SOIL FERTILITY AND MICROBIAL BIOMASS CARBON, NITROGEN AND PHOSPHORUS DYNAMICS UNDER DIFFERENT AMENDMENTS AND CROPPING SYSTEMS IN GHANA

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

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Vincent Logah

February, 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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Prof. E.Y. Safo

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February, 2009

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

Organic and inorganic amendments are used by growers to ensure productivity of cropping systems in Ghana. However, there is dearth of information on how soil biochemical properties are affected by these amendments and cropping systems over time. This study focused on the effect of soil amendments on soil organic carbon (SOC), microbial biomass, total nitrogen, available phosphorus and exchangeable cations, etc. during cropping cycles in the semi – deciduous forest zone of Ghana. It also involved monitoring and modelling rates of mineralization of N over time.

A field experiment was conducted in 2006 and 2007 at the Central Agricultural Station, Kwadaso near Kumasi. The field experiment was a split plot arranged in a randomized complete block design with three replications. Three different amendments (poultry manure, poultry manure + chemical fertilizer, chemical fertilizer) and a control constituted the sub-plots whereas selected cropping systems (continuous maize, maize/soybean intercrop and maize/cowpea rotation) were assigned to the main-plots. Soil samples under each amendment and cropping system were taken at 21, 42, 63 and 84 days after amendment (DAA) within each season of cropping and analysed for soil fertility parameters. The results revealed seasonal variations in the level of microbial biomass carbon, nitrogen and phosphorus. There was a buildup of biomass C over the seasons which ranged from 25 - 248 mg/kg soil in 2006 - major season to 87 - 713 mg/kg soil and 546 - 770 mg/kg soil in 2006 -.minor and 2007 - major seasons, respectively. Biomass N showed more temporal fluctuations than biomass C and constituted averagely 2.5 - 2.6 % of soil total N. The microbial biomass thus, served as a repository of soil total N under amendments and cropping systems in Ghana.

Observed seasonal rates of mineralization showed good fits of correlation ($r = 0.89^{**}$, 0.82^{*}, and 0.84^{*} in 2006 - major, 2006 - minor and 2007 - major seasons, respectively) with the predicted rates following the use of the N model. The model gave good range (26 – 41%) of median unbiased absolute percentage error (MdUAPE) between observed and predicted values. The study has added to knowledge on the mineralization of N under different amendments and cropping systems in Ghana. It has established that cropping systems have similar mineralization rates if subjected to the same amendments. Soil NO_3^- - N variation within the seasons exhibited 'Birch effect' which was characterized by immobilization in amended plots, and lower $NH_4^+ : NO_3^-$ ratios.

The research provided a systematic monitoring of soil nutrients under amendments and cropping systems in Ghana. Available P and exchangeable K levels showed general decline in all seasons of study. Results have shown that poultry manure is a good store of P and that plants' need of P could be met through its application. The study indicated higher immobilization of P than any other nutrient element (e.g. C and N) and has established that P could be immobilized at the peak of crop growth for 21 days and be released within 21 days; the release not concurring with peak nutrient demands of short - season annual crops hence the need for synchronization. Soil exchangeable K showed positive correlation ($r = 0.77^{**}$) with NH_4^+ - N. The results showed that fixed K could be released with time during a cropping cycle. The highest SOC levels were generally recorded at 63 DAA. This study has established that crop yield is a function of final SOC at harvest. Besides, it has shown that peak crop demand of N, P and K occurred at 42 DAA (i.e. 6th week). It is, therefore, recommended that application of amendments should take into consideration their peak nutrient release pattern to ensure synchrony.

CHAPTER ONE

1.0 INTRODUCTION

Soil fertility decline is a major problem confronting crop production in Ghana. This is caused by crop nutrient removal and losses through soil erosion. As a result, most of the soils are poor in the essential plant nutrients required for optimum crop growth leading to low crop yield. The often low yield by virtue of the decline thus renders many cropping systems unproductive.

Each cropping system practised in Ghana has an impact on soil fertility and microbial biomass dynamics. Grant *et al.* (2002) stated that intensification and diversification of cropping systems influence soil physical, chemical and microbiological characteristics. The presence of a large and diverse soil microbial community is crucial to the productivity of any ecosystem. This diversity is influenced by almost all crop and soil management practices, including the type of crops grown. Plants and their exudates influence soil microorganisms and the soil microbial community found near roots (Duineveld *et al.*, 1998; Ibekwe and Kennedy, 1999; Ohtonen *et al.*, 1999). Microbial biomass is seen to exert a controlling influence on the dynamics of soil organic matter (SOM) and availability of many nutrients (Magdoff and Weil, 2004). It is also frequently used as an early indicator of changes in soil chemical and physical properties resulting from soil management and environmental stresses in agricultural ecosystems (Jordan *et al.*, 1995).

Even though microbial biomass is important in the breakdown of SOM resulting in the availability of nutrients, little is known about its seasonal variation or changes with crop rotations and other agronomic practices such as intercropping (Ladd and Forster, 1988; Stern, 1993). Determination of microbial N is important for the quantification of N-dynamics in agricultural ecosystems because it controls soil organic N availability and loss, especially in high input systems (Moore *et al.,* 2000). However, not much work has been done on microbial biomass C, N and P as affected by amendments and cropping systems. The few works done were centered on only one or two cropping systems in temperate climates, results of which may be of limited importance and applicability in a tropical environment like Ghana.

Tulu (2002) indicated that different crops remove different amounts of mineral nutrients from the soil. In this regard, the practices of mixed cropping, crop rotation, continuous cropping, among others, deplete the soil of essential plant nutrients in varying quantities depending on the nutrient demand of crops. If the nutrient removal rate is not balanced by soil amendments aimed at nutrient management and soil fertility maintenance, the soil gets poor and productivity is drastically reduced. This is the normal trend in Ghana. Fertilizer application and other soil amendments are carried out without taking into consideration the nutrient removal pattern of crops grown and the impact of commonly practised cropping systems on general soil fertility. This is due to lack of information or data in the area. The consequence is either under-application of soil amendments (normally chemical fertilizers) which do not meet the nutrient requirement of crops or over-application of chemical fertilizers, which are expensive. Chemical fertilizers are expensive and if farmers can use exact amount of what is required, then farming will be cheaper (Tulu, 2002). It is recognized that the productivity levels of cropping systems cannot be increased and sustained if current practices such as over- or under-application of nutrients are continued (Arihara, 2000). It is therefore, very important to study how soil fertility and microbial biomass change with different cropping systems since this will help plan soil amendment practices. According to Grant *et al.* (2002), sustainability of cropping systems requires that nutrients removed from the soil be balanced by nutrient replacement. This however, cannot be achieved unless the trend of change or dynamics of crop nutrients in the various cropping systems is understood.

Working on the hypothesis that significant differences would be observed between the effects of amendments and cropping systems on general soil fertility and microbial biomass, the objectives of this study were to:

i. monitor soil organic carbon as affected by amendments in the various cropping systems.

ii. examine the effect of the selected cropping systems on mineralization of N.

iii. investigate the pattern of change of microbial biomass C, N and P with time under the amendments.

iv. determine the effect of amendments on essential plant nutrients (N, P, K, Ca, Mg, etc.) in the soil over time.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 What is soil fertility in crop production?

Soil fertility can be defined as the nutrient supplying ability of the soil. According to Follet *et al.* (1987), soil fertility means the capability of the soil to supply nutrients that enhance plant growth. Although the term is normally confused with soil productivity, there is a clear-cut difference between the two, in that soil productivity is the soil's ability to produce a crop. Productivity is a function of a soil's natural fertility plus nutrients added as fertilizer, organic residue and other sources; soil physical and biological properties; climate; management and other non-inherent factors used to produce crops (Follet and Wilkinson, 1985).

Soil fertility plays such a key role in the productivity of cropping systems that its decline has become a major biophysical constraint to crop production in the West African sub - region including Ghana. Ranamukhaarachchi *et al.* (2005) stated that soil fertility decline often threatens food production, inducing poverty in developing countries. From the record of past achievements, history shows that civilization and fertility of a soil are closely interlinked. The flourished civilization of the Mesopotamians, Babylonians, Asorians, etc, declined as the fertility of their soils had declined (Tulu, 2002). According to Rahman and Ranamukhaarachchi (2003), soil fertility often changes in response to land use systems and land management practices. Saleque *et al.* (2004) found that increase in cropping intensities enhanced nutrient mining from the soil, because nutrient removal by crops has exceeded annual replacement with fertilizers. Intensive cropping promotes high levels of nutrient extraction from the soil without providing opportunities for natural regenerating processes (Narang *et al.,* 1990). According to Maciaszek *et al.* (1987), the use of legumes in rotation with non - legumes helps restore soil productivity. However, modern agricultural systems have caused progressive degradation of soil structure and depletion of soil fertility due to reduction in soil organic matter (Masciandaro *et al.,* 1997).

In Ghana, farmers do not choose cropping systems to maintain the fertility status of soils. It is the market situation and price that often dictate the selection of crops, which is mainly to raise family incomes. This situation, when continued will eventually affect the sustainability in agricultural production in a given land (Ranamukhaarachchi *et al.,* 2005). Already, most Ghanaian soils contain low organic matter of less than 1.0 % (NSFMAP, 1998) which is inadequate to sustain crop production. Above all, most of the soils are developed on thoroughly weathered parent materials. They are old and have been leached over a long period of time (Benneh *et al.,* 1990) and are therefore of low inherent fertility (NSFMAP, 1998). Based on these facts, it is obvious that soil fertility decline in Ghana would be on the increase if pragmatic actions are not quickly taken to curtail this menace.

In order to improve the productivity of cropping systems so as to arrest the worsening economic conditions in the country, there is the need to study nutrient dynamics in the various cropping systems. The knowledge of soil fertility variation in different cropping systems provides a strong foundation for sustainable agricultural production (Ranamukhaarachchi *et al.,* 2005). Anderson *et al.* (1997) reported that cropping systems have different effects on soil properties and thereby governing the soil conditions. This is partly due to the nature of nutrient uptake by the different crops (BARC, 1997). The present challenge is to sustain soil fertility in cropping systems operating at high productivity.

2.2 Cropping systems

The role of cropping systems in agricultural production is becoming increasingly important. Thus, for a developing country like Ghana to boost its food production so as to meet the demands of the increasing population, attention needs be given not only to the enhancement of productivity of cropping systems but to their sustainability as well. While developed countries are mainly concerned about the adverse impacts of intensive cropping systems on the environment (soil, water and air) and society (rural displacement, urban sprawl, etc.), developing countries are confronted with an ever growing demand for agricultural production, besides needing to sustain their already fragile resource base (Sanchez *et al*., 1997; Smaling *et al.,* 1997).

Among the cropping systems practised in Ghana, crop rotation, continuous cropping and bush fallowing, and intercropping/mixed cropping are the most dominant. These cropping systems, however, differ from one land use system to the other (NSFMAP, 1998) and are often characterized by low crop yield due to low soil fertility. Given the widespread prevalence of nutrient stresses worldwide, a thorough understanding of acquisition, utilization and recycling of both organic and mineral forms of nutrients at the level of the cropping system is essential (Arihara, 2000).

2.2.1 Crop rotation

Crop rotation is the practice of growing a sequence of different crops on the same piece of land. Long-term studies indicate that crop rotation, in conjunction with other fertility management practices, is fundamental to long-term agricultural productivity and sustainability (Mitchell *et al.,* 1991; Aref and Wander, 1998). The impact of crop rotation on soil quality and plant health and productivity has been reviewed previously (Francis and Clegg, 1990; Bullock, 1992; Thurston, 1992). According to Hall and Nasser (1996), crop rotations remain one of the most important disease management strategies available in many cropping systems. However, some reviews have discounted the importance of crop rotation for disease management (Karlen *et al.,* 1994; Cook *et al.*, 1995; Weller *et al.*, 2002).

In maize/cowpea rotations, cowpea has been reported to potentially contribute considerable amounts of nitrogen to succeeding crops (Sanginga *et al.,* 1996). According to Kombiok *et al.* (1997), maize yielded 3 t/ha more when it followed cowpea than when it followed maize or sorghum in a rotation. Crops grown in rotation affect soil fertility and often have higher yields than those grown in a monoculture (Anderson *et al.,* 1997). Relative to continuous production, cereal yield benefits are realized when cereals are planted in rotation with legumes (Clegg, 1992; Copeland *et al.*, 1993). In the U.S Corn Belt, continuous corn has repeatedly resulted in lower yields than corn in rotation (Anderson *et al.*, 1997). According to Adetunji (1996), maize grain yields were significantly increased when cowpea was rotated with maize as compared with continuous maize.

2.2.2 Continuous cropping and bush fallowing

In continuous cropping systems, lands are cultivated year after year. It is the commonest practice where there is acute land 'hunger' due to the rapid increase in population. It has been reported that continuous cropping results in lower exchangeable Ca, K, Mg (Riffaldi *et al.*, 1994; Juo *et al.*, 1996), organic C, total N contents and enzyme activities (Riffaldi *et al.*, 1994) and effective cation exchange capacity (Juo *et al.*, 1996) than those under natural bush and planted fallow. Surface soil under continuous maize cultivation also results in soil acidification (Juo *et al.*, 1996) compared with the fallow plots as depicted by lower pH values and greater exchangeable Al and Mn. Bell *et al.* (1995), in addition to soil acidification and depletion of soil K, observed depletion of Zn, organic C and total N in soil under long - term cropping of peanut, soybean and maize in the summer, and wheat in the winter. Kabeerathumma *et al.* (1993) reported decrease in soil available Zn and Cu under continuous cropping of cassava with fertilizer treatment alone, while farmyard manure had the reverse effect. Bell *et al.* (1995) observed significant reduction in crop growth (50 - 100 %) and yield when they compared sites continuously cropped with peanut, soybean and maize in the summer, and wheat in the winter with sites which had never been cropped.

2.2.3 Intercropping/ mixed cropping

Intercropping is a crop intensification practice whereby two or more crops are grown together simultaneously on the same field (Ofori and Stern, 1989). The crops are not necessarily sown at exactly the same time and their harvest times may be quite different, but they are usually grown together for a significant part of the growing period (Willey, 1979). Under situations of crop failure due to considerable intercrop competition, sole cropping could often give greater stability (Harwood and Price, 1975). However, the predominance of intercropping in lower rainfall high risk areas leaves little doubt about the possibilities of improved stability in crop yield and income (Jodha, 1976). Over many generations, low-external-input farmers particularly in the tropics have learnt to manage and sustain their production systems without a substantial effect on the environmental resource base. The role of intercropping as a means to enhance agricultural production and productivity has become paramount since agricultural land is a diminishing quantum (Midmore, 1993). Greater nutrient uptake by intercropping has been shown by several workers, for example, N (Adu - Gyamfi *et al.,* 1997; Barik *et al.,* 1998; Sakala, 1998), K, Ca, and Mg (Dalal, 1974). This has very often been claimed as the basic cause to determine whether greater uptake was the cause of or the effect of greater yields. Apart from the possible differences in rooting pattern and vertical root distribution, the mechanisms by which nutrient uptake is increased are far from clear. One possibility is that, even where growing periods are similar, component crops may have their peak demands for nutrients at different stages of growth, a temporal effect which may help to ensure that demand does not exceed rate at which nutrients can be supplied (Alhassan, 2000). However, differences in competitive abilities of component crops for soil N may stimulate N fixation (Rerkasem *et al.,* 1988).

In maize/soybean intercropping system, Dalal (1977) reported that grain yield of soybean was very greatly reduced when it was planted with maize. Intercropping soybean and maize reduces the yield of the former crop considerably, but has little influence on that of the latter (Hiebsch, 1981; Chui and Shibbles, 1984). According to Francis *et al.* (1986), the total corn yield in strip intercropping of corn and soybean was between 10 and 40 % higher than corn in monocrop fields, while soybean yields were reduced between 10 and 30 % because of competition for light, water and nutrients. According to Ennin *et al.* (2002), intercropping maize and soybean reduced both maize and soybean grain yields.

2.3 Maintenance of soil fertility in cropping systems

To ensure high productivity of cropping systems, there is the need to put in measures aimed at maintaining the fertility of the soil resource base on which crop production depends. Maintaining innate soil fertility is, therefore, an urgent priority in tropical cropping systems (Arihara, 2000). According to Grant *et al.* (2004), effective nutrient management is a critical part of crop production not only to improve financial returns, but also to maintain soil quality and reduce the likelihood of damage to the environment. Howarth (2005) stated that management of nutrients to maintain productivity and quality of cropping systems is a challenge that must be met through a combination of organic amendments and management of SOM.

In Ghana, the traditional method of soil fertility maintenance by the slash – and – burn agriculture and the bush fallow system is giving way to modern technology of soil management as the population increases and land gets scarce (NSFMAP, 1998). Even though some areas of the country such as the southern and northern regions still have adequate lands for fallowing and rejuvenating declined soil fertility, the situation may not last long as a result of the tremendously increasing population. One of the efficient methods of soil fertility maintenance in the traditional agriculture is practised in the 'compound' farming system by farmers in the Guinea and Sudan savanna agro-ecologies. The areas surrounding their dwellings are intensively cultivated and soil fertility is maintained by applying crop residues, household refuse and animal manure. The practice has resulted in the build-up of relatively high soil fertility level for continuous cropping and yields from these fields are much higher than the 'distant' farms which in some cases are still under the bush-fallow rotational system (NSFMAP, 1998).

The main sources of nutrients to maintain soil fertility at Anloga in the Volta Region have been of organic origin namely: guano, poultry manure and cowdung. The application of animal manure is an important tool for an integrated nutrient management strategy because application can simultaneously increase SOM levels and supply nutrients for growth (Magdoff and Weil, 2004). The mix of faeces, urine and bedding material present in many types of animal manure generally provides a combination of recalcitrant and labile organic materials. For example, annual application of 34 Mg/ha of fresh dairy manure provided all necessary nutrients to crops and tripled SOM levels in experiments at Rothamstand (Jenkinson, 1991). The rate of SOM accumulation is usually highest in the first ten years of manure application and slows down thereafter (Sommer-feldt *et al.*, 1988). Increases are generally lower when initial SOM levels are already high. Magdoff and Amadon (1980) showed that yearly applications of 66 Mg/ha of fresh dairy manure were needed to increase SOM from 5.2 to 5.5 % over the course of 11 years on a land on which silage corn was produced using conventional tillage. Although organic amendments such as crop residues, manure or composts are essential in the sustainability of cropping systems, they cannot prevent nutrient mining entirely (Bationo *et al.*, 1998). The addition of organic amendments corresponds in most cases to a recycling process, which cannot compensate for nutrient exported through crop products. As a result, the use of external inputs such as inorganic plant nutrients is essential requirement for soil productivity. In Michigan (on Typic Hapludafs) Sanchez *et al.* (2001) compared plots under continuous corn monocropping fertilized with only NPK to plots under more diverse system consisting of corn-soybean-wheat rotation with clover cover crops and composted manure added. After 70 days of incubation, net mineralization in the rotation system soil was 90 % higher than that in the monocrop soil. Inorganic fertilizers generally enhance carbon inputs through increased biomass production but excessive application can have negative effects on active SOM and soil N pools such as microbial biomass (McCarty and Meisinger, 1997). Microbial biomass is usually lower in soils with long - term inorganic N applications than soils that have received organic amendments (Collins *et al.*, 1992). Fauci and Dick (1994) analysed soils and found that of the crops that received additional N, microbial C and N were lowest in plots with inorganic N amendment, intermediate in plots fertilized with pea vine residues and highest in manure plots. The differences were closely related to the quantity and quality of substrate added.

Moore *et al.* (2000) indicated that application of poultry manure and combinations of poultry manure with NPK fertilizer gave high residual effects on soil chemical composition and increased plant height, dry matter yield, plant nutrient uptake and grain yield of maize significantly. They concluded that residual effects of poultry manure and combined application of reduced quantities of NPK fertilizer gave higher SOM, N, P, K, Ca, Mg and micronutrients contents compared to application of 300 kg/ha 15-15-15 NPK fertilizer and control.

2.4 Microbial biomass

The microbial biomass is involved in the decomposition of organic materials and thus, the cycling of nutrients in soils. It is also frequently used as an early indicator of changes in soil chemical and physical properties resulting from soil management and environmental stresses in agricultural ecosystems (Jordan *et al.*, 1995). Although the soil microbial biomass C constitutes only 1 – 3 % of total soil C and the biomass N up to 5 % of total soil N, they are the most labile C and N pools in soils (Jenkinson and Ladd, 1981). Therefore, nutrient availability and productivity of agroecosystems mainly depend on the size and activity of the microbial biomass (Friedel *et al.*, 1996). Microbial biomass can contribute substantial amounts of nutrients in the soil (Marumoto *et al.*, 1982). Recognition of the importance of the soil microorganisms has led to the increased interest in measuring the nutrients held in their biomass (Singh *et al.*, 1989; Martikainen and Palojarvi, 1990).

In any ecosystem, the interaction between plants and microbial processes constitutes nutrient cycling. Strong positive correlations have been found between the amount of nutrients held in the microbial biomass and amounts of mineralizable nutrients held in the microbial biomass, and amounts of mineralizable nutrients in the soil (Carter and McLeod, 1987; Dalal and Mayer, 1987; Smith, 1993), indicating that nutrient cycling is closely linked to the turnover of microbial biomass. The turnover time for N immobilized in the microbial biomass was found to be about ten times faster than that derived from plant material (Smith and Paul, 1990). Soil microbial biomass is a very important reservoir of phosphorus in the soil (Oberson *et al.*, 1997). According to Morel *et al.* (1997), microbial population plays a central role in P cycling and availability. Dalal *et al.* (1991) indicated that microbial biomass is a labile source of C, N, P and S. Measurements of microbial biomass have been used to assess the effect of the different cropping systems on soil fertility (Hassink *et al.,* 1991). Anderson and Domsch (1986) and Insam and Domsch (1989) proposed that the ratio of microbial biomass C to total C in a soil may serve as a quantitative indicator of C loss or accumulation. Close relationships between total N, microbial biomass N and active N in soils have been reported by McCarty *et al.* (1995), with correlation coefficients of $r > 0.91$. In their study, Moore *et al.* (2000) observed that the highest microbial C and N contents were found in multicropping systems of oats and meadow and lowest values found in continuous corn and soybean systems.

Changes in microbial biomass C and microbial biomass N contents in response to cropping systems seem to be related to the amount and diversity of crop residues, the proportion of easily decomposable organic compounds to the soil, root density, microclimate and soil structure (Moore *et al.*, 2000). The ratio of microbial biomass C to microbial biomass N is often used to describe the structure and the state of the microbial community. A high microbial biomass C to microbial biomass N ratio indicates that the microbial biomass contains a higher proportion of fungi, whereas a low value suggests that bacteria predominate in the microbial population (Campbell *et al.*, 1991). In their study, Moore *et al.* (2000) found the microbial C: microbial N ratios of the soils from two different experimental sites to be 4.3 and 6.4 in 1996, and 7.6 and 11.4 in 1997. Temporal fluctuations in microbial biomass values have been reported as a result of variation in soil moisture and temperature, stage of plant growth and available substrate (Insam, 1990; Kaiser *et al.*, 1995; Chang and Juma, 1996). Soil and crop management practices, including crop rotations and N fertilization, can influence soil biological activities through their effects on the quantity, structure and distribution of SOM. Cropping systems with high organic matter inputs and easily available SOM compounds tend to have higher microbial biomass contents and activities because they are preferred energy sources for microorganisms (Vaughan and Malcolm, 1985). According to Magdoff and Weil (2004), changes in microbial population occur with added fertilizer and tillage. Nitrogen fertilization increased numbers of fungi and Gram negative bacteria in rhizosphere of rice (Emmimath and Rangaswami, 1971). Even though microbial biomass is important in the breakdown of SOM resulting in the availability of nutrients, little is known about its seasonal variation or changes with crop rotations and other agronomic practices such as intercropping (Ladd and Forster, 1988; Stern, 1993).

2.5 Role and dynamics of SOM/SOC in cropping systems

The SOM is composed mainly of 55 % C, 5 – 6 % N, and 1 % P and S (Howarth *et al.*, 2002). It is a large reservoir of C that can act as a sink or source of atmospheric carbon dioxide (Lugo and Brown, 1993). It is also an important source of inorganic nutrients for plant production in natural and managed ecosystems (Fritzsche *et al.*, 2002). Moreover, SOM governs structural stability and cation exchange capacity of soils either directly through its chemical structure and surface properties, or indirectly as a source of energy and nutrients for soil biota (Zech *et al.,* 1997). These effects are especially important in cultivated tropical soils, where SOM is frequently related to soil fertility and productivity (Fritzsche *et al.,* 2002). Schoenau and Campbell (1996) stated that SOM content has a large impact on both soil quality and nutrient cycling. Decomposition of SOM releases nutrient for plant uptake. Generally, 2 to 5 % of SOM decomposes annually (Paul and Clark, 1996).

The knowledge of SOM dynamics in cropping systems is very important if crop production is to be increased sustainably. Grant *et al.* (2004) indicated that changes in soil organic C are of increasing importance because organic matter can serve both as a source and sink for atmospheric C. Ayoola and Adeniyam (2006) reported contribution of roots and their exudates to organic carbon content of soil. According to Peterson *et al.* (1998), cropping intensification increased crop residue production and organic C storage in the soil. Eliminating fallow (Nyborg *et al.,* 1995) and increasing the cropping frequency increases inputs of both above - and below - ground residues to the soil (Peterson *et al.,* 1998), resulting in higher SOM content. Wienhold and Halvorson (1998) in their study demonstrated that total soil organic C content was greater under annual cropping compared with a crop-fallow system. Ridley and Hedlin (1968) showed that organic matter content was lower when corn was grown continuously (5.0 %) or rotated with wheat (5.1 %) than when cereal crops seeded with narrow spacing such as wheat (7.2 %), oat (6.3 %) or barley (6.8 %) were grown.

Changes in organic matter content may depend on the level of organic matter initially present in the soil (Grant *et al.*, 2002). In a thick Black Chernozem soil at Melfort, with high organic matter (5.3-5.8%), Campbell *et al.* (1991) could not detect differences in organic matter due to crop rotation or fertilization and suggested that it is difficult to increase SOM in a soil that already has very high organic matter content. However, in a thin Black Chernozem at India Head and with a drier Brown Chernozem at Swift Current (Campbell *et al.*, 1991), SOM content increased with extended rotations and adequate fertilization. Rate of increase in organic C will vary with available water, inherent fertility of the soil, rates of fertilizer applied and the length of time that management is imposed (Peterson *et al.*, 1998). Thus, intensification of cropping combined with reduced tillage systems and fertilizer management targeted to the production level of a cropping system can increase organic matter content and improve the quality of soils (Campbell *et al.*, 1996).

Stevenson (1982) reported trends in organic matter system dynamics. Long-term crop rotations have generally resulted in a slow decrease in organic matter content. In a study where barley was grown continuously and manure applied annually, the SOM kept increasing and still had not reached equilibrium when the experiment was terminated after 94 years (Stevenson, 1982). According to Jenkinson (1990), most of SOM in agricultural soils is degradation resistant and turns over much more slowly. The labile fraction, which plays a prominent role in soil nutrient dynamics (Parton *et al.*, 1987), and which may function as a temporal nutrient reservoir (Paul, 1984), declines with cultivation (Cambardella and Elliot, 1994), and when a fallow period is included in the rotation system (Biederbeck *et al.*, 1994).

2.6 Role and dynamics of essential plant nutrients in cropping systems

The soil supplies 13 out of the 16 elements that are known to be essential for crop growth of which N, P and K are the most commonly deficient in agricultural soils (Follet *et al.*, 1987). Each of these nutrients plays a remarkable role in plant nutrition, deficiency of which produces either visible or hidden symptoms.

2.6.1 Nitrogen

Nitrogen (N) is the nutrient that is most frequently limiting to crop production and the nutrient applied in the greatest amounts (Campbell *et al.*, 1986). It is a part of all plant proteins and a component of DNA and RNA. Nitrogen is required for assurance of optimum crop quality as protein content of crops is directly related to N supply (Grant and Flaten, 1998). It is also of major concern with regards to environmental sustainability because nitrate leaching can reduce ground water quality and N_2O emissions can contribute to the greenhouse gas effect and global warming (Campbell *et al.*, 1995).

An efficient cropping system will attempt to balance crop demands for N with timing and rate of N supply so that crop yield is optimized while N is neither over-depleted from the soil nor accumulated in quantities that results in the contamination of ground waters or surface waters (Grant *et al.*, 2002). As crop production increases, so does N removal from the system (Peterson, 1996). Therefore, total nutrient removal with continuous cropping will be substantially higher than with a fallow system. Kolberg *et al*. (1996) showed that inclusion of corn in a more intensive winter wheat-corn-fallow rotation led to greater depletion of soil N than did a winter wheat-fallow rotation, particularly at lower rates of applied N. With increased nutrient removal, responses to fertilizer application become more likely (Campbell *et al.,* 1991). For example, changing from a wheat-fallow to a wheat-corn-fallow rotation required a 44 % increase in N fertilizer inputs (Kolberg *et al.,* 1996). Therefore, in intensive cropping systems, N fertilization becomes increasingly important. Ranamukhaarachchi *et al*. (2005) studied soil N dynamics in highlands and medium highlands of Bangladesh and observed that there was no significant effect of cropping systems on soil N. They reported that the observed low N content of the soils after the study was due particularly to low organic matter content and partially to losses. Nitrogen losses mainly occur through leaching, surface runoff, denitrification and ammonia volatilization (Cai *et al.,* 2002). In their study on N losses, Bijay and Sekhon (1977) observed that losses of N in the form of nitrate occurred due to leaching with cropping systems consisting of shallow rooted crops. Crop uptake of N is relatively inefficient and often results in average losses of 50% because of leaching, volatilization or denitrification (Zublena, 1997).

2.6.2 Phosphorus

Phosphorus (P) is involved in energy dynamics of plants (Zublena, 1997). Without it, plants cannot convert solar energy into the chemical energy needed for the synthesis of sugars, starches and proteins. Phosphorus, nitrogen and other nutrients need to be available to the crop in balance to optimize crop yield and quality and efficiency of crop production (Halvorson and Black, 1985).

Cropping intensification and diversification will influence both P supply and demand in cropping systems (Grant *et al.*, 2002). Phosphorus dynamics can be affected by cropping intensification and diversification. Intensified cropping in the absence of P inputs from fertilizer or organic amendments will result in depletion of soil P. Mckenzie *et al.* (1992) evaluated the effect of cropping system and fertilizer management on P in two long-term rotation studies in Alberta. They found that without fertilizer application, continuous cropping resulted in the greatest reduction of almost all soil organic and inorganic P pools. However, when continuous cropping was coupled with the addition of N and P fertilizers, there was a positive effect of cropping on P availability (Selles *et al.*, 1995). Bowman and Halvorson (1997) reported increases in P availability under a continuous cropping system compared with wheat-fallow systems even though P inputs were generally greater in the latter system. The increased P availability was attributed to redistribution of soil P from lower depths through biocycling in residue and litter production. The type of crop grown will also influence P depletion because crops differ in their yield potential and in the amount of P removed in the harvested portion. Selles *et al.* (1995) reported that P exported from the system was higher in cereals (4.9 - 7.4 kg/ha/y) than in the lower yielding flax and lentil (3.3 - 3.7 kg/ha/y).

Increasing crop yield will increase P removal, but there may not be as great an impact on the P fertilizer requirements as there is with N because the amount of P removed by crops is small relative to the total P in most soils. For example, in the Brown soil zone in India, the soil available P has been constant over 30 years of cropping (Roberts *et al.*, 1999). The preceding crop may have an important influence on P nutrition of crops due to its effect on mychorrizal activity. The extended hyphae of the fungi can penetrate into the soil considerably further than the root hairs of the plant, thereby increasing the zone of absorption of immobile nutrients such as P. Mychorrizal interactions are important for uptake of P and Zn particularly under low fertility conditions (Kucey and Paul, 1983). Severe early growth problems can occur due to P deficiency when corn is planted on fields that were fallowed the previous year (O'Halloram *et al.,* 1986). Vivekanandan and Fixen (1991) reported that early dry matter production and P uptake were higher in a ridge planted corn-soybean rotation than in a moldboard plowed corn-fallow system, where no P fertilizer was added. Rao *et al.* (2005) indicated that knowledge of P dynamics in the soil - plant system, and especially of the short and long-term fate of P fertilizer management practices, is essential for the sustainable management of tropical agroecosystem. Although much of the phosphorus added to the soil may be fixed by chemical reactions with Fe, Al and Ca and becomes unavailable for crop uptake, the study of its dynamics is still necessary to enhance efficient management.

2.6.3 Potassium

Except nitrogen, potassium is a mineral nutrient plants require in the largest amounts (Marschner, 1995). Potassium (K) is involved in photosynthesis, sugar transport, water and nutrient movement, protein synthesis and starch formation (Zublena, 1997). It also helps to improve disease resistance, tolerance to water stress, winter hardiness, tolerance to plant pests and uptake efficiency of other nutrients.

Ranamukhaarachchi *et al.* (2005) studied soil fertility and land productivity under different cropping systems and observed that the cropping systems had no significant effects on K content in soil in both highlands and medium highlands. Srinivasa *et al.* (1999) reported a significant decline in K release due to continuous cropping. Recycling of crop residues or applications of high dose K fertilizer may provide a long-term sustainability to cropping systems (Singh *et al.*, 2002). Sadananda and Mahapatra (1972) observed in a study with different cropping systems that the exchangeable K in soils increased after potato, maize and groundnut crops whereas, it decreased after rice and jute cropping systems. Potato requires high amount of K for tuber bulking (BARC, 1997). Increases in soil K depletion have been observed in India. The categories of low and high levels of available K in soils have decreased by 0.6 % and 6.4 % respectively, while the area of the medium category increased by 7 % (Hasan, 2002), relative to data presented by Ghosh and Hasan (1980). According to Zublena (1997), K removal by crops under good growing conditions is usually high and is often three to four times that of P and is equal to that of N. In many cases where levels of soluble K in the soil are high, plants tend to take up more K than they really need (Zublena, 1997). However, it is well-known that the availability of K to plants does not only depend on the size of the available pool in the soil, but also on the transport of K from soil solution to the root zone and from the root zone into plant roots (Barber, 1995).

In Ghana, the intensity of cropping systems is presently not high enough to cause widespread K deficiency under the small holder farming situation (NSFMAP, 1998). Furthermore, the amount of K released in the ash after burning is adequate for the yield levels for the limited period of cropping. The picture, however, will change drastically when sedentary agriculture becomes the pattern of crop production and production is intensified (NSFMAP, 1998). Under such a circumstance, K management will become very important in sustaining or increasing crop yield. Proper K management requires a thorough understanding of soil K behaviour and of the various K inputs and outputs of cropping systems (Hoa, 2002).

2.6.4 Exchangeable calcium and magnesium

Calcium (Ca) is one of the essential elements obtained from the soil by plants and used in relatively large quantities. It is a macronutrient and also a secondary element since it is usually added to the soil indirectly during the application of materials containing the primary fertilizer elements - NPK (Hesse, 1998). Andrews and Norris (1961) carried out an experiment between two legumes, one temperate and one tropical to find their differential response to varying levels of calcium on poor soils. Their result showed that the temperate legume produced slight growth and three weeks symptoms in the form of upward cupping of the first trifoliate leaves.

Magnesium (Mg) is an essential part of the chlorophyll molecule. It is also involved in energy metabolism in the plant and is required for protein formation (Zublena, 1997). According to Hesse (1998), Mg occurs in soil, principally in the clay minerals, being common in micas, vermiculites and chlorites. Welte and Werner (1963) investigated the uptake of Mg by plants as influenced by hydrogen, calcium and ammonium ions. They found that hydrogen ions suppressed Mg uptake most and with a strongly acid substrate, Mg deficiency could be remedied by applying Mg and the pH raised. Zublena (1997) stated that depletion of Ca and Mg reserve in the soil by crop removal is rarely a problem in limed soils because of the large quantity of these nutrients that are present in liming materials. However, some crops, such as peanuts, may require more Ca than the crops can remove.

Higher soil Ca and Mg levels have been reported in no tillage system compared with conventional tillage (Ferrer, 1984; Hargrove *et al.*, 1982) but Blevins *et al.* (1977) found no significant effects in exchangeable Ca under different tillage methods. Higher Ca and Mg contents were found in the oat/soybean soil surface compared to the oat/grain sorghum cropping systems (Ruben and Gallaher, 1976).

2.7 Soil pH and acidity

Soil pH is the deciding factor for the availability of essential plant nutrients (Rahman and Ranamukhaarachchi, 2003). Nitrates and phosphates are taken up at higher rates in weak acidic conditions (Mengel and Kirkby, 1982). Fageria and Baligar (1998) found that soil pH and base saturation are important soil chemical properties that influence nutrient availability and crop growth. The soil pH influences the occurrence and the activities of soil microorganisms and eventually affects both organic matter decomposition and nutrient availability (Mengel and Kirkby, 1982). Although temperature, soil moisture and the quality of carbon and nutrients determine the overall organic carbon turnover in soil, soil matrix characteristics (such as clay content, Al and Fe contents and soil pH) moderate carbon turnover in soil (Dalal, 2001).

Soil pH less than 5.5 promotes fungal activity and at higher levels makes bacteria more abundant (Trolldenier, 1971). The nitrification process and its rate brought about by *Nitrosomonas* and *Nitrobacter* bacteria depends considerably on soil pH because these bacteria prefer more neutral soil conditions. In strongly acid soils the native nitrate content is therefore, extremely low (Mengel and Kirkby, 1982). Bacterial growth rates are generally more sensitive to low pH than fungal growth rates (Walse *et al.,* 1998). Microbial biomass and lignin decomposition appears to be not significantly affected by soil acidity at pH range of 4.5 - 6.5 (Donelly *et al.,* 1990). However, in acidic pH less than 4.5, microbial activity as well as nutrient turnover is greatly reduced (Santa, 2000). The combined impact of H^+ and Al^{3+} on microbial activity and organic matter decomposition could be modelled with ion exchange expression, such as Vanselow expression (Walse *et al.,* 1998). Acidic soil pH dissolves Al and other metals from the mineral soil surfaces, which enter the soil solution. In podsols, Al is mobilized in the alluvial horizons under the predominant influence of organic acidity, and then leaches down the profile as organically bound Al, Al - organic matter complexes, where Al is apparently bound to bidentate organic sites (Nissinen *et al.,* 1999).

2.7.1 Soil pH buffering and amelioration.

Soil organic matter exerts a major influence on the pH buffering of soils, both because it contributes much of the soil cation exchange capacity (CEC) and because of the dissociation of weak acid functional groups on the SOM molecules (Magdoff and Bartlett, 1985). Buffering of soil pH by organic matter and the variation of SOM's CEC with pH changes are very important considerations in cropping systems.

Aluminium toxicity is a major limitation for productivity on acid soils in large areas of the more humid regions of the world (Magdoff and Weil, 2004). It is estimated to be a major constraint on 17 % agricultural soils worldwide, on 42 % in the humid to subhumid tropics, and on 25 % in the humid to subhumid subtropics (Wood *et al.*, 2000). Organic matter in the form of chicken manure applied to the soil surface is effective in reducing Al saturation in subsoil horizons, a desirable effect not easily achieved by using agricultural limestone, which is relatively immobile in soils. The manure probably forms Ca-complexes that move Ca down profile with percolating water, thus ameliorating the acid subsoil layers (Hue and Licudine, 1999). Organic matter is credited with ameliorating acidity by other mechanisms too. At pH between 3.5 and 4.5, adding 10 % humified organic matter (peat) to soil greatly reduced exchangeable Al by binding the Al^{3+} in nonexchangeable forms (Hargrove and Thomas, 1981). Complexation of Al^{3+} by SOM is another important mechanism to ameliorate Al toxicity (Parfitt *et al.*, 1999).

2.8 N Mineralization

Mineralization refers to the microbial transformation of an element from organic to its inorganic form. According to Gary (2001), the need to understand and elucidate the role of active C and N pools in cropping systems continues to be critical for predicting N mineralization and availability in cropping systems. Jarvis *et al.* (1996) stated that better quantification of the N mineralization contribution in cropping systems would help minimize N loses to the environment and allow more accurate recommendations for crop production. If N mineralization can be predicted more reliably, more precise guidance can be provided so that supplemental N can be applied to optimize crop production without the risks of over-application (Gary, 2001). The natural N supply for plants and microorganisms results principally from the mineralization of organic compounds (Runge, 1983). This process occurs in two steps: ammonification and nitrification, which play key roles in making N available to plants and microbes. The nitrogen available for crop growth following application is often estimated from the ammoniacal N plus a portion of the soil organic nitrogen (Sluijsmans and Kolenbrander, 1997).

Snapp and Borden (2005) studied soil N dynamics in cereals and legumes cropping systems and observed that soil NO_3^- levels increased gradually over time whereas the soil NH_4^+-N pool size remained constant. In their study on mineralization, Das *et al.* (1997) observed that the lowest NH_4^+ and NO_3^- concentrations were obtained during the rainy season and the highest during the winter, with extractable NH_4^+ being always higher than extractable NO_3^-. In Ghana, Nye and Stephens (1962) observed a gradual increase of NO_3^- during the dry season and a more rapid increase as soon as the rains began. The NO_3^- levels fall during the rainy season and remain low until the beginning of the dry season. Sanchez *et al.* (2001) evaluated N mineralization potential for a long-term cropping system trial in southern Michigan and observed that cover crop with mixed quality residues was associated with approximately 30 % higher N mineralization over 70 days incubation compared to that associated with a monoculture cereal cover crops.

