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EVALUATION OF INTERACTIVE EFFECTS FROM COMBINED CATTLE MANURE AND MINERAL FERTILIZER APPLICATION IN SOLE MAIZE CROPPING SYSTEM

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BSc. AGRICULTURE (HONS)

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EVALUATION OF THE INTERACTIVE EFFECTS FROM COMBINED MANURE AND MINERAL FERTILIZER IN SOLE MAIZE CROPPING SYSTEM

BY

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DECLARATION

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

A field experiment and a laboratory incubation study were conducted at Kpongu in the Upper west region of Ghana (Guinea Savannah Agro - ecological zone) and the Soil Science Laboratory of KNUST respectively to determine the added benefits in maize grain yield from the combined application of different rates of manure and mineral fertilizer and the mechanisms for interactive effects from combined applications. Nine treatments (three levels of mineral fertilizer at 0, 50 and 100 % of the 60-40-40 NPK kg / ha recommended rate (RR) by three levels of manure at 0, 50, 100 % of 5 t / ha RR) were applied on the field in a factorial experiment arranged in Randomized Complete Block Design (RCBD) with three replications. The same treatments were applied to 207 g of the field soil on mass basis in the incubation study over a 70 day period to determine the mechanism(s) causing added benefits, be it the improved nutrient synchrony, priming effect or the general fertility improvement mechanisms.

The use of 60: 40: 40 kg / ha NPK + 5 t manure gave the largest stem girth (5.11 cm at 4 WAP, 6.51 cm at 6 WAP and 7.05 cm at 8 WAP) and highest grain yield of 4678 kg / ha. Synergistic interaction resulting in appreciable added benefits in grain yield were observed from 30: 20: 20 kg / ha NPK + 5 t manure (1305 kg / ha), 60: 40: 40 kg / ha NPK + 2.5 t manure (1122 kg / ha) and 60: 40: 40 kg / ha NPK + 5 t manure (1371 kg / ha) while an antagonistic interaction (- 44 kg / ha) was realized from 30: 20: 20 kg / ha NPK + 2.5 t manure on the field.

Soil analysis after harvest showed that N stock had increased by 66 and 33 % for 60:40:40 kg / ha NPK + 5 t manure and 30: 20: 20 kg / ha NPK + 2.5 t manure respectively. The use of 30:20:20 kg / ha NPK + 2.5 t increased soil P by 3.71 % while 30:20:20 kg / ha NPK + 5 t increased soil P by 0.60 %. The value cost ratio analysis showed that 30: 20: 20 kg / ha NPK + 5 t manure and 60: 40: 40 kg / ha NPK + 2.5 t manure were the most economically viable combined treatment.

The laboratory incubation study showed that combined application of manure and mineral fertilizer improved the synchrony between crop nitrogen demand and soil nitrogen release. This was confirmed by a principal component analysis (PCA) which gave the improved nutrient synchrony mechanism a higher percentage cumulatively (45.72 %). The next most contributing mechanism to the manure-mineral fertilizer interaction observed was the priming mechanism which dominated 43.15 % of the principal components while the least was general fertility improvement (11.13 %).

It is therefore recommended that resource poor farmers could cut the cost of mineral fertilizer by 50 % and supplement it with good quality cattle manure without compromising on maize yield and profitability.

DEDICATION

I dedicate this work to Dr. Andrews Opoku for his immense contribution to my academic life. His tireless effort has guided me this far.

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This study has been successful through the efforts of several individuals who contributed in diverse ways. I may not be able to mention all names due to space factor; however, I need to express my sincere gratitude to some key personalities for their instrumental effort in the planning, initiation and execution of this study.

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CHAPTER ONE

1.0 INTRODUCTION

The attainment of food security in sub-Saharan Africa has up till now not materialized mainly due to soil fertility depletion (Hoffman, 2011) which is caused primarily by physical soil loss from erosion, leaching of nutrients from agricultural fields and nutrient mining from crop harvest at the local levels (Sanchez, 2002). These losses are common to many tropical cropping systems where fertilizer use is low and little or no agricultural residues are returned to the soil to maintain its fertility (Negassa *et al*., 2001).

In early times, the use of mineral fertilizer was thought of as the most appropriate remedy to soil fertility problems due to its rapid nutrient release (IFPRI, 2002) without much consideration to its inability to improve the soil physically and its adverse effect on the environment. In addition to these disadvantages, mineral fertilizers are expensive and the average Ghanaian farmer may not have the purchasing power to acquire it (Tetteh *et al*., 2008).

In recent times, the attention of researchers has shifted to organic resources due to the above mentioned problems (Suge *et al*., 2011). There is unending literature reporting the efficiency and effectiveness of farmyard manure and other organic nutrient sources in maintaining soil fertility (physical and chemical), improving crop yields and sustaining productivity (Negassa *et al*., 2001; Vanlauwe *et al*., 2002a ; Suge *et al*., 2011). Nonetheless, the use of organic resources are also limited by the disadvantages of low nutrient concentration and the corresponding large amounts required for application (Vanlauwe *et al*., 2006) and the accumulation of heavy metals such as mercury (Hg), cadmium (Cd) and cupper (Cu) upon continuous application (DFID, 2004).

In this light, one of the appropriate options to maintaining soil fertility has been to combine both organic and inorganic sources to tap a combined effect of their advantages. Research findings have shown that combining mineral fertilizer and organic inputs result in greater benefits in crop productivity per unit nutrient applied through positive interactions between biological, chemical and physical soil properties than either inputs alone (Vanlauwe *et al*., 2001 a; Nziguheba *et al*., 2002; Mucheru *et al*., 2007).

Palm *et al*. (1997) proposed the terms **added benefits** for synergistic effect from a positive interaction and **added disadvantage** for antagonistic effects from negative interaction between manure and mineral fertilizer. The term additive effect may also be used when the effect of one input adds on to the effect of another (no interaction) and more research is still needed to understand the actual mechanisms which underlie these interactions.

Different mechanisms have been attributed by different authors to cause synergistic effects between organic and inorganic fertilizers. Vanlauwe *et al*. (2001a) proposed improved synchrony between nutrient release from combined application and crop nutrient demand as a potential mechanism and later proposed general fertility improvement as another potential mechanism (Vanlauwe *et al*., 2001b). Giller (2002) also reported of priming effect which suggests a stimulation of decomposition and rapid nutrient release for plant use by the addition of a labile N or C from the manure as a probable mechanism.

Studies conducted in Ghana on combined manure and mineral fertilizer use reported of improvement in yield, however, the added benefits in yield due to synergy is often not quantified and consequently the actual mechanisms underlying these interactive effects are scantly known (Opoku, 2011).

It is imperative for agricultural research to identify the most effective combinations of organic and mineral inputs to the soil, dive more into the mechanisms underlying the interactive effects of these combined inputs and direct them towards a more synergistic use. Knowledge of the actual mechanism for synergy would enable researchers and farmers to enhance the conditions that favour such mechanism(s) for greater yields.

The general objective of this study was to increase the productivity of smallholder maize farmers from the combined application of cattle manure and mineral fertilizer. The specific objectives were to;

i. determine the effect of combined cattle manure and inorganic fertilizer application on maize growth and grain yield

ii. quantify the interactive effects from combined application of cattle manure and inorganic fertilizer on maize yield.

iii. determine the effect of combined application of manure and mineral fertilizer on soil N, P and K stocks.

iv. assess the cost effectiveness of investment in combined application.

v. unravel the mechanism(s) for the interactive effects underlying synergy.

The above specific objectives were based on the null hypothesis that:

i. Maize yield from combined manure and mineral fertilizer rates would produce statistically similar yields as a sum of yields from individual applications.

ii. Any increase in yield from combined applications of cattle manure and mineral fertilizer would be as a result of one of the following mechanisms: improved nutrient synchrony, general fertility improvement or priming of soil nutrients.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil fertility management

The ability of the soil to supply essential elements for plant growth without a toxic concentration of any element defines its fertility status (Deenik, 2005). Plants require a balanced nutrient supply from the soil for proper growth but Africa loses 4.4 million t N, 0.5 million t P, and 3 million t K every year from its cultivated land (FAO, 2005) leading to reduced crop yields. Sanchez *et al*. (1997) reported that soil fertility depletion is the fundamental biophysical root cause for declining per capita food production in sub-Saharan Africa, hence the need for an appropriate approach to replenish the declining soil fertility. Vanlauwe *et al*. (2002a) proposed the combined use of mineral fertilizer and farmer- available organic resources as one appropriate Integrated Soil Fertility Management (ISFM) practice to replenish the declining soil fertility as it fosters positive interaction between the biological, physical and chemical soil properties (Mucheru *et al*., 2007). Vanlauwe *et al*. (2010) defined ISFM as the application of soil fertility management practices and the knowledge which necessarily include appropriate application of mineral fertilizer and organic input in combination with the utilization of improved germplasm to adapt these to local conditions, which maximize fertilizer and organic resource use efficiency and crop productivity. The combined use of organic and inorganic nutrient inputs leads to increased nutrient use efficiency, higher crop yields and increased profitability from fertilizers (Mucheru *et al*., 2007; Lundaka and Kelly, 2012) due to the positive effect the two nutrient inputs have on the soil.

2.2 Effect of mineral fertilizer and manure application on some soil properties

2.2.1 pH

Long- term study by Wu *et al*. (2008) reported of significantly lowest ($P < 0.05$) soil pH (average 5.33) in control plots compared to significantly high pH (5.89) from NPK and 5.63 under organic matter treatments in paddy soils which dropped with time in the treated plots compared to the control at all sampling times, suggesting the ability of chemical fertilizer and organic manure to alleviate soil acidification to some extent. The application of alkaline fertilizer (e.g. calcium magnesium phosphate fertilizer) to the soil has been reported (Wu *et al*., 2008) to return some alkaline substance to the soils and thus increase the soil pH. The application of organic manure could also improve soil acidity by increasing the soil organic matter, promoting the soil maturation, improving the soil structure, and enhancing the soil base saturation percentage, which is in line with the reports of Zhang *et al*. (2009) and Li *et al*. (2010).

2.2.2 Soil organic carbon

Wu *et al*. (2008) observed a remarkable increase in soil organic carbon (22 %) under NPK application due to the return of more biomass to the soil while organic manure resulted in the highest SOC (72.5 %) than the control. This could have been due to the ability of organic manure and chemical fertilizer to improve soil aggregation, soil water retention, and reduce bulk density of the soil, promoting crop growth and the return of more root residues to the soil (Hyvonen *et al*., 2008).

Sleutel *et al*. (1996) reported of insignificant variability in SOC in several manure treatments in the short term. The authors observed the highest increase (2.17 %) in SOC in plots treated with 80 t farm yard manure after four years of 40 t farm yard manure, 40 t FYM + equivalent NPK, 80 t FYM applications and a control and explained that long - term applications of animal manure could increase soil organic matter by adding organic matter contained in the manure and / or by increased organic matter in crop residues due to higher crop yields in soils receiving manure (Whalen and Chang, 2002).

2.2.3 Microbial biomass carbon

Soil microbial processes are of particular import as they are crucial for plant nutrient supply given their central role in soil organic matter decomposition and nutrient dynamics (Wardle, 2002). Wadle (2002) found a marked increase in microbial biomass carbon (MBC) for every increase in dose of municipal solid waste compost (MSWC) from 2.5 to 20 t / ha with the highest (205 µg / g) MBC produced under 20 t / ha and the least (35 µg / g) from the control after the application of MSWC to 1 kg soil (Xu *et al*., 2008). The peaks of MBC were observed 30 days after incubation in all treatments (except control) after which it declined. The observed decline in soil MBC after 30 days is consistent with the work carried out by Sparling (1985) and may be associated with a nutrient shortage or the ‘protective capacity’ of the soil biomass beyond which excess microbes are automatically killed or lysed or could be due to the higher level of soluble organic - C in MSWC - enriched soils as reported by Garcia-Gill *et al*. (2000). Microbial biomass C is a very sensitive soil quality index that changes rapidly with changes in fertilizer application, climatic and environmental factors affecting the soil even before a change in soil organic carbon is noticed (Xu *et al*., 2008). The combined application of manure and chemical fertilizer has major effects on soil physico - chemical and biological properties, and it increases crop yields. After application of two doses of N: P: K at 80: 24: 20 and 120: 36: 30 kg / ha supplied through inorganic fertilizer alone, combined rabbit manure and inorganic fertilizer and combined vermicompost and inorganic fertilizer, Lazcano *et al*. (2012) observed that the total phospholipids fatty acids (PLFA) content of the soil, indicative of viable microbial biomass, ranged between 18 and 22 μg / g dry weight soil and was significantly higher in response to application of manure compared to inorganic fertilizer. Microbial biomass was higher in the plots where organic fertilizers were incorporated with inorganic fertilizers than in those without organic fertilizers due to the supply of organic C substrates for microbial use (Arancon *et al.*, 2006; Dinesh *et al.*, 2010).

2.2.4 Soil enzyme activity

Soil enzyme activity is known to be positively correlated with the organic matter content of the soil, and with the water soluble soil organic C (Chang *et al.*, 2007; Gilani and Bahmanyar, 2008). Similar to microbial biomass, microbial activity is a reliable indicator of the amount of easily decomposable organic C, and it has shown to be significantly higher in fresh than in humified organic materials (Monaco *et al.*, 2008). Soil microbial and enzyme activity are considered as indicators of soil quality as they are responsible for the degradation of organic substrates and release of plant nutrients (Gil-Sotres *et al.*, 2005). Lazcano *et al.* (2012) observed that both manure and vermicompost increased the potential activity of the soil enzymes that degrade organic C, N and P compounds between 12 % and 22 % as compared to soils amended with inorganic fertilizers. Presumably, the higher enzyme activity in the soils where manure and vermicompost were added contributed to maintain the availability of inorganic N and P in the soil as compared to inorganic fertilizers. Similar increases in enzyme activities (19 – 38 %) have been reported by Dinesh *et al.* (2010) in a short-term study comparing inorganic with integrated fertilizer regimes. Enzyme activity typically increases shortly after the addition of organic amendments to the soil (Gianfreda and Ruggiero, 2006). Xu *et al*. (2008) reported of an increase in urease activity in the soil up to 60 days of incubations and then declined till 120 days. Perucci (1990) reported of an associated increase in soil enzyme (urease) activity as MBC decreases and suggested that the release of the enzymes was linked to the lysis of microbial cells at the end of their life cycle.

2.2.4.1 Role of urease in soil fertility

Soil urease originates mainly from plants (Polacco, 1977) and micro - organisms found as both intra and extra - cellular enzymes (Mobley and Hausinger, 1989). Urease enzyme is responsible for the hydrolysis of urea fertilizer applied to the soil into NH_3 and CO_2 with an accompanying rise in soil pH (Andrews *et al*., 1989; Byrnes and Amberger, 1989). This, in turn, results in a rapid N loss to the atmosphere through NH_3 volatilisation (Simpson and Freney, 1988).

Urease activity in soils is influenced by many factors such as cropping history, organic matter content of the soil, soil depth, soil amendments, heavy metals, and environmental factors such as temperature (Yang *et al*., 2006). Studies with soil samples taken from horizons of different soil profiles revealed decreased activities with increased soil depth. The differences were attributed to decreases in soil organic matter content with depth (Myers and McGarity, 1968). Generally, urease activity increases with increasing temperature (Jones *et al*., 2007). It is suggested that higher temperatures increase the activity coefficient of this enzyme. It is therefore recommended that urea be applied at times of the day when temperatures are low. This is because during such times the activation energy is low, thus, resulting in minimum loss of N by the volatilization process (Jones *et al*., 2007).

2.2.5 Nitrogen

In most soils, 95 – 98 % of total nitrogen (N) is contained in organic compounds and the remainder is in inorganic forms that are readily available to plants (Stevenson, 1982). In the tropics, available N is rarely adequate for plant growth unless replenished efficiently from unavailable forms to available forms such as NH_4^+ and NO_3^-. Fertilization, being the main practice of soil management, has great impact on the fractions of soil organic N, directly through changing the composition of soil N and indirectly through affecting crop growth (Kelley and Stevenson, 1996; Bird *et al*., 2002). Wu *et al*. (2008) reported that the average available N was highest in OM treatment (1.6 times of that in the control) and second highest in NPK treatment (1.2 times of that in the control), indicating the necessity of organic manure for soil fertility management. Considering the long - term fertilizer efficiency, the results also suggested that returning straw annually to the soil could improve soil fertility. Sekhon *et al*. (2011) observed an increase in total N which ranged from 7.14 mg / kg N / year from the application of 150: 75: 75 kg / ha N- P_2O_5- K_2O to 29.7 mg / kg N / year from the 150 kg / ha N + poultry manure application. The total N contents were higher by 22.4 % in farmyard manure, 32.7 % in poultry manure and 5.4 % in green manure amended plots, compared with 150: 75: 75 kg / ha N- P_2O_5- K_2O . Lazcano *et al*. (2012), observed no differences in the concentration of N-NH_4^+ and N-NO_3 of the soil between different regimes and doses when two doses of N: P: K at 80: 24: 20 and 120: 36: 30 kg / ha were supplied through inorganic fertilizer alone, combined rabbit manure and inorganic fertilizer or combined vermicompost and inorganic fertilizer, and explained that the increase availability of N was the result of higher enzyme activity in the soils where manure and vermicompost were added compared to inorganic fertilizer alone.

2.3 Interactive effects between combined manure and mineral fertilizer application

FAO (2006) reported that organic sources and recycling do not suffice on their own to meet increased demands for food on a fixed land area while due to possible environmental concerns and economic constraints, crop nutrient requirements often cannot be met solely through the application of mineral fertilizers. A judicious combination of mineral fertilizer with organic sources of nutrients has been promoted as a feasible option for synergistic effect (Vanlauwe *et al*., 2001a; Mucheru *et al*., 2002). Considering the diverse meanings of the word interaction, Palm *et al*. (1997) proposed the terms **added benefits** and **added disadvantages** as better phrases for interactive effects. Added benefits described synergistic interaction from combined application where yield is significantly higher than yield from the sum of individual applications while added disadvantages described a turn of events from antagonistic interaction where yield from combinations is significantly lower than sum of yields from sole applications. When additive effects occur, there is no interaction between the adjoined fertilizers and the yield of one just adds on to the yield of another. Several trials established in the various sub - regions of Africa aimed at quantifying potential added benefits in treatments with combined applications of organic resources and mineral N.

2.3.1 Synergistic effects (Added benefits)

Vanlauwe *et al*. (2001b) reported added benefits of 488 and 579 kg grains / ha in Sekou and Glidji respectively when the following treatments: 0 N, 45 kg / ha urea + 45 kg / ha organic manure and 90 kg / ha urea + 90 kg / ha organic manure were applied. Okalebo *et al*. (2003) applied wheat straw and soya bean haulms with urea and obtained an added yield benefit of 684 kg grain / ha as compared to a sum of their individual effects. In a similar but earlier study, Zhang *et al.* (1998) reported that precise application of manure and mineral fertilizer to maize can be as effective as commercial mineral N Fertilizer for yield response. In their study, Boateng *et al*. (2006) reported that available N and P in soil increased with increase in organic matter and recommended the combined application of poultry manure and NPK because of the complementary and synergistic effects of the fertilizers on maize growth and yield.

2.3.2 Antagonistic effects (Added disadvantages)

Antagonistic effect or added disadvantage is quite rare and may occur under conditions of poor quality manure and / or severe moisture stress at a critical stage of the plant growth (Vanlauwe *et al*. 2001a) especially at grain filling. Mucheru *et al*. (2002) observed added disadvantages in grain yields which were not significantly different from 0 (ranging from -250 to 550 kg / ha maize grain yield) under combined manure and mineral fertilizer applications and explained that the negative interaction obtained was as a result of lack of rains after germination. In another experiment in Central Kenya, Mucheru *et al*. (2002), compared the interaction between cattle manure, *Leucaena leucocephala*, *Calliandra calothyrsus* and *Tithonia diversifolia* with mineral fertilizer and observed that in both long and short rainy seasons, interaction for *Leucaena leucocephala* and mineral fertilizer was negative because the *Leucaena* was of poor N quality.

2.4 Mechanisms for interactive effects

Different mechanisms have been assigned by researchers for interactive effects between mineral fertilizer and organic resources when they are combined and applied to the soil. The general mechanisms mentioned are improved nutrient synchrony

(Vanlauwe *et al*., 2002b), general soil fertility improvement (Vanlauwe *et al*., 2001b) and priming of soil properties (Kuzyakov *et al*., 2000; Giller, 2002).

2.4.1 Improved nutrient synchrony

This mechanism explains that, when organic and inorganic fertilizers are applied together, the organics supply microbes with energy through the C that it contains to drive decomposition processes which leads to a temporal immobilization of fertilizer N (Myers *et al*., 1994; Palm *et al*., 2001a) to build their body tissues. This immobilized N is made available at a later stage of plant growth when the microbes have decomposed the manure and made nutrients available and some have died and released their nutrients to the plant when it needs nutrients most. In effect, the peak of nutrient supply coincides with highest crop nutrient demand point, so that the nutrients are efficiently used and little or none is lost to the environment. Kapkiyai *et al*. (1998) reported that a combination of organic and mineral nutrient sources has been shown to result into synergy and improved synchronization of nutrient release and nutrient demand and uptake by plants leading to higher yields.

Testing the improved nutrient synchrony mechanism with ^{15}N labelled fertilizer, Vanlauwe *et al*. (2002b) concluded that interactions between OM and fertilizer - N not only exist in the laboratory but also under field conditions.

2.4.1.1 Development stages of maize

The growth stages of maize have been classified into five vegetative stages and two reproductive stages as shown in Fig 2.1 where VE to V1 is germination and emergence stage, V3 to V10 is early vegetative development stage, VT is late vegetative development stage, R1 is flowering stage and R6 is physiological maturity stage.

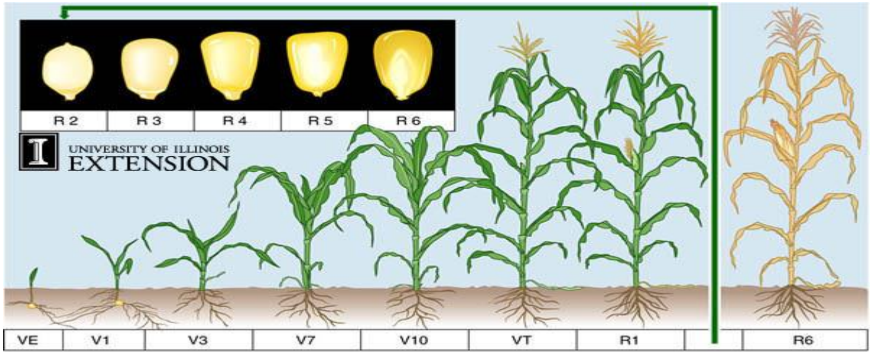


Figure 2.1. Stages of maize growth (Adopted from weedsoft.unl.edu)

Table 2.1 shows the various stages of N and P uptake at various stages of maize growth.

Table 2.1. Stages of maize nutrient uptake in kg / ha

Stages	N uptake	P uptake
	kg / ha	
VE to V6 (seedling emergence to leaf sheath)	3.6	3.6
V6 to V 12 (leaf sheath to tassel)	21.6	12.6
V12 to V18 (tassel to cob)	27.9	12
V18 to VT-R1 (cob, shank and silk)	4.5	9
VT-R1 to R6 (grain filling to maturity)	28.8	22.2

Adopted from IFA (1992)

The various stages of maize growth have different nutrient demands. Maize takes up nutrients slowly in the early stages of growth, however, the rate of uptake increases rapidly to a maximum before and after tasseling (IFA, 1992). Fertilizer application is best scheduled in accordance with this pattern of uptake in order to avoid serious losses by volatilization or leaching and to ensure that N levels are high in the soil when the crop demand is also high (before and after tasseling) (IFA, 1992). At germination and emergence (stages VE to V1), nutrient reserves in the seed feed the emerging seedling for the first week until the primary roots develop and begin to supply the plant with water and nutrients from the soil (Belfield and Brown, 2008). At the early vegetative development stages (V3 to V10), the adventitious root system develops from the first stem node below the soil surface and takes over the main root function approximately 10 days after emergence, three weeks after emergence the growing point is at the soil surface and, having formed all the leaves, develops an embryonic tassel at V5. Nutrient uptake at these stages is slow and minimal (IFA, 2002).

One of the most critical stages in the development of the maize plant is the late vegetative phase (V10 to VT) where the stem elongates rapidly, with a high demand for water and nutrients (N, P and K). Leaf enlargement is complete by 5 weeks and the roots quickly fill most of the root zone. Ears begin to form within the plant soon after tassel initiation (V5). Any adverse effect suffered at this stage, such as nutrient or water stress, insect damage, or too high a plant population, will significantly affect yield (IFA, 1992).

At the flowering stage (R1), plants would have finished producing all its leaves, tassels fully emerge and pollen sheds 40 to 50 days after emergence, with the length of time depending on variety and environmental conditions (IFA, 1992). Silks emerge from the uppermost ear and sometimes from the second ear. Pollination and fertilization of the ears occurs. During this period there is a high demand for water, and the uptake of N and P is rapid, although K uptake is almost complete.

As pollen supply is abundant, poor seed set is usually due to nutrient or water deficits that either delay silking or result in kernel abortion after pollination, hence fertilization does not occur for all kernels and seed set is greatly reduced (IFA, 1992). This is commonly referred to as pollen blasting.

IFA (1992) reported that cobs, husks and shanks are fully developed by day 7 after silking. The plant then uses significant energy and nutrients to produce kernels on the ear. Initially the kernels are like small blisters containing a clear fluid; this is referred to as the kernel blister stage. As the kernels continue to get filled, the fluid becomes thicker and whiter in colour. This is called the 'milk stage'. Next is the 'kernel dough stage', at which point the fluid within the kernels becomes thicker as starch accumulates. During these kernel filling stages N and P uptake continues at a rapid rate until the plant reaches physiological maturity.

2.4.2 General soil fertility improvement mechanism

Vanlauwe *et al*. (2001b) observed added benefits from combined application of manure and mineral fertilizer in two of four sites, which experienced serious moisture stress during the early phases of grain filling. The positive interaction reported in these two sites was attributed to the ability of combined fertilizer sources to reduce moisture stress in the 'mixed' treatments compared to the sole urea treatments because of the presence of organic materials (surface and sub - surface placed). Organic resources can have multiple benefits besides the short - term supply of available N. Such benefits could be an improved soil P status by reducing the soil P sorption capacity, improved water holding capacity leading to better soil moisture conditions, improved pH and cation exchange capacity and less pest and disease pressure in legume - cereal rotations (Vanlauwe *et al*., 2001b).

Palm *et al.* (1997) reported that the relatively better performance from the integration of organics with 30 kg / ha N in comparison to sole mineral N sources was due to the provision of additional benefits (besides N) by the organic inputs to the soil chemical and physical properties that in turn influenced nutrient acquisition and plant growth. Mutuo *et al*. (2000) and Wallace (1996) reported that principal among the additional benefits are soil moisture holding capacity and provision of other macro - nutrients like calcium and magnesium. Zingore *et al*. (2008) also reported that the positive interactive effects might also be due to the alleviation of other growth limiting factors such as micronutrients which constitutes evidence for the occurrence of the mechanism supporting general soil fertility improvement.

