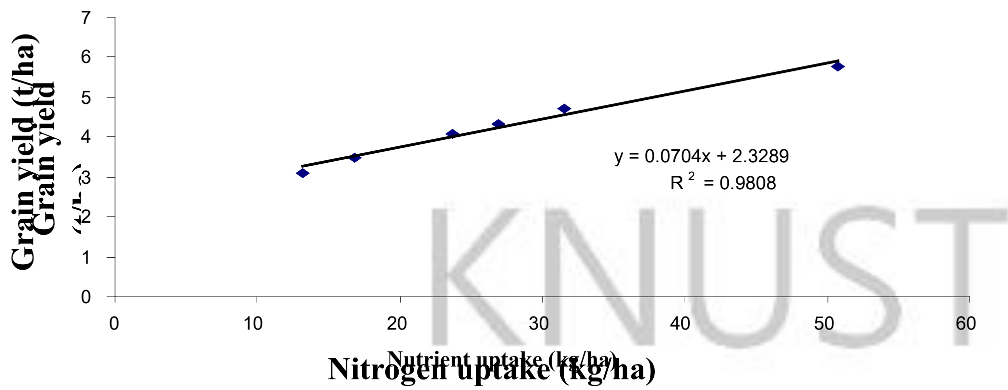


Fig. 30. Relationship between total N uptake from 2:1 compost and maize grain yield.

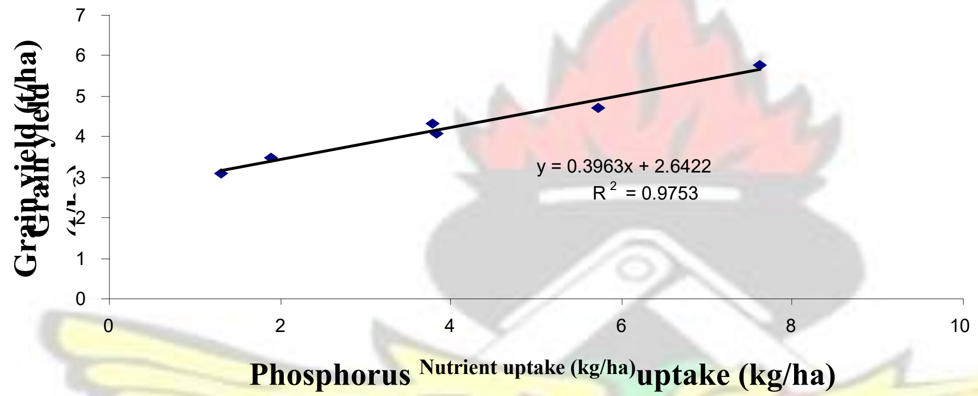


Fig. 31. Relationship between total P uptake from 2:1 compost and maize grain yield.

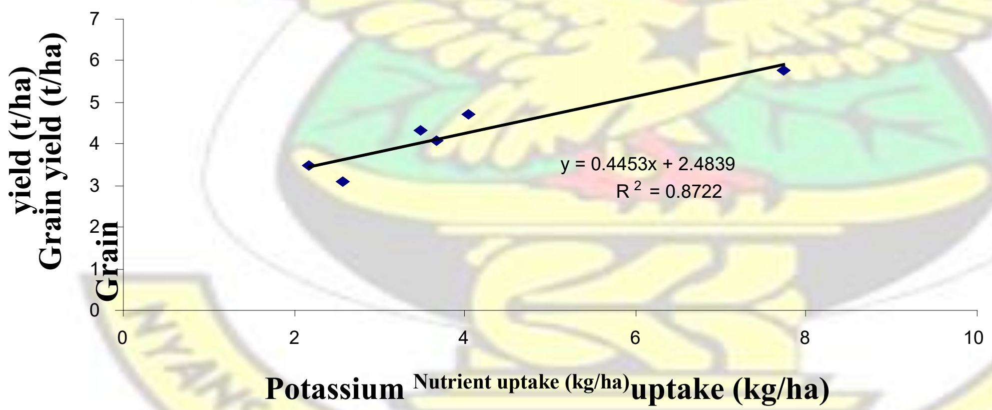


Fig. 32. Relationship between total K uptake from 2:1 compost and maize grain yield.

Table 13 compares the nutrient recovery rates of the two compost types, cowdung and NPK at the end of the cropping season. The highest nitrogen recovery rate was observed in the 1:1 compost at 3 t/ha whiles the lowest was observed in the 100% NPK. The highest phosphorus recovery rate was recorded by the 1:1 compost at 3 t/ha whiles the lowest was recorded by the 2:1 compost at 3 t/ha. The results further indicated that the 2:1 compost at 5 t/ha recorded the highest potassium recovery rate whiles the 1:1 compost at 5 t/ha produced the least.

Table 13. Percentage N, P and K recovery rates of composts, cowdung and NPK

Treatments	N	P	K
		% recovery	
1:1compost at 3 t/ha	128.4	100.5	33.9 1.2
1:1 compost at5 t/ha	76.5	19.7	32.1
100% NPK	28.5	4.4	15.7 4.3
50% NPK	45.2	7.7	48.7
2:1compost at 3 t/ha	37.6	3.8	11.14
2:1 compost at 5 t/ha	45.3	21.4	
Cowdung	36.3	20.8	

4.10.3 Data of minor rainy season, 2007

4.10.3.1 Residual experiment

4.10.3.1.1. Plant height

Table 14 shows plant heights of maize at 50% flowering. The trend indicated highest and lowest values for 1:1 compost at 5 tons + 100% NPK (177.7 cm) and cowdung (136.6 cm) respectively.

4.10.3.1.2 Leaf area

Leaf area at 50% flowering for the various treatments is shown in Table 14. The largest leaf area was recorded by 2:1 compost at 3 t/ha whiles 50% NPK produced the least. Significant differences were established between 3 and 5 t/ha application rates of the 2:1 compost. The results further indicated that the 3 and 5 t/ha application rates of the 1:1 compost and 3 t/ha rate of the 2:1 compost performed significantly better than the 100% NPK.

Table 14. Effect of compost and inorganic fertilizer and their combinations on plant height and leaf area at 50% flowering in a Ferric Acrisol, Kwadaso (minor season, 2007)

Treatment	Plant height (cm)	Leaf area (cm^2)
1:1compost at 3 t/ha	168.2	94.7
1:1 compost at 5 t/ha	171.7	99.1
1:1 compost at 3t/ha+100% NPK	167.7	94.8
1:1 compost at 5 t/ha+100% NPK	177.7	99.9
1:1 compost at 3t/ha+50% NPK	137.1	73.0
1:1 compost 5t/ha+50% NPK	129.0	70.0
100% NPK	170.8	73.7
50% NPK	149.0	64.0
2:1compost at 3 t/ha	156.5	104.0
2:1 compost at5 t/ha	163.5	80.0
2:1 compost at 3t/ha+100% NPK	185.5	86.6
2:1 compost at 5 t/ha+100% NPK	171.7	94.5
2:1 compost at 3t/ha+50% NPK	168.5	90.6
2:1 compost 5t/ha+50% NPK	159.8	87.4
Cowdung	161.5	84.5
Control	136.6	82.2
SED	24.8	13.2
CV (%)	10.1	8.2

4.10.3.1.3 Maize grain yield

Table 15 shows results of maize grain yields after harvest. The control treatment produced grain yields which were significantly higher than 1:1 compost at 3 t/ha, 1:1 compost at 3 tons + 50% NPK, 1:1 compost at 5 tons + 50% NPK, 2:1 compost at 3 tons + 100% NPK and cowdung treatments. The highest and lowest grain yields of 2.52 and

0.54 tons respectively were however produced by 2:1 compost at 3 tons + 50% NPK and 1:1 compost at 3 tons + 50% NPK respectively. The highest grain yield obtained represented more than 200% increases over the control. Unlike the major rainy season of 2007, no significant differences in yield were observed on plots in which composts were combined with either 50% or 100% NPK except 2:1 compost at 3 tons + 50% NPK and 2:1 compost at 5 tons + 50% NPK.

4.10.3.1.4 Hundred seed weight

The highest and lowest hundred seed weights of 25.89 and 20.01 kg/ha were produced by the 1:1 compost at 3 tons + 100% NPK and the control respectively (Table 15). The results showed that 1:1 compost at 3 t/ha, 1:1 compost at 3 tons + 100% NPK, 2:1 compost at 5 t/ha, 2:1 compost at 3 tons + 100% NPK and 50% NPK produced hundred seed weights which were significantly different from the control. The 50% NPK treated plots produced seed weights which were significantly higher than 100% NPK treated plots.

Table 15. Effect of compost and inorganic fertilizer and their combinations on maize grain yield in a Ferric Acrisol, Kwadaso (minor season, 2007)

Treatments	Grain yield (t/ha)	Increase over control (%)	100 seed Weight (g)

1:1compost at 3 t/ha	1.07	32.09	24.05
1:1 compost at5 t/ha	1.70	109.8	23.12
1:1 compost at 3t/ha+100% NPK	2.03	150.62	25.89
1:1 compost at 5 t/ha+100% NPK	1.85	128.39	23.12
1:1 compost at 3t/ha+50% NPK	0.54	-33.33	20.45
1:1 compost 5t/ha+50% NPK	0.91	12.35	22.52
100% NPK	1.88	132.10	25.13
50% NPK	1.73	113.58	22.84
2:1compost at 3 t/ha	1.75	116.04	24.18
2:1 compost at5 t/ha	2.29	182.72	22.74
2:1 compost at 3t/ha+100% NPK	0.84	3.70	22.83
2:1 compost at 5 t/ha+100% NPK	1.43	76.54	21.65
2:1 compost at 3t/ha+50% NPK	2.52	211.11	25.65
2:1 compost 5t/ha+50% NPK	1.65	103.70	21.95
Cowdung	1.16	43.21	20.01
Control	0.81		22.12
SED	0.78		3.22
CV (%)	5.90		2.80

4.10.3.1.5 Maize biomass yield

Table 16 shows the biomass yields of the treatments at harvest. The highest biomass yield was obtained by the 2:1 compost at 5 t/ha + 100% NPK which represented 101.5% increase over the control. The lowest biomass yield was obtained by the control. However, the 2:1 compost at 3 and 5 t/ha application rates represented 43% and 51% respectively over the control. Unlike the 2:1 compost, the 3 t/ha application rate of the 1:1 compost was significantly higher than 5 t/ha rate and represented 84% and 42% increase respectively over the control. In comparing biomass yields of the compost types to that of NPK, 2:1 compost at 5 t/ha and 1:1 compost at 3 t/ha performed significantly higher than 100% NPK. On the whole, both compost types produced biomass yields which were significantly higher than that of cowdung.

Table 16. Effect of compost and inorganic fertilizer and their combinations on maize biomass yield in a Ferric Acrisol, Kwadaso (minor season, 2007)

Treatment	Biomass yield (t/ha)	Increase over Control (%)
1:1compost at 3 t/ha	7.53	83.66
1:1 compost at5 t/ha	5.84	42.44
1:1 compost at 3t/ha+100% NPK	5.61	36.83
1:1 compost at 5 t/ha+100% NPK	6.01	46.59
1:1 compost at 3t/ha+50% NPK	4.83	17.80
1:1 compost 5t/ha+50% NPK	5.51	34.39
100% NPK	4.47	9.02
50% NPK	4.19	2.20
2:1compost at 3 t/ha	5.85	42.68
2:1 compost at5 t/ha	6.20	51.23
2:1 compost at 3t/ha+100% NPK	4.99	21.71
2:1 compost at 5 t/ha+100% NPK	8.28	101.95
2:1 compost at 3t/ha+50% NPK	6.37	55.37
2:1 compost 5t/ha+50% NPK	5.85	42.68
Cowdung	4.54	10.73
Control	4.10	-
SED	1.69	
CV (%)	18.80	

4.10.4 Data of major rainy season, 2008

4.10.4.1 Plant height

Plant heights of the treatments during the season are as shown in Table 17. The highest and lowest plant heights were recorded by 1:1 compost at 3 t/ha and 1:1 compost at 3 t/ha + 50% NPK. On the whole, plant height of the control was not statistically different from the other treatments except 1:1 compost at 3 t/ha.

4.10.4.2 Leaf area

Data on leaf area at 50% flowering stage is presented in Table 17. The largest leaf area among all the treatments was obtained by the 2:1 compost at 5 tons + 100% NPK and the least was by the control. In all cases, leaf area of all treatments was significantly higher than the control.

Table 17. Effect of compost and inorganic fertilizer and their combinations on plant height and leaf area at 50% flowering in a Ferric Acrisol (major season, 2008)

Treatment	**Plant height (cm)**	**Leaf area (cm^2)**
1:1compost at 3 t/ha	83.8	121.9
1:1 compost at5 t/ha	72.0	114.2
1:1 compost at 3t/ha+100% NPK	71.0	114.0
1:1 compost at 5 t/ha+100% NPK	71.5	125.8
1:1 compost at 3t/ha+50% NPK	62.3	105.1
1:1 compost 5t/ha+50% NPK	79.8	125.1
100% NPK	76.2	128.5
50% NPK	80.3	107.9 95.2
2:1compost at 3 t/ha	76.2	122.8
2:1 compost at5 t/ha	75.5	118.5
2:1 compost at 3t/ha+100% NPK	78.8	125.2
2:1 compost at 5 t/ha+100% NPK	79.8	104.6
2:1 compost at 3t/ha+50% NPK	67.8	130.8
2:1 compost 5t/ha+50% NPK	78.2	101.3
Cowdung	75.2	64.7
Control	68.5	
SED	14.8	20.92
CV (%)	8.8	11.0

4.10.4.3 Maize grain yields

During the major cropping season of 2008, 1:1 compost at 3 tons + 100% NPK produced the highest maize grain yield (6.03 tons) which was 170% more than the control, which had the lowest yield (Table 18). Statistically, all treatments produced grain yields which were higher than the control except cowdung. A lower application rate of 3 t/ha of the 1:1 compost produced grain yields 8% more than a higher rate 5 t/ha of the same compost. A lower application rate of 3 tons of the 2:1 compost produced grain yields 7% more than a higher application rate of 5 t/ha of the same compost. Unlike data obtained for grain yields of 2007, no significant differences were established among 1:1 and 2:1 composts at 3 t/ha.

In comparing the compost types to NPK fertilizer, it was evident from the results that 2:1 compost at 5 t/ha produced grain yields 4% more than 100% NPK (Table 18).

4.10.4.2 Hundred seed weight

The results of this study indicated that although 1:1 compost at 3 tons + 100% NPK treatment gave the highest grain yield, 2:1 compost at 5 tons + 100% NPK gave the highest 100 seed weight (Table18). Unlike the 2007 major cropping season, significant differences were established between 3 t/ha compost + 50% NPK and 5 t/ha compost + 50% NPK during the 2008 major cropping season. Significant differences were established between 3 and 5 t/ha application rates of the 2:1 compost.