Many studies have focused on fates of N inputs during one or more growing seasons and many chemical and biological assays have been developed to predict N availability to crops (Bundy and Meisinger, 1994). However, less is known about the actual rates of short-term microbial biomass N transformations in systems that differ in C availability and soil N supplying capacity. Agricultural soils that differ in organic matter inputs would be expected to differ in rates of soil N transformations, competition for NH_4^+ by immobilizers and nitrifiers and fates of NO_3^- (Martin and Louise, 2003). NH_4^+ has been found to be the preferred form of N for assimilation by microbes in many cultivated soils (Azam *et al.*, 1993). Nevertheless, nitrification is often considered the major fate of NH_4^+ in agricultural soils (Robertson, 1997), where NH_4^+ is usually present in low concentrations (less than 2 µg NH_4^+-N/g soil) compared to NO_3^-. In some agricultural soils, no NO_3^- immobilization has been observed (Shai and Norton, 2000); while in others NO_3^- immobilization was recorded after 1 - 4 weeks (Schimel, 1986) or several months (Kissel and Smith, 1978). Carbon inputs often increase NO_3^- immobilization (Recous *et al.*, 1990). Predicting the effect of management on residue N mineralization could enhance synchronization of N supply and crop demand. Environmental conditions, crop and soil management all influence the rate of N mineralization from indigenous soil N and added organic sources (Snapp and Borden, 2005). According to Gary (2001), soil N mineralization was greater where highly labile N sources such as manure or alfalfa residues were amended to soil. Empirical models have been used widely in literature to predict nitrogen mineralization under laboratory conditions. The use of these models aims to evaluate or predict observed phenomena or experimental data with the objective of helping the development of adequate soil management practices (Camargo *et al.*, 1997). The use of simulation models under field conditions to predict N mineralization have, however, received little attention.

2.9 Soil physical properties and soil fertility relationships

2.9.1 Soil texture

Soil texture is the most fundamental attribute of soil fertility. Farmers around the world recognize that soil fertility increases with clay content and that high- clay soils are prone to drought in dry areas and to flood in wet areas (Woomer and Swift, 1994). Scholes (1990) indicated that plant production on clay soils is lower than that on sandy soils in arid areas, but higher in wet areas. This is because of the interacting effects of clay on soil water status and soil nutrient status. The quantity of ions that a soil can retain against leaching is determined by the magnitude of the ion exchange capacity. The ion exchange capacity is located on soil organic matter and clay surfaces.

SOM also follows a linear relationship with clay content. Most of the N in terrestrial ecosystems and a large part of the P is found within the SOM. Therefore, soils with large amounts of SOM have high rates of N and P mineralization and higher inorganic N and P availability (Scholes, 1990). The degree to which a soil is organised into water-stable aggregates influences many soil ecosystem functions, including the accumulation of SOM (Tisdale and Oasde, 1982). Cropping systems that promote accumulation usually also promote soil aggregation. The soil properties that contribute to the formation and stabilization of macroaggregates include soil texture, clay and mineralogy, exchangeable cations, Fe and Al oxides, calcium carbonate as well as SOM (Le Bissonnais, 1996).

2.9.2 Soil temperature

Many studies have quantified the influence of temperature on rates of litter decomposition (Witkamp and Drift, 1961; Witkamp and Frank, 1969), N mineralization (Kladivko and Keeney, 1987; Foster, 1989) and soil respiration (Wildung *et al.*, 1975; Singh and Gupta, 1977). These rates increase exponentially with soil temperature over a range of 10 to 30°C. O'Connell (1990) showed that temperature control of litter decomposition is similar to that of soil respiration and the optimum temperature is in the same range. The exact location of the optimum temperature for soil and litter respiration is probably related to the mean maximum temperature experienced at a given site (Osborne and MacAuley, 1988).

2.10 Effects of cropping systems on soil physical properties

Soil physical properties play a critical role in creating favourable conditions for crop growth and soil quality. Achmad *et al.* (2004) found that the effects of cropping systems on soil physical properties are often related to changes in SOM. Sarkar *et al.* (2003) observed that addition of organic materials in cropping systems increased organic carbon, aggregates stability, moisture retention capacity and infiltration rate of the surface soil while reducing the bulk density. Application of inorganic fertilizer decreased the stability of macroaggregates and moisture retention capacity but increased the bulk density values (Sarkar *et al.*, 2003). The stability of soil aggregates often decreases under annual crops, such as wheat or corn. Annual tillage temporarily decreases soil compaction by loosening surface and subsurface soil, while continuous long-term cultivation of land can have detrimental effects on soil quality (Achmad *et al.*, 2004).

On cropland, residue management provides one of the greatest opportunities to positively influence soil infiltration rate and hydraulic conductivity and thereby increase the amount of water entering the soil to be stored for plant use (Magdoff and Weil, 2004). Although the return of crop residues is not likely to maintain SOM and related soil quality properties at the levels seen under natural vegetation, residue return usually results in marked increases in soil water entry and storage compared with the levels observed where residues are burned or removed. The relative effects of management on these soil physical properties might be much more marked than effects on the total SOC content (Whitbread *et al.*, 2000). In their study, Elliot and Efetha (1999) found that maintaining crop residues on the soil surface by using zero tillage for 11 years resulted in a 42 % increase in mean infiltration rate over that by conventional tillage in a continuously cropped cereal or fallow system.

2.11 Summary of literature review

The literature reviewed suggests that cropping systems have significant impact on fertility status of soils. Continuous cropping is most often characterized by low soil fertility which is more pronounced in the tropics. Effective nutrient management is therefore, a critical part of crop production not only to improve financial returns, but also to maintain soil quality and reduce the likelihood of damage to the environment. One remarkable way of achieving this is through nutrient dynamics studies. However, there is a gap in literature regarding systematic study or monitoring of soil organic carbon, N, P, K, Ca, Mg, etc. as affected by specific nutrient management practices in tropical cropping systems. Also, information available on dynamics of mineralized nutrients (e.g. NH_4^+ - N and NO_3^- - N, etc.) in cropping systems is limited. The review indicates that microbial biomass exerts a controlling influence on the dynamics of soil organic matter and availability of many nutrients. Mineralization of nutrients is known to be influenced by soil microbial activity. Even though microbial biomass is important in the sustainability of the process, little is known about its seasonal variation or changes with crop rotations and other agronomic practices such as intercropping. This is much more evident with regard to microbial P whose role in phosphorus cycling and availability cannot be overemphasized. These observations further substantiated justification for this study and formed the basis for the formulation of its objectives.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

The study was conducted at the Soil Research Institute (SRI), Kwadaso, which is about 8 km away from the city of Kumasi. Geographically, the area lies between latitudes 06°.39' and 06°. 43' North and longitudes 01°.39' and 01°.42' West of the Greenwich meridian. It is located in the semi-deciduous forest zone of Ghana (Taylor, 1952).

3.1.2 Climate

The area is characterized by a bimodal rainfall distribution. The major rainy season starts from March - July and the minor season starts from September - November. There is a short dry period in August. The mean annual precipitation is about 1500 mm while mean monthly temperatures range from 24 - 28 °C. Generally, relative humidity is high in the mornings being about 90 % at 0600 hours and falling to between 60 and 70 % in the afternoon (1500 hours).

3.1.3 Soil type

The study was conducted on Asuansi soil series classified by Adu (1992) as Ferric Acrisol according to FAO (1990) and Typic Haplustult according to USDA (1998). Specifically, this soil occurs at the upper to middle slope of the Kumasi - Asuansi/Nta - Ofin Compound Association.

3.2 Field experiment

3.2.1 Crop cultivars used

Early maturing (90 days) crop cultivars namely: Dorke SR (maize), Ahoto (soybean) and Soronko (cowpea) were obtained from Crop Research Institute (CRI) at Fumesua near Kumasi. All the cultivars gave good germination percentage (by visual inspection).

3.2.2 Amendments

There were three different amendments and a control as shown in Table 3.1

Table 3.1 Amendments and their rates of application

Amendment	Rate of application
Control	No PM and No NPK
Poultry manure (PM)	4 t/ha
Poultry manure + chemical fertilizer - NPK 15- 15 - 15 + N (PM + CF)	2 t/ha PM + 30 - 30 -30 kg/ha NPK + 15 kg N/ha
Chemical fertilizer (CF) - NPK 15 - 15 – 15 + N	60- 60-60 kg/ha + 30 kg N/ha

3.2.3 Selected cropping systems

Three cropping systems were selected for this study. These were continuous maize (CM) cropping, maize/soybean (M/S) intercropping and maize/cowpea (M/C) rotation. The sequence of cropping carried out during the entire period of the study is shown in Table 3.2 whilst Plates 1 and 2 show the field experiments involving some of the cropping systems.

Table 3.2 Seasonal cropping pattern

2006 - Major season	2006 - Minor season	2007 - Major season
Maize	Maize	Maize
Maize - soybean intercrop	Maize - soybean intercrop	Maize - soybean intercrop
Maize	Cowpea	Maize

3.2.4 Land preparation and sowing

The field was ploughed thoroughly clearing off vegetation and was harrowed to a fine tilth after four days. It was then lined and pegged. The maize seeds were sown at 80 cm x 40 cm at 3 seeds/ hill and were thinned to two per hill one week after germination. Two soybean seeds were sown per hill (at a spacing of 40 cm x 10 cm) as row intercrop between the maize rows. A 60 cm x 20 cm spacing was employed for sowing cowpea seeds at a rate of two seeds per hill. Overall plant stands for maize, soybean and cowpea were 31,250, 250,000 and 83,334 stands/ha respectively.

3.2.5 Experimental design and field layout

The experiment was a split plot arranged in a randomized complete block design (RCBD) with three replications. The cropping systems constituted the main-plots and the amendments were assigned to the sub-plots. The total land area measured 42.5 m x 14.0 m (595.0 m^2). Each replication (block) had 12 plots, each of dimension 3.0 m x 4.0 m (12.0 m^2). Spacing between replications was 1.0 m with 0.5 m between plots. The treatment combinations and the field layout are shown in Fig. 3.1.

3.2.6 Crop husbandry practices

The amendments (PM, PM + CF, and CF) were applied by side placement to their respective treatment plots two weeks after planting (WAP). However, the control plots did not receive any amendment. At five WAP, plots amended with PM + CF, and CF were 'top dressed' with N. Application rates were reduced to half during the minor season (SRDI, 2002). Plates 3 and 4 show the field experiments under the different amendments. Weed control was carried out manually with hand hoe.

3.2.7 Growth parameter measured.

In order to assess the effects of amendments and cropping systems on plant growth, maize plant height at harvest was measured at the end of each season.

3.2.8 Soil sampling

3.2.8.1. Initial characterization of soil

To assess the nutrient status of the soil before cropping, soil samples were randomly taken at a depth of 0 – 15 cm from the plots within each block and bulked as three composite samples, representative of the block. These were then subjected to analysis after air – drying, crushing and sieving through a 2 mm sieve. However, for NO_3^- - N, NH_4^+ -N and microbial biomass analyses, field - moist samples were used.

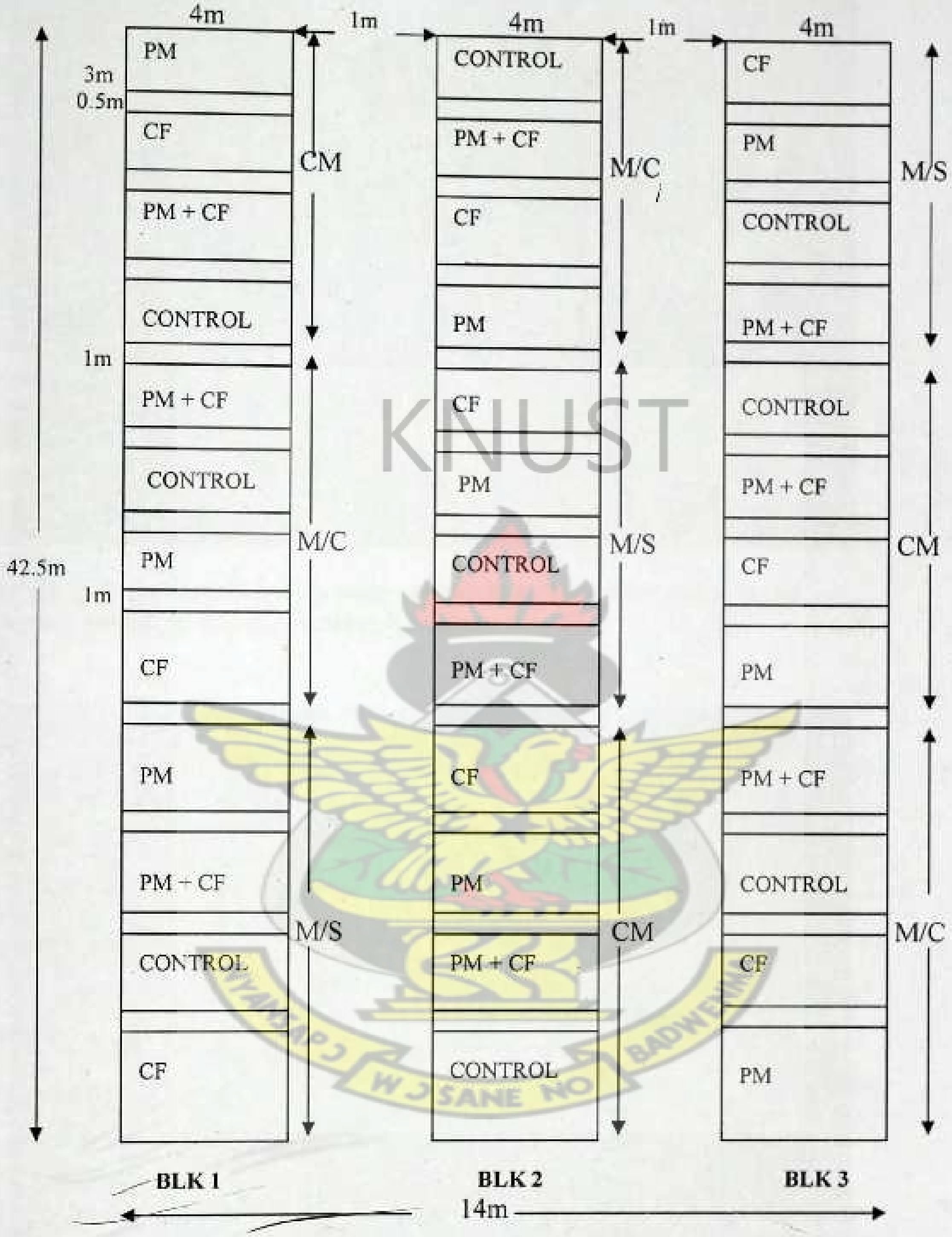

Fig. 3.1. Treatment combinations and field layout

Plate 1. Field experiment showing cowpea in rotation with maize in the minor season on a Ferric Acrisol, Kwadaso.

Plate 2. Field experiment showing maize / soybean (M/S) intercrop in the minor season on a Ferric Acrisol, Kwadaso.

Plate 3. Field experiment showing maize crops under PM and CF amendments in the major season on a Ferric Acrisol, Kwadaso

Plate 4. Field experiment showing maize / soybean (M/S) intercrop under PM + CF and CF amendments in the major season on a Ferric Acrisol, Kwadaso.

3.2.8.2 Soil sampling during the seasons.

Ten plants were selected at random from the middle rows of each plot. Soil samples were taken near the base of each plant at a depth of 0 - 15 cm (Moore *et al.*, 2000) using auger. The ten auger soil samples were thoroughly mixed and sub - sampled to obtain representative sample for each amended plot. Part of the fresh samples were used for microbial and mineralization analyses. The remaining samples were air - dried and passed through a 2 mm sieve. In all, four samplings were made during each season at intervals of 3, 6, 9 and 12 weeks after application of amendments.

3.3 Laboratory/ analytical methods

The physico - chemical properties of the soils were determined in the laboratory of the Soil Research Institute, Kwadaso, Kumasi.

3.3.1 Nitrogen mineralization

3.3.1.1 Nitrate -nitrogen (NO_3^--N) determination

The determination of nitrate in the soil sample involved an extraction with 0.5 *M* K_2SO_4. Ten grams of fresh soil was shaken in 30 ml of extractant (0.5 *M* K_2SO_4) for 30 minutes. After filtration through Whatman No. 42 filter paper, nitrate in the clear solution was determined by the colorimetric method. A 2 ml aliquot of the extract was pipetted into a test tube. To this was added 1 ml salicylic acid solution which was prepared by dissolving 5 g salicylic acid in 95 ml concentrated sulphuric acid (Anderson and Ingram, 1998). The resulting solution was allowed to stand for 30 minutes after which 10 ml of 4.0 *M* sodium hydroxide solution was added and mixed well. Following 1 hour of full colour development, the absorbance of the yellow colour was read at a wavelength of 410 nm on a spectronic 21 D spectrophotometer.

A standard series of 0, 2, 4, 6 and 8 mg/l NO_3^--N was prepared in 50 ml volumetric flasks from a 50 mg/l NO_3^--N stock solution. The absorbance for each standard was then read on the spectrophotometer. A standard curve was obtained by plotting a graph of absorbance against standard concentrations. The solution concentrations for sample and blank were determined from the curve. The blank value was then subtracted from the sample value to give a value for corrected concentration, C.

Calculation:

$$NO_3^- \text{-N (mg/kg soil)} = \frac{C \times V}{W}$$

where

C = corrected concentration (mg/l)

V= extract volume (ml)

W = weight of sample (g)

3.3.1.2 Ammonium - nitrogen (NH_4^+-N) determination

The NH_4^+-N was determined from the same extract as NO_3^--N above. A 2 ml aliquot of the extract was pipetted into a test tube to which two different reagents (RI and RII) were added. RI was prepared by mixing three separately prepared solutions namely: 4 % EDTA (5 ml), 0.05 g/ml sodium nitroprussite (100 ml) and 1.12 g/ml sodium salicylate (50 ml). RII was prepared by dissolving 0.2 g of sodium dichlorocyanate in 10 ml of distilled water and transferred to a 200 ml flask. The volume was made up to the mark with a buffer solution of 0.0746 *M* $Na_2HPO_4.12H_2O$ (adjusted to pH 12.3). The resulting solution was allowed to stand for 2 hours after the addition of 3 ml and 5 ml of RI and RII, respectively.

Working standards of 0, 5, 10, 15 and 20 mg/l were prepared from 1000 mg/l NH_4^+-N stock solution. The absorbance of the sample, blank and working standards were read on the spectrophotometer at a wavelength of 660 nm. A graph of absorbance against standard concentrations was plotted. Solution concentrations for the sample and blank were then determined. The blank value was subtracted from the sample value to give a value for corrected concentration, C.

Calculation:

$$NH_4^+\text{-N (mg/kg soil)} = \frac{C \times V}{W}$$

where

C = corrected concentration (mg/l)

V = final digest or extract volume (ml)

W = weight of sample (g)

3.3.1.3 Modelling mineralization rate

The sub - model of the nitrogen model (Greenwood, 2001) was used to predict the rate of mineralization. According to Greenwood (2001), the sub-model was adapted from Ruhlmann (1999). The nitrogen model assumes that mineralization varies greatly from soil to soil, partly as a consequence of differences in organic carbon content and soil texture. The key input parameters of the sub-model are organic carbon (%) and percentage by weight of soil mineral particles that are < 20 μm. The model considers that mineralization rates are also dependent on previous cropping, wetting and drying cycles and cultivation practices. With the sub-model, it is possible to calculate the decomposable % C (CDEC) and then the mineralization rate from the input data. It has been helpful in predicting mineralization rate which is used as input data for the nitrogen model described by Greenwood (2001). The nitrogen model then estimates the response of arable crops to N-fertilizer and to crops residue application and the amount of nitrate leached below different depths from the soil.

The empirical model of Whitmore and Handayanto (1997) was used to establish the relationship between the expected and observed mineralization of poultry manure which was applied as amendment. The equation for the model is shown below:

$$N_{mineralized} = C_{decomposed}(1/Z - E/Y)$$

where

Z = C: N ratio of the decomposing substrate

E = microbiological efficiency (0.45)

Y = C: N ratio of the soil organic matter formed

C = organic carbon

3.3.1.4 Evaluation of model performance

The performance of the N sub-model in predicting mineralization rates was evaluated by determining the closeness of the relationship between observed and predicted values using the coefficient of correlation (r) and the median unbiased absolute percentage error (MdUAPE).

$$\text{MdUAPE} = 100 \times \text{Median} \frac{[\text{Simulated}_i - \text{Observed}_i]}{0.5\,[\text{Observed}_i + \text{Simulated}_i]}$$

The MdUAPE avoids problems such as bias in favour of lower prediction that occurs when using the regular MdUAPE in expressing goodness of fit between predictions and observations (Armstrong and Callopy, 1992; Makridakis, 1993).

3.3.2 Soil microbial biomass analysis

3.3.2.1 Soil microbial carbon and nitrogen

Soil microbial carbon and nitrogen were monitored under the different amendments and cropping systems. The method of chloroform fumigation and extraction (FE) as described by Ladd and Amato (1989) was used to determine the microbial biomass. Ten grams field - moist soil sample, after passing through a 4 mm mesh, was put in a crucible and placed in a desiccator. A shallow dish containing 30 ml of alcohol -free chloroform was placed by it. A crucible containing a control sample (10 g) was placed in a separate desiccator without chloroform. The desiccators were covered and allowed to stand at room temperature for 5 days (Anderson and Ingram, 1998). Immediately after fumigation, 50 ml of 0.5 *M* K_2SO_4 solution was added to the soil samples to extract microbial carbon and nitrogen from the lysed microorganisms. Total nitrogen in the extract was then determined by the Kjeldahl method. The amount of microbial carbon in the extract was determined using the colorimetric method. An aliquot (5 ml) of the extract was pipetted into 250 ml Erlenmeyer flask. To this were added 5 ml of 1.0 *N* (0.1667 *M*) potassium dichromate and 10 ml concentrated sulphuric acid. The resulting solution was allowed to cool for 30 minutes after which 10 ml of distilled water was added. A standard series was developed concurrently with carbon concentrations ranging from 0, 2.5, 5.0, 7.5, 10.0 mg/ml C. These concentrations were obtained when volumes of 0, 5, 10, 15 and 20 ml of a 50 mg/ml C stock were pipetted into labelled 100 ml volumetric flasks and made up to the mark with distilled water. The absorbances of the standard and sample solutions were read on a spectronic 21D spectrophotometer at a wavelength of 600 nm. A standard curve was obtained by plotting absorbance values of the standard solutions against their corresponding concentrations. Extracted carbon concentration of the samples was determined from the standard curve. For biomass C and N calculations, k -factors of 0.35 (Sparling *et al.*, 1990) and 0.45 (Jenkinson, 1988; Ross and Tate, 1993) were used, respectively. The following equations according to Sparling and West (1998) were used to estimate the microbial C and N from the extracted C and N respectively:

Microbial C (mg) = E_c/k

Microbial N (mg) = E_N/k

where

E_N = the extracted nitrogen produced following fumigation

E_c = the extracted carbon produced following fumigation

k = the fraction of the killed biomass extracted as carbon or nitrogen under standardized conditions

3.3.2.2 Soil microbial phosphorus

For microbial biomass P analysis, 5 g of field-moist soil was weighed into a crucible and fumigated in a dessicator with 30 ml of alcohol-free chloroform for 5 days. Both fumigated and unfumigated soil samples were shaken with 35 ml Bray's No.1 extracting solution (0.03 *M* NH_4F + 0.025 *M* HCl) for 10 minutes and filtered. Correction for adsorption of P during fumigation was made by simultaneously equilibrating unfumigated soil with a series of P containing standard solutions followed by extraction with the Bray-1 solution. The amount of chloroform released P was determined according to the relationship between P added (from standard solutions or microbial lysis) and P extracted by the Bray-1 solution (Oberson *et al.*, 1997). Phosphorus adsorption during equilibrium is described by the following equation according to Barrow and Shaw (1975) and adapted by Morel *et al.* (1997):

$$Ext_p = Ext_0 + b_1 Pad^{b2}$$

where

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

Ext_0 = Pi concentration extracted without P addition,

b_1, b_2 = coefficients estimated by non- linear regression of mean values of Ext_p against Pad

Pad = amount of P added (0 - 20 mg/kg)

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

$$P_{chl} = [(Ext_{chl} - Ext_0)/b1]^{1/b2}$$

where

P_{chl} = chloroform released P (mg/kg).

Ext_{chl} = Pi concentration in extracts of fumigated samples.

The amount of microbial P is estimated by assuming a kp factor of 0.4 (Brookes *et al.*, 1982; McLaughlin and Alston, 1986).

3.3.3 Soil pH

Soil pH was determined using a H1 9017 Microprocessor pH meter in a 1:2.5 suspension of soil and water. A 20 g soil sample was weighed into plastic pH tube to which 50 ml water was added from a measuring cylinder. The suspension was stirred frequently 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.

3.3.4 Soil organic carbon

A modified Walkley and Black procedure as described by Nelson and Sommers (1982) was used in the determination of organic carbon. One gram of soil sample was weighed into an Erlenmeyer flask. A reference sample and a blank were included. Ten millilitres of 1.0 *N* (0.1667 *M*) potassium dichromate was added to the sample and the blank flasks. Concentrated sulphuric acid (20 ml) was carefully added to the soil from a measuring cylinder, swirled and allowed to stand for 30 minutes in a fume cupboard. Distilled water (250 ml) and 10 ml concentrated orthophosphoric acid were added and allowed to cool. A diphenylamine indicator (1 ml) was then added and titrated with 1.0 *M* ferrous sulphate solution.

Calculation:

Calculation:

The organic carbon content of soil was calculated as:

$$\% \text{ organic carbon} = \frac{M \times 0.39 \times \text{ mcf } (V_1 - V_2)}{w}$$

where

M = molarity of ferrous sulphate

V_1 = ml ferrous sulphate solution required for blank

V_2 = ml ferrous sulphate solution required for sample

w = weight of air - dry sample in gram

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

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

3.3.5 Total nitrogen

This was determined by the Kjeldahl digestion and distillation procedure as described in Soils Laboratory Staff (1984). A 0.5 g soil sample was weighed into a Kjeldahl digestion flask. To this 5 ml distilled water was added. After 30 minutes, concentrated sulphuric acid (5 ml) and selenium mixture were added and mixed carefully. The sample was then digested for 3 hours until a clear digest was obtained. The digest was diluted with 50 ml distilled water and mixed well until no more sediment dissolved and allowed to cool. The volume of the solution was made to 100 ml with distilled water and mixed thoroughly. A 25 ml aliquot of the solution was transferred to the reaction chamber and 10 ml of 40 % NaOH solution added followed by distillation. The distillate was collected in 2.0 % boric acid and was titrated with 0.02 *N* HCl using bromocresol green as indicator. A blank distillation and titration was also carried out to take care of the traces of nitrogen in the reagents as well as the water used.

Calculation:

The % N in the sample was expressed as:

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

where

N = concentration of HCl used in titration

a = ml HCl used in sample titration

b = ml HCl used in blank titration

w = weight of air-dry soil sample

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

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

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

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

A 5 g soil sample was weighed into a shaking bottle (50 ml) and 35 ml of extracting solution of Bray's No.1 added. The mixture was shaken for 10 minutes on a reciprocating shaker and filtered through a Whatman No. 42 filter paper. An aliquot of 5 ml of the blank, the extract, and 10 ml of the colouring reagent (ammonium molybdate and tartarate solution) were pipetted into a test tube and uniformly mixed. The solution was allowed to stand for 15 minutes for the blue colour to develop to its maximum. The absorbance was measured on a spectronic 21D spectrophotometer at a wavelength of 660 nm at medium sensitivity.

A standard series of 0, 1, 2, 3, 4 and 5 mgP/L was prepared from 20 mg/L phosphorus stock solution.

Calculation:

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

Where

a = mg/L P in sample extract

b = mg/L P in blank

mcf = moisture correcting factor

35 = ml extracting solution

15 = ml final sample solution

w = sample weight in gram

3.3.7 Exchangeable cations

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

3.3.7.1 Exchangeable bases extraction

A 5 g soil sample was weighed into a leaching tube and leached with 100 ml buffered 1.0 *M* ammonium acetate solution at pH 7.

3.3.7.1.1 Determination of calcium and magnesium

To analyse for calcium and magnesium, a 25 ml aliquot of the extract was transferred into an Erlenmeyer flask. To this were added 1 ml portion of hydroxylamine hydrochloride, 1 ml of 2.0 % potassium cyanide, 1 ml of 2.0 % potassium ferrocyanide, 10 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution. The solution was titrated with 0.01 *M* EDTA (ethylene diamine tetraacetic acid) to a pure turquoise blue colour.

3.3.7.1.2 Determination of calcium only

A 25 ml aliquot of the extract was transferred into a 250 ml Erlenmeyer flask and the volume made up to 50 ml with distilled water. Following this, were added 1 ml hydroxylamine, 1 ml of 2.0 % potassium cyanide and 1 ml of 2.0 % potassium ferrocyanide solution. After a few minutes, 5 ml of 8.0 *M* potassium hydroxide solution and a spatula of murexide indicator were added. The resultant solution was titrated with 0.01 *M* EDTA solution to a pure blue colour.

Calculation:

The concentrations of calcium + magnesium or calcium were calculated using the equation:

$$\text{Ca + Mg (or Ca) (cmol/kg soil)} = \frac{0.01 \times (\text{Va} - \text{Vb}) \times 1000}{\text{w}}$$

where

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

Va = ml of 0.01 *M* EDTA used in sample titration

Vb = ml of 0.01 *M* EDTA used in blank titration

0.01 = concentration of EDTA

3.3.7.1.3 Determination of exchangeable potassium and sodium

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

Calculation:

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

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

where

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

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

w = weight (g) of air- dried sample

mcf = moisture correcting factor

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

The soil sample was extracted with unbuffered 1.0 *M* KCl solution. Ten grams of soil sample was weighed into a 200 ml plastic bottle and 50 ml of 1.0 *M* KCl solution added. The mixture was shaken on a reciprocating shaker for 2 hours and filtered. An aliquot of 25 ml of the extract was pipetted into a 250 ml Erlenmeyer flask and 4-5 drops of phenolphthalein indicator solution added. The solution was titrated with 0.025 *N* NaOH until the colour just turned permanently pink. A blank was also included in the titration.

Calculation:

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

where

a = ml NaOH used to titrate with sample

b = ml NaOH used to titrate with blank

M = molarity of NaOH solution

w = weight (g) of air- dried sample

2 = 50/25 (filtrate/ pipetted volume)

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

3.3.7.3 Effective cation exchange capacity (ECEC)

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

3.3.8 Particle size analysis

Soil texture with regard to each amendment was determined by the hydrometer method (Boyoucos, 1962). A 50 g of air-dried soil was weighed into a measuring cylinder and 50 ml of calgon (sodium hexamethaphosphate) added. The suspension was shaken and allowed to stand. Corrected hydrometer readings at 40 seconds and 5 hours were taken.

Calculation:

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

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

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

where

A= corrected hydrometer reading at 40 seconds

B = corrected hydrometer reading at 5 hours

W = weight of dry soil

The textural class was then determined from the textural triangle.

3.3.9 Soil bulk density

The mass (M_o) of an empty cylindrical core sampler of inner radius 2.5 cm and of height 5.0 cm, was determined on an electronic balance. The core sampler was used to take moist soil sample at a depth of 0 - 15 cm from each plot. The mass of the moist soil

(M_t) was derived by subtracting the mass of empty core sampler (M_o) from the mass of empty core sampler (M_o) + mass of moist soil (M_t). The dry mass (M_s) of soil sample was determined (after drying the moist soil sample to equilibrium in an oven at 105 °C) by subtracting mass of water (M_w) from M_t.

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

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

where

$\pi = 22/7$

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

h = height (cm) of the cylindrical core sampler

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

$$Pb\ (\text{g/cm}^3) = \frac{\text{mass of dry soil sample } (M_s)}{\text{volume of soil } (Vt)}$$

3.4 Poultry manure and residue characterization

Poultry manure which was applied as an amendment was obtained from Mfum farms, Mim, along the Nkawie road in the Ashanti region. Before application, a representative sample was taken, dried in the oven at 40 °C (Anderson and Ingram, 1998) and ground to pass through a 1 mm sieve. Organic carbon, total nitrogen, phosphorus, potassium, calcium, polyphenol and lignin contents were determined and used to assess the quality of the manure.

Crop residues were retained on all amended plots at harvest. To assess their quality and contribution to the nutrient status of the soil, representative samples were taken, dried in the oven at 70 °C and milled to pass through a 1 mm sieve. Organic carbon, total nitrogen, phosphorus, potassium, calcium, polyphenol and lignin contents were determined.

3.4.1 Nitrogen

Total N was determined by the Kjeldahl method in which poultry manure and plant material were each oxidized by sulphuric acid and hydrogen peroxide with selenium as catalyst. Twenty grams oven-dried sample was ground in a stainless steel hammer mill and passed through a 1 mm sieve. A 0.5 g sample was digested in a 10 ml concentrated sulphuric acid with selenium mixture as catalyst. The resulting clear digest was transferred into a 100 ml conical flask and made to volume with distilled water. A 5 ml aliquot of the sample and a blank were pipetted into the Kjeldahl distillation apparatus separately and 10 ml of 40 % NaOH solution was added followed by distillation. The evolved ammonia gas was trapped in a 25 ml of 2 % boric acid. The distillate was titrated with 0.1 *M* HCl with bromocresol green-methyl red as indicator (Soils Laboratory Staff, 1984).

Calculation:

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

where

a = ml HCl used for sample titration

b = ml HCl used for blank titration

M = molarity of HCl

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

DM = dry matter

w = weight of sample

3.4.2 Organic carbon

Organic carbon content of both poultry manure and crop residues was determined using the dichromate-acid oxidation method. Ten millilitres (10 ml) each of concentrated sulphuric acid, 0.5 *N* potassium dichromate solution and concentrated orthophosphoric acid were added to 0.05 g of sample in Erlenmeyer flask. The solution was allowed to stand for 30 minutes after addition of distilled water. It was then back titrated with 0.5 *N* ferrous sulphate solution with diphenylamine indicator.

The organic carbon content was calculated from the equation:

$$\% \text{ carbon} = \frac{N \times (a-b) \times 3 \times 10^{-3} \times 100 \times 1.3}{\text{w}}$$

where

N = normality of ferrous sulphate

a = ml ferrous sulphate solution required for sample titration

b = ml ferrous sulphate solution required for blank titration

w = weight of oven- dried sample in gram

3 = equivalent weight of carbon

1.3 = compensation factor allowing for incomplete combustion

3.4.3 Phosphorus, potassium, sodium, calcium and magnesium

A 0.5 g of organic material (poultry manure and crop residues) was ashed in a muffle furnace, after which the ash was dissolved in 1.0 *M* HCl solution and filtered. The filtrate was diluted to 100 ml with distilled water.

3.4.3.1 Phosphorus

A 5 ml aliquot of the filtrate was taken into a 25 ml volumetric flask. Five millilitres of ammonium vanadate solution and 2 ml stannous chloride solution were added. The volume was made up to 25 ml with distilled water and allowed to stand for 15 minutes for full colour development. A standard curve was developed concurrently with phosphorus concentrations ranging from 0, 5, 10, 15 to 20 mg P/kg organic material. The absorbance of the sample and standard solutions were read on a spectronic 21D spectrophotometer at a wavelength of 470 nm. The absorbance values of the standard solutions were plotted against their respective concentrations to obtain a standard curve from which phosphorus concentrations of the samples were determined.

3.4.3.2 Potassium and sodium

Potassium and sodium in the leachate were determined using a Gallenkamp flame analyzer. Standard solutions of potassium and sodium were prepared with concentrations of 0, 20, 40, 60, 80 and 100 mg/litre of solution. The emission values which were read on the flame analyzer were plotted against their respective concentrations to obtain standard curves.

3.4.3.3 Calcium and magnesium

A 10 ml aliquot of the ash solution was pipetted into an Erlenmeyer flask. One millilitre each of potassium cyanide and potassium ferrocyanide solutions were added to complex interfering cations like Cu and Fe. To determine calcium + magnesium concentration, the solution was titrated with 0.01 *M* EDTA solution in the presence of Eriochrome Black T indicator. In calcium determination, potassium hydroxide solution (5 ml) was added to raise the pH to 12 so as to precipitate magnesium, leaving calcium in solution. The solution was titrated with EDTA using murexide as indicator. The difference between the first and second titres represents magnesium concentration in the solution.

3.4.4 Polyphenols

One gram each of dried, milled and sieved poultry manure and plant material were weighed into 50 ml separate conical flasks. Ethanol (20 ml) was added to the organic materials and heated to 60 °C to extract the polyphenol. The extraction was repeated after the alcohol extract was decanted into another flask. After the third extraction, the volume of the extract was made to 50 ml by adding ethanol. Standard solutions of tannic acid (with concentrations of 0, 20, 40, 80 and 100 mg tannic acid per litre) were prepared. The samples and tannic acid standards were subjected to colour development. Absorbance values of the standard and sample solutions were read on the spectrophotometer at a wavelength of 760 nm. A standard curve was obtained by plotting absorbance values against concentrations of the standard solutions and used to determine sample solution concentrations.

Calculations:

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

where

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

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

3.4.5 Soluble organic fraction and lignin

3.4.5.1 Soluble organic fraction (lipids and sugars)

One gram of organic residue was extracted for 1 hour with 20 ml of ethanol: benzene (1:1, v: v) in a sealed pyrex tube at 60 °C, cooled and centrifuged. This was repeated twice and the combined extract evaporated slightly and made to 50 ml in a flask. Ten mililitres aliquot was taken for dry weight determination. The dry weight was taken as lipid fraction (Kachaka *et al.,* 1993). The residue was hydrolyzed with 25 ml of 1.0 *N* sulphuric acid in a sealed pyrex tube at 100 °C for 1 hour, cooled and centrifuged. The supernatant solution was saved in another container and the process repeated with two washings of distilled water to remove most of the sulphuric acid from the residue. A 10 ml aliquot was taken for dry weight determination which was considered as the sugar fraction.

3.4.5.2 Lignin

After the alcohol and dilute sulphuric acid extraction, 2 ml of 72 % sulphuric acid was added to the residue and shaken for 4 hours. The solution was transferred into a 100 ml

Erlenmeyer flask with 40 ml distilled water, boiled for 2 hours and filtered. Sugar which represents cellulose was determined in the hydrolysate. The residue was washed with water, dried at 60 °C for 48 hours, weighed and then ashed in a muffle furnace. The lignin content of the residue was considered as the loss in weight on ignition.

3.7 Statistical analysis

Data on all parameters/response variables (e.g. SOC, N, P, K, NO_3^- -N, NH_4^+ -N, exchangeable bases, etc.) were subjected to analysis of variance (ANOVA) using the GenStat statistical package (GenStat, 2007). Means were separated using the Least Significant Difference (LSD) method at 5 % level of probability. Regression and correlation analyses were carried out to determine the nature and magnitude of relationships between and among principal parameters.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 INITIAL SOIL PROPERTIES

4.1.1 RESULTS

The soil of the study area was initially characterized in order to assess its fertility status before the establishment of the cropping systems and application of amendments. The results of the initial physico - chemical analyses of the Asuansi soil series (Ferric Acrisol) at Kwadaso are presented in Table 4.1.

Table 4.1. Descriptive statistics of the initial soil properties taken at the study site

Soil property	Min	Max	Mean	SD	CV *
NO_3^--N (mg N/kg soil)	3.85	4.09	3.97	0.19	4.8
NH_4^+-N (mg N/kg soil)	3.91	4.23	4.04	0.17	4.2
Microbial biomass C (mg C/kg soil)	95.25	133.35	114.30	19.05	16.7
Microbial biomass N (mg N/kg soil)	12.46	20.67	17.26	4.28	24.8
Microbial biomass P (mg P/kg soil)	7.75	23.26	15.72	4.28	49.4
Soil pH	6.59	6.89	6.69	0.17	2.5
SOC (%)	1.08	1.42	1.36	0.42	30.9
Total N (%)	0.06	0.08	0.07	0.01	12.5
Available P (mg/kg soil)	45.21	51.11	45.13	4.69	10.4
Exchangeable cations (cmol/kg soil)					
K^+	0.33	0.43	0.38	0.05	13.4
Ca^{2+}	5.60	7.04	5.71	1.05	18.4
Mg^{2+}	0.25	0.87	0.50	0.27	53.4
Na^+	0.11	0.12	0.12	0.01	8.3
$Al^{3+} + H^+$	0.10	0.15	0.12	0.02	16.7
ECEC (cmol/kg soil)	6.39	8.61	6.83	0.79	11.6
Bulk density (g/cm^3)	1.52	1.54	1.50	0.05	3.3

* Coefficient of variation (CV) expressed in percentage, SD: standard deviation, SOC: soil organic carbon, values are means of three replications.

Ammonium -N and NO_3^- - N contents of the soil ranged between 3.91 – 4.23 mg N/kg soil and 3.85 – 4.09 mg N/kg soil, respectively. Among the microbial properties, biomass phosphorus showed the highest variability whilst biomass carbon showed the least. The soil pH ranged from 6.59 - 6.89 with a mean of 6.69. It was the least variable soil property with a CV < 3 %. All other chemical properties showed CV > 10 % except for NO_3^- - N, NH_4^+ - N and exchangeable Na^+. Mean soil organic carbon and total nitrogen contents were generally low and varied from 1.08 - 1.42 % and 0.06 - 0.08 %, respectively. Available phosphorus content varied from 45.21 to 51.11 mg/kg soil. Variability in soil exchangeable bases content increased in the order of $Na^+ < K^+ < Ca^{2+} < Mg^{2+}$ Magnesium was the most variable exchangeable cation (CV = 53.4 %) with a mean value of 0.50 cmol/kg soil. Soil bulk density ranged from 1.50 – 1.54 g/cm^3 with a low CV of 3.3 %. The results for particle size distribution indicated that the soil of the study site was of the textural class - sandy loam (Appendix 1a and 1b).

4.1.2 DISCUSSION

Analysis of the Asuansi soil series collected at the experimental site included mean, minimum and maximum values of the soil parameters (Table 4.1). It gave an overview of the soil in terms of its chemical and physical properties. The low soil organic carbon and total N contents were the result of high temperatures resulting in rapid organic carbon decomposition in combination with a generally low input of organic material. Organic matter is closely associated with the nutrient status of soil because it contributes much to the soil CEC (Magdoff and Bartlett, 1985). It is also an important source of inorganic nutrients for production in natural and managed ecosystems

(Frizsche *et al.*, 2002). The low ECEC recorded in Table 4.1 was due to the low organic carbon content of the soil. The recorded mean pH value was near neutral. This was by virtue of the medium exchangeable calcium content of the soil. Adjei – Gyapong and Asiamah (2002) reported pH of 6.4 on top soils of Asuansi soil series.

4.2 CHARACTERIZATION OF POULTRY MANURE AND MAIZE RESIDUES

4.2.1 RESULTS

Tables 4.2a, 4.3a and 4.3b show data on some chemical properties of the poultry manure used in the study and maize residues left under each amendment on the field at harvest.

