

**A STUDY OF GREENHOUSE GAS EMISSIONS THROUGH APPLICATION OF
MINERAL AND ORGANIC NITROGENOUS FERTILIZER SOURCES**

**A thesis submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture,
College of Agriculture and Natural Resources, Kwame Nkrumah University of Science and
Technology, Kumasi, Ghana, in partial fulfillment of the requirements for the award of**

Degree of

MASTER OF SCIENCE

IN

SOIL SCIENCE

BY

SAMUEL JOE ACQUAH

BSc. (PHYSICAL SCIENCES) UCC (2006)

JUNE, 2012

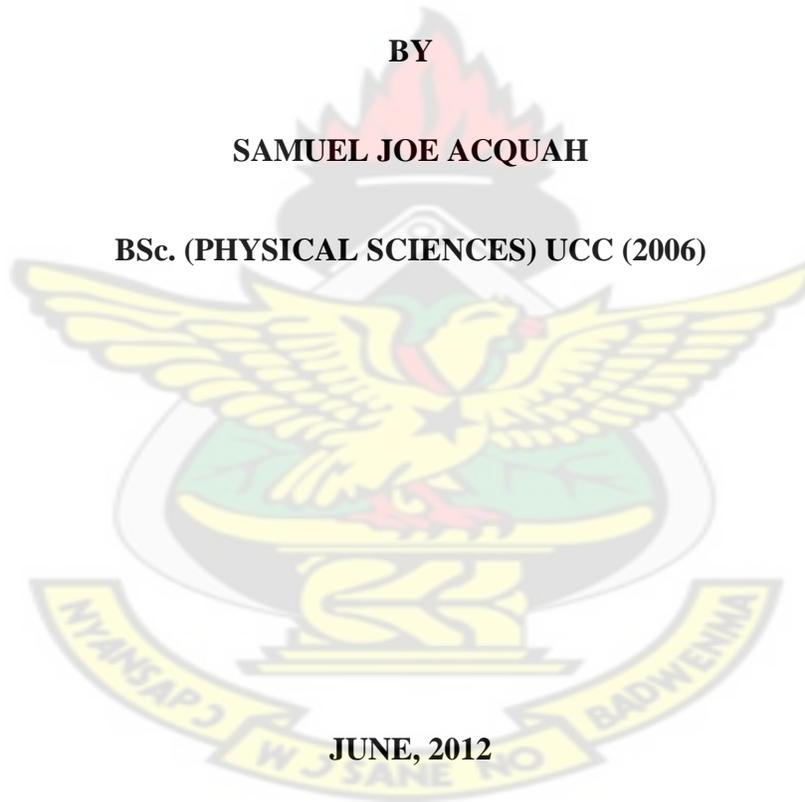
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KNUST

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DEDICATION

To the Glory of God, this work is dedicated to the memories of my father, the late Mr. Stevens Richmond Acquah and grandmother, the late Maame Efua Eduwa, who planted in me the seed of hard work, commitment and the fear of God which is the beginning of wisdom.



DECLARATION

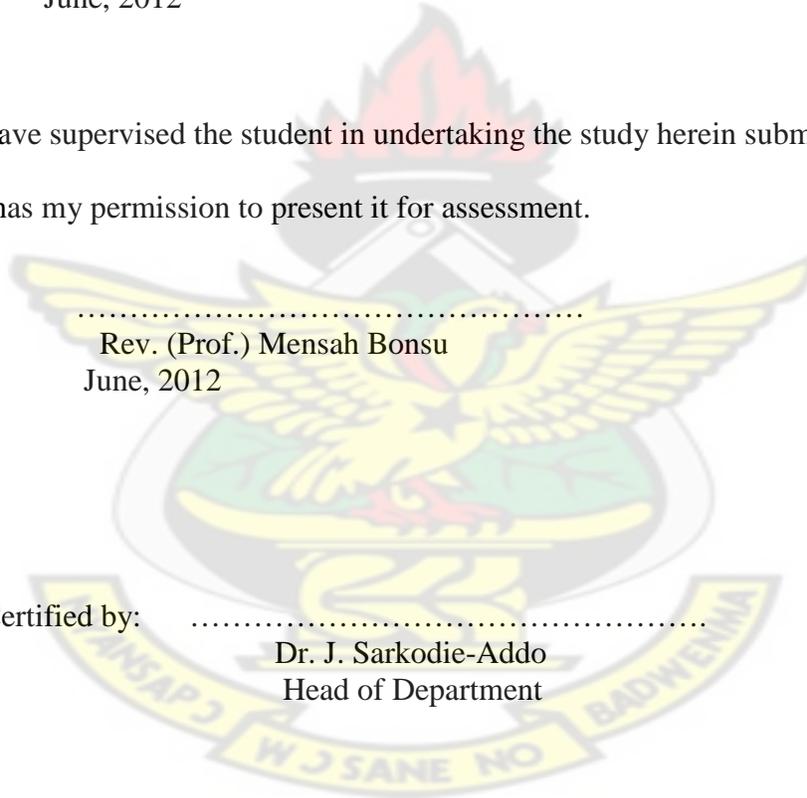
I, the undersigned, hereby declare that this thesis is my own work undertaken under supervision and that all sources used or quoted have been duly acknowledged by means of completed references.