Table 18. Effect of compost and inorganic fertilizer and their combinations on maize grain yield in a Ferric Acrisol, Kwadaso (major season, 2008)

Treatments	Grain yield (t/ha)	Increase over control (%)	100 seed Weight (g)
1:1compost at 3 t/ha	4.50	108.33 92.13	31.25
1:1 compost at5 t/ha	4.15	179.17	28.26
1:1 compost at 3t/ha+100% NPK	6.03	137.96	33.16
1:1 compost at 5 t/ha+100% NPK	5.14	60.19	30.34
1:1 compost at 3t/ha+50% NPK	3.46	63.89	27.97
1:1 compost 5t/ha+50% NPK	3.54	77.31	31.66
100% NPK	3.83	157.41	31.58
50% NPK	5.56	167.13	33.08
2:1compost at 3 t/ha	5.77	150.00	32.00
2:1 compost at5 t/ha	5.40	140.74	29.00
2:1 compost at 3t/ha+100% NPK	5.20	113.89	29.07
2:1 compost at 5 t/ha+100% NPK	4.62	126.39	33.90
2:1 compost at 3t/ha+50% NPK	4.89	120.83	33.35
2:1 compost 5t/ha+50% NPK	4.77	42.13	31.61
Cowdung	3.07	-	33.03
Control	2.16		31.24
SED	1.81		2.39
CV (%)	4.00		2.40

4.10.4.3 Maize biomass yield

Results of maize biomass yield obtained during the 2008 major cropping season is presented in Table 19. The 1:1 compost at 3 tons + 100% NPK produced the highest biomass yield which was 168% more than the control (with the least biomass yield). Generally, all treatments produced biomass yields which were significantly higher than the control except 1:1 compost at 3 tons + 50% NPK.

Table 19. Effect of compost and inorganic fertilizer and their combinations on maize biomass yield in a Ferric Acrisol, Kwadaso (major season, 2008)

Treatment	Biomass yield (t/ha)	Increase over Control (%)
1:1compost at 3 t/ha	9.11	90.99
1:1 compost at5 t/ha	10.85	127.46
1:1 compost at 3t/ha+100% NPK	12.76	167.51
1:1 compost at 5 t/ha+100% NPK	9.29	94.76
1:1 compost at 3t/ha+50% NPK	6.16	29.14
1:1 compost 5t/ha+50% NPK	10.97 7.90	129.98 65.62
100% NPK	15.80	231.24
50% NPK	10.59	122.01
2:1compost at 3 t/ha	10.28 9.29	115.51 94.76
2:1 compost at5 t/ha	10.94	129.35
2:1 compost at 3t/ha+100% NPK	11.46	140.25
2:1 compost at 5 t/ha+100% NPK	9.90	107.55
2:1 compost at 3t/ha+50% NPK	9.55	100.21
2:1 compost 5t/ha+50% NPK	4.77	-
Cowdung		
Control		
SED	3.70	
CV (%)	20.60	

4.11 Evaluation of soil chemical properties after three continuous cropping seasons

4.11.1 Soil pH

During the major cropping season of 2008 the 1:1 compost at 5 tons + 100% NPK and 2:1 compost at 5 tons + 100% NPK treatments significantly (P<0.05) influenced soil pH

(Fig. 33). During the major cropping season of 2007, a pH range of 5.2 (for 1:1 compost at 5 tons + 100% NPK) to 5.7 (1:1 compost at 5 t/ha) was observed. Furthermore, during the minor cropping season of 2007, a pH range of 5.2 (2:1 compost at 5 tons + 100% NPK) to 5.8 (cowdung) was observed. Soil pH data obtained during the major cropping season of 2008 indicated a range of 4.7 (1:1 compost at 5 tons + 100% NPK treatment) to 5.4 (1:1 compost at 5 t/ha treatment).

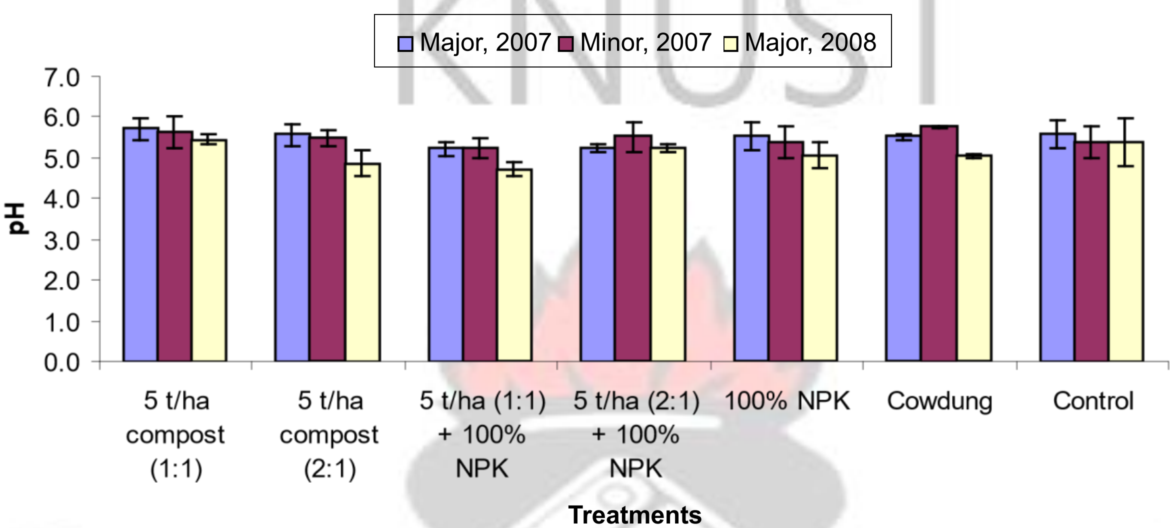


Fig. 33. Effects of treatments on soil pH in a Ferric Acrisol, Kwadaso. Bars denote SED at 5%.

4.11.2 Available phosphorus

Data on soil available P over the three cropping seasons is shown in Fig. 34. Available P on 1:1 compost at 5 t/ha treated plots ranged from 8 - 13 mg/kg soil across the three cropping seasons. A range of 11.1 - 18.8 mg/kg soil was observed on 2:1 compost at 5 t/ha treated plots over the same period. As at the end of the third cropping season, available P levels on 2:1 compost at 5 t/ha plots were 41% more than 1:1 compost at 5 t/ha treated plots. However, results of the first cropping season showed no significant differences between the two treatments.

During the residual studies, 2:1 compost at 5 t/ha showed a significantly higher ($P<0.05$) P effect relative to 1:1 compost 5 t/ha. A combined application of both compost types with

NPK failed to produce significant differences in P levels across the three seasons. A continuous decline was observed from the first to the third cropping season on sole NPK treated plots. After discontinuation of cowdung application during the residual studies, cowdung amended plots produced approximately 84% more available P than the major season of 2007. On the whole, available P levels at the end of the third cropping season ranged from 4.7 – 22.4 mg/kg soil with an average of 12.7 mg/kg soil.

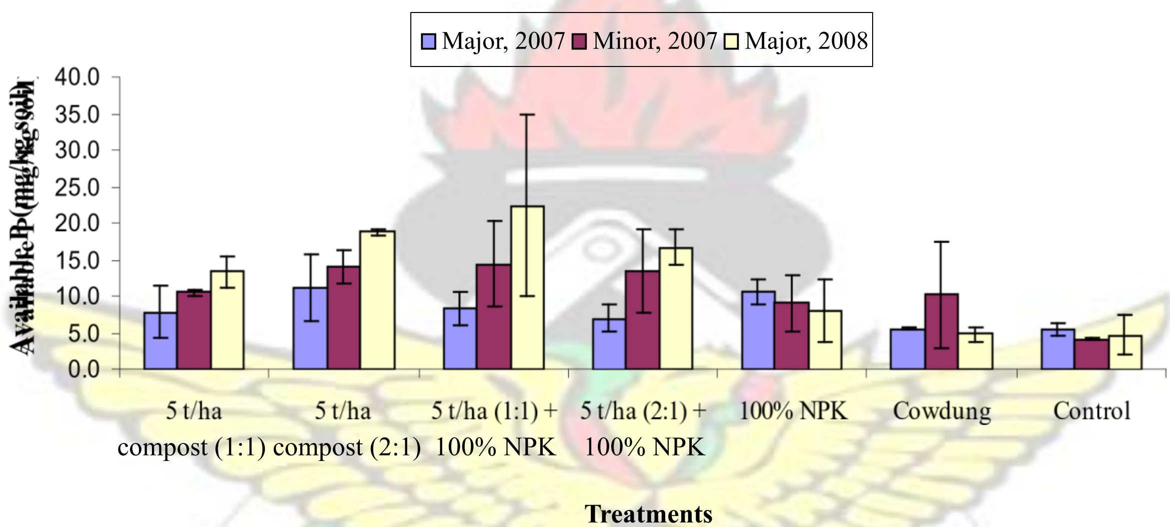


Fig. 34. Effects of treatments on soil available phosphorus in a Ferric Acrisol, Kwadaso. Bars denote SED at 5%.

4.11.3 Total soil nitrogen

The changes in total soil N resulting from three continuous cropping seasons are shown in Fig. 35. The results indicated that significant differences in soil N existed among the 1:1 compost at 5 tons + 100% NPK, 2:1 compost at 5 tons + 100% NPK and the control plots respectively. Significant differences were also observed between 100% NPK and the control plots over the same period. Total soil N levels in all treatments were significantly higher than the control during the major and minor cropping seasons of 2007 and 2008.

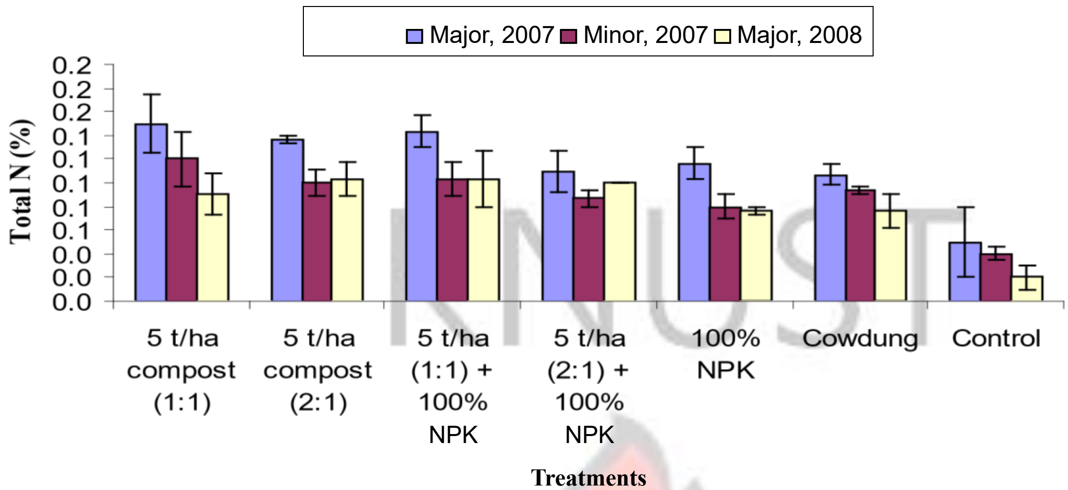


Fig. 35. Effects of treatments on soil total N in a Ferric Acrisol, Kwadaso. Bars denote SED at 5%.

4.11.4 Soil organic carbon

Figure 36 shows the changes in soil organic carbon over the three cropping seasons. On the whole, organic carbon contents from the first to the third cropping season declined by 66, 40, 40, 10, 50, 38 and 88% for the 1:1 compost at 5 t/ha, 2:1 compost at 5 t/ha, 1:1 compost at 5 t/ha + 100% NPK, 2:1 compost at 5 t/ha + 100% NPK, 100% NPK, cowdung and the control plots respectively.

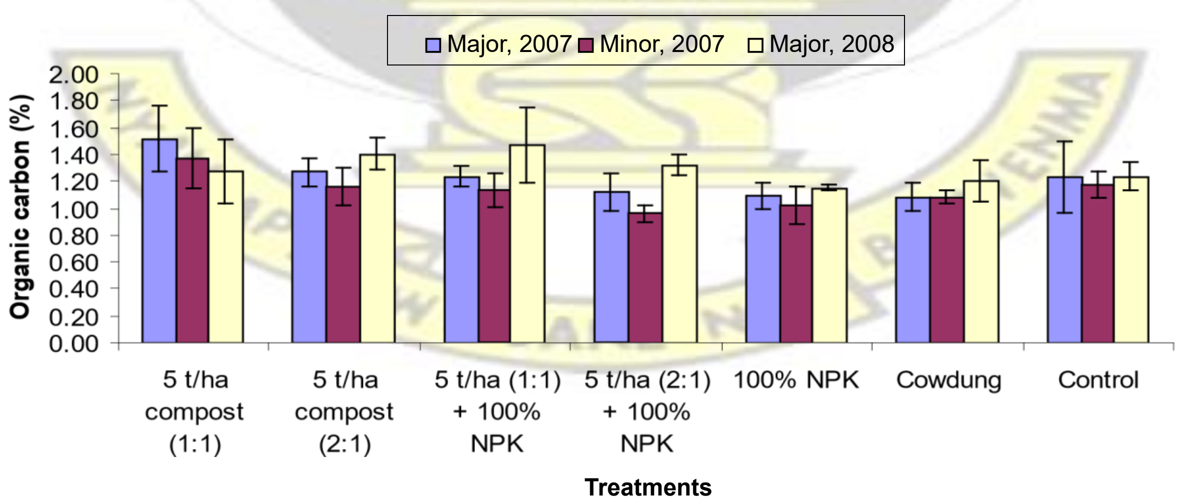


Fig. 36. Effects of treatments on soil organic carbon in a Ferric Acrisol, Kwadaso. Bars denote SED at 5%.

4.11.5 Exchangeable calcium, magnesium, potassium and sodium

Figures 37 - 40 show the results of exchangeable Ca, Mg, K and Na over the three cropping seasons. Exchangeable calcium contents ranged from 2.7 - 5.5, 3.2 - 4.9 and 3.2 – 6.0 cmol / kg for the 2007 major, 2007 minor and 2008 major cropping seasons respectively (Fig. 37). Exchangeable Mg ranges of 2.0 - 2.8, 1.5 - 2.5 and 1.3 - 2.3 cmol / kg soil were observed for the 2007 major, 2007 minor and 2008 major cropping seasons respectively (Fig. 38). The results indicated that exchangeable Mg contents for the control, 1:1 compost at 5 t/ha and 2:1 compost at 5 t/ha declined with the seasons whiles the 1:1 compost at 5 tons + 100% NPK and 2:1 compost at 5 tons + 100% NPK treatments increased slightly during the residual test over the major season of 2007.