Table 4.2a. Some chemical properties of the poultry manure used in the study

Chemical property	Min	Max	Mean	SD	CV *
Total Nutrients (%)					
N	2.69	2.77	2.73	0.05	1.8
P	0.87	1.00	0.93	0.07	7.5
K	1.60	1.83	1.69	0.12	7.1
Ca	2.00	2.40	2.10	0.26	12.4
Mg	0.94	1.22	1.11	0.15	13.5
Na	0.71	0.92	0.80	0.11	13.8
Polyphenol (%)	3.25	3.53	3.36	0.15	4.4
Lignin (%)	12.70	13.30	13.00	0.30	2.3
OC (%)	34.99	35.00	35.13	0.33	0.9
C:N ratio	12.8	13.0	12.9	0.21	1.6
C:P ratio	35.0	40.7	37.8	2.86	7.6
Lignin:N ratio	4.6	4.8	4.8	0.10	2.0
Polyphenol:N ratio	1.2	1.3	1.2	0.07	5.8

Values are means of three replications, * CV: coefficient of variation expressed in percentage, SD: standard deviation, OC: organic carbon.

The mean nitrogen, phosphorus and potassium contents of the poultry manure were 2.73, 0.93 and 1.69 %, respectively. The recorded mean C: N ratio was < 20 whilst C: P ratio was < 40. The mean lignin: N and polyphenol: N ratios were 4.8 and 1.2, respectively with coefficients of variation < 6 % (Table 4.2a). Generally, the recorded chemical properties of the poultry manure gave CV values < 15 %. A significant positive correlation (r = 0.47*) between observed and calculated rates of mineralization of poultry manure was recorded during the study (Table 4.2 b). Rates of mineralization generally decreased with time. Observed mineralization rate was highest at 21 days following amendment (0.57 kg/ha/day) and declined to 0.11 kg/ha/day at 84 DAA.

Table 4.2b. Calculated and observed mineralization rates (NO_3^- - N plus NH_4^+ -N) of poultry manure used in the study

DAA	Observed (kg/ha/day)	Calculated (kg/ha/day)	r
21	0.57	0.62	0.47*
42	0.43	0.47	
63	0.53	0.49	
84	0.11	0.49	

Calculated from $N_{mineralized} = C_{decomposed} (1/Z - E/Y)$ (Whitmore and Handayanto, 1997). DAA: days after amendment. * Significant at P < 0.05.

Table 4.3a. Some chemical properties of maize residues left on the field after harvest

Amendment	Total content N	P	K	Ca	Mg	Polyphenol	Lignin	Org. C
	%							
CTRL	0.84	0.10	1.00	0.62	0.13	6.97	16.40	48.23
PM	0.87	0.11	1.09	0.63	0.15	6.88	16.70	49.11
PM + CF	0.88	0.12	1.13	0.62	0.15	6.82	17.21	49.05
CF	0.90	0.14	1.19	0.59	0.12	6.90	17.03	48.56
LSD (0.05)	0.03	0.02	NS	NS	NS	0.13	0.57	0.03
CV (%)	3.6	15.7	21.3	9.8	9.8	1.9	3.4	0.1

Values are the means of three replications; CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, NS: Not significant at $P < 0.05$.

Nitrogen content of maize residues varied from 0.84 % under no amendment (CTRL) to 0.90 % for the chemical fertilizer (CF) amended plots (Table 4.3a). Nitrogen concentration of the residues under the amendments was in the decreasing order of CF > PM + CF > PM > CTRL. Phosphorus content was highest in residues under CF – amendment (0.14 %) and lowest for the CTRL (0.10 %). Potassium content of residues was similar ($P > 0.05$) for plots under amendments and the control (Table 4.3a).

The C: N ratio of maize residues ranged between 54.0 for plots amended with chemical fertilizer to 56.5 for plots under PM amendment. The least C: P ratio was recorded in soils treated with chemical fertilizer whilst the control plots recorded the highest. Plots that received poultry manure amendment produced residues with C: P ratio that differed significantly ($P < 0.05$) from residues of chemical fertilizer treatment (Table 4.3b).

Table 4.3b. Mean C: N, C: P, Lignin: N and Polyphenol: N ratios of the maize residues

Amendment	C:N Ratio	C:P Ratio	Lignin: N Ratio	Polyphenol : N Ratio
CTRL	56.2	482.3	19.5	8.3
PM	56.5	446.5	19.2	7.9
PM + CF	55.7	408.8	19.6	7.8
CF	54.0	346.9	18.9	7.7
LSD (0.05)	NS	78.4	NS	0.3
CV (%)	5.1	18.8	5.1	4.2

Values are the means of three replications; CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer. NS: Not significant at $P < 0.05$.

4.2.2 DISCUSSION

The mean C: N ratio of 12.9 recorded for poultry manure (Table 4.2a) was low (less than 20 according to Lloyd *et al.* 2003). This indicates that the manure used in this study was of high quality. Another parameter indicating quality of organic materials was the C: P ratio. The higher C: P ratio recorded for the maize residues (Table 4.3b) than for the poultry manure suggested that the poultry manure was of higher quality than the maize residues. An organic material of C: P ratio less than 300 is of high quality (White and Ayoub, 1983). Polyphenols are reactive compounds that can form stable polymers with many forms of N (Stevenson, 1986). In Tables 4.2a and 4.3b, the poultry manure showed low Polyphenol: N ratio (mean of 1.2) whilst the maize residues showed high ratios (7.7 – 8.3). One would therefore, expect faster decomposition of the manure than the residues if both are applied separately as amendments.

The declined rate of mineralization of poultry manure over time (Table 4.2b) is in conformity with published data. Camargo *et al.* (1997) found mineralization rates of incubated organic materials to decrease over time.

4.3 SOC/SOM DYNAMICS

4.3.1 RESULTS

At six weeks following amendment (42 DAA), the levels of soil organic carbon had declined by 21 – 25 % and 4 – 7 % in the 2006 - major and 2006 - minor season, respectively (Tables 4.4a and 4.4b). During the 2007- major season, the decline in SOC following 42 days of amendments application was 2 – 3 % except in CF – amended plots which showed no decline (Table 4.4c). Conversely, at 9 weeks following amendment (63 DAA), organic carbon content of all soils increased by 14 - 35 % and 13 – 22 % over values obtained at 42 DAA in 2006 - major and 2006 - minor seasons, respectively. The least SOC content was recorded on the 42nd day following amendment whilst the highest was registered at the 63 DAA during both seasons in 2006. The 2007 - major season however, recorded the highest level following 84 days after amendment. Soils amended with poultry manure generally produced the highest levels of soil organic carbon in both seasons of 2006. In 2007 - major season however, complementary application of poultry manure and chemical fertilizer (PM + CF) produced the highest level of soil organic carbon (1.19 - 1.33 %). The control plots recorded the least during both years of study (0.77 – 1.28 %). Cropping systems had no significant effect on soil organic carbon content in 2006 - major season (Table 4.4a). Significant differences ($P < 0.05$) were however observed between CM and M/S

Table 4.4a. Soil organic carbon variation in 2006 - major season

Treatments	Organic carbon (%)			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	0.98	0.77	1.04	1.02
PM	1.25	0.98	1.12	1.07
PM + CF	1.22	0.92	1.19	1.14
CF	1.08	0.85	1.08	1.06
LSD (0.05)	0.19	0.19	0.12	NS
Cropping system				
CM	1.20	0.90	1.22	1.17
M/S	1.09	0.87	1.00	0.95
M/C	1.09	0.85	1.11	1.10
LSD (0.05)	NS	NS	NS	NS

Values are the means of 3 replications; DAA - days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, CM: Continuous maize, M/S: Maize /soybean, M/C: Maize /cowpea.

Table 4.4b. Soil organic carbon variation in 2006 - minor season

Treatments	Organic carbon (%)			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	1.10	1.04	1.17	1.04
PM	1.17	1.09	1.33	1.17
PM + CF	1.14	1.09	1.30	1.17
CF	1.12	1.07	1.24	1.10
LSD (0.05)	NS	NS	NS	NS
Cropping system				
CM	1.26	1.23	1.30	1.26
M/S	1.05	0.98	1.21	1.06
M/C	1.09	1.02	1.26	1.04
LSD (0.05)	0.17	0.17	NS	NS

Values are the means of 3 replications; DAA - days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, CM: Continuous maize, M/S: Maize /soybean, M/C: Maize /cowpea.

cropping systems at 21 and 42 DAA in 2006 – minor season (Table 4.4b) and at 42 and 63 DAA in 2007 - major season (Table 4.4c). Soil organic carbon content as observed in the 2006 - minor season was about 10 % greater than that obtained during the 2006 - major season but was 4 % less than that obtained during the 2007- major season under the amendments and cropping systems. Generally, there were no significant differences in SOC between amendments and cropping systems over cropping seasons (Table 4.4d). However, plots under PM + CF gave value in 2007–major season which was statistically higher than values from same plots in 2006-major and minor seasons. Plots under CM cultivation recorded significantly higher value ($P < 0.05$) in 2007-major season than in the previous seasons of 2006 (Table 4.4d).

Table 4.4c. Soil organic carbon variation in 2007 - major season

	Organic carbon (%)			
Treatments	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	1.06	1.03	1.12	1.28
PM	1.21	1.19	1.28	1.33
PM + CF	1.25	1.23	1.33	1.37
CF	1.09	1.09	1.17	1.21
LSD (0.05)	0.17	0.15	NS	0.11
Cropping system				
CM	1.25	1.23	1.31	1.37
M/S	1.06	1.04	1.11	1.22
M/C	1.14	1.13	1.26	1.30
LSD (0.05)	NS	0.16	0.19	NS

Values are the means of 3 replications; DAA - days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, CM: Continuous maize, M/S: Maize /soybean, M/C: Maize / cowpea.

Table 4.4d. Soil organic carbon variation under treatments over cropping seasons

Seasons of cropping	Amendment				Cropping system		
	CTRL	PM	PM+CF	CF	CM	M/S	M/C
2006 – major	0.95	1.11	1.12	1.02	1.12	0.98	1.04
2006-minor	1.09	1.19	1.18	1.13	1.26	1.08	1.10
2007-major	1.12	1.25	1.30	1.14	1.29	1.11	1.21
LSD (0.05)	NS	NS	0.15	NS	0.16	NS	NS

CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, CM: Continuous maize, M/S: Maize / soybean, M/C: Maize / cowpea.

4.3.2 DISCUSSION

The SOM is the source of nutrients for crops that maintain soil fertility and productivity in farming systems (Powell *et al.*, 1999). A decline in organic matter is considered to create an array of negative effects on crop productivity, and therefore maintaining or improving the organic matter content is a prerequisite for ensuring soil quality, future agricultural productivity and sustainability (Katyal *et al.*, 2001). In general, SOC recorded in both years of study ranged from 0.77 – 1.37 % (1.33 - 2.36 % SOM) (Tables 4.4a - 4.4c) which is low (Ranamukhaarachchi *et al.*, 2005) but did not show decline over cropping seasons (Table 4.4d). According to Metson (1961), a productive soil should have an organic matter content of at least 4 % (2.32 % SOC). The generally low organic carbon recorded during the seasons was due to the low inherent soil fertility, high soil temperature and aeration favouring faster microbial activity (breakdown). Application of amendments (especially PM and PM + CF) during the two years of experimentation could not raise the organic carbon content in the respective amended plots to the optimum (2.32 %). This suggests that apart from the inherent soil fertility and the prevailing climatic conditions, appreciable rate of increase in SOC will depend on the length of time that management is imposed. Magdoff and Amadon (1980) showed that yearly applications of 66 Mg/ha of fresh dairy manure were needed to increase SOC from 3.0 to 3.2 % over a course of 11 years on a land on which silage corn was produced using conventional tillage. Seasonal variation of SOC in this study (Table 4.4d) indicated no appreciable increase in plots under amendments except in PM + CF plots which recorded significantly higher values in 2007-major season over values in 2006 –major season. This suggests that SOC content gives a picture of large changes in the soil in the long term.

Havlin *et al.* (1990) reported less organic carbon contents in soils from crop rotations that involved soybean and related this to the lower amounts of crop residues left after soybean as compared with those left after corn harvest. Clear comparisons revealed that organic carbon was, generally, lowest in plots under continuous soybean, followed by corn - soybean rotation and highest in continuous maize and maize - oat - meadow rotation systems, with no significant difference between the latter two systems (Moore *et al.*, 2000). The data from this study (Tables 4.4b and 4.4c) showed higher levels of SOC in CM than in M/S and M/C cropping systems, with significant ($P < 0.05$) differences between CM and M/S systems at the 21 and 42 DAA in the 2006 – minor season and at 42 and 63 DAA in 2007-major season. This was because CM cropping is a crop intensification system. Peterson *et al.* (1990) indicated that cropping intensification increased crop residue production and organic carbon storage in the soil. This further explain why results in Table 4.4d indicated significant increase in SOC in CM plots over cropping seasons whereas M/S and M/C plots recorded no significant increase. Between 63 and 84 days following amendments application in 2006-major season, there was virtually no change in SOC with respect to both the amended and the control plots. This suggested some apparent short term stability in organic carbon content in these plots.

4.4. NITROGEN MINERALIZATION

4.4.1 RESULTS

4.4.1.1 Soil nitrate – nitrogen

There were no significant differences ($P > 0.05$) between amendments on soil NO_3^- -N (Figs. 4.1a, 4.1c and 4.1e). The control however, recorded the highest values at 63 DAA in 2006 - major season (Fig 4.1a), 84 DAA in 2006 - minor season (Fig. 4.1c), and 21, 42 and 84 DAA in 2007 - major season (Figs. 4.1e). The 2006 - major season registered an increase in the level of NO_3^- -N from 21 to 42 days and peaked at 63 days after amendments application (Fig. 4.1a). This was followed by a sharp decline at 84 DAA. In contrast, values obtained in the 2006 - minor season followed increasing pattern (Fig. 4.1c). In 2007- major season, there was an increase in the level of NO_3^- -N between 21 to 42 DAA except for CF plots (Fig. 4.1e). At 63 DAA, there was a sharp decline which was characterized by immobilization in amended plots including the control except in plots amended with only chemical fertilizer (CF) (Fig. 4.1e).

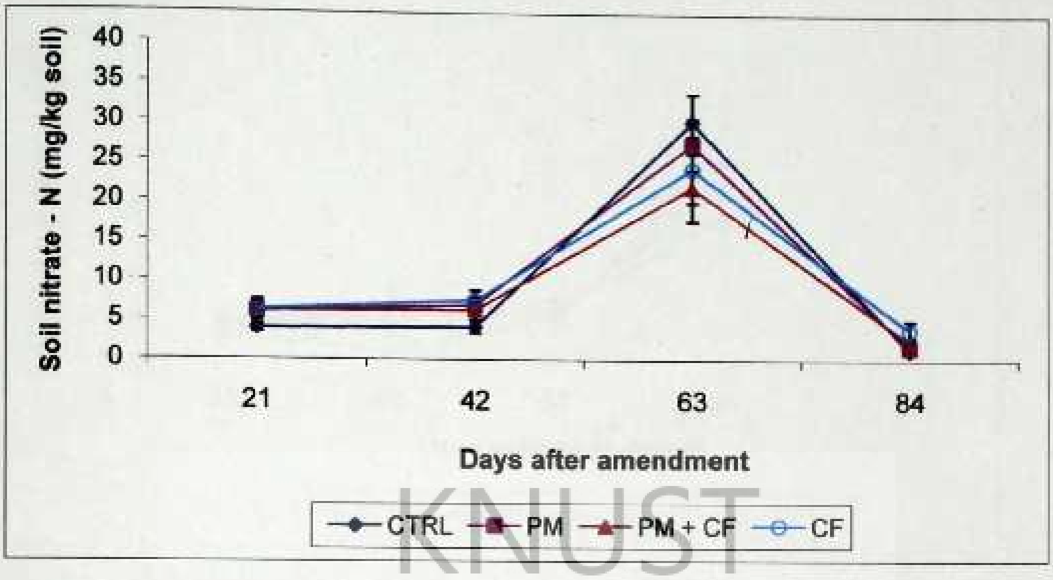

Fig. 4.1a. Soil nitrate -N under no amendment (CTRL), poultry manure (PM), poultry manure + chemical fertilizer (PM + CF) and chemical fertilizer (CF) amendments in 2006- major season on a Ferric Acrisol, Kwadaso.

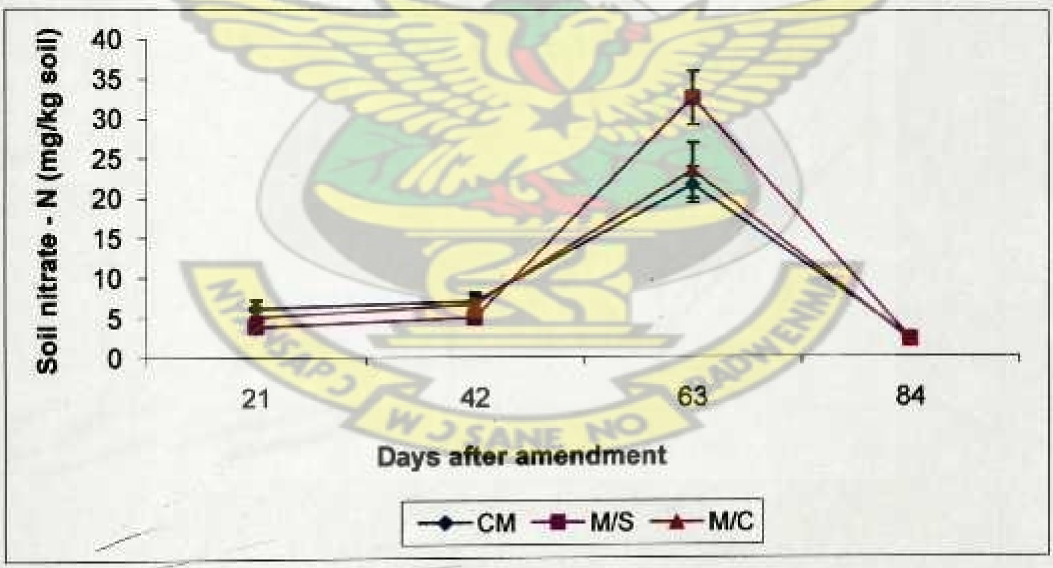

Fig. 4.1b. Soil nitrate -N under continuous maize (CM), maize/ soybean (M/S) intercrop and maize / cowpea (M/C) rotation systems in 2006 – major season on a Ferric Acrisol, Kwadaso.

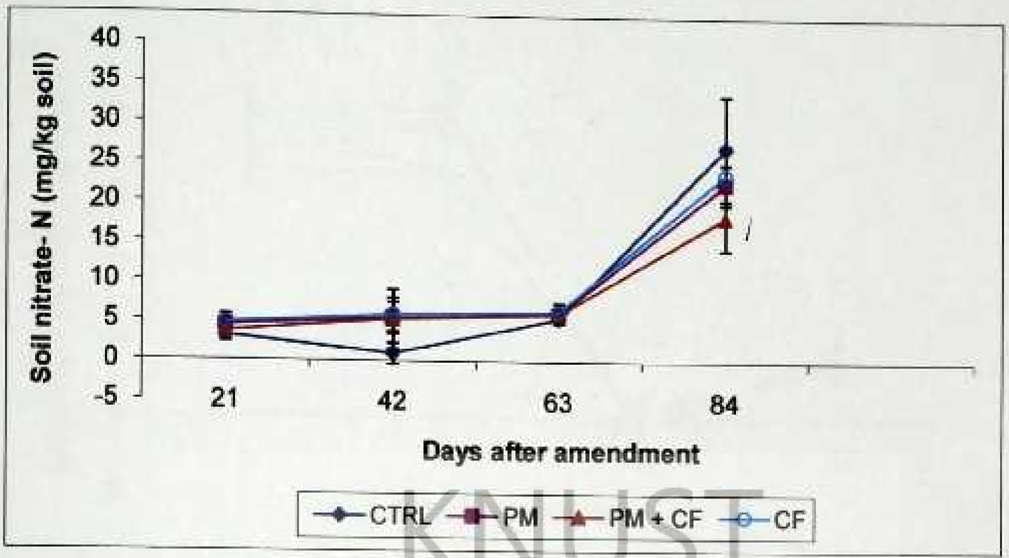

Fig. 4.1c. Soil nitrate -N under no amendment (CTRL), poultry manure (PM), poultry manure + chemical fertilizer (PM + CF) and chemical fertilizer (CF) amendments in 2006- minor season on a Ferric Acrisol, Kwadaso.

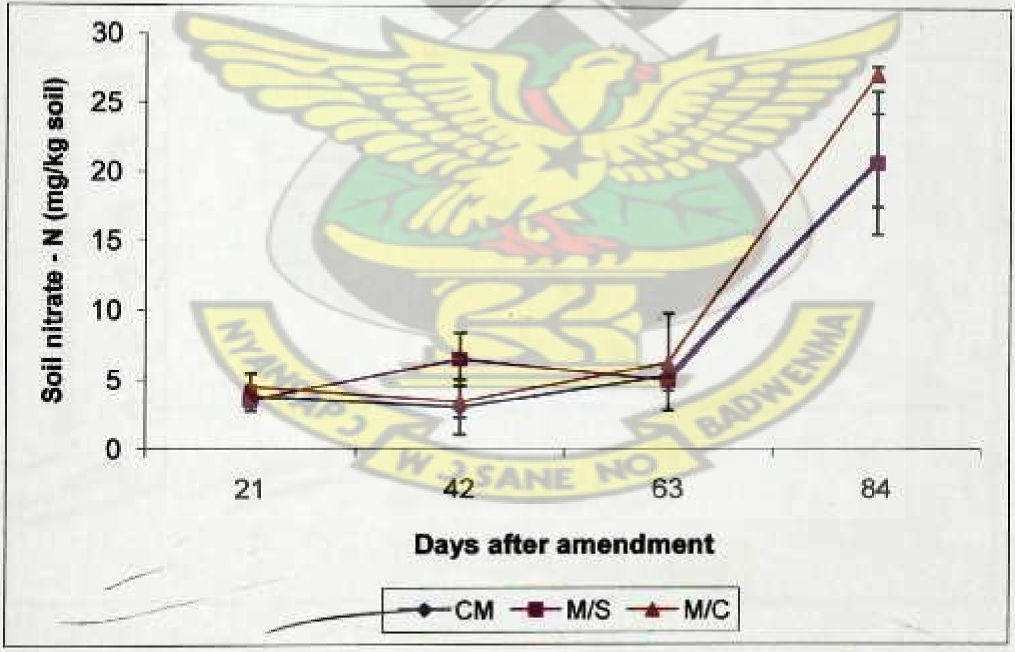

Fig. 4.1d. Soil nitrate -N under continuous maize (CM), maize/ soybean (M/S) intercrop and maize / cowpea (M/C) rotation systems in 2006 – minor season on a Ferric Acrisol, Kwadaso.

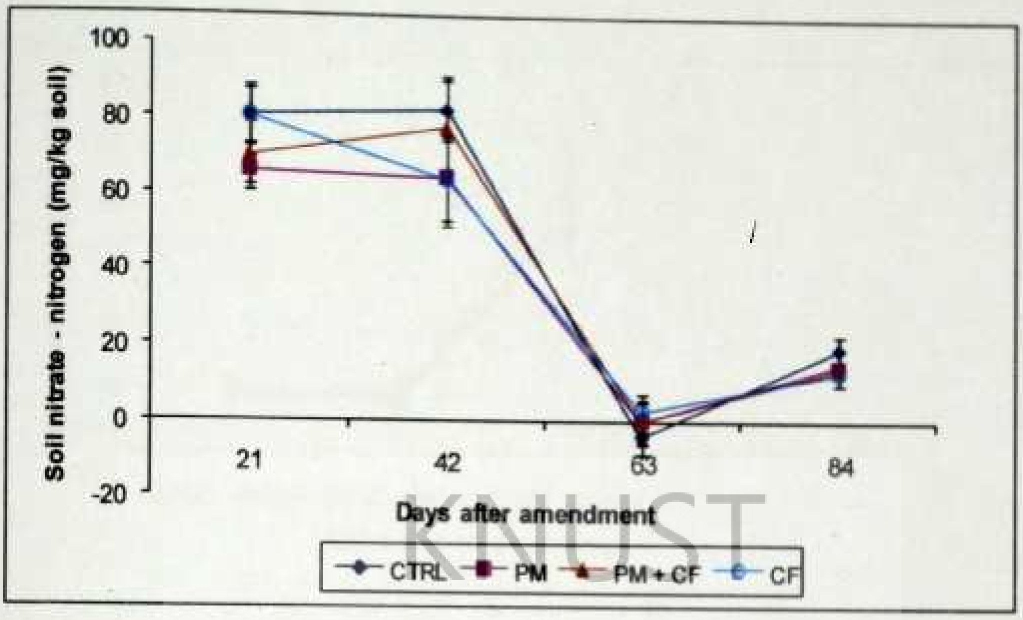

Fig. 4.1e. Soil nitrate- N under the control and amendments in 2007 – major season on a Ferric Acrisol, Kwadaso.

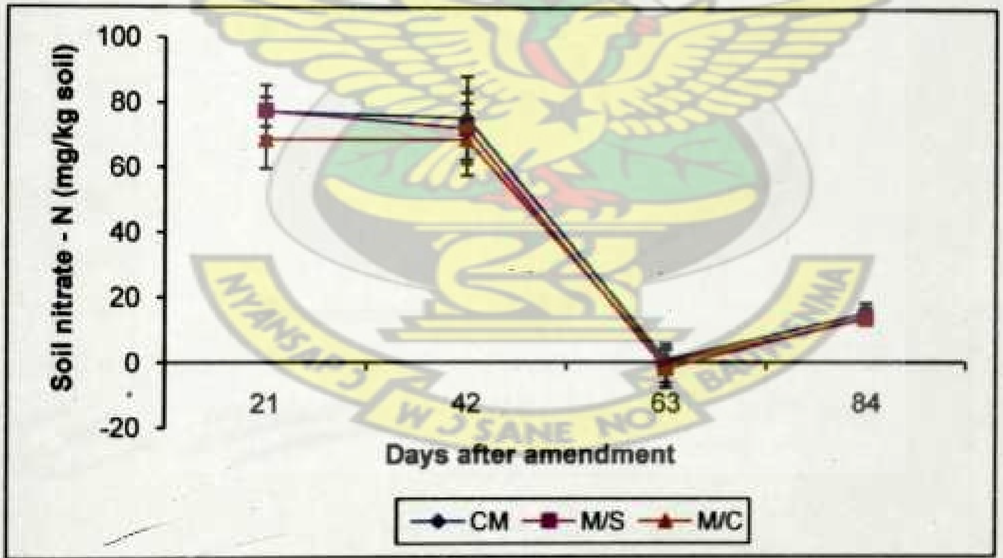

Fig. 4.1f. Soil nitrate- N under the cropping systems in 2007 – major season on a Ferric Acrisol, Kwadaso.

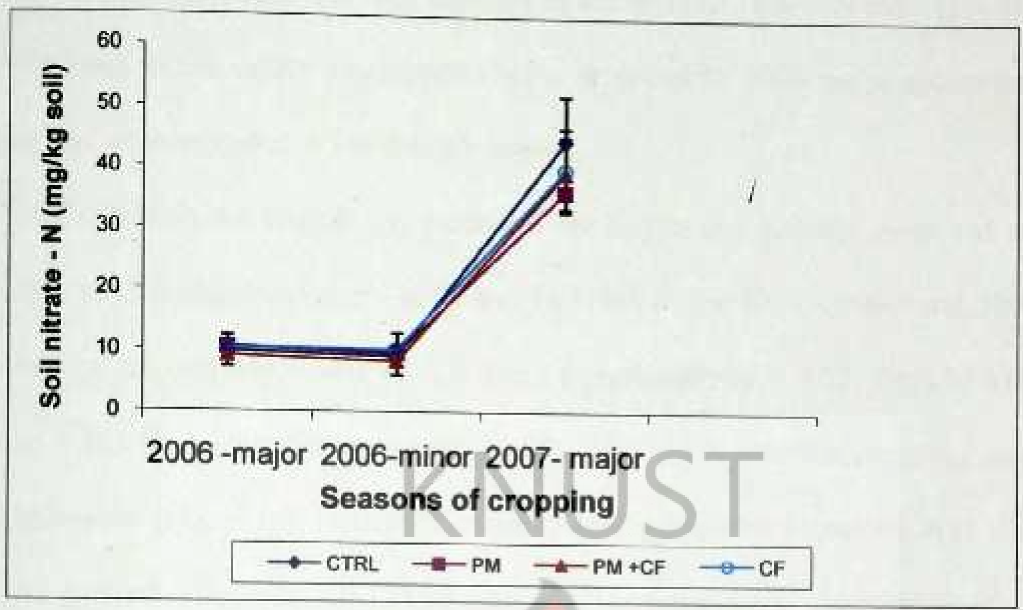

Fig. 4.1g. Variation of soil nitrate –N under amendments over cropping seasons on a Ferric Acrisol, Kwadaso.

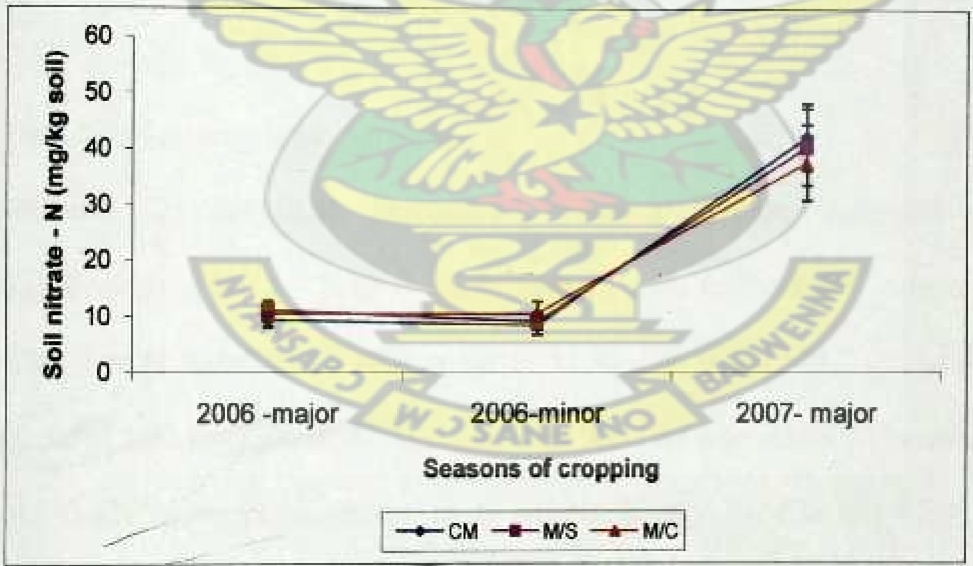

Fig. 4.1h. Variation of soil nitrate –N under cropping systems over cropping seasons on a Ferric Acrisol, Kwadaso.

The seasons generally recorded changes in the level of NO_3^- - N over time (Fig. 4.1g). The least values under amendments were recorded in 2006-major seasons whilst the highest were recorded in 2007-major season.

Nitrification in the cropping systems did not follow any specific trend and showed no significant differences except at 63 and 84 DAA in the 2006 - major and 2006 - minor seasons, respectively, where M/C differed significantly ($P < 0.05$) from M/S (Figs. 4.1b and 4.1d). However, differences ($P < 0.05$) in NO_3^- - N between cropping seasons were observable (Fig. 4.1h). Nitrate-N under cropping systems increased over the seasons. The highest values for CM, M/S and M/C systems were observed in 2007 –major season. A correlation analysis carried out (Table 4.5) showed a strong relationship between total nitrogen and NO_3^- - N with $r = 0.88^*$. This indicated that the amount of mineralization that occurred depended on the available soil substrate (total nitrogen).

4.4.1.2 Soil ammonium - nitrogen

Following 21 days after amendment, chemical fertilizer amended soils differed significantly in NH_4^+ - N ($P < 0.05$) from all soils in the 2007 – major season (Fig. 4.2e). On the average, CF soils recorded 11.95 mg/kg soil NH_4^+ - N whilst the control recorded 3.93 mg/kg soil. At 42 DAA, there were no significant differences in NH_4^+ - N ($P > 0.05$) between amendments in all seasons (Figs. 4.2a, 4.2c and 4.2e). At 63 and 84 DAA, chemical fertilizer treated plots produced significantly higher NH_4^+ - N than PM and PM + CF amended plots (Fig. 4.2a). Differences in NH_4^+ - N between cropping systems were statistically the same throughout the seasons except at 21 and 42 DAA in

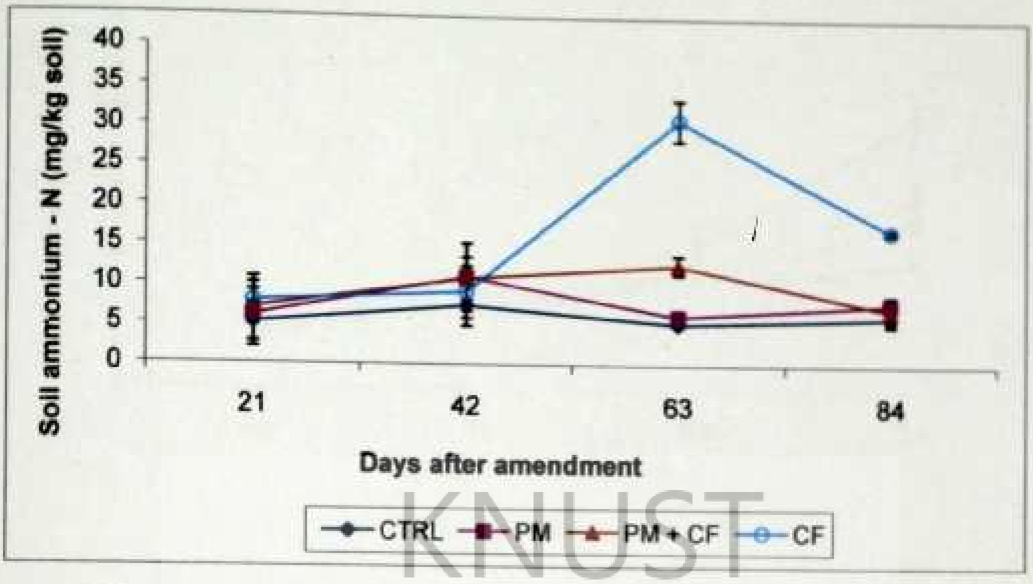

Fig. 4.2a. Mineralized soil ammonium-nitrogen under no amendment (CTRL), poultry manure (PM), poultry + chemical fertilizer (PM + CF) and chemical fertilizer (CF) amendments in 2006- major season on a Ferric Acrisol, Kwadaso.

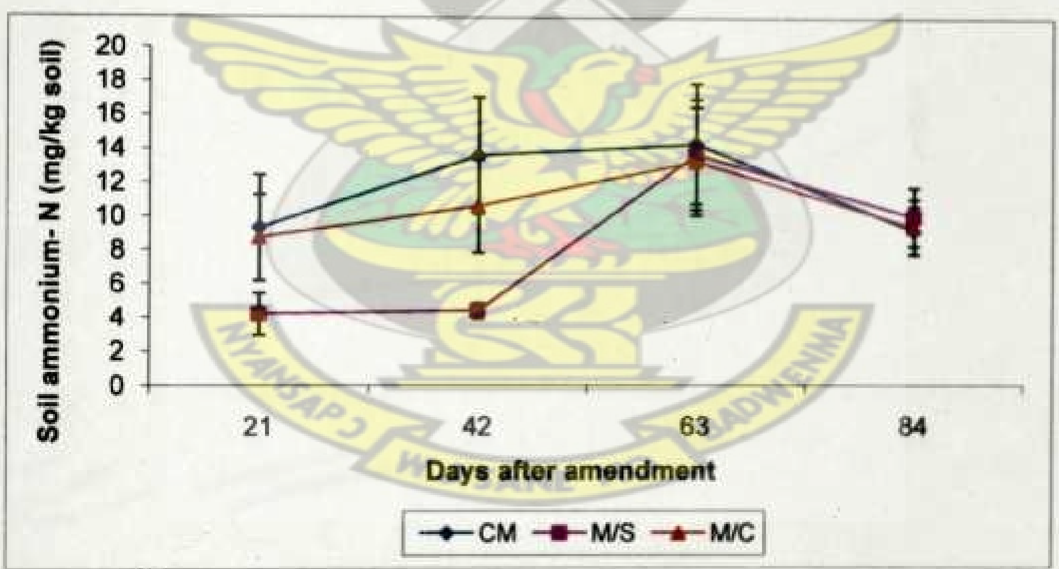

Fig. 4.2b. Mineralized soil ammonium-nitrogen under continuous maize (CM), maize/soybean (M/S) intercrop and maize / cowpea (M/C) rotation cropping systems in 2006- major season on a Ferric Acrisol, Kwadaso.

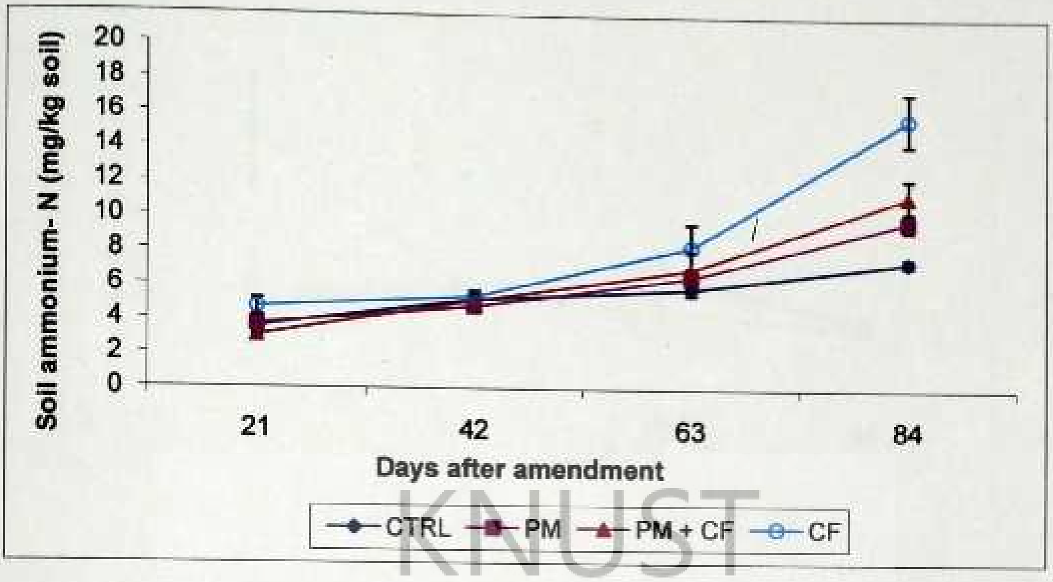

Fig. 4.2c. Mineralized soil ammonium-nitrogen under no amendment (CTRL), poultry manure (PM), poultry + chemical fertilizer (PM + CF) and chemical fertilizer (CF) amendments (CF) in 2006- minor season on a Ferric Acrisol, Kwadaso.

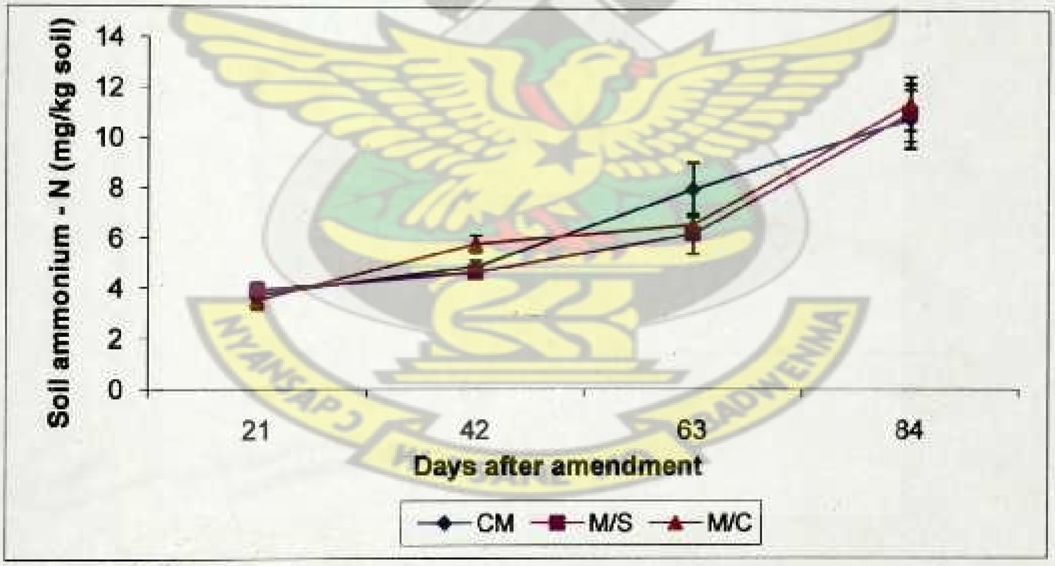

Fig. 4.2d. Mineralized soil ammonium – nitrogen under continuous maize (CM), maize/soybean (M/S) intercrop and maize / cowpea (M/C) rotation systems in 2006 – minor season on a Ferric Acrisol, Kwadaso.

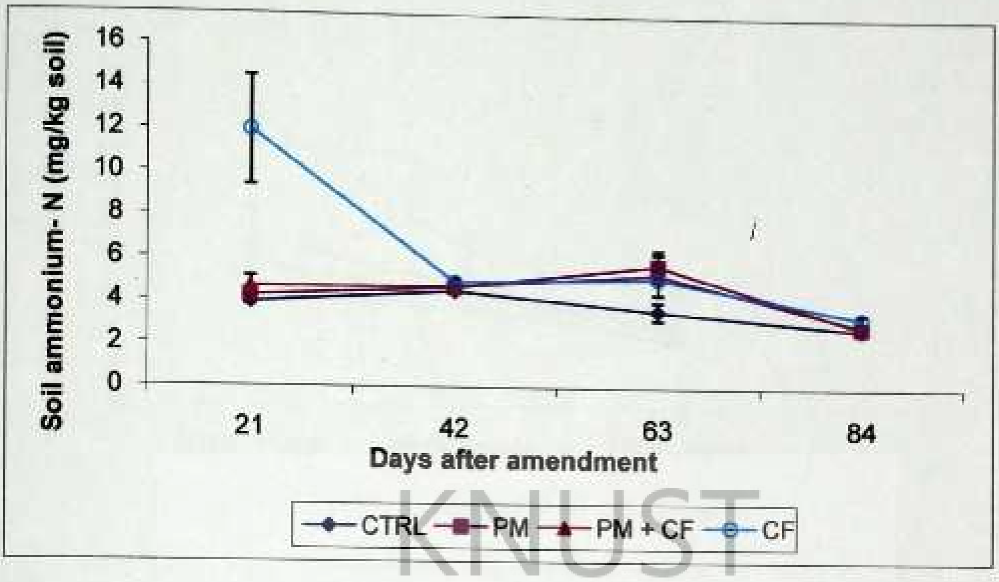

Fig. 4.2e. Variation of soil mineralized ammonium – nitrogen under amendments in 2007 –major season on a Ferric Acrisol, Kwadaso.