In their findings, Vanlauwe *et al*. (2001b) reported that any organic matter - related improvement in soil conditions affecting plant growth enhances the efficiency of the applied N in the fertilizer combined with the organic resource and consequently leads to better plant growth. Upon improvement in these soil properties by organic resources, the mineral fertilizer combined to it is efficiently absorbed by plants and used effectively (Vanlauwe *et al*., 2001b).

2.4.3 Priming mechanism

Priming refers to strong short - term changes in the turnover of soil nutrients caused by the addition of easily decomposable organic materials of comparatively moderate treatments of the soil (Kuzyakov *et al*., 2000). Changes may be positive or negative depending on whether nutrients are rapidly mineralized or immobilized. In the course of priming effects, large amounts of C, N and other nutrients can be released or immobilized in to the soil in a very short time. The term ‘priming effect’ could be differentiated in two approaches depending on whether the studies were made with special attention to N or to C. In studies of C turnover the priming effect is defined as an extra decomposition and release of organic C after addition of easily-decomposable organic substances to the soil (Dalenberg and Jager, 1989) while in studies on N, it is defined as the extra soil N which is taken up by plants after addition of mineral N fertilizer, compared with non-N treated plants (Jenkinson *et al*., 1985; Leon *et al*., 1995).

2.4.3.1 Sources of the extra released nutrients

Many researchers have defined different sources of the extra nutrients released through priming. The most common idea is that substances released in additional mineralization are derived from soil organic matter, especially, from its fractions. This nutrient release arises through the activity of microorganisms, as no real priming effects have been observed under sterile conditions. The dynamics of the growth and of activity of microorganisms (particularly bacteria), and released nutrients indicate a close relationship between microbial biomass and real priming effects. Dalenberg and Jager (1989) labelled different C pools (microbial biomass and components of the soil organic matter) to study the source of C released. It was observed that that $^{14}CO_2$ released from the soil after the addition of plant residues and individual organic substances derives directly from the microbial biomass. Soil drying leads to the death of a part of the microbial biomass and leads to the additional release of CO_2 after rewetting (Pulleman and Tietema, 1999; Magid *et al*., 1999). Griffths (1994) proposed that the interaction between soil microorganisms, soil fauna and plants is regarded as one of the keys for understanding priming effects. Substances released by soil fauna can cause priming effects by stimulating microbial activity. Mucigels released by earthworms have also been found to produce a rapid priming response (Lavelle *et al*., 1995).

In many studies on the transformation of substances added to the soil, a side effect can be detected: an increased release of the soil - derived carbon as CO_2 or nitrogen as NH_4^+ or NO_3^- compared to the mineralization in the soil without any additions. This is a result of the interactions between the transformation of the added substances and the natural soil cycles of both elements. The most important mechanisms for real priming effects are the acceleration or retardation of soil organic matter turnover due to increased activity or amount of microbial biomass. Isotopic exchange, pool substitution, and different uncontrolled losses of mineralized N from the soil are also responsible for apparent N priming effects (Kuzyakov *et al.*, 2000). Many studies, however, showed that the presence of plants is not essential for priming effects to occur.

2.4.3.2 Contribution of organic carbon priming to maize yield

It is generally accepted that low amount of soil carbon limits the amount of energy available for soil microorganisms, and in turn the rate of soil carbon mineralization (Fontaine *et al.*, 2003). Priming effect is often supposed to result from a global increase in microbial activity due to the higher availability of energy released from the decomposition of fresh organic matter which increases soil organic carbon (SOC) content (Fontaine *et al.*, 2003). The critical limit of total soil organic carbon content below which crop yield declines by about 20 % is 1.1 % for most soils of the tropics (Aune and Lal, 1997). Priming of organic carbon leading to an increase in SOC content increases crop yields by influencing three mechanisms: (1) increasing available water capacity; (2) improving supply of nutrients; and (3) enhancing soil structure and other physical properties. Generally, the soil available moisture content increases by 1 to 10 g for every 1 g increase in soil organic matter (SOM) content (Emerson, 1995). SOC enhances cation exchange capacity (CEC), improves biotic activity of micro-organisms and improves the supply of nutrients to crops (Bationo *et al*., 2006). Crop yields can be increased by 20 – 70 kg / ha for wheat, 10 – 50 kg / ha for rice and 30 – 300 kg / ha for maize with every 1 Mg / ha increase in soil organic carbon pool in the root zone (Blanco, 2010). Decline in 1 g / kg of SOC decreased effective CEC by 43mmol / kg in soils of low activity clays (e.g., the West African Sahel) reducing the ability of the soil to retain nutrients (Bationo and Mokwunye, 1991).

2.4.3.3 Contribution of mineral N priming to maize yield

This type of priming is also termed added nitrogen interaction (ANI) (Kuzyakov *et al*., 2000). It is defined as the extra soil N which is taken up by plants after addition of mineral N fertilizer, compared with non-N treated plants (Leon *et al*., 1995). The priming of mineral N accelerates the mineralization of SOM which serves as a substrate and energy source to microbes (Vanlauwe *et al.*, 1994). Experiments with ^{15}N labelled fertilizers showed that plants given fertilizer N take up more N from the soil than plants not given N, that is, the priming effect or ANI (Jenkinson *et al.*, 2006). Pool substitution is the process by which added labelled N stands proxy for native unlabelled N that would otherwise have been removed from that pool. Microbial immobilization of N, whether driven by the decomposition of soil organic matter or by the decomposition of plant roots, can lead to pool substitution and is the dominant cause of apparent ANIs. Denitrification and plant uptake of N can also, under special circumstances, lead to pool substitution and thus give rise to apparent ANIs.

2.5 Effect of mineral fertilizer and manure application on maize growth and yield

2.5.1 Growth of maize

In a study in which 0, 200, 400 and 600 kg / ha of NPK 15-15-15 were applied on DMSRW maize variety, Law-Ogbomo and Law-Ogbomo (2009) observed that, while plants in untreated plots were almost stunted, plant height increased with successive increment in fertilizer application rate up to 600 kg / ha. The application of 600 kg NPK resulted in the tallest maize height of 49.35 cm at 4 WAP, 138.25cm at 6 WAP and 168.35 at 8 WAP. This observation agreed with the report of Babatola *et al.* (2002) that increasing levels of fertilizer application increased growth and yield of crops. Fashina *et al.* (2002) also reported, that the availability of sufficient growth nutrients from inorganic fertilizer led to improved cell activities, enhanced cell multiplication and enlargement and luxuriant growth in plants.

Asghar *et al.* (2010) conducted a study to investigate the effect of four different levels of mineral fertilizer (0- 0- 0; 100- 50- 30; 175- 80- 60 and 250- 110- 85 kg / ha NPK) on two maize varieties (Golden and Sultan) and observed similar results as Law-Ogbomo and Law-Ogbomo (2009). Plant height increased linearly with increasing NPK levels in both maize cultivars. The application of 250-110-85 kg / ha NPK produced the tallest plants (198.55 cm) against the minimum (143.60 cm) recorded in the control. It was followed by 175-80-60 kg / ha NPK with plant height of 184.67 cm which was found better than treatment 100-50-35 kg / ha NPK which produced plant height of 173.63 cm. Similar increases in plant height with increases in mineral fertilizer levels have been reported by Maqsood *et al*. (2001), Ayub *et al*. (2002) and Sharar *et al*. (2003).

Boateng *et al.* (2006) realized from a study where 0, 2, 4, 6, 8 t / ha of poultry manure (pm), 60- 40- 40 kg NPK / ha, 2 × 2 t pm / ha (split applications) and 2 t pm + 30-20-20 kg NPK / ha with the mineral fertilizer treatments used as checks, that the different manure levels significantly plant height but the general growth was poor due to inadequate rains. The use of 6t manure recorded the tallest plants with 42 cm at 4 WAP, 80 cm at 6 WAP, 150 cm at 8 WAP, 165 cm at 10 WAP and 170 cm at 12 WAP. These figures were statistically similar to plant height from the application of 60-40-40 kg NPK / ha, 2 × 2 t pm / ha (split applications) and 2 t pm + 30-20-20 kg NPK / ha and out - performed 8 tons. This was an indication of a probable law of decreasing returns as reported by Lamer (1985) that, at the addition of a certain minimum effective dose of nutrients and a quick response has followed in the plant, the metabolism of the plant reaches a saturation point beyond which the addition of more nutrients have a negative response in plant output. Farhad *et al.* (2009) reported that the observance of maximum height (230 cm) in maize from 12 t / ha poultry manure after application rates of 4, 6, 8, 10, 12 t / ha and a control was the result of more nutrient availability from the highest manure level applied, as reported in works done by Mitchell and Tu (2005) and Warren *et al.* (2006).

Law-Ogbomo and Law-Ogbomo (2009) reported that stem girth was greatest with 600 kg / ha NPK throughout the sampling period compared to non-fertilized plots, which reflected a retention of appreciable amount of more assimilates in the stem for leaf production due to high nutrients availability (Fashina *et al.*, 2002).

Plants fertilized with 600 kg / ha NPK had the significantly greatest leaf area index (LAI) at 4, 6 and 8 WAP (Law-Ogbomo and Law-Ogbomo, 2009) probably due to higher number of leaves as influenced by the highest NPK level. Boateng *et al.* (2006) realized from their study that though LAI was significantly affected by the different levels of manure at all sampling times, the general growth was poor due to inadequate rains (511 mm of rain during the growth season). It was reported in their study (Boateng *et al*., 2006) that the application of 8 t manure attained the highest LAI which suggested the supply of high N for leaf enlargement and confirmed the consequent high yield observed from 8 t manure.

2.5.2 Grain yield of maize

The highest grain yield (7.95 t / ha) was observed from the application of 400 kg / ha NPK 15- 15- 15 (Law-Ogbomo and Law-Ogbomo, 2009) instead of 600 kg / ha which produced the tallest plants though it has been reported by Saeed *et al.* (2001) that, a high plant height is positively correlated with maize grain yield. The use of 600 kg / ha produced grain yield of 5.85 t / ha which was significantly lower than yield from 200 kg / ha NPK (7.01 t / ha) while the control had the lowest grain yield (3.52 t / ha) (Law-Ogbomo and Law-Ogbomo, 2009). These authors explained that 400 kg / ha NPK might be the optimum fertilizer level while 600 kg / ha NPK was an excessive dose, agreeing to the reports of Uguru (1996) and Sridhar and Adeoye (2003) that excessive inorganic fertilizer application can induce nutrient imbalance and acidity which interferes with the absorption and utilization of other elements that would have improved yield. Law-Ogbomo and Law-Ogbomo (2009) reported that the application of more nutrients from the use of 250: 110: 85 kg / ha NPK was not economical because the yield (6.03 t / ha) obtained was not significantly different from the yield (5.90 t / ha) obtained under 175: 80: 60 kg / ha NPK application. This was partly due to increased nitrogen use efficiency and adequate nutrients supply as in the reports by Kogbe and Adediran (2003) and Sharar *et al*. (2003).

With the availability of more nutrients to the plants, Farhad *et al*. (2009) observed that 12 t / ha poultry manure produced the highest grain yield (5.11 t / ha), followed by 10 t / ha in that subsequent order. Boateng *et al*. (2006) reported that 8 t poultry manure attained the highest grain yield (3.08 t / ha) which was not significantly different from yields from 6 t, 60-40-40 kg / ha NPK and 2 t poultry manure + 30-20-20 kg NPK / ha but greater than 2 t / ha pm and the control. From their observation it was reported that the 8 t poultry manure rate with C: N ratio less than 14.6 (rated good quality by Bationo *et al*., 2007) served as an alternative to chemical fertilizer and could be recommended and directly incorporated into the soil as a fertilizer source (Palm *et al.,* 2001a).

2.6 Economic analysis of combined application of manure and mineral fertilizer

The combined application of organic resources and mineral fertilizers is increasingly gaining recognition as a viable approach to address soil fertility decline in sub - Saharan Africa (SSA) (Chivenge *et al*., 2011). A number of benefits for combined use have been identified, however, all inputs used (inorganic fertilizer, organic manure and plant residues) are not costless and may be available to households in different quantities and quality. With the imperfect markets for inorganic fertilizer and output, and missing markets for organic manure, use of these much depends on the farmers' characteristics and resource endowments (Lundaka and Kelly, 2012). Most of the evidence of the benefits of ISFM has been shown using physical crop output and only a few economic studies have been done on the different inputs costs and benefits. The use of physical crop output alone may not be enough to prove the profitability or not of ISFM because maximum agronomic yield may not necessarily be profitable yield when input costs are high (Lundaka and Kelly 2010). Increasing crop production in itself is important for addressing hunger; however, the ability of farmers to continue achieving such yields depends on the profitability of the crop and the farmers' ability to save and reinvest in agricultural inputs or other income generating activities (Nziguheba *et al.*, 2010). Value-to-cost ratio has been used to evaluate the economic profitability of agricultural investments.

2.6.1 Value cost ratio

Many researchers have used the value-to-cost ratio (VCR) to evaluate the profitability of farm enterprises. Value-to-cost ratio in agricultural terms is simply the ratio of the outputs of a farm, expressed in monetary terms, relative to the costs of inputs, also expressed in monetary terms. Economic viability is defined when the value cost ratio is greater than or equal to 2 (Morris *et al.*, 2007). When VCR is 1, the enterprise is breaking even. A VCR less than 1 indicates a loss. Prices of inputs used in VCR calculations are usually collected during the cropping season at actual, local market prices (not subsidized). Farm gate crop prices at harvest time and peak prices occurring later in the year, when the surplus crop was actually sold are also used for output prices. Lundaka and Kelly (2010) also analyzed the financial benefits of combining organic and inorganic fertilizers using cost estimates, some of which included benefit - cost ratio, returns over variable costs and return to family labour. The study took into account (Lundaka and Kelly, 2012) cash expenditures alone and the combination of cash expenditures and full costs associated with the use of family labour, considering the fact that though manure may be available in large quantities, its preparation, transportation, and application were labour demanding which and might have reduced its net benefit and use.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study 1: Quantification of added benefits from combined application of manure and mineral fertilizer

3.1.1 The study site

The experiment was carried out at Kpongu in the Upper west region of Ghana. The site is located in the guinea savanna agro-ecological zone (lattitude 09°57'48.6'' N and longitude 002°30'31.4'' W and at an elevation of 286 m above sea level). This zone is characterized by a uni - modal rainfall pattern which starts from July to October followed by a long dry season for the rest of the year. It receives a mean rainfall amount of 1000 mm / annum, with an average annual temperature of 28.1 °C, relative humidity of 61 %, wind speed of 138 km / day, 7.3 hours of sunshine and solar radiation of 19.6 MJ / m^2/ day (Gerken *et al.*, 2001). The vegetation is mainly guinea savannah consisting ground cover grasses of different heights interspersed with short drought and fire resistant trees. The soil of the site is mainly Savannah Ochrosols and groundwater laterites (Gerken *et al.*, 2001).

3.1.2 Land preparation and experimental design

The site was slashed, ploughed and harrowed to a fine tilth. The layout consisted of three blocks with nine plots each across the slope. A plot measured 4 m x 3 m with a meter alley each between blocks and another meter alley between plots resulting in a total field size of 490 m^2.

The trial was a factorial experiment laid in Randomized Complete Block design. Nine treatments (three levels of mineral fertilizer by three levels of manure) were allocated randomly to each plot.

The most commonly used fertilizer recommended rate (RR) for N: P_2O_5: K_2O for maize in the Guinea savannah agro - ecological zone of Ghana is 60-40-40 kg / ha (Kwakye, 1980) while RR for cattle manure is 5 Mg / ha (Williams *et al*., 1995). Table 3.1 shows the treatment description used on the field.

Table 3.1.Treatment description

Treatment	N: P_2O_5: K_2O	Manure
	—Kg / ha—	−t / ha−
T1 - (0 % RR F, 0 % RR M)	0 : 0 : 0	0
T2 - (0 % RR F, 50 % RR M)	0 : 0 : 0	2.5
T3 - (0 % RR F , 100 % RR M)	0 : 0 : 0	5
T4 - (50 % RR F, 0 % RR M)	30: 20 : 20	0
T5 - (50 % RR F, 50 % RR M)	30: 20 : 20	2.5
T6 - (50 % RR F,100 % RR M)	30: 20 : 20	5.0
T7 - (100 % RR F, 0% RR M)	60: 40: 40	0
T8 - (100 % RR F, 50 % RR M)	60: 40: 40	2.5
T9 - (0 % RR F, 100 % RR M)	60: 40: 40	5.0

*RRM is recommended rate of manure

*RRF is recommended rate of fertilizer

3.1.3 Soil sampling

Twenty seven soil samples were taken from the experimental site before planting, (one from each plot) at 15 cm depth with an auger. The samples were brought to the analytical laboratory section of the Savannah Agricultural Research Institute, Wa station, and bulked to form a composite. Part of the composite sample was air dried and sieved through a 2 mm wire mesh for soil property analysis in the laboratory.

Three soil samples were taken from each plot and bulked to make one sample for a plot after harvest. Twenty - seven samples were obtained in all and analyzed for total N, available P and exchangeable K using the procedures listed below. Table 3.2 shows the initial physico – chemical properties of the study site soil before planting.

Table 3.2. Initial physico - chemical properties of the soil in the study site

Property	Value
Clay (%)	3.00
Silt (%)	4.04
Sand (%)	92.96
Soil moisture (%)	5.15
Bulk density (g / cm^3)	1.50
Soil pH (1:1 H_2O)	5.75
Organic carbon (%)	0.61
Organic matter (%)	1.05
Total nitrogen (%)	0.06
Available pitrogen (mg / kg)	15.80
Available phosphorus (mg / kg)	9.97
Available potassium (mg / kg)	98.65
Exchangeable potassium (cmol / kg)	0.85
Exchangeable Ca (cmol / kg)	1.60
Exchangeable Mg (cmol / kg)	0.58

3.1.4 Laboratory procedure for soil analysis

3.1.4.1 Soil texture

Soil texture was determined using particle size analysis (Anderson and Ingram, 1993). 50 g of air dried soil was weighed into a conical flask and a dispersing agent (Sodium metabisuphite) added. After shaking on a reciprocal shaker at 400 r.p.m for 18 hours, the samples were transferred to sedimentation cylinders and topped up with distilled water to make the 1000 ml mark. A hydrometer was used to measure the density of the suspension of soil and water at 40 seconds and 3 hours and a thermometer used to measure the temperature at each reading.

Calculation

% Sand= 100 - {H1 - 0.2 * (T1-20) - 2.0}*2,   % Clay = {H2 + 0.2 * (T2-20) - 2.0}*2

% Silt = 100- (% Sand+% Clay)

Where H1 is first hydrometer reading

H2 is second hydrometer reading

T1 is temperature of suspension at first hydrometer reading

T2 is temperature of suspension at second hydrometer reading

3.1.4.2 Soil moisture

Core samplers of known weight with lids at both ends were used to sample soil for soil moisture analysis using the gravimetric method. The soil was trimmed to the level of the samplers, its weight taken and oven dried at 105 ^{o}C to a constant weight. The weight of the soil was found by subtracting the weight of the core sampler from the total core sampler - soil weight.

Soil moisture = $\frac{(W1-W2)}{W1} * 100\%$

where W1 is weight of wet soil

W2 is weight of dried soil

3.1.4.3 Bulk density

Core samplers of known weight and volume (π r2h) with lids at both ends were used to sample soil without compacting. The soil was trimmed to the level of the samplers and oven dried at 105 ^{o}C to a constant weight. The ratio of the difference in weight after oven - drying to the volume of the core samplers were used to determine the bulk density of the soil.

$$Bulk\ density = \frac{(W2 - W1)}{V}$$

Where W2 is weight of cylinder and dried soil
W1 is the weight of cylinder alone
V is the volume of the cylinder

3.1.4.4 Soil pH

Soil pH was determined by the electronic method with distilled water in a 1:1 ratio (Black, 1965). 10 g of the soil sample in a 50 ml beaker was mixed with 10 ml of distilled water, stirred for five minutes and left for 30 minutes to suspend. A pH meter (Eutech Instruments pH 510) zeroed by putting its glass electrode into distilled water was used to take the pH of the suspended solution at a temperature of 26.9 ^{o}C.

3.1.4.5 Organic Carbon

The modified Walkley and Black procedure as described by Nelson and Sommers (1982) was used to determine organic carbon. 2 g of soil was weighed into 250 ml conical flask and 10ml of 1.0 N potassium dichromate ($K_2Cr_2O_7$) solution added (solution turns green). 20ml of concentrated H_2SO_4 was added and left to cool on an asbestos sheet for 30 minutes. A blank without soil was done alongside. 200 ml of distilled water was added and followed by 10 ml of H_3PO_4, orthophosphoric acid, and 1ml of diphenalamine indicator solution (solution turns blue - black). The mixture was titrated against 1.0 M $FeSO_4$, ferrous sulphate, solution which changed the mixture from blue-black to permanent green at the end point. Same was done for the blank.

$$\% \text{ Organic Carbon} = \frac{M * (Vbl - Vs) * 0.39}{ms} \text{ where}$$

M is molarity of FeSO4

Vbl is ml FeSO4 of blank

Vs is ml FeSO4 of soil sample titration

Ms is weight of soil in grams

0.39 is the moisture correction factor

3.1.4.6 Total nitrogen

Soil total nitrogen was analyzed using Kjeldahl digestion method. 10 g soil was weighed into a 250 ml Kheldahl digestion flask and 10 ml of distilled water was added to it. 10ml of concentrated H_2SO_4 was added followed by one tablet of selenium and potassium sulphate mixture and 0.10 g of salicylic acid. The mixture was made to stand for 30 minutes and heated mildly to convert any nitrates and nitrites into ammonium compounds. The mixture was then heated more strongly (300 to 350 ^oC) to digest the soil to a permanent clear colour. The digest was cooled and transferred to a 100ml volumetric flask and made up to the mark with distilled water. A 20ml aliquot of the solution was transferred into a tecatar apparatus allowed to flow into the flask. The distilled ammonium was collected into a 10ml boric acid, bromocerol green and methyl red solution. The distillate was titrated with 0.01 M HCl solution. A blank digestion, distillation and titration were also carried out as a check against traces of nitrogen in the reagents and water used.

$$\% \text{ N} = \frac{(a-b) * 1.4 * M * V}{s * t}$$

Where a is ml HCl used for sample titration

B = ml HCl used for blank titration

S = weight of soil taken for digestion in grains

M = molarity of HCl

1.4 = 14 * 10^{-3} * 100 % (14 is the atomic weight of N)

V = the total volume of digest

T = volume of aliquot taken for distillation

3.1.4.7 Available nitrogen (NH_4^+ and NO_3^-)

Preparation of extract:

20 ml of 0.5 *M* K_2SO_4 was added to 5 g of wet soil sample and shaken for an hour and filtered. 1 ml aliquot is picked for NH_4^+-N and 1 ml for NO_3^-—N. Soil moisture should be determined to allow the expression of NH_4^+ and NO_3^- on dry weight basis.

3.1.4.7.1 NH_4^+-N- Indophenol blue method

1 ml of each standard and sample were pipetted into marked test tubes and 5 ml of a solution of 34 g sodium salicylate, 25 g sodium citrate and 25 g sodium tartrate in 750 ml water was added to each test tube, mixed well and left for 15 minutes. 5 ml of a solution of 30 g sodium hydroxide, 10 ml sodium hypochlorite in 750 ml water was

added to each test tube, thoroughly mixed and left for an hour for full colour development. Each standard and sample absorbance is taken at 655 nm.

Calculation:

$NH_4^+ = \frac{C * V}{W}$

Where C= corrected concentration (µg / ml)

V= extract volume (ml)

W= weight of sample (g)

3.1.4.7.2 NO_3-N – Salicylic acid method

1 ml of each standard and sample were pipetted into marked test tubes and 1 ml of 5 % salicylic acid solution was added to each test tube, mixed well with a vortex mixer and left to stand for 30 minutes. 10 ml of 4 *M* sodium hydroxide was added, mixed and left for an hour for full colour development. Each standard and sample was read at 410 nm and NO_3-N was calculated as follows:

$NO_3\text{-N} = \frac{C * V}{W}$

Where C= corrected concentration (µg / ml)

V= extract volume (ml)

W= weight of sample (g)

3.1.4.8 Available phosphorus

Available phosphorus was also determined with Bray P 1 method (Bray and Kurtz, 1945). 2 g soil sample was extracted with 20 ml of Bray 1 solution (0.03 M NH_4F and

0.025 M HCl). The mixture was shaken on a Stuart reciprocal shaker for 1 minute and immediately filtered through Whatman no. 42 filter paper. A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6.0 was prepared by pipetting respectively mg P / L 0, 10, 20, 30, 40, 50 ml of 12 mg P / L into 100 ml volumetric flask and made up to the mark with distilled water. Phosphorus in the sample was determined on a pye - unicam spectrophotometer at a wavelength of 660 nm by the blue ammonium molybdate method with ascorbic acid as the reducing agent.

$$P\ (mg / kg) = \frac{(a-b) * Vs * df}{g}$$

Where a is mg P / L in sample extract

b is mg P / L in blank

Vs is the volume of extract

df is dilution factor

g is sample weight in grams

3.1.4.9 Exchangeable cations

Calcium, magnesium and potassium in the soil were determined in 1 *M* ammonium acetate (NH_4OAc) extract (Black, 1986). A 10 g sample was transferred into a leaching tube and leached with 250 ml of buffered 1 *M* ammonium acetate (NH_4OAc) solution at pH 7.

3.1.4.10 Exchangeable calcium and magnesium

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

Calculation:

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

where:

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

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

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

0.01 = concentration of EDTA used

3.1.4.11 Calcium

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

3.1.4.12 Exchangeable potassium

Exchangeable potassium in the percolate was determined by flame photometry. A standard series of potassium was prepared by diluting both 1000 mg / L potassium to 100 mg / L. This was done by taking a 25 mg portion of each into a 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg / L standard solution were put into 200 ml volumetric flasks. One hundred millilitres of 1 *M* NH4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg / L. Potassium was measured directly in the percolate by flame photometry at wavelengths of 766.5 nm.

Calculations:

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

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

where:

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

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

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

mcf = moisture correcting factor

3.1.5 Manure collection and analysis

Cattle manure was collected in sacks from different cattle kraals at Kpongu, Wa. Collected samples were taken randomly from each sack and mixed thoroughly to form a composite for analysis. Table 4.2 (chapter 4) shows the characteristics of the manure before application.

3.1.6 Laboratory analysis of manure

The manure samples were air dried for five days, milled with Perten's laboratory mill 3310 and analyzed for total N (Kjeldahl digestion), phosphorus (Bray P - 1), potassium (Flame photometry method) and carbon (wet oxidation method). The dry matter content of the manure was determined. The analysis indicated that manure contained 138: 20.5: 29.5 kg / ha N: P: K for each full recommended rate (5 t / ha) applied. Table 3.3 shows the chemical properties of the cattle manure before application.