.....
Samuel Joe Acquah
June, 2012

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

.....
Rev. (Prof.) Mensah Bonsu
June, 2012

Certified by:
Dr. J. Sarkodie-Addo
Head of Department



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Combining official duties as a technologist and a postgraduate student has been a great challenge and a herculean task I have ever had to face and overcome. But the avid support, guidance, motivation, patience and tolerance of my supervisor Rev. (Prof.) Mensah Bonsu saw me through it all. It is to him I owe my profound gratitude.

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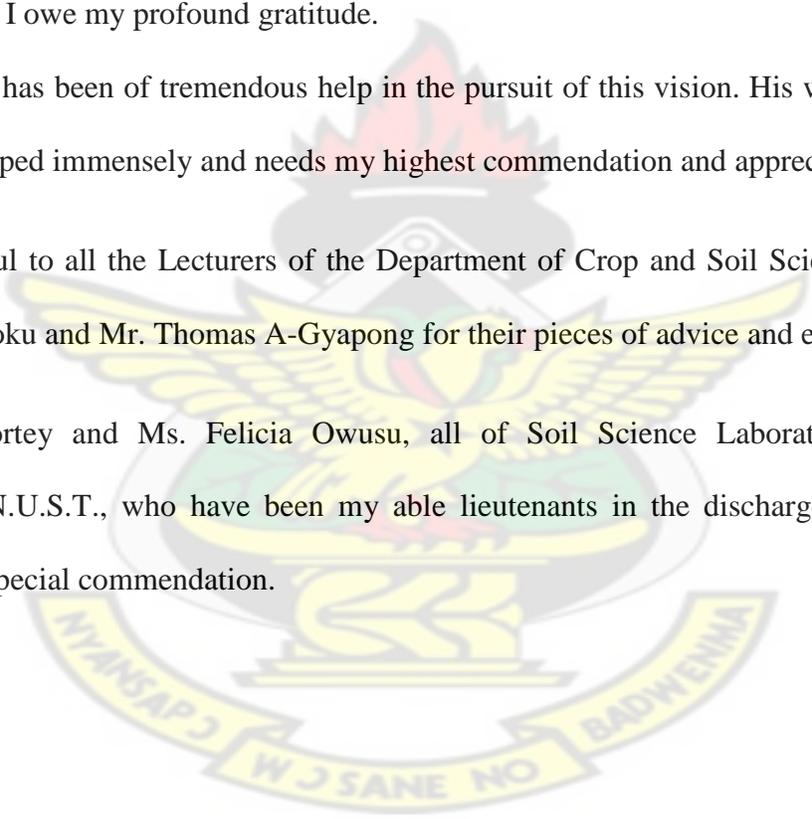