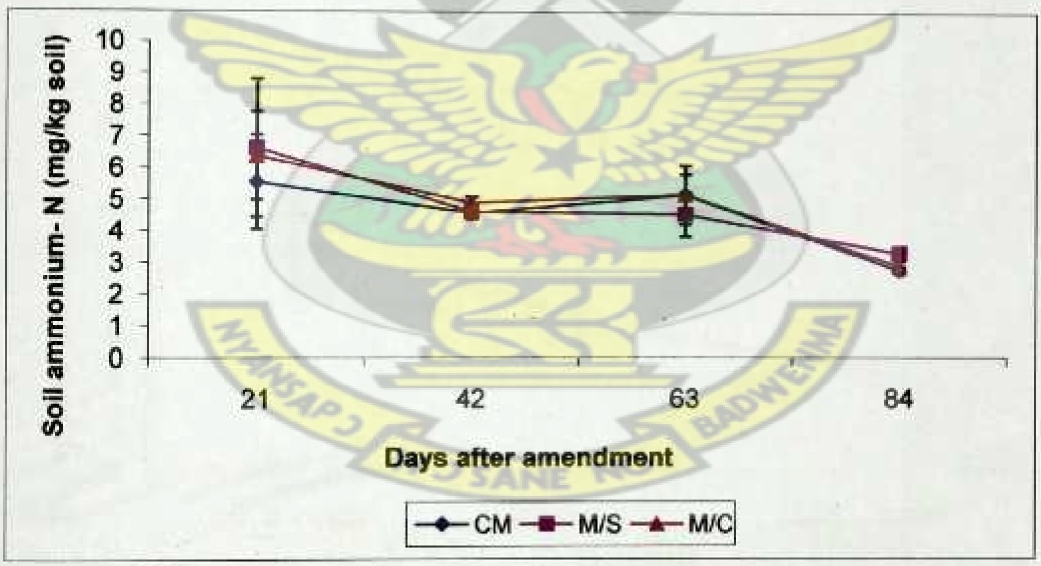

Fig. 4.2f. Variation of mineralized ammonium – nitrogen with respect to the cropping systems following amendment in 2007- major season on a Ferric a Ferric Acrisol, Kwadaso.

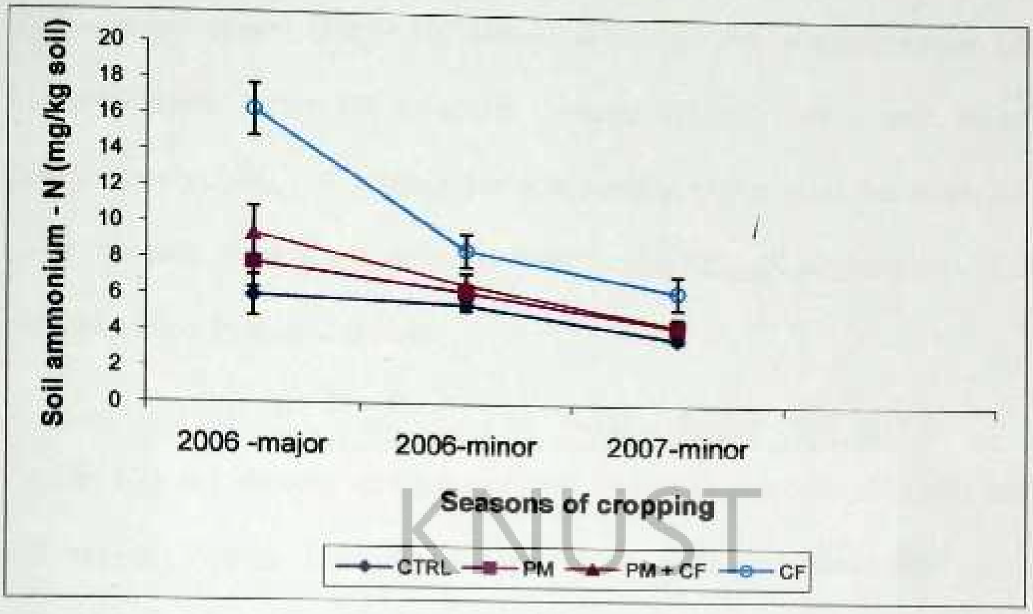

Fig. 4.2g. Variation of mineralized soil ammonium – N under amendments over cropping seasons on a Ferric Acrisol, Kwadaso.

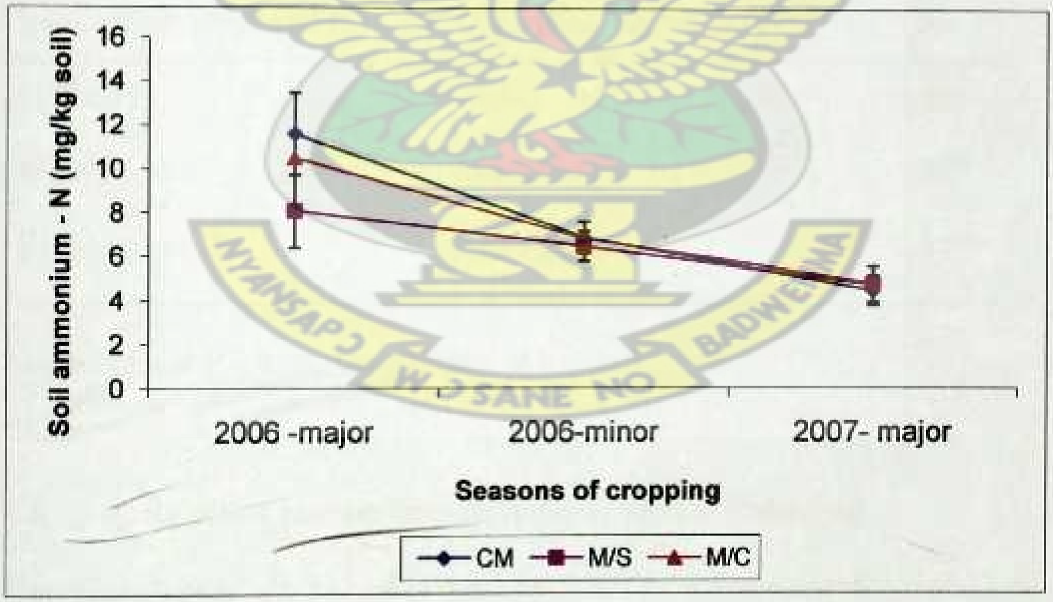

Fig. 4.2h. Variation of mineralized soil ammonium – N under cropping systems over cropping seasons on a Ferric Acrisol, Kwadaso.

2006 – major season (Fig. 4.2b) and 42 DAA in 2006 – minor season (Fig. 4.2d). Ammonification under the cropping systems did not follow any specific trend. Comparatively, NH_4^+- N levels were occasionally higher than the levels of NO_3^- -N under cropping systems and amended plots. Unlike NO_3^- -N, ammonium - N showed no immobilization in amended plots.

Figures 4.2g & h showed seasonal variations in soil ammonium – N under amendments and cropping systems. Generally, the least values were recorded in 2007 –major season whilst 2006- major season produced the highest. A significant positive correlation was found between NH_4^+- N and exchangeable K (Table 4.5).

Table 4.5. Coefficients of correlation (r) between some soil chemical properties

Independent parameter (x)	Dependent parameter (y)	r
% Total N	Nitrate – N	0.88*
Nitrate – N	Microbial N	0.87*
Exchangeable K	Ammonium – N	0.77**

*Significant at $P < 0.05$, **significant at $P < 0.01$

4.4.1.3 Ratio of soil ammonium - nitrogen to nitrate – nitrogen

The ratios of NH_4^+ -N: NO_3^- -N varied considerably in the seasonal cycles (Tables 4.6a - 4.6c). At 21 DAA in 2006 - major season, plots that received PM amendment recorded the least value of 1.0 which differed significantly ($P < 0.05$) from those of PM + CF and CF amended plots (Table 4.6a). At 42 DAA in 2006 - minor season, plots under CF amendment recorded the highest value (2.7) whilst PM amended plots gave the least (0.5) following 84 DAA (Table 4.6b). The 2007- major season however, recorded the lowest (-1.1) at 63 DAA for PM treated soils and highest (0.3) for CF treated plots on the 84 DAA (Table 4.6c). Cropping systems significantly ($P < 0.05$) influenced NH_4^+-N: NO_3^--N ratios in all seasons of study.

Table 4.6a. Variation of NH_4^+-N: NO_3^--N ratio under treatments in 2006 - major season

	NH_4^+-N : NO_3^--N ratio			
Treatments	21 DAA	42 DAA	* 63 DAA	84 DAA
Amendment				
CTRL	1.3	3.6	0.2	9.4
PM	1.0	1.5	0.2	8.2
PM + CF	1.2	1.4	0.8	6.7
CF	1.3	2.9	0.9	17.4
LSD (0.05)	0.19	0.24	0.07	1.51
Cropping system				
CM	1.5	2.1	0.7	5.5
M/S	1.1	2.2	0.6	11.6
M/C	1.8	2.7	0.6	14.2
LSD (0.05)	0.21	0.38	NS	1.89

Values are the means of 3 replications; DAA - days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, * 63 DAA: marked by occurrence of Birch effect.

Table 4.6b. Variation of NH_4^+-N: NO_3^--N ratio under treatments in 2006 - minor season

Treatments	NH_4^+-N : NO_3^--N ratio			
	21 DAA	42 DAA	63 DAA	* 84 DAA
Amendment				
CTRL	2.3	2.0	1.2	0.6
PM	1.8	1.0	1.3	0.5
PM + CF	0.9	1.3	1.3	1.4
CF	1.9	2.7	1.5	0.9
LSD (0.05)	0.14	0.26	0.22	0.13
Cropping system				
CM	1.9	3.2	1.7	0.3
M/S	2.4	0.8	1.4	0.8
M/C	0.9	1.3	1.0	0.9
LSD (0.05)	0.19	0.30	0.20	0.09

Values are the means of 3 replications; DAA - days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, *84 DAA: day marked by occurrence of Birch effect.

Table 4.6c. Variation of NH_4^+-N: NO_3^--N ratio under treatments in 2007-major season

Treatments	NH_4^+-N : NO_3^--N ratio			
	* 21 DAA	* 42 DAA	** 63 DAA	* 84 DAA
Amendment				
CTRL	0.1	0.1	-0.4	0.2
PM	0.1	0.1	-1.1	0.2
PM + CF	1.0	0.1	-0.5	0.2
CF	0.2	0.1	0.3	0.3
LSD (0.05)	0.01	NS	0.01	0.04
Cropping system				
CM	0.1	0.1	-1.3	0.2
M/S	0.1	0.1	0.1	0.3
M/C	0.1	0.1	-0.1	0.2
LSD (0.05)	NS	NS	0.02	0.04

Values are the means of 3 replications; DAA - days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, * 21 DAA, *42 DAA, *84 DAA: days characterized by Birch effect, ** 63 DAA: day characterized by immobilization of NO_3^--N.

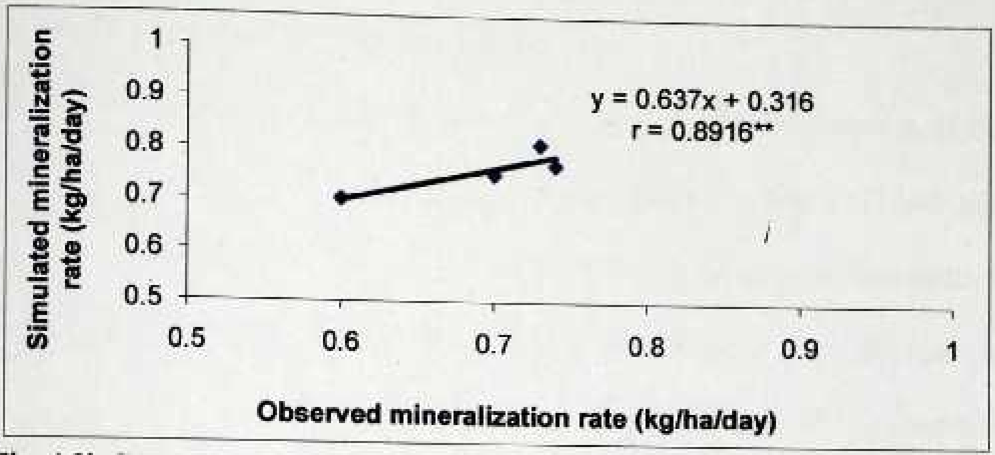

Fig. 4.2i. Comparison of mean measured and predicted total mineralization (NO_3^- - N plus NH_4^+ - N) rates in 2006 – major season on a Ferric Acrisol, Kwadaso.

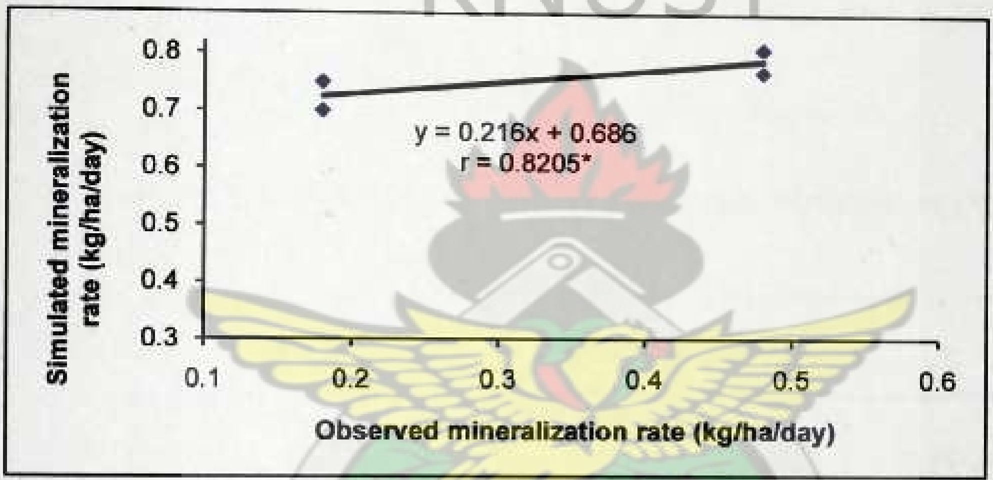

Fig. 4.2j. Comparison of mean measured and predicted total mineralization (NO_3^- - N plus NH_4^+ - N) rates in 2006 – minor season on a Ferric Acrisol, Kwadaso.

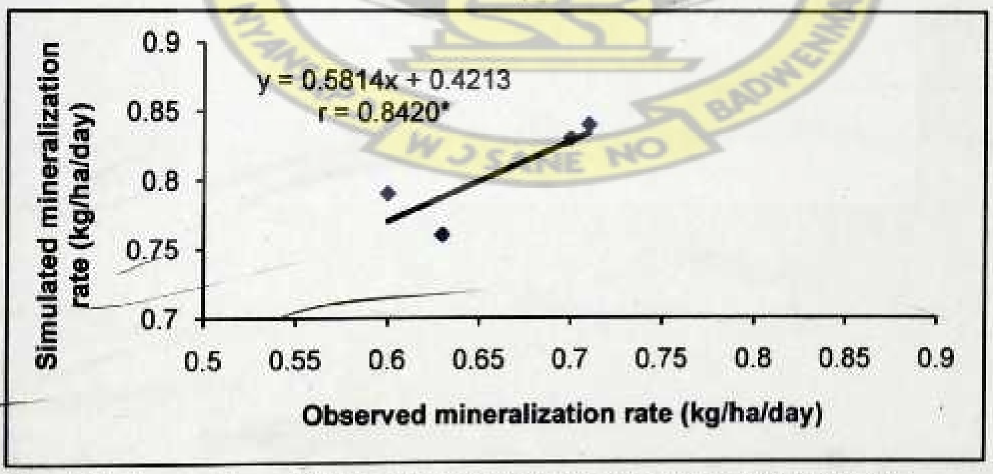

Fig. 4.2k. Comparison of mean measured and predicted total mineralization (NO_3^- - N plus NH_4^+ - N) rates in 2007 – major season on a Ferric Acrisol, Kwadaso.

4.4.1.4 Modelling mineralization rates

Once the study has shown significant changes in mineralization at sampling periods (Figs. 4.1a - 4.1f and 4.2a - 4.2f), it is important to predict rates of mineralization during the seasonal cycles. Figures 4.2i – 4.2k show predicted and measured rates of total mineralization (NO_3^- plus NH_4^+) during the seasons. The nitrogen sub - model (Ruhlmann, 1999; Greenwood, 2001) predicted higher rate of N mineralization in 2006 and 2007- major seasons (Fig. 4.2i & k) than in the minor season of 2006 (Fig. 4.2j). The lowest (26 %) and highest (41 %) MdUAPE were recorded in 2006-major and 2006- minor seasons, respectively (Table 4.7).

Table 4.7. Performance of nitrogen model to predict rates of mineralization

Season	MdUAPE (%)	r
2006-Major	26	0.8916**
2006-Minor	41	0.8205*
2007-Major	32	0.8420*

MdUAPE: median unbiased absolute percentage error, *significant at $P < 0.05$, **Significant at $P < 0.01$.

4.4.1 DISCUSSION

4.4.2.1 Soil nitrate - nitrogen

The insignificant differences in nitrification following amendments application (Figs. 4.1a, 4.1c and 4.1e) have been reported in literature. The nitrogen available for crop growth following application is often estimated from the ammoniacal N plus a portion of the soil organic nitrogen (Sluijsmans and Kolenbrander, 1997). This study confirmed an earlier observation by Paul and Beauchamp (1996) that the organic nitrogen fraction in manure was not available compared to the soil organic N.

Nitrate - N at the level of the amendments and cropping systems followed an increasing pattern in the minor season (Figs. 4.1c, 4.1d). A similar observation was made by Snapp and Borden (2005) when they found in cereals and legumes cropping systems that NO_3^- levels increased gradually over time. In Ghana, Nye and Stephens (1962) observed a gradual increase in NO_3^- during the dry season and a more rapid increase as soon as the rains began. The relatively higher nitrate - nitrogen recorded at 63 and 84 days following amendment in 2006 - major and 2006 - minor seasons, respectively and also at 21, 42 and 84 DAA in 2007 - major season was possibly due to 'Birch effect'. There is often a marked seasonality of organic matter decomposition in the wet and dry tropics due to a flush of decomposition associated with the rewetting of dry soils (Birch, 1964; Cabrera, 1993; Appel, 1997). This can lead to a pronounced flush of nitrate in the soil at the onset of the rains which is susceptible to leaching in cultivated soils. The soil of the study area experienced short dry spells which were followed by resumption of rains. Results of this study showed that the 'Birch effect' was characterized by immobilization of nitrate in the amended plots as the control nitrate values were consistently higher than those of the amended plots. The flush of nitrate associated with occurrence of 'Birch effect' by virtue of the decomposition of organic matter was carried out by nitrifying bacteria (*Nitrobacter* and *Nitrosomonas*). Mclaren (1969) stated that these microorganisms obtain most of their energy from the process itself. The microbes in obtaining their energy from the process, immobilized the nitrate in the amended plots.

This study has established that sampling periods rather influenced mineralization significantly than amendments and cropping systems.

If microorganisms are dynamic controllers of nutrient dynamics in a soil, an increase in microbial biomass should result in increased nutrient supply to the plant. Since nitrogen mineralization is an index of the rate of supply of plant available N, it should be affected favourably by an increase in microbial biomass (Hema, 1995). This study revealed a positive correlation ($r = 0.87^*$) between microbial biomass N and NO_3^- -N (Table 4.5).

4.4.2.2 Soil ammonium - nitrogen

The recorded NH_4^+ - N during the cropping seasons (Figs. 4.2a – 4.2f) showed changes in its level in the soil over time (especially at the level of the amendments). This could be due to the microbiological activity and the influence of crop uptake at different stages of growth and was in contrast with the observation of Snapp and Borden (2005) who reported constant pool size of NH_4^+ - N. Like nitrate -N, values recorded for ammonium-N in the 2006 - minor season followed increasing pattern over time. Comparatively, levels of NO_3^- -N and NH_4^+ - N did not show consistency. The NO_3^- -N levels were higher than NH_4^+ - N at the 21 and 42 DAA (Fig. 4.1e) whilst NH_4^+ - N was higher at the 63rd day (Fig. 4.2e). At the 84 DAA (Figs. 4.1c and 4.2c), NO_3^- -N was higher than NH_4^+ - N. Das *et al.* (1997) observed that the lowest NO_3^- -N and NH_4^+ - N concentrations were obtained during the rainy season and the highest during the dry season, with extractable NH_4^+ - N always higher than extractable NO_3^- -N. Ammonium-N is less subject to leaching or denitrification losses, so N maintained as NH_4^+- N in the soil should be available for late - season uptake (Tsai *et al.*, 1992). Data from this study indicated no immobilization of NH_4^+ by soil microbes as was recorded for NO_3^-. This contrasted a report by Azam *et al.* (1993) that the NH_4^+ - N has been found to be the preferred form of N for assimilation by microbes in many cultivated soils. In some agricultural soils, no NO_3^- immobilization has been observed (Shai and Norton, 2000); while in others NO_3^- immobilization was recorded after 1 - 4 weeks (Schimel, 1986) or several months (Kissel and Smith, 1978).

4.4.2.3 Soil ammonium – nitrogen to nitrate – nitrogen ratios

The effects of amendments and cropping systems on NH_4^+ - N: NO_3^- - N ratios have received little attention in most studies. The few instances reported in literature focused only on the effect of crop uptake on these ratios. For example, Warncke and Barber (1973) investigated the relative rates of NH_4^+ and NO_3^- uptake by corn using solution – culture experiments in a controlled - climate chamber. The researchers used five NH_4^+ - N : NO_3^- - N ratios ranging from 8.40 to 0.17 and found no significant differences in relative rates of absorption of NO_3^- and NH_4^+. This study however, investigated the impact of amendments under different cropping systems on NH_4^+ -N: NO_3^- -N ratios. Generally, the lowest ratios were produced at 63 DAA in 2006 - major season, 84 DAA in 2006 - minor season and at all sampling periods in 2007-major season. These low ratios were due to the high levels of NO_3^- -N recorded by virtue of 'Birch effect'. This observation was consistent with the occurrence of 'Birch effect'. The negative values recorded in CTRL, PM, PM + CF, CM, and M/C plots at 63 DAA in 2007- major season (Table 4.6c) were due to nitrate –N immobilization at 63 DAA (Figs. 4.1e and 4.1f) in these plots.

4.4.2.4 Modelling mineralization rates

Most studies on modelling of mineralization involved the use of empirical models under laboratory conditions. For instance, Stanford and Smith (1972) proposed an exponential model to study N - mineralization from organic matter incubated at constant temperature and moisture. According to them, the variation of mineralization rate was very small for 39 soils. This study, however, considered mineralization rates (NO_3^- - N plus NH_4^+ - N) under field conditions. The study has established that a range of 0.18 - 0.73 kg N /ha/day could be recorded as total mineralized N (NO_3^- - N plus NH_4^+ - N) during a cropping season under Ghana's climatic conditions. Barber (1995) reported an annual release value varying from 10 - 200 kg/ha/year (i.e. 0.03 - 0.55 kg/ha/day) for soils with nitrogen content ranging from 0.02 – 0.4 % (weight/weight) and bulk density of 1.3 g/cm^3. Mineralization varies greatly from soil to soil as a consequence of differences in organic matter content and soil texture (Ruhlmann, 1999). In a study where poultry manure litter samples were incubated with soil to measure net mineralization, Gordillo and Cabrera (1997) found that the rate constant of mineralization of the slow pool did not vary significantly among poultry litter samples, with an average value of 0.036/day. In the same study, the rate constant for the fast pool varied among poultry litter samples with an average value of 1.2/day (Gordillo and Cabrera, 1997). The rate of mineralization is influenced by nutrient supply, temperature, pH, aeration, moisture, organic matter and the presence of inhibitors (Barber, 1995).

The high rates of mineralization recorded in this study explain why most Ghanaian soils are characterized by nitrogen deficiencies as most of the mineralized nitrogen is subjected to leaching. Acquaye (1973) reported nitrogen deficiency in savanna soils of northern Ghana.

4.5 SOIL MICROBIAL BIOMASS CARBON, NITROGEN AND PHOSPHORUS

4.5.1 RESULTS

4.5.1.1 Soil microbial carbon and nitrogen

Soil microbial biomass carbon and nitrogen were generally influenced similarly by amendments (Figs. 4.3a, 4.3c, 4.3e, 4.3i and 4.3k). Significant differences ($P < 0.05$) were however, observed between cropping systems 21 days following amendment in 2006 - major and minor seasons (Figs. 4.3b and 4.3L). At 63 DAA in 2007 - major season, chemical fertilizer plots recorded significantly higher ($P < 0.05$) microbial biomass nitrogen than all plots (Fig. 4.3m). Microbial biomass nitrogen was observably affected by sampling periods in both years of study (Figs. 4.3i - 4.3n). However, biomass carbon was significantly influenced ($P < 0.05$) only in 2006 - minor season (Figs. 4.3c and 4.3d). There were fluctuations in microbial biomass carbon and nitrogen at the sampling periods. The least and highest values were generally obtained at 42 and 63 DAA respectively (Figs. 4.3a & b, 4.3i, 4.3j, 4.3m and 4.3n). Microbial biomass carbon recorded during the 2006 - major and minor seasons ranged from 25 – 248 mg C/kg soil and 87 – 713 mg C/kg soil, respectively. For the 2007 – major season, a range of 546 – 770 mg C/kg soil was registered. Biomass N under amendments ranged from 10.4– 33.6 mg/kg soil, 12.1– 33.9 mg/kg soil and 13.1 – 35.7 mg/kg soil in

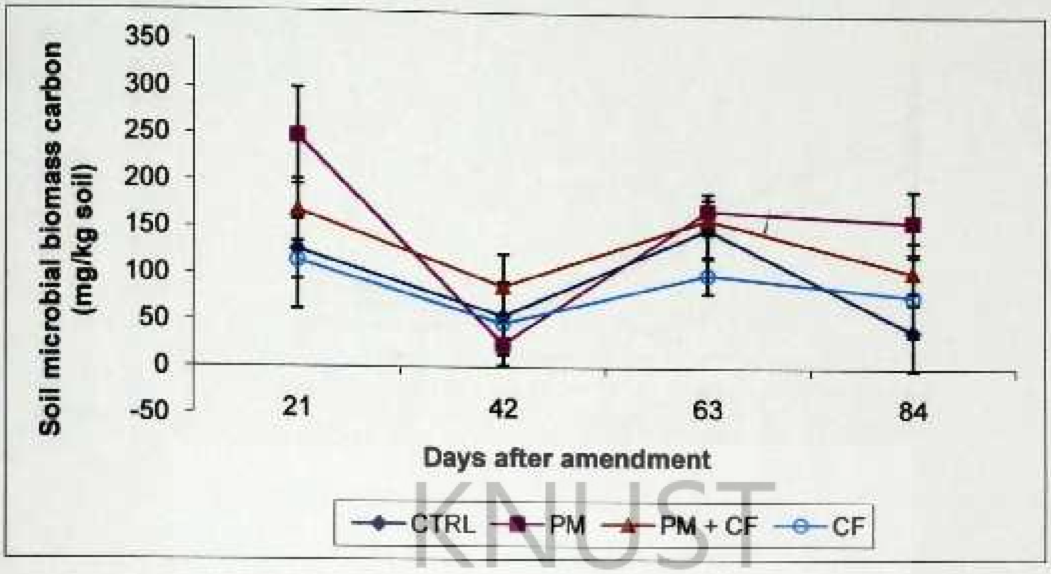

Fig. 4.3a. Soil microbial biomass carbon dynamics under amendments in 2006 -major season on a Ferric Acrisol, Kwadaso.

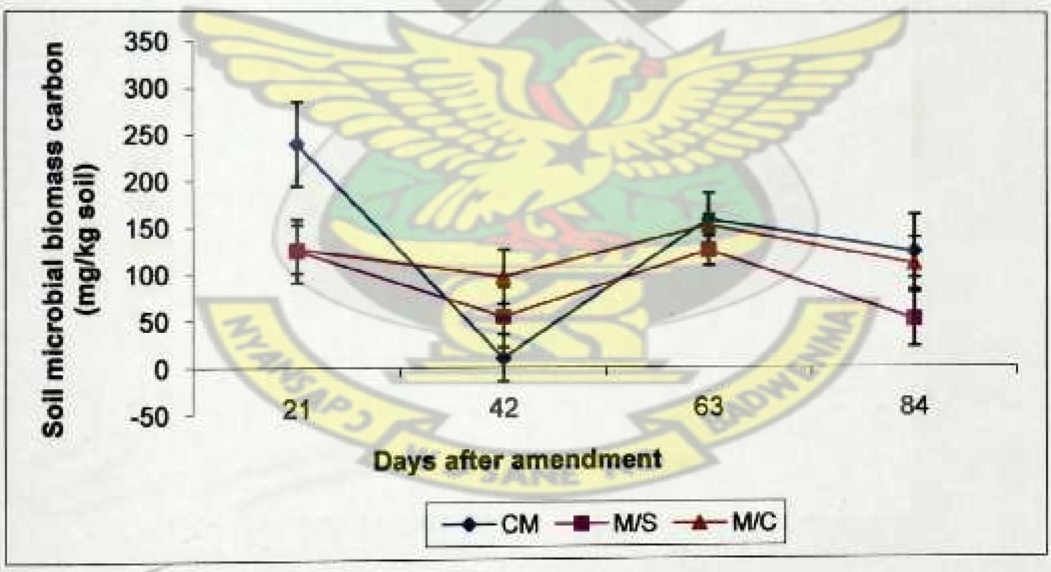

Fig. 4.3b. Soil microbial biomass carbon dynamics under cropping systems in 2006 – major season on a Ferric Acrisol, Kwadaso.

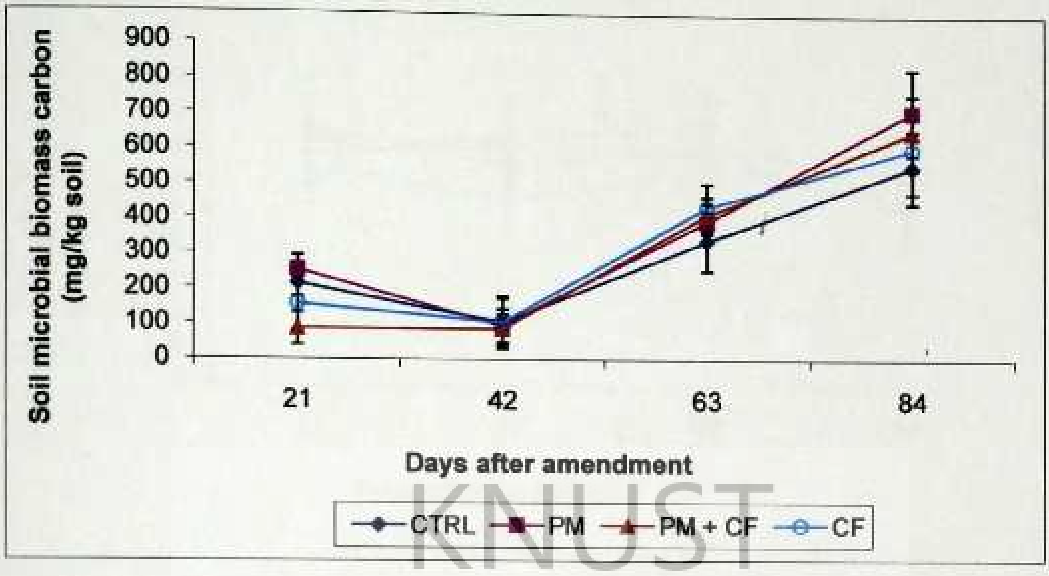

Fig. 4.3c. Soil microbial biomass carbon dynamics under amendments in 2006 – minor season on a Ferric Acrisol, Kwadaso.

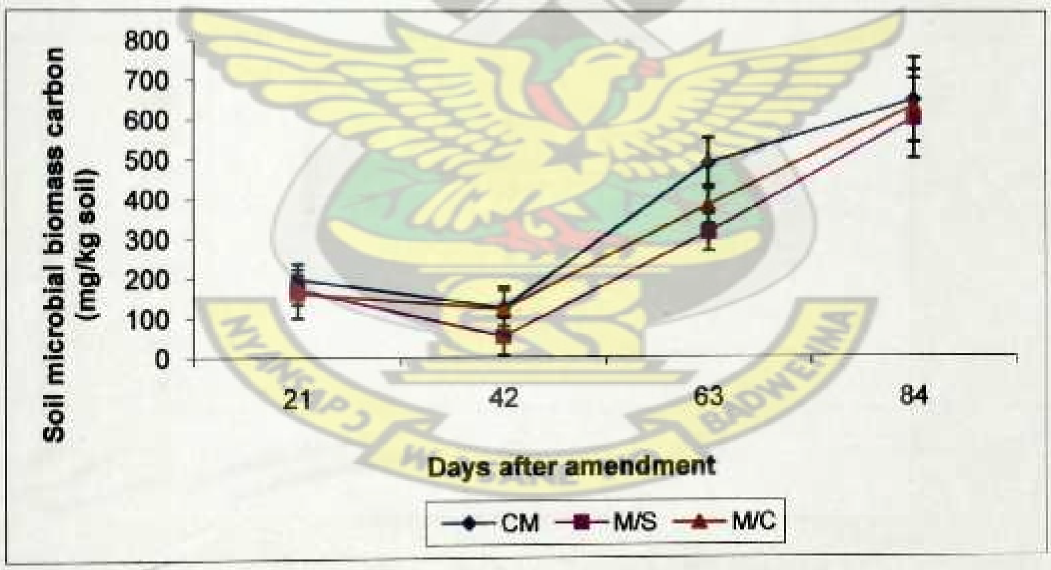

Fig. 4.3d. Soil microbial biomass carbon dynamics under cropping systems in 2006 - minor season on a Ferric Acrisol, Kwadaso.

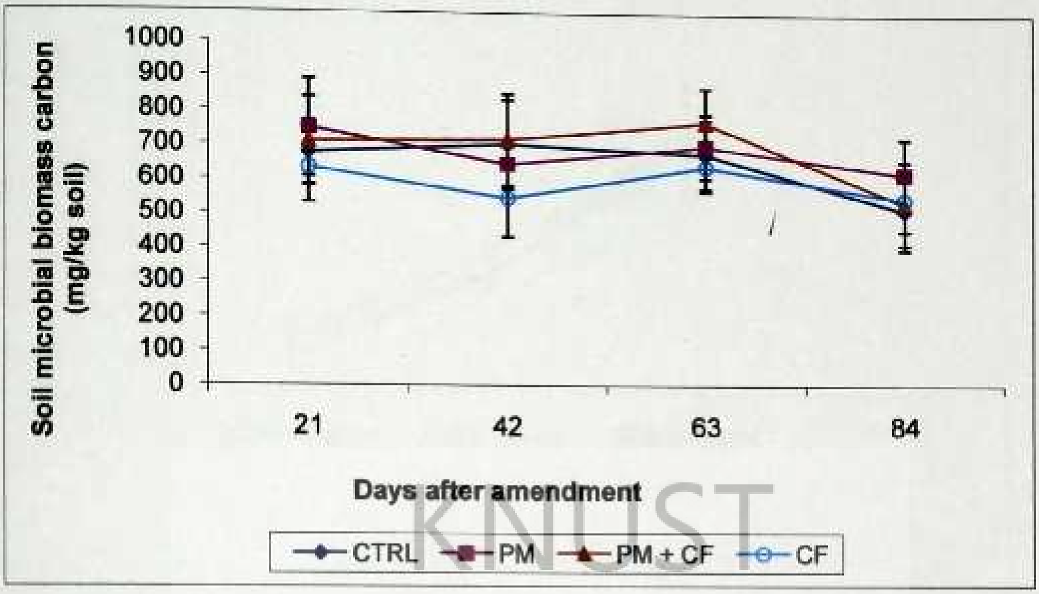

Fig. 4.3e. Dynamics of soil microbial biomass carbon under amendments during the 2007 - major season on a Ferric Acrisol, Kwadaso.

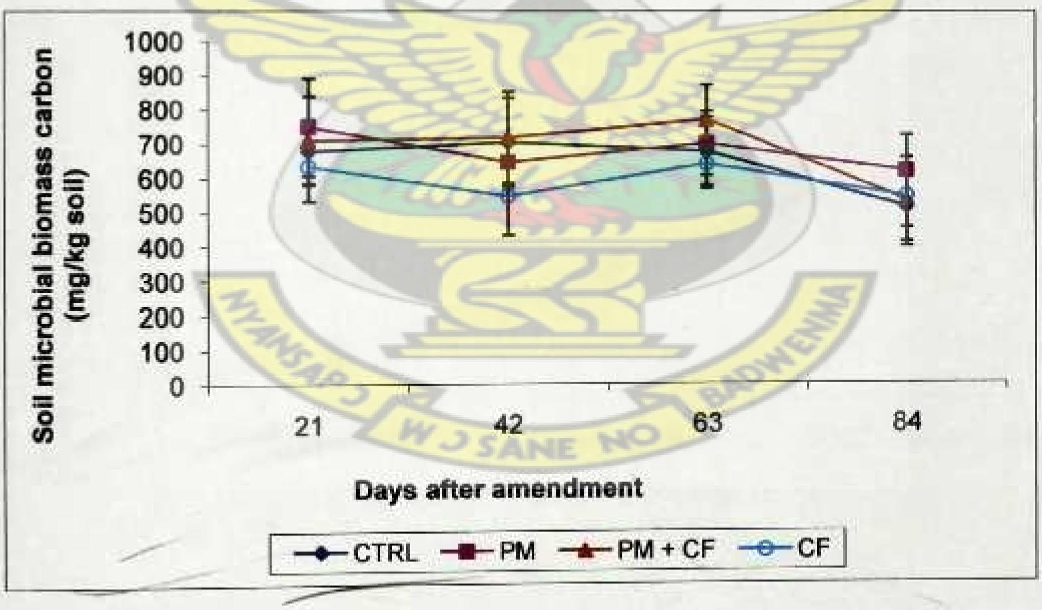

Fig. 4.3f. Dynamics of soil microbial biomass carbon under the different cropping systems during the 2007 - major season on at Ferric Acrisol, Kwadaso.

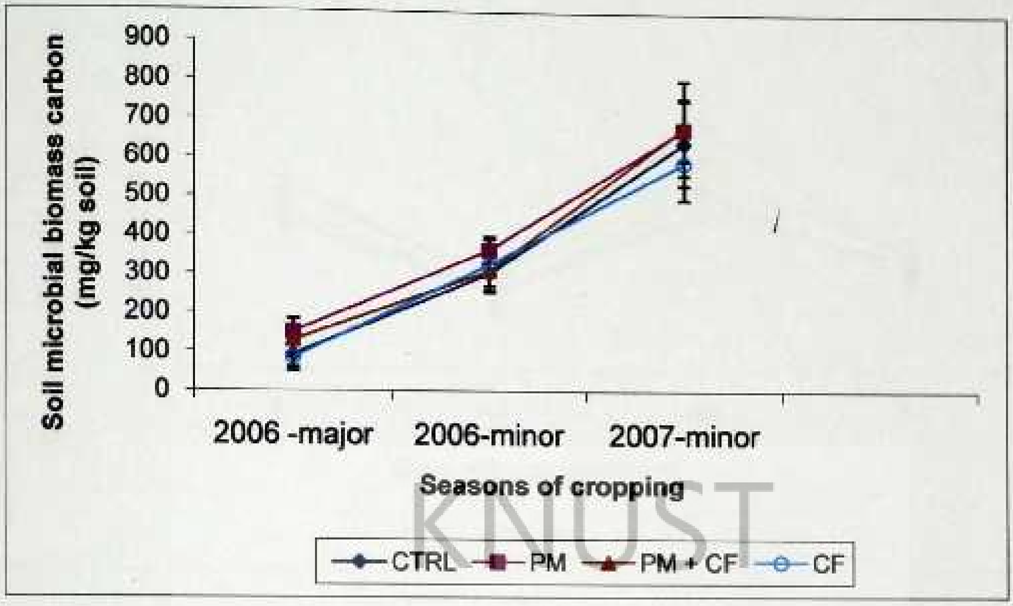

Fig. 4.3g. Variation of soil microbial biomass carbon under amendments over cropping seasons on a Ferric Acrisol, Kwadaso.

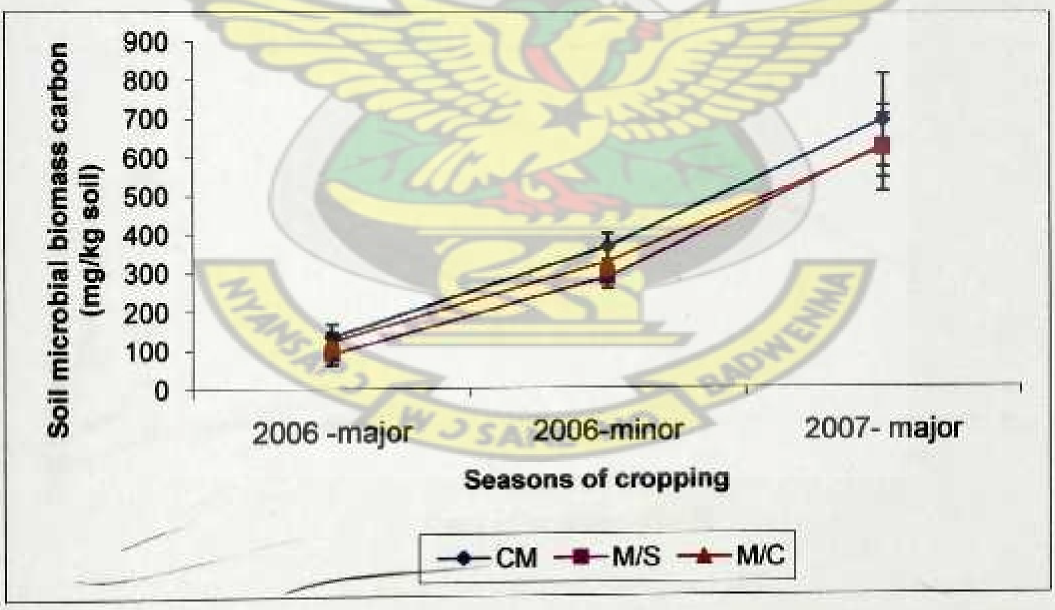

Fig. 4.3h. Variation of soil microbial biomass carbon under cropping systems over cropping seasons on a Ferric Acrisol, Kwadaso.