Table 3.3. Cattle manure characterization

Nutrient	Value
Carbon (%)	23.65
Total Nitrogen (%)	2.76
Total Phosphorus (%)	0.41
Total Potassium (%)	0.59
Dry matter content (%)	51.73
C:N Ratio	8.58

3.1.6.1 Total nitrogen

A spatula full of a mixture of Sodium Sulphate, Copper and Selenium was added to 2g of the manure sample weighed into a digestion flask and a 30 ml of H_2SO_4 was added to the mixture to convert organic and nitrate nitrogen to ammonium sulphate, NH_2SO_4.The mixture was digested on a bench flame connected to an extra ctant for about one and half hours, allowed some time to cool and decanted into a 100 ml volumetric flask, topped with distilled water to the 100ml mark (system 1002) and followed by distillation which was done by a Kjedahl Distillation Unit where 10ml of

4 % boric acid was poured into a conical flask and four drops of bromocresol green methyl red indicator was added. 15 ml of 40% NaOH was added to 10ml of the digest in another conical flask heated to vapourize ammonia, condensed, and collected over into the boric acid and indicator solution which changes from red to blue and was removed when flask was about 100ml full. The blue solution was titrated against 0.1 N HCl until a red end point was obtained. The titre value was read and used to obtain the amount of Nitrogen.

3.1.6.2 Total phosphorus

10 g of the manure sample was put in a furnace for 4 hours to be ashed. 20ml of Bray – P 1 solution was added to 2 g of the ashed sample in a shaking bottle, shaken on a Stuart Reciprocating Shaker for one minute and filtered with a filter paper. 10 ml of the filtrate was pipetted into a 25 ml volumetric flask (the test is run along a blank which is water) and added with 1ml of ammonium molybdate and HCl solution after which L - ascorbic acid was also added. This is the colour development stage. It turned blue. Transmittance was measured by a Jenway 6051 calorimeter at 600nm wavelength after the solution was topped up with distilled water, shaken and allowed to stand for 30 minutes for colour change. The solution was compared with standard solutions to determine the amount of Phosphorus.

3.1.6.3 Total potassium

10 g of the manure sample was ashed for 4 hours in a furnace. 100 ml of ammonium acetate (pH 7) was added to 1g of the ashed sample in a shaking bottle, shaken in a Stuart Reciprocating Shaker for one and half hours, filtered and filtrate compared

against standards of 2, 4, 6 and 8. A Jenway Flame Photometer read the emission of the solution at 600 µm.

3.1.6.4 Organic carbon

10 ml of 1.0 N potassium dichromate and 20 ml of concentrated H_2SO_4 were added to 0.5 g of the manure sample in a flat bottom flask, shaken and allowed to stand for 30 minutes. It is run along a blank test without manure. 200 ml of distilled water (H_2O), 10ml of orthophosphoric acid and small amounts of diphenalamine indicator were added and titrated against 1 N ferrous sulphate. The titre value was read and used to determine the amount of carbon.

3.1.6.5 Dry matter

The average weight of five handfuls of fresh manure samples was recorded oven dried at 70 ^{o}C for 24 hours and reweighed for their dry weights. The dry matter content was calculated as the ratio of the average dried weight and the average fresh weight expressed as a percentage.

$$\% \text{ dry matter} = \frac{average\ dried\ weight}{average\ fresh\ weight} \text{ x } 100\ \%$$

3.1.7 Manure application

The appropriate quantities of manure were broadcasted and incorporated with a hoe into the soil at a depth of 10 cm.

3.1.8 Seed acquisition and germination test

The test crop used for the study was a maize variety called Akposoe, an extra early maturing maize (75 days). It was obtained from the ANTIKA Agro input company in Wa. A germination test was done using a germination tray filled with top soil. Fifty maize seeds were sown on this tray and monitored for germination and emergence. A total of 48 seeds germinated and emerged after seven days representing a germination percentage of 96 %.

3.1.9 Seed sowing

The maize was cultivated in the rainy season as a sole crop using the dibbling method. This was done about two weeks after the manure application. Two seeds of the Akposoe maize were planted per hill at a planting distance of 0.8 m x 0.4 m. About 90 % of the sown seeds emerged after one week. Refilling was done one week after planting (WAP) to maintain the required plant population and scare crows were placed at vantage points to scare birds away.

3.1.10 Crop management practices

3.1.10.1 Weed control

Weeding was done as and when necessary. The first weeding was done chemically with glyphosate a day after seeds were sown. The second weeding was done with a hoe, 3 WAP.

3.1.10.2 Mineral fertilizer application

The mineral fertilizer application was done 2 WAP using the dibbling method (5 - 8 cm away from the plant) at a recommended rate of 60-40-40 kg / ha of N- P_2O_5 - K_2O. The fertilizers used were urea, triple superphosphate (TSP) and murate of potash (MOP). The necessary conversions (based on the required recommended rate of the experiment) were made to determine the amount of the fertilizer needed for each 12 m^2 plot. The urea was applied in split while the triple superphosphates and murate of potash were applied in single doses. The second split urea was applied 5 WAP.

3.1.11 Data collection

3.1.11.1 Growth parameters

Data was collected on plant height, stem girth, the leaf area index (LAI) and days to 50 % tasselling at 4, 6 and 8 WAP. Five plants were randomly tagged on each plot with labels 1 to 5. Three leaves of each plant were also randomly labelled, 1 to 3 before the measurements were taken.

3.1.11.2 Determination of growth parameters

Plant height was determined using a calibrated meter rule, taking measurements from the base of the plant to the terminal leaf before tasseling and the tip of the inflorescence after tasselling. A thread was used to girdle the base of the stem and spread on a rule to determine stem girth. The product of the length and width of the leaf were multiplied by a correction factor (0.75) to determine the leaf area. The computed ratio of the leaf area to the ground area covered gave the leaf area index.

3.1.12 Grain yield

The grain yield from each cob harvested from the net plot was calculated and the results were then used to compute the yield per hectare.

$$\text{Grain yield (kg) per hectare} = \frac{10000\ \text{m}^2\ \text{x}\ \text{grain (kg)}}{\text{Harvest area (m}^2\text{)}}$$

3.1.13 Added benefits from combined applications

Added benefit (AB) = $Y_{comb} - (Y_{fert} - Y_{con}) - (Y_{om} - Y_{con}) - Y_{con}$

where AB = for Added Benefits,

Y_{con} = mean grain yields in the control treatment,

Y_{fert} = mean grain yields in the treatments with sole application of fertilizer,

Y_{om} = mean grain yields in the treatment sole organic matter application and

Y_{comb} = mean grain yields in the treatments with both fertilizer and organic matter input.

3.1.14 Economic analysis

The information used for value - cost ratio analysis in this study was collected at the specific time of each activity in the course of the season. The data was mainly from farmers and agro-input retailers and market women using the farm gate prices of the various inputs. Labour for collection, transport and application of manure and fertilizer were also taken into account.

3.1.14.1 Value cost ratio

Value cost ratio was calculated by using the formula:

$$VCR = \frac{(Y-Yc)}{X}$$ (adopted from Nziguheba *et al*., 2010)

where Y = monetary value of the crop in intervention (treated) plots,

Yc = monetary value of the crop harvested in control plots, and X is the monetary cost of inputs (seeds and fertilizers).

3.2 Study 2: Evaluation of the mechanisms for interactive effects from combined cattle manure and mineral fertilizer application

3.2.1 Soil collection and analysis

Soil was collected from the experimental field at Kpongu, Wa, and stored in a cool place for the incubation study. Initial soil analysis was done to characterize it before incubation. Table 3.4 shows the physical and chemical properties of the soil before incubation.

3.2.2 Treatment description for incubation study

The treatments used for the incubation study is outlined in Table 3.4

Table 3.4. Treatment description for incubation study

Treatments (%)	N	P_2O_5	K_2O	Manure
	kg / ha			t / ha
Control	0	0	0	0
0 % RRF, 100% RRM	0	0	0	5
50% RRF, 50% RRM	30	20	20	2.5
0 % RRF, 50 % RRM	0	0	0	2.5
100 % RRF, 0 % RRM	60	40	40	0
50 % RRF, 100 % RRM	30	20	20	5
50 % RRF, 0 % RRM	30	20	20	0
100 % RRF, 100 % RRM	60	40	40	5
100 % RRM, 50 % RRM	60	40	40	2.5

3.2.3 Incubation procedure

Roots, stones and debris were removed from the fresh soil which was not air dried so as to minimize the disturbance of microbial activity. Triplicates of the nine treatments used on the field were repeated five times in a Completely Randomized Design in plastic containers. The quantity of soil (207.43 g) to fill each container was calculated on mass basis in relation to the volume of the containers and the field bulk density of the soil (mg / m^3). The amount of manure and mineral fertilizer to apply were based on the recommended rates and the mass of soil in the containers. Deionized water (9.34 ml) was added to make soil moisture up to 70 % field capacity (FC). The soil was mixed thoroughly with the water and the amendment and covered with gas permeable parafilm to minimize water losses and kept in an incubation chamber with temperature ranging from 25.6 ^{o}C to 33.3 ^{o}C. The moisture content was monitored and adjusted to maintain it at field capacity which called for a periodic change of the parafilm. Destructive sampling was done at five sampling times at 7, 28, 42, 56 and 70 days after incubation for analysis. Analyses were done on the following parameters: pH, soil moisture content (SMC), available phosphorus (P), organic carbon (OC), microbial biomass carbon (MBC), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), soil urease activity and micronutrients (Fe and Cu).

3.2.4 Laboratory analysis of soil before incubation

The table below shows the initial physico - chemical properties of the soil used for the laboratory incubation study.

Table 3.5. Initial physico - chemical and biological properties of the soil used for incubation

PROPERTY	VALUE
Clay (%)	3.20
Silt (%)	3.98
Sand (%)	92.82
Soil moisture (%)	3.2
Soil pH (1:1 H_2O)	6.44
Organic carbon (%)	0.42
Mineral nitrogen (mg / kg)	8.72
Available phosphorus (mg / kg)	1.99
Microbial biomass C (mg / kg)	0.002
Urease activity (mg NH_4 / kg / hr)	19.4
Iron (mg / kg)	8.64
Cupper (mg / kg)	1.02

3.2.5 Laboratory procedure for soil analysis

3.2.5.1 Microbial biomass carbon

Microbial biomass carbon was determined using the fumigation technique as described by Anderson and Ingram (1993). 15 g of fresh soil samples were placed into 50ml beakers while the moisture content of other subsamples were being determined to allow the expression of the result on dry weight basis. One set of the samples (fumigated samples) were placed into a dessicator with a beaker containing 25 ml wash chloroform at the center. A twin set of samples used as the control (non-fumigated samples) were placed in another dessicator without chloroform. Vacuum was applied to the fumigated samples until the chloroform was rapidly boiling. The dessicator was then closed and stored under a darkened condition for 72 hours at room temperature together with the control samples. The fumigated samples were evacuated repeatedly within the 72 hour interval. The samples (fumigated and non - fumigated) were transferred into shaking bottles, 50 ml of 0.5 M K_2SO_4 were added and shaken at 30 rev / min for 25 minutes. The solutions were centrifuged to obtain clear extracts. 10 ml of the extracts were pipetted into block digester tubes with the addition of 5 ml potassium dichromate and 7.5 ml conc. H_2SO_4. Tubes were placed in a pre - heated block digester at 150 °C for 30 minutes, removed and allowed to cool. Digests were transferred into 100 ml conical flasks and 0.3 ml of [C12H8N2]3FeSO_4 (phenanthroline monohydrate- ferrous sulphate) indicator was added. The digests were titrated against 0.2 M ferrous ammonium solution. The endpoint was a colour change from green to brown.

$$MBC = C_{fumigated} – C_{control}$$

3.2.5.2 Nitrate - N

Nitrate- N was determined by the salicylic acid method.

3.2.5.3 Ammonium -N

Ammonium - N was determined by the indolephenol - blue method. Mineral Nitrogen of the soil was determined by summing up nitrate - N and ammonium - N from each treatment.

3.2.5.4 Soil urease activity

10 ml of 0.2 *M* urea solution was added to 2 g soil and incubated for 6 hours. Ammonium released was trapped and determined by the indolephenol - blue method with a correction factor of 10.

Urease activity= $\frac{absorbance\ (y) * 10}{0.0199}$

3.2.5.5 Iron and Cupper

Iron and Cu were determined by the atomic absorption spectrophotometer (AAS) method (FAO, 2008). 20 ml EDTA ammonium acetate solution was added to 5 g soil and shaken on a reciprocating shaker for 2 hours. The solution was filtered, 1 ml aliquot was taken and diluted to 15 ml and read on the AAS machine to determine Fe and Cu contents

3.2.6 Calculations

3.2.6.1 Priming Effect

Priming effect was calculated using the equation adopted from Kuzyakov *et al*. (2000) as:

Priming effect = N release $_{Combined}$ – (N released $_{Fertilizer}$ - N $_{Control}$) - (N released $_{Manure}$ - N $_{Control}$) - N $_{Control}$

where combined N $_{released}$ is nutrient released from combined application plot, fertilizer N $_{released}$ is nutrient released from fertilizer amended plot, manure N $_{released}$ is the nutrient released from manure amended plot, control N is the nutrient released from control plots.

3.2.6.2 Nitrogen and phosphorus synchrony index

Nitrogen synchrony Index (NSI) and phosphorus synchrony Index (PSI) were used to determine the synchrony between nutrient release from various treatments and crop nutrient requirement at various sampling times of the incubation. The amounts of mineral N and available P measured in the soil at various sampling times were transformed into unit - less values with the aid of a linear scoring function with scoring values ranging from 1 to 10. One (1) corresponds to the optimum nutrient requirement by maize for a preceding growth stage and 10, the optimum nutrient requirement for the growth stage in question. The transformed values of mineral N and available P were used to estimate the N synchrony index and the P synchrony index as follows:

$NSI = (\sum_{t=i}^{n} Ni)/n$ and PSI= $(\sum_{t=i}^{n} Pi)/n$

where Ni is N synchrony score value, Pi is P synchrony score value and n is the number of times nutrients were measured during the incubation.

3.2.7 Statistical analysis

All data obtained were subjected to analysis of variance (ANOVA) using GENSTAT statistical package and significant means were separated with Fischer's least significant difference at 5 %.

3.3 Principal component analysis of the studied mechanisms

Principal Component analysis (PCA) was carried out to determine the relative contributions of each of the studied mechanisms (improved nutrient synchrony, priming effect and general fertility improvement) to the interaction between the applied manure and mineral fertilizer. Indices of nitrogen and phosphorus synchrony, priming effect and improvement in soil N and P stock were the data set used for the PCA.

CHAPTER FOUR

4.0 RESULTS

4.1 Effect of manure and mineral fertilizer application on growth and yield of maize

4.1.1 Effect of manure and mineral fertilizer application on plant height

None of the increasing levels of mineral fertilizer or cattle manure influenced ($P > 0.05$) an increase in plant height at all sampling times (Table 4.1).

Table 4.1. Main effect of sole mineral fertilizer and manure application on plant height

	Plant height (cm)		
Fertilizer (kg / ha NPK)	4 WAP	6 WAP	8 WAP
0: 0: 0	56.2	145.8	180.7
30: 20: 20	45.5	154.0	196.2
60: 40: 40	45.3	153.2	195.2
F pr (0.05)	0.60	0.66	0.39
LSD	25.68	20.46	25.85
Manure (t / ha)			
0	52.9	141.9	176.5
2.5	45.2	157.6	201.3
5	48.9	153.5	194.3
F pr (0.05)	0.82	0.27	0.14
LSD	25.68	20.46	25.85
F pr (fertilizer*manure)	0.55	0.99	0.98
CV (%)	14.8	13.6	4.2

Interaction between manure and mineral fertilizer application did not significantly (P > 0.05) affect plant height at all sampling times.

4.1.2 Effect of mineral fertilizer and manure application on stem girth

The application of mineral fertilizer had no significant effect (P > 0.05) on stem girth at 4 WAP while 5 and 2.5 t manure significantly increased stem girths (P < 0.05) compared to the control (Table 4.2) at 4 and 6 WAP. The application of 60:40:40 kg / ha NPK significantly increased stem girth relative to the control at 6 WAP and 8 WAP.

Table 4.2. Main effect of mineral fertilizer and manure application on stem girth

	Stem girth (cm)		
Fertilizer (kg / ha NPK)	4 WAP	6 WAP	8 WAP
0: 0: 0	4.41	5.33	5.68
30: 20: 20	4.74	5.89	6.34
60: 60: 40	4.65	6.11	6.67
F pr(0.05)	0.39	0.004	0.005
LSD	0.52	0.50	0.54
Manure (t/ha)			
0	3.98	5.30	5.81
2.5	4.75	5.86	6.29
5	5.06	6.16	6.59
F pr(0.05)	0.001	0.022	0.032
LSD	0.52	0.50	0.54
F pr (Fertilizer*manure)	0.91	0.68	0.50
CV (%)	11.3	8.7	2.0

The use of 5 t manure significantly increased stem girth (6.59 cm) compared to the control (5.81 cm).

The conjoint use of manure and mineral fertilizer (as shown in Fig. 4.1) significantly increased stem girth at 4 to 8 WAP. At 4 WAP, the interaction from 30:20:20 kg / ha NPK + 5 t manure produced the largest stem girth which was not statistically different from 5 t manure, 60:40:40 kg / ha + 2.5 t manure and 60:40:40 kg / ha + 5 t manure. The largest girth was produced by 60:40:40 kg / ha NPK + 5 t manure which was statistically similar to 5 t manure, 30:20:20 kg / ha NPK + 2.5 t manure, 30:20:20 kg / ha NPK + 5 t manure, 60:40:40 kg / ha NPK + 2.5 t manure, 60:40:40 kg / ha NPK + 5 t manure and 30:20:20 kg / ha NPK at 6 WAP. At 8 WAP, 60:40:40 kg / ha NPK + 5 t manure effected the largest stem girth which was not different from 60:40:40 kg / ha NPK + 2.5 t manure while the control recorded the least.

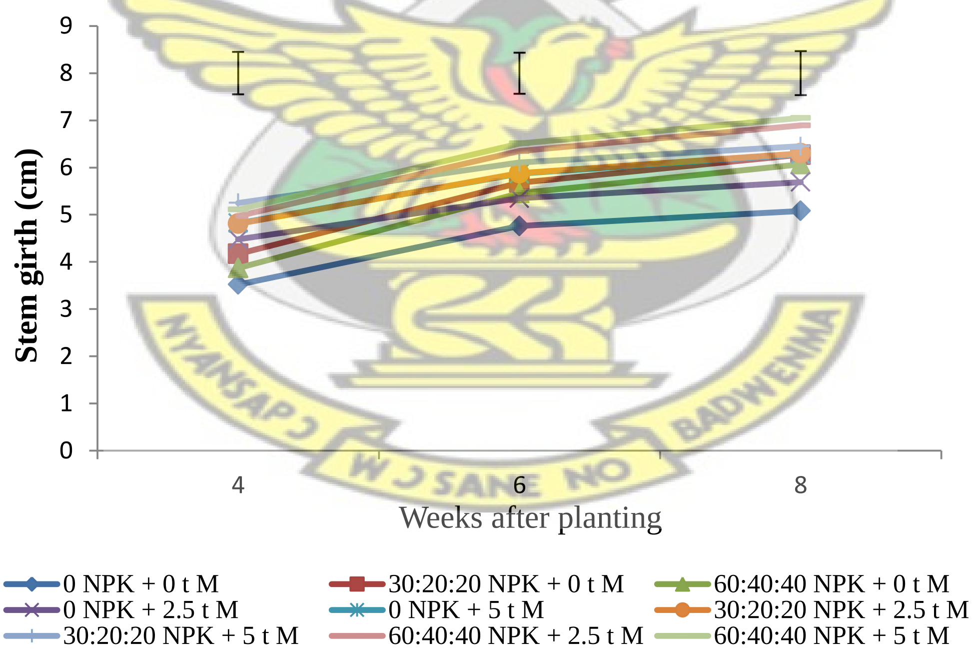


Figure 4.1. Combined effect of manure and mineral fertilizer on stem girth

Note: Error bars represent LSD at 5 %

4.1.3 Effect of manure and mineral fertilizer application on leaf area index

As indicated in Table 4.3, the increasing levels of sole mineral fertilizer did not significantly increase (P > 0.05) leaf area index (LAI) at 4, 6 and 8 WAP. The application of 5 and 2.5 t manure significantly increased LAI at 4 WAP, over the control at 4 WAP. The use of 5 t manure had the highest LAI relative to the control at 8 WAP. The application of 5t manure increased the highest LAI, 6 WAP relative to the control. The combined use of manure and mineral fertilizer did not affect LAI at 4, 6 and 8 WAP.

Table 4.3. Main effect of mineral fertilizer and manure application on leaf area index

	LAI		
Fertilizer (kg / ha NPK)	4 WAP	6 WAP	8 WAP
0: 0: 0	0.081	0.16	0.19
30: 20: 20	0.091	0.18	0.21
60: 40: 40	0.086	0.17	0.20
F pr (0.05)	0.62	0.45	0.47
LSD (0.05)	0.21	0.033	0.04
Manure (t / ha)			
0	0.070	0.15	0.18
2.5	0.092	0.17	0.20
5	0.096	0.19	0.22
F pr (0.05)	0.045	0.10	0.11
LSD (0.05)	0.21	0.03	0.04
F pr (Fertilizer*manure)	0.91	0.85	0.84
CV (%)	13.2	19.5	2.5

4.1.4 Effect of manure and mineral fertilizer application on the grain yield of maize.

The main effects of manure and mineral fertilizer on maize grain yield are shown in table 4.4 below. The application of 60:40:40 kg / ha NPK alone significantly ($P < 0.05$) produced the highest grain yield (3618 Kg / ha) with an excess of 1116 kg / ha grain yield over 30:20:20 kg / ha NPK alone and 2363 kg over the control. Sole 5 t manure application significantly produced the highest grain yield (3451 kg / ha) followed by 2.5 t manure which produced 2515 kg / ha grain yield while 0 t manure gave the least grain yield (1400 kg / ha).

Table 4.4. Main effect of mineral fertilizer and manure application on grain yield of maize

Fertilizer (kg / ha NPK)	Grain Yield (kg / ha)
0: 0: 0	1249
30: 30: 20	2502
60: 60: 40	3618
F pr (0.05)	> 0.001
LSD (0.05)	317.10
Manure (t / ha)	
0	1400
2.5	2515
5	3451
F pr (0.05)	> 0.001
LSD (0.05)	317.10
F pr (fertilizer*manure)	0.001
CV (%)	12.9

The combined effect of manure and mineral fertilizer on maize grain yield is represented in Fig 4.2 below. The combined use of 60:40:40 kg / ha NPK + 5 t manure influenced the highest ($P < 0.05$) grain yield (4678 kg / ha) followed by yields from the application of 30:20:20 kg / ha NPK + 5 t manure (3907 kg / ha) and 60:40:40 kg / ha NPK + 2.5 t manure (4027 kg / ha). The application of 60:40:40 kg / ha NPK resulted in grain yield which was not statistically different ($p > 0.05$) from that of 30:20:20 kg / ha NPK + 2.5 t manure. The control had the least grain yield (610 kg / ha)

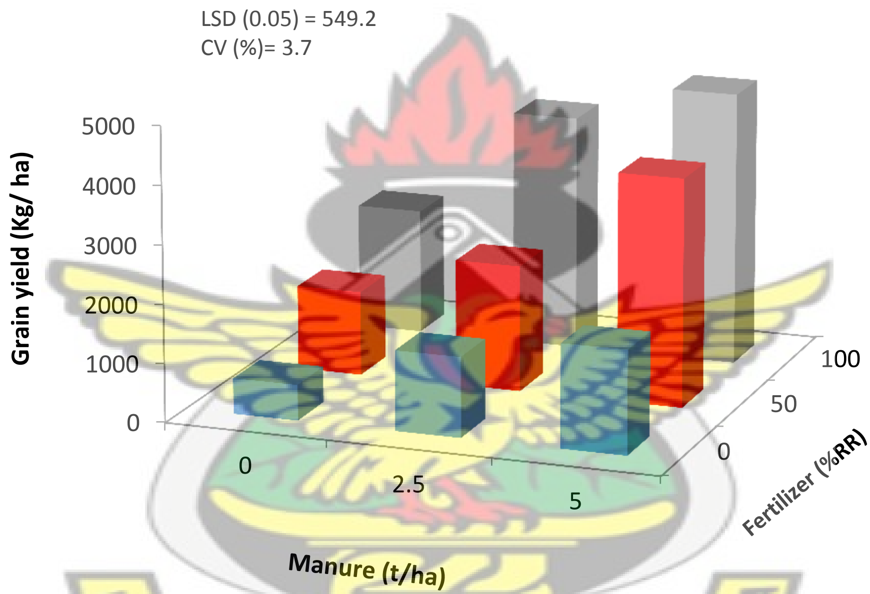


Figure 4.2. Combined effect of manure and mineral fertilizer application on grain yield of maize

4.1.5 Response of maize yield to Nitrogen supplied through fertilizer and / or manure

Figure 4.3 below shows the response of maize yield to nitrogen supplied through manure or mineral fertilizer or both. Grain yield increased linearly with increase in amount of applied N from mineral fertilizer and manure, with 60:40:40 kg / ha NPK + 5 t manure producing the highest grain yield. Ninety- four percent (94.7 %) of the variation observed in grain yield was due to the amount of nitrogen supplied through the treatments.

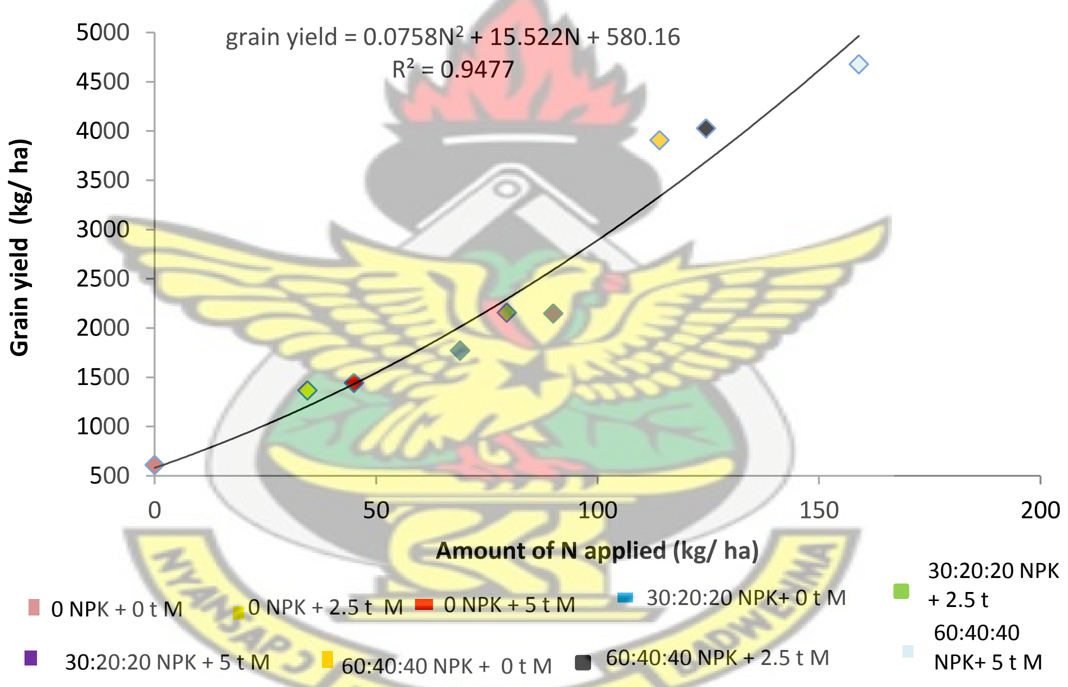


Figure 4.3. Fertilizer response curve of maize grain yield

4.1.6 Effect of combined application of manure and mineral fertilizer on added benefit

Figure 4.4 shows the added benefit in grain yield obtained from combined application of manure and mineral fertilizer. All the combined applications except 30:20:20 kg / ha NPK + 2.5 t manure resulted in sufficient added benefits in terms of grain yield. The 30:20:20 kg / ha NPK + 2.5 t manure recorded an added disadvantage of 44 kg / ha grain yield.