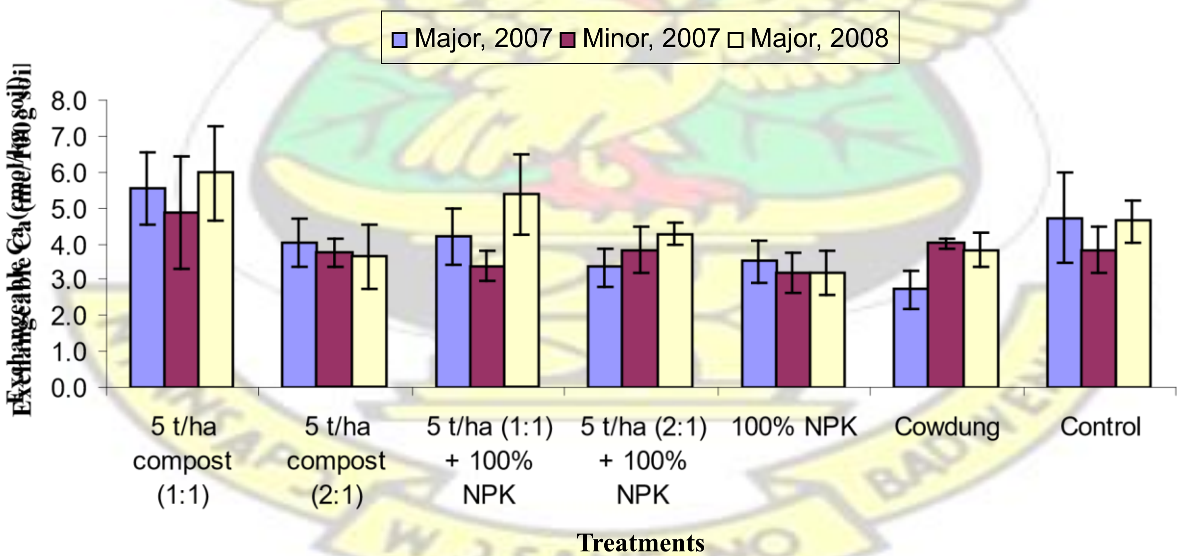


Fig. 37. Effects of treatments on soil exchangeable Ca in a Ferric Acrisol, Kwadaso. Bars denote SED at 5%.

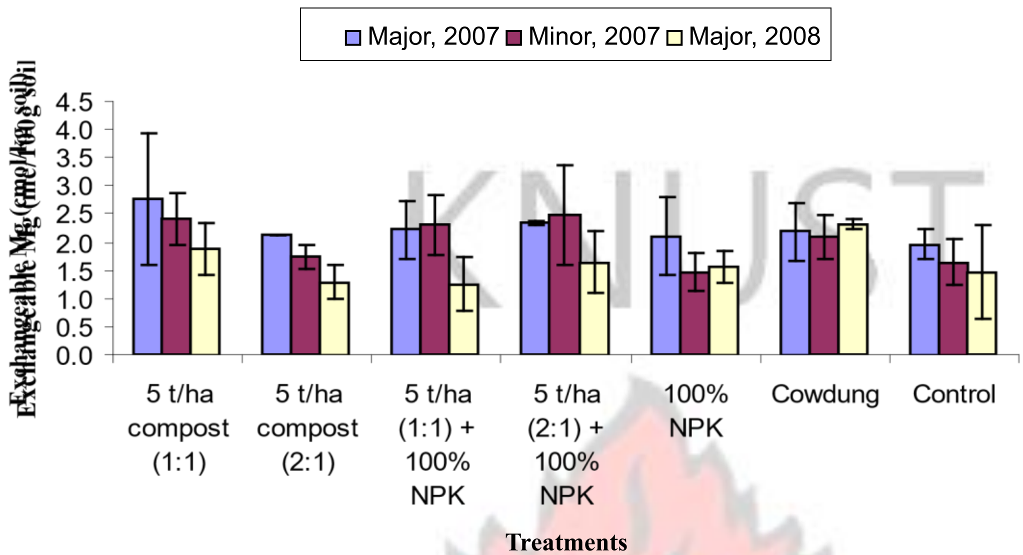
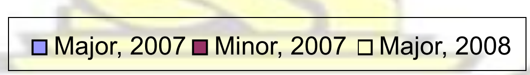


Fig. 38. Effects of treatments on soil exchangeable Mg in a Ferric, Kwadaso. Bars denote SED at 5%.

Exchangeable K contents varied from 0.08 - 0.2, 0.2 - 0.3 and 0.2 - 0.4 cmol / kg soil for the 2007 major, 2007 minor and 2008 major cropping seasons respectively (Fig. 39). Residual K values obtained in all treatments were significantly higher than that of the 2007 major cropping season except the 100% NPK, cowdung and control. Exchangeable Na contents also varied from 0.09 – 0.2, 0.02 – 0.06 and 0.05 – 0.09 cmol / kg soil for the 2007 major, 2007 minor and 2008 major cropping seasons respectively (Fig. 40).



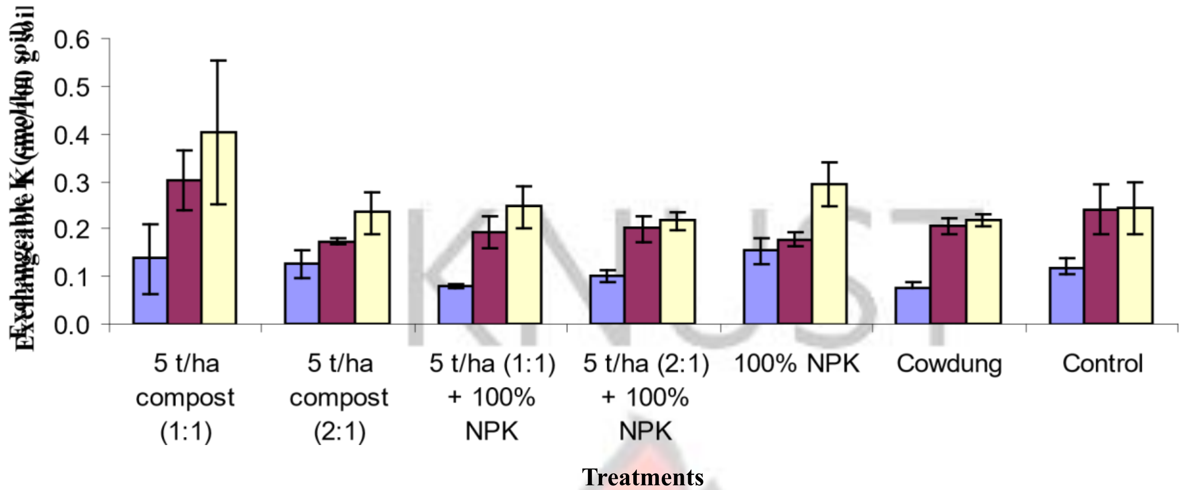


Fig. 39. Effects of treatments on soil exchangeable K in a Ferric Acrisol, Kwadaso. Bars denote SED at 5%.

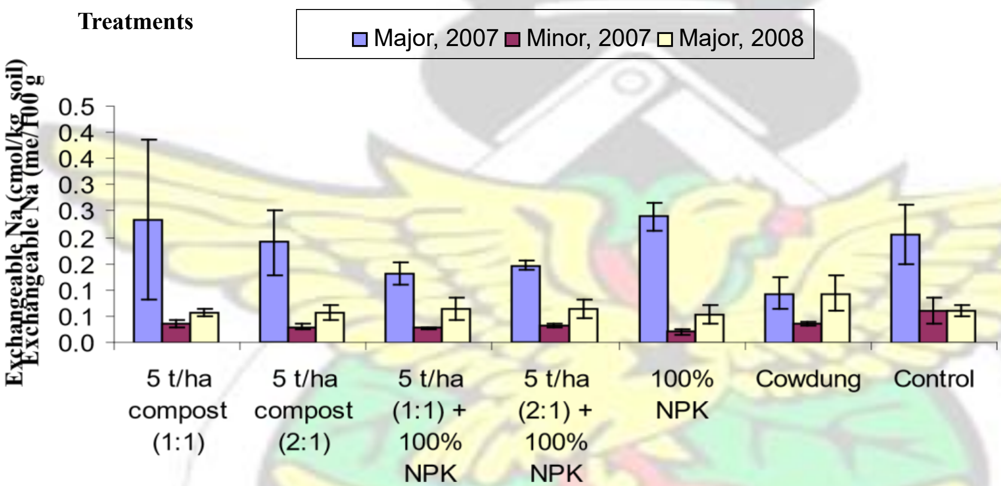


Fig. 40. Effects of treatments on soil exchangeable Na in a Ferric Acrisol, Kwadaso. Bars denote SED at 5%.

4.12 Evaluation of some soil physical properties after three continuous cropping seasons

Three main soil physical properties were assessed at the end of the third cropping season: texture, bulk density and aggregate stability. A summary of results on texture and bulk density characteristics of the soil in the upper 0 – 15 cm is presented in Table 20. Soils sampled were dominantly sandy loam. On the whole, bulk density ranged from 1.32 – 1.41 Mg m^{-3}.

The size distribution of aggregates after wet sieving of the soil samples from the various treatments is shown in Fig. 41. The percentage of large macroaggregates (>2000 μm) was greatest under cowdung but subsequently declined in the other treatments in the order: 5 t/ha compost (1:1) > 5 t/ha compost (2:1) > NPK > control. Small macro aggregate pools (250 – 2000 μm) was greatest under 2:1 compost at 5 t/ha but not significantly different from cowdung and 1:1 compost at 5 t/ha. Stability within soil microaggregates (53 – 250 μm) was highest in the control and declined in descending order among the treatments as follows: control > NPK > 5 t/ha compost (2:1) > 5 t/ha compost (1:1) > cowdung. The proportion by weight of aggregate stability within the silt and clay fraction (<53 μm) was lowest in cowdung and highest in 2:1 compost at 5 t/ha but not significantly different from the control and NPK treatments respectively.

Table 20. Selected physical properties of the soil after three cropping seasons

Treatment	Sand	Silt	Clay	Texture	BD (Mg/m^3)
		%			
5 t/ha compost (1:1)	69.78	26.62	3.60	Sandy loam	1.34 ± 0.10
5 t/ha compost (2:1)	70.90	21.46	7.64	Sandy loam	1.32 ± 0.04
5 t/ha compost (1:1) + 100% NPK	67.62	26.79	5.59	Sandy loam	1.34 ± 0.10
5 t/ha compost (2:1) + 100% NPK	70.72	27.18	2.10	Sandy loam	1.33 ± 0.10
100% NPK	60.18	35.71	4.11	Sandy loam	1.37 ± 0.00
Cowdung	69.32	26.53	4.15	Sandy loam	1.35 ± 0.01
Control	66.18	25.75	8.07	Sandy loam	1.41 ± 0.01

- Values represent the mean of 3 replicates

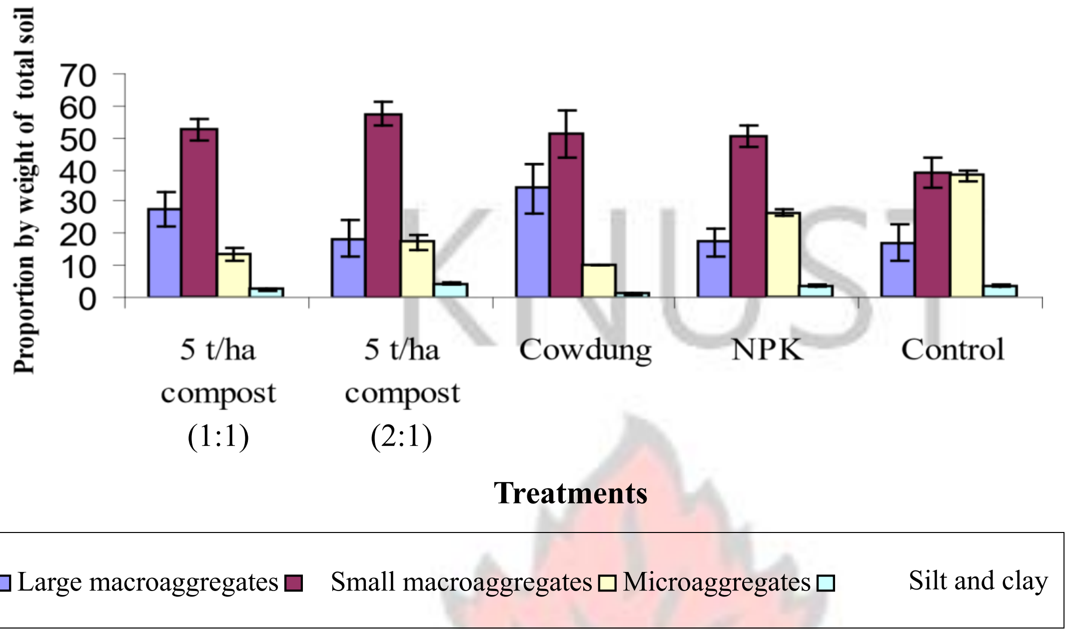
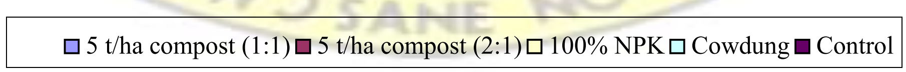


Fig. 41. Effects of soil management on the size distribution of aggregates following wet sieving. Bars denote SED at 5%.

4.13 Evaluation of some soil biological parameters after three cropping seasons

Bacterial viable counts on a logarithmic scale showed that cowdung treated plots recorded the highest value whilst the lowest value was recorded on the control plot (Fig. 42). Significant differences in bacteria populations were established between NPK and cowdung treated plots (Fig. 42). Total microbial load on a logarithmic scale ranged from 4.6 in the control to 5.4 on cowdung treated plots. Incubation periods of 3 – 4 and 5 – 7 days respectively were recorded for bacteria and fungi at a temperature of 37^0C.



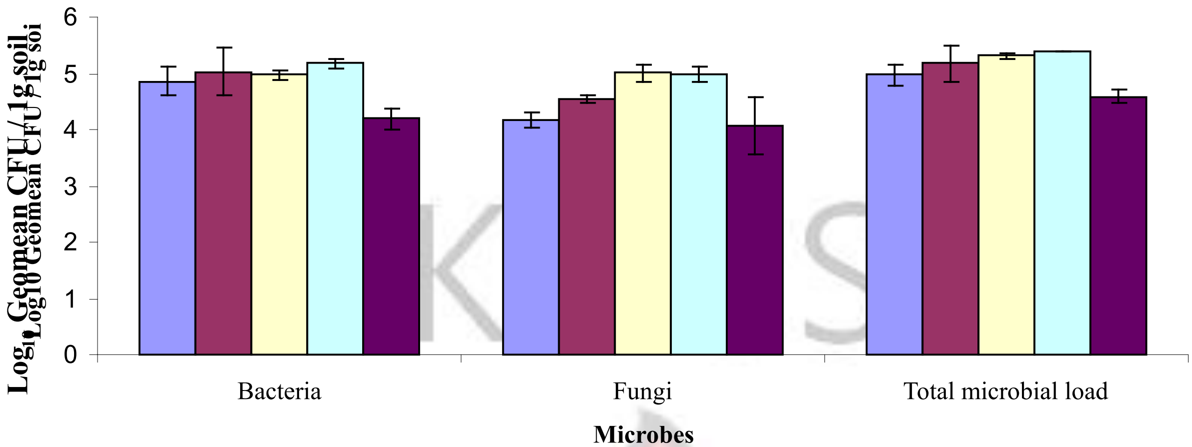


Fig. 42. Effects of treatments on soil bacterial and fungal populations in a Ferric Acrisol, Kwadaso. Bars indicate SED at 5%.