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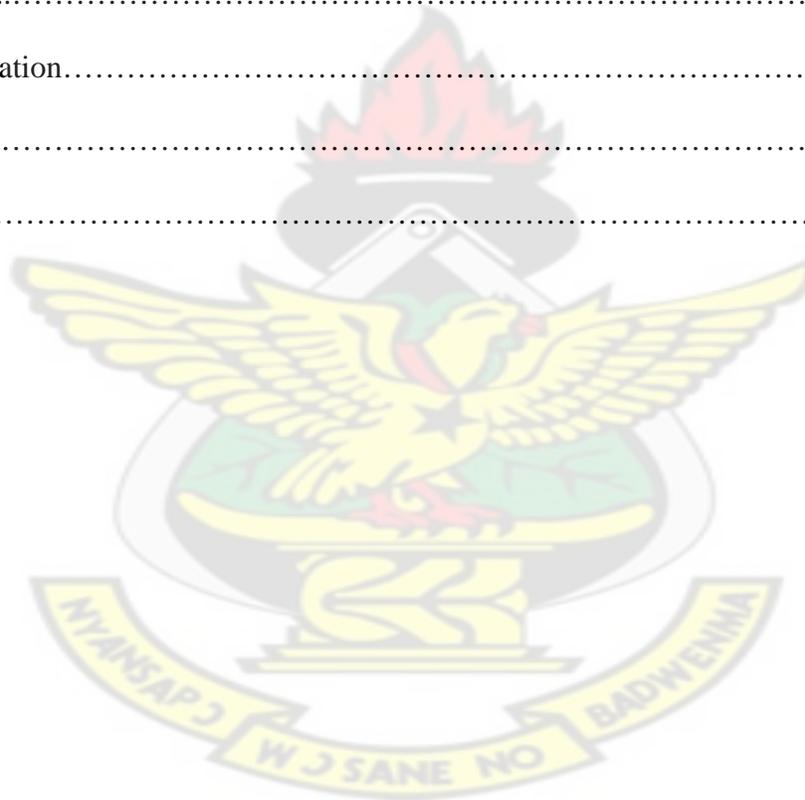
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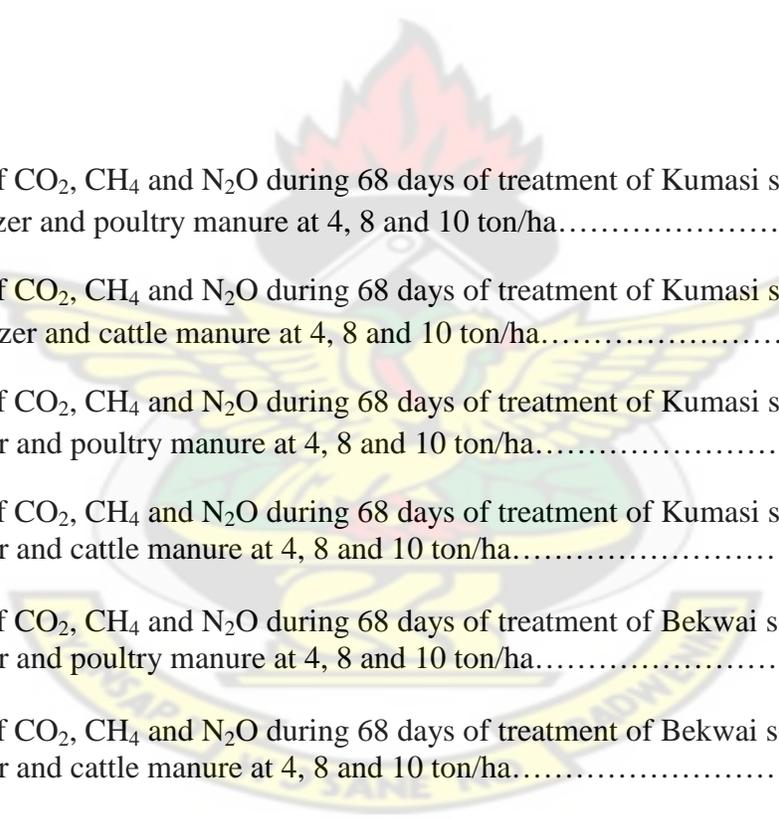
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LIST OF ACRONYMS