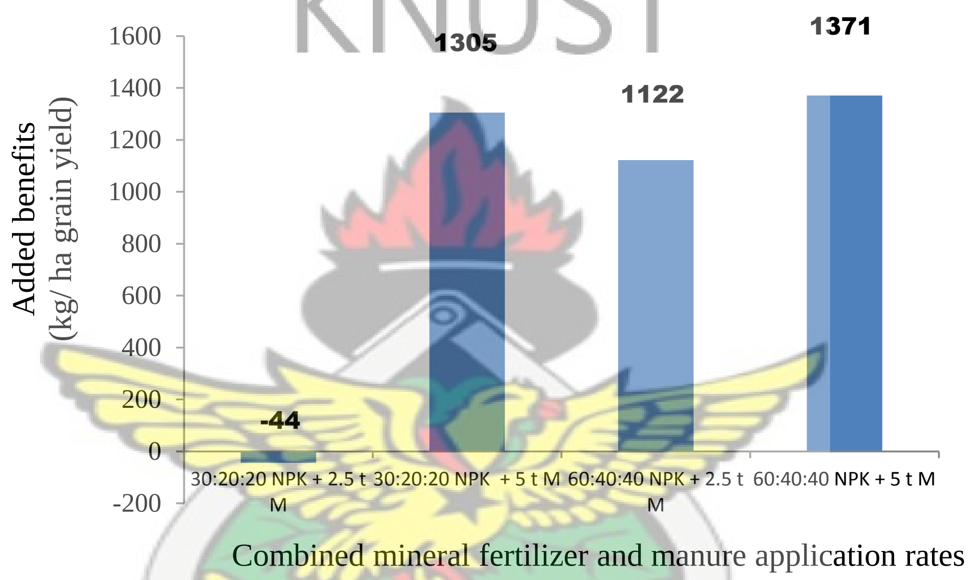


Figure 4.4. Added benefit in maize grain yield from combined application of manure and mineral fertilizer application

4.1.7 Returns on investment from manure and mineral fertilizer application

The applications of 60:40:40 kg/ha NPK + 2.5 t manure and 30:20:20 kg / ha NPK + 5 t manure (Fig. 4.5) were the most economically viable inputs (VCR = 2) among the all treatments while 5 t manure was the least economical (VCR < 2).

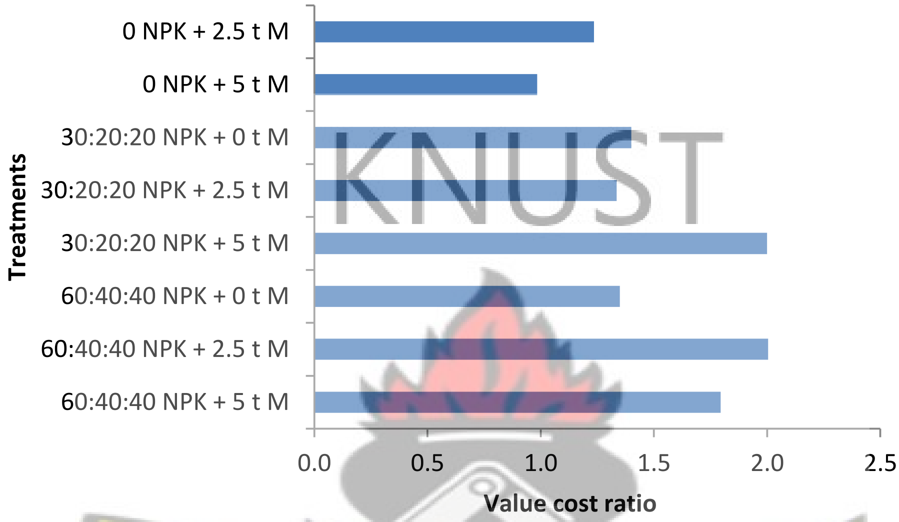


Figure 4.5. Value cost ratio of the applied treatments

4.1.8 Effect of manure and mineral fertilizer application on soil nutrient stock

After harvest, N content from the control (Fig 4.6a), 60:40:40 kg / ha NPK, 2.5 t manure, 5 t manure and 30:20:20 kg / ha NPK + 5 t manure fell below the initial soil N stock before planting (120 kg / ha) (Table 4.1) while 60:40:40 kg / ha NPK + 2.5 t manure and 30:20:20 kg / ha NPK maintained their N stock relative to the initial soil N. The use of 60:40:40 kg / ha NPK + 5 t manure and 30:20:20 kg / ha NPK + 2.5 t manure increased the N content of the soil by 66 % and 33 % respectively compared to the soil N before planting.

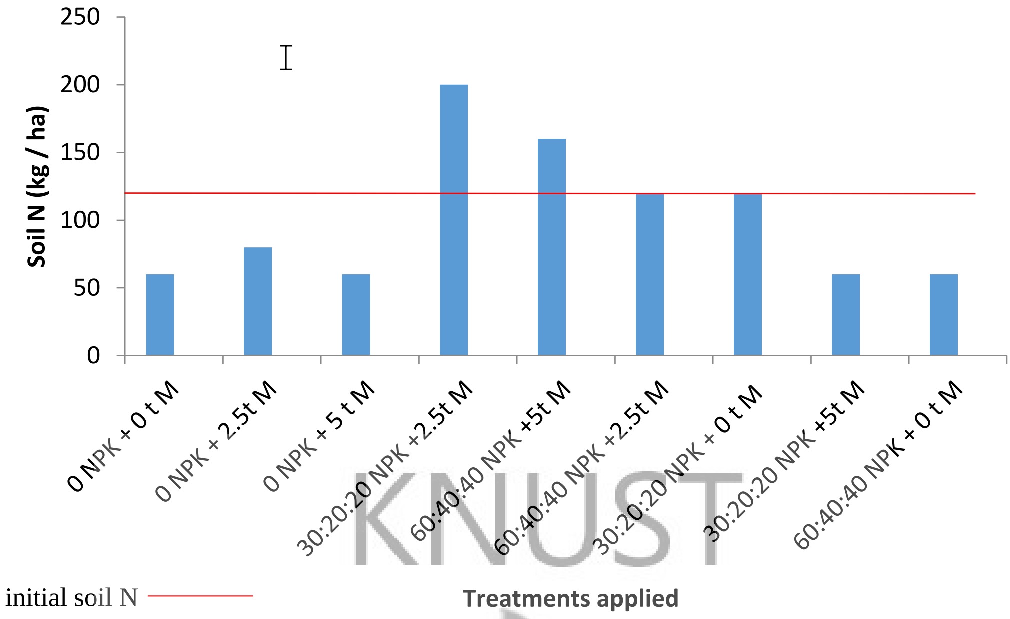


Figure 4.6a. Combined effect of manure and mineral fertilizer application on soil N stock

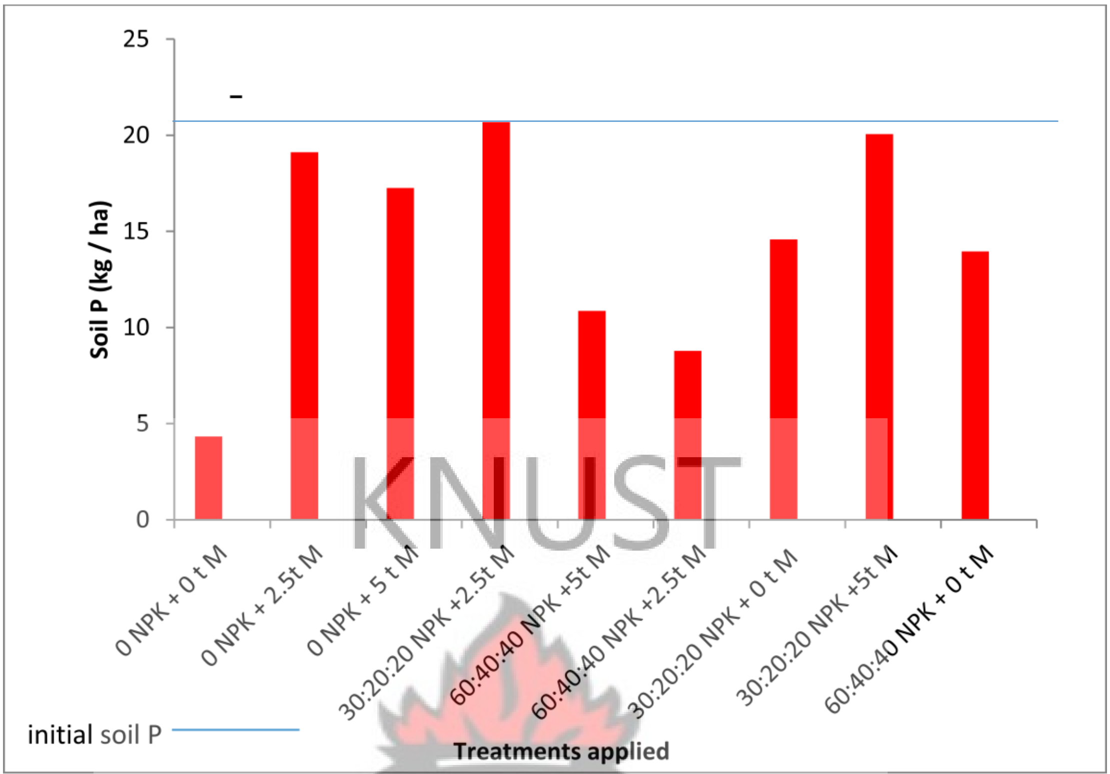


Figure 4.6 b. Combined effect of manure and mineral fertilizer application on soil P stock

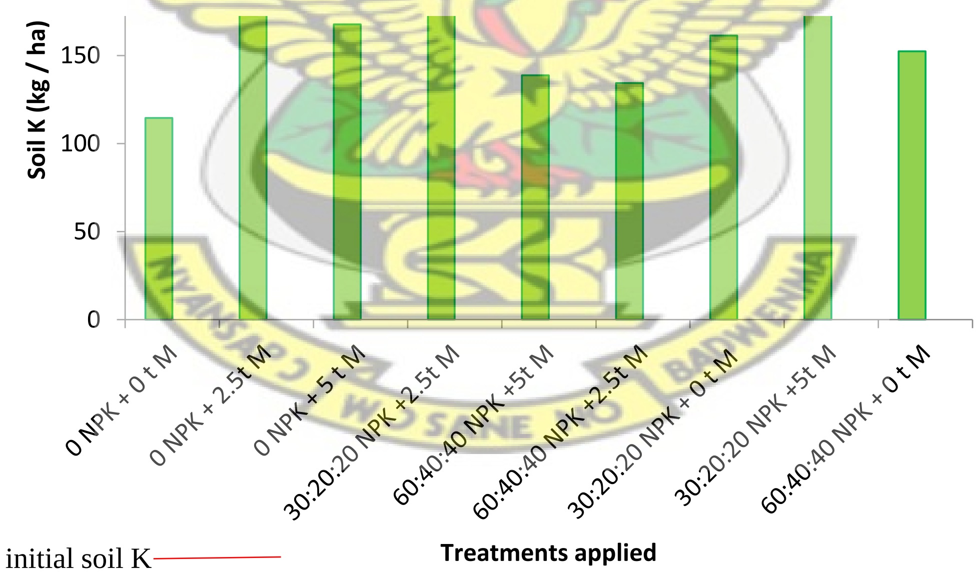


Fig. 4.6 c. Combined effect of manure and mineral fertilizer application on soil K stock

From Fig. 4.6 b., the nutrient inputs except 30:20:20 kg / ha NPK + 2.5 t manure and 30:20:20 kg / ha NPK + 5 t manure reduced the soil P stock relative to the initial soil P (19.94 kg / ha). The application of 30:20:20 kg / ha NPK + 2.5 t manure increased soil P by 3.71 % above the initial soil P before planting while 30:20:20 kg / ha NPK + 5 t increased soil P by 0.60 %. The soil K stock was lower than the initial soil K (197.3 kg / ha) for all the treatments applied.

4.2 Mechanisms for interactive effects from manure and mineral fertilizer

4.2.1 Effect of manure and mineral fertilizer application on mineral N (NH_4-N and NO_3 - N) release

The main effect of sole manure and mineral fertilizer on nitrogen release is indicated in Table 4.5 below. Mineral N at 28 DAI and reduced steadily in the succeeding days after incubation relative to 7 DAI for increasing mineral fertilizer applications (except for increases by 30:20:20 kg / ha NPK at 42 DAI and 60:40:40 at 56 and 70 DAI). Except at 42 DAI, the 60:40:40 kg / ha NPK applications had mineral N content about twice or more that of 30:20:20 kg / ha NPK applied at all sampling times. The application of 5 t manure had N significantly higher than 2.5 t manure at 7, 56 and 70 days after incubation.

Table 4.5. Main effect of mineral fertilizer and manure application on N mineralization

	Mineral N (kg / ha)				
Fertilizer(kg / ha NPK)	7 DAI	28 DAI	42 DAI	56 DAI	70 DAI
0	42.66	17.74	36.00	25.08	14.52
30:20:20	48.92	34.34	64.52	46.66	25.76
60:40:40	97.6	77.56	70.70	85.68	104.88
F pr (0.05)	>0.001	>0.001	>0.001	>0.001	>0.001
LSD	1.46	1.50	5.4	1.38	1.48
Manure					
0	42.82	25.52	66.58	39.24	54.68
2.5 t	71.06	58.90	53.90	50.50	43.06
5 t	75.30	45.20	50.74	67.68	47.42
F pr (0.05)	>0.001	>0.001	>0.001	>0.001	>0.001
LSD	1.46	1.50	5.4	1.38	1.48
F pr (fertilizer*manure)	>0.001	>0.001	>0.001	>0.001	>0.001
CV (%)	2.3	3.5	9.6	2.6	3.1

The conjoint effect of manure and mineral fertilizer on nitrogen mineralization is shown in Fig. 4.7. There was an increase in soil N from all the nutrient inputs at 7 days after incubation relative to the initial soil N (17.44 kg / ha) except the control. All the nutrient inputs except the control, 30:20:20 kg / ha NPK + 2.5t manure and 5 t met the tasselling N demand (49.5 kg / ha) (IFA, 1992) from about 35 to 42 DAI. At the initial stages of grain filling, all the nutrient inputs except the control, 2.5 t manure and 5 t manure supplied N above the grain filling N demand (32.3 kg / ha) (IFA, 1992) from 42 to 70 DAI. At the tail end of grain filling, only 60:40:40 kg / ha NPK +

0 t M, 60:40:40 kg / ha NPK + 2.5t manure and 60:40:40 kg / ha NPK + 5 t manure supplied N above the grain filling demand with 60:40:40 kg / ha NPK + 0 t manure supplying the highest.

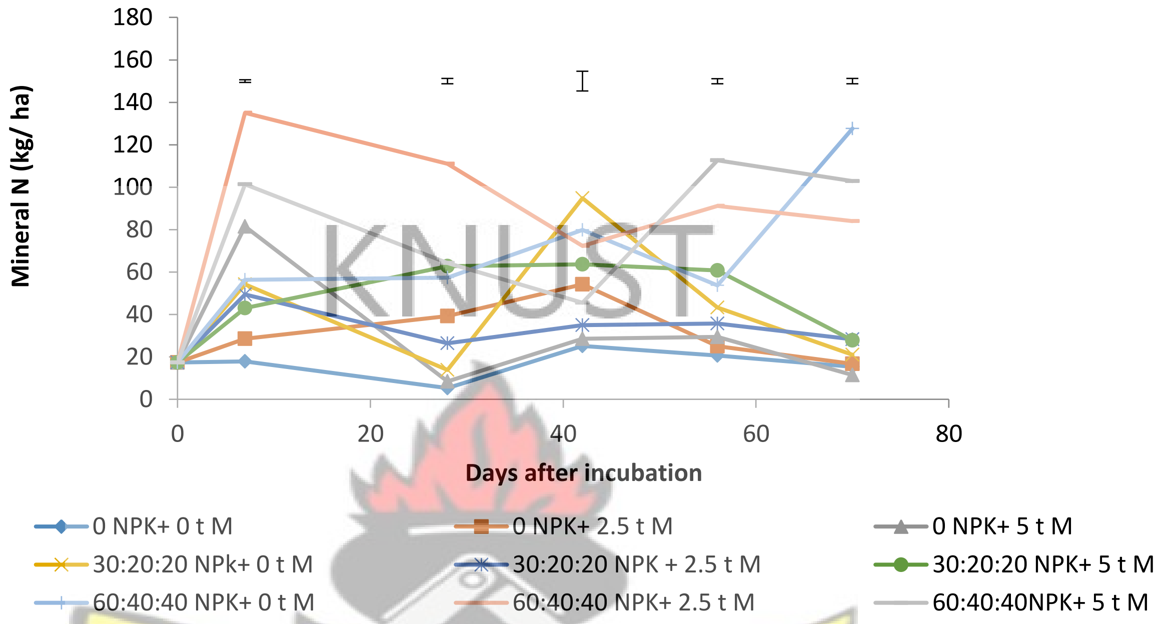


Figure 4.7. Combined effect of manure and mineral fertilizer application on N mineralization

4.2.2 Effect of manure and mineral fertilizer application on phosphorus release

The main effect of manure and mineral fertilizer on P mineralization is shown in Table 4.6. Increasing levels of manure and mineral fertilizer significantly increased (P < 0.05) P release. Similarly, increasing the levels of cattle manure from 0 to 2.5 t / ha increased the rate of P released but an increase in the rate from 2.5 to 5 t / ha declined the amount of P released throughout the incubation period. The use of NPK fertilizer levels released P steadily from 7 to 28 DAI and the rate declined at 42 DAI. Phosphorus release rose again from 56 DAI through to 70 DAI for both NPK levels.

In general, mineral fertilizer rates released more P (ranging from 12.98 to 53.36 kg / ha) than their counterpart manure levels (ranging from 10.42 to 50.68 kg / ha).

Table 4.6.Main effect of mineral fertilizer and manure application on P mineralization

	Available P (kg / ha)				
Fertilizer (kg / ha NPK)	7 DAI	28 DAI	42 DAI	56 DAI	70 DAI
0	5.40	7.88	7.94	13.52	32.14
30:20:20	12.98	15.08	12.96	21.78	51.30
60:40:40	14.00	26.48	18.22	15.88	53.36
F pr (0.05)	>0.001	>0.001	>0.001	>0.001	>0.001
LSD	0.52	1.64	0.64	0.56	1.50
Manure					
0	9.94	10.44	13.08	15.70	35.40
2.5 t	12.00	27.06	14.66	18.28	50.68
5 t	10.42	11.94	11.00	16.32	50.64
F pr (0.05)	>0.001	>0.001	>0.001	>0.001	>0.001
LSD	0.52	1.64	0.64	0.56	1.50
F pr (fertilizer*manure)	<0.001	<0.001	<0.001	<0.001	<0.001
CV (%)	4.9	10.1	5	3.3	3.3

Generally, the different levels of manure released P steadily throughout the incubation period which only heightened at 70 DAI. Figure 4.8 shows the combined effect of manure and mineral fertilizer application on P mineralization. Phosphorus release was generally slow during the first 28 DAI except for 60:40:40 kg / ha NPK + 2.5 t manure which peaked at 28 DAI. The use of 30:20:20 kg / ha NPK + 2.5 t manure released the highest P, 7 DAI. None of the nutrient inputs met the maize P tasselling (35 to 42 DAI) demand (25 kg / ha) except 60:40:40 kg / ha NPK + 2.5 t manure. Only 60:40:40 kg / ha NPK + 5 t manure and 60:40:40 kg / ha NPK + 2.5 t manure supplied P above the grain filling P demand (22.5 kg / ha) at 56 DAI (which represented the initial stages of grain filling on the field) though they were not statistically different from each other. All the nutrient inputs but the control supplied P above the grain filling P demand at 70 DAI (the tail end of grain filling).

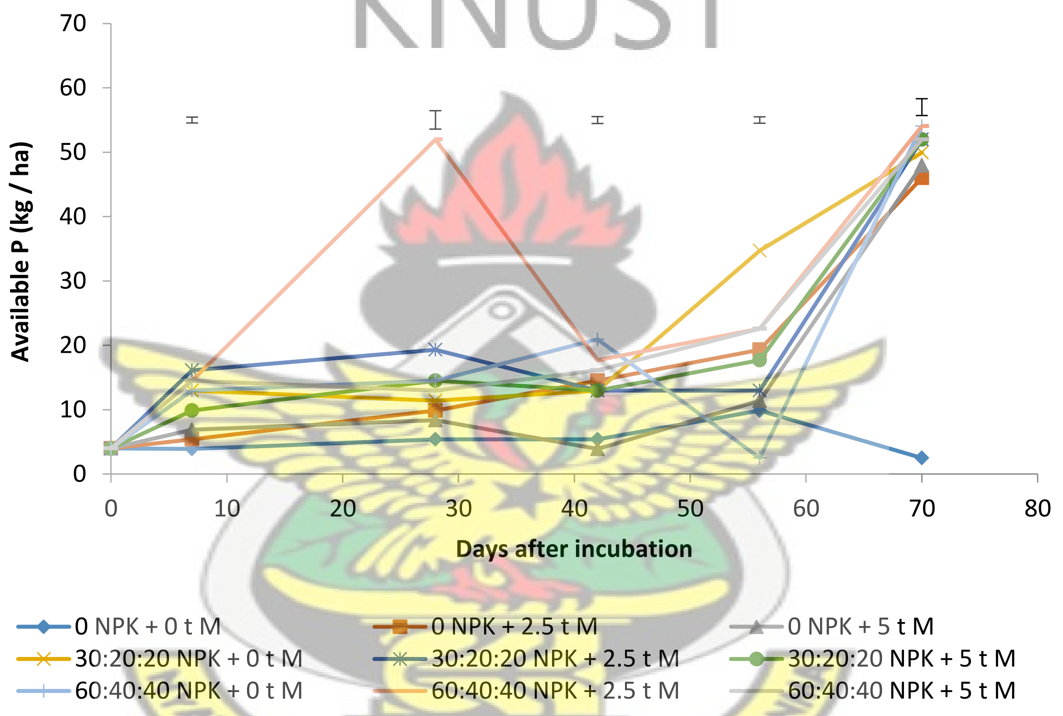


Figure 4.8. Combined effect of manure and mineral fertilizer application on P release

4.2.3 Contribution of manure and mineral fertilizer application rates to nutrient synchrony

All the nutrient inputs had the highest nitrogen synchrony index (10) at 7 DAI (Table 4.7) after which the synchrony index of 30:20:20 kg / ha NPK reduced to 4 while 5 t manure reduced to 2 at 28 DAI. A low index of 3 was observed from 30:20:20 kg / ha + 2.5 t manure and 2 from 5 t manure at 42 DAI. The highest index (above 5) at 56 DAI was observed under 60:40:40 kg / ha NPK + 5 t manure while the other nutrient inputs had low synchrony indices (below 5). Very low synchrony indices were observed from all the nutrient management options at 70 DAI. Cumulatively, 60:40:40 kg / ha NPK + 2.5 t manure had the highest NSI of 7 followed by 6.8 under 60:40:40 kg / ha NPK + 5 t manure and 6.4 under 60:40:40 kg / ha NPK. The least cumulative NSI was obtained from 5 t manure.

Table 4.7. Nitrogen synchrony index

Treatments applied	Nitrogen synchrony index (NSI)					
	7 DAI	28 DAI	42 DAI	56 DAI	70 DAI	Mean NSI
30:20:20 kg / ha NPK + 2.5 t manure	10	10	3	1	1	5
30:20:20 kg / ha NPK + 5 t manure	10	10	9	1	1	6.2
60:40:40 kg / ha NPK + 2.5 t manure	10	10	10	4	1	7
60:40:40 kg / ha NPK + 5 t manure	10	10	5	8	1	6.8
30:20:20 kg / ha NPK	10	4	10	1	1	5.2
60:40:40 kg / ha NPK	10	10	10	1	1	6.4
2.5 t manure	10	10	7	1	1	5.6
5 t manure	10	2	2	1	1	3.2

The indices showing the synchrony between P release and P demand by maize are shown in Table 4.8. From the table, all the nutrient inputs had the highest phosphorus synchrony index at 7 DAI. The highest P synchrony index was observed from 60:40:40 kg / ha NPK + 2.5 t manure at 28 DAI while index from the remaining treatments decreased compared to the value recorded at 7 DAI with 2.5 t and 5 t manure recording the least P synchrony index. Phosphorus synchrony indices were lowest (1) for all the nutrient inputs at 42, 56 and 70 DAI. On the average, PSI was low (below 5) for all the nutrient inputs throughout the incubation, with the highest PSI of 4.6 from 60:40:40 kg / ha NPK + 2.5 t manure and the lowest PSI from 2.5 and 5 t manure.

Table 4.8. Phosphorus synchrony index

	Phosphorus synchrony index (PSI)					
Treatments applied	7 DAI	28 DAI	42 DAI	56 DAI	70 DAI	Mean PSI
30:20:20 kg / ha NPK + 2.5 t manure	10	6	1	1	1	3.8
30:20:20 kg / ha NPK + 5 t manure	10	4	1	1	1	3.4
60:40:40 kg / ha NPK + 2.5 t manure	10	10	1	1	1	4.6
60:40:40 kg / ha NPK + 5 t manure	10	4	1	1	1	3.4
30:20:20 kg / ha NPK	10	4	1	1	1	3.4
60:40:40 kg / ha NPK	10	4	1	1	1	3.4
2.5 t manure	10	3	1	1	1	3.2
5 t manure	10	3	1	1	1	3.2

4.2.4 Contribution of manure and mineral fertilizer application to N and OC priming

4.2.4.1 Contribution of manure and mineral fertilizer application to N priming

Nitrogen priming effect on maize grain yield as influenced by combined manure and mineral fertilizer applications is indicated in Fig. 4.9. A positive priming effect was observed from 60:40:40 kg / ha NPK + 5 t manure throughout the incubation period until after 60 days (corresponding to the tail end of grain filling on the field). The use of 30:20:20 kg / ha NPK + 2.5 t manure on the other hand had a negative priming effect throughout the incubation period until after 60 days. The remaining combined treatments had alternating positive and negative priming effects throughout the incubation period.