Figures 43 - 45 show the relationships between soil pH and bacterial population, fungal population and total microbial load respectively. The results indicated negative correlations between pH and soil bacteria, fungi and total microbial loads with R^2 values of 0.41, 0.50 and 0.52 respectively.

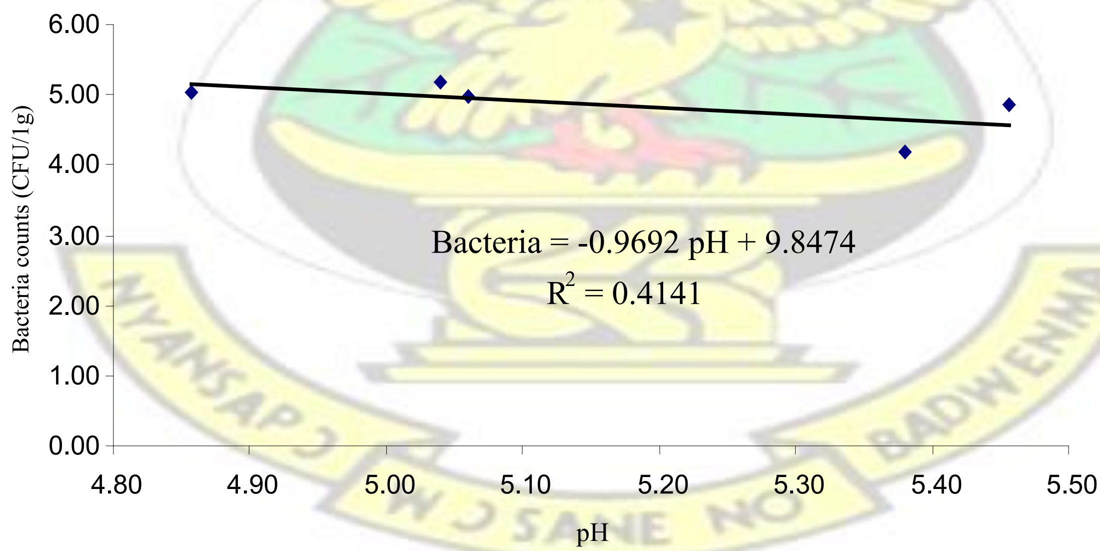


Fig. 43. Relationship between soil pH and bacterial population in a Ferric Acrisol, Kwadaso.

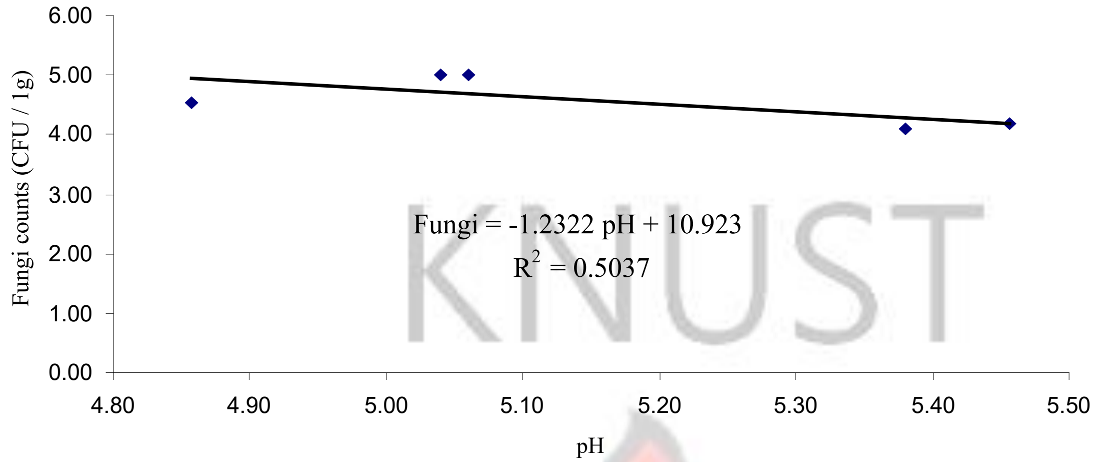


Fig. 44. Relationship between soil pH and fungal population in a Ferric Acrisol, Kwadaso.

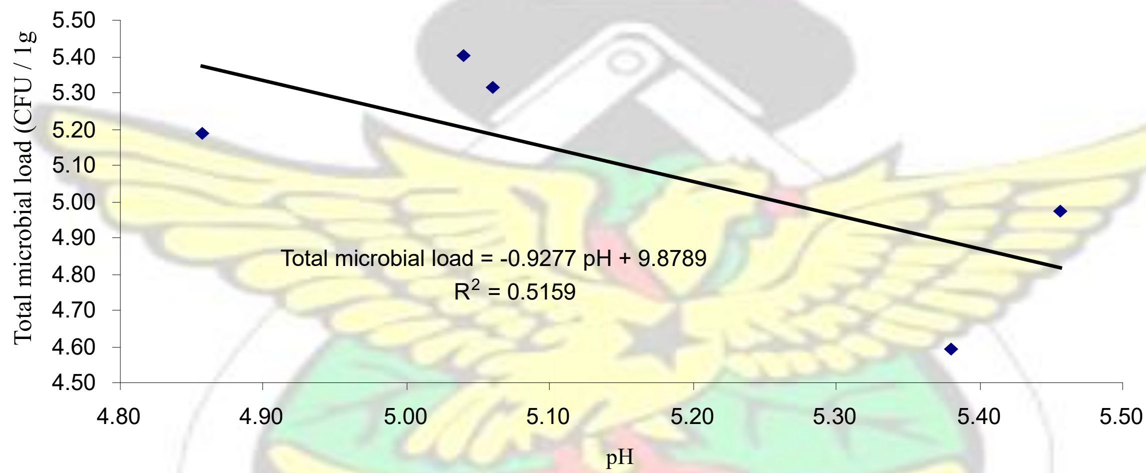


Fig. 45. Relationship between soil pH and total microbial load in a Ferric Acrisol, Kwadaso

The effects of the different soil management practices on microbial biomass carbon, nitrogen and phosphorus after the three cropping seasons were assessed (Figs. 46 – 48). The highest and lowest microbial biomass C contents were recorded on cowdung and 1:1 compost at 5 t/ha treated plots respectively (Fig. 46). Significant differences were observed among all treatments except the control and 100% NPK plots. Biomass C content under 2:1 compost at 5 t/ha was 35% more than 1:1 compost at 5 t/ha. Microbial biomass N content ranged from 1.4 - 8.2 mg N kg^{-1} soil with a mean value of 6.2 mg N kg^{-1} soil. Microbial biomass N content in the control was 400, 24, 18 and 7% more than 1:1 compost at 5 t/ha, 2:1 compost at 5 t/ha, 100% NPK and cowdung treated plots respectively (Fig. 47). Microbial biomass P content ranged from 3.6 - 6.3 mg P kg^{-1} soil with a mean value of 5 mg P kg^{-1} soil (Fig. 48). Microbial biomass P was significantly higher ($P<0.05$) in the control and lower in 1:1 compost at 5 t/ha.

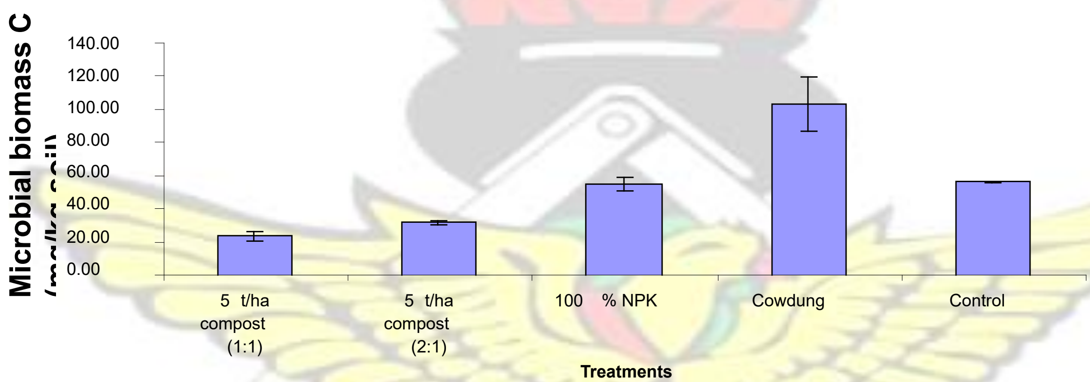


Fig. 46. Effects of treatments on soil microbial biomass C in a Ferric Acrisol. Bars denote SED at 5%.

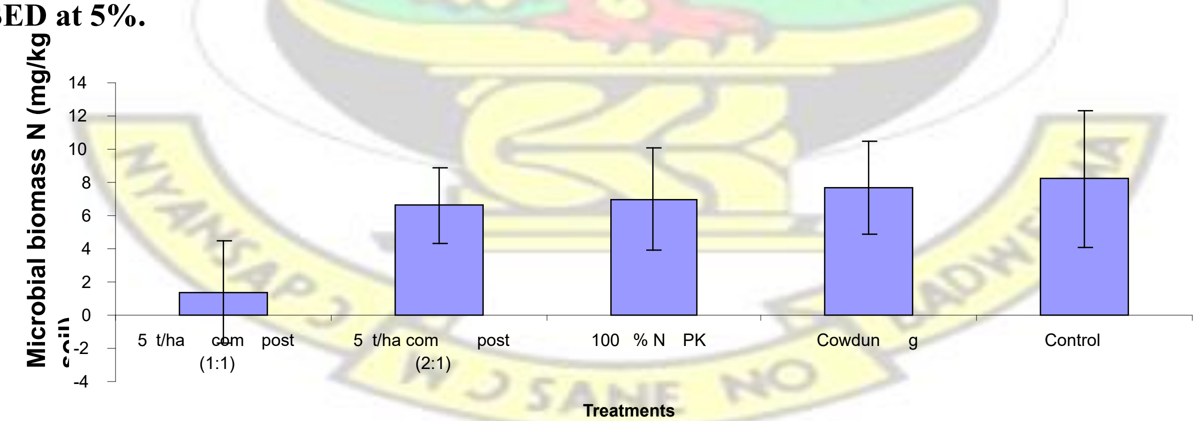


Fig. 47. Effects of treatments on soil microbial biomass N in a Ferric Acrisol. Bars denote SED at 5%.

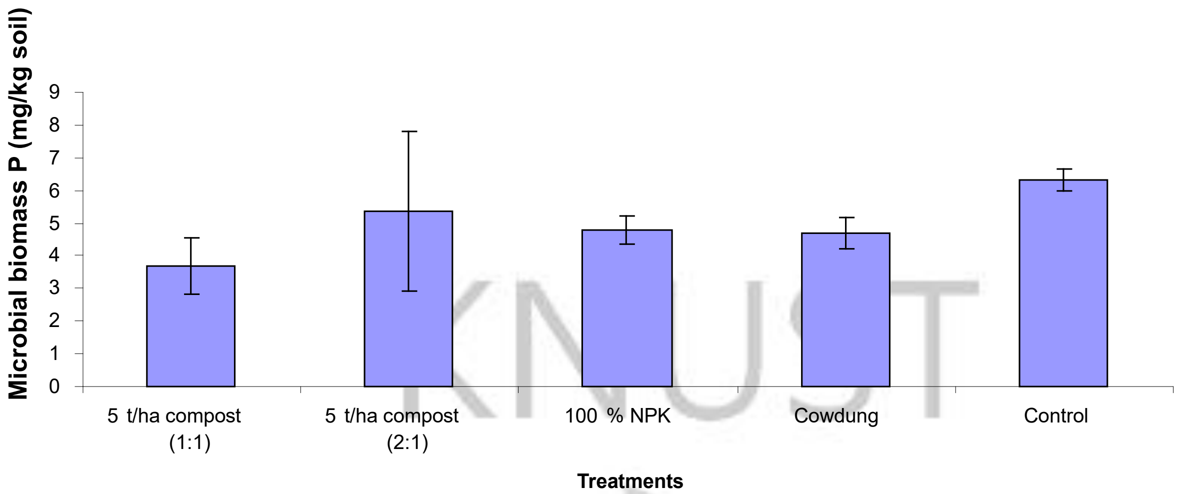


Fig. 48. Effects of treatments on soil microbial biomass P in a Ferric Acrisol. Bars denote SED at 5%.

Microbial biomass carbon to organic carbon ratio (microbial quotient) of the treatments under consideration varied from 18.37 to 85.63 (Table 21). The highest ratio was recorded under cowdung and the lowest in 1:1 compost at 5 t/ha compost. On the whole, microbial quotients under the various treatments can be arranged in the following order: cowdung>100% NPK>control>2:1 compost at 5 t/ha compost> 1:1

Table 21. Effects of treatments on microbial quotient

Treatments	Microbial biomass carbon (mg/kg)	Soil organic carbon (mg/kg)	Microbial quotient
5 t/ha compost (1:1)	23.34	1.27	18.37
5 t/ha compost (2:1)	31.67	1.40	22.62
100% NPK	55.00	1.15	47.69
Cowdung	103.33	1.21	85.63
Control	56.34	1.24	45.55

CHAPTER FIVE 5.0 DISCUSSION

5.1 Resource quality and manure management practices in the Upper East region The variations in N content of cowdung sampled during the survey could mainly be due to differences in losses during handling, contamination with sand in the kraal and addition of legume and other residues to dung (Appendix 6). Similarly, several authors (e.g. Tanner and Mugwira 1984; Mugwira and Mukurumbira 1986; Mureithi *et al*. 1994) have reported that the quality of manure from livestock in communal areas are highly variable, with N levels as percentage of dry matter (DM) ranging from 0.27 to 1.14%. Tanner and Mugwira (1984) and Mugwira and Mukurumbira (1986) classified cattle manure into quality groups of low, medium and high based on average N contents of 0.80, 1.01 and 1.39% respectively. The fact that all manures sampled from the region had mean N content less than 0.8% imply that current management practices by most farmers do not result in manures with high N content. Beauchamp (1986) indicated that low total N would lead to immobilization of both soil and dung N at the initial stages of the dung application.