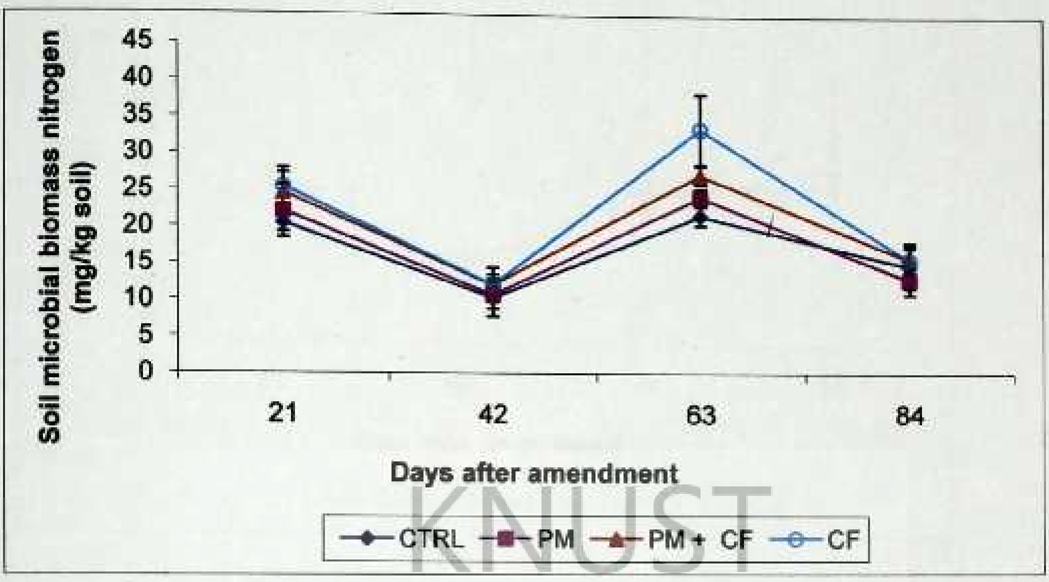

Fig. 4.3i. Soil microbial biomass nitrogen dynamics under amendments and control in 2006-major season on a Ferric Acrisol, Kwadaso.

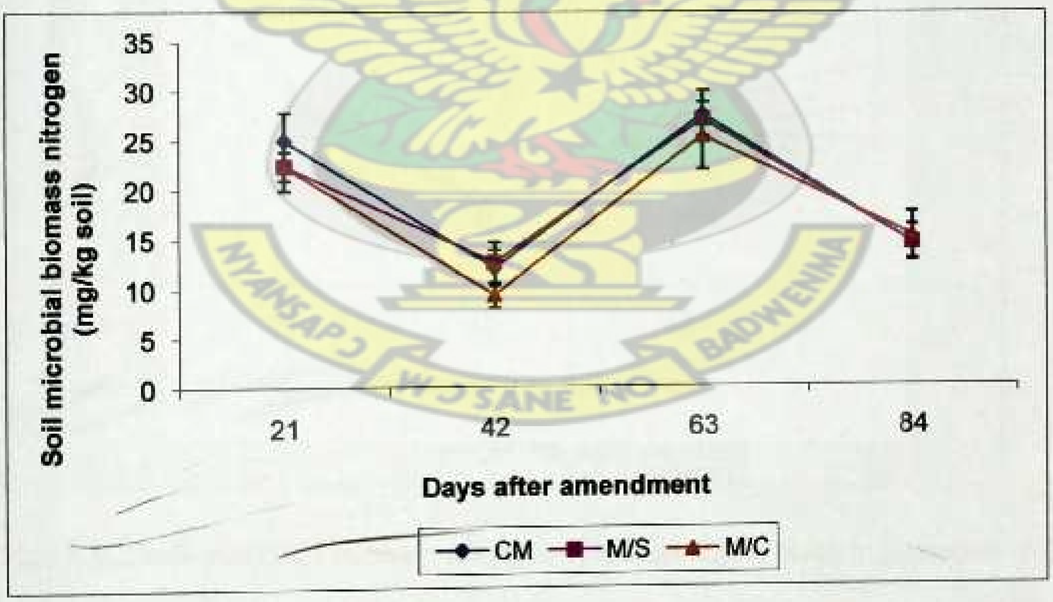

Fig 4.3j. Soil microbial biomass nitrogen dynamics under the different cropping systems in 2006-major season on a Ferric Acrisol, Kwadaso.

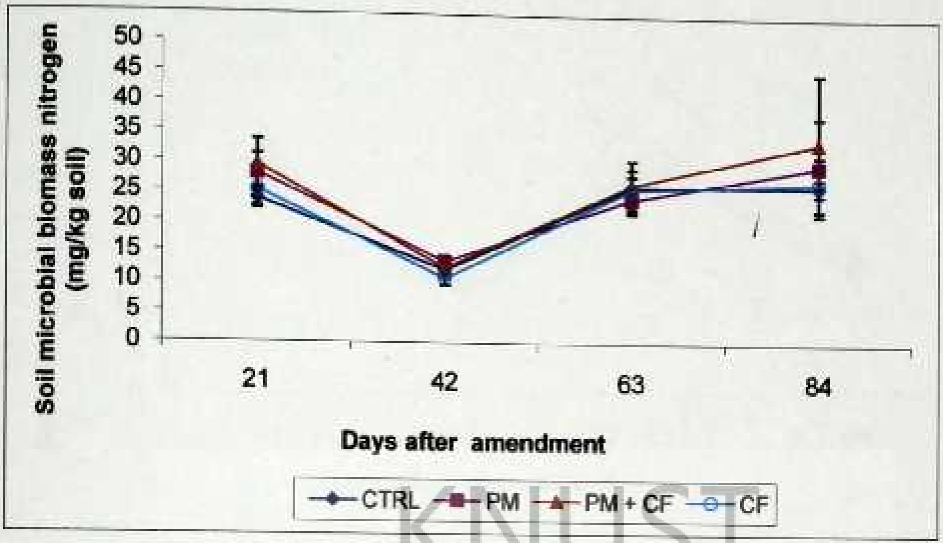

Fig. 4.3k. Soil microbial biomass nitrogen dynamics under amendments and control in 2006-minor season on a Ferric Acrisol, Kwadaso.

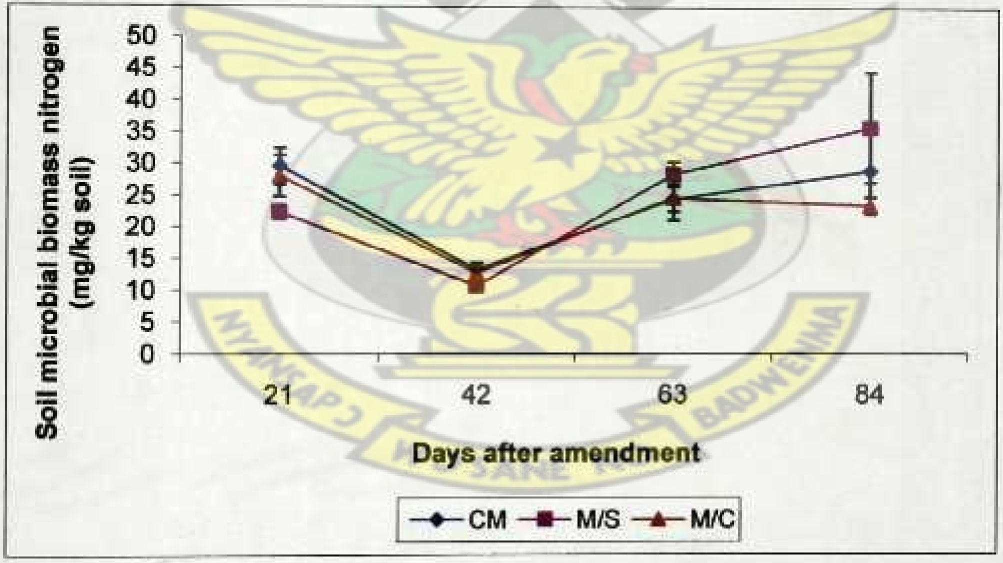

Fig. 4.3L. Soil microbial biomass nitrogen dynamics under cropping systems in 2006 - minor season on a Ferric Acrisol, Kwadaso.

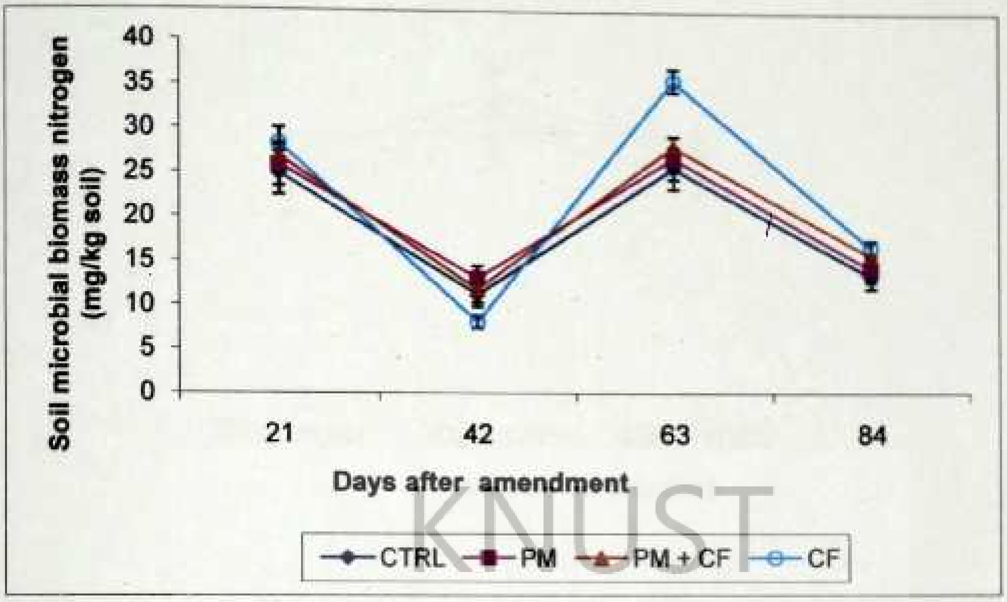

Fig. 4.3m. Soil microbial biomass nitrogen dynamics under amendments and control in 2007- major season on a Ferric Acrisol, Kwadaso.

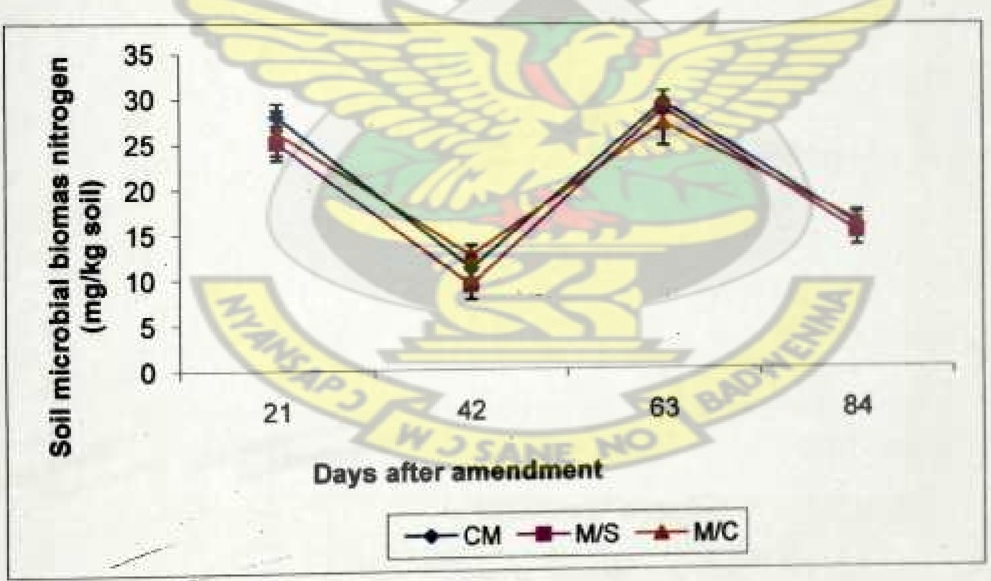

Fig. 4.3n. Soil microbial biomass nitrogen dynamics under cropping systems in 2007-major season on a Ferric Acrisol, Kwadaso.

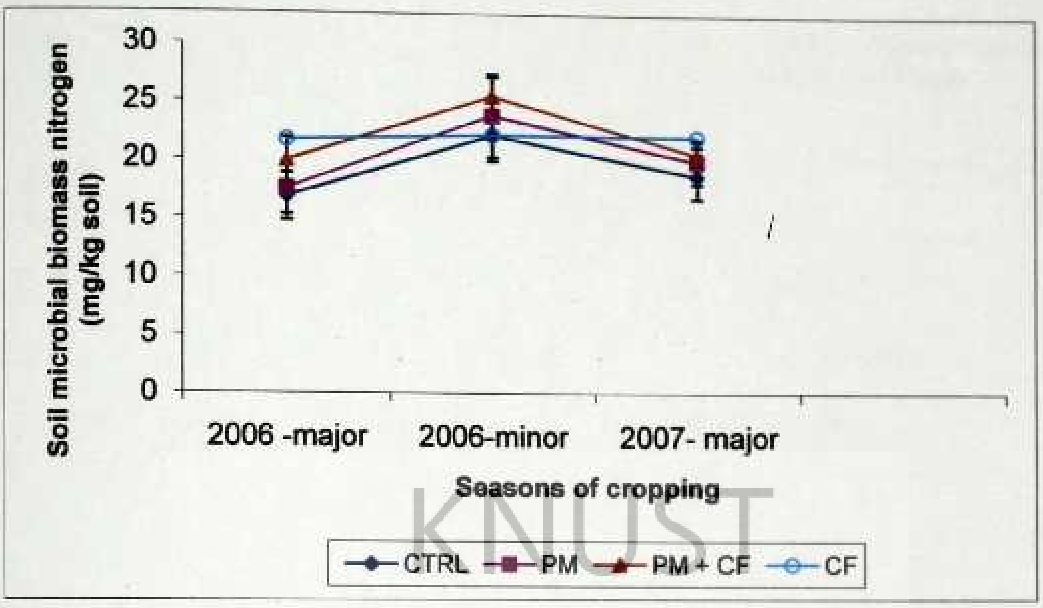

Fig. 4.3o. Variation of soil microbial biomass nitrogen under amendments over cropping seasons on a Ferric Acrisol, Kwadaso.

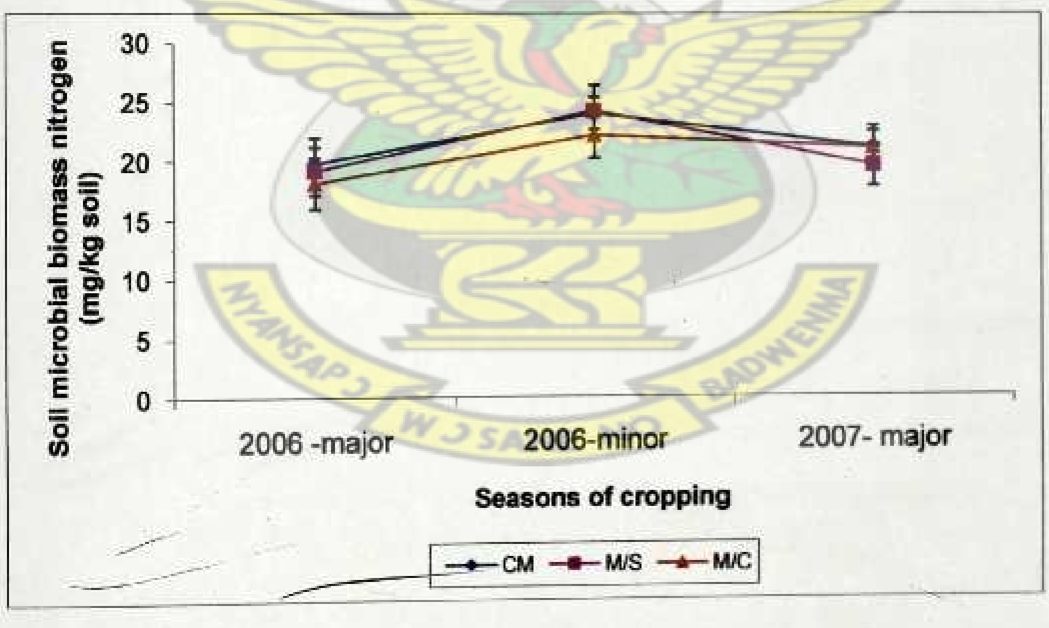

Fig. 4.3p. Variation of soil microbial biomass nitrogen under cropping systems over cropping seasons on a Ferric Acrisol, Kwadaso.

Table 4.8a. Regression equations and coefficients of correlation (r) of the relationship between soil exchangeable Ca (y) and microbial biomass carbon (x) during the seasons of study

Season	Regression equation	r
2006 - Major	y = 139.21x - 737.10	0.93*
2006 - Minor	y = 34.54x + 109.61	0.76 (NS)
2007 - Major	y = 0.02x – 6.73	0.99*

*Significant at P < 0.05, NS: Not significant at P < 0.05.

Table 4.8b. Regression equations and coefficients of correlation (r) of the relationship between soil exchangeable Na (y) and microbial biomass carbon (x) during the seasons of study

Season	Regression equation	r
2006-Major	y = 953.84x – 116.81	0.92*
2006-Minor	y = 227.17x + 164.99	0.73*
2007-Major	y = 1606.7x – 388.12	0.78*

Table 4.8c. Regression equations and coefficients of correlation (r) of the relationship between ECEC (y) and microbial biomass carbon (x) during the seasons of study

Season	Regression equation	r
2006-Major	y = 94.17x – 697.02	0.97*
2006-Minor	y = 34.99x + 14.77	0.74*
2007-Major	y = 45.51x – 253.94	0.98*

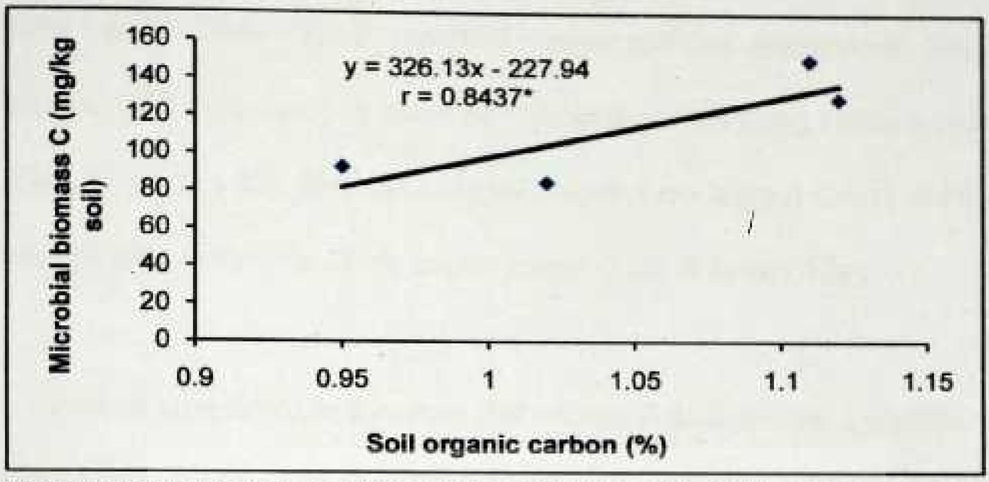

Fig. 4.3q. Relationship between SOC and microbial biomass C in 2006 -major season on a Ferric Acrisol, Kwadaso.

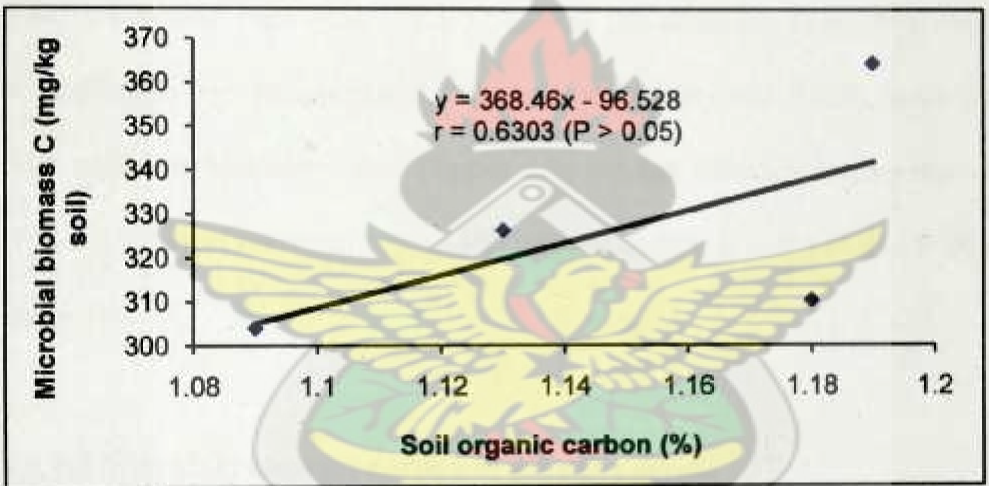

Fig. 4.3r. Relationship between SOC and microbial biomass C in 2006 - minor season on a Ferric Acrisol, Kwadaso.

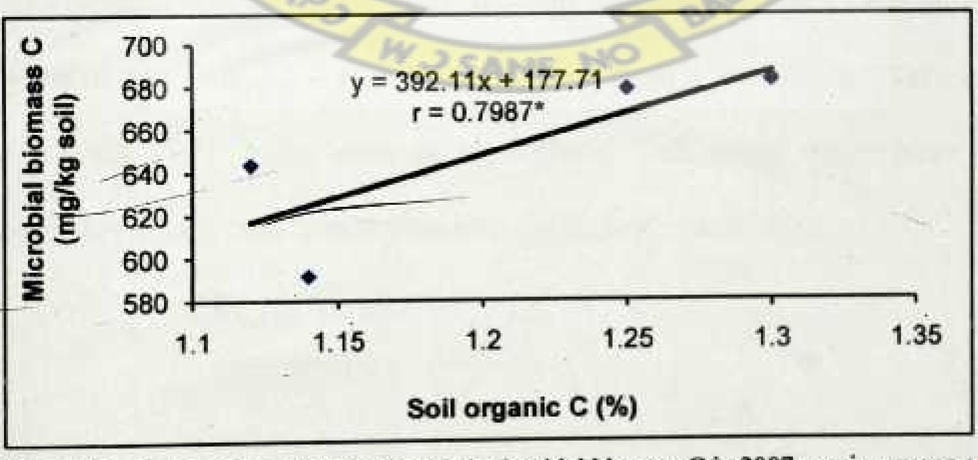

Fig. 4.3s. Relationship between SOC and microbial biomass C in 2007 - major season on a Ferric Acrisol, Kwadaso.

2006 - major, 2006 - minor and 2007 - major seasons, respectively. Results indicated build up of biomass carbon under amendments and cropping systems over the seasons (Figs. 4.3g and 4.3h). Biomass nitrogen recorded the highest values under amendments and cropping systems in 2006 - minor season (Figs. 4.3o and 4.3p).

It has been established in literature that microbial biomass has a significant role in the availability of many nutrients. To verify this assertion, correlation analyses were used to determine the relationship between soil chemical and microbiological properties (Tables 4.8a – 4.8c and Figs. 4.3q - 4.3s). Among the chemical properties monitored under amendments, soil exchangeable calcium and sodium and ECEC positively correlated with microbial biomass carbon (Tables 4.8a – 4.8c). Biomass carbon showed significant ($P < 0.05$) fits of correlation with soil organic carbon ($r = 0.84^*$ and 0.80^*) (Figs. 4.3q and 4.3s).

4.5.1.2 Microbial biomass carbon to nitrogen ratios

Tables 4.9a – 4.9c show computed biomass carbon: nitrogen ratios (Cmic: Nmic) during the cropping seasons. There were seasonal variations in the Cmic: Nmic ratios. The ratios ranged from 3.5 - 18.9, 2.9 - 28.9 and from 4.3 - 67.5 in 2006 - major, 2006 - minor and 2007- major seasons, respectively. The second observation (42 DAA) in 2007- major cropping season produced the highest ratios.

Table 4.9a. Variation of Cmic : Nmic ratios in the 2006- major season

	Cmic : Nmic ratio			
Treatments	21 DAA	42 DAA	63/DAA	84 DAA
Amendment				
CTRL	5.9	8.7	7.1	6.0
PM	11.2	8.5	7.2	13.7
PM + CF	11.0	9.1	6.0	7.4
CF	7.8	12.8	5.2	6.2
LSD (0.05)	5.77	NS	NS	5.10
Cropping systems				
CM	10.6	4.7	5.4	11.4
M/S	4.0	5.8	5.0	3.5
M/C	6.1	8.9	7.7	10.3
LSD (0.05)	2.87	1.81	NS	5.62

Cmic: microbial biomass carbon, Nmic: microbial biomass nitrogen.

Table 4.9b. Variation of Cmic : Nmic ratios in the 2006- minor season

	Cmic : Nmic ratio			
Treatments	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	8.8	5.1	17.9	20.7
PM	9.2	6.6	17.3	28.9
PM + CF	2.9	7.8	16.0	28.8
CF	7.0	6.0	22.0	22.9
LSD (0.05)	1.8	NS	5.60	4.88
Cropping systems				
CM	7.0	8.9	24.9	25.8
M/S	7.5	4.3	12.2	20.8
M/C	5.5	6.4	17.8	22.0
LSD (0.05)	2.24	NS	5.24	4.93

Cmic: microbial biomass carbon, Nmic: microbial biomass nitrogen, DAA - days after amendment.

Table 4.9c. Variation of Cmic : Nmic ratios in the 2007- major season

Treatments	Cmic:Nmic ratio			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	27.2	62.9	26.4	38.3
PM	29.0	49.4	26.1	43.3
PM + CF	26.4	60.7	27.4	33.9
CF	22.4	67.5	17.9	32.7
LSD (0.05)	6.29	7.57	9.16	NS
Cropping systems				
CM	7.0	62.5	24.8	37.5
M/S	7.5	65.8	24.1	32.4
M/C	5.5	64.0	24.3	35.5
LSD (0.05)	1.24	NS	NS	4.93

Cmic: microbial biomass carbon, Nmic: microbial biomass nitrogen, DAA - days after amendment.

Table 4.10. Rainfall recorded at experimental site during the experimental period at Kwadaso

Month	Rainfall (mm)		Rainy days	
	2006	2007	2006	2007
May	209.9	141	14	12
Jun	122	225.6	13	15
Jul	69.3	328.4	8	15
Aug	55.4	67.1	7	11
Sep	171.7	-	12	-
Oct	201.9	-	17	-
Nov	35.3	-	4	-
Dec	60.9	-	3	-

- Study terminated in August, 2007.

4.5.1.3 Microbial biomass phosphorus

Soil microbial phosphorus content under the different cropping systems and amendments did not follow any specific trend (Figs. 4.4a - 4.4f). At 21 DAA in 2006-major season, biomass phosphorus was similar ($P > 0.05$) for the amendments and cropping systems (Figs. 4.4a and 4.4b). However, significant differences ($P < 0.05$) were observed between amendments following 21 DAA in 2006 - minor and 2007-major seasons (Figs. 4.4c and 4.4e). Negative values were recorded in all plots at the 42 and 63 DAA (Figs. 4.4c and 4.4d) signifying immobilization of phosphorus at the peak of crop growth. Soil microbial phosphorus at the 84 DAA was positive throughout the entire study period (Figs. 4.4a - 4.4f).

Figures 4.4g and 4.4h indicate variation of biomass P over cropping seasons. The lowest soil microbial phosphorus was recorded in the 2006 - minor season which was characterized by immobilization under amendments and cropping systems except in maize/soybean (M/S) plots (Fig.4.4h). The highest values were generally recorded in the 2007- major season under amendments (Fig. 4.4g) whilst cropping systems gave the highest in 2006 - major season. Values recorded in 2006 and 2007 major seasons were generally positive at the levels of amendments and cropping systems.

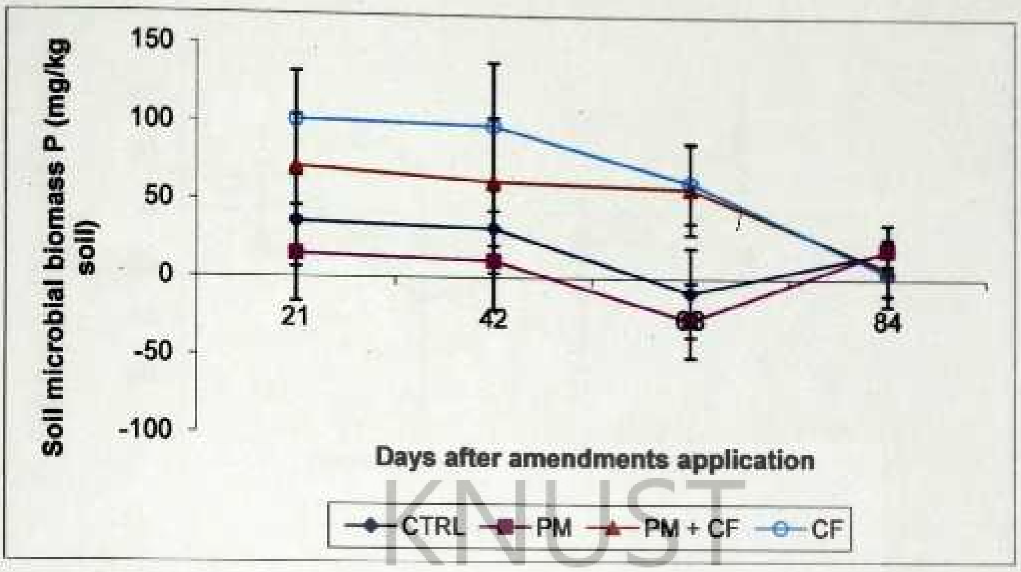

Fig. 4.4a. Soil microbial biomass P dynamics as affected by amendments in 2006 - major season on a Ferric Acrisol, Kwadaso.

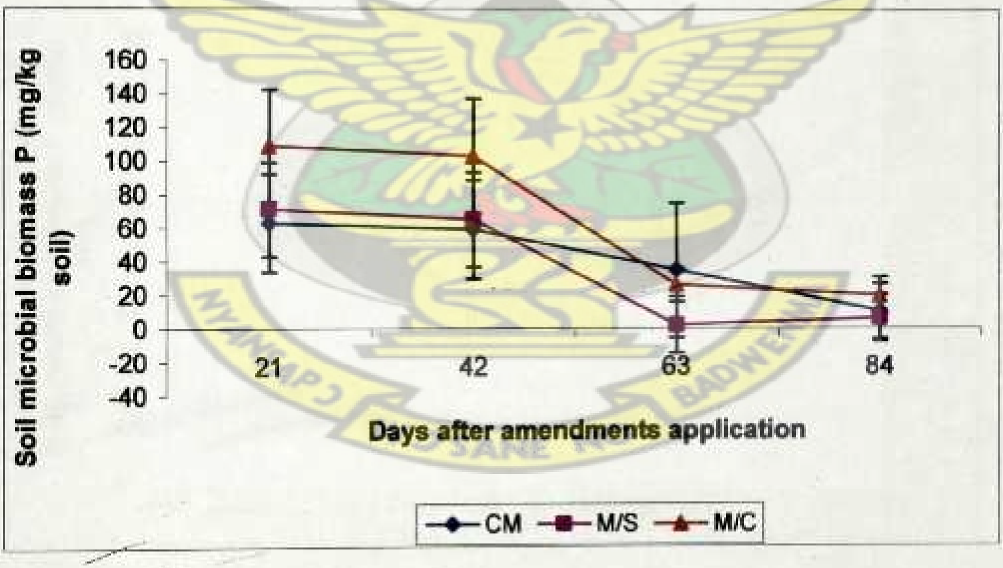

Fig. 4.4b. Soil microbial biomass P dynamics as affected by cropping systems in 2006- major season on Ferric Acrisol, Kwadaso.

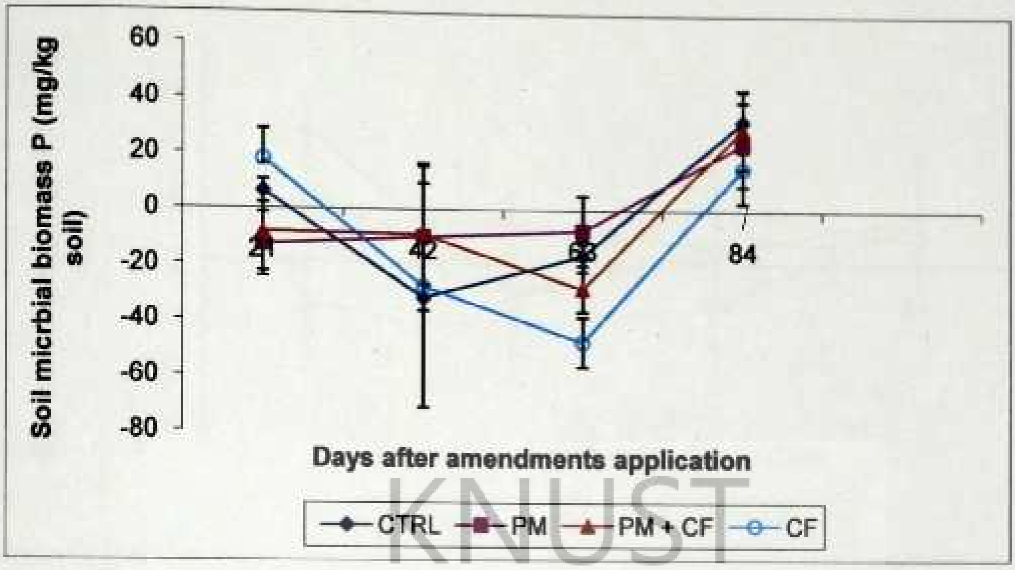

Fig. 4.4c. Soil microbial biomass P dynamics as affected by amendments in the 2006- minor season on Ferric Acrisol, Kwadaso.

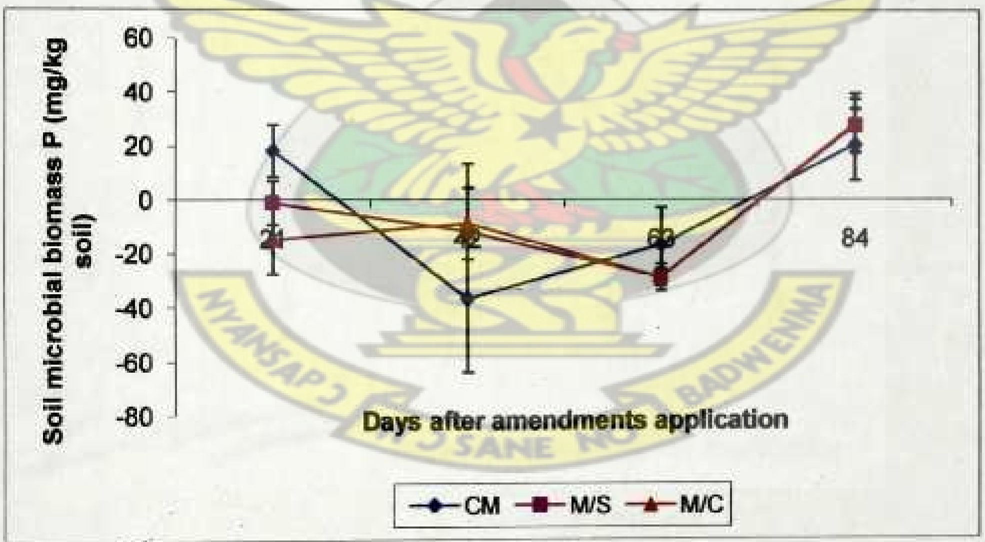

Fig. 4.4d. Soil microbial biomass P dynamics as affected by cropping systems in the 2006-minor season on Ferric Acrisol, Kwadaso.

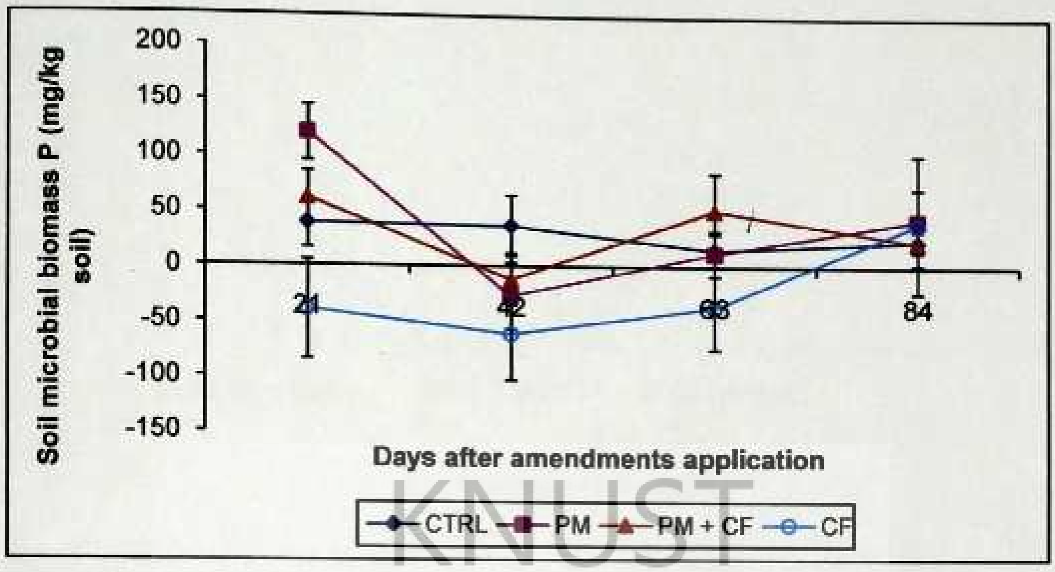

Fig. 4.4e. Soil microbial biomass P dynamics under amendments in 2007-major season on a Ferric Acrisol, Kwadaso.

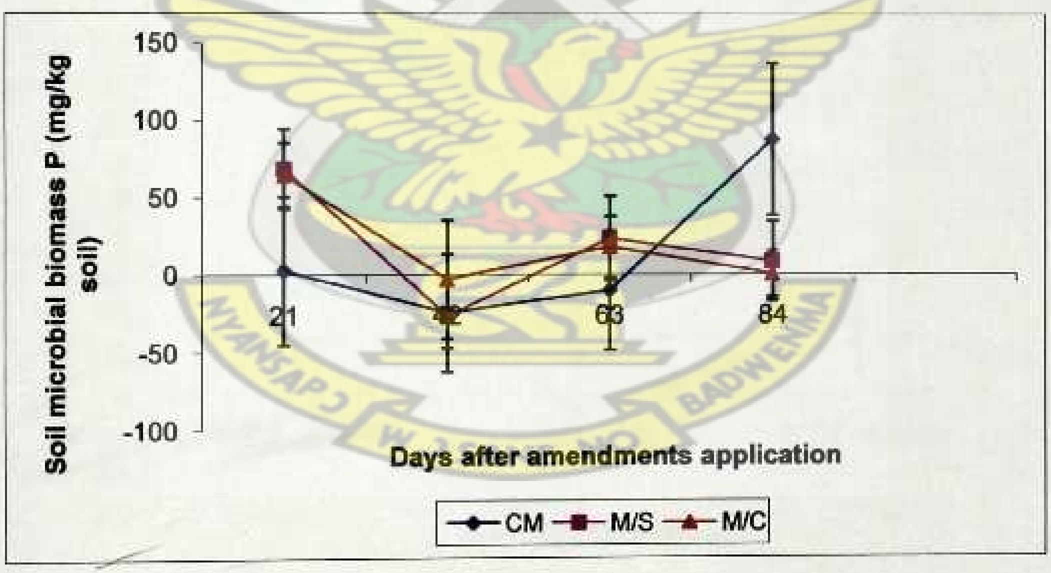

Fig. 4.4f. Soil microbial biomass P dynamics under cropping systems in 2007-major season on a Ferric Acrisol, Kwadaso.

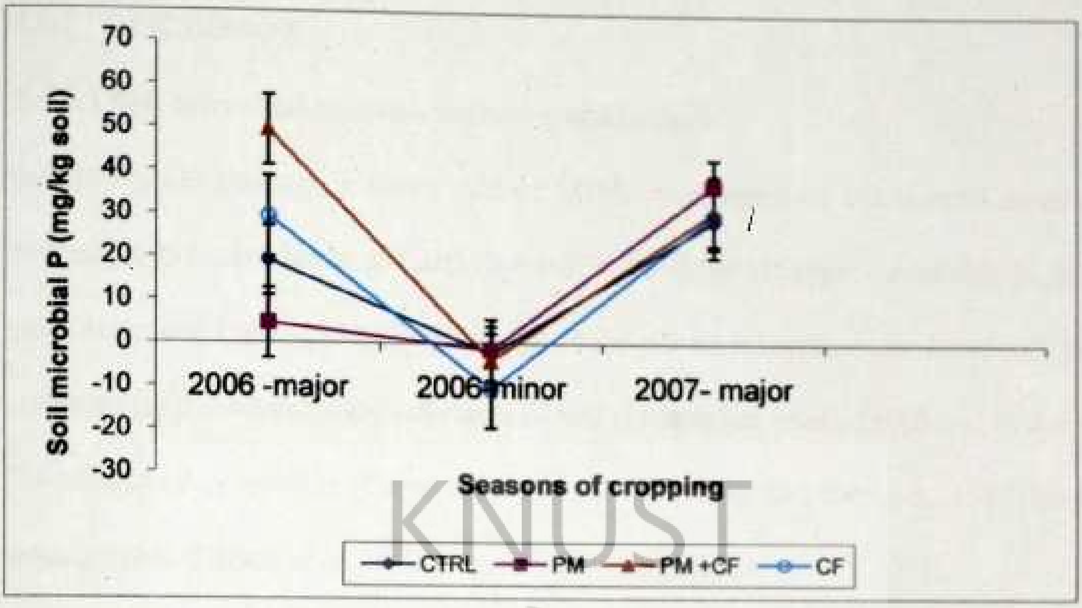

Fig. 4.4g. Seasonal variation of soil microbial biomass P under amendments on a Ferric Acrisol, Kwadaso.