IPCC Inter-governmental Panel on Climate Change

GHG Greenhouse Gas

CO₂ Carbon dioxide

CH₄ Methane

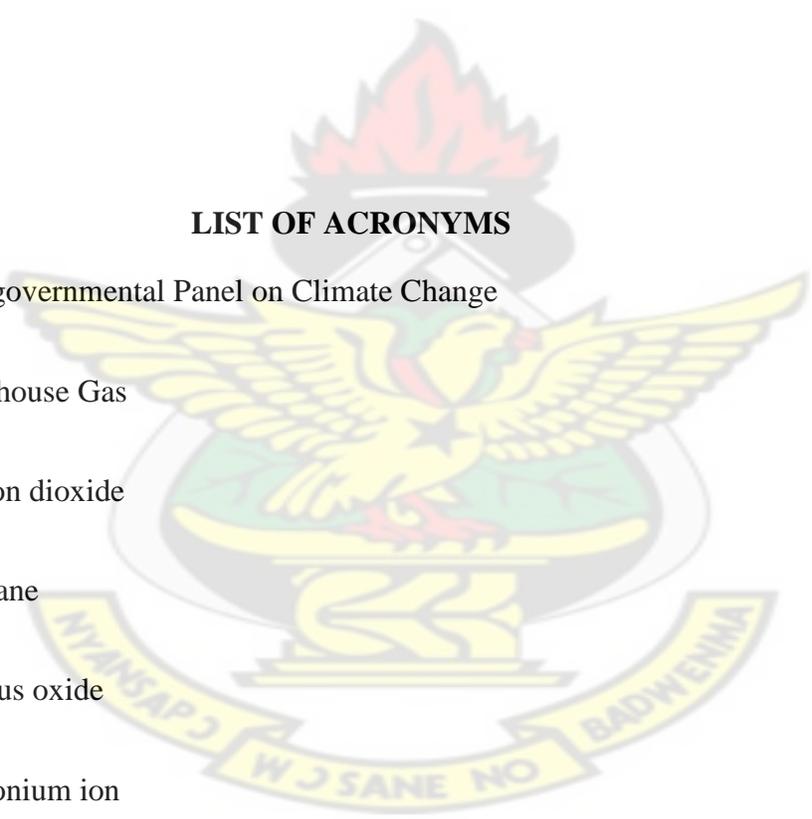
N₂O Nitrous oxide

NH₄⁺ Ammonium ion

NO₃⁻ Nitrate ion

NO₂⁻ Nitrite ion

CFCs Chloro-fluorocarbons



CO Carbon monoxide

O₃ Ozone

Tg Teragram (10¹²)

VOCs Volatile organic compounds

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ABSTRACT

Agricultural practices contribute largely to emissions of the greenhouse gases especially CO₂, CH₄ and N₂O, which potentially affect climate change mainly through trapping of long wave radiation emitted from the earth. This study was aimed at determining the emissions of these three important greenhouse gases (GHGs) released from two different agricultural soil types, two organic and two inorganic fertilizers known to potentially contribute to GHG emissions and hence, climate change and global warming.

Carbon dioxide was the highest greenhouse gas emitted and the estimated emission ranged from 3121 to 10597 kg CO₂ ha⁻¹. The second highest GHG was nitrous oxide and was in the range of 61.1 to 470 kg N₂O ha⁻¹.

Methane, the third in terms of emission ranged from 64.4 to 280 kg CH₄ ha⁻¹.

Emission factors which are relevant in the estimation of greenhouse gases when enough activity data have been generated were estimated for the species of gases as CO₂: 28.0 g kg⁻¹, CH₄: 1.47 g kg⁻¹ and N₂O: 2.11 g kg⁻¹.

The study showed that CO₂ emissions were high in all poultry manure treatments. The CH₄ emissions were virtually low both in the poultry manure as well as cattle manure treatments. The emissions of N₂O estimated for both the poultry manure and cattle manure treatments under the study were higher compared with that of CH₄.

CHAPTER ONE

1.0 INTRODUCTION

Soil is the largest terrestrial pool of carbon, nitrogen and sulphur and is intimately involved in the main fluxes of the important greenhouse gases (GHGs), namely, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and carbon monoxide (CO) on the land and the atmosphere (TSBF, 2002). Soil is also a fundamental resource on which human populations are dependent for food, fuel and fibre. Land use shifts and their sustainability are an important part of climate change, and it is through the response of the plant-soil system that climate change will have its main impact on humankind.

Soil fertility is concerned with the ability of soil to provide requisite nutrients for plant growth. The supply of the nutrients should be in the right amount and balance for the effective growth of plants. The traditional approach to soil fertility management is through the use of mineral fertilizers, organic resource application in the form of animal manure, compost and green manure from nitrogen-fixing legumes.

Volatilization of nitrogen in denitrification and chemical reactions involving nitrates under aerobic conditions in nitrogenous mineral fertilizers applied to the soil result in the emission of nitrous oxide gas (Rosenzweig and Hillel, 1998). During the decomposition and mineralization of organic matter applied to the soil, CO₂, CH₄ and N₂O gases are emitted into the atmosphere (IPCC, 1996; Rosenzweig and Hillel, 1998).