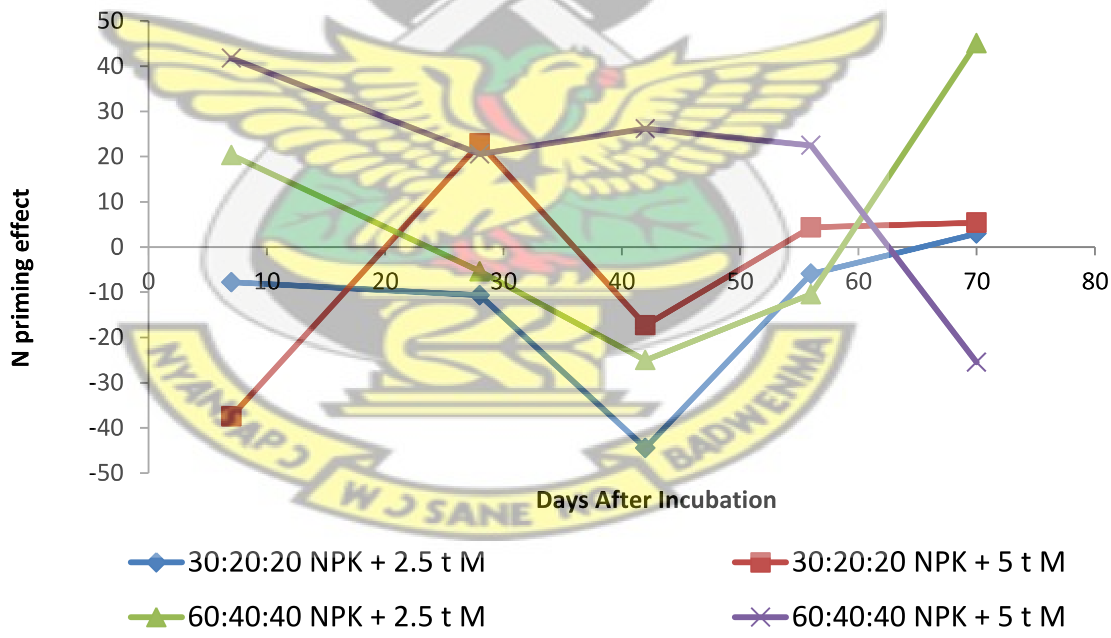


Figure 4.9. Nitrogen priming effect as influenced by combined manure and mineral fertilizer application

4.2.4.2 Organic carbon priming effect from combined manure and mineral fertilizer application

Figure 4.10 shows organic carbon priming effect on maize grain yield as influenced by integrated application of manure and mineral fertilizer application. A positive priming effect was observed from 60:40:40 kg / ha NPK + 2.5 t manure throughout the incubation period with the highest effect at 70 DAI. The use of 30:20:20 kg / ha NPK + 5 t manure started with a negative priming effect which rose to a positive value at 28 DAI, peaked at 56 DAI and declined again to a negative effect at 70 DAI. The application of 60:40:40 kg / ha NPK + 5 t manure had a positive priming effect from 7 to 56 DAI. The application of 30:20:20 kg / ha NPK+ 2.5 t manure had a negative priming effect on organic C at 7, 56 and 70 DAI.

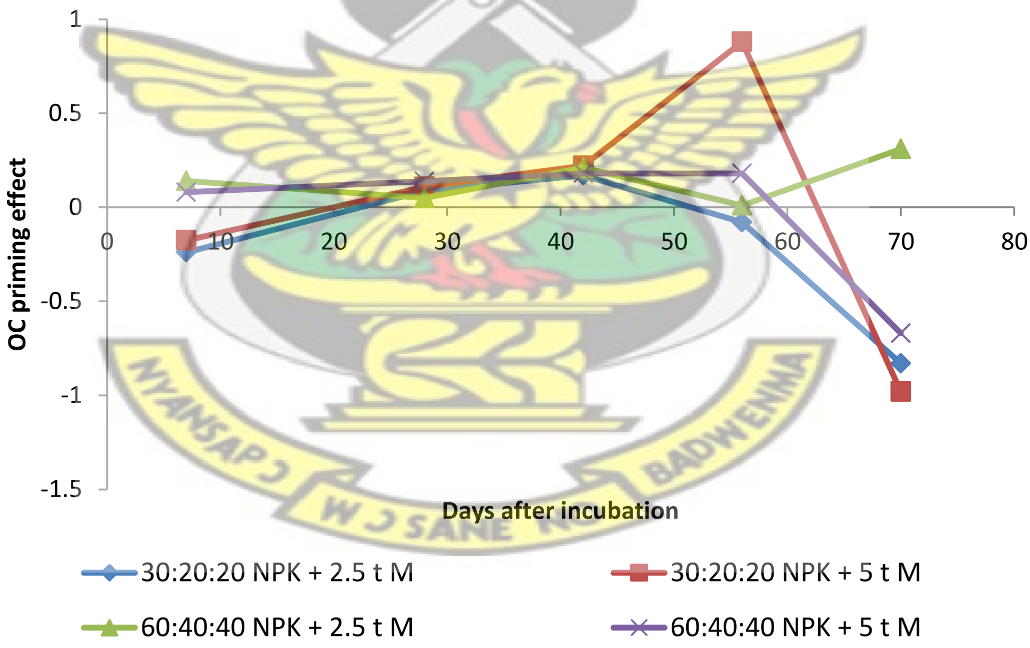


Figure 4.10. Organic carbon priming as influenced by combined applications

4.2.5 Contribution of manure and mineral fertilizer application to general fertility improvement

4.2.5.1 Effect of manure and mineral fertilizer application on soil pH

Soil pH increased under 30: 20: 20 kg /ha NPK at 7 DAI (Table 4.9) and from the increasing levels of both nutrient sources at 42 DAI compared to the pH (6.44) of the soil before the addition of nutrient inputs (Table 3.5). Soil pH decreased for all increasing mineral fertilizer levels at 56 and 70 DAI and also decreased by 0 t manure at 7 DAI, 0 and 2.5 t manure at 28 DAI, 2.5 and 5 t manure at 56 DAI and 70 DAI compared to the initial soil pH (6.44, Table 3.5). Decreases in soil pH relative to the control following the application of 60:40:40 kg / ha NPK were 3.93 % at 7, 11.62 % at 28 DAI, 6.16 % at 42 and 3.95 % at 70 DAI while 30:20:20 kg / ha NPK decreased soil pH by 9.12 % at 28 and 2.38 % at 42 DAI.

Table 4.9. Main effect of mineral fertilizer and manure application on soil pH

	Soil pH				
Fertilizer (kg / ha NPK)	7 DAI	28 DAI	42 DAI	56 DAI	70 DAI
0	6.61	6.82	7.75	6.25	6.31
30:20:20	6.62	6.25	7.57	6.24	6.32
60:40:40	6.36	6.11	7.30	6.27	6.07
F pr (0.05)	<0.001	<0.001	0.401	0.854	<0.001
LSD	0.058	0.28	0.69	0.132	0.087
Manure					
0	6.27	6.33	7.53	6.28	6.20
2.5 t	6.58	6.31	7.51	6.37	6.34
5 t	6.74	6.54	7.59	6.12	6.17
F pr (0.05)	<0.001	0.18	0.97	0.003	0.002
LSD	0.058	0.28	0.69	0.132	0.087
F pr (fertilizer*manure)	<0.001	0.01	0.99	<0.001	0.013
CV (%)	0.9	4.4	9.2	2.1	1.4

The application of 2.5 t manure (Table 4.9) significantly increased soil pH at 7, 56 and 70 DAI compared to the control while 5 t manure increased soil pH at 7, 28 and 42 DAI and decreased pH at 56 and 70 DAI.

The combined effect of manure and mineral fertilizer (Fig. 4.11) significantly influenced soil pH at 7, 28, 56 and 70 DAI. The highest soil pH was observed under the application of 2.5 t manure at all sampling times except 42 DAI. Compared to the control, 60:40:40 kg / ha NPK reduced soil pH by 17.7 %. The highest pH was observed under the application of 30:20:20 kg / ha NPK + 5 t manure 7 DAI. Except for 60:40:40 kg / ha NPK + 0 t manure at 7 DAI, all the other nutrient inputs put the soil in the neutral range.

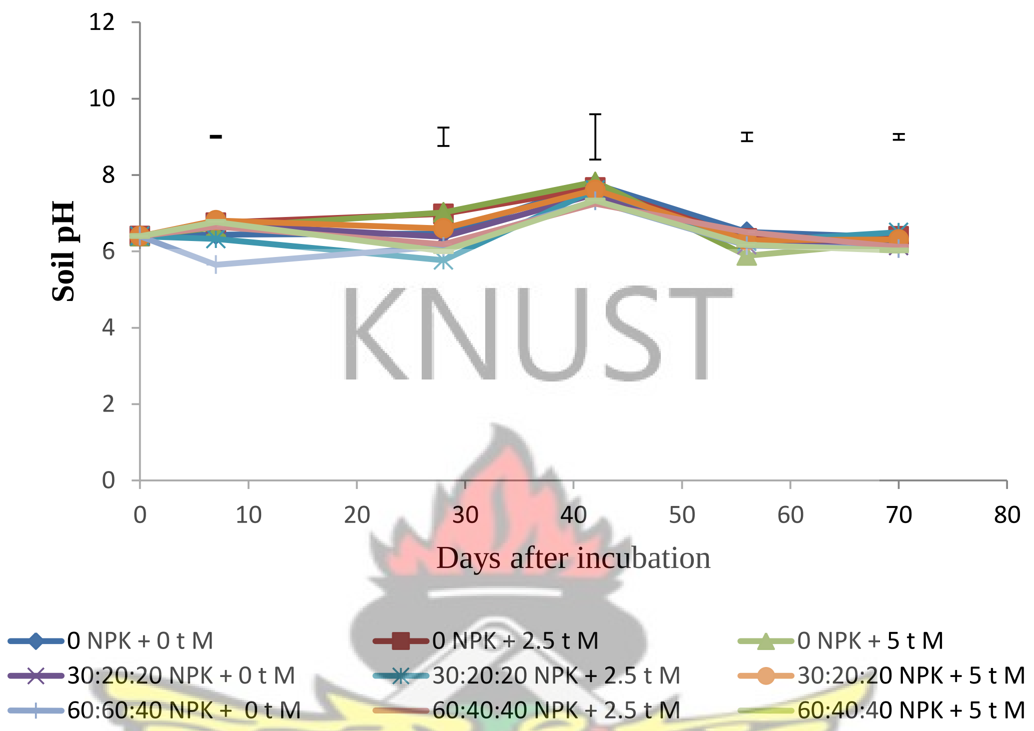


Figure 4.11. Combined effect of manure and mineral fertilizer application on soil pH

4.2.5.2 Effect of manure and mineral fertilizer application on Soil organic carbon

The main effects of manure and mineral fertilizer on soil organic carbon (SOC) are represented in table 4.10. It was observed that none of the increasing levels of mineral fertilizer significantly affected SOC except for 7 and 56 DAI. The use of 60:40:40 kg / ha NPK significantly reduced soil organic C by 10.20 % at 7 DAI relative to the control while 30:20:20 kg / ha NPK increased SOC by 32.97 % compared to 60:40:40 kg / ha NPK at 56 DAI. Manure at 5 t significantly increased SOC by 17.30 % at 7 DAI, 9.23 % at 28 DAI and 35.11 % at 56 DAI compared to the control.

Table 4.10. Main effect of mineral fertilizer and manure application on soil organic carbon

	Soil organic carbon (%)				
Fertilizer (kg / ha NPK)	7 DAI	28 DAI	42 DAI	56 DAI	70 DAI
0	0.49	0.59	0.59	0.62	1.38
30:20:20	0.51	0.62	0.59	0.91	0.83
60:40:40	0.44	0.60	0.57	0.61	1.96
F pr (0.05)	0.011	0.43	0.81	<0.001	0.393
LSD (0.05)	0.042	0.042	0.074	0.063	1.70
Manure					
0	0.43	0.59	0.58	0.61	1.08
2.5 t	0.48	0.58	0.59	0.59	1.77
5 t	0.52	0.65	0.59	0.94	1.32
F pr (0.05)	0.002	0.003	0.074	<0.001	0.69
LSD (0.05)	0.042	0.042	0.074	0.063	1.70
F pr (fertilizer*manure)	<0.001	0.077	0.079	<0.001	0.19
CV (%)	9	7	12.7	8.9	43.4

The combined application of 30:20:20 kg / ha NPK + 5 t manure produced the highest SOC at 7 and 56 DAI, aside which none of the combined nutrient management options affected SOC. Figure 4.12 shows the combined effect of manure and mineral fertilizer on SOC.

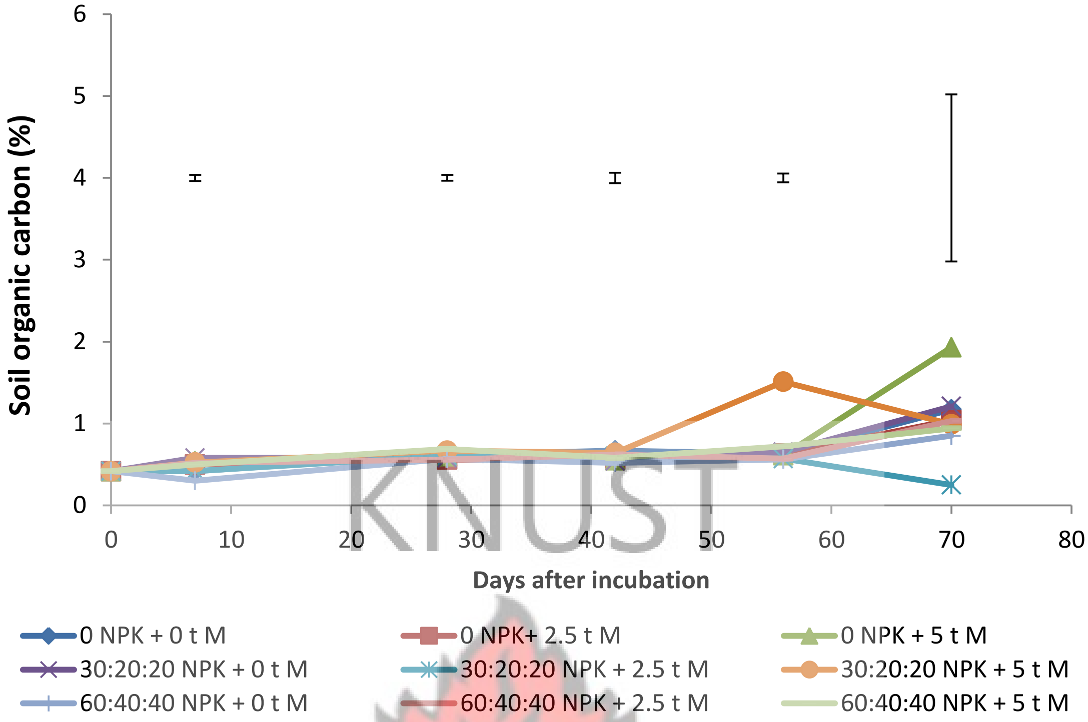


Figure 4.12. Combined effect of manure and mineral fertilizer application on SOC

4.2.5.3 Effect of manure and mineral fertilizer application on Iron

The highest Fe content was recorded under application of 30:20:20 kg / ha NPK at all sampling times except 28 DAI (Table 4.11). Compared to 30:20:20 kg / ha, 60:40:40 kg / ha NPK had lower Fe content at all sampling times except 28 DAI. The use 60:40:40 kg / ha NPK significantly increased soil Fe content by 20 % at 28 DAI, 1.03 % at 42 DAI, 15.1 % at 56 DAI and 27.91 % at 70 DAI. Manure at a rate of 2.5 t produced a higher Fe contents at 7, 28 and 70 DAI compared to 5 t manure but lesser than the control.

Table 4.11. Main effect of mineral fertilizer and manure application on iron

	Fe (mg / kg)				
Fertilizer(kg / ha NPK)	7 DAI	28 DAI	42 DAI	56 DAI	70 DAI
0	26.89	13.70	49.75	16.93	11.52
30:20:20	35.73	11.70	68.20	18.55	16.90
60:40:40	24.63	17.13	50.28	15.93	15.98
F pr (0.05)	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	0.71	0.80	1.25	0.75	1.37
Manure					
0	23.07	18.36	67.63	22.43	16.95
2.5 t	33.29	14.23	47.60	9.50	15.40
5 t	30.88	9.95	53.00	19.48	12.05
F pr (0.05)	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	0.71	0.80	1.25	0.75	1.37
F pr (fertilizer*manure)	<0.001	<0.001	<0.001	<0.001	<0.001
CV (%)	2.5	5.7	2.2	4.4	9.3

Figure 4.13 shows the combined effect of manure and mineral fertilizer on Fe content of the soil after incubation. The combined rates of manure and mineral fertilizer significantly influenced Fe with 30:20:20 kg / ha NPK + 5t manure supplying the highest Fe at 7 DAI. Iron release peaked for all treatments 42 DAI with the highest observed under 30:20:20 kg / ha NPK + 0 t manure. The use of 60:40:40 kg / ha NPK + 0 t manure significantly increased Fe content followed by 30:20:20 kg / ha NPK + 2.5t manure at 70 DAI.

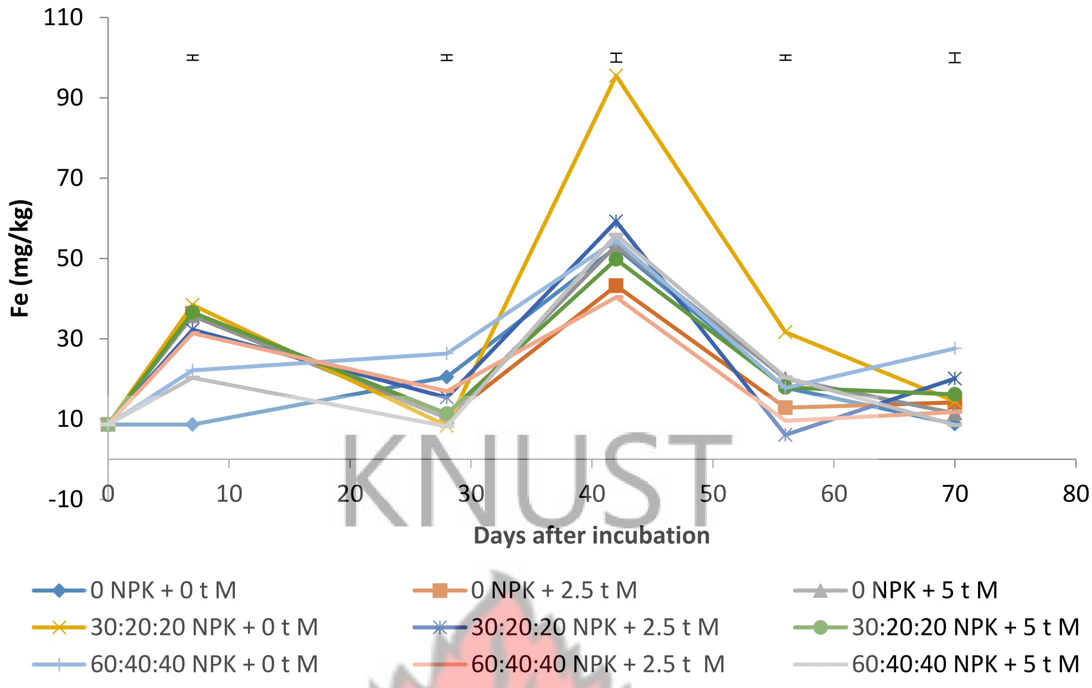


Figure 4.13. Combined effect of manure and mineral fertilizer application on soil Fe content

4.2.5.4 Effect of manure and mineral fertilizer application on Copper

The use of 60:40:40 kg / ha NPK significantly reduced Cu at 7, 42 and 70 DAI compared to the control (Table 4.12). However, the use of 5 t manure significantly increased Cu at 7 and 42 DAI and significantly reduced Cu at 70 DAI compared to the control.

Table 4.12. Main effect of mineral fertilizer and manure application on copper

	Cu (mg/kg)				
Fertilizer (kg / ha NPK)	7 DAI	28 DAI	42 DAI	56 DAI	70 DAI
0	1.33	1.92	1.79	1.21	1.54
30:20:20	1.36	1.84	1.97	1.30	1.28
60:40:40	1.13	1.79	1.72	1.32	1.21
F pr (0.05)	0.003	0.48	0.008	0.11	<0.001
LSD (0.05)	0.13	0.23	0.15	0.19	0.10
Manure					
0	1.03	1.81	1.69	1.29	1.41
2.5 t	1.28	1.89	1.51	1.24	1.36
5 t	1.50	1.85	2.28	1.31	1.25
F pr (0.05)	<0.001	0.79	<0.001	0.42	0.01
LSD (0.05)	0.13	0.23	0.15	0.19	0.10
F pr (fertilizer*manure)	0.018	0.47	0.004	0.01	<0.001
CV (%)	10.3	12.5	8.2	8.4	7.7

From Figure 4.14, the combined application of manure and mineral fertilizer significantly influenced Cu with the highest Cu content observed under 30:20:20 kg / ha NPK + 5 t manure at 7 and 42 DAI whilst the lowest was recoded under 60:40:40 kg / ha NPK + 0 t manure at 7 DAI. The highest copper content was recorded under the application of 30:20:20 kg / ha NPK + 2.5 t manure at 28 and 56 DAI. Copper content from all the combined nutrient inputs peaked at 42 DAI with the highest value observed under 30:20:20 kg / ha NPK + 5 t manure.

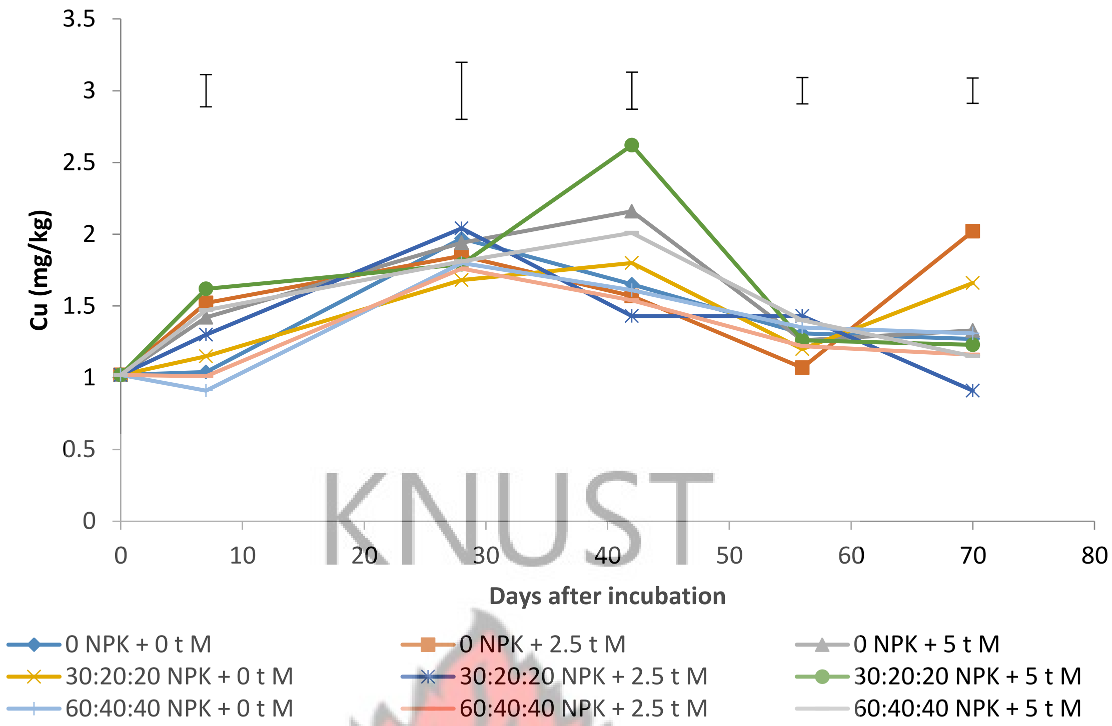


Figure 4.14. Combined effect of manure and mineral fertilizer application on soil Cu content

4.2.5.5 Effect of manure and mineral fertilizer application on Microbial biomass carbon

Increasing NPK rates significantly increased microbial biomass carbon (MBC) at 7, 28 and 56 DAI except for 30:20:20 kg / ha at 7 DAI and significantly decreased MBC at 42 and 70 DAI relative to the control (Table 4.13). The use of 2.5 significantly reduced MBC at 28, 42, 56 and 70 DAI relative to 0 t manure while 5 t manure also reduced MBC at most sampling times except 56 DAI. Peaks of MBC were observed from 5 t manure at 56 DAI and 30: 20: 20 kg / ha NPK at 42 and 56 and declined at 70 DAI for both sole nutrient sources.

Table 4.13. Main effect of mineral fertilizer and manure application on microbial biomass carbon

	Microbial biomass carbon (mg/kg)				
Fertilizer (kg / ha NPK)	7 DAI	28 DAI	42 DAI	56 DAI	70 DAI
0	150	73	1600	1500	730
30:20:20	130	440	1400	900	630
60:40:40	260	730	700	1200	410
F pr (0.05)	>0.001	>0.001	>0.001	>0.001	>0.001
LSD (0.05)	46	200	450	270	200
Manure					
0	190	440	1800	1100	830
2.5 t	240	410	700	970	580
5 t	130	400	1200	1500	370
F pr (0.05)	>0.001	0.92	>0.001	>0.001	>0.001
LSD (0.05)	46	200	450	270	200
F pr (fertilizer*manure)	<0.001	<0.001	<0.001	<0.001	<0.001
CV (%)	24.9	49.6	36.7	23.2	35.6

Increases in MBC under the combined manure and mineral fertilizer application (Fig 4.15) were low from 0 to 28 DAI with 60:40:40 kg / ha NPK + 2.5 t manure giving the highest MBC 28 DAI. Microbial biomass carbon peaked at with at 56 DAI and 42 DAI under the application of 60:40:40 kg / ha NPK + 5 t manure and 30:20:20 kg / ha + 0 t manure respectively. The amount of MBC from all the nutrient management options declined at 70 DAI with the control performing best.