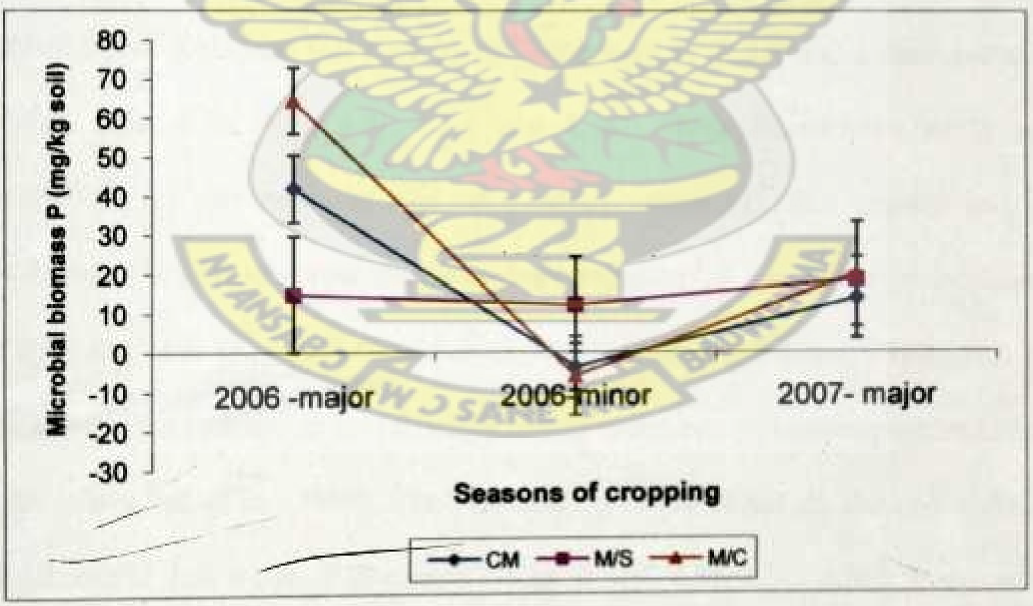

Fig. 4.4h. Seasonal variation of soil microbial biomass P under cropping systems on a Ferric Acrisol, Kwadaso.

4.5.2 DISCUSSION

4.5.2.1 Soil microbial biomass carbon and nitrogen

Soil microbial biomass, a living part of SOM, is an agent of transformation of added and native organic matter and acts as a labile reservoir for plant - available N, P and S (Jenkinson and Ladd, 1981). The activity of the microbial biomass is commonly used to characterize the microbiological status of soil (Nannipieri *et al.*, 1990) and to determine the effects of cultivation (Beyer *et al.*, 1991; Anderson and Domsch, 1993) and field management (Perrott *et al.*, 1992) on soil microorganisms.

Results of the study showed temporal fluctuations in microbial biomass carbon and nitrogen. The fluctuations occurred between sampling periods within the major seasons. There was a general decline in biomass carbon and nitrogen 42 days following amendment. This was followed by an increase at 63 DAA and a decrease at 84 DAA (Figs. 4.3a, 4.3b, 4.3i, 4.3j, 4.3m and 4.3n). These fluctuations could be due to variations in soil moisture and temperature, stage of plant growth and available substrate. Similar observations have been reported by several other workers (Insam, 1990; Kaiser *et al.*, 1995; Lovell *et al.*, 1995; Chang and Juma, 1996). Soil microbial properties are influenced by variations in soil moisture and temperature, nutrient supply, etc. (Campbell *et al.*, 1999). The microbial biomass N values showed more temporal fluctuations than those of biomass C (Figs. 4.3a – 4.3f, 4.3i - 4.3n). Joergensen (1995) in his study reported more temporal fluctuations of biomass N than biomass C. Microorganisms differ much more in their N content than in their C content, depending on their stage of growth (Jenkinson and Ladd, 1981). This is one reason for the larger variations in k_N values (fraction of the killed biomass extracted as N under standardized conditions) compared with k_C values (fraction of the killed biomass extracted as biomass C) found in literature (Joergensen, 1995). Therefore, small shifts in the structure of the microbial community can result in large changes in Nmic (Campbell *et al.*, 1991).

Significantly higher microbial biomass carbon was expected under PM amendment. However, the recorded values did not show significance (Figs. 4.3a, 4.3c and 4.3e). Wander *et al.* (1995) and Shannon *et al.* (2002) observed significantly higher microbial biomass C in soils under organic compared to conventional management.

The data showed higher microbial biomass carbon in the 2007- major season than in 2006 - minor and 2006 - major seasons (Figs. 4.3g & h). This was as a result of the cumulative effect of the amendments as well as crop residues left on the field at harvest during the previous seasons. The highly carbonaceous residues served as energy source for microbial growth during the subsequent season (2007). According to Ross (1987), crop residues can have a large effect on soil microbial biomass and activity, which in turn, affect the ability of soil to supply nutrients to plants through SOM turnover. Efficient nutrient management in cropping systems could therefore, lead to buildup of microbial biomass over time. Higher amount of rainfall was recorded in 2007- major season (May - August) than in 2006 - major season (May-August) and 2006- minor season (Sep - Dec) (Table 4.10). This also accounted for the higher microbial C in 2007.

Insam (1990) reported that microbial biomass increased significantly with increased rainfall distribution.

Good fits of correlation (Figs. 4.3q and 4.3s) were found between microbial biomass C and organic carbon in the 2006 – major and 2007 – major seasons. This is in conformity with findings of Beck *et al.* (1997) and Leiros *et al.* (2000), who reported good correlation between biomass C and organic carbon. However, Insam and Domsch (1989) and Zak *et al.* (1994) found no correlation between the biomass C and organic C. Published data on the relation of microbial biomass C to organic carbon are inconsistent, showing either a positive correlation or no correlation as both the organic carbon quality and the microbial community structure are associated with soil type (Jozef, 2004). The good fits of correlation obtained in this study could be explained by the fact that microbial biomass concentration depended on the organic matter availability to microbial activity as suggested by Insam and Domsch (1989) and Anderson and Domsch (1989). Results pointed to high correlations between microbial biomass C and chemical properties associated with nutrient status of soil, namely exchangeable calcium, sodium and ECEC. This is in agreement with published data. For example, close relationship of microbial biomass and its activity with the concentration of exchangeable bases have been found in many investigations (Ladd *et al.*, 1990; Wolters and Joergensen, 1991; Leiros *et al.*, 2000). In addition, a close positive relationship between the microbiological parameters and ECEC has been observed in some studies (Ladd *et al.*, 1990; Wolters and Joergensen, 1991). The ECEC connection with nutritional status of soil consists in its role in prevention of nutrient leaching from the soil (Jozef, 2004).

4.5.2.2 Soil microbial biomass carbon to nitrogen ratios

The ratio of Cmic: Nmic is often used to describe the structure and state of the microbial community. A high Cmic: Nmic ratio indicates that the microbial biomass contains a higher proportion of fungi, whereas a low value suggests that bacteria predominate in the microbial population (Campbell *et al.*, 1991). Lower ratios were found in 2006- major season than in the subsequent seasons (Tables 4.9a – 4.9c). The differences found for these ratios between the two years are mainly due to the variations in biomass C (Cmic) values already discussed. The Cmic: Nmic ratio is affected by soil properties such as moisture content, pH and substrate availability (Moore *et al.*, 2000). Joergensen (1995) reported C: N ratios of the microbial biomass varying from 5.2 in an arable land to 20.8 in a forest soil, with an average of 6.8 for 82 soils. In their study, Moore *et al.* (2000) found the Cmic: Nmic ratios of the soils from two different experimental sites to be 4.3 and 6.4 in 1996, and 7.6 and 11.4 in 1997. However, differences in these ratios are expected between microbial populations cultivated under laboratory conditions and those grown under natural conditions (Joergensen, 1995). This study recorded mean ratios of 8.1, 14.2 and 35.1 in 2006-major, 2006-minor and 2007-major seasons, respectively. The ratios in 2006 -major and 2006-minor seasons (i.e. first year of study) compared favourably with those recorded (6.4 in 1996 and 11.4 in 1997) by Moore *et al.* (2000).

4.5.2.3 Soil microbial phosphorus

It may be inferred from the results of the study that microbial biomass P was sensitive to factors that could have influenced the size and structure of microbial biomass. These include microclimate (soil moisture and temperature) and fertilizer (amendment) practices (Moore *et al.*, 2000).

The negative microbial P values obtained under amendments and cropping systems (Figs. 4.4c, 4.4d, 4.4e and 4.4f) were by virtue of immobilization of phosphorus. This overlaps with an observation made by Tetteh (2004), who reported phosphorus immobilization under decomposing organic materials. The implication is that soil microorganisms immobilized a lot more added phosphorus than the available inorganic phosphorus. This is very important in Ghanaian soils which are often associated with high phosphorus fixation, thus, reducing its availability to plants (Tetteh, 2004). The immobilized P by microbes will be released gradually thus protecting the released P from physico - chemical adsorption reactions (Tetteh, 2004). This study indicated that phosphorus could generally be immobilized at the peak of crop growth for 21 days and be released within 21 days (Figs. 4.4c and 4.4d). If the immobilized P will be passed on from one generation of microbes to the other, then there will be a persistent competition between microbes and plants for P. At 84 DAA in the seasons, results indicated no immobilization of phosphorus in the soil of any of the amended plots (microbial P values were positive). This means that immobilized P was released thus adding to the available P in the soil. This, however, might have not been used by the crops (asynchrony) since the released P did not coincide with the peak nutrient demand of the crops but rather with their physiological maturity.

Evidence from this study indicates that phosphorus was immobilized more than carbon and nitrogen. This could be traced to the fact that the element forms an integral part of the cell nucleus of the microbes and is required in the form of phosphate (PO_4^{3-}) radical to combine with adenosine diphosphate (ADP) for energy transfer within the microbial cellular tissue (Barber, 1995). This resulted in higher microbial affinity for the P thereby causing immobilization. From this study, it can be deduced that if the phosphorus immobilized was released 84 DAA, then management practices should be geared towards making the release concur with peak nutrient demand of short - season maize crops (crops with < 110 days from emergence to maturity according to Popp *et al.*, 2006). This will enhance synchrony and improve soil fertility. This implies that full - season annual crops of 120 days from emergence to maturity (Popp *et al.*, 2006), could easily synchronize the released P with their peak nutrient demand.

4.6 SOIL TOTAL NITROGEN

4.6.1 RESULTS

Figures 4.5a - 4.5f compare the dynamics of soil total nitrogen under the different amendments and cropping systems throughout the study period. Chemical fertilizer (CF) - amended plots consistently showed the highest nitrogen content of 0.08 to 0.12 % whilst the control showed the least (0.05 - 0.08 %). Total nitrogen levels under the amendments were in the following decreasing order: CF > PM + CF > PM > CTRL (Figs. 4.5a, 4.5c & 4.5e). Significant differences ($P < 0.05$) were generally observed between CF and the CTRL. Like organic carbon, the highest total nitrogen level was found at the 63 DAA during the seasonal cycles in 2006. Preceding this, there was a

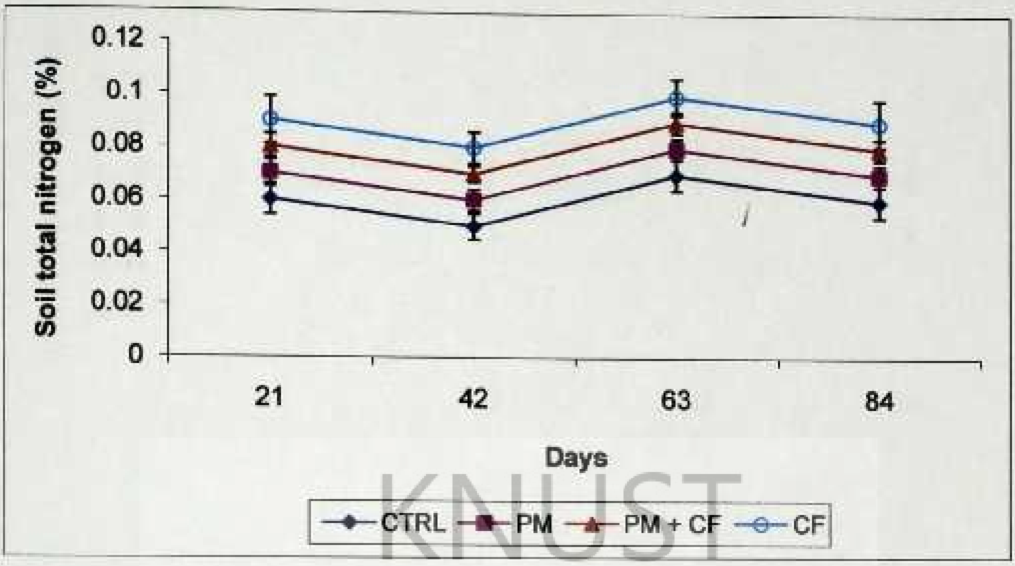

Fig. 4.5a. Effect of no amendment (CTRL), poultry manure (PM), poultry manure + chemical fertilizer (PM + CF) and chemical fertilizer (CF) amendments on soil total nitrogen content in 2006- major season on a Ferric Acrisol, Kwadaso.

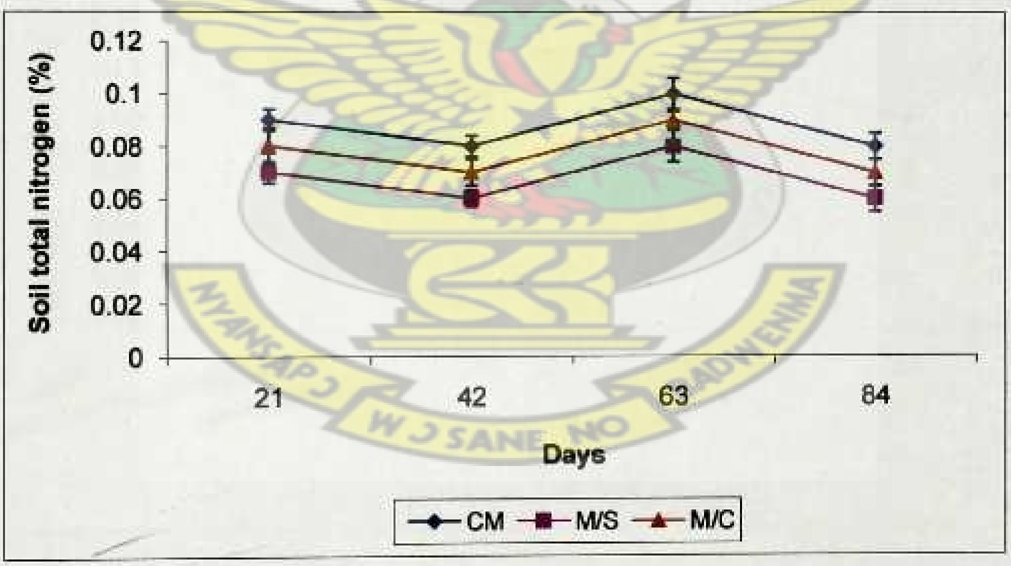

Fig. 4.5b. Effect of cropping systems (continuous maize - CM, maize/ soybean intercrop (M/S) and maize / cowpea rotation (M/C) on soil total nitrogen in the 2006- major season on a Ferric Acrisol, Kwadaso.

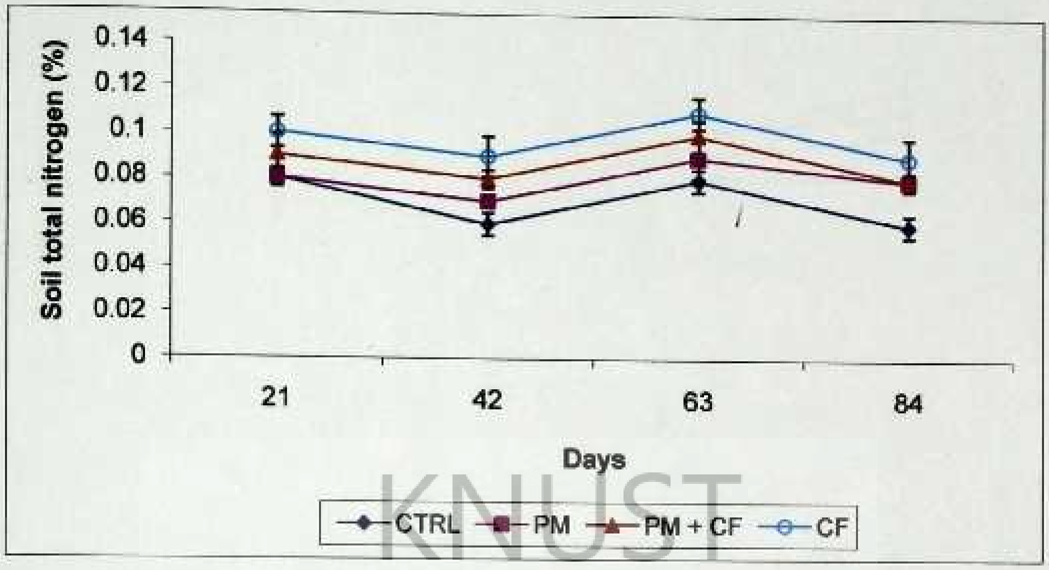

Fig 4.5c. Effect of no amendment (CTRL), poultry manure (PM), poultry manure + chemical fertilizer (PM + CF) and chemical fertilizer (CF) amendments on soil total nitrogen content in 2006- minor season on a Ferric Acrisol, Kwadaso.

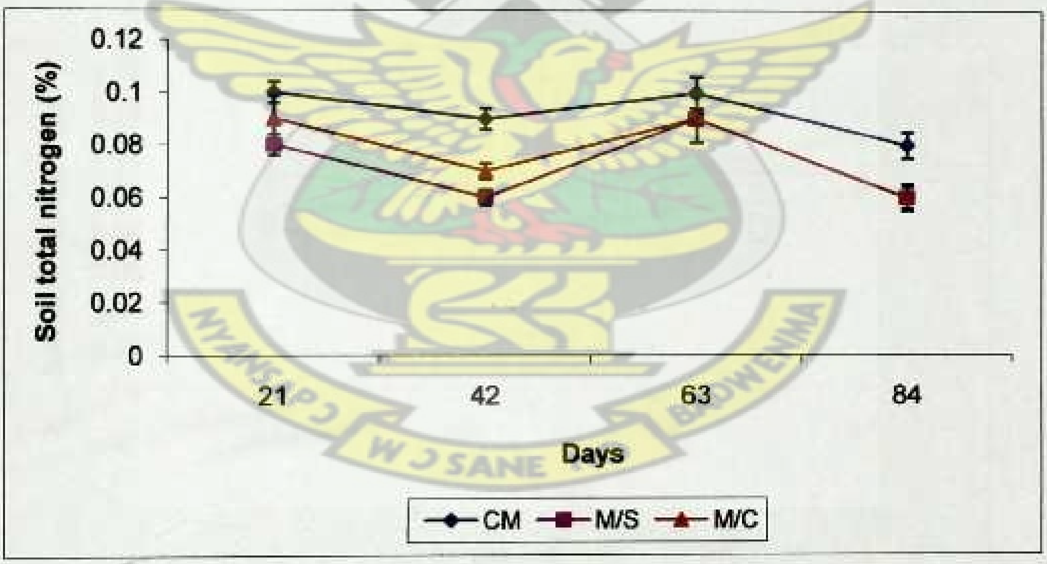

Fig. 4.5d. Effect of continuous maize (CM), maize/soybean (M/S) intercrop and maize/cowpea (M/C) rotation cropping systems on soil total nitrogen in 2006- minor season on a Ferric Acrisol, Kwadaso.

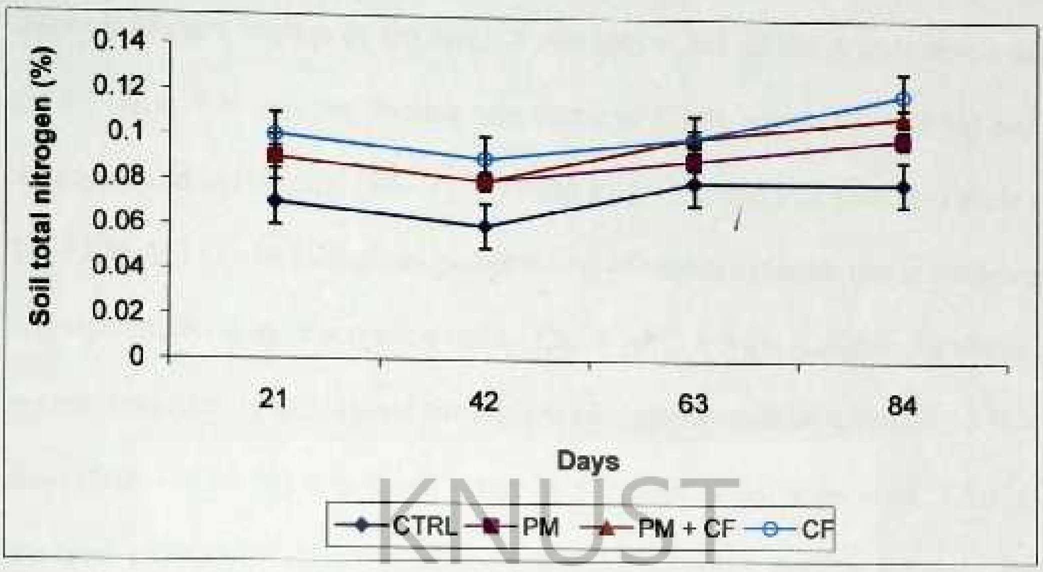

Fig. 4.5e. Effect of no amendment (CTRL), poultry manure (PM), poultry manure + chemical fertilizer (PM + CF) and chemical fertilizer (CF) amendments on soil total nitrogen content in 2007- major season on a Ferric Acrisol, Kwadaso.

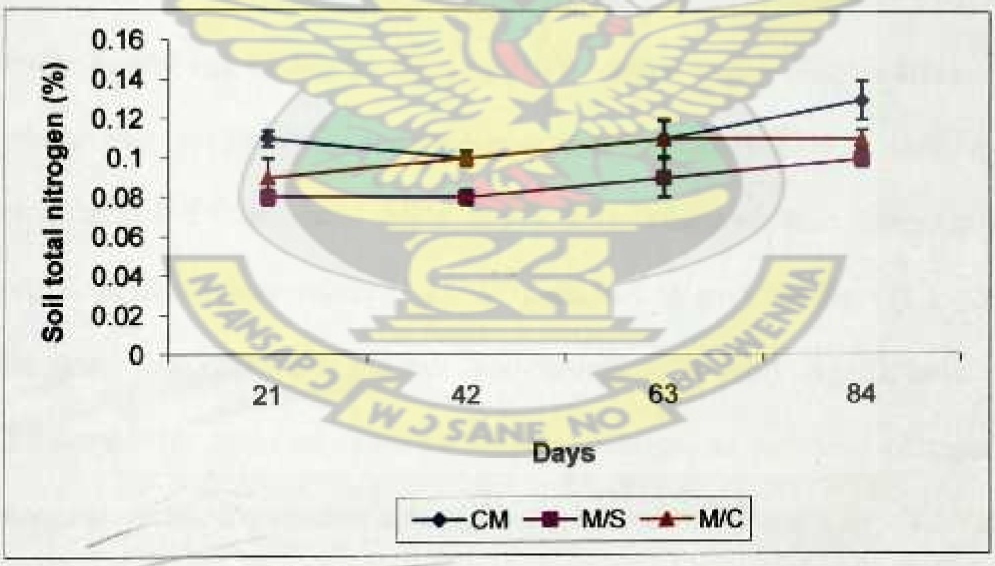

Fig. 4.5f. Effect of continuous maize (CM), maize/soybean (M/S) intercrop and maize / cowpea (M/C) rotation cropping systems on soil total nitrogen in 2007- major season on a Ferric Acrisol, Kwadaso.

disproportionate decline in the level of nitrogen at the 42 DAA over levels recorded at the 63 DAA. The greatest decline was found in CTRL plots (17 – 25 %) and the least was observed in CF plots (10 - 11 %). The PM + CF and PM amended plots registered 11 -12 % and 11 -14 % decline, respectively. Nitrogen contents under cropping systems were generally in the decreasing order: CM > M/C > M/S. Continuous maize cropping system consistently maintained the highest nitrogen content of 0.08 to 0.13 % whilst the least (0.06 – 0.08 %) was found under M/S system (Figs. 4.5b, 4.5d, 4.5f). Generally, the level of nitrogen under the amendments and cropping systems was low during the 2 years of experimentation.

The ratios of Nmic: total N in soils under no amendment (CTRL) were statistically different ($P < 0.05$) from the CF at all sampling periods except at 63 DAA in 2006-major season and 63 and 84 DAA in 2007 – major season (Tables 4.11a – 4.11c). The control plots produced the highest Nmic: total N ratios (1.9 – 4.4) whilst the least were recorded by CF amended plots (0.9 - 3.4). Maize/soybean intercrop consistently produced the highest values (1.2 – 6.0) whilst CM gave the least (1.1 - 3.6) over the seasons. Generally, amendments and cropping systems significantly ($P < 0.05$) influenced the ratios of microbial biomass nitrogen to soil total nitrogen during the seasonal cycles. Correlation analyses were carried out (Figs. 4.5g – 4.5i) to assess the effect of substrate availability on mineralization of N during the seasonal cycles. In all seasons of study, soil total N showed positive correlations with ammonification of total nitrogen. Figure 4.5j indicated a strong positive relationship ($r = 0.91^{**}$) between ammonium – N and nitrate – N.

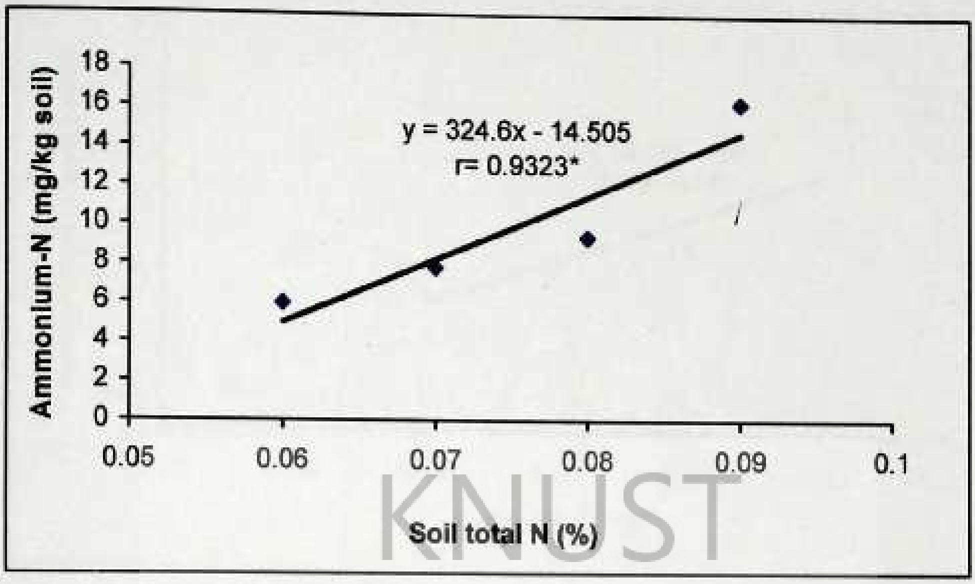

Fig. 4.5g. Relationship between soil total N and ammonium – N in 2006 - major season on a Ferric Acrisol, Kwadaso.

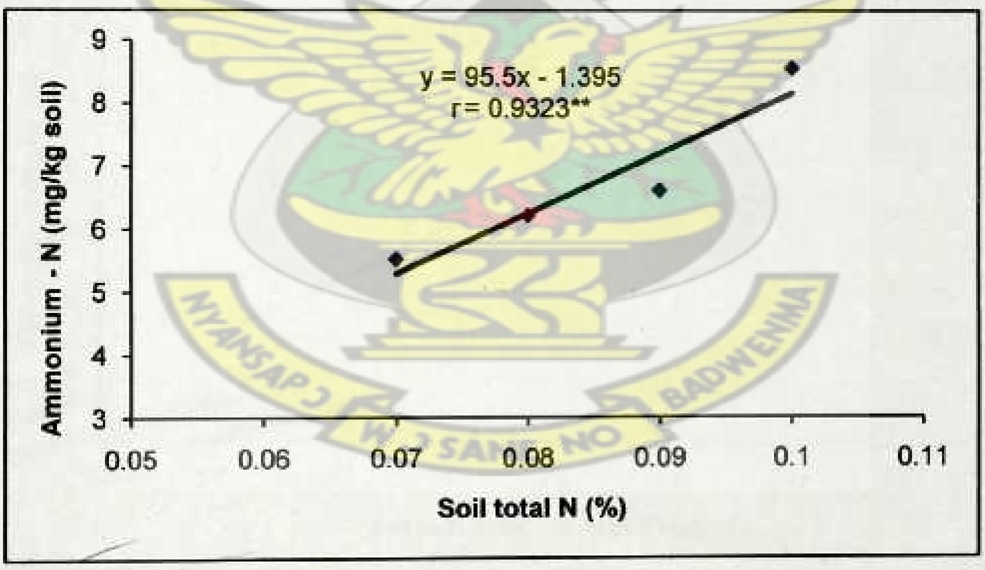

Fig. 4.5h. Relationship between soil total N and ammonium-N in 2006 - minor season on a Ferric Acrisol, Kwadaso.

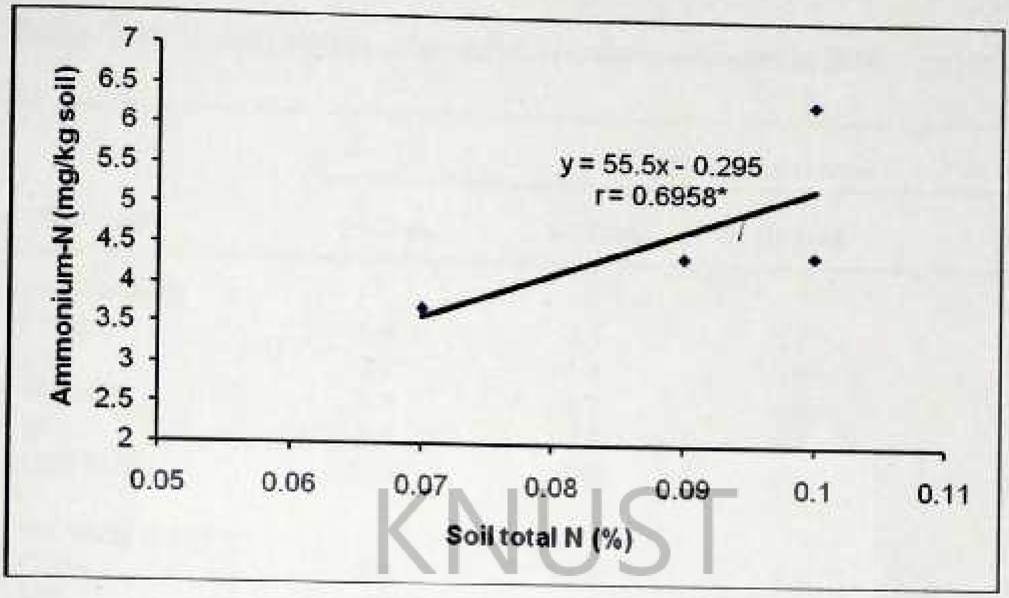

Fig. 4.5i. Relationship between soil total N and ammonium – N in 2007- major season on a Ferric Acrisol, Kwadaso.

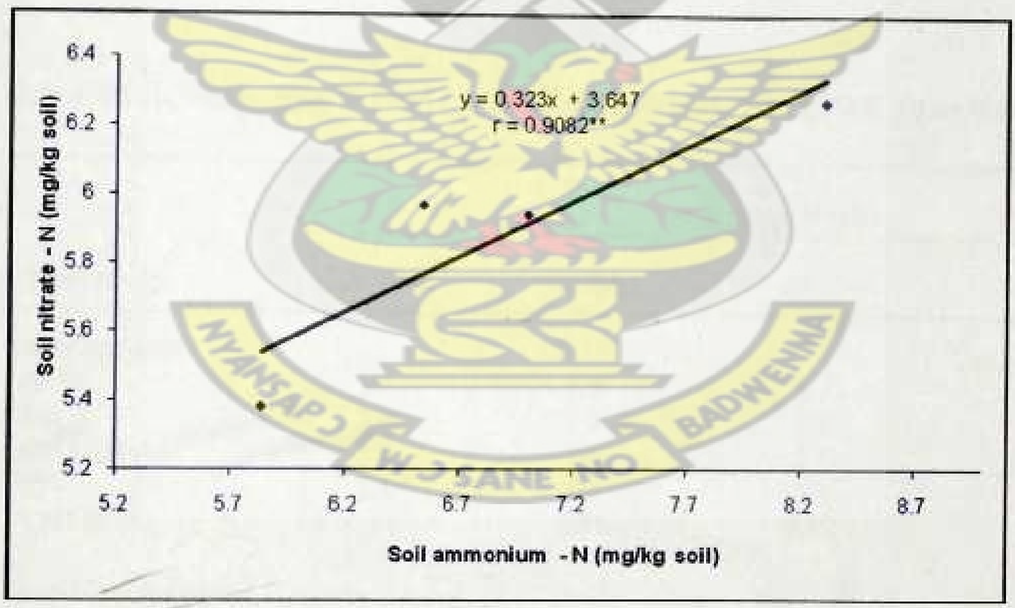

Fig. 4.5j. Correlation between mean soil ammonium-N and nitrate-N on a Ferric Acrisol, Kwadaso.

Table 4.11a. Nmic: total N ratio variation under treatments in 2006 - major season

Treatments	Nmic :total N ratio			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendments				
CTRL	3.4	2.1	3.1	2.5
PM	3.2	1.8	3.0	1.8
PM +CF	3.1	1.7	3.0	2.0
CF	2.8	1.5	3.4	1.7
LSD (0.05)	0.49	0.55	NS	0.41
Cropping systems				
CM	2.8	1.5	2.8	1.8
M/S	3.2	2.1	3.4	2.4
M/C	2.8	1.3	2.8	2.2
LSD (0.05)	0.39	0.48	0.57	0.33

total N: total nitrogen, Nmic: microbial biomass nitrogen, ratio expressed in %

Table 4.11b. Nmic: total N ratio variation under treatments in 2006 - minor season

Treatments	Nmic : total N ratio			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendments				
CTRL	3.0	2.0	3.3	4.4
PM	3.5	1.9	2.7	3.7
PM +CF	3.3	1.6	2.7	4.2
CF	2.5	1.2	2.4	3.1
LSD (0.05)	0.44	0.70	0.62	0.71
Cropping systems				
CM	3.0	1.5	2.4	3.6
M/S	2.8	1.8	3.1	6.0
M/C	3.1	1.8	2.7	3.9
LSD (0.05)	NS	NS	0.39	0.54

total N: total nitrogen, Nmic: microbial biomass nitrogen, ratio expressed in %

Table 4.11c. Nmic: total N ratio variation under treatments in 2007 - major season

Treatments	Nmic : total N ratio			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendments				
CTRL	3.6	1.9	3.2	1.7
PM	2.9	1.6	3.0	1.4
PM +CF	3.0	1.5	2.8	1.4
CF	2.8	0.9	3.3	1.4
LSD (0.05)	0.69	0.41	NS	NS
Cropping systems				
CM	2.6	1.1	2.7	1.2
M/S	3.1	1.2	3.2	1.5
M/C	2.9	1.3	2.5	1.5
LSD (0.05)	1.01	NS	0.49	NS

total N: total nitrogen, Nmic: microbial biomass nitrogen, ratio expressed in %

4.6.2 DISCUSSION

Soil total nitrogen levels of 0.05 - 0.13 % under amendments and cropping systems were low. This was particularly due to the low soil organic carbon levels (0.77 - 1.37 % or 1.32 - 2.36 % organic matter) found in this study following amendment and was in conformity with the findings of Ranamukhaarachchi *et al.* (2005) who reported low nitrogen levels under cropping systems in Bangladesh. According to Howarth (2005), the soil organic matter is composed of 5 - 6 % nitrogen. The observation could also be partially ascribed to N losses which occur mainly through leaching, surface runoff, denitrification, etc. In their study on N losses, Bijay and Sekhon (1977) observed that losses of N in the form of nitrate occurred due to leaching with cropping systems consisting of shallow rooted crops. Crop uptake of N is relatively inefficient and often results in average losses of 50 % because of leaching, volatilization or denitrification (Zublena, 1997). The highest N level observed in chemical fertilizer plots was as result of the NPK amendment imposed on these plots, which was later followed by a 'top dress' with sulphate of ammonia. The nitrogen content of these fertilizers made a significant contribution to the total N initially in the soil (0.07 %) (Table 4.1).

Significant differences in total N were observed among the cropping systems (Figs. 4.5d and 4.5f). These contrast the findings of Ranamukhaarachchi *et al.* (2005) who in their study, found insignificant differences between similar cropping systems in Bangladesh. The lower total nitrogen levels recorded under M/S cropping system as compared with M/C in this study (Figs. 4.5d and 4.5f) is attributable to inter-species competition between maize and soybean. Intercropping maize with soybean purposely to improve nitrogen status of soil may therefore, not necessarily lead to achievement of objective. It is not clear why CM cropping system contrary to expectation, showed the highest level of the nitrogen. However, the trend could be as a result of the highest organic carbon content observed under this system.

Biomass N values expressed as percentages of soil total N give an estimation of the quantities of nutrient in the microbial biomass and substrate availability (Sparling *et al.*, 1990). On the average, microbial biomass N contributed 2.5 and 2.6 % to the total N in soils under amendments and cropping systems, respectively over the study period at Kwadaso. The microbial biomass thus, served as a repository of soil total nitrogen under amendments and cropping systems in Ghana. Moore *et al.* (2000) reported that biomass N made up to 2.4 % of soil total N under cropping systems. The ratios of

Nmic: Ntotal can range from 1 - 7 % (Joergensen, 1995). Generally, lower values were recorded under CF amendment than for the control. This finding was consistent throughout the sampling periods within the seasons except at 63 DAA in 2006 (Table 4.11a) and 2007 (Table 4.11c) major seasons. The higher total N observed in CF plots than in the control (Figs. 4.5a, 4.5c and 4.5e) accounted for this observation as both plots produced similar Nmic values (Figs. 4.3i and 4.3k).

The regression equations relating soil total N to ammonium-N (Figs. 4.5g, 4.5h and 4.5i) have shown that substrate availability plays a key role in N mineralization. The natural N supply for plants and microorganisms results principally from the mineralization of organic compounds (Runge, 1983). A linear relationship between nitrate - N and ammonium - N was found with $r = 0.91^{**}$ (Fig. 4.5j). The implication was that appreciable proportion of ammonium- N resulting from ammonification of organic N was translated into nitrate - nitrogen through the process of nitrification. When ammonium is added to the soil or released from nitrogen in organic matter, it is usually nitrified rapidly to nitrate. When nitrification readily occurs, most of the mineral nitrogen occurs as nitrate (Barber, 1995).

4.7. SOIL AVAILABLE PHOSPHORUS

4.7.1. RESULTS

The highest values of available P (defined as inorganic phosphate extracted by Bray 1 solution) were found in chemical fertilizer amended plots whilst the least were recorded in plots under no amendment (CTRL) (Figs. 4.6a, 4.6c and 4.6e). Higher values were

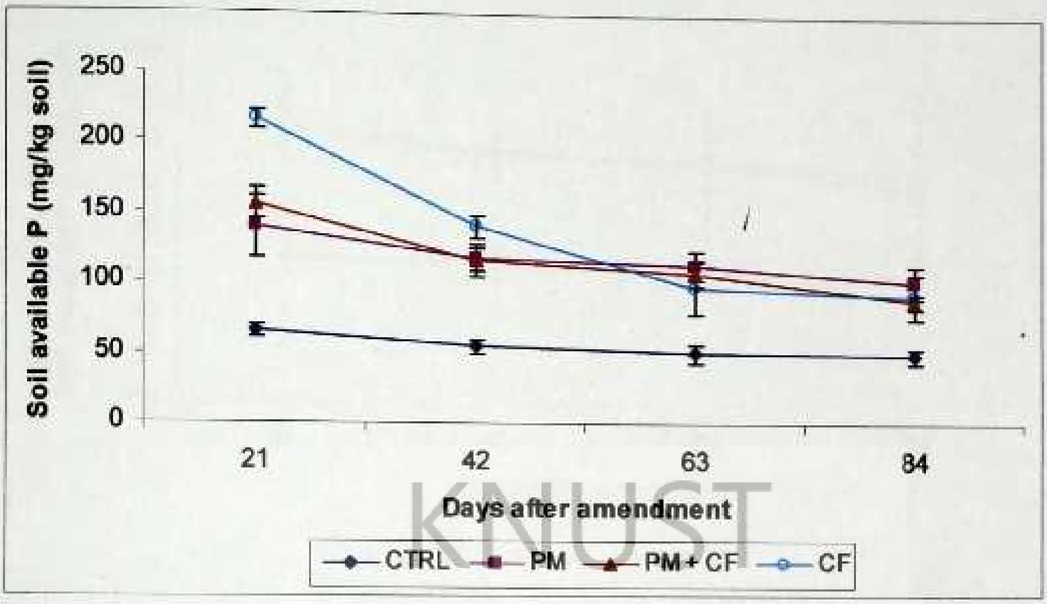

Fig. 4.6a. Effect of no amendment (CTRL), poultry manure (PM), poultry manure + chemical fertilizer (PM+CF) and chemical fertilizer (CF) amendments on soil available phosphorus in 2006 - major season on a Ferric Acrisol, Kwadaso.