The livestock sector is solely responsible for 80 % of the estimated global greenhouse gas emissions derived from agriculture and land use; and also accounts for about 20 % of greenhouse gases emitted into the atmosphere, far exceeding the contribution from transport (Stern, 2006).

In addition to the CO₂ released from the activities of livestock, CH₄ and N₂O have greater potential in raising the atmospheric temperature, sea levels and changing weather patterns. These three gases are the key GHGs responsible for global warming, and hence climate change.

Climate change, which is a global phenomenon, is the result of increasing concentrations of infrared-absorbing gases (CO₂, CH₄, N₂O, CFCs) released into the atmosphere by human activities such as burning of fossil fuels, cement production, agriculture, and land use changes - deforestation and bush-burning (IPCC, 1996; Rosenzweig and Hillel, 1998). The impact of human activities emanating from soil fertility management on the emission of the GHG has not been given much attention in the tropics, which, paradoxically, has the weakest capacity to respond scientifically to this global challenge. Direct and indirect emissions of CO, CO₂, CH₄, and N₂O from agricultural activities have not been studied to any great extent and hence, there is the urgent need to research into this area. This is imperative because:

- i. there are indications that Ghana, like many West African countries, have poor gas emission inventory in the Agriculture Sector (Bonsu, 2010).

- ii. depletion of the ozone layer by some specific GHGs (e.g. CFCs) will bring about health hazards, especially skin cancer ;
- iii. specific scientific information generated from this study will assist in developing the right policy framework for managing the overall agro-ecological environment in the country.

It is expected that the outcome of this research work will go a long way to assist policy makers and farmers to have a fair knowledge of the contributions of organic and inorganic mineral fertilizers to the global warming menace so as to intensify their public awareness campaigns and activities on climate change and its concomitant effects on agriculture in particular and humanity, generally. Information on GHG emissions is also crucial for developing and assessing the potential for mitigating climate change implications resulting from organic and inorganic fertilizer applications. Again, understanding climate change and how urgent it is to address current and potential impacts will strategically spur developing countries to plan at the household, community and national levels which can limit the damage caused by climate change.

Main Objective

The main objective of this study was to obtain quantitatively the emissions of GHGs resulting from the mixing of mineral nitrogenous fertilizers with varied amount of organic N-fertilizer sources.

Specific Objectives

The study had the following specific objectives:

- i. To monitor emissions of nitrogenous gas from different nitrogenous-based fertilizers
- ii. To estimate the mass of GHGs (CO_2 , CH_4 , and N_2O) emitted from the decomposition of various organic manure
- iii. To determine emission factors of GHGs from the decomposition of organic manures mixed with mineral N fertilizers
- iv. To ascertain climate change implications with the emissions of CO_2 , CH_4 , and N_2O .

These objectives were set against these hypotheses:

H_0 : Decomposition of manures mixed with N-based fertilizers does not emit GHGs

H_A : Decomposition of manures mixed with N-based fertilizers releases GHGs into the atmosphere.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 EARTH'S'S ATMOSPHERE AND GREENHOUSE EFFECT IN RELATION TO CLIMATE CHANGE

According to a TSBF Report (2002), “The last three decades have seen a rate of change in the global environment unprecedented in human history. Most of this change has been induced by human activity of both industrial and agricultural origin”

Greenhouse effect is the capacity of greenhouse gases in the atmosphere to trap heat emitted from the surface of the earth (Pidwimy, 2006). The greenhouse effect act as a thermal blanket regulating the temperature of the earth's surface, without which, the average earth's temperature would be 33°C cooler (Pidwimy, 2006). The anthropogenic modification of this natural process resulting in increased levels of heat-trapping gases (greenhouse gases) in the atmosphere have presented the current rapid warming of the earth, altering the global weather patterns, particularly rise in temperature of the earth's atmosphere, sea levels and stormy activities, called climate change. The greenhouse effect causes the atmosphere to trap more heat energy at the earth's surface and within the atmosphere by absorbing and re-emitting long wave energy or radiation. Of the long wave energy emitted back to space, 90 % is intercepted

and absorbed by greenhouse gases (GHG). Without the greenhouse effect the earth's average global temperature would be -18°C , rather than the present 15°C (Pidwimy, 2006). The gases involved in the human-induced enhancement of the greenhouse effect include (Table 2.1): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CF_xCl_x); and tropospheric ozone (O_3).