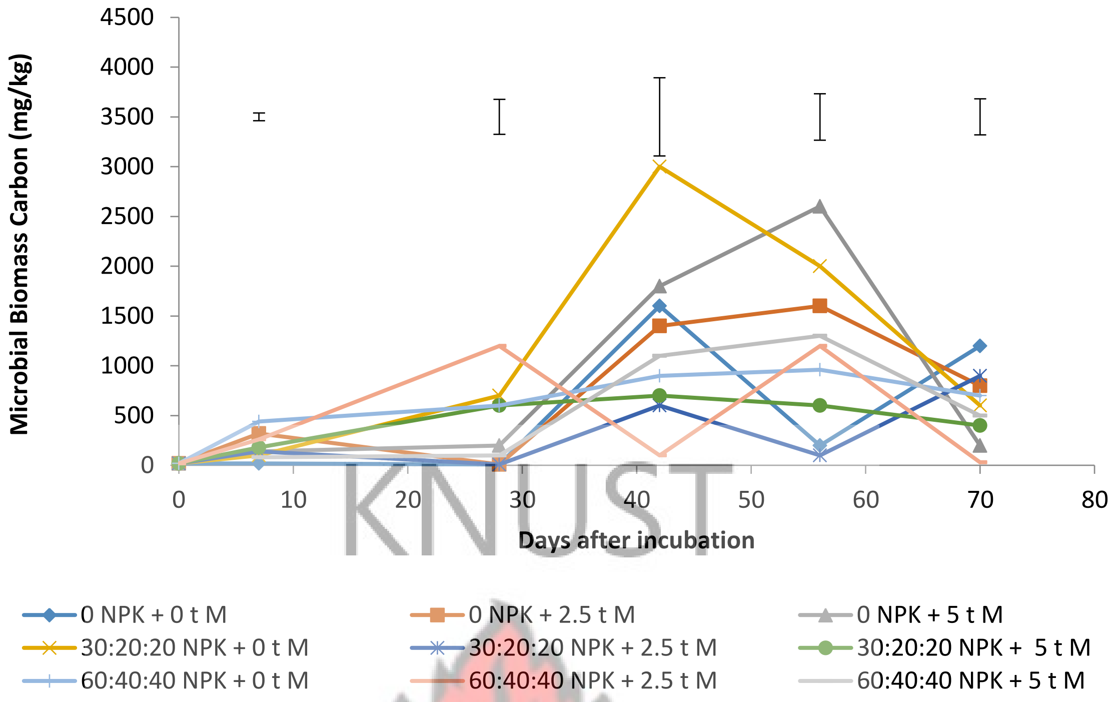


Figure 4.15. Combined effect of manure and mineral fertilizer application on microbial biomass carbon

4.2.5.6 Effect of manure and mineral fertilizer application on urease activity

Urease activity generally declined at each sampling time compared to the preceding one under sole applications of both nutrient sources except for 60: 40: 40 kg / ha NPK and 0 t manure at 42 DAI (Table 4.14). The use of 60:40:40 kg / ha NPK significantly increased urease activity at 7 and 28 DAI relative to the control and reduced urease activity at 56 and 70 DAI compared to the control.

Table 4.14. Main effect of manure and mineral fertilizer application on soil urease activity

	Urease activity (mg NH_4 / kg / hr)				
Fertilizer(kg / ha NPK)	7 DAI	28 DAI	42 DAI	56 DAI	70 DAI
0	25.29	19.93	14.74	7.65	6.19
30:20:20	23.29	21.08	17.25	9.55	8.11
60:40:40	27.97	20.10	27.98	5.03	3.86
F pr (0.05)	<0.001	0.125	<0.001	<0.001	<0.001
LSD (0.05)	0.667	1.205	0.951	0.328	0.107
Manure					
0	22.45	19.26	28.81	6.20	4.85
2.5 t	30.65	20.57	15.08	7.04	6.033
5 t	23.45	21.28	16.08	8.99	7.28
F pr (0.05)	<0.001	0.008	>0.001	>0.001	>0.001
LSD (0.05)	0.667	1.205	0.951	0.328	0.107
F pr (fertilizer*manure)	>0.001	>0.001	>0.001	>0.001	>0.001
CV (%)	2.6	6	4.8	4.5	5.3

The urease activity peaked under 60:40:40 kg / ha NPK at 7 DAI and declined afterwards. The highest urease activity was observed under 2.5 t manure at 7 DAI and the least from the same manure rate at 70 DAI (Table 4.14).

Figure 4.16 shows the combined effect of manure and mineral fertilizer on soil urease activity after incubation. It was observed that urease activity under all the combined nutrient inputs generally declined with time. The combined application of manure and mineral fertilizer significantly increased urease activity with the highest activity observed under 60:40:40 kg / ha NPK + 2.5 t manure 7 DAI whilst the control produced the least. Urease activity increased steadily under 60:40:40 kg / ha NPK at 7 and 28 DAI and peaked at 42 DAI after which it declined.

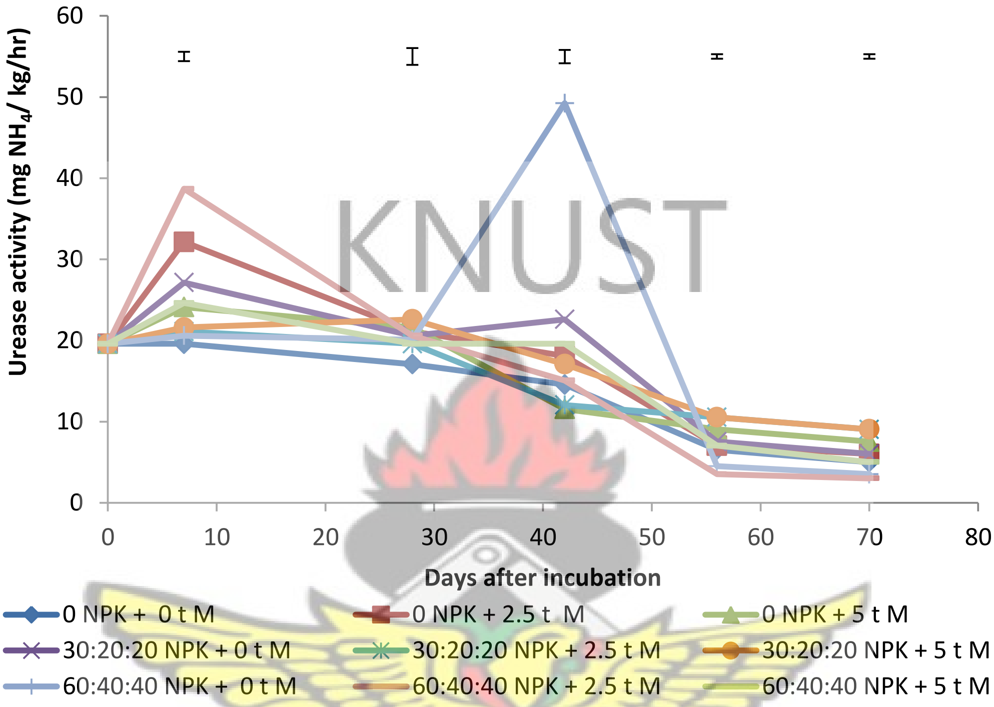


Figure 4.16. Combined effect of manure and mineral fertilizer application on soil urease activity

4.2.6 Principal component analysis of the mechanisms

The principal component (PC) bi - plot (Fig. 4.17) showed that, all the mechanisms (priming effect, general fertility improvement and the improved nutrient synchrony) were closely related and contributed strongly to synergistic effect.

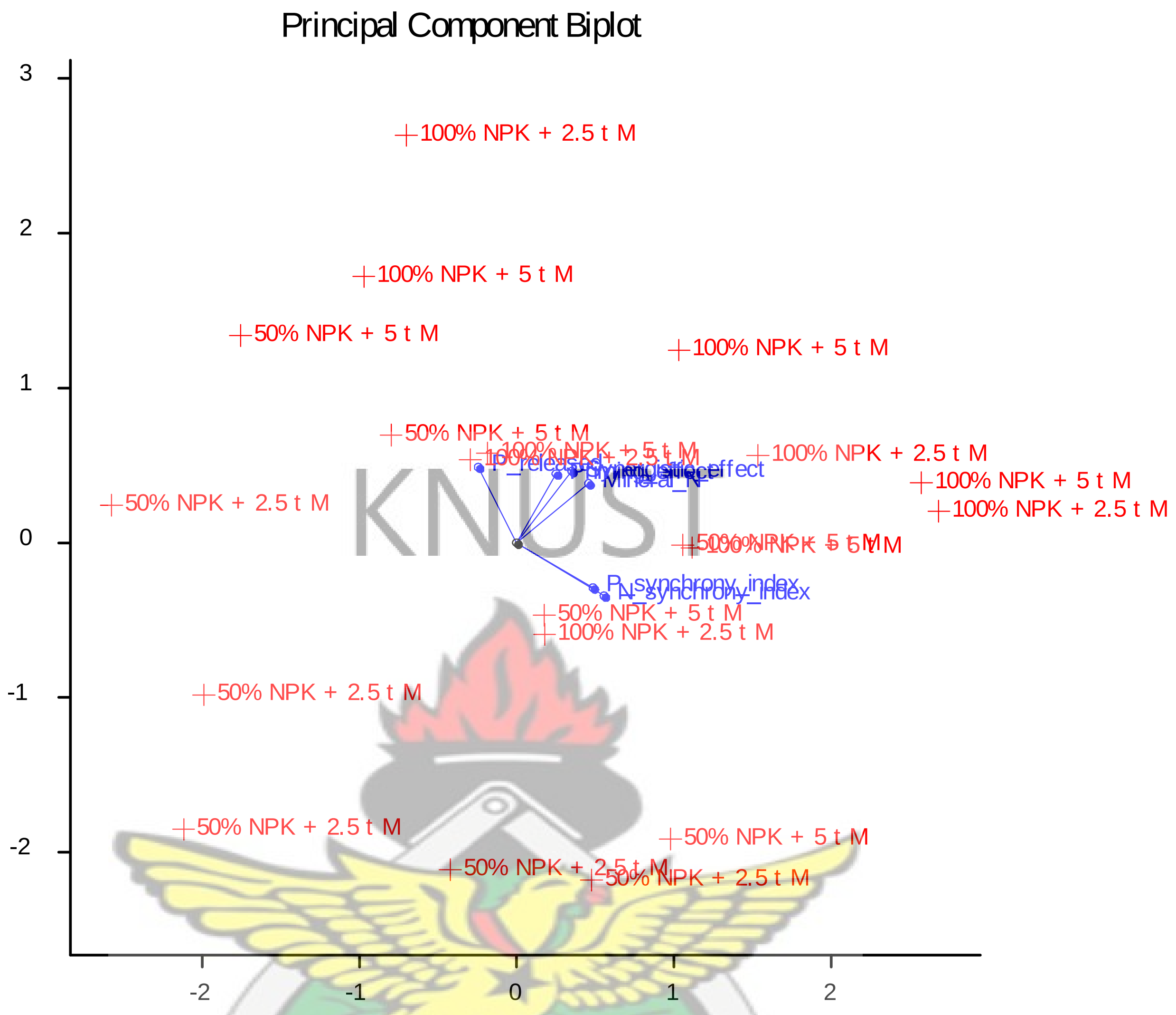


Figure 4.17. Principal component bi - plot showing the relations of the mechanisms to synergy

Five principal components cumulatively explained the variation in interaction between manure and mineral fertilizer as shown in Table 4.15. Principal component one and two explained 69.40 % (more than 50 %) of the variation in interaction. Principal component one (PC1) explained 41.27 % of the variation which was dominated by N synchrony index (from the rotated component matrix table, Table 4.16). Principal component two (Table 4.15) explained about 28.13 % of the variation in the interaction and priming effect dominated this component.

Table 4.15. Principal component table

Measurements	PC1	PC2	PC3	PC4	PC5
Eigen values	2.064	1.406	0.751	0.557	0.222
% Contribution	41.27	28.13	15.02	11.13	4.45
Cumulative percent (%)	41.27	69.40	84.42	95.55	100

Table 4.16. Rotated component matrix

Vectors	1	2	3	4	5
Mineral N	0.318	0.583	-0.219	0.700	-0.144
N synchrony index	0.641	-0.130	-0.017	-0.033	0.755
P released	-0.375	0.499	-0.587	-0.353	0.376
P synchrony index	0.579	0.028	-0.371	-0.509	-0.517
Priming effect	0.110	0.627	0.685	-0.354	0.014

The third component also explained 15.02 % of the variation and priming effect again is the main contributing variable for this component. Mineral N, representing the general fertility improvement mechanism is highly loaded on component four which explains 11.13 % of the variation in the data. Component five explains 4.45 % of the total variation in the data with N synchrony index heavily loaded on it.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Contribution of manure and mineral fertilizer application to maize growth and yield

5.1.1 Effect of manure and mineral fertilizer application on the growth parameters of maize

The increasing mineral fertilizer rates did not significantly affect stem girth 4 WAP (Table 4.2) due to the short moisture stress experienced on the field after fertilizer application (2 WAP) to about 5 WAP (Appendix 7) which led to reduced solubility and transport of mineral nutrients and a decline in photosynthetic activities which could have influenced stem enlargement. This observation agrees with the report of Alam (1999) that water stress causes a decrease in the cytokinin transport from roots to shoots and / or an increase in the amount of leaf abscisic acid which causes changes in the cell wall extensibility, a decline in the concentrations of photosynthetic enzymes and growth of biomass leading to a reduction in the efficiency of key plant processes such as photosynthesis.

The observed increase in stem girth by 6.1 % (Table 4.2) following the application of 5 t manure and 21 % by the application of 2.5 t manure was perhaps due to the maintenance of soil moisture by manure and increase in soil nutrients (Barios *et al.*, 1997).

The application of 30:20:20 kg / ha NPK + 5 t manure (Fig. 4.1) produced the highest stem girth (5.25 cm) probably due to the availability of more nutrients from the two fertilizers for plant development. The observation that 5 t manure recorded stem girth which was statistically similar to the combined applications may be due to the balanced nutrients supplied by the manure and additional enhancement of soil physical properties which affirms the findings of Palm *et al.* (1997) that the use of organic inputs equivalent to 30 kg / ha N provided additional benefits to the soil chemical and physical properties and led to improved nutrient acquisition and plant growth. Stem girth peaked at the 60:40:40 kg / ha NPK at 6 and 8 WAP due to the supply of nitrogen through the second urea dose which met the restart of the rains after the temporal dry spell leading to solubilization and availability of nutrients which affirms the findings of Barber (1995).

At 6 and 8 WAP, when vegetative growth was gradually tapering and giving way for the reproductive phase, 60: 40: 40 kg / ha NPK + 5t manure still had the largest stem girth reflecting a retention of appreciable amount of assimilates in the stem due to high amount of nutrients supplied by the highest combined applications (Fashina *et al*., 2002).

The increasing levels of mineral fertilizer alone did not significantly affect ($P > 0.05$) LAI at 4 WAP (Table 4.3), contrasting the findings of Fashina *et al.* (2002) that the increasing levels of NPK produced more leaf number and a consequent increase in LAI. The observed result could be due to the moisture stress (Appendix 7) at the early part of vegetative growth according to the report by Cakir (2004) that short-term effects of water deficits delay leaf tip emergence and reduce leaf area.

In line with Barrios (1997), 5 t manure recorded the highest LAI at 4, 6 and 8 WAP, followed by 2.5 t manure, confirming the fact that manure does not only supply nutrients but also maintains soil moisture and moderates the effects of a temporal moisture stress. It is not surprising that though sole applications of different levels of NPK did not influence LAI, sole levels of manure did. Soil conditions such as moisture, pH and CEC were made better from organic fertilizer treatments for effective utilization of nutrients which was evident in the LAI of plants receiving manure.

5.1.2 Effect of manure and mineral fertilizer application on the grain yield of maize

The results in Table 4.4 indicated that increasing levels of manure and mineral fertilizer increased grain yield probably due to the supply of more nutrients at each increased rate, which led to a consequent increase in growth and yield (Fashina, 2002). It was noted that the rate of yield increase reduced as inputs increased due to Michellin's Law of less than proportionate effect. The highest grain yield produced under 60: 40: 40 kg / ha NPK + 5 t manure application (Fig. 4.2) may be due to the availability of more nutrients supplied in balanced proportions (Shah and Arif, 2000) from the two nutrient inputs. The fact that the application of 30: 20: 20 kg / ha NPK + 5 t manure produced similar yields to that of 60: 40: 40 kg / ha NPK + 2.5 t manure implied that mineral fertilizer could be reduced and supplemented with manure without sacrificing grain yield. Combined 30: 20: 20 kg / ha NPK + 2.5t manure produced grain yield statistically similar to 60: 40: 40 kg / ha NPK due to the ability of manure to condition the soil for effective utilization of fertilizer nutrients. Sharma and Gupta (1998) reported that the precise application of manure and mineral fertilizer to maize could be as effective as sole mineral N fertilizer for yield response.

5.1.3 Added benefits from combined applications of manure and mineral fertilizer

All the combined nutrient inputs except 30:20:20 kg / ha NPK + 2.5 t manure resulted in synergistic interactions leading to appreciable added benefits in grain yield (Fig. 4.4) with 60: 40: 40 kg / ha NPK + 5 t manure producing the highest. This confirms the findings by Vanlauwe *et al.* (2001b). Considering the high rate of manure applied in the 60: 40: 40 kg / ha NPK + 5 t manure treatment and its high quality, manure might have supplied high micronutrient levels to balance the full dose of macronutrients supplied through mineral fertilizer, reducing nutrient deficiency to plants(Vanlauwe *et al.*, 2001b). Giller (2002) reported that a synergistic interaction between organic and inorganic resources could be the result of priming effect on soil nutrients caused by an enhancement in soil microbial and enzyme activities.

An added disadvantage of 44 kg / ha was observed from 30: 20: 20 kg / ha NPK + 2.5 t manure. This observation could not be aligned with the reports of Vanlauwe *et al.* (2001a) and Mucheru *et al.* (2002) since the manure used in this study was of a high quality (N % = 2.75, Table 3.3) according to the ratings of Bationo *et al.* (2007) and there was enough rain at grain filling. This finding could therefore be attributed to the low nutrients supplied through the lower rates of the NPK and manure in 50 % NPK + 2.5 t manure.

5.1.4 Returns on investment from manure and mineral fertilizer application

The highest VCR (2.0) obtained from combined application of 60: 40: 40 kg / ha NPK + 5 t manure and 30: 20: 20 kg / ha NPK + 5 t manure (Fig. 4.5) implied that they were economically viable with respect to the threshold of 2 set by FAO (2005). Resource poor farmers could therefore reduce mineral fertilizer by at most 50 % and supplement with available high quality manure without compromising grain yield.

5.1.5 Effect of mineral fertilizer and manure applications on soil nutrient stock

The decrease in N stock after harvest in relation to the initial N stock (Fig. 4.6.a) from 60: 40: 40 kg / ha NPK plots could be due to rapid N losses through volatilization and leaching since there was no manure to improve CEC and hold mineral fertilizer N at exchangeable sites (Vanlauwe *et al.*, 2001b). The use of 2.5 t and 5 t manure alone supplied low N levels which led to further depletion of inherent soil N by plants and the consequent low N stock after harvest. The statistically similar grain yields obtained from 30: 20: 20 kg / ha NPK + 5 t manure and 60: 40: 40 kg / ha NPK + 2.5 t manure is an indication that the plants might have utilized all the supplied nitrogen from 30: 20: 20 kg / ha NPK + 5 t manure and also utilized some of the inherent soil N to make statistically similar yields as 60: 40: 40 kg / ha NPK + 2.5 t manure , which led to the decline in N on plots receiving 30: 20: 20 kg / ha NPK + 5 t manure. It is not surprising that 60: 40: 40 kg / ha NPK + 2.5 t manure maintained the initial soil N stock. The soil N pool increase by 60: 40: 40 kg / ha NPK + 5 t manure could be due to the high N applied through the highest levels of the two nutrient sources. O'Leary *et al*. (2002) reported that when N inputs to the soil system exceed crop needs, there is a possibility that excessive amounts of nitrate (NO_3^-) may enter the ground. The added disadvantage in yield observed under the application of 30:20:20 kg / ha NPK + 2.5 t manure could be due to the high N stock left in the soil by this treatment after harvest which implies that the nitrogen was under - utilized by the plants.

All the treatments except 30: 20: 20 kg / ha NPK + 2.5 t manure and 30: 20: 20 kg / ha NPK + 5 t manure reduced the soil P level (Figure 4.6.b) below the initial soil P (19.94 kg / ha) probably due to P fixation by Fe^{2+} and Al^{3+} (Lallgee, 2003) since the use of 30:20:20 kg / ha NPK + 2.5 t manure reduced the pH at 7, 28 and 56 DAI below the initial 6.44 (Fig. 4.11) and the application of also reduced pH at 56 and 70 DAI below the initial 6.44 bringing more Al^{2+} and Fe^{2+} into solution. Lallgee (2003) reported of a significant relationship (r = 0.78) between pH and P - fixation. The high P stock in soil treated with 30: 20: 20 kg / ha NPK + 2.5 t manure after harvest implied that P was under - utilized by the plants and could explain the high N stock left by the same nutrient inputs, since P is a component of plant ATP, a source of energy for the plant's nutrient uptake (Quansah, 2010). It could also be related to the low yield (added disadvantage of -44 kg / ha, Figure 4.4) observed under the application of 30: 20: 20 kg / ha + 2.5 t manure in support of the reports of Hue (1995) that, inadequate P uptake by plants will result in a decreased synthesis of RNA, the protein maker, leading to depressed growth and yield.

Soil K levels from all the treated plots decreased below the initial soil K (197.3 kg / ha) level after harvest (Fig. 4.6.c). The high level of exchangeable K (0.85 cmol / kg) from the initial soil analysis (Table 3.2) and the application of murate of potash, might have triggered luxury consumption of K by plants leading to reduced soil K stock after harvest. More so, from the initial soil analysis, Ca^{2+} concentration was low (1.6 cmol / kg), while the concentration of Mg was moderate (0.58 cmol / kg) which could have led to increased K uptake by plants as asserted Havlin *et al.* (1999).

5.2 Mechanisms for interactive effects from combined manure and mineral fertilizer

5.2.1 Improved N and P release - crop demand synchrony

The steady decline in mineralized N from 28 DAI by increasing mineral fertilizer except 30: 20:20 kg / ha NPK at 56 DAI (Table 4.5) could be due to the susceptibility of ammonium to volatilization loses because the first N product formed from the application of an ammoniacal fertilizer like urea (O'Leary *et al.*, 2002). More energy was supplied to soil microbes by 5 t manure to release more N (Vanlauwe *et al.*, 2001a) compared to 2.5 t manure leading to the significantly high N from the former than the latter. Considering the high quality of the manure (Bationo *et al.*, 2007), N release should have been high at the initial stages of the incubation (7 to 28 DAI) but a decline in N release was observed from most of the nutrient inputs at the initial stages of incubation. The cropping history of the study site indicated that manure had never been applied; consequently, a low microbial population (MBC > 20 mg / kg) acted on the applied nutrients and released low rates of N. In a related study, Jangid *et al*. (2008) observed that microbial diversity in terms of species richness and evenness was higher in soils amended with poultry litter than inorganic fertilizer. The introduced substrate (manure) caused microbial numbers to increase leading to the rise in N mineralization in the course of the incubation study. Should the improved nutrient synchrony mechanism be at play, combined applications must have met N demand at the critical N demand stages of the crop in question (Vanlauwe *et al*., 2001 a). The International Fertilizer Industry Association (1992) reported that the critical nutrient demand stages of maize growth are the tasselling (49.5 kg / ha N) and grain filling (32.3 kg / ha N) stages. All the combined nutrient inputs (Fig. 4.7) except 30:20:20 kg / ha NPK + 2.5 t manure synchronized crop nitrogen demand and supply at the tasselling stage (35 to 42 DAI). The use of 30:20:20 kg / ha NPK + 2.5 t manure could not supply enough N for this critical stage due to the low amount of N supplied by this combination, hence the observed added disadvantage of 44 kg / ha in grain yield. A deficiency in N and P supply at the tasselling stage leads to poor seed set and a consequent reduced yield (IFA, 1992).

At the initial stages of grain filling (from 42 DAI), all the combined nutrient inputs released N above the grain filling N demand but according to the order of supplied nutrients rates, hence the higher the supplied rate, the higher the amount of N released as stated by Fashina *et al*. (2002).

At the stage in incubation representing the end of the grain filling stage on the field (56 to 70 DAI), only 60:40:40 kg / ha NPK + 5 t manure and 60:40:40 kg / ha NPK + 2.5 t manure met the grain filling N demand, hence the higher yields observed from these treatments. The calculated NSI (Table 4.7) showed that 60:40:40 kg / ha NPK + 2.5 t manure best synchronized crop nitrogen demand and release by supplying 70 % (NSI = 7) of the maize nitrogen requirements cumulatively at various incubation sampling times followed by 68 % (NSI = 6.8) from 60:40:40 kg / ha NPK + 5 t manure, hence the high grain yields of 4627 kg / ha observed under 60:40:40 kg / ha NPK + 5 t manure and 4027 kg / ha observed from 60:40:40 kg / ha NPK + 2.5 t manure on the field.

The high P supply from mineral fertilizer (Table 4.6) was due to the fast release of nutrients from mineral fertilizer (IFPRI, 2002) compared to the slow nutrient release from manure (Suge *et al.*, 2011). Phosphorus release from manure was slow and peaked at 70 DAI when microbial decomposition and mineralization had reached optimum rates and some of the microbes had lysed to release their immobilized P (Lazcano *et al.*, 2012). The rise in P after 56 days of incubation could be due to the increase in release after soil microbes had taken their required P and some of them had lysed to release immobilized nutrients (Lazcano *et al.*, 2012). Phosphorus release was generally slow (except with 60: 40: 40 kg / ha NPK + 2.5 t manure) at the initial stages of incubation for all combined nutrient inputs (Fig. 4.8) due to low microbial population (> 20 mg / kg MBC) and activity of the site as a result of the omission of organic resource application from previous land use (Jangid *et al.*, 2008). The PSI values (Table 4.8) indicated that, all the nutrient inputs met the full P requirement at 7 DAI but this was only maintained by 60:40:40 kg / ha NPK + 2.5 t manure at 28 DAI. Only 10 % or less of the required P was supplied by all the nutrient management options at 42, 56 and 70 DAI. In essence, P mineralization only followed slightly the improved nutrient synchrony mechanism by Vanlauwe *et al.* (2001a) since treatments only met the P demand at 7 DAI and supplied less than 50 % of the maize P requirement cumulatively for the incubation period.

5.2.2 Priming of soil N and OC

The application of 60:40:40 kg / ha NPK + 5 t manure (Fig. 4.9) provided sufficient organic substrate for microbial activity leading to high N mineralization and the consequent positive priming effect of 41.77, 20.56, 26.16 and 22.49 mg / kg at 7, 28, 42 and 56 DAI respectively. This observation supports the report of Hejnak *et al*. (1996) that the size of the priming effects increases with the amount of the added organic substances. The observed positive priming effect could also be ascribed to the ammonium released from the 100 % ammoniacal fertilizer (urea) applied through 60:40:40 kg / ha NPK + 5 t manure, coupled with the ammonia from bacteria decomposition of the manure (O'Leary *et al*., 2002), as Stout (1995) also reported that ammonia causes more priming effects than nitrate. With the substantial amount of organic C supplied through the 2.5 t manure, the relatively lower nutrients supplied through the 50 % NPK in 30: 20: 20 kg / ha + 2.5 t manure treatment was immobilized throughout the incubation period explaining the negative priming effect of -7.78, -10.68, -44.46 and -5.93 mg /kg observed at 7, 28, 42 and 56 DAI respectively by this treatment. The positive priming of OC (0.14 % at 7 DAI, 0.049 % at 28 DAI, 0.21 % at 42 DAI, 0.01 % at 56 DAI and 0.31 % at 70 DAI) observed throughout the incubation from 60: 40: 40 kg / ha NPK + 2.5 t manure (Fig. 4.10) and the positive priming effect from 60: 40: 40 kg / ha NPK + 5 t manure (0.08 % at 7 DAI, 0.138 % at 28 DAI, 0.18 % at 56 DAI) may be due to the supply of C from the manure as asserted by Sanchez (2002). The full dose of manure supplied through the use of 30: 20: 20 kg / ha NPK + 5 t manure led to the observed positive priming effects on OC at 28 and 56 DAI. The negative priming effect observed from 30:20:20 kg / ha NPK+ 2.5 t manure could be due to the use of OC by microbes to meet their energy needs (Kuzyakov *et al*., 2000) which probably contributed to the added disadvantage in grain yield observed on the field.