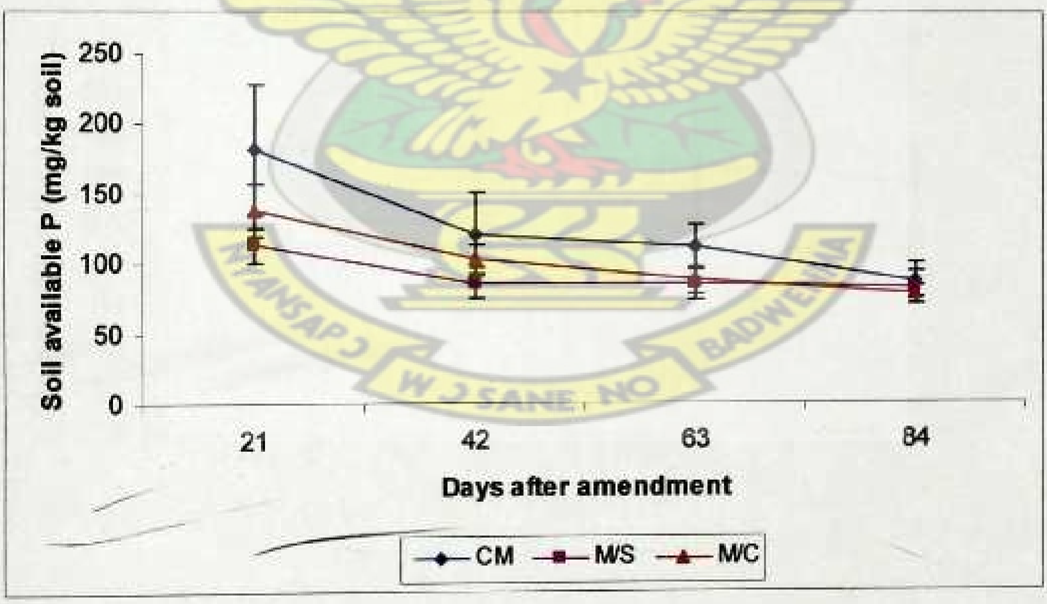

Fig. 4.6b. Effects of continuous maize (CM), maize/soybean (M/S) intercrop and maize / cowpea (M/C) rotation cropping systems on soil available phosphorus in 2006- major season on a Ferric Acrisol, Kwadaso.

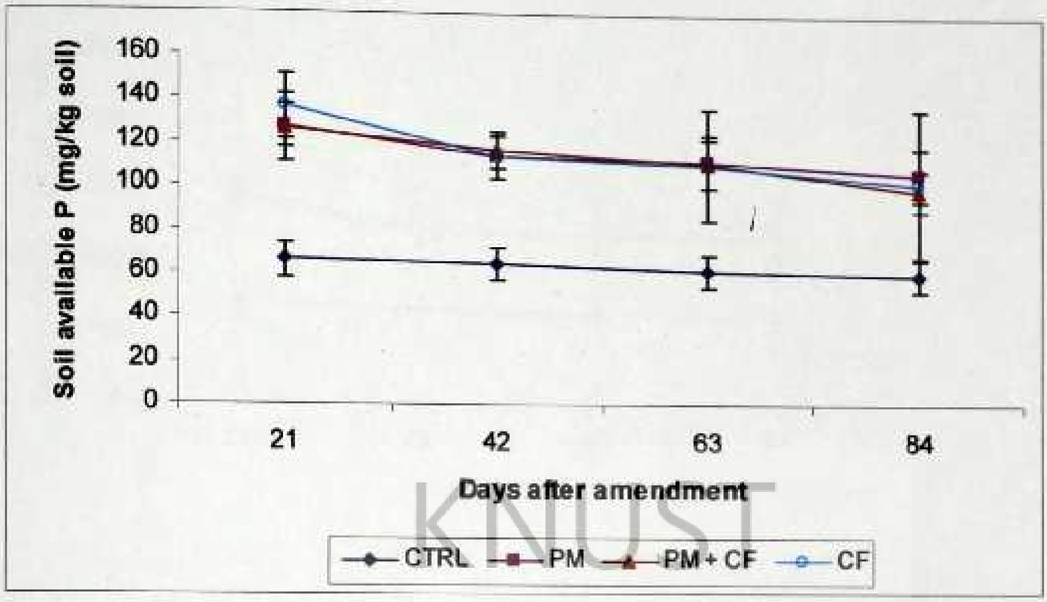

Fig. 4.6c. Effect of no amendment (CTRL), poultry manure (PM), poultry manure + chemical fertilizer (PM+CF) and chemical fertilizer (CF) amendments on soil available P in 2006 - minor season on a Ferric Acrisol, Kwadaso.

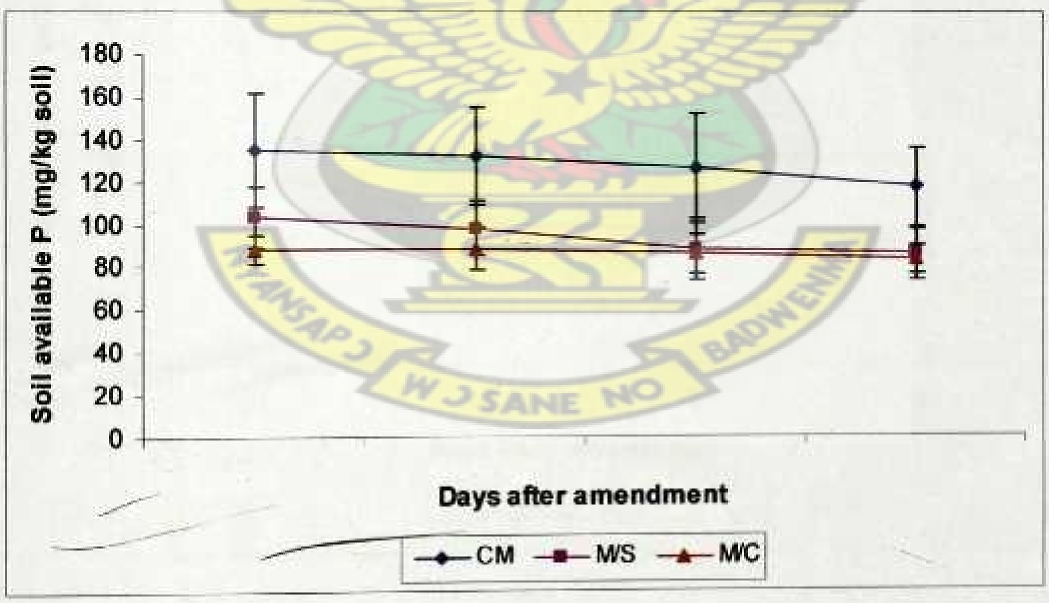

Fig. 4.6d. Effect of continuous maize (CM), maize/soybean (M/S) intercrop and maize / cowpea (M/C) rotation cropping systems on soil available phosphorus in the 2006 - minor season on a Ferric Acrisol, Kwadaso.

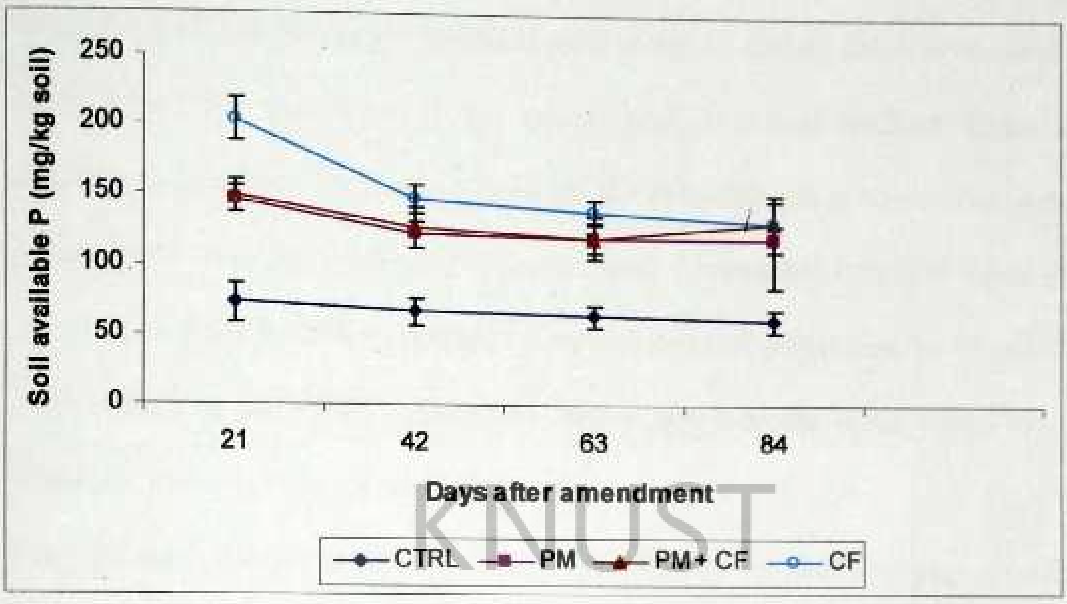

Fig. 4.6c. Effect of amendments on soil available phosphorus in 2007-major season on a Ferric Acrisol, Kwadaso.

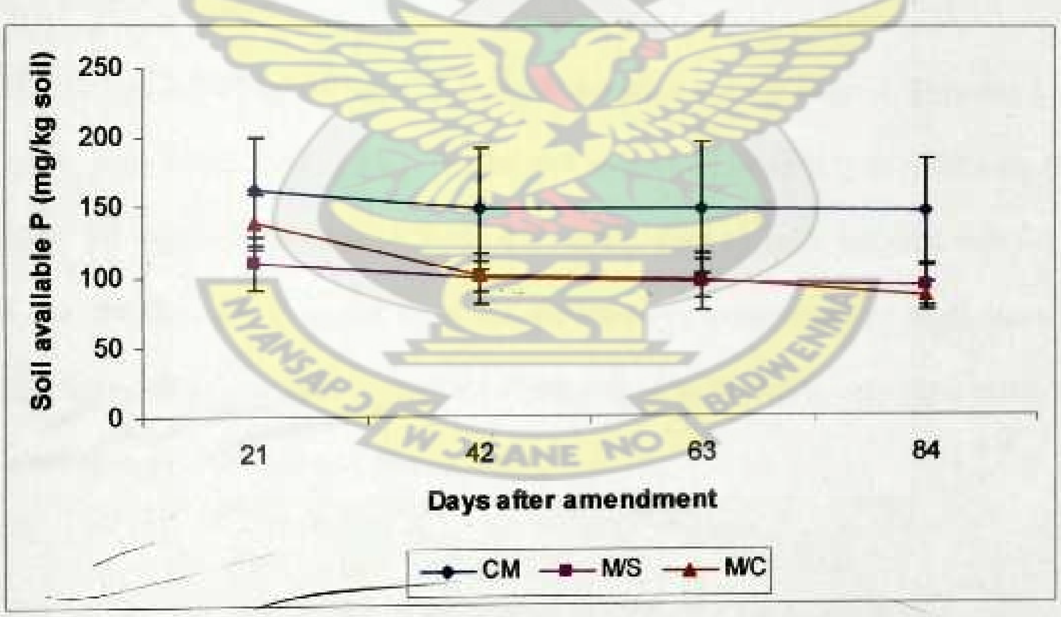

Fig. 4.6f. Effect of cropping systems on soil available phosphorus in 2007-major season on a Ferric Acrisol, Kwadaso.

found for chemical fertilizer - amended plots at the 21 and 42 DAA in the first year of study (Figs. 4.6a and 4.6c). In the second year, chemical fertilizer amended plots consistently produced the highest level of the available phosphorus (Fig. 4.6e). The control plots however, produced the lowest level of available P in both years of study. There was a sharp decline in available P content especially between the 21 and 42 DAA (Figs. 4.6a, 4.6c and 4.4e). The sharpest decline was recorded in CF plots (16 – 35 %), whilst the control produced the least (2 – 16 %).

The soil available phosphorus contents were similar for the cropping systems even though continuous maize cropping system produced relatively higher values throughout the entire study period (Figs. 4.6b, 4.6d and 4.6f).

4.7.2 DISCUSSION

Results indicated high levels of P in amended plots and the control. This was by virtue of the high initial level of 45.13 mg/kg soil recorded (Table 4.1) coupled with P inputs from the crop residues which were left on the field at each seasonal harvest (Table 4.3a). Besides, the P inputs from the amendments contributed to high levels in the respective plots. The bulk of applied P remains in soils due to very slow diffusion and immobilization (Prasad and Power, 1997).

The decline in P availability in the control plots during each season was gradual, while the reduction resulting from the application of chemical fertilizer was relatively sharp. This trend could be explained by the 'A'- value concept (Fried and Dean, 1952) that the quantities of P absorbed from two sources (soil and fertilizer) will be in direct proportion to the amounts available. This indicated that more P would be expected to be taken by crops on CF plots and so explained the sharpest decline observed in these plots, especially between the 21 and 42 DAA as seen from the curves in Figs. 4.6a, 4.6c and 4.6e.

Apart from the 'A'- value concept, one more reason could be advanced for the decline of P in amended plots. The occasional heavy rainfall at the study area could result in some P loss through leaching as the applied P was water soluble. However, despite the general decline in available P during each season, the amounts recorded prior to harvest (i.e. 4th sampling period) were still enough to sustain growth of subsequent crops. Significant differences ($P < 0.05$) between amendments and the control were observed with respect to available P. The relatively low level of the native available P (CTRL) and the high content of the available P in PM, PM + CF and CF plots accounted for the significant differences between these amendments and the control. The study indicated that P was readily available in PM plots. This is confirmed by the statistically similar values of available P recorded during the sampling periods (especially after 1st or 2nd sampling period during the 1st year) relative to CF plots. Poultry manure can therefore be a good store of phosphorus. However, over – application of manure will oversupply P, eventually leading to its excessive buildup which may cause runoff from the land to threaten eutrophication of lakes, streams and estuaries (Magdoff and Weil, 2004).

4.8 SOIL EXCHANGEABLE BASES

4.8.1 Results

4.8.1.1 Potassium

The mean soil exchangeable K under the different cropping systems and amendments are presented in Tables 4.12a – 4.12c. At the level of the amendments, the least K values were found at 21 DAA during the 2006 - minor season (Table 4.12b). This was followed by a sharp increase at 42 DAA. The increments were 221 % in PM plots, 269 % in plots amended with PM + CF, 300 % in both CTRL and CF plots. The highest values were recorded at 84 DAA under amendments and cropping systems (Table 4.12b). Like ammonium - nitrogen, the level of soil exchangeable K followed an increasing pattern in 2006 - minor season.

Table 4.12a. Soil exchangeable K dynamics under treatments in 2006 – major season

Treatments	Soil exchangeable K (cmol/kg soil)			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	0.46	0.35	0.35	0.33
PM	0.77	0.45	0.41	0.38
PM + CF	0.96	0.43	0.42	0.40
CF	0.83	0.50	0.42	0.38
LSD (0.05)	0.18	0.11	NS	NS
Cropping systems				
CM	0.54	0.48	0.41	0.39
M/S	0.84	0.38	0.37	0.33
M/C	0.88	0.48	0.40	0.38
LSD (0.05)	0.21	NS	0.08	NS

DAA: days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer CF: chemical fertilizer, CM: Continuous maize, M/S: Maize/soybean, M/C: Maize - cowpea.

Table 4.12b. Soil exchangeable K dynamics under treatments in 2006 – minor season

Treatments	Soil exchangeable K (cmol/kg soil)			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	0.14	0.56	0.59	0.68
PM	0.19	0.61	0.62	0.75
PM + CF	0.16	0.59	0.62	0.76
CF	0.16	0.64	0.64	0.64
LSD (0.05)	0.04	0.07	NS	NS
Cropping systems				
CM	0.18	0.65	0.77	0.83
M/S	0.16	0.51	0.67	0.69
M/C	0.15	0.54	0.65	1.02
LSD (0.05)	NS	NS	NS	0.23

DAA: days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer CF: chemical fertilizer, CM: Continuous maize, M/S: Maize/soybean, M/C: Maize - cowpea.

Table 4.12c. Soil exchangeable K dynamics under treatments in 2007 – major season

Treatments	Soil exchangeable K (cmol/kg soil)			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	0.56	0.47	0.46	0.49
PM	0.78	0.49	0.76	0.53
PM + CF	0.69	0.47	0.50	0.52
CF	0.62	0.42	0.47	0.52
LSD (0.05)	NS	NS	0.18	NS
Cropping systems				
CM	0.75	0.54	0.80	0.54
M/S	0.58	0.41	0.44	0.47
M/C	0.66	0.44	0.77	0.53
LSD (0.05)	NS	NS	0.17	NS

4.8.1.2 Calcium

The soil exchangeable calcium values were similar under amendments (Figs. 4.7a, 4.7c and 4.7e). However, at the level of cropping systems, CM gave values that differed significantly ($P < 0.05$) from M/S and M/C systems (Figs. 4.7b, 4.7d and 4.8f). Generally, higher values were recorded in the minor season than in the major seasons. No observable differences were observed between sampling periods in both years of study.

4.8.1.3 Magnesium

Among the cropping systems, CM generally recorded the highest level of soil exchangeable magnesium during the 2 years of experimentation (Figs. 4.8b, 4.8d and 4.8f). Exchangeable magnesium varied among amendments and ranged from < 1.2 cmol/kg soil in CF plots to > 3.2 cmol/kg soil under PM + CF amendment. Amendments generally did not significantly affect exchangeable Mg content of soils (Figs. 4.8a, 4.8c and 4.8e). Values recorded in 2006 - major season were relatively lower than those recorded in 2006 - minor season. It is known that soil microbial biomass influences the availability of many nutrients. However, Figs 4.8h and 4.8i show low correlation between microbial biomass carbon and exchangeable magnesium which indicated that exchangeable magnesium was not influenced by microbial activity in 2006 – minor and 2007- major seasons. In 2006 – major season, microbial activity influenced the soil exchangeable magnesium content (Fig. 4.8g).

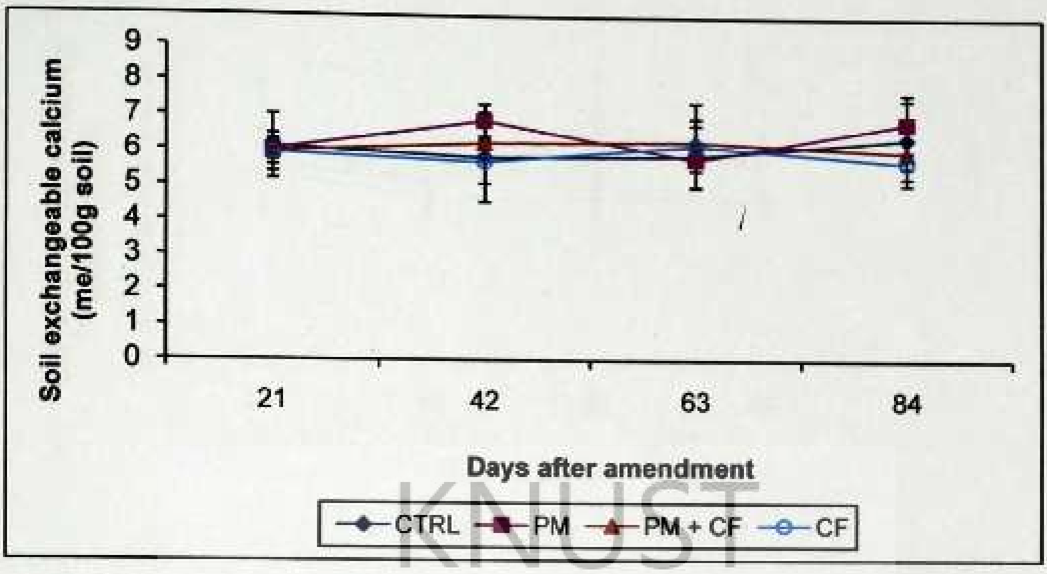

Fig. 4.7a. Soil exchangeable calcium content as affected by no amendment (CTRL), poultry manure (PM), poultry manure + chemical fertilizer (PM + CF) and chemical fertilizer (CF) amendments during 2006 - major season on a Ferric Acrisol, Kwadaso.

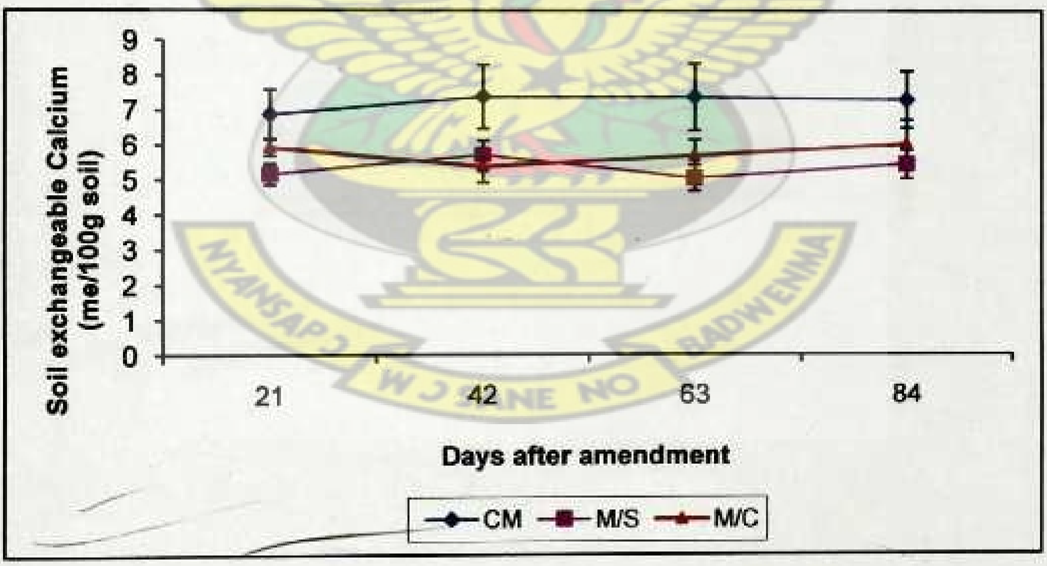

Fig. 4.7b. Soil exchangeable calcium content as affected by continuous maize (CM), maize/soybean (M/S) intercrop and maize / cowpea (M/C) rotation cropping systems during 2006- major season on a Ferric Acrisol, Kwadaso.

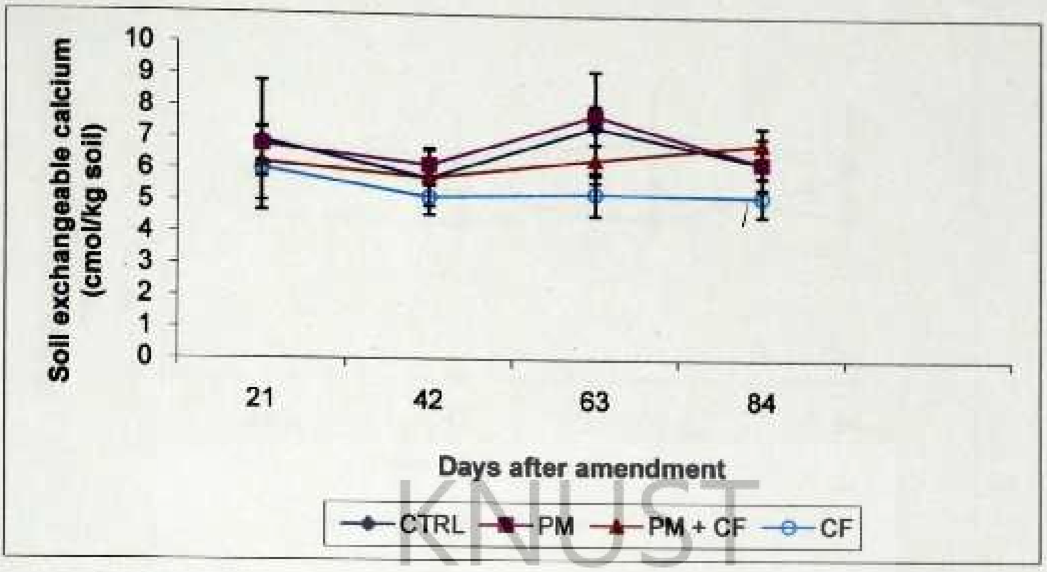

Fig. 4.7c. Soil exchangeable calcium content as affected by no amendment (CTRL), poultry manure (PM), poultry manure + chemical fertilizer (PM + CF) and chemical fertilizer (CF) amendments during 2006- minor season on a Ferric Acrisol, Kwadaso.

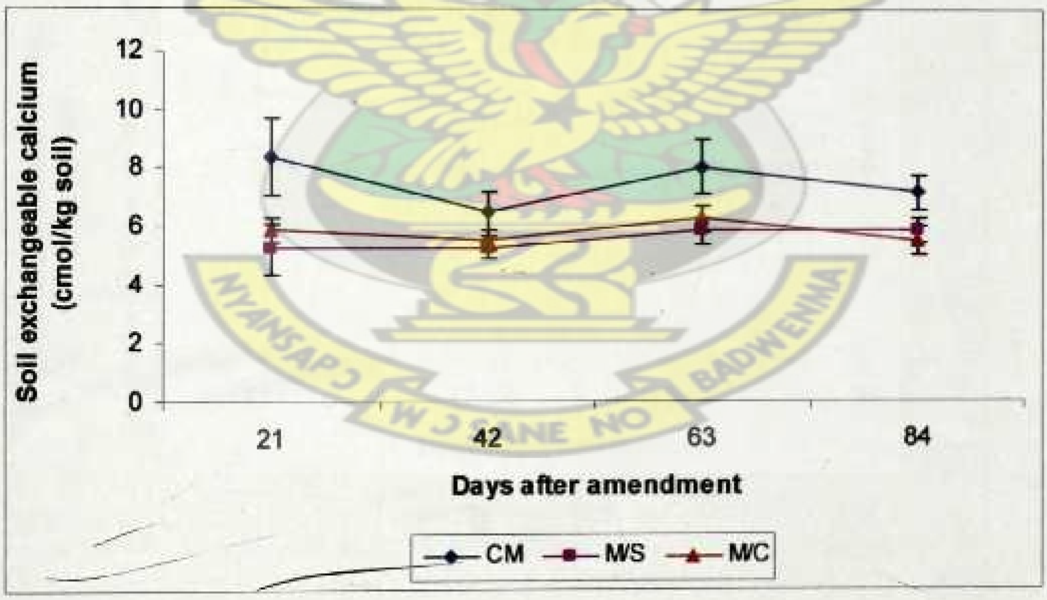

Fig. 4.7d. Soil exchangeable calcium content as affected by continuous maize (CM), maize/ soybean (M/S) intercrop and maize/cowpea (M/C) rotation cropping systems during 2006- minor season on a Ferric Acrisol, Kwadaso.

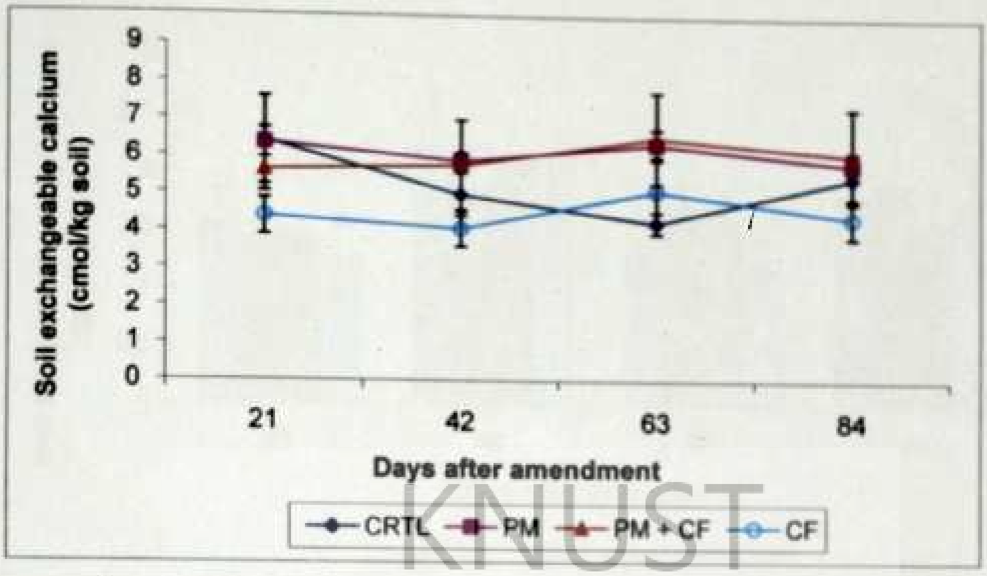

Fig. 4.7e. Soil exchangeable calcium content as affected by amendments and the control in 2007- major season on a Ferric Acrisol, Kwadaso.

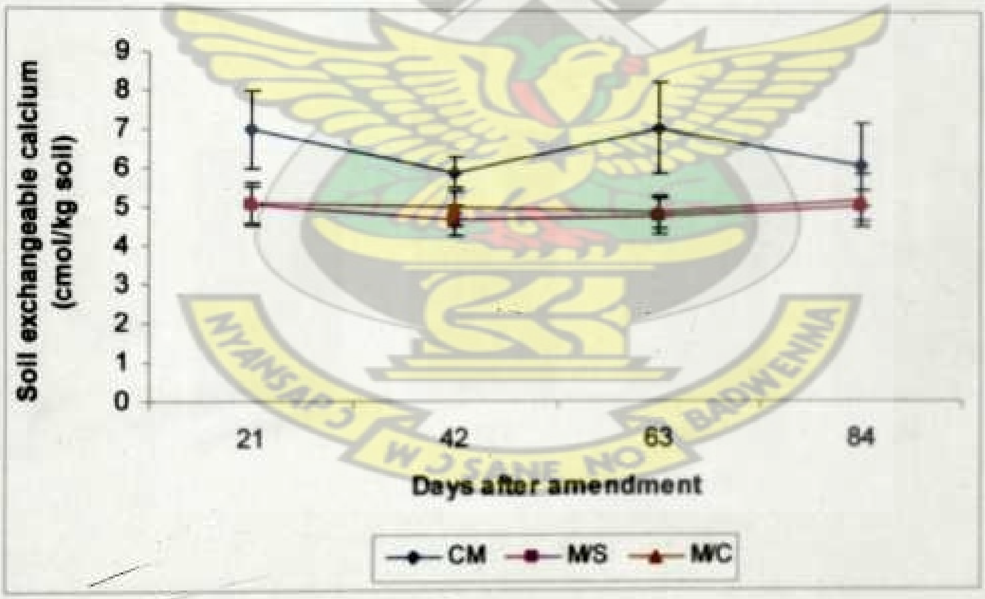

Fig. 4.7f. Soil exchangeable calcium content as affected by the cropping systems during 2007- major cropping season on a Ferric Acrisol, Kwadaso.

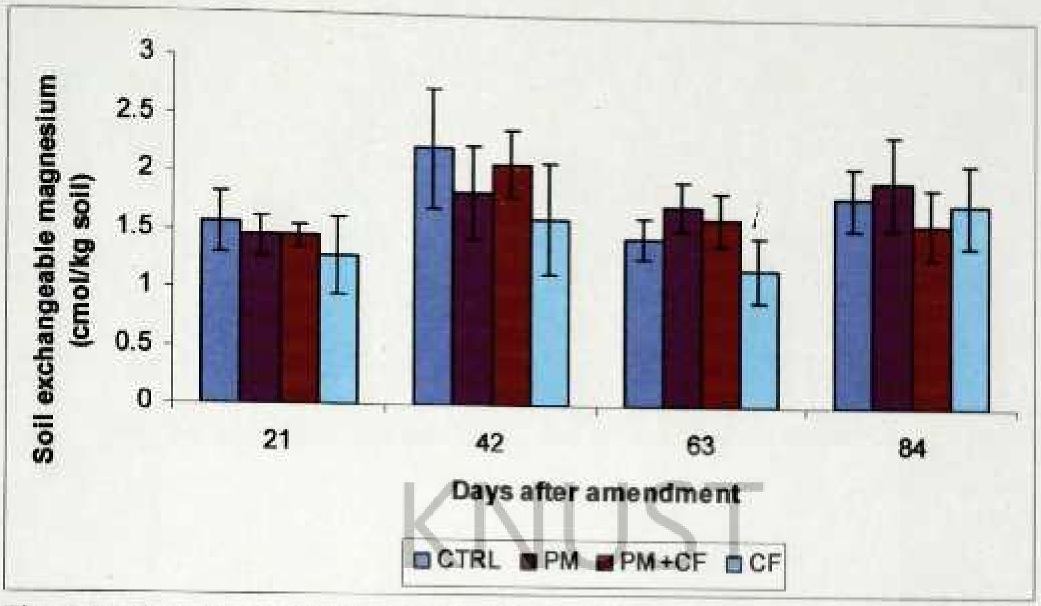

Fig. 4.8a. Soil exchangeable magnesium content under amendments and control in 2006 - major season on a Ferric Acrisol, Kwadaso.

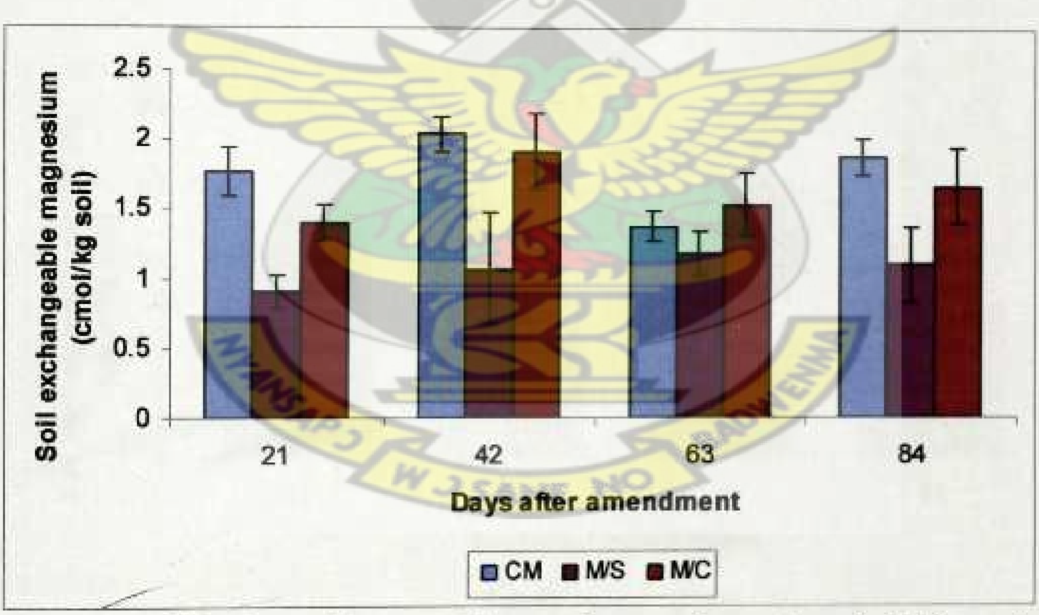

Fig. 4.8b. Soil exchangeable magnesium under cropping systems in 2006 - major season on a Ferric Acrisol, Kwadaso.

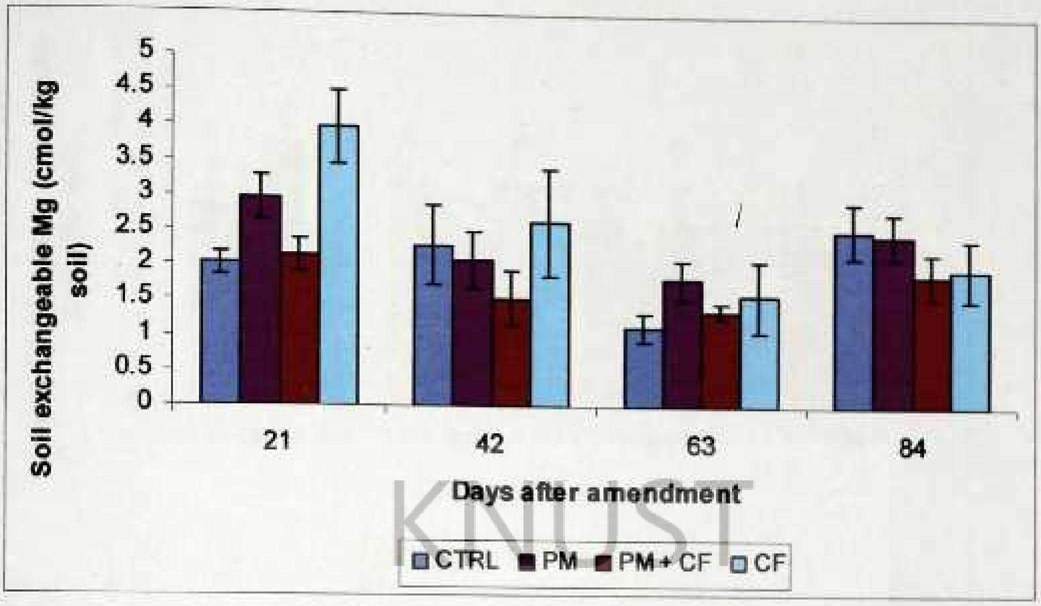

Fig.4.8c. Soil exchangeable magnesium under amendments and control in 2006-minor season on a Ferric Acrisol, Kwadaso.

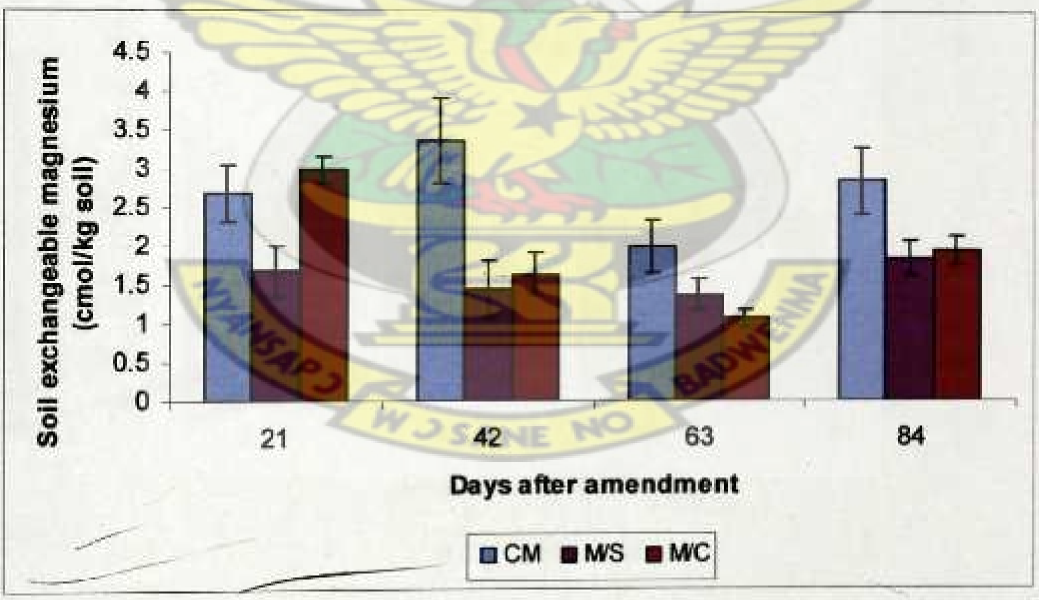

Fig. 4.8d. Soil exchangeable magnesium under cropping systems in 2006-minor season on a Ferric Acrisol, Kwadaso.

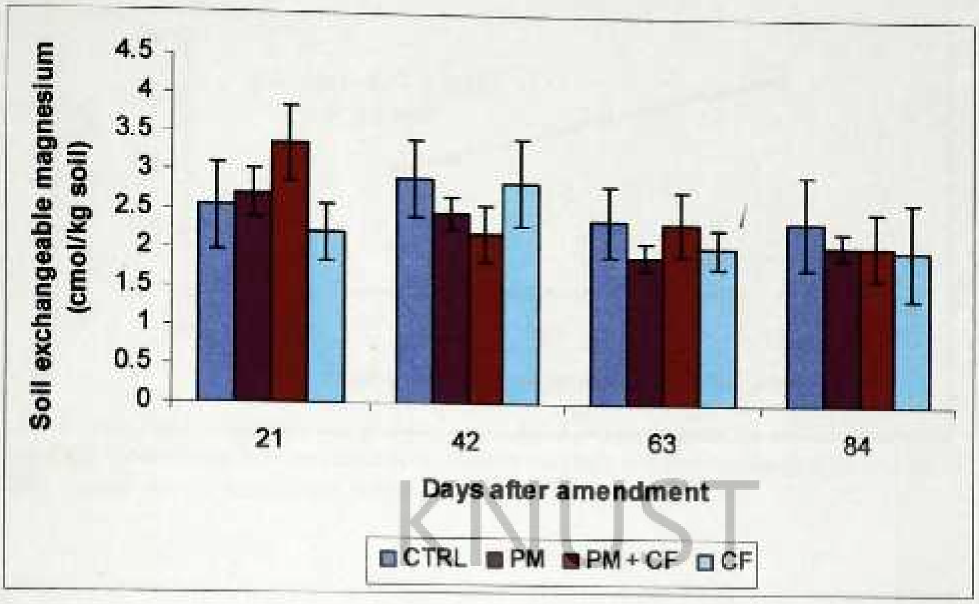

Fig. 4.8e. Soil exchangeable magnesium under amendments and control in 2007 - major season on a Ferric Acrisol, Kwadaso.