The ash contents of cowdung sampled from the survey area ranged from 22.37 to 99.85% with an average of 45% (Appendix 6). Ash content values ranging 27 to 92% in manure sampled from smallholder farms in Zimbabwe have been reported (Nhamo *et al*., 2004). The high values in ash contents are an indication of the high contamination from sand, which is a common problem with manures from smallholder farm where manure usually accumulates on loose sandy soils and consequently mixes with it over time. Sand contaminations may also occur when digging out the manure. Mugwira (1985) also reported that communal area cattle manure contains high fractions of sand due to the mixing of manure with soil during trampling by the livestock. Additionally, Mugwira (1984) also indicated high sand contents in cattle manure and used this parameter as a measure of manure quality. Ash content used as an index of manure quality in this study is important in that it can be estimated by hand texturing of the manure in the field unlike others which require chemical analysis. This could be important for use by farmers as a quick test of manure quality.

The main sources of plant nutrients for growing crops identified during the survey were cowdung, poultry manure, compost and chemical fertilizers with cowdung being the most predominant due to the larger livestock populations in the area. This raises a question as to why some farmers in the area continue to indicate that they do not have enough cowdung. A similar question was posed by Lekasi (2000), when it was reported that a small scale farm in Zimbabwe can produce cattle manures that are able to supply 100 kg N within a period of six months and this supply may be in excess of the farm requirement for a 0.01 ha small farm. It is possible that the dung produced may be of low quality, rather than high quantity and thus not effective in raising crop yields to the satisfaction of farmers. Murwira *et al*. (2004) indicated in a study that farmers' value manure quantity as being more important than quality. These findings thus highlight the possibility that, what may be required in the high potential areas may be a better focus on manure quality and its management as indicated by Kimani and Lekasi (2004). The problem of low manure availability in smallholder farms can be addressed through increasing its use efficiency. One such strategy is placement of the manure in the planting hole instead of broadcasting, which was a common practice among farmers in the study area. Spot application reduces leaching and volatilization losses and maximizes yield. Spot placement or dribbling of manure into the planting furrow each year, rather than broadcast application at high rates every few years, are promising ways of increasing the recurrent crop yield decline from cattle manure (Munguri *et al*. 1995). Spot placement however requires farmer knowledge, skills, labour inputs as well as good manure preparation (Ransom *et al*. 1995). Empowering farmers through greater understanding and application principles of manure is therefore paramount (Murwira, 2003).

Inorganic fertilizer use can be one option of rapidly replenishing exhausted soils. Piéri (1989) reported that the use of inorganic fertilizer has been widely reported as a means of increasing crop production across West Africa. It was observed from this survey that, many farmers were aware of the potential contribution of inorganic fertilizer to crop production but still refrained from using them. Forty percent of the respondents attributed their reason for not using inorganic fertilizer to the prohibitive high prices and the abundance of cowdung on their farms. Thirty eight percent of the respondents were of the view that inorganic fertilizers had no residual effect on their soil. However, 31% cited poverty as a major set-back for not using inorganic fertilizers because they mainly financed their farming activities through income generated from farms and therefore a drought year would imply difficulties in purchasing inputs for the following season. Furthermore, failure to obtain credit facilities also hindered the use of mineral fertilizers. Similar observations were made by Fofana *et al*. (2006) who reported that farmers mainly refrained from inorganic fertilizer use because of the low agronomic efficiency, inadequate and unreliable product markets and difficult access to inputs. They further established that farmers were gradually realizing the adverse impact of sole and excessive use of chemical fertilizers and the need for organic matter replenishment onto their agricultural lands.

5.2 Resource management and its effects on cowdung quality

Over 80% of the respondents stored cowdung in the open. Manure nutrients, especially nitrogen, are subject to many potential loss pathways after the animal excretes them. Volatilization to the atmosphere is a major loss pathway for nitrogen. Kimani and Lekasi (2004) reported that nutrient losses, especially nitrogen, were bound to occur due to leaching during the rains or even denitrification when the sheds become soggy and anaerobic conditions prevail. Phosphorus and potassium are not subject to volatilization but can be lost in uncontrolled runoff. Many of the actual and apparent losses of nutrients in manure occur during collection and storage. During the survey, it was observed in the extensive systems where animals grazed freely that manuring was done in-situ. Where they were confined overnight at the kraal, the dung was heaped besides the kraal as a continuous process throughout the year. Similar methods of manure collection have been reported for the communal grazing areas of Zimbabwe (Nzuma *et al*., 1998). Kimani and Lekasi (2004) indicated in their study that, a limitation to this method of manure collection was that, most of the urinary N is leached down the soil profile and considerable amounts of N is lost via volatilization.

It is true that cattle fed on high quality supplements produce high quality manures. For example, Jama *et al*. (1997) showed that high P-content manure (0.49% P) can be obtained if the grass fed to zero - grazed improved breed dairy cows is supplemented with the fresh leaves of *Calliandra calothrysus*. The effect of the resultant high quality manure increased crop yield both during the season of application as well as during the subsequent season due to residual effects. However, the practicality of this finding at the smallholder farm level is sometimes doubtful. This is because in most situations farmers feed their livestock opportunistically - a feeding situation where a farmer feeds the livestock with whatever feed may be available at a particular time. Therefore, improved quality associated with improved diets is more practical in the more intensive systems for instance under zero grazing units which are generally associated with resource poor farmers practicing alley farming using leguminous plants such as Gliricidia and Leucaena (Kang et al., 1990).

There is growing evidence that some farmers can accurately assess the quality of organic fertilizers and use this knowledge strategically (Lekasi *et al*., 2001). For example, of the different manure resources identified, most farmers ranked poultry manure as being the ‘strongest’ followed by pig, sheep, goat and lastly cattle. Their definition for ‘strongest’ was on the basis of the manure being used quickly and thus the need to manure fields on yearly basis. Harris and Yusuf (2001) reported that farmers in Kano Close-Settled Zone, Nigeria, appreciated differences among manures from different source animals and also between manure produced in the dry season and that stored since the previous dry season.

Furthermore, some farmers used texture and longevity of composting as some of the quality characteristics. On the whole, it can be said that the quality of manure can be improved by its management.

5.3 Resource quality of 1:1 and 2:1 composts

Considering the characteristics of the cowdung before and after composting (i.e. comparing tables 4 and 5), it is seen that composting cowdung can enhance its fertilizer value. At the end of the composting process, N content in cowdung had increased by 53 and 102% respectively for the 2:1 and 1:1 compost mixtures. All other chemical properties of the cowdung increased appreciably with composting except magnesium. The quality obtained was further translated into enhanced crop growth and yields since both compost types produced relatively higher yields than cowdung throughout the three cropping seasons. This confirmed the null hypothesis that improvement in cattle manure quality increases maize yields. The observed improvement in maize yield suggests improved nutrient supply and availability and therefore *Stylosanthes guinensis* may be a potentially good organic amendment for optimizing the quality of cowdung. The potential of optimizing cattle manure use for maize was also studied by Munguri *et al*. (1995) in Chinyika area of Zimbabwe.

As composting progressed, nitrogen content declined from the initial values in both compost types (1.90 - 1.46% and 1.89 - 1.10% for 1:1 and 2:1 composts respectively) up to the end of the study period (Table 5). This trend in N decline from both compost types contradicts the findings by Dresboll and Thorup-Kristensen (2005) who observed a tendency where the nitrogen content of their treatments increased with time during composting of wheat straw. Nitrogen losses have also been reported for compost made of several types of bulking agents and either manure or sewage sludge (Barrington *et al*., 2002). Witter and Lopez-Real (1988) also observed nitrogen losses (17%) when composting with straw and sewage sludge enriched with lime. Ammonia volatilization consisted of over 92% of all nitrogen losses. Factors controlling the magnitude of N losses from compost have been investigated in several studies. Martins and Dewes (1992) measured the different pathways of nitrogen losses and found that they represented 47 – 77% of the initial total nitrogen content of the compost. Hansen *et al*. (1989) measured nitrogen and dry matter losses of 23 – 32% and 13 – 23% respectively when composting poultry manure with either sawdust or corn cob at a C/N ratio of 20 or 25. The true merits of composting are thus often queried given the N losses associated with the composting process. It has been reported however, that comparing final to initial concentrations of nutrients can be misleading because of simultaneous dry matter losses (Breitenbeek and Schellinger, 2004; Eghball *et al*., 1997; Tiquia *et al*., 2002). Losses of N occur from labile N pools and are thus more likely when there is a high proportion of labile material. This is however controlled by the availability of easily decomposable C and N, and N losses tend to decrease abruptly as soon as ammonium - N is immobilized.

Total carbon content declined by 36 and 43% in 1:1 and 2:1 composts mixtures respectively (Table 3). This may have been due to microbial decomposition of C and release as CO_2 from the composts. Michel *et al*. (2004) also reported 54 – 79% C losses from straw – amended dairy manure in Ohio. Larney *et al*. (2006) reported significantly higher C losses with composting (67%) due to greater decomposition. The C: N ratio of both compost mixtures declined as composting progressed and attained final values of 23 and 30 for 1:1

and 2:1 mixtures respectively. During the composting process, the C: N ratio of the initial feedstock typically declines because whiles carbon is being oxidised, nitrogen is mineralized by the micro-organisms. A number of researchers have observed a significant reduction in C: N ratios when different sources of organic materials have been composted. For example, Thambirajah *et al*. (1995) observed a substantial reduction in C: N ratio when they composted empty oil palm fruit bunches (with a relatively high lignin content) with manure added to the substrate. Eventhough C declined in both compost types with time, compost is rich in stable C and this has immediate implications for replenishment of soil organic matter and maintenance of soil quality. The decline in C: N ratio of both compost types implied that, available carbon for microbial breakdown was being rapidly used up as composting progressed resulting in increased labile fractions of organic matter.

As at the end of composting process, pH for both compost types had dropped from 8.40 to 6.58 and 8.60 to 7.23 for 1:1 and 2:1 compost types respectively. Wong *et al*. (2001) reported that decreases in compost pH may be due to ammonification and mineralization of organic matter by the activities of microorganisms. Gaind and Gaur (2003) showed an increase in pH value during the first seven days due to ammonification followed by a gradual decrease to a final pH ranging between 6.5 and 6.9. Good pH values for composting are between 5.5 and 8.0 and between 4.0 and 7.0 for the end product (Winblad and Kilama, 1980). In the first moments of the composting process, the pH may drop to around 5.0 as organic acids are formed; then microbial ammonification will cause the pH to rise into the range of 8.0 - 8.5. A high pH is generally a sign of immature compost. Nzuma *et al*. (1998) reported that N contents in manure could be related to the pH of the manures during the composting process. In heaps where conditions are aerobic, the compost pH is normally high (8.0 – 9.0). This tends to stimulate N losses via volatilization. On the other hand, compost stored under anaerobic conditions tends to produce organic acids that lead to lower pH (< 7) and therefore minor losses via volatilization (Kihanda and Gichuru, 1999). Al-Kanani *et al*. (1992) also reported a well established link between N loss via ammonia volatilization and pH, with volatilization decreasing as pH decreased. Thus an alkaline pH favours the formation of NH_3 from NH_4^+ which might result in NH_3 volatilization.

The effective action of different microorganisms on the decomposition of the composts resulted in the overall reduction in the size of the composting material to give a deep brown chocolate compost colour. Diverse groups of microorganisms were present in both compost types, which included fungi and bacteria (Plates 7 – 12). *Bacillus* species were the most predominant isolated bacterial species. Their prevalence could be attributed to their ubiquitous distribution in nature. *Bacillus* species in the compost confirmed a study by Blanc *et al*. (1997) who isolated the species from hot compost among the groups of bacteria isolated from poultry manure compost. Blanc *et al*. (1997), further indicated that *Bacillus* species were able to survive in compost piles due to their adaptability to mesophilic temperatures. *Aspergillus* species were the predominant fungi isolated from the compost. The presence of *Aspergillus* species in the compost could have been aided by their ability to adapt to moderately high temperatures (25 – 30 ^{0}C) as reported by Gray and Briddlestone (1981) and the presence of their conidia which is almost everywhere (i.e. in soil, air and water). According to Hargerty *et al*. (1999) *Aspergillus* species are among the most predominant fungi in compost classified as thermophilic fungi in composting which degrade or break down the organic waste. All the fungi isolated can be classified as saprophytes which obtain energy by breaking down the final stages of the compost pile when the compost had been changed to a more easily digested form.

Germination indexes for both compost types were greater than 70% (i.e. 71.10 and 83.80% for 1:1 and 2:1 compost types respectively). Germination index is a biological method for determining phytotoxicity levels in organic substrates (Zucconi *et al*., 1981). According to Zucconi *et al*. (1981), germination index values greater than 50% indicates a phytotoxin-free compost. Based on the germination index, it appears that both compost types had reached maturity by the 90th day of composting. Compost maturity is very important because immature composts still exhibit microbial activities when applied to the soil and thus there is a danger of microorganisms competing with the plants for available soil nitrogen (nitrogen block). Furthermore, immature compost may also contain high levels of organic acids which can damage plant growth when used for agricultural applications. Compost maturity assessment is therefore crucial in determining the availability of the nutrients.

5.4 Decomposition and nutrient release patterns of 1:1 and 2:1 composts

A partial N immobilization was observed in both compost types during the first 14 days of the laboratory incubation study (Fig. 4). This finding is similar to the results of Mugwira and Mukurumbira (1984) which showed a depression in plant growth in the first two weeks in manured pots. Castellanous and Prat (1981) also observed immobilization of N in soils treated with aerobically composted dairy cattle and beef feedlot manures. Much longer periods of immobilization from cattle manure of up to 105 days have been observed (Fauci and Dick, 1994). On the contrary, Delve *et al*. (2001) observed that all manure types released N in the first week of incubation but immobilized N for 17 – 28 weeks, resulting in a lack of response in *Zea mays* (L) growth to any of the manures in both pot and field experiments.

Some flushes of net mineral N were observed from the 4th week up to the end of the laboratory incubation study (Fig. 4). Nhamo *et al*. (2004) reported that under field conditions, these flushes occur after the initial wetting of the soil by rains and provide N to young plants early in the season. It is the balance between this initial mineralization and leaching losses together with crop uptake that determines the initial benefits of manures or composts to crops.