5.2.3 General fertility improvement mechanism

5.2.3.1 Effect of manure and mineral fertilizer on the chemical properties of the soil

The relatively lower soil pH from 60:40:40 kg / ha NPK at 7, 28, 42 and 70 DAI and 30:20:20 kg / ha NPK at 28 and 42 DAI (Table 4.9) could be attributed to nitrification of the ammonia (from urea) (O'Leary *et al*., 2002) which had acidic effect on the soil. The increase in soil pH with manure could be attributed to the reduction of exchangeable Al as a result of Al precipitation or chelation of organic colloids (Hue, 1992) in the soil which was previously acidic (pH = 5.75, Table 3.2). It could also be attributed to high levels of exchangeable bases (K, Mg and Ca) which were confirmed by the high soil K levels from all the nutrient inputs after harvest. The observed increase in soil pH with manure was in line with the reports of Bayu *et al*. (2005) and Mugendi *et al*. (2010). The highest pH observed from 30: 20: 20 kg / ha NPK + 5 t manure at 7 DAI (Fig. 4.11) could be due to the effect of manure which increased soil pH by reducing exchangeable Al as a result of Al precipitation or chelation of organic colloids (Hue, 1992) in the soil. This suggests that organic manure could be used to alleviate soil acidification to some extent.

The significant increase in SOC from the use of 5 t manure (Table 4.10) could be due to the supply of carbon by the organic resource which was absent in mineral fertilizer. Vanlauwe and Giller (2006) reported that organic resources contain C, which drives all microbial and faunal activities. The lack of response of SOC to mineral fertilizer use (Table 4.10) at 28, 42 and 70 DAI could be due to the fact that mineral fertilizer could only increase SOC indirectly after it had aided the development of more plant biomass (Sleutel *et al*., 2006), which was not so in this case because no crops were planted in the incubation. Soil microbes had to break down less of the full mineral fertilizer dose since it was reduced by 50 %, implying less energy use (Demoling *et al*., 2007), hence the more organic C retained by the application of 30: 20: 20 kg / ha NPK + 5t manure (Fig. 4.12). It also explains the synergistic interaction observed from this combined nutrient input on the field.

The increase in Fe from the sole 30: 20: 20 kg / ha NPK (Table 4.11) at most sampling times (except 28 DAI) could be associated with the reduced pH (at 42 and 56 DAI, Table 4.9) from the mineral fertilizer use compared with the control. Low pH has been reported to solubilize and make available more micronutrients into soil solution (Ayeni *et al*., 2010). The high Fe content observed under 2.5 and 5 t manure at most of the sampling times (Table 4.11) is an indication that manure had a balanced supply of both macro and micronutrients, and affirmed the observation of Adeniyan and Ojeniyi (2006) that Fe content of the soil increased with the application of poultry manure. The micronutrient supply from the manure could have been the reason for high Fe content from 30: 20: 20 kg / ha NPK + 5 t manure (Fig. 4.13) at 7 DAI and 30: 20: 20 kg / ha NPK + 2.5 t manure at 70 DAI.

The use of 5 t manure increased Cu content in this study (Table 4.12), similar to the increases in Cu by 5 and 10 t poultry manure due to the high micronutrient content of manure as reported by Ayeni *et al*. (2010).The highest Cu content observed from 30:20:20 kg / ha NPK + 5 t manure at 42 DAI and 30:20:20 kg / ha NPK + 2.5t manure at 28 and 56 DAI (Fig. 4.14) suggested the supply of micronutrients by manure. Similar effect was observed for Fe from both individual nutrient inputs.

5.2.3.2 Effect of manure and mineral fertilizer application on the biological properties of the soil

The high MBC from most mineral fertilizer inputs compared to the low rates from manure (Table 4.13) could be due to the fact that nutrients released from mineral fertilizer and from manure which were tapped by microbes for their activities are the same as asserted by Sanchez *et al.* (2002). The decrease in MBC with the application of 2.5 and 5 t manure (Appendix 5) deviates from the reports of O'Leary *et al.* (2002); Monaco *et al*. (2008); Lin *et al*. (2010), probably due to the heat of decomposition of the manure which raised soil temperature and affected microbial proliferation (Xu *et al*. 2008). Deslippe *et al*. (2012) and Yergeau *et al*. (2012) reported that a small amount of warming in the soil could have large effects on microbial community structure. The decline in MBC from both nutrient sources at 70 DAI could be due to the exhaustion in nutrient supply to microbes after the peak at 42 and 56 DAI when protective capacity had been reached (Xu *et al*., 2008). The suppressing effect of manure on microbial biomass (Xu *et al*. 2008) was also observed from the combined application of 60: 40: 40 kg / ha NPK + 2.5 t manure at 28 DAI. At 56 DAI enough nutrients were still being supplied by 60: 40: 40 kg / ha NPK + 5 t manure to soil microbes leading to increase in microbial numbers and the consequent highest MBC. The significant effect of manure on urease activity throughout the incubation period could be due to the ammonification of amines in the manure into ammonium which serves as substrate to soil urease (Mobley and Hausinger, 1989; O'Leary *et al*., 2002). The decline in urease activity at each succeeding sampling time for both nutrient sources (Table 4.14) could be due to the decline in NH_4^+ supply (Appendix 4) to microbes as nitrification continued (Xu *et al*., 2008). The increase in soil urease activity associated with the decrease in MBC (Appendix 6) suggested that the release of the enzymes was linked to the lysis of microbial cells at the end of their life cycle as reported by Perucci (1990).The observance of high urease activity from the use of 2.5 t and 5 t manure application and their combination with 60: 40: 40 kg / ha NPK (Fig. 4.16) with N supplied as urea explains the highest urease activity from 60: 40: 40 kg / ha NPK + 2.5 t manure , 7 DAI. Urease activity increases when urea is present, since the urease enzyme is responsible for the hydrolysis of urea fertilizer applied to the soil into NH_3 and CO_2 (Andrews *et al.*, 1989; Byrnes and Amberger, 1989).

5.3 Relative contribution of the key mechanisms to added benefits

The findings from the PCA (Tables 4.15 and 4.16) showed that the mechanism contributing most to synergistic interaction between manure and mineral fertilizer is improved nitrogen synchrony which dominated PC1 (41.27 %) and PC5 (4.45 %). The next most contributing mechanism was priming effect which dominated PC2 (28.13 %) and PC3 (15.02 %). The least contributing mechanism to synergy was the general fertility improvement mechanism which was represented with N and P release and dominated PC4 (11.13 %).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Results from the field experiment showed that 60:40:40 kg / ha NPK + 5 t manure influenced the largest stem girth at all sampling times which implied the accumulation of more assimilates for crop yield. The application of 60:40:40 kg / ha NPK + 5 t manure produced the highest maize grain yield, in line with the treatment's ability to influence the highest growth rate.

Synergistic interactions were observed from the application of 60:40:40 kg / ha NPK + 5 t manure, 60:40:40 kg / ha NPK + 2.5 t manure and 30:20:20 kg / ha NPK + 5t manure with the greatest added benefit in grain yield (1371 kg / ha) from 60:40:40 kg / ha NPK + 5 t manure while the use of 30:20:20 kg / ha NPK + 2.5 t manure resulted in antagonistic interactions with and added disadvantage of 44 kg / ha grain yield.

Soil N increased by 66 % under 60:40:40 kg / ha NPK + 5 t manure application and 33% under while 30:20:20 kg / ha NPK + 2.5 t manure application after harvest. The use of 30:20:20 kg / ha NPK + 2.5 t manure increased soil P by 3.71 % above the mean initial soil P after harvest while 30:20:20 kg / ha NPK + 5 t increased soil P by 0.60 % but none of the combined treatments increased soil K.

The applications of 30:20:20 kg / ha NPK + 5 t manure and 60:40:40 kg / ha NPK + 2.5 t manure were the most economically viable treatments (VCR = 2) in terms of costs of applied nutrient sources, transport and labour and benefits obtained from the treatment.

The laboratory incubation study demonstrated that improved nutrient synchrony, priming and general fertility improvement mechanisms contributed partly to synergistic effect between organic and inorganic nutrient sources with improved nutrient synchrony mechanism contributing most, followed by priming effects and general fertility improvement in that order.

6.2 Recommendation

It could be recommended that resource poor farmers may reduce full mineral fertilizer doses by 50 % and supplement it with available organic resources without compromising grain yield and returns on investment.

The timing of fertilizer application should be critically considered for effective nutrient synchrony since it is the most contributing mechanism

In further studies, this work should be repeated at different locations and under different agro-ecological zones to confirm results.

REFERENCES

Adeniyan, O. N. and Ojeniyi, S. O. (2006). Comparative effectiveness of different levels of poultry manure with NPK fertilizer on soil fertility, nutrient uptake and uptake of maize. Moor Journal of Agricultural Research. 4, 194-197 7.

Alam, S. M. (1999). Nutrient Uptake by Plants Under Stress Conditions. Nuclear Institute of Agriculture Tando Jam, Sindh, Pakistan

Anderson, J. M. and Ingram, J. S. I. (Eds.), (1993). Tropical Soil Biology and Fertility: a Handbook of Methods. CAB International, Wallingford, UK.

Andrews R. K, Blakeley R. L. and Zerner B., (1989). Urease: A Ni (II) metalloenzyme. In The Bioinorganic Chemistry of Nickel, ed. J. R. Lancaster, pp. 141-166. VCH Publishers, New York.

Arancon, N. Q., Edwards, C. A. and Bierman, P. (2006). Influences of vermicomposts on field strawberries: Part 2. Effects on soil microbiological and chemical properties. Bioresour Technology 97:831–840

Asghar, A., Ali, A., Syed, W. H. Asif, M, Khaliq, T and Abid, A. A. (2010). Growth and yield of maize cultivars affected by NPK applications in different proportion. Pakistan Journal of Sciences. 62 (4): 211 to 216.

Aune, J. B. and Lal, R. (1997). Agricultural productivity in the tropics and critical limits of properties of Oxisols, Ultisols and Alfisols. Tropical Agriculture 74 : 96–103

Ayeni, L .S. and Adetunji, M.T., (2010). Integrated Application of Poultry Manure and Mineral Fertilizer on Soil Chemical Properties, Nutrient Uptake, Yield and growth components of maize. University of Agriculture, Department of Soil Science and land management, Abeokuta. Nature and Science. Vol. 8(1)

Ayub, M., Nadeem, M. A. Sharar M. S. and Mahmood, N. (2002). Response of maize (*Zea mays* L.) fodder to different levels of nitrogen and phosphorus. Asian J. Pl. Sci. 1: 352 -354

Babatola, L. A., Adebayo, O. B. and Lawal, O. I. (2002). Effects of different rates of poultry manure and NPK on performance of *Celosia argentia*. Proceeding of Horticultural Society of Nigeria, Ibadan. 14-19, May 2002: pp. 54-56.

Barber, S. A. (1995). Soil nutrient bioavailability- a mechanistic approach.2nd edition, New York: John Wiley and Sons, Inc.

Barios, E., Kwesiga, F., Buresh, R. J. and Sprent, J. I. (1997). Light fraction soil organic matter and available nitrogen following trees and maize. Soil science society of America journal 61: 826- 831

Bationo, A. and Mokwunye, A. U. (1991). Role of manures and crop reissued in alleviating soil fertility constraints to crop production with special reference to Sahelian zones of West Africa. Fertilizer Research 29: 125–177.

Bationo, A., Kihara, J. Vanlauwe, B., Waswa, B. and Kimetu, J. (2006). Soiul organic carbon dynamics, functions and management in West Africa agro-ecosystems. Science direct. Agricultural systems

Bationo, A., Waswa, B., Okeyo, M. J., Maina, F., Kihara, J. (2007). Innovations as Key to the green revolution in Africa. Vol. 1. Exploring the scientific facts. pp 123-133

Bayu, W., Rethman, N. F. G. and Hammes, P. S. (2005). The role of manure in sustainable soil fertility manage-ment in sub-Saharan Africa. Journal of Sustainable Agriculture, 25, 113-136. doi:10.1300/J064v25n0209

Belfield, S. and Brown, C. (2008). Field Crop Manual: Maize A Guide to Upland Production in Cambodia. NSW Department of primary Industries.

Bird J. A., Van Kessel C., Horwath W. R. (2002). Nitrogen dynamics in humic fractions under alternative straw management in temperate rice. Soil Science Society of America Journal,66: 478–488

Black, C. A.(ed) (1965): Method of Soil Analysis Agronomy. N0.9 Part 2 Amer.Soc Agronomy, Madison, Wisconsin

Black, C. A. (1986) (Ed). Methods of soil analysis. Part I. Physical and meteorological properties including statistics of measurement and sampling. Part II. Chemical and microbiological properties. Agronomy series A.S.A. Madison. WIS. USA.

Blanco, H. (2010). Implications of crop residue harvest on soil organic pool and greenhouse gas emmissions. Department of Agronomy and Horticulture, University of Nabraska. Lincoln.

Boateng, S. A., Zickermann, J. and Kornahrens, M. (2006). Poultry Manure Effect on Growth and Yield of Maize. West Africa Journal of Applied Ecology (WAJAE) –ISSN: 0855-4307

Boateng, S. A., Kornahrens, M. and Zickermann, J. (2007). Nitrogen use efficiency of poultry manure by maize. Journal of Science and Technology, Ghana. Vol. 27. No. 2.

Bray, R. H and Kurtz, L. T. (1945). Determination of total organic and available forms of phosphorus in soils. Soil Sci. 59:39-45. jillinois Agricultural Experiment Station, Urbana, ILl

Byrnes B. H and Amberger A., (1989). Fate of broadcast urea in a flooded soil when treated with N-(n-butyl)thiophospheric triamide, a urease inhibitor. Fertil. Res. 18: 221-231.

Cakir, R. (2004). Effect of water stress at different development stages on vegetative and reproductive growth of corn. Field Crops Research 89 (2004) 1–16

Chang, E. H. Chong, R. S. and Tsai, Y. H. (2007). Effect of different application rates of organic fertilizer on soil enzyme activity and microbial population. Soil Sci. Plant Nutr. 53:132-140.

Chivenge P, Vanlauwe, B. and Six, J. (2011). Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis Plant Soil, Springer 342:1–30.

Dalenberg, J. W. and Jager, G. (1989). Priming effect of some organic additions to ^{14}C-labeled soil. Soil Biology & Biochemistry 21, 443-448.

Deenik, J. (2005). Basic concepts in soil fertility workshop. Department of tropical plant and soil sciences.

Demoling, F., Figueroa, D. and Bååth, E. (2007). Comparison of factors limiting bacterial growth in different soils. Soil Biol Biochem 39:2485–2495

Department for International Development, (DFID).(2004). Agriculture and Natural Resource Team of United Kingdom.

Deslippe, J. R., Hartmann, M., Simard, S. W. and Mohn, W. W. (2012). Long-term warming alters the composition of arctic soil microbial communities. FEMS Microbiol. Ecol. 2012, 82, 303-315.

Dinesh, R., Srinivasan, V., Hamza, S. and Manjusha, A. (2010). Short-term incorporation of organic manures and biofertilizer influences on the biochemical and microbial characteristics of soils under an annual crop [Turmeric (Curcuma longa L.)]. Bioresour Technology 101:4697–4702

Emerson, W. W. (1995). Water retention, organic carbon and soil texture. Australian Journal of Soil Research 33 : 241–251

Farhad, W., Saleem, M. F., Cheema, M. A. and Hammad, H. M. (2009). Effect of poultry manure levels on the productivity of spring maize (Zea mays L.). The Journal of Animal & Plant Sciences 19(3): 2009, Pages:122-125 ISSN: 1018-7081122

Fashina, A. S., Olatunji, K. A. and Alasiri, K. O. (2002). Effects of different plant population and poultry manure on yield of Ugu (Telfairia occidentalis) in Lagos State, Nigeria in Proceedings of the annual Conference of Horticultural Society of Nigeria (HORTON), pp. 123-127.

Fontaine, S., Mariotti, A. and Abbadie, L. (2003). The priming effect of Organic matter: a question of microbial competition. Vol. 35, Issue 6, pp 837-843.

Food and Agriculture Organization (2005). Fertilizer use by crops in Ghana. Land and Plant Nutrition Management Service. Land and Water Development Division.

Food and Agriculture Organization (FAO) of the United Nations, Rome (2006). Plant nutrition for food security. A guide for integrated nutrient management. Fertilizer and plant nutrition bulletin 16

Food and Agriculture Organization. (2008). Guide to laboratory establishment for plant nutrient analysis. Fertilizer and plant nutrition bulletin 19.

Garcia-Gil, J. C., Plaza, C., Soler-Rovira, P. and Polo, A. (2000). Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. Soil Biol. Biochem. 32,1907-1913.

Gerken, A., Suglo, J. V., Braun, M., (2001). Pesticide policy in Ghana. MoFA/PPRSD, ICP Project, Pesticide Policy Project/GTZ. Accra, Ghana.

Gianfreda, A. L. and Ruggiero, P. (2006). Enzyme activities in soil. W.P. Nannipieri, K. Smalla (ed.): Soil biology. Nucleic acids and proteins in soil. Springer-Verlang ;8:257-311

Gilani, S. S. and Bahmanyar, M. A. (2008). Impact of organic amendments with and without mineral fertilisers on soil microbial respiration. Journal of Applied Science. 8: 642-647.

Giller, K. E. (2002). Targetting management of organic resources and mineral fertilizes: Can we match scientists fantasies with farmers' realities? In: Vanlauwe B., Sanginga, N., Diels, J. and Merckx, R. (eds). Balanced Nutrient Management Systems for the moist savannah and humid forest zones of Africa. CAB International, Wallingford, U.K. pp 155-177

Gil-Sotres, F. Trasar-Cepeda, M. C. Ciardi, C. Ceccanti, B., Lerós, M. C. and Seoane, S. (2005). Different approaches to evaluating soil quality using biochemical properties. Soil Biol Biochem. 37: 877-887.

Griffths, B. S. (1994). Soil nutrient flow. In: Darbyshire, J.F. (Ed.), Soil Protozoa. CAB International, Wallingford, pp. 65-92.

Havlin, J. L., Beaton, J. D., Tisdale, S. L. and Nelson, W. L. (1999). Soil fertility and fertilizers: An introduction to nutrient management (6th edition). Upper Saddle River, Printice-Hall. pp. 1-94

Hejnak, V. Jefimov, V. N. and Osipov, A. I. (1996). The use of fertilizer and soil Nitrogen by Spring Barley. Rostlina Vyroba 42, 67-72.

Hoffman, U. (2011). Assuring Food Security in Developing Countries under the Challenges of Climate Change: Key Trade and Development Issues of a Fundamental Transformation of Agriculture. pp. 1

Hue N. V. (1995). Sewage Sludge. In: Rechcigl, J. E. (ed) Soil amendment and environmental quality. Lewis Publ., Boca Raton. FL. P. 193 – 239.

Hue, N. V. (1992). Correcting soil acidity of a highly weathered ultisol with chicken manure and sewage sludge. Communications in Soil Science and Plant Analysis, 23, 241-264. doi:10.1080/00103629209368586

Hyvonen, R., Persson, T., Andersson, S., Olsson, B. and Agren, G. I. (2008). Impact of long-term nitrogen addition on carbon stocks in trees and soils in northern Europe. Biogeochemistry 89: 121–137.

International Fertilizer Industry Association (IFA). (1992). Nutrient management guidelines for some major field crops. pp 241

International Food Policy Research Institute, (IFPRI). (2002). Sustainable options for ending hunger and poverty. Green Revolution: Blessing or curse. Washington DC. USA

Jangid, K., Williams, M. A., Franzluebbers, A. J., Sanderlin, J. S., Reeves, J. H., Jenkins, M. B., Endale, D. M., Coleman, D. C., & Whitman, W. B. (2008). Relative impacts of land-use, management intensity and fertilization upon soil microbial community structure in agricultural systems. Soil Biology & Biochemistry, 40, 2843- 2853.

Jenkinson, D. S., Fox, R. H. and Rayner, J. H. (2006). Interactions between fertilizer nitrogen and soil nitrogen—the so-called 'priming' effect. Journal of Soil science. Vol. 36. Issue 3.

Jenkinson, D. S., Fox, R. H. and Rayner, J. H., (1985). Interactions between fertilizer nitrogen and soil nitrogen, the so-called `priming' effect. Journal of Soil Science 36, 425- 444.

Jones, C. A. Koenig, R. T. Ellsworth, J. W, Brown, B. D. and Jackson, G. D. (2007). Management of urea fertilizer to minimize volatilization. Washington state university extension.

Kapkiyai, J. J., Karanja, N. K., Woomer, P. L and Qureshi, J. N. (1998). Soil organic carbon fractions in a long term experiment and the potential for their use as a diagnostic assays in highland farming's of central Kenya. African Crop Science Journal, 6, 19-28.

Kelley, K. R. and Stevenson, F. J. (1996). Organic forms of N in soil.Piccolo A, editor. Humic substances in terrestrial ecosystem. Amsterdam (Netherlands): Elsevier. p. 407–427

Kogbe, J. O. S. and Adediran, J. A. (2003). Influence of nitrogen, phosphorus and potassium application on the yield of maize in the savanna zone of Nigeria. African Journal of Biotechnology 2 (10): 345 – 349. ISSN 1684-5315.

Kuzyakov, Y., Friedelb, J. K. and Stahra K. (2000). Review of mechanisms and quantification of priming effects. Soil Biology & Biochemistry 32 (2000) 1485-1498. Institute of Soil Science and Land Evaluation, University of Hohenheim, D-70593 Stuttgart, Germany. Institute of Organic Farming, University of Agricultural Sciences, A-1180 Vienna, Austria

Kwakye, P. K. (1980). The effects of method of dung storage and its nutrient (NPK) content and crop yield in the north east savanna zone of Ghana. Paper 20. Organic recycling in Africa. FAO Soils Bulletin 43, Rome, Italy.

Lalljee, B. (2003). Phosphorous Fixation As Influenced By Soil Characteristics Of Some Mauritian Soils. University of Mauritius

Lamer, M. (1985). The world Fertilizer Economy. The Food Research Institute of Stanford University.

Lavelle, P., Lattaud, D., Trogo, D. and Barois, I. (1995). Mutualism and biodiversity in soils. Plant and Soil 170, 23-33.

Law- Ogbomo, K. E. and Law- Ogbomo, J. E. (2009). The Performance of *Zea mays* as Influenced by NPK fertilizer application. Not Sci. Biol. 1 (1) 2009, pp 59-62

Lazcano, C., Gomez-Brandon, M., Revilla, P. and Dominguez, J. (2012). Short term effects of organic and inorganic fertilizers on soil microbial community structure and function. A field study with sweet corn. Biol Fertil Soils. Springer- Verlag Berlin Heidelberg 2012.

Leon, M., Laine, P., Ourry A. and Boucaud, J. (1995). Increased uptake of native soil nitrogen by roots of Lolium multiflorum after nitrogen fertilization is explained by a stimulation of the uptake process itself. Plant and Soil 173, 197- 203.

Li, B. Y., Huang, S. M., Wei, M. B., Zhang, H. L. and Shen, A. L. (2010). Dynamics of soil and grain micronutrients as affected by long-term fertilization in an aquic Inceptisol. Pedosphere 20: 725–735.

Lin, X. J., Wang, F., Cai, H. S., Lin, R. B., He, C. M., Li, Q. H. and Li, Y. (2010). Effects of different organic fertilizers on soil microbial biomass and peanut yield. Institute of Soil and Fertilizer.

Lundaka, R. and Kelly. V. (2012). The financial benefits of integrated soil fertility management. Using inorganic fertilizer in combination with other ISFM practices. Post-doctoral Fellow (Policy),CABI Africa,ICRAF Complex,United Nations Avenue,P.O Box 633-00621,Gigiri,Nairobi,Kenya.

Magid, J., Kjaergaard, C., Gorissen, A. and Kuikman, P. J. (1999). Drying and rewetting of a loamy sand soil did not increase the turnover of native organic matter, but retarded the decomposition of added C-14-labelled plant material. Soil Biology & Biochemistry 31, 595±602.

Maqsood, M., Abid, A. M., Iqbal, A. and Hussain, M. I. (2001). Effect of variable rate of nitrogen and phosphorus on growth and yield of maize (golden). Online J. Biool. Sci., 1: 19-20.

Mitchell, C. C. and Tu, S. (2005). Long term evaluation of poultry litter as a source of nitrogen for cotton and corn. Agron. J. 97: 399-407.

Mobley H. L. T. and Hausinger R. P. (1989). Microbial urease: significance, regulation and molecular characterization. Microbiol. Rev., 53: 85- 108.

Monaco, S. Hatch, D. J., Sacco, D., Bertora, C. and Grignani, C. (2008). Changes in chemical and biochemical soil properties induced by 11-yr repeated additions of different organic materials in maize-based forage systems. Soil Boil.Biochem.40:608-615.

Morris, M., Kelly, V. Kopicki, R. and Byerlee, D. (2007). Fertilizer use in African agriculture: Lessons learned and good practice guidelines, the worldbank, Washington D.C.

Mucheru, M., Mugendi D. N., Kung'u, J. B., Mugwe, J. and Bationo, A. (2007). Effects of organic and mineral fertilizer inputs on maize yield and soil chemical proper-ties in a maize cropping system in Meru South District, Kenya. Agroforestry Systems, 69, 189-197. doi:10.1007/s10457-006-9027-4

Mucheru, M., Mugendi, D. N., Micheri, A., Mugwe, J., Kungu, J., Otor, S. and Gitari, J. (2002). Improved food production by use of soil fertility amendment strategies in the central highlands of Kenya. In: Bationo A. and Swift, M.J. (eds). Proceedings of the 8th meeting of the African network for Soil Biology and fertility research. Nairobi, Kenya. In Press.

Mugendi, D. N., Monicah-Munah, Pypers, P., Mugwe, J., Kungu, J., Vanlauwe, B. and Merckx, R. (2010). Maize productivity as influenced by organic inputs and mineral fertilizers in a Nitisol soil in Meru South District. 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1-6 August 2010, Brisbane.

Mutuo, P. K., Mukalama, J. P. and Agunda, J. (2000). On- farm testing of organic and inorganic phosphorus sources on maize in Western Kenya. TSBF Report, Cali, 22.