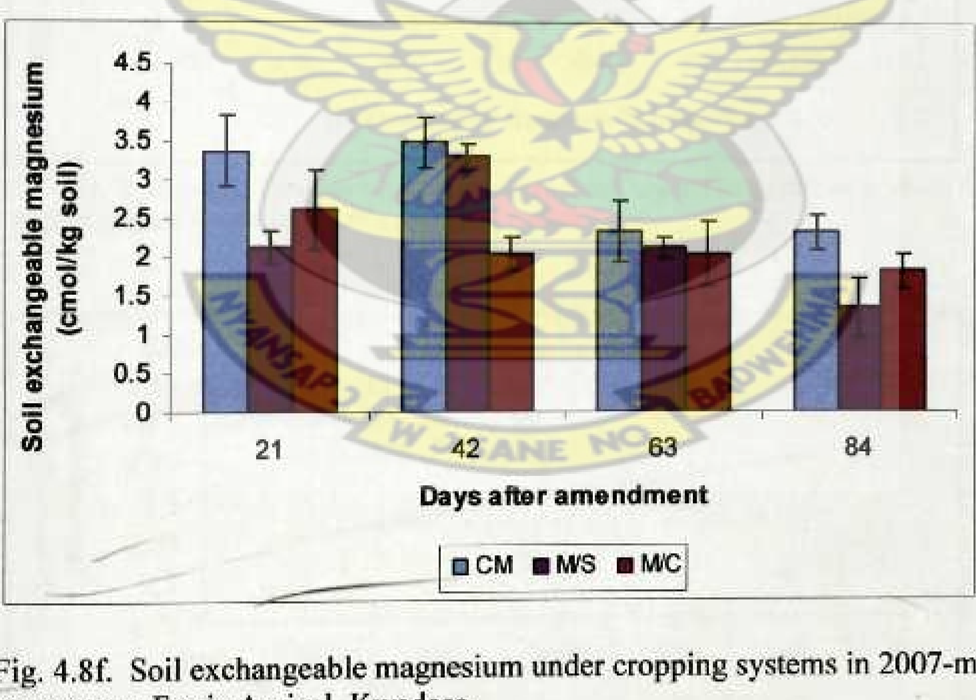

Fig. 4.8f. Soil exchangeable magnesium under cropping systems in 2007-major season on a Ferric Acrisol, Kwadaso.

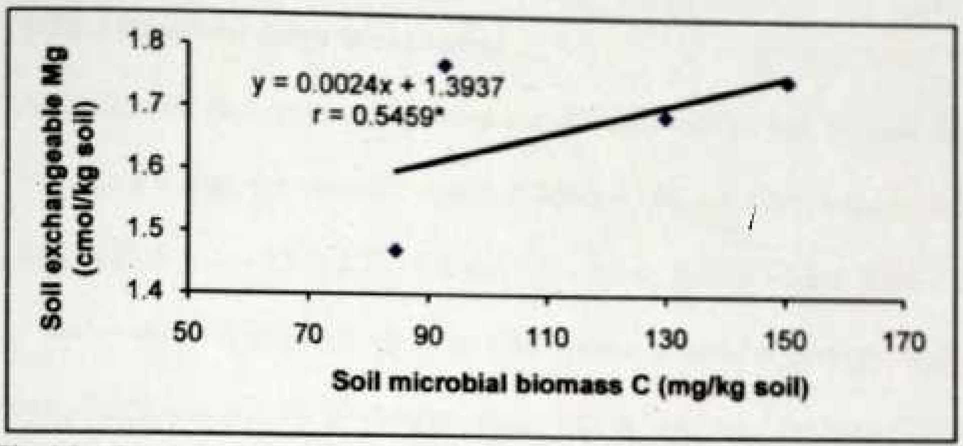

Fig. 4.8g. Correlation between microbial biomass carbon and soil exchangeable Mg. in 2006 - major season on a Ferric Acrisol, Kwadaso.

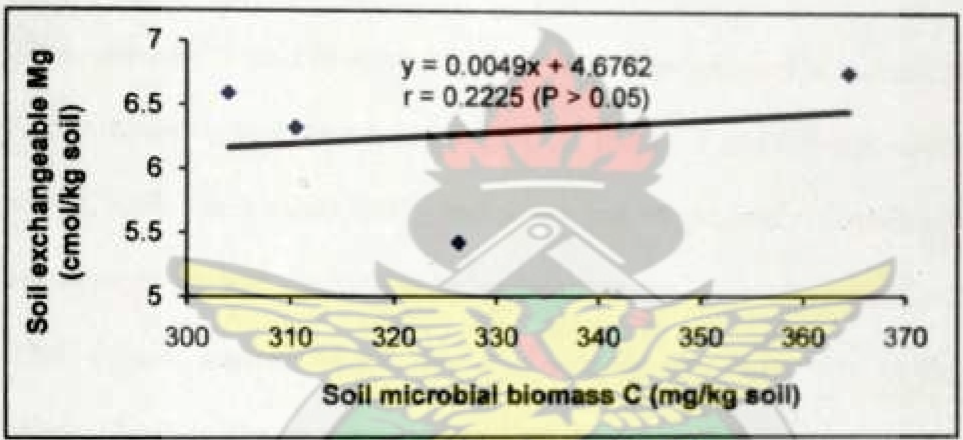

Fig. 4.8h. Relationship between microbial biomass C and soil exchangeable magnesium in 2006 - minor season on a Ferric Acrisol, Kwadaso.

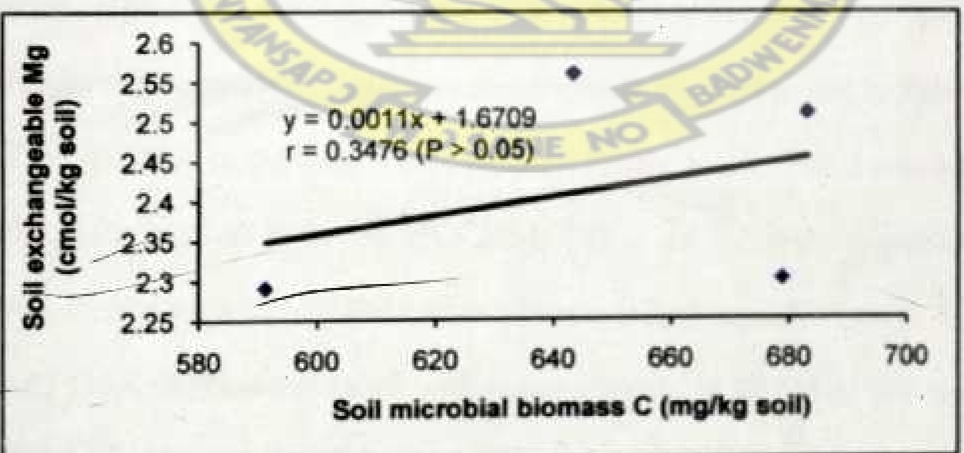

Fig. 4.8i. Relationship between microbial biomass C and soil exchangeable magnesium in 2007 - major season on a Ferric Acrisol, Kwadaso.

4.8.1.4 Calcium: magnesium ratios

Amendments and cropping systems significantly influenced the soil exchangeable Ca: Mg ratios during the seasonal cycles (Tables 4.14a – 4.14c). Values under amendments ranged from 3.4 – 12.9, 2.3 – 7.5 and 1.6 – 3.3 in 2006 – major, 2006 – minor and 2007 – major seasons, respectively. The CM system generally gave the highest ratios at all sampling periods in 2006 – major season whilst M/C gave the least (Table 4.14a).

4.8.1.5 Sodium

Plots amended with PM gave higher levels of exchangeable sodium (Tables 4.13a – 4.13c). Lower values were found for CTRL, PM + CF and CF- amended plots in 2006 – major, 2006 - minor and 2007 - major seasons, respectively. Significant effects of PM amendment on soil exchangeable sodium content were observable, especially in the 2006 - major season. At 42 days after amendments imposition in the 2006 - major season, level of the nutrient in cropping systems and amended plots declined (Table 4.13a). The reductions were 2.9, 15.2, 16.0 and 17.2 % in PM, PM + CF, CTRL and CF plots, respectively and 3.4, 7.4 and 25.7 % in CM, M/C and M/S cropping systems, respectively. Conversely, there was an increase in the level of soil exchangeable sodium at the 42 DAA in the 2006 - minor season (Table 4.13b). The increments were 12.1, 45.3, 61.9 and 100 % in PM + CF, PM, CTRL and CF plots, respectively and 26.2, 48.6, 81.2 % in M/C, M/S and CM cropping systems, respectively. The level of sodium at 63 DAA declined compared with values obtained at 42 DAA. The reductions were 23.8, 35.7, 36.4 and 37.5 % for the CTRL, PM + CF, PM and CF amendments,

Table 4.13a. Soil exchangeable Na dynamics under treatments in 2006 – major season

Treatments	Soil exchangeable Na (cmol/kg soil)			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	0.25	0.21	0.16	0.22
PM	0.34	0.33	0.21	0.24
PM + CF	0.33	0.28	0.18	0.22
CF	0.29	0.24	0.15	0.23
LSD (0.05)	0.08	0.05	0.03	NS
Cropping systems				
CM	0.29	0.28	0.19	0.21
M/S	0.35	0.26	0.17	0.24
M/C	0.27	0.25	0.17	0.23
LSD (0.05)	0.07	NS	NS	NS

DAA: days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer CF: chemical fertilizer, CM: Continuous maize, M/S: Maize/soybean, M/C: Maize - cowpea.

Table 4.13b. Soil exchangeable Na dynamics under treatments in 2006 – minor season

Treatments	Soil exchangeable Na (cmol/kg soil)			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	0.63	1.02	0.60	0.53
PM	0.75	1.09	0.77	0.62
PM + CF	0.66	0.74	0.51	0.48
CF	0.55	1.10	0.67	0.60
LSD (0.05)	0.12	0.24	0.20	NS
Cropping systems				
CM	0.64	1.16	0.71	0.58
M/S	0.70	1.04	0.54	0.54
M/C	0.61	0.77	0.67	0.55
LSD (0.05)	NS	0.24	NS	NS

DAA: days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer CF: chemical fertilizer, CM: Continuous maize, M/S: Maize/soybean, M/C: Maize - cowpea.

respectively in the 2006 - major season and 29.4, 31.1, 39.1 and 41.2 % in PM, PM + CF, CF and CTRL plots, respectively in the 2006 - minor season. A similar trend was observed in the 2007 – major season as in the minor season (Tables 4.13b and 4.13c). There was an increase in the level of the exchangeable sodium at 42 days following amendment and a reduction at the 63 days following amendment. Results obtained in 2006 - minor season indicated higher levels of sodium under amendments and cropping systems compared with the major seasons'.

Table 4.13c. Soil exchangeable Na dynamics under treatments in 2007 – major season

Treatments	Soil exchangeable Na (cmol/kg soil)			
	21 DAA	42 DAA	63 DAA	84 DAA
Amendment				
CTRL	0.14	0.22	0.13	0.16
PM	0.17	0.29	0.15	0.16
PM + CF	0.14	0.20	0.13	0.16
CF	0.11	0.17	0.12	0.16
LSD ($P < 0.05$)	0.04	0.06	NS	0.03
Cropping systems				
CM	0.14	0.24	0.15	0.17
M/S	0.15	0.17	0.12	0.15
M/C	0.13	0.25	0.13	0.17
LSD ($P \leq 0.05$)	NS	0.07	NS	NS

DAA: days after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer CF: chemical fertilizer, CM: Continuous maize, M/S: Maize/soybean, M/C: Maize - cowpea.

The exchangeable sodium percentage (ESP) was computed for each season (Tables 4.14a – 4.14c). In 2006 – major season, ESP ranged from 2.1 – 4.1 % for plots under amendments and 2.2 - 4.6 % for cropping systems. Higher values of 4.8 - 11.4 % and 5.0 - 12.5 % were recorded in 2006 - minor season for plots under amendments and cropping systems respectively. In 2007- major season, the mean ESP ranged from 1.4 to 3.1 % for amended plots and 1.3 - 3.2 % for cropping systems (Table 4.14c).

Table 4.14a. Effect of treatments on Ca/Mg ratio and ESP in the 2006 - major season

	Soil exchangeable Ca/Mg ratio				* ESP (%)			
Treatments	21 DAA	42 DAA	63 DAA	84 DAA	21 DAA	42 DAA	63 DAA	84 DAA
Amendment								
CTRL	4.9	3.7	4.6	5.9	3.1	2.1	2.1	2.7
PM	4.7	12.9	4.0	7.3	4.1	3.5	2.6	2.6
PM +CF	4.2	3.4	4.7	6.6	3.8	3.3	2.1	2.8
CF	4.9	5.8	10.9	3.8	3.7	3.3	2.1	3.0
LSD (0.05)	NS	0.69	0.52	0.54	0.42	0.40	NS	NS
Cropping system								
CM	7.0	7.9	9.8	7.9	3.2	3.0	2.2	2.3
M/S	5.3	8.2	3.7	5.4	4.6	3.3	2.4	3.1
M/C	4.9	3.2	4.7	4.4	3.2	3.3	2.2	3.0
LSD (0.05)	0.26	0.71	0.65	0.51	0.46	NS	NS	0.47

* ESP (Exchangeable sodium percentage) = (Exchangeable Na/ECEC) × 100

Table 4.14b. Effect of treatments on Ca/Mg ratio and ESP in the 2006 - minor season

	Soil exchangeable Ca/Mg ratio				* ESP (%)			
Treatments	21 DAA	42 DAA	63 DAA	84 DAA	21 DAA	42 DAA	63 DAA	84 DAA
Amendment								
CTRL	3.2	4.0	6.9	2.7	6.5	10.5	6.1	5.3
PM	2.4	4.7	4.9	2.8	7.0	10.9	7.0	6.1
PM +CF	3.1	6.3	4.9	5.0	7.1	8.5	5.7	4.8
CF	2.3	3.1	7.5	3.0	5.1	11.4	8.1	7.0
LSD (0.05)	0.46	0.29	1.76	0.57	1.91	2.01	1.89	1.30
Cropping system								
CM	3.5	2.3	5.2	3.0	5.3	9.9	6.1	5.0
M/S	2.3	5.9	5.1	4.1	8.0	12.5	6.3	6.0
M/C	2.5	5.5	7.9	2.9	6.3	9.0	7.7	6.0
LSD (0.05)	0.58	0.26	1.41	0.62	1.03	0.98	1.48	NS

* ESP (Exchangeable sodium percentage) = (Exchangeable Na/ECEC) × 100

Table 4.14c. Effect of treatments on Ca/Mg ratio and ESP in the 2007 - major season

	Soil exchangeable Ca/Mg ratio				* ESP (%)			
Treatments	21 DAA	42 DAA	63 DAA	84 DAA	21 DAA	42 DAA	63 DAA	84 DAA
Amendment								
CTRL	2.8	2.2	2.4	2.6	1.4	2.5	1.7	1.9
PM	2.6	2.6	3.5	2.9	1.7	3.1	1.6	1.8
PM +CF	2.0	3.3	3.3	2.1	1.5	2.3	2.3	1.8
CF	2.3	1.6	2.6	2.9	1.5	2.2	1.5	2.2
LSD (0.05)	0.36	0.44	0.46	0.43	0.21	0.43	0.38	0.40
Cropping system								
CM	2.3	2.7	3.5	1.9	1.3	2.3	1.4	1.8
M/S	2.6	2.1	2.3	1.7	1.9	2.2	1.6	2.1
M/C	2.4	2.6	3.0	3.5	1.5	3.2	1.6	2.2
LSD (0.05)	0.27	0.34	0.53	0.47	0.57	0.57	NS	0.34

* ESP (Exchangeable sodium percentage) = (Exchangeable Na/ECEC) × 100

4.8.2 DISCUSSION

4.8.2.1 Soil exchangeable potassium

The data (Tables 4.12a - 4.12c) showed a general decline in exchangeable potassium during the 2006 - major season. A similar observation was made by Wicks *et al.* (1988) when they found a decline in exchangeable potassium in cultivated soils over time. However, the trend in the 2006 - minor season followed an increasing pattern. The low exchangeable K registered at 21 DAA in the 2006 - minor season (Table 4.12b) suggested possible fixation of the nutrient which was released with time during the season. The release was sharp at 42 days after amendment and became gradual at subsequent sampling periods. When potassium is added to the soil, some of it goes into exchangeable positions and some into nonexchangeable positions. This mechanism is termed fixation. Barber (1995) demonstrated the release of nonexchangeable potassium by exhaustive cropping of the soil. In contrast, Srinivasa *et al.* (1999) reported a significant decline in K release due to continuous cropping. The strong positive correlation obtained between exchangeable K and NH_4^+ - N (Table 4.5) could be due to the fact that both have the same coordination numbers (8 or 12) and are also similar in ionic size (i.e. 1.33 for K^+ and 1.43 for NH_4^+) and are therefore held on soil exchange sites with a similar strength. The strength of the bond of exchangeable K to the soil varies with the type of exchange site and the nature of other cations present (Barber, 1995). The insignificant differences observed among cropping systems at most sampling periods (Tables 4.12a – 4.12c) with respect to exchangeable K substantiate a claim by Ranamukhaarachchi *et al.* (2005) that similar cropping systems in Bangladesh did not significantly affect exchangeable K content of low and medium highland soils in general.

4.8.2.2 Soil exchangeable calcium

The highest exchangeable calcium recorded in soils under continuous maize cropping system contrasts with the observation made by Riffaldi *et al.* (1994) and Juo *et al.* (1996) that continuous cropping resulted in lower exchangeable calcium. Continuous cropping usually results in soil acidification (Juo *et al.*, 1996). Results obtained in this study (Appendix 2a – 2c) however indicated lower exchangeable acidity values for plots under CM cropping system than M/S and M/C systems.

4.8.2.3 Soil exchangeable magnesium

The data (Figs. 4.8a - 4.8f) showed fluctuations in soil exchangeable magnesium content with respect to both the amendments and the cropping systems. Relatively higher Mg contents were recorded under CM cropping system suggesting to some extent, a greater conservation of the element by this cropping system. Lower values were registered in M/S cropping system compared with CM. This could be due to the influence of both crop components (maize and soybean) on soil exchangeable magnesium content. This is so since different crops remove different amounts of nutrients from the soil (Tulu, 2002). Both crops with their different nutrient requirements possibly competed for the nutrient to meet their varying demands, thereby leading to greater exploitation from the soil. Ruben and Gallaher (1976) reported higher magnesium content in oat/soybean soil surface compared to oat/grain sorghum cropping system.

It was expected that soil exchangeable magnesium would show distinct positive correlations with microbial biomass C since microbial biomass controls the availability of many nutrients (Magdoff and Weil, 2004). However, results (Figs. 4.8h and 4.8i) indicated low and insignificant correlation between the exchangeable magnesium and biomass C over the seasons. This contrasts the observation of Jozef (2004) who reported a strong positive correlation (r = 0.80*) between the soil exchangeable magnesium and the biomass C.

4.8.2.4 Soil exchangeable calcium: magnesium ratios

The CM system generally recorded the highest Ca/Mg ratio during the 2006 – major season (Table 4.14a). This contrasts the observation of Ruben and Gallaher (1976) who found higher Ca/Mg ratios under cereal/legume (oat/soybean) intercropping systems than sole cropping systems. The cereal/legume (maize/soybean) intercropping system recorded rather the lowest ratios in this study (Table 4.14c.).

4.8.2.5 Soil exchangeable sodium

The higher soil exchangeable sodium content recorded in the PM - amended plots was not totally surprising because the manure was collected from poultry birds which were fed with rations containing sodium chloride (NaCl). In Table 4.3a, total Na recorded in the poultry manure was 0.71 %. This might have made a substantial contribution to the level of the nutrient in these plots. The lower level of exchangeable sodium recorded on the 63 DAA over that obtained on the 42 DAA was not clear since one would not expect peak demand of the nutrient at this stage due to possible suberization of the root endodermis which does not enhance effective nutrient uptake. Other nutrient elements such as nitrogen, phosphorus, potassium, etc. considered in this study showed peak demand at 42 DAA. The dynamics of sodium under cropping systems and amendments is yet to be reported in literature.

The ESP varied considerably from the major to the minor season in 2006. Values recorded in 2006 - minor season were about 2 -3 times those recorded in the 2006 - major season. The higher values recorded in the 2006 -minor season was not clear but could be attributed partly to poor rainfall distribution. Northcote and Skeen (1972) stated that the ESP if more than 6 could result in sodic soils. There was a decline in values recorded in 2007- major season over those found in 2006 - minor season. Since 2007- major season recorded higher rainfall distribution (Table 4.10) than 2006 - major season, it could be inferred that rainfall possibly influenced the ESP.

4.9 CROPS GRAIN YIELDS

4.9.1 Maize grain yield

4.9.1.1 Results

Generally, maize grain yield declined in the 2006 - minor season (Table 4.15) compared to values recorded in both 2006 and 2007 - major seasons. Application of CF and PM + CF increased maize grain yield relative to the control from the 2006 - minor to the 2007- major season of cropping. All the amendments gave yields that were significantly higher than the control in the three seasons of cropping. Irrespective of the type of amendment applied, there was a decline in maize grain yield by 51 % from the first to the second cropping cycle. In 2007 – major season, yield increment of 265.5 % was obtained over that of the previous minor season (2006). Plots under CM cropping system significantly out-yielded ($P < 0.05$) the M/S system. Similarly, plots under M/C cultivation gave yield that was significantly ($P < 0.05$) higher than that of M/S cropping system (Table 4.15). Yield produced under the two cropping systems (CM and M/C) were about twice that recorded in M/S cropping system during the first year of study.

Table 4.15. Maize grain yield as affected by amendments and cropping systems

	Maize grain yield (kg/ha)		
Treatment	2006 -Major	2006-Minor	2007-Major
Amendment			
CTRL	1611	875	2913
PM	2103	1085	3858
PM + CF	2459	1165	4070
CF	2546	1085	4601
LSD (0.05)	274.9	132.7	383.1
Cropping system			
CM	2546	1472	4210
M/S	1642	633	3139
M/C	2351	-	4232
LSD (0.05)	335.4	103.8	673.0

CTRL = Control, PM = Poultry manure, PM + CF = Poultry manure + chemical fertilizer, CF = Chemical fertilizer, CM = Continuous maize, M/S = Maize/soybean intercrop, M/C = Maize/ cowpea rotation.

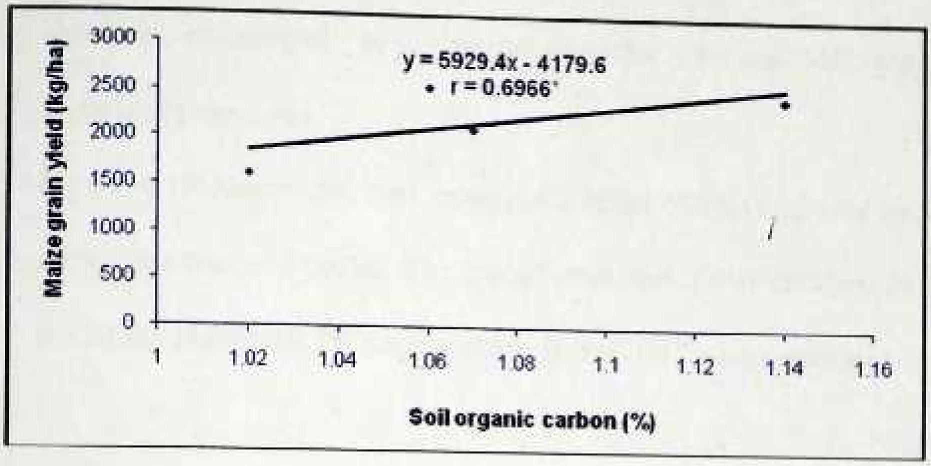

Fig. 4.9a. Relationship between soil organic carbon at 84 DAA and maize grain yield in 2006 - major season on a Ferric Acrisol, Kwadaso.

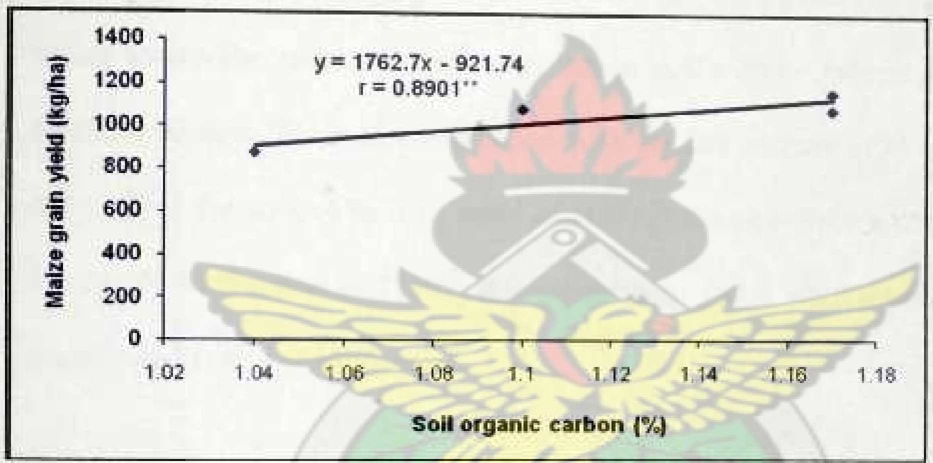

Fig. 4.9b. Relationship between soil organic carbon at 84 DAA and maize grain yield in 2006 - minor season on a Ferric Acrisol, Kwadaso.

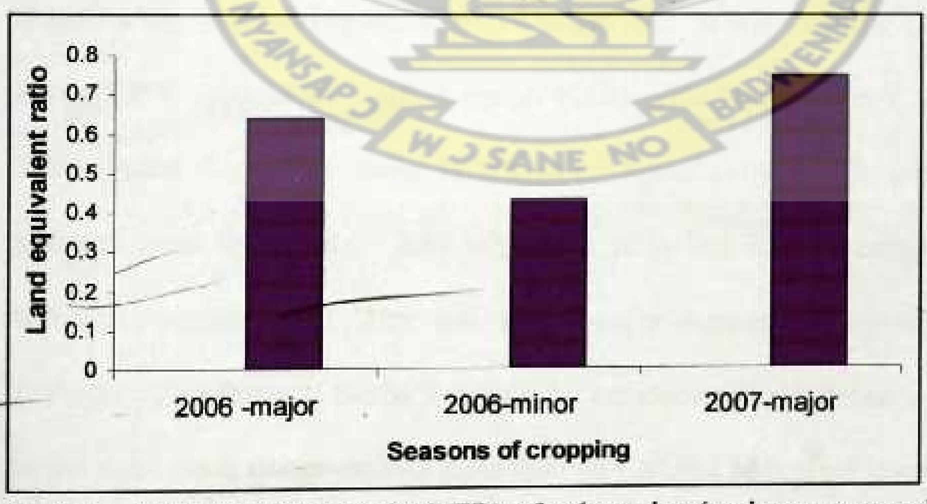

Fig. 4.10. Land equivalent ratio (LER) of sole maize (maize grown under CM cropping system) or maize intercropped with soybean (maize grown under M/S system).

However, maize grain yields produced under CM and M/C cropping systems were statistically the same.

Figure 4.10 shows the land equivalent ratios (LERs) of sole or intercropped maize during the seasonal cycles. The lowest ratio (0.43) was obtained in 2006- minor season whilst the highest (0.75) was recorded in the 2007- major season.

4.9.1.2 DISCUSSION

Maize grain yields obtained in the major seasons were generally higher than those in minor season due to poor rainfall distribution in the minor cropping season. However, fertilizer alone (CF) or in combination with poultry manure (PM + CF) significantly out-yielded the control in both years of study. This observation corroborates with the finding of Kapkiyai *et al.* (1998) that maize grain yields were significantly affected by manure and fertilizer application.

Among the amendments in both years, the application of CF alone or PM + CF significantly increased grain yield of maize due to the positive effect of integrated nutrient management on yield of maize. Maize grain yields under CM cropping system were higher than those under M/S system. Specifically, yields under M/S cropping systems were about one - half the yields achieved in CM cropping system. This difference suggests that there was inter-species competition between the maize and soybean components of the M/S system for resources. The difference could also be due to the more plant stands on M/S plots than on CM and M/S plots (section 3.2.4. pp. 35). This partly explains why the fertility status of soils under M/S cropping system was lower than that of CM cropping system in this study. Greater nutrient uptake by intercropping has been shown by several workers (Dalal, 1974; Adu – Gyamfi *et al.*, 1997; Barik *et al.*, 1998; Sakala, 1998). The lower yield obtained under the M/S cropping system (Table 4.15) contrasts the findings of Francis *et al.* (1986) that total corn yield in strip intercropping of corn and soybean was between 10 and 40 % higher than corn in monocrop fields. The observation however, agrees with a report by Ennin *et al.* (2002) that intercropping maize and soybean reduced maize grain yields. Maize grain yields produced under CM and M/C cropping systems were statistically the same (Table 4.15). This contrasts a report by Adetunji (1996) that maize grain yields were significantly increased when cowpea was rotated with maize as compared with continuous maize.

Positive correlations between final soil organic carbon contents and maize grain yields were recorded during the seasonal cycles in 2006 (Figs. 4.9a and 4.9b). Kapkiyai *et al.* (1998) found positive correlation between the final soil organic content under cattle manure and fertilizer amendments with crop yield. In India, Kanchikerimath and Singh (2001) reported linear correlations between 26 - year average yields of crops and the final soil organic carbon in experimental plots. Strickling (1975) found that SOC levels accounted for 82 - 84 % of the variation in corn yield. The effect of SOC on yield was due to enhancement of water infiltration resulting in improved aggregation (Strickling, 1975). However, Lucas *et al.* (1977) reported that it was difficult to demonstrate the influence of SOC on crop yields since SOC levels are usually related to climate, topography and soil texture.

The LERs throughout the study were less than unity (Fig. 4.10). This was caused by lower grain yield of maize intercrops than sole crops. The LER of maize was computed by expressing intercrop grain yield as a ratio of sole crop grain yield (Willey and Osiru, 1972). Land equivalent ratio > 1 is indicative of substantial agronomic advantage of intercrops over sole cropping, whereas LER < 1 is indicative of sole crop advantage over intercrops. A LER of 1 indicates no change in crop performance in either cropping system. Results obtained in this study strongly suggested that there was more efficient utilization of land resources with sole maize cropping than planting maize as intercrop with soybean.

4.9.2 SOYBEAN AND COWPEA GRAIN YIELDS

4.9.2.1 RESULTS

In both seasons of the first year of study, the highest soybean grain yield was obtained on the control plots (Table 4.16). The least was recorded for plots under PM + CF amendment in 2006 - major season. The control yielded about 3 - 4 times the level of yield in plots amended with PM + CF and CF in the 2006 - minor season. The second year however, recorded the highest yield on plots under PM amendment and the least on CTRL and PM + CF plots. There was a decline in the yield of soybean from the 1st season to the 2nd season by 72 %. Statistically, amendments influenced soybean grain yield more in both seasons of the first year than in the second year.

The highest cowpea grain yield (930 kg/ha) (Table 4.17) was recorded under CF amendment whilst the least (438 kg/ha) was obtained on control plots. Application of chemical fertilizer doubled the yield compared to that of the control. Significant differences (P < 0.05) were observed between amendments.

Table 4.16. Soybean grain yield under the different amendments

	Soybean grain yield (kg/ha)		
Amendment	2006 - Major	2006 – Minor	2007 - Major
CTRL	387	133	293
PM	288	120	481
PM + CF	160	40	293
CF	288	32	347
LSD (0.05)	90.1	19.8	127.6

CTRL = Control, PM = Poultry manure, PM + CF = Poultry manure + chemical fertilizer, CF = Chemical fertilizer.

Table 4.17. Cowpea grain yield as affected by the amendments

Amendment	Yield (kg/ha)
CTRL	438
PM	684
PM+ CF	449
CF	930
LSD (0.05)	188.6

4.9.2.2 DISCUSSION

Among the amendments, application of chemical fertilizer produced the highest yield of cowpea. The least was recorded in control plots. Olofintoye (1986) similarly observed increased grain yield of cowpea by virtue of fertilizer application. In pot experiment by Stewart and Reed (1969), yield and plant growth of cowpea increased with increasing fertilizer application.

The control recorded the highest soybean grain yield (Table 4.16). This observation was consistent throughout both seasons in 2006. It can therefore, be inferred from results of this study that amendments application under maize - soybean intercrop system may not necessarily lead to yield increase of soybean. The effect of amendments on the grain yield of soybean cultivated as an intercrop has not been reported in literature.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The main purpose for studying soil fertility dynamics under amendments and cropping systems is to minimize nutrient losses to the environment and allow more accurate recommendations for sustainable crop production, thereby increasing the productivity of cropping systems. Soil fertility plays such a key role in tropical cropping systems that its study with respect to management practices has become necessary.

From the detailed analyses and interpretation of data on soil fertility parameters under cropping systems in this study, the following conclusions can be drawn. Continuous cropping if coupled with adequate nutrient management will not lead to soil fertility depletion over time. Efficient nutrient management in cropping systems could lead to buildup of microbial biomass C over time. Crop residues left on the field at harvest resulted in microbial buildup even in plots under no amendment subsequently. Biomass nitrogen showed more temporal fluctuations than biomass carbon and could contribute an average value of up to 2.6 % of soil total nitrogen. The microbial biomass thus, served as a repository of soil total nitrogen under amendments and cropping systems in Ghana. Microbial biomass dynamics show the short term micro - changes occurring in the soil whereas soil organic carbon content gives a picture of large changes in soil fertility in the long term. The study indicated higher immobilization of phosphorus than any other nutrients (carbon and nitrogen) and has established that phosphorus could be immobilized at the peak of crop growth for 21 days and be released within 21 days; its release not concurring with peak nutrient demands of crops hence the need for synchronization. There was also a likelihood of microbes and crops competing for the nutrient. It was anticipated that phosphorus released after immobilization would be utilized by the growing crops but the release did not concur with the peak nutrient demand of the crops suggesting a possible take up by new generation of microbes. Thus, phosphorus fixation by clay minerals if coupled with immobilization by microbes would decrease availability to crop plants, hence the need to synchronize release with the nutrient demand of crops.

The research provided a systematic monitoring of soil nutrients as affected by specific nutrient management practices in Ghanaian cropping systems. It has added to knowledge on the mineralization of nitrogen under different amendments and cropping systems in Ghana. Results have shown that NO_3^- - N unlike NH_4^+ - N, could be subject to immobilization under amendments during a cropping cycle. Modelling of mineralization rate has established that with the N model, a range of 0.18 - 0.73 kg N /ha/day could be recorded as total mineralized N (NO_3^- -N plus NH_4^+ - N) under amendments during a cropping season under Ghana's climatic conditions. These high rates of mineralization account for the many reported cases of nitrogen deficiencies in Ghanaian soils as most of the mineralized N is subjected to losses through leaching and erosion. The study has also confirmed findings by other scientists that soil nitrate levels increased after dry spells upon the resumption of the rains. This study has established that cropping systems have similar mineralization rates if subjected to the same amendment practices and that 'Birch effect' is characterized by immobilization of nitrate and lower NH_4^+-N: NO_3^- - N ratios under amendments.

The research has demonstrated that poultry manure is a good store of phosphorus and that plants' need of phosphorus could be met through its application. However, over – application of the manure could oversupply P, eventually leading to its excessive buildup which may be transported in runoff to threaten eutrophication of water bodies. Despite fixation and immobilization, the bulk of applied P could remain in the soil prior to harvest.

This study has demonstrated that the peak demand of most plant nutrients such as nitrogen, phosphorus, potassium, etc. occurred at the 6^{th} week following amendment. The highest level of SOC generally occurred at 9^{th} week after amendment. It has been established through this study that crop yield is a function of final soil organic carbon content at harvest in Ghanaian cropping systems. The level of soil basic cations was generally higher in the minor than in the major cropping season. The higher rainfall distribution associated with major cropping seasons contributed to higher leaching losses of the exchangeable bases. Soil exchangeable calcium and magnesium contents were not influenced by amendments. Application of poultry manure resulted in significant increases in soil exchangeable sodium content over the control.

Generally, the results of the study indicated significant effects of amendments and cropping systems on soil microbial biomass C and P over cropping seasons. Nitrate – N and ammonium -N showed seasonal variations as result of the influence of amendments and cropping systems. However, differences in rates of N mineralization between cropping systems were insignificant within each season of cropping. Statistical differences in soil total N, available P and exchangeable sodium were observed between amendments. Cropping systems influenced soil exchangeable calcium and magnesium. The hypothesis of this study (pp. 3) was therefore accepted on the basis of these general observations.

5.1 RECOMMENDATIONS

Since peak demand of most nutrients (e.g. nitrogen, phosphorus, potassium, etc.) by crops occurred at 42 DAA (i.e. 6th week), proper timing of amendments application should be encouraged taking into consideration their peak nutrient release pattern to ensure synchrony. Where accessibility to chemical fertilizer is a problem, application of poultry manure could be considered as an alternative means to meet the phosphorus need of crops. It is recommended that a soil which is characterized by phosphorus immobilization should be cropped with full - season annual crops to enhance synchrony of released P with peak nutrient demand. Considering the results of this study, it is recommended that in an area where agricultural land is a diminishing quantum, continuous cropping could be sustained with effective nutrient management.

Future monitoring of nutrient dynamics under cropping systems if possible should involve biennials and perennials. Prospective studies need be carried out on the dynamics of micronutrients under different nutrient management practices in Ghanaian cropping systems.

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APPENDIX

NOTE: It is important to state here that interactions between amendments and cropping systems (from the statistical analysis - ANOVA) for parameters considered in the study were not significant and therefore not added to this Thesis. Adding them would not provide any important information but would only increase the volume of the thesis.

APPENDIX 1 Soil physical properties

1. a. Soil textural class under amendments in the first year of study (2006)

Amendment	% Sand	% Silt	% Clay	Textural class
CTRL	73.76	20.21	6.03	Sandy loam
PM	72.62	21.29	6.09	Sandy loam
PM + CF	74.32	17.57	8.11	Sandy loam
CF	71.22	16.75	12.03	Sandy loam

1. b. Soil textural class under amendments in the second year of study (2007)

Amendment	% Sand	% Silt	% Clay	Textural class
CTRL	75.62	16.31	8.07	Sandy loam
PM	73.06	18.89	8.05	Sandy loam
PM + CF	73.20	20.72	6.08	Sandy loam
CF	73.34	20.64	6.02	Sandy loam

1.c. Seasonal variations in soil bulk density under treatments

	Soil bulk density (g /cm³)		
Treatment	2006 - Major	2006 – Minor	2007-Major
Amendment			
CTRL	1.54	1.51	1.51
PM	1.50	1.49	1.47
PM + CF	1.51	1.50	1.49
CF	1.52	1.52	1.50
LSD (0.05)	NS	NS	NS
CV (%)	11.2	7.5	7.7
Cropping system			
CM	1.50	1.48	1.48
M/S	1.53	1.52	1.51
M/C	1.53	1.52	1.50
LSD (0.05)	NS	NS	NS
CV (%)	5.9	6.6	7.2

CV: coefficient of variation, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, CM: Continuous maize, M/S: Maize – soybean, M/C: Maize – cowpea.

APPENDIX 2 Data on other soil chemical properties recorded in the study

2. a. Effect of treatments on soil exchangeable acidity and ECEC in the 2006-major season

Treatments	Exchang. Acidity (cmol/kg soil)				ECEC (cmol/kg soil)			
	21 DAA	42 DAA	63 DAA	84 DAA	21 DAA	42 DAA	63 DAA	84 DAA
Amendment								
CTRL	0.09	0.09	0.09	0.07	8.47	8.70	8.26	8.85
PM	0.06	0.08	0.10	0.07	8.63	9.58	8.76	9.53
PM +CF	0.12	0.09	0.13	0.10	8.79	9.13	8.25	8.34
CF	0.12	0.13	0.14	0.14	8.45	8.19	7.69	8.25
LSD (0.05)	0.03	0.02	0.03	0.03	NS	1.34	NS	NS
Cropping system								
CM	0.09	0.09	0.11	0.08	9.57	10.27	9.47	9.87
M/S	0.09	0.11	0.16	0.10	7.55	8.34	7.35	7.93
M/C	0.10	0.11	0.16	0.11	8.57	8.14	7.97	8.40
LSD (0.05)	NS	0.01	0.02	0.02	1.14	1.27	0.86	1.48

2. b. Effect of treatments on soil exchangeable acidity and ECEC in the 2006-minor season

Treatments	Exchang. Acidity (cmol/kg soil)				ECEC (cmol/kg soil)			
	21 DAA	42 DAA	63 DAA	84 DAA	21 DAA	42 DAA	63 DAA	84 DAA
Amendment								
CTRL	0.06	0.08	0.07	0.07	9.77	9.72	9.81	10.10
PM	0.06	0.06	0.08	0.06	10.75	10.03	11.07	9.99
PM +CF	0.09	0.09	0.12	0.06	9.28	8.74	9.01	10.10
CF	0.11	0.10	0.13	0.12	10.83	9.63	8.31	8.58
LSD (0.05)	0.01	0.02	0.02	0.02	NS	NS	2.75	NS
Cropping system								
CM	0.07	0.08	0.09	0.09	11.99	11.78	11.61	11.50
M/S	0.09	0.06	0.12	0.10	8.81	8.30	8.55	9.03
M/C	0.08	0.11	0.09	0.10	9.70	8.58	8.74	9.11
LSD (0.05)	NS	0.01	0.01	NS	1.55	1.80	1.57	1.61

2. c. Effect of treatments on soil exchangeable acidity and ECEC in the 2007 – major season

Treatments	Exchang. Acidity (cmol/kg soil)				ECEC (cmol/kg soil)			
	21 DAA	42 DAA	63 DAA	84 DAA	21 DAA	42 DAA	63 DAA	84 DAA
Amendment								
CTRL	0.09	0.10	0.09	0.10	9.75	8.70	7.74	8.64
PM	0.08	0.09	0.09	0.09	10.10	9.25	9.32	8.73
PM +CF	0.10	0.11	0.10	0.11	9.67	8.79	9.66	9.01
CF	0.12	0.14	0.12	0.12	7.45	7.67	7.88	7.25
LSD (0.05)	0.02	0.02	NS	0.02	1.20	NS	NS	NS
Cropping system								
CM	0.09	0.10	0.09	0.11	11.14	10.29	10.44	9.28
M/S	0.10	0.12	0.10	0.12	8.04	7.68	7.59	7.18
M/C	0.10	0.12	0.12	0.12	8.59	7.85	8.00	7.88
LSD (0.05)	NS	0.01	0.02	NS	1.18	1.38	1.20	1.59

APPENDIX 3 Growth parameter measured during the study

Treatments	Maize shoot height (cm) 2006 - Major	2006 - Minor	2007 - Major
Amendment			
CTRL	185.2	172.0	210.7
PM	195.0	183.7	223.1
PM + CF	196.9	197.8	223.2
CF	190.7	185.3	229.2
SED (0.05)	4.38	4.95	4.64
Cropping system			
CM	196.9	189.4	223.4
M/S	182.6	180.0	220.3
M/C	196.3	-	220.9
SED (0.05)	5.05	5.41	NS

SED: standard error of differences of means.