Of these gases, the single most important gas is CO_2 , which accounts for about 55 % of the change in the intensity of the earth's greenhouse effect. The contributions of the other gases are 25 % for CF_xCl_x , 15 % for CH_4 and 5 % for N_2O . Ozone's contribution to the enhancement of greenhouse effect is still yet to be quantified (Pidwimy, 2006).

Table 2.1: Gases involved in the Greenhouse Effect: Past and present concentration and sources

Greenhouse Gas	Concentration 1750	Concentration 2003	Percent Change	Natural and Anthropogenic Sources
CO_2	280 ppm	376 ppm	34 %	Organic decay; Forest fires; Volcanoes; Burning fossil fuels; Deforestation; Land-use change
CH_4	0.71 ppm	1.79 ppm	152 %	Wetlands; Organic decay; Termites; Natural gas & oil extraction; Biomass burning; Rice cultivation; Cattle; Refuse landfills
N_2O	270 ppb	319 ppb	18 %	Forests; Grasslands; Oceans; Soils: Soil cultivation; Fertilizers; Biomass burning; Burning of fossil fuels
CFCs	0	880 ppt	Not Applicable	Refrigerators; Aerosol spray propellants; Cleaning solvents

O ₃	Unknown	Varies with latitude and altitude in the atmosphere	Global levels have generally decreased in the stratosphere and increased near the earth's surface	Created naturally by the action of sunlight on molecular oxygen and artificially through photochemical smog production
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Source: Pidwimy, 2006

ppm = parts per million

ppb = parts per billion

ppt = parts per trillion

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This is better appreciated if the occurrences in the earth atmosphere are known. The atmosphere of the earth mainly comprises nitrogen and oxygen, with small amounts of hydrogen, helium, argon, neon, and other gases namely N₂O, CH₄ and CO₂ which are classified as the major greenhouse gases (Fig. 2.1) being the main contributors to climate change. The earth's atmosphere acts much like a giant greenhouse. The gases allow solar radiation which comes in the form of shortwave to pass through the atmosphere (Fig. 2.2, Point 1), heats up the earth's and some radiation emitted back to the atmosphere in the form of long wave (infrared) radiation (Points 2&3). Some of the outgoing radiation is trapped in the atmosphere by certain atmospheric gases as water vapour, carbon dioxide and methane (greenhouse gases) and re-emitted in all directions (Point 4.), keeping earth warm enough to support life.

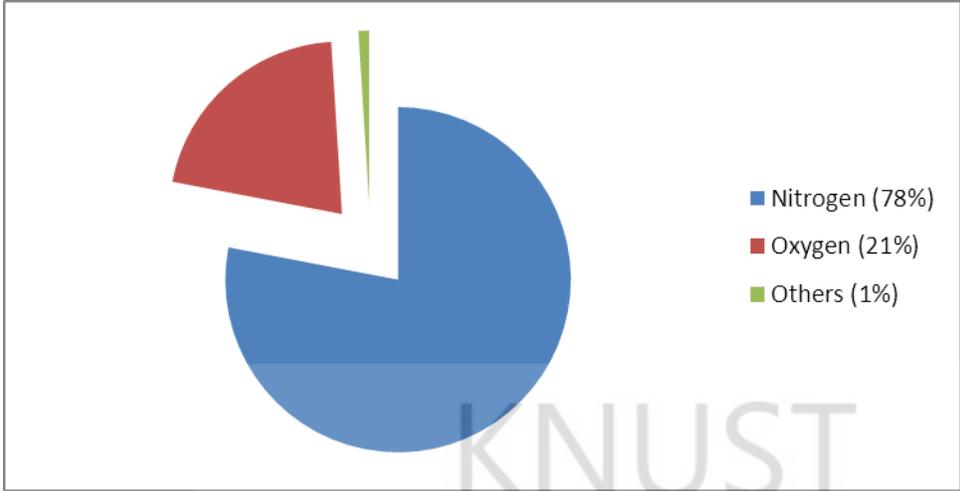


Fig. 2.1: Constituents of the atmosphere (Source: Wood and Knipmeyer, 1998).