Myers, M. G. and McGarity J. W. (1968). The urease activity in profiles of five great soil groups from northern New South Wales. Plant Soil. 28(1):25-37.

Myers, R. J. K., Palm, C. A., Cuevas, E., Gunatilleke, I. U. N. and Brossard, M. (1994). The synchronization of nutrient mineralization and plant nutrient demand. In: Woomer, P.L. and Swift, M.J. (eds). The biological management of tropical soil fertility. John Wiley and sons, Chichester, UK. pp 81-186

Negassa, W., Negisho, K., Friesen, D. K., Ransom, J., Yadessa, A. (2001). Determination of optimum farmyard manure and N, P fertilizers for maize on farmers' fields. pp. 387- 393.

Nelson, D. W. and Sommers, L. W. (1982). Total carbon, organic carbon and organic matter. In: Page, A. L., Miller, R. H and Keeney, D. R. (eds.). Methods of soil analysis. Part 2. Second edition. Chemical and microbiological properties. American Society of Agronomy and Soil Science Society of America. Madison, Wisconsin USA. pp. 301-312.

Nziguheba, G., Merckx, R., Palm, C. A., and Mutuo, P. (2002). Combining Tithonia diversifolia and fertilizers for maize production in a phosphorus deficient soil in Kenya. Agroforest. Syst. 55, 165–174.

Nziguheba, G., Palm C. A., Berhe, T., Denning, G., Dicko A., Diouf, O., Diru, W., Flor, R. Frimpong, F., Harawa, R. K., Kaya, B., Manumbu, E., McArthur, J., Patrick Mutuo, P., Ndiaye, M., Niang, A., Nkhoma, P., Nyadzi, G., Sachs, J., Sullivan, C., Teklu, G., Tobe L. and Sanchez, P. A. (2010). The African Green Revolution: Results from the Millennium Villages Project

O' Leary, M., Rehm, G., and Schmitt, M. (2002). Understanding Nitrogen in Soils. University of Minnesota. Extension Service. P. 5.

Okalebo, J.R., Palm C. A., Lekasi, J. K., Nandwa, S. M., Otieno, C. O., Waigwa, M. and Ndungu, K. W. (2003). Use of organic and inorganic resources to increase maize yields in some Kenyan infertile soils. A five year experience. In Bationo, A. (ed). Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa. Academy Science Publishers, Nairobi, Kenya. pp 359- 372

Opoku, A. (2011). Sustainability of Crop Residues and Manure Management In Smallholder Cereal – Legume - Livestock Systems in the Savannas of West Africa. pH.D thesis. KNUST

Palm, C. A., Gachengo, C. N., Delve, R. J., Cadisch, G. and Giller, K. E. (2001a). Organic inputs for soil fertility management: Some rules and tools. Agriculture ecosystems and Environment 83: 27- 42

Palm, C. A., Myers R. J.K. and Nandwa, S. M. (1997). Organic- Inorganic nutrient interaction in soil fertility replenishment. In: Buresh, R.J., sanchez, P.A. and Calhoun, F. (eds). Replenishing soil fertility in Africa. Soil Science society of America, Madison Wisconsin. pp 193- 218

Perucci, P. (1990). Effect of the addition of municipal solid waste compost on microbial biomass and enzyme activities in soil. Biol. Fertil. Soils 10, 221-226.

Polacco, J. C. (1977). Is nickel a universal component of plant ureases? Plant Sci. Lett. 10: 249-255.

Pulleman, M. and Tietema, A. (1999). Microbial C and N transformations during drying and rewetting of coniferous forest floor material. Soil Biology & Biochemistry 31, 275-285.

Quansah, G. W. (2010). Effect of Organic and Inorganic fertilizers and their combinations on the growth and yield of maize in the Semi- deciduous forest zone of Ghana. Hue (1995). MSc. Thesis, Kwame Nkrumah University of Science and Technology. pp 10-16

Saeed, I. M., Abbasi, R. and Kazim, M. (2001). Response of maize (*Zea mays*) to nitrogen and phosphorus fertilization under agro-climatic condition of Rawalokol, Azad Jammu and Kaslim and Kashmir, Pak. J. Biological Sci., 4: 949-952.

Sanchez, P. A., Shepherd, K. D., Soule, M. J., Place, F. M., Buresh, R. J. and Izac, A. N. (1997). Soil fertility replenishment in Africa. An investment in natural resources.

Sanchez, P. A. (2002). Soil fertility and hunger in Africa. Science 295:2019–2020

Sekhon, K. S., Singh, J. P. and Mehla, D. S. (2011). Long-term effect of manure and mineral fertilizer application on the distribution of organic nitrogen fractions in soil under a rice–wheat cropping system, Archives of Agronomy and Soil Science, 57:7, 705-714

Shah, K. P. and Arif, M. (2000). Management of organic farming: Effectiveness of farmyard manure and nitrogen for maize productivity. Sarhad J. Agric., 16:461-5. Sarhad J. Agric; 16:461-5

Sharar, M. Ayub, S., M., Nadeem, M. and Ahmad, N.. (2003). Effect of different rates of nitrogen and phosphorus on growth and grain yield of maize (*Zea mays* L.).Asian J. Plant Sci., 2:347-349.

Sharma, M. P. and Gupta, J. P. (1998). Effect of organic materials on grain yield and soil properties in maize wheat cropping system. Indian J. Agric. Sci. 68(11): 715 – 717.

Simpson, J. R. and Freney J. R. (1988). Interacting processes in gaseous nitrogen loss from urea applied to flooded rice fields. In: Proceedings of International Symposium on Urea Technology and Utilization (Pushparajah E, Husin A, and Bachik AT, Eds), pp. 281-290. Malaysian Society of Soil Science, Kuala Lumpur.

Sleutel, S., Neve, S. D., Nemeth, T. Toth, T. and Hofman, G. (1996). Effect of manure and mineral fertilizer application on the distribution of organic carbon in different soil fractions in long- term field experiments. Science direct. Europ P. Agronomy 25 (2006) 280- 288.

Sparling, G. P. (1985). The soil biomass. In: D. Vaughan and R. E. Malcolm (eds), Soil Organic Matter and Biological Activity, p. 223. Martinus Nijo/ Dr W. Junk, Dordrecht.

Sridhar, M. K. C. and Adeoye, G. O. (2003). Organo-mineral fertilizer from urban wastes. The Field, 68:91-111.

Stevenson, F. J. (1982). Organic forms of soil nitrogen. In: Stevenson FJ, editor. Nitrogen in agricultural soils. Madison (WI): ASA, SSSA. p. 67–122.

Stout, W. L. (1995). Evaluating the added nitrogen interaction effect in forage grasses. Communication in Soil Science and Plant Analysis 26, 2829-2841.

Suge, J. K., Omunyin, M. E. and Omami, E. N. (2011). Effect of organic and inorganic sources of fertilizer on growth, yield and fruit quality of eggplant (*Solanum melongena* L)

Tetteh, F. M., Issaka, R. N., Ennin, S. and Buri, M. M. (2008). Soil Fertility Initiative , Fertilizer Update and Reccommendation Trials. Soil research Institute of Ghana. pp 33.

Uguru, M. I. (1996). Crop production techniques. Fulladu Publication Company, Nsukka, Nigeria.

Vanlauwe, B. and Giller, K. E. (2006). Popular myths around soil fertility management in Sub-saharan Africa. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT), P.O. Box 30677, Nairobi, Kenya. Plant Production Systems, Department of Plant Sciences, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands

Vanlauwe, B., Aihou, K., Aman, S., Iwuafor, E. N. O., Tossah, B. K., Diels, J., Sanginga, N., Mercks, R. and Deckers, J. (2001 a). Maize yield as affected by organic inputs and urea in the west African moist savannah. Agronomy journal 93: 1191-1199

Vanlauwe, B., Dendooven, L., Merckx, R. (1994). Residue fractionation and decomposition the significance of the active fraction. Plant and Soil 158, 263-274.

Vanlauwe, B., Diels, J., Aihou, K., Iwuafor, E. N. O., Lyasse, O., Sanginga. N., Merckx, R. (2002a). Direct interactions between N fertilizer and organic matter: evidence from trials with 15 N-labelled fertilizer. In: Vanlauwe B, Diels J, Sanginga N, Merckx R (eds) Integrated plant nutrient management in Sub-Saharan Africa. CAB International, Wallingford, pp 173–184

Vanlauwe, B., Palm, C. A., Murwira, H. K., Merckx, R. (2002b). Organic resource management in Sub-Saharan Africa: validation of a quality-driven decision support system. Agronomy 22:1–8

Vanlauwe, B., Tottonel, P. and Makulama, J. (2006). Within- farm soil fertility gradients affect response of maize to fertilizer application in western Kenya. Nutrient cycling in Agroforestry 76: 171- 182

Vanlauwe, B., Wendt, J. and Diels J. (2001b). Combined application of organic matter and Fertilizer. In: Tian, G., Ishida, F. and Keating J.D.H (eds). Sustaining Soil Fertility in West Africa. SSSA special publication no. 58. Soil Science Society of America. Madison, USA. pp 247- 280.Volume 9 (Jan – Jun 2006). pp12 – 18.

Vanlauwe B., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U., Pypers, P., Shepherd, K., Smaling, E., Woomer, P. L. and Sanginga, N. (2010). Integrated soil fertility management: operational definition and consequences for implementation and dissemination 19th World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Wallace, J. S. (1996). The water balance of mixed tree- crop systems. In: Ong, C.K. and Huxley, P. Eds., Tree Crops Interactions, a Physiological Approach, CAB In-ternational, Wallingford, 73-158.

Wardle, A. D. (2002). Communities and Ecosystems: Linking the aboveground and belowground components (MPB-34).

Warren J. G., Phillips, S. B., Mullins, G. L., Keahey, D. and Penn, C. J. (2006). Environmental and production consequences of using alum-amended poultry litter as a nutrient source for corn. J. Environ. Qual., 35: 172-182.

weedsoft.unl.edu.(2013). University of Illinois Extension.

Whalen, J. K. and Chang, C. (2002). Macroaggregate characteristics in cultivated soils after 25 years annual manure applications. Soil Sci Soc Am J 66:1637–1647

Williams, T. O. Powell, J. M. and Fernandez-Rivera, S. (1995). Manure utilisation, drought cycles and herd dynamics in the Sahel: implications for crop land productivity. In: Powell *et al*. 1995. Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa.

Wu, X. C., Li, Z. P. and Zhang, T. L. (2008). Long-term effect of fertilization on organic carbon and nutrients content of paddy soils in red soil region. Ecology andEnvironment 17: 2019–2023.

Xu, H., Xiao, R. and Song, T. (2008). Effect of different fertilization on microbial biomass carbon from the red soil in tea garden. Front. Agric. China. 2008. 2(4). 418-422.Higher education press and Springer- Verlag. 2008.

Yang Z, Liu, S., Zheng, D., and Feng, S. (2006). Effects of cadium, zinc and lead on soil enzyme activities. J. Environ. Sci. 18(6): 1135-1141.

Yergeau, E., Bokhorst, S., Kang, S., Zhou, J. Z., Greer, C. W., Aerts, R. and Kowalchuk, G. A. (2012). Shifts in soil microorganisms in response to warming are consistent across a range of Antarctic environments. ISME J. 2012, 6, 692-702.

Zhang, H. S., Meal, D. and Tomko J. (1998). J. Plant Nut. 21:287-296.

Zhang, H. M., Wang, B. R., Xu, M. G. and Fan, T. L. (2009). Crop yield and soil responses to long-term fertilization on a red soil in Southern China. Pedosphere 19: 199–207.

Zingore, S., Delve,R. J., Nyamangara, J. and Giller, K.E. (2008). Nutrient Cycling in Agroecosystems 80:267–282

APPENDICES

Appendix 1. Calculation of added benefits

i. 60:60:40 Kg/ha NPK + 5 t manure

Added benefit (AB)= Ycomb- (Yfert-Ycon) – (Yom-Ycon)-Ycon

AB= 4678-(2148-610)- (1769-610)-610
AB= 4678- 1538- 1159-610
AB= 1371 Kg/ha grain yield

ii. 60:60:40 Kg/ha NPK + 2.5 t manure

Added benefit (AB)= Ycomb- (Yfert-Ycon) – (Yom-Ycon)-Ycon

AB= 4027- (2148-610)- (1367-610)-610
AB= 4027- 1538- 757-610
AB= 1122 Kg/ha grain yield

iii. 30:30:20 Kg/ha NPK + 5 t manure

Added benefit (AB)= Ycomb- (Yfert-Ycon) – (Yom-Ycon)-Ycon

AB= 3907-(1443-610)-(1769-610)-610
AB=3907- 833- 1159- 610
AB= 1305 Kg/ha grain yield

iv. 30:30:20 Kg/ha NPK + 2.5 t manure

Added benefit (AB)= Ycomb- (Yfert-Ycon) – (Yom-Ycon)-Ycon

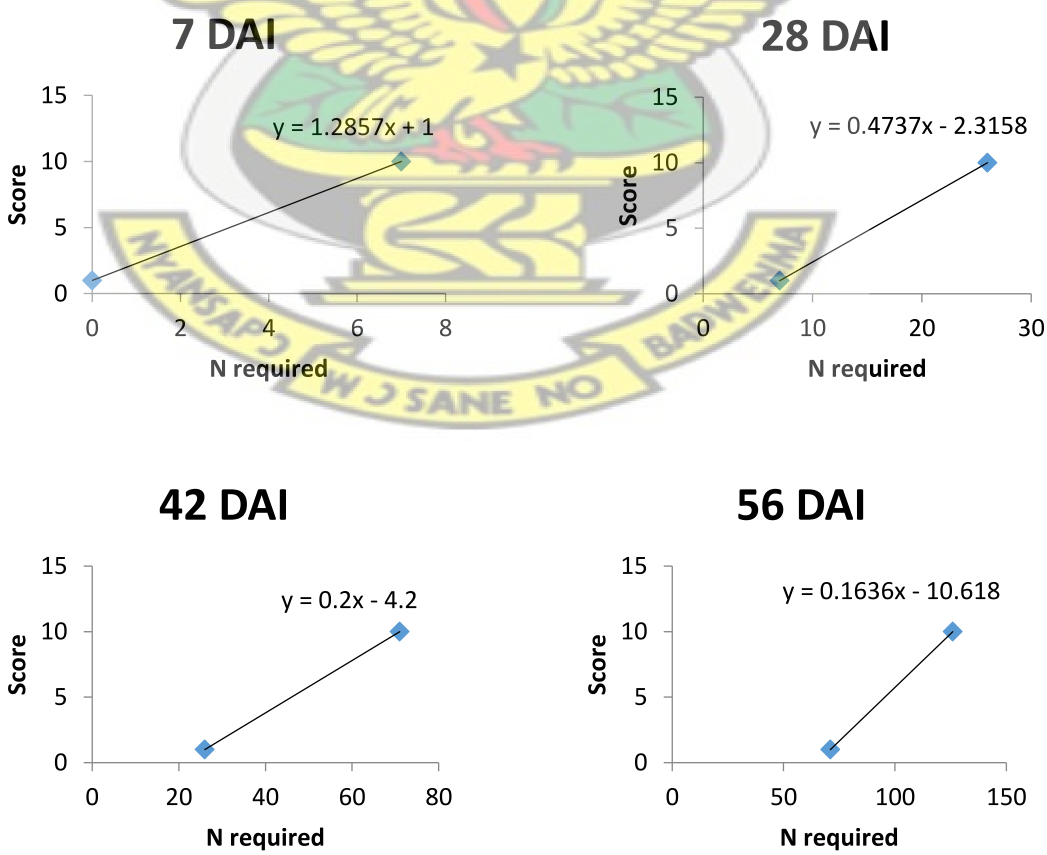
AB= 2156- (1443-610)- (1367-610)- 610
AB= 2156- 833- 757- 610
AB=-44 Kg/ha grain yield

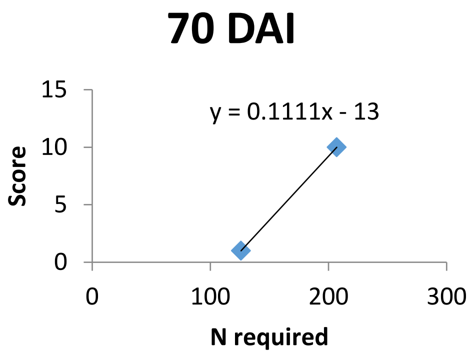
Appendix 2. Monetary value of data used for value cost ratio

Item	Unit cost ₵ (50 kg bag)	Amount applied (kg / ha)	Cost ₵ / ha
Fertilizer (Unsubsidized):			
Urea (60 kg N / ha)	50	130.43	130
TSP (40 kg P_2O_5 / ha)	100	86.96	174
MOP (40 kg K_2O / ha)	100	66.67	133
Sub-Total			**437**
Fertilizer transport			35
Fertilizer application			400
Manure (5 t / ha)	2	5000	200
Manure collection	2.5	5000	250
Manure transport	1.25	5000	125
Manure application			327
Maize seeds (5 kg)	10	20	40
Total cost			**1814**
Maize (yield)	40		

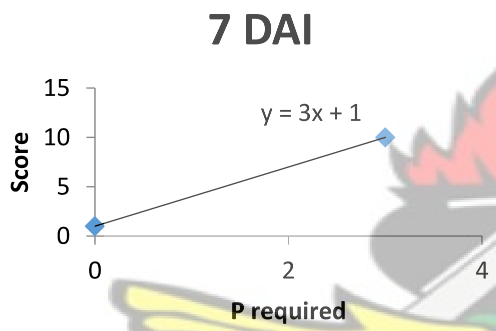
Appendix 3. Linear functions used to calculate NSI and PSI at various stages of incubation

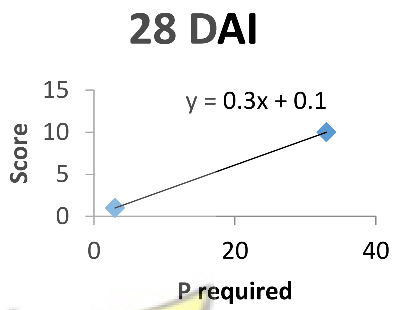
3.1. Nitrogen synchrony index functions

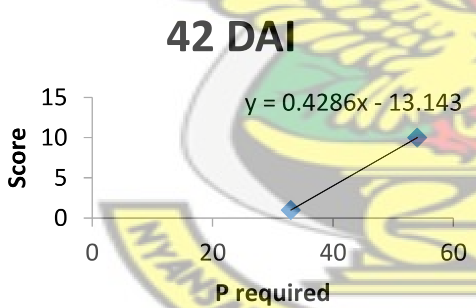


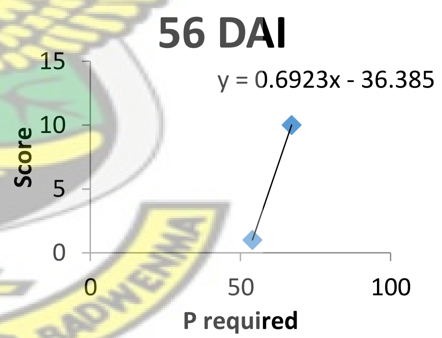


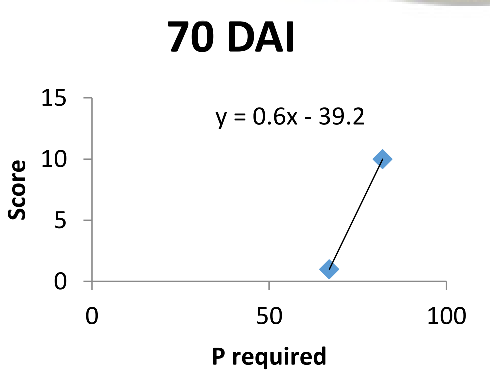
Appendix 3.2. Phosphorus synchrony index functions











Appendix 4. NH_3 emission and NO_3^- release

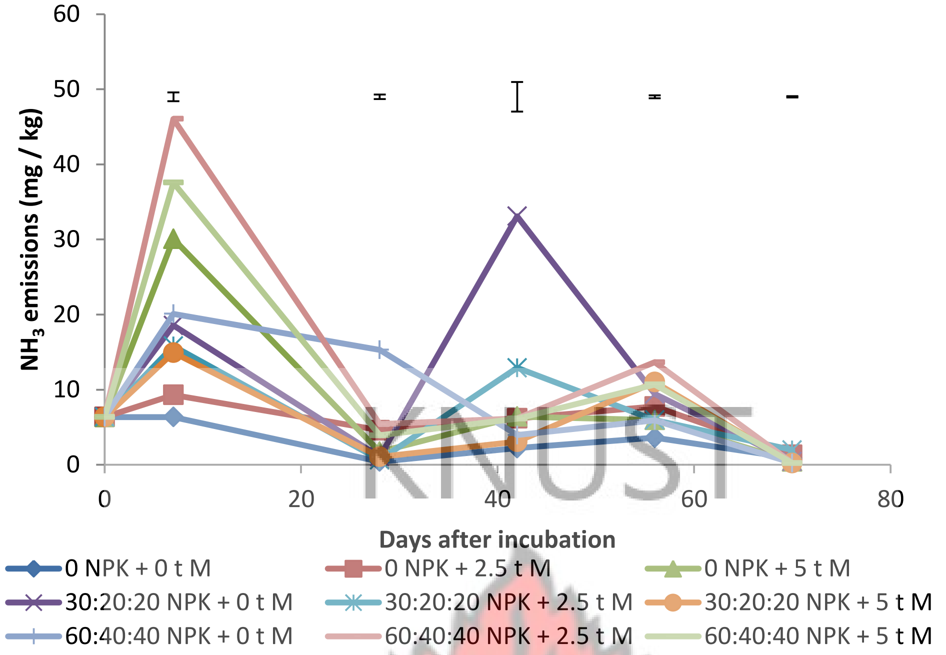


Figure 1. Combined effect of manure and mineral fertilizer application on NH_3 emmissions

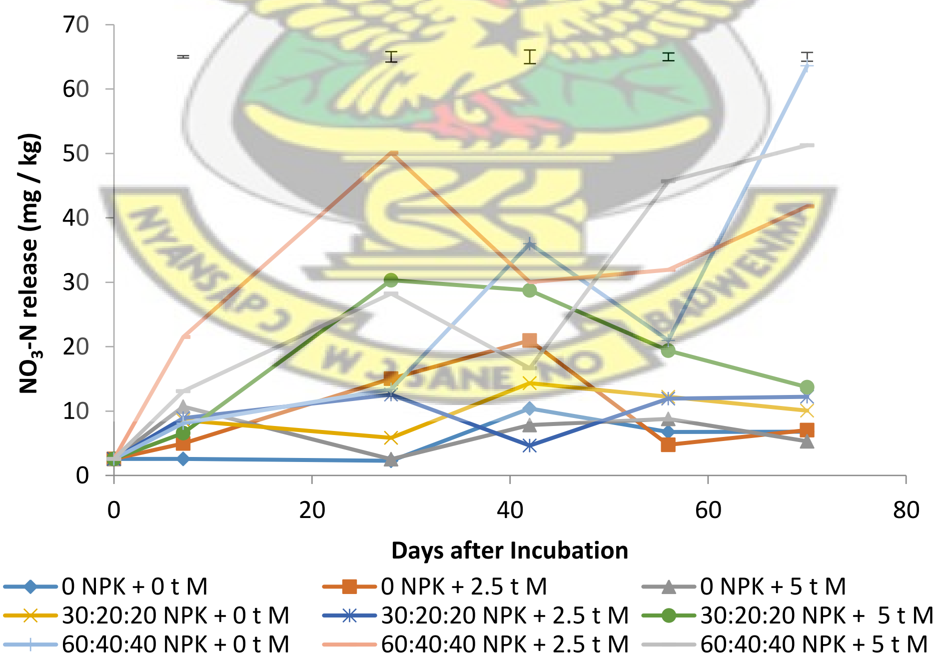
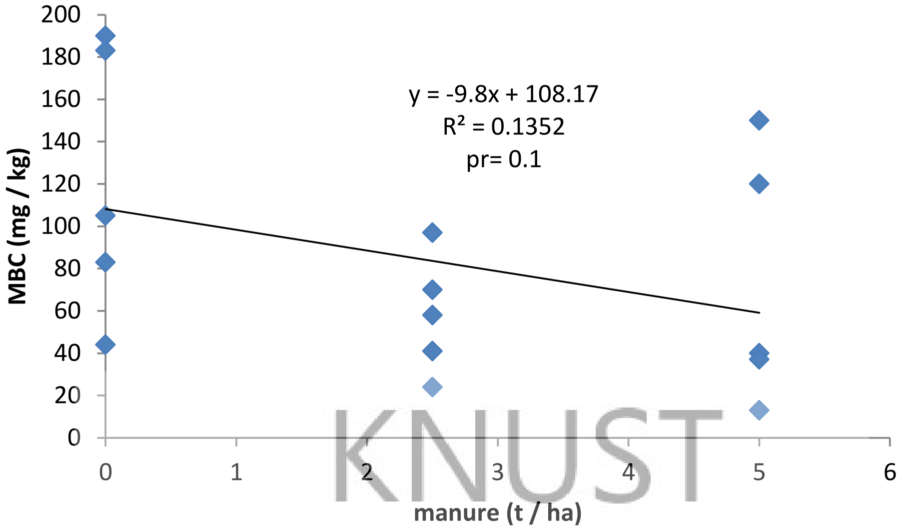
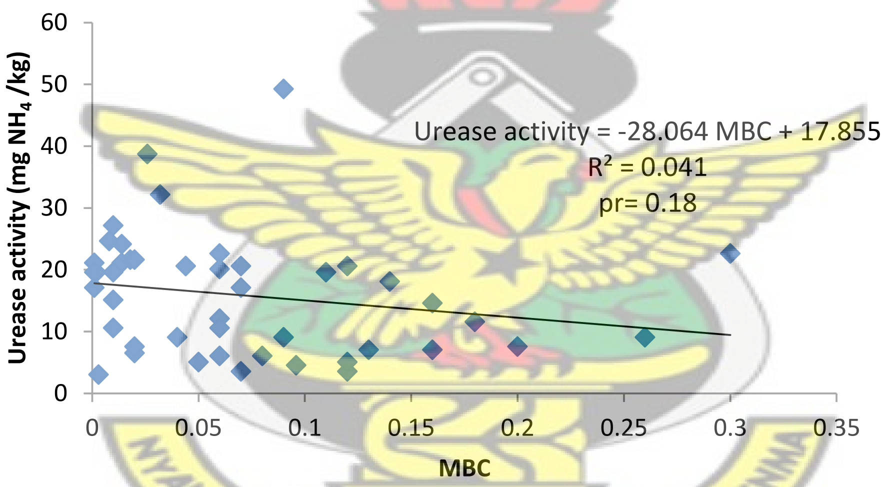


Figure 2. Combined effect of manure and mineral fertilizer on NO_3 release

Appendix 5. Microbial biomass carbon as influenced by manure application



Appendix 6. Urease activity as influenced by microbial biomass carbon



Appendix 7. Rainfall data of the field for the growing season (July to November, 2013)