Unlike the laboratory observations, no immobilization of N was observed during the field incubation study of the two compost types (Fig. 10). This phase of mineralization was not expected because it was calculated (Castellanos and Pratt 1981; van Faassen and van Dijk 1987) that N immobilization would occur if the C: N ratio of the compost exceeds 15 to 20. Nogales (1982) also reported that in general, the mineralization process is enhanced when the organic products that are added to the soil has an adequate C:N ratio less than 20. Several other authors (e.g. Myers *et al*., 1994; Cadish *et al*., 1993) have reported an initial immobilization of mineral N in the decomposition of organic materials with C:N > 25. The C: N ratio for both compost types were however greater than 20. These findings may suggest that under the field conditions, both compost types had sufficient N to meet microbial demands from the initial phase of mineralization. Furthermore, some soil properties may also have had an effect on the N mineralization patterns observed from the start to the end of the incubation study. Deenik (2006) reported that the amount and type of clay in a soil affects N mineralization reactions. Mineralization tends to be greater in coarse-textured soils, low in clay and less as the soil clay content increases. Murwira *et al*. (1995) noted mineralization to be lower in clay than in sandy soils because of its shielding effect. Several other authors (Ko¨rschens, 1980; Nichols, 1984; Van Veen *et al*., 1984) have reported that the capacity of soils to protect organic matter against microbial decomposition seemed to depend on the soil clay content. Finely textured soils high in clay are abundant in micropores in which organic matter can find physical protection from microbial decomposition. Due to the findings cited above and the results obtained as at the end of this study, it can be said that the soil had low clay (<10%) with a relatively high sand content which could have enhanced the entire mineralization process. Interpretation of results under controlled conditions should thus be made with caution as incubation studies which usually exist under optimum conditions rarely occur in the field (Stark *et al*., 2007). Another soil property which may have had an effect on N mineralization rates of the composts was C: N ratio. On the average, the C: N ratio of the soil in which this study took place was 13.2. Agbenin and Goladi (1996) reported that C:

N ratio of soils higher than 10 is a critical ratio for net N mineralization to occur in soils.

C: N ratio of the composts during the field incubation study declined sharply from the 2nd to the 4th week for both compost types (Fig. 13). This decline suggested that the available carbon for microbial breakdown was being rapidly used up during this period of decomposition. Kanchikerimath and Singh (2001) in a study attributed decreasing C: N ratio to an increase in labile fraction of organic matter. Correlation analysis between C: N ratio and N release under field conditions indicated R^2 values of less than 0.40 in both compost types (Figs. 14 and 15). This study has therefore shown that C: N ratio on its own cannot be used to explain the mineralization and immobilization patterns of decomposing organic materials because these two parameters were not highly correlated. Tetteh (2004) found that the most probable factor is the microbial biomass because in situations where microbial populations are high, the introduction of organic materials into the soil will result in microbes taking up nutrients especially N, P and C for energy, multiplication and other microbiological functions. Tetteh (2004) then concluded that under warm, humid environmental conditions such as in Ghana, the microbial biomass was the main factor governing immobilization or mineralization of N.

The results obtained from the laboratory incubation study have shown that phosphorus immobilization would occur if any of the compost types were to be applied to the soil (Fig. 7). Hue and Sobieszczyk (1999) explained that following mineralization, phosphorus is quickly adsorbed onto the surface of positively charged particles; its availability in solution is therefore typically low even when the total content is high. Furthermore, microbes might have probably taken up the released phosphorus. Microbes require adequate amounts of phosphorus for growth and other physiological activities.

Iglesias - Jimenez *et al*. (1993) also reported low mineralization rates of P immediately after application in a municipal waste compost, but after a residence time of three months, provided sufficient P for plant growth. Although correlation between the C:N ratio and N release showed R^2 values of less than 0.40, that of phosphorus was relatively highly correlated with R^2 values greater than 0.70 for both composts (Figures 16 and 17). However, unlike N, much needs to be learned about how the C: N ratio of the composts affect P availability before progress can be made on the management of P synchrony.

5.5 Temperature and its effects on compost

On the whole, initial temperatures of both compost types were high but declined with time (Fig 3). Carpenter–Boggs *et al*. (1998) made similar observations and indicated in a study with separated dairy manure solids containing wood shavings as bedding material that temperatures were highest during the early periods of the composting process. This trend is usually the case because the thermophilic community may not have been well established during the early periods. Palmisano and Barlaz (1996) also reported that as temperatures drop, actinomycete population increases and more complex substrates can be attacked by extracellular enzymes. As temperatures drop further the remaining substrates which are even more resistant to decomposition are degraded by fungal populations. A prolonged high–temperature phase however favours the development of thermophilic species which continue to persist when temperatures are maintained between 40 – 60ºC (Larney *et al*., 2005). Temperatures higher than 70ºC during the thermophilic stage of composting can lead to a rapid loss of organic matter, resulting in a significant loss of N (Sanchez-Monedero *et al*., 1996). Hence, maintaining moderate temperatures is another means of lowering N loss (Raviv *et al*., 1999).

5.6 Effects of soil amendments on maize grain yield

Under the three seasons of crop growth, both compost types performed significantly higher in yield than the control. Ayoola (2006) reported that crop yields were usually least in unfertilized/control plots because crops had to use the limited nutrients that the soil could supply without any external inputs. These wide gaps established between yields from the control and compost plots could be used to attract the attention of farmers and help them understand easily the value of compost in maize production.

Complementary use of organic manure and mineral fertilizers has been proved to be a sound soil fertility management strategy in many countries of the world (Lombin *et al.,* 1991). Results obtained during the major rainy season of 2007 showed that in all cases a combined application of compost plus NPK fertilizer was more favourable in increasing yields than using compost alone (Table 9). This finding is however contrary to that by Makinde *et al.* (2001) who reported that maize yields from sole inorganic fertilizer and a mixture of organic and inorganic fertilizer applications were similar and was significantly higher than yields from organic fertilizer application. The results are however in agreement with the findings of Titiloye (1982) who reported that the most satisfactory method of increasing maize yield was by judicious combination of organic wastes and inorganic fertilizers. Kapkiyai *et al*. (1998) explained that a combination of organic and inorganic nutrient sources results in synergy and improved synchronization of nutrient release and uptake by plants leading to higher yields. Furthermore, Murwira and Kirchmann (1993) also observed that nutrient use efficiency of a crop is increased through a combined application of organic manure and mineral fertilizer. The highest yields therefore obtained from the compost + inorganic fertilizer combination, shows that the maize plants benefited more from this combination than from sole composts and NPK. A similar conclusion was made by Kang and Balasubramanian (1990) that high and sustained crop yields could be obtained with judicious and balanced NPK fertilization combined with organic matter amendments.

It is generally believed that combining organics with inorganic fertilizer will increase synchrony and reduce losses by converting inorganic N into organic forms. Studies have however shown that this is not always true. This may explain why grain yield of 1:1 compost at 3 t/ha was relatively higher than when it was supplemented with half rate NPK (Table 9). Janzen and Schaalji (1992) also found that fertilizer N losses were twice as large as when green manure plus fertilizer was applied to barley. Their interpretation was that green manure promoted high levels of nitrate and available C in the soil, enhancing de-nitrification. This indicates that N losses can be quite high from both organic and inorganic sources, contrary to the popular belief that application of organic resources will result in lesser losses.

The 33% increase in maize yield of the 1:1 compost at 3 t/ha over the same compost at 5 t/ha was unexpected (Table 9). This observation may be explained by the relatively higher nutrient recovery rates of the 1:1 compost at 3 t/ha over the 5 t/ha rate (Table 13). Furthermore, the literature indicates that there is an economically efficient level of manure application. Beyond a particular point, increased manure application rates do not improve yields (Fraser *et al*., 2006). Mathers and Stewart (1980) also explained that high rates of manure application led to lower yields, probably because high rates of application resulted in high salt and ammonia levels in the soil. In contrast, Tiarks *et al*. (1974) found that corn silage yield increased by as much as 30% (coinciding with improvements in soil quality) as cattle manure rates increased, particularly when manure was incorporated into the soil.

After discontinuation of compost application when residual effects of the various treatments were being tested, maize yields from compost amended plots remained higher than those on control plots confirming other reports (Dilz *et al*., 1990; Murwira and Kirchmann, 1993) that compost additions can have significant carry over effects for several years. Whereas combined organic and inorganic treated plots gave the best yields during the major season of 2007, sole compost treated plots compared relatively well with the combined treatments during the residual test (Table 15). Muller Saman and Kotschi (1994) explained that during the first growing season only part (30 - 60%) of the manure becomes available. The rest is fixed at first, or is serving to build up the soil's humus and nutrient supplies.

Generally, grain yields obtained from all treatments declined during the residual test compared to the major cropping season of 2007. This observation is in agreement with that of Murwira (2002) who reported that residual yields in the second and third years in pitted manure were lower. The relatively low grain yields obtained during the residual study could also be explained by the low and poor rainfall distribution during the season which did not probably favour adequate soil moisture and nutrient availability and therefore may have contributed to the overall low maize yields (Appendix 7). Horie *et al.* (1995) observed that possible climate changes might affect yield trends due to decreased photosynthesis, increased respiration, shortened vegetative and grain filling period. On the other hand, it can be said that a decline in yield is a complex phenomenon and may not be answered precisely on the basis of this present data set.

5.7 Effects of soil amendments on the chemical properties of the soil

A major component of sustainable land use is to sustain and improve the quality of the soil resource base (Manna *et al.,* 2007). All the treatments in this study had no significant effects on soil pH after cropping continuously over three seasons except the compost + inorganic fertilizer treatments (Fig. 33). Likewise, Hati *et al.* (2007) reported that soil pH did not change significantly with application of manure and fertilizer even after 26 years. Lagomarsino *et al.* (2008) also reported that pH did not change significantly after four years of adding organic amendments. Tembhare *et al.* (1998) explained that, the high buffering capacity of the soil and nominal presence of weak salts namely carbonates or bicarbonates, which on dissolution release free cations might be the possible cause for the stability of the soil reaction.

Mean P levels as at the end of the third cropping season was below 15 mg/kg soil (Fig. 34). The results of this study confirms the findings of Pieri (1986) that P is one of the most limiting nutrients to crop growth in tropical soils. Changes in available P were generally low in all the plots because P is relatively immobile and strongly adsorbed by soil particles (Ige *et al*., 2005). Thomas and Peaslee (1973) reported that most soils containing extractable P of less than 15 mg/kg as determined by Bray 1 method could be defined as being deficient in available P for optimal plant growth. Similar values have been suggested by Olsen and Engelsted (1972).

The continuous decline in total N from the first to the third cropping season under sole NPK treatments (Fig. 35) was because nutrients from this source were readily available and could have resulted in higher N uptake by crops and/or loss through leaching. As at the end of the second cropping season, total N content under 5 t/ha (1:1) + 100% NPK, 5 t/ha (2:1) +

100% NPK and 100% NPK had declined by 40, 22 and 50% respectively (Fig. 35). The lower reduction in total N under inorganic + organic fertilizer relative to sole inorganic fertilizer plots shows that this nutrient was conserved better where a combination of inorganic and organic fertilizers was applied.

Maintaining or improving soil organic carbon is difficult in arid and semi-arid regions in view of the rapid oxidation of organic matter due to high temperature. Conversely, soil organic carbon influences a wide range of physical, chemical and biological properties of soil and is considered the most important indicator of soil quality (Carter *et al*., 1999). Regular addition of organic manures is the only way to increase soil organic carbon status (Katyal *et al*., 2001). Under this study, soil organic carbon did not increase significantly among the treatments as at the end of third cropping except for the compost types and 100% NPK amended plots (Fig. 36). Similarly, a remarkable decline of soil organic carbon was observed at Barrackpore and Ranchi in India during the initial 10 years even after application of NPK + FYM but improved gradually with advancement of time (Manna *et al*., 2007). Several other workers have studied the composition and losses of SOC under intensive cropping and continuous cultivation (Dalal and Mayer, 1986; Dawe *et al*., 2000; Swarup *et al*., 2000).

The low soil organic carbon levels recorded on NPK treated plots relative to both compost types confirms other reports that the incorporation of organic materials into the soil could be an efficient way of maintaining desired soil organic matter level (Janzen *et al*., 1992). Contrary to the results of this study, Vineela *et al*. (2008) reported increased soil organic carbon levels due to long-term fertilization and/or manuring (16–29 years). In addition, Hati *et al*. (2007) documented that soil organic carbon (SOC) was significantly influenced by fertilizer and organic manure applied after 28 years of cropping. It can thus be said that long-term experiments provide the best assessment on the impact of organic and inorganic fertilizer amendments on soil organic carbon. This notwithstanding, trends in soil fertility changes in many short-term trials at the beginning and end of the cropping sequence have been reported (Marcote *et al*., 2001; Blaise *et al*., 2005). Lagomarsino *et al*. (2008) documented that only drastic changes can modify soil organic carbon in the short-term. Nonetheless, in the context of soil fertility management, long-term fertilizer experiments are valuable assets for determining changes in nutrient dynamics and balances and for assessing soil quality and system sustainability (Mandal *et al*., 2007). Soil type can also be one of the important parameters that regulate organic C status of the soil. Ali *et al*. (1966) observed that soil organic carbon content increased with an increase in clay content in soils. The major portion of soil organic carbon is retained through clay–organic matter interactions indicating the importance of the inorganic part of the soil as substrate to bind the organic carbon (Manna *et al*., 2005).

5.8 Effects of soil amendments on the physical properties of the soil

Maintenance of optimum soil physical conditions is an important component of soil fertility management (Hati *et al*., 2007). Characteristics such as soil texture, waterholding capacity, bulk density, biological activity and others can be used to characterize soil quality. Many changes in soil quality after manure additions are linked to the effects of organic matter content on soil structure and biological activity (Bronick and Lal, 2005; Tisdall and Oades, 1982). Another indicator of soil physical quality is aggregate stability (Gregorich *et al*., 2002). If a soil has low binding capacity, it means that soil aggregates can break down easily, which is a symptom of poor soil structure. Soil structure plays a key role in the ability of soil to store organic matter (Balabane, 1996). Soil organic matter can be physically protected from microbial attack within soil aggregates, and contributes to the productivity and physical well-being of soils (Campbell *et al*., 1996). Several workers have reported positive influence of soil aggregation on soil quality, crop productivity and soil nutrients-carrying capacity (Six *et al*., 1998).

The results obtained in this study indicate that aggregate stability within large macroaggregates followed the order cowdung > 1:1 compost at 5 t/ha > 2:1 compost at 5 t/ha> NPK > control reflecting the importance of organic matter in soil aggregate stability (Fig. 41). This trend thus suggests that organic matter from cowdung and composts application may have contributed to the relatively large macroaggregates. A study by Benbi *et al*. (1998) conducted in India found that application of farmyard manure increased aggregate stability by 12% compared to the control. Weinfurtner (2001) explained that, for the stabilization of macroaggregates (> 250 μm), plant residues and applied organic matter are of importance. Furthermore, Haynes and Beare (1996) also made known that stabilization within large macroaggregates was favoured by the binding actions of soil humic substances, polysaccharides and fungal hyphae. Loveland and Webb (2003) found that addition of cattle and dairy manure increased aggregate stability. Emerson (1977) also observed that organic matter stabilizes soil aggregates by forming and strengthening bonds among clay domains and between quartz particles and clay domains.

Large macroaggregates contains the most active and youngest components of soil organic carbon entering the soil (Buyanovsky *et al*., 1994). Shang and Tiessen (1998) found that in semi-arid soils, large proportions of soil organic matter exist within the macroaggregate fraction. It has been documented that organic matter can be protected from microbial attack by physical protection within stable macroaggregates (Elliott, 1986; Gupta and Germida, 1988). These materials protected within aggregates provide the particulate organic matter (POM) that acts as nucleation sites for the growth of fungi and other soil microbes (Jastrow, 1996; Angers and Giroux, 1996).