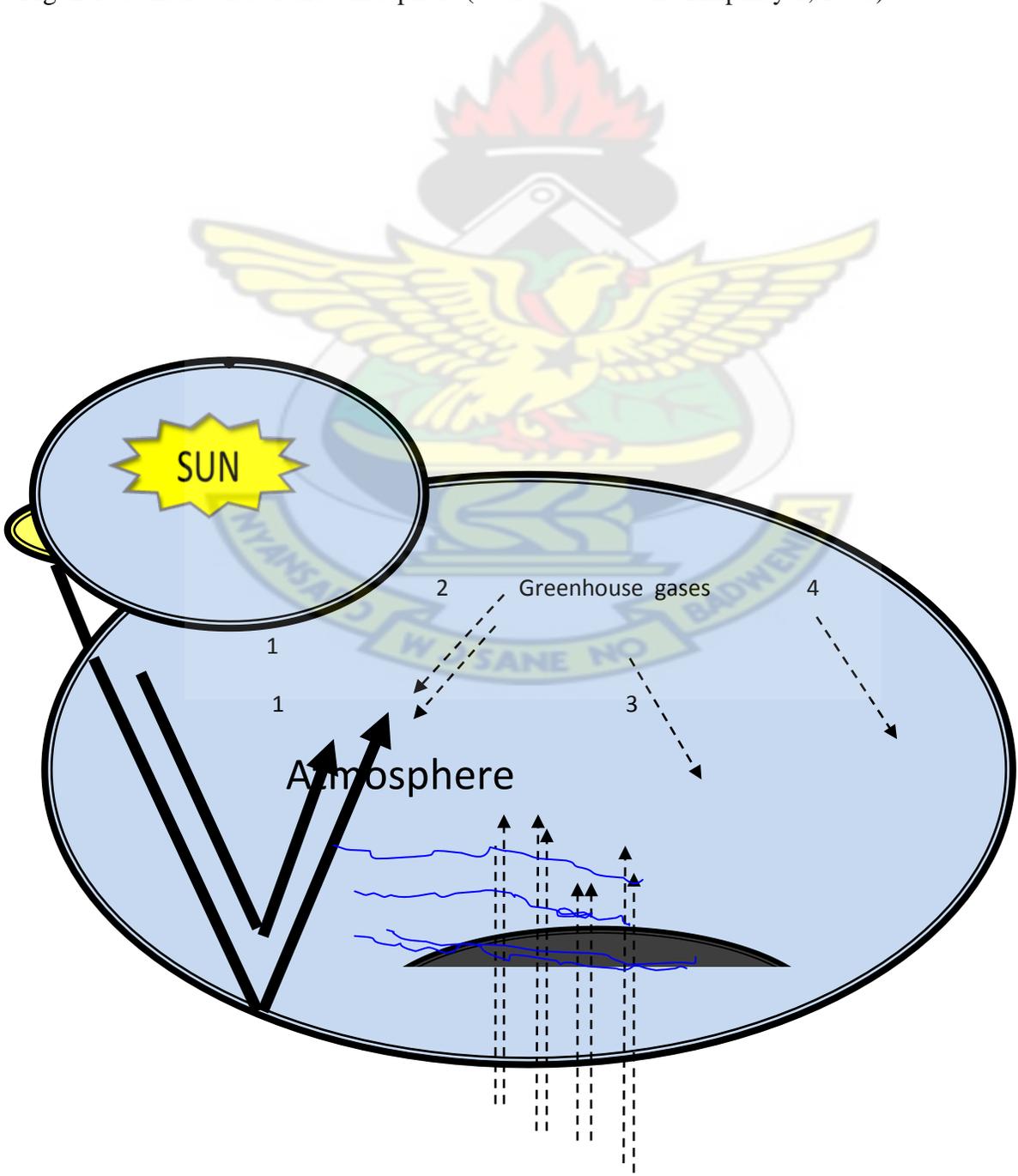




Fig.2.2: The Atmosphere and the Greenhouse Effect (Source: U. S. Department of State, 1992).

2.2 AGRICULTURAL EMISSION OF CARBON DIOXIDE (CO₂)

Carbon dioxide, the most prominent GHG, is released as a consequence of agricultural land-use, biomass burning, and energy production. Agriculture land-use change generally causes the release of CO₂ that had previously been sequestered in plants biomass and soil organic matter (Rosenzweig and Hillel, 1998).

On a global basis, soil is second only to the ocean for carbon it contains, holding 1.5 to 3 times as much carbon as living terrestrial vegetation. When land supporting a natural ecosystem is converted to agricultural use, a large percentage of the carbon present in the ecosystem is burned or rapidly decomposed, and the organic matter in the soil is gradually oxidized as the soil is cultivated and cropped (Rosenzweig and Hillel, 1998).

Conversion of natural ecosystems into agricultural land continues briskly today, with cropland and pasture still expanding globally (FAO, 1993). Land clearing, being the second largest source of CO₂ emissions after fossil fuel combustion, currently accounts for approximately 10 to 30 % of total net CO₂ emissions (IPCC, 1996). Much land clearing

occurs in areas of tropical forests. Approximately 11 million hectares of tropical forest are now being converted each year, while only about 1 million hectares are reforested (Burke and Lashof, 1990). Conversion of tropical forests to agricultural use currently releases an amount of carbon estimated to range between 0.6 and $2.6 \times 10^9 \text{ t yr}^{-1}$ (IPCC, 1996).

In 1980, half of the world's CO_2 emissions from deforestation in the tropics were generated in five countries: Brazil, Colombia, Indonesia, the Ivory Coast, and Thailand (Houghton *et al.*, 1987).

Estimates of carbon release by some developed countries from industrial sources and those released through land use changes in some developing countries are presented in Table 2.2 by Rosenzweig and Hillel (1998).

Table 2.2: Carbon released by some Countries from industrial sources and Land use Changes

Country	Carbon from Industrial Sources (million tons)	Country	Carbon from land use changes (million tons)
U.S.A.	1135	Brazil	454
Russia	901	Indonesia	124
China	413	Burma	83
Japan	226	Mexico	64

Germany	181	Thailand	62
U.K.	141	Colombia	59
Poland	112	Nigeria	57
France	111	Zaire	57
Italy	88	Malaysia	50
India	78	India	41

Source: Rosenzweig and Hillel, 1998.

From Table 2.2 the carbon released from industrial sources far exceeds carbon released from land use changes. More estimates of the gains and losses of carbon per hectare associated with changes in land use are needed to improve global calculation of CO₂ fluxes (Rosenzweig and Hillel, 1998).

As crop production continues over time, soil organic matter declines further (albeit at a slowing rate), resulting in more CO₂ releases, until a steady state is reached or until the field is abandoned (Houghton *et al.*, 1983). However, the release of CO₂ from different agricultural practices varies.

Table 2.3: Average Carbon Loss from Conversion of Different Ecosystem Types to Agricultural Land Use

Ecosystem Type	Mean loss of carbon (%)
Temperate forest	34.0

Temperate grassland	28.6
Tropical forest	21.0
Tropical savanna	46.0

Source: Schlesinger, 1986.

2.3.0 AGRICULTURAL METHANE (CH₄) EMISSIONS

Methane (CH₄) is the second most important GHG after CO₂. Although CH₄ is very much less prevalent than CO₂, it is about 25.5 times more powerful per molecule in terms of radiative forcing than CO₂ (IPCC, 1990). In reality, one gram of CH₄ traps 70 times more heat than the same quantity of CO₂ over 20 years, and that the aforementioned quotation “25.5 times more potent in trapping heat as CO₂” holds on a molecule to molecule basis of CH₄ : CO₂ (Lindau *et al.*, 1993). Hence, its rising concentration is a matter of great concern.

The primary sources for the additional methane added to the atmosphere (in order of importance) are rice cultivation, domestic grazing animals (manure and fermentation of feed from ruminants such as cattle, sheep and goats), termites, landfills, coal mining, and oil and gas extraction (Johnson and Johnson, 1995; Pidwimy, 2006).

Agriculture is the largest anthropogenic source of methane, being responsible for about 40 % of emissions. Methane emissions into the atmosphere are from natural and man-made sources. Natural sources of methane account for 30 % and the remaining 70 % of the total

global methane being contributed by human activities (Fisher and Burns, 1996). The concentration of methane in the atmosphere keeps rising at the rate of $1\% \text{ yr}^{-1}$, and has more than doubled in the atmosphere since 1750 and could double again in the next century. This is because emission of CH_4 exceeds the concentration of hydroxyl ions in the troposphere that react with CH_4 to form water vapour and CO_2 . Besides, CH_4 stays in the atmosphere for at most a decade as related to the 120 years residence time of CO_2 in the atmosphere (IPCC, 1995; Fisher and Burns, 1996).

The major agricultural sources of methane are fields of wetland rice known as rice paddies, manure and fermentation of feed from ruminants such as cattle, sheep and goats, and biomass burning. In both rice paddies and ruminants, methane is produced in the process of carbohydrate (including cellulose) decomposition carried out by anaerobic bacteria (Cicerone and Oremland