Results from this study indicated that aggregate stability within microaggregates was significantly highest in the control (Fig. 41). In other words, well decomposed compost and cattle manure applications did not significantly enhance aggregate stability in this fraction relative to the control and NPK plots. Indeed, this was an unexpected result. It can however be said that, tillage especially during the incorporation of the compost and cowdung may have resulted in microaggregate destabilization. Thus, mode of application (surface applied or incorporation into soil) should be further investigated under the conditions of this study to ascertain its effects on aggregate stability within this fraction.

Texture of the soil was almost similar to pre-plant soil analysis result (Table 20). This gives an indication that the soil structure was already affected since the land had been used for the past decade. The percentage contribution from the silt and clay fraction to the total weight of the soil was relatively low. This may have been due to the small proportion of the silt and clay fraction of the total soil (clay content $< 10\%$).

5.9 Effects of soil amendments on soil microorganisms

Much research has been done on how plants respond to different methods of soil treatment to improve soil fertility in the tropics, especially methods involving residue management that will improve the soil environment by ecologically and economically feasible means (Palm *et al*., 2001). However, little is known about how microorganisms in tropical soils respond to such methods of improving maize yields (Grimsby, 2005). Bastida *et al*. (2008) reported that although the application of organic amendments is considered a suitable tool for improving soil fertility, few studies have been conducted in semi-arid climates to evaluate the joint effect of such practice on the structure and function of the soil's microbial community. An understanding of microbial processes is therefore important for the management of farming systems, particularly those that rely on organic inputs of nutrients (Smith and Paul, 1990). In this study, it was observed that bacteria counts on all organically amended plots (composts, cowdung) were higher than the control and NPK plots (Fig. 42). The decrease in bacteria numbers in the control and NPK treated plots relative to the organically amended plots may have been due to decreased soil organic matter content since heterotrophic microorganisms depend on this as a carbon and food source. Thus, the addition of the organic materials may have caused an increase in the growth of bacteria, because they must digest the heavily degradable cellulose and lignin to make it available to the plants. This has confirmed works by Bulluck *et al*. (2002), Freitas *et al*. (2003), Martyniuk and Wagner (1978) and Min *et al*. (2003) who reported that soil microbial populations increased as a result of organic amendments, compared to soils which received only inorganic fertilizers. They found that additions of cattle manure and hay-manure compost positively affected soil microbial populations and activity compared to those soils which used inorganic fertilizers. They also found that although inorganic fertilizer additions to soil had a positive effect on soil microbial populations, the effect was more noticeable in soils amended with manure.

Grimsby (2005) explained that when inorganic fertilizer is added to a soil poor in organic matter and carbon is the growth limiting factor for the microbial community, the heterotrophic bacteria would theoretically not benefit from the added nitrogen and phosphorus. Thus, the added mineral fertilizer therefore was used by autotrophic plants, and not of benefit to the microflora. On the whole, the 2:1 compost applied at 5 t/ha treated plots had 5% more bacteria counts than the 1:1 compost applied at 5 t/ha. The relatively higher bacterial abundance on the 2:1 compost amended plots may be due to its relatively high C: N ratio (Table 5).

Fungi populations in the control and NPK treated plots were higher than the organically amended plots (Fig. 42). This may have been due to effects of tillage on fungal populations. The rhizosphere of the control and NPK treated plots from where fungi were extracted were not tilled prior to application of treatments unlike the organic amendments which were buried. It has been observed that tillage reduces organic matter content (Balesdent *et al*., 1999) and soil microbial populations (Ibekwe *et al*., 2002). Grimsby (2005) indicated that large scale monoculture farming with mineral fertilizing in temperate climate has shown a decrease in the quantity of fungi in the soil, and has also caused the diversity of microorganisms to decrease in agricultural land subject to this treatment. Gimbsy (2005) concluded that the relative decline in microbial life is suspected to be a result of the continuous working of the soil, destroying aggregates and stopping efficient gas flux. Decrease in content of soil organic matter may also be a contributing factor, since heterotrophic microorganisms depend on this as a carbon source. Lalfakzuola *et al*. (2008) observed that, number of fungi was significantly greater in the control, NPK and NPK + FYM plots than FYM treatment and maximum fungal number was noted on control plots. Vineela *et al*. (2008) counted more fungi under inorganic treatments relative to organics and indicated that change in rhizosphere soil pH may be a cause for such variation. Vineela *et al*. (2008) concluded that highest bacteria counts were found on combined organic and inorganic whiles the highest fungal counts were found with recommended NPK fertilizers. This shows the importance of studying separately fungi and bacteria in order to determine precisely the response of microbial communities after soil amendment. In this study, the two groups of microorganisms exhibited different reactions to the treatments.

Microbial biomass has been suggested as an integrative signal of the microbial significance in soils because it is one of the few fractions of soil organic matter that is biologically meaningful, easily measurable and sensitive to management (Powlson, 1994). Wani *et al*. (2003) reported that although microbial biomass represents a small percentage of soil organic matter, it plays a significant role in nutrient cycling and ecosystem functioning because it is labile and dynamic in nature. Tetteh (2004) concluded that microbial biomass was a better indicator of soil fertility than total soil organic matter.

Statistically, the results of this study indicated that soil microbial biomass N of all treatments under consideration were at par (Fig. 47) as at the end of the third cropping season. The lack of differences in microbial biomass N among the treatments may have been due to the time of sampling which was beyond the initial flush of decomposition. Manna *et al*. (2007) observed that microbial biomass N was subject to time of sampling and reported highest values accumulated at the tillering stage and the lowest at the dough stage of maize. Tetteh (2004) indicated that sudden changes in moisture, temperature and organic matter can also be a contributory factor to the rapid changes in microbial activities. Other authors (e.g. Goyal *et al*., 1992; Agbenin and Goladi, 1997) have indicated that manure application favourably influenced soil microbial biomass N.

The increased biomass C on cowdung amended plots may be the result of increased microbial populations and activity, therefore suggesting a relatively better stability of organic carbon in this treatment (Fig. 46). This has confirmed other reports that manure applications typically result in increased soluble C in soil (Gregorich *et al*., 1998; Liang *et al*., 1998). Microbial biomass carbon under NPK plots was not significantly different from the control. Correspondingly, Lalfakzuola *et al*. (2008) revealed that fertilizer treatments (inorganic and organic) showed insignificant variation ($P \leq 0.05$) i n microbial biomass carbon when compared to control plots. Masto *et al*. (2006) reported that microbial biomass carbon was low in the control and unbalanced fertilizer treatments and increased significantly with manure and optimum NPK application. Similar results have been reported by several other workers (Goyal *et al*., 1992; Chakrabarti *et al*., 2000; Kaur *et al*., 2005). Kaur *et al*. (2005) observed microbial biomass carbon tended to be smaller in unfertilized soils or those fertilized with chemical fertilizers compared to soil amended with organic manures. Contrastingly, in the present investigation microbial biomass carbon of the control was higher than the compost amended plots. The reduction in microbial biomass under the two compost types and NPK relative to cowdung might be due to high levels of mineral N availability (Lovell *et al*., 1995), changes in substrate quality and root growth and the build-up of recalcitrant compounds. The results of this study further suggest that both compost types lowered the amount of soil microbial biomass carbon. Ananyeva *et al*. (1999) observed that a decrease in microbial biomass carbon implies a decrease in total microbial biomass. It was not clear why microbial biomass P of the control treatment was significantly higher than the compost and NPK amended plots (Fig. 48). This is because, a significantly higher amount of microbial phosphorus in the control implied that greater amounts of phosphorus was held by microbes and less P adsorbed by the highly reactive surfaces of Al and Fe oxides and hydroxides.

Several previous reports (Sparling, 1997; Anderson, 2003; Fließbach and Ma¨ der, 1997; Ma¨der *et al*., 2002; Marinari *et al*., 2006) support microbial quotient as a valuable soil index. Many authors (Insam and Domsch, 1989; Sparling, 1992) have suggested that the microbial quotient indicates changing soil processes and soil health, and is a more useful measure than either microbial biomass carbon or total organic carbon. The highest and the lowest values of microbial biomass carbon/soil organic carbon ratio were associated with cowdung and 1:1 compost at 5 t/ha amended plots respectively (Table 22). The reduction in microbial quotient under the compost types relative to cowdung is indicative of a shift in the state of equilibrium of the soil system, and is consistent with Anderson and Domsch's (1990) predictions that microbial biomass C/organic C ratio eventually declines in conditions where organic matter input is low, and suggests that the microbial quotient can be used as an indicator of changes in organic matter availability. Furthermore, the considerable increase of microbial quotient under cowdung amended plots was probably due to the available carbon fraction still present in the soil as at the time of sampling. Saggar *et al*. (2001) explained that generally microbial quotient will increase in soils with enlarged pool of soil organic carbon. Moreover, the increase reflects organic substrates availability for microbial growth (Anderson, 2003). A lower microbial quotient suggests a better use of the available organic substrates. Ma¨der *et al*. (2002) suggested that a decrease of the microbial quotient was related to a significant increase of microbial diversity in soil because a diverse microbial community is able to better transform C from organic debris into biomass.

CHAPTER SIX 6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

The primary aim of this study was to evaluate management practices that can improve the quality of manure (cowdung) through composting with *Stylosanthes guinensis*.

i. A preliminary survey in all the districts of the Upper East region of Ghana was conducted to seek information on manure production, its management and usage. Cowdung samples were collected from the survey area and composted. The resultant composts (1:1 and 2:1 types) were chemically, physically and microbiologically analyzed in the laboratory and assessed under a field trial to test their effects on crop yield. Decomposition rates and nutrient release characteristics of the composts were also evaluated under laboratory and field conditions.

ii. This study has shown that majority of farmers in the Upper East region of Ghana use cowdung as a principal nutrient source due to its abundance. The dung is mostly collected from the compound, where the animals are kept during the night. During the day, the animals graze large remote areas, complicating the collection of dung. The manure is spread on the field prior to sowing, but the amount of manure applied decreases with increasing distance to the farmlands. It was observed that, nitrogen losses up to 100% were sometimes obtained by the time the dung was incorporated into the soil. The main pathway for nutrient losses, especially N in the dung was through leaching from open solid manure storage.

iii. Most farmers in the survey area produced compost for their own use. However, not many farmers understand what composting encompasses and there is a general inadequacy of knowledge on some of the composting methods in use. The consequence is that farmers tend to lose interest in the composting technology especially when no net benefit is derived.

iv. Under controlled laboratory conditions, the 1:1 and 2:1 composts showed net N and P immobilizations during the first two weeks of incubation. On the other hand, net Ca and Mg mineralization were observed over the same period. Peak total N mineralization rates for the 1:1 and 2:1 compost types were observed on the 6^{th} and 4^{th} week of incubation respectively.

v. C: N ratio for the 1:1 and 2:1 composts during the decomposition studies declined steadily up to the end of the 8^{th} week suggesting that composting was an effective way of converting high C: N ratio materials into a fertilizer and soil organic matter amendment. There was a positive correlation between the C: N ratio and the amounts of N and P mineralized from both compost types, an indication that C: N ratio influenced the release of N and P at different stages of decomposition.

vi. The 1:1 and 2:1 composts influenced the physico-chemical properties of the soil at the end of the third cropping season as follows:

- nitrogen and phosphorus contents of the compost amended plots were significantly higher than the control.
- mean soil nitrogen and phosphorus contents were low and moderate respectively for both compost types. A residual test on phosphorus availability indicated that

phosphorus level on 2:1 compost at 5 t/ha plots was 41% more than on 1:1 compost amended plots at the same application rate.

vii. A t - test (5%) indicated that at 3 t/ha application rate of the 1:1 and 2:1 composts, 1:1 compost performed better than 2:1 compost in terms of maize grain yield (Appendix 8a). This therefore provides the statistical evidence that at 3 t/ha rate of both compost types, maize grain yield is best supported by 1:1 compost. Maize grain yields obtained from both compost types compared very well with full rates of the NPK fertilizer. In all the three cropping seasons, combined rates of the compost and NPK fertilizer produced grain yields relatively higher than sole treatments from each.

6.2 CONCLUSIONS

From the preliminary survey, various analyses and interpretation of data on decomposition rates and nutrient release characteristics of the compost as well as crop performance, the following conclusions were drawn:

i. Losses from manure especially through leaching can be reduced by roofing the stall and prevented by hard flooring. Volatilization of ammonia can be minimized by using straw to absorb ammonia from freshly excreted faeces and urine.

ii. A striking feature of the cowdung sampled during the survey was the wide range of nutrient concentrations confirming the null hypothesis of this study that animal management, feed and feeding practices have significant impact on the quality of excreta.

Hence, at the small holder level where farmers feed their cattle on a free range system as was observed in the study area, the focus should be geared towards manure management.

iii. Managing manures through composting can enhance the fertilizer value. The composting process and the organic materials that are added determine the quality of the final manure and, it has been established that *Stylosanthes guinensis* can be used in improving the quality of cowdung. Furthermore, the fact that maize grain yields obtained from both compost types compared very well with full rates of the NPK fertilizer emphasizes the benefit of composting cowdung with *Stylosanthes guinensis*.

iv. Under field conditions, no immobilization of N and P should be expected from both compost types. This is an important finding in areas, such as Ghana, where most soils fix large quantities of P due to their high contents of Al and Fe oxides and hydrous oxides. The establishment of time for peak mineralization must guide management for timing of compost application to avoid immobilization coinciding with peak demand for plant N. This study has thus added to knowledge on peak N release and time of application for both compost types such that nutrient release and time of maximum nutrient uptake can be synchronized.

v. The positive influence of the two composts on the physico - chemical properties of the soil suggests that regular applications could result in the long – term improvement of the productivity of the experimental site.

vi. It has been confirmed that, to derive maximum benefits from both compost types it may have to be applied in combination with experimentally determined amounts of mineral fertilizers. However, a long – term investigation is necessary to establish the continued effects of the composts on the productivity of the experimental soil.

6.3 Recommendations for further study

i. Studies need to be carried out with a comprehensive range of potential organic materials for composting can be characterized and a guide developed on how smallholder farmers can create ideal compost mixes. Once the organic materials have been characterized, the mix ratio should be determined as mass or volume of each organic material (e.g. number of buckets of each material to be mixed).

ii. There is the potential to further improve on the quality of compost produced from the composting methods reported in this study. This can be achieved by improving the aeration, moisture regimes, temperature and C: N ratio of the compost heap. It is essential that predictions of compost quality and fertilizer value are tested in crop response trials under different agroclimatic conditions.

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APPENDICES

Appendix 1. Questionnaire used during the survey in the Upper East region

1. Location…………………………………………………………………..………..
2. Gender: Male [ ] Female [ ]
3. Level of Education:
   i) Illiterate [ ] ii) Primary [ ] iii) Middle [ ] iv) Secondary [ ]
   v) Commercial / Technical / Vocational [ ]
   vi) Others, specify…………………………………………………………………
4. Marital status:
   i) Single [ ] iii) Separated [ ] ii) Married [ ] iv) Divorced [ ]
5. Family size:
   i) < 5 [ ] ii) 5 – 10 [ ] iii) 6 – 15 [ ] iv) 16 – 20 [ ] v) > 20 [ ]
6. Ethnicity………………………………………………………..…………….………
7. Religion:
   i) Christian [ ] ii) Moslem [ ]
   iii) Traditional [ ]
   iv) No religion [ ]
   v) Others, specify…………………………………………………………..……

8. Age: (i) 16 – 25 [ ] (ii) 26 – 35 [ ] (iii) 36 – 45 [ ]
(iv) 46 – 55 [ ] (v) 56 – 65 [ ] (vi) Over 66 [ ]
9. Main occupation/income source…………………………………………………………..
10. Other secondary occupation……………………………………………………………….
11. Do you use any farm implements?
Yes [ ] No [ ]

12. If yes, source;
i) Own [ ] ii) Family [ ] iii) Hire [ ] iv) Other(s), specify…………………………………………………………………….
13. If hired,

Type(s) of implement(s)	Number(s)	Amount paid (GH¢)

14. Do you own cattle?
Yes [ ] No [ ]
15. If yes

No. of cattle	Breed	Bedding used	Type of food	Type of housing	Type of roof

16. How long have you reared cattle?
i) < 5 years [ ] ii) 6 – 10 years [ ] iii) 11 – 15years [ ] iv) 15 – 20 years [ ] v) > 20years [ ]
17. How do you feed cattle?
i) Purchased concentrate [ ]
ii) Grazing [ ]

iii) Housed and feed [ ] iv) Other(s), specify…………………………………………………………………….

18. What is the main purpose for rearing cattle?

i) Sale [ ] ii) Meat [ ]

iii) Milk [ ] iv) Source of labour v) Manure vi) Other(s), specify…………… ………………… ………………… ………………….

19. Have you received any form of tanning with regards to cowdung use:

Yes [ ] No [ ]

20. If yes, source of training

i) NGO's [ ]

ii) MOFA / Extension staff [ ] iii) Friends/Family [ ] iv) Other(s) specify……………………………………………………………………..

21. Do you use other types of manure apart from cowdung?

Yes [ ] No [ ]

22. If Yes, specify the type used…………………………………………………………

23. If No, specify reason for not using……………………………………………………..

24. Do you always get the quantity of cowdung needed?

Yes [ ] No [ ]

25. How often do you collect cowdung from kraal?

i) Daily [ ] ii) Once a week

iii) Twice a week [ ]

iv) Once a month

v) Other (s) specify…………………………………………………………………….. 26. How do you store/keep cowdung?, specify………………………………………

27. By what means do you bring cowdung onto the farm?

i) Self/family [ ] ii) Transport [ ] iii) Others specify…………………………………………………………………….

28. What type of labour do you use in your farming activities?

i) Self [ ] ii) Permanent [ ] iii) Family [ ] iv) Hired [ ] v) Others [ ]

29. Which crops do you apply cowdung it to?

i) Root crops [ ] ii) Vegetables [ ] iii) Tree crops [ ]

iv) Cereals [ ]

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

30. What is the size of your farm ………………………………………………………….

31. How much cowdung do you apply per bed/plot/piece of land…………………………

32. Do you use compost

Yes [ ] No [ ]

33. If yes, how long have been using it…………………………………………………….

34. Do you always get the quantity need

Yes [ ] No [ ]

35. Do you pay for it?

Yes [ ] No [ ]

36. If No, would you be willing to buy such a product.

Yes [ ] No [ ]

37. What materials do you use in composting?

List …………………………………………………..

…………………………………………………….

…………………………………………………….

38. What are the constraints associated with the use/no use of under listed materials?

Constraints	**Poultry**	**Cowdung**	**Household refuse**
Acquisition			
Labour			
Collection			
Finance			

Application			
Health hazards			
State of decomposition			
Other(s) specify			

39. What are your views on using:

i) Cowdung for crop production.

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

ii) Synthetic fertilizer

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

40. Any other comments?...

Appendix 2. Demographic features of respondents

Respondents	Frequency	Percentage (%)
Family size		
<5	30	15
5 – 10	148	74
6 – 15	12	6
16 – 20	6	3
>20	4	2
Level of education		
Illiterates	156	78
Primary	2	1
Middle	12	6
Secondary/tertiary	30	15
Ethnicity		
Frafra	50	25
Kasena	40	20
Kusasi	34	17
Fulani	26	13
Sisala	2	0.9
Others	48	24
Occupation		
Farming	188	94
Others	12	6
Years of cattle rearing		
<5	10	5
6 – 10	12	6
11 – 15	20	10
15 – 20	136	68
>20	22	11
Main reason for cattle rearing Sale		
	4	2
Meat	8	4

Milk	6	3
Labour	14	7
Manure	168	84
Religion Christians		
	60	30
Moslems	132	66
Others	8	4

Total number of respondents = 200

Appendix 3. Respondents' assessment on manure management

Respondents	Frequency	Percentage (%)
Housing floor		
No bedding	72	36
Bedding	128	64
Bedding material Straw		
	68	34
Grass	14	7
Sawdust	14	7
Others	104	52
Manure storage		
Inside kraal	114	57
Heaped outside	82	41
Composted	4	2
Sources of training on manure usage		
NGO's	64	32
Friends/family	104	52
Others	32	16
Manure usage Sale		
	2	0.9
Application onto farms	168	84
Fuel	26	13
Others	4	2.1
Mineral fertilizer usage Sole		
NPK	40	20
Cowdung + NPK	72	36
Others	88	44

Total number of respondents = 200

Appendix 4. Respondents' assessment on composting

Respondents	Frequency	Percentage (%)
Knowledge		
Yes	98	49
No	98	49
Scarcity of materials	4	2
Time of compost preparation		
Major rainy season	180	90
Minor rainy season	16	8
Anytime (based on available material)	4	2
Method of compost preperation		
Heap	116	58
Pit	80	40
Mud	4	2
Mode of compost application		
Spot	44	22
Broadcast	148	74
Spraying	8	4

Appendix 5. Respondents' willingness to use compost

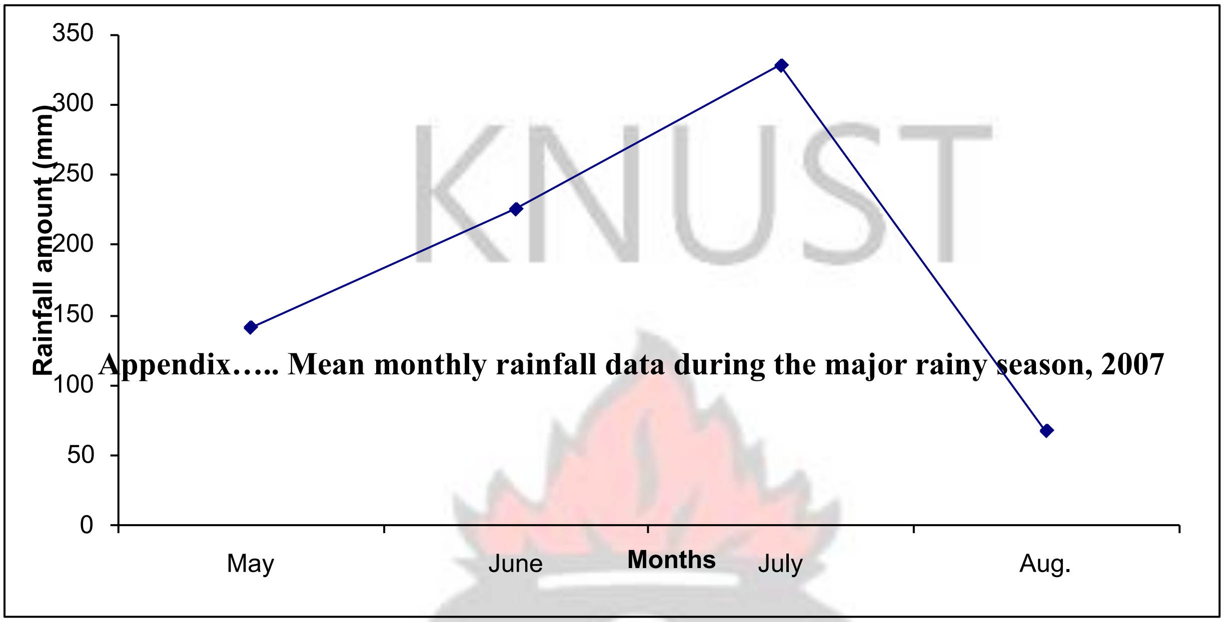
Perception	Frequency	Percentage (%)
Willing	84	42 6
Not willing	12	52
Indifferent	104	
Total	**200**	**100**

Appendix 6. Selected chemical properties of fresh and heaped cowdung samples from the Upper East region

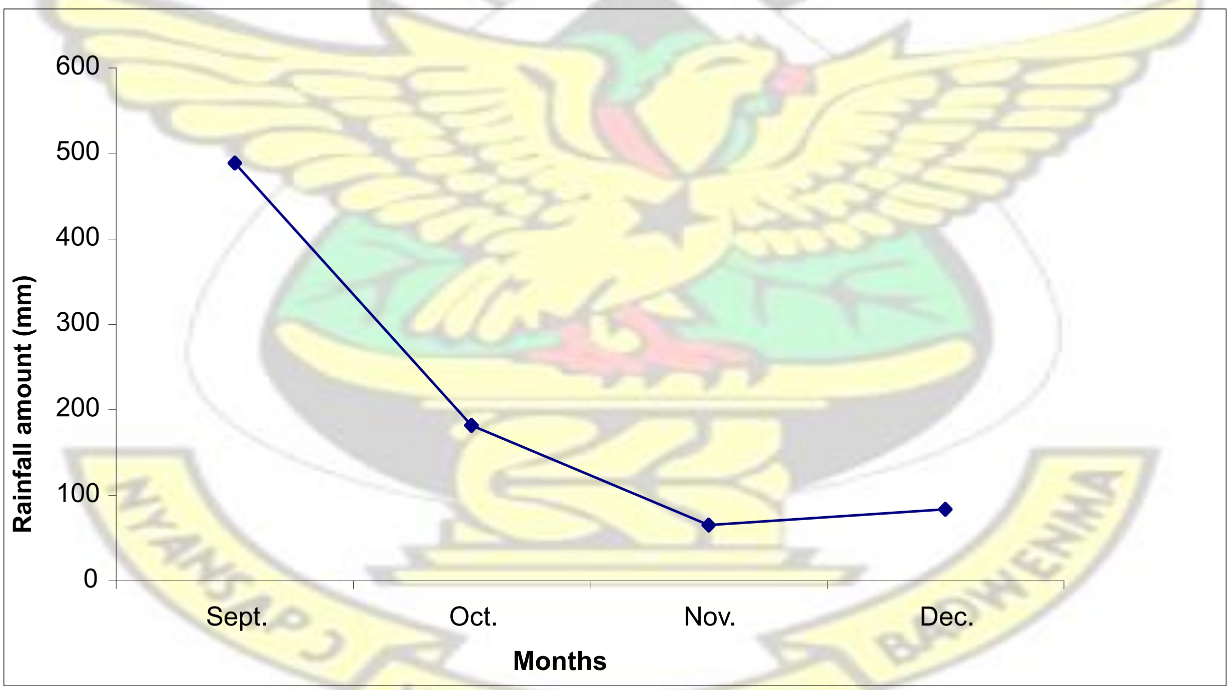
LOCATION	N	P	K	Ca	Mg	Ash	Org. M	Org. C	Polyphenols	C:N Ratio
	%									
Zebilla	1.01(0.34)	0.37(0.13)	0.38(0.16)	0.69(0.50)	0.59(0.20)	30.20	61.00	30.50	2.44	30.20
Kasena Nankana	1.14(0.47)	0.28(0.19)	0.22(0.48)	0.41(0.53)	0.72(0.22)	22.37	51.00	25.50	2.44	22.37
Builsa	0.60(0.27)	0.44(0.23)	0.34(0.25)	0.49(0.68)	0.81(0.42)	50.83	61.00	30.50	2.90	50.83
Bawku	1.14(0.35)	0.32(0.39)	0.46(0.70)	0.59(0.61)	0.94(0.35)	22.81	52.00	26.00	2.25	22.81
Bongo	0.27(0.57)	0.50(0.79)	0.34(0.92)	0.61(1.54)	1.00(0.65)	99.85	53.91	26.96	2.58	99.85
Bolgatanga	0.52(0.07)	0.76(0.48)	0.46(1.54)	0.37(3.52)	0.84(2.24)	57.69	60.00	30.00	1.45	57.69
Garu Tempane	0.60(0.37)	0.35(0.30)	0.26(0.52)	0.54(0.35)	1.12(0.86)	31.69	38.00	19.00	1.60	31.67
Mean (N = 7)	**0.75(0.35)**	**0.43(0.36)**	**0.35(0.65)**	**0.53(1.10)**	**0.86(0.71)**	**45.06**	**53.84**	**26.88**	**2.24**	**39.93**
Standard deviation	**0.34(0.17)**	**0.16(0.22)**	**0.09(0.47)**	**0.11(1.13)**	**0.18(0.72)**	**7.56**	**8.19**	**4.10**	**0.53**	**27.83**

- Values in brackets represent heaped cowdung samples on farmer's fields after one year decomposition.

Appendix 7. Mean monthly rainfall patterns during the cropping season



7a. Major rainy season, 2007



7b. Minor rainy season, 20007

Appendix 8. Some t – test analysis

8a. T-test comparing quality of 1:1 and 2:1 compost types at 3 t/ha rate on maize grain yields, major season, 2007

Treatment	Mean yield (t/ha)	t-calc.	t-tab.
1:1 compost	4.99	2.27	2.05
2:1 compost	3.08		

8b. T-test comparing quality of 1:1 and 2:1 compost types at 5 t/ha rate on maize grain yields, major season, 2007

Treatment	Mean	t-calc.	t-tab.
1:1 compost	3.76	0.38	2.05
2:1 compost	4.08		

8c. T-test comparing quality of 1:1 and 2:1 compost types at 3 t/ha rate on maize grain yields, minor season, 2007

Treatment	Mean yield (t/ha)	t-calc.	t-tab.
1:1 compost	1.07	0.91	2.05
2:1 compost	1.75		

8d. T-test comparing quality of 1:1 and 2:1 compost types at 5 t/ha rate on maize grain yields, minor season, 2007

Treatment	Mean	t-calc.	t-tab.
1:1 compost	1.79	0.76	2.05
2:1 compost	2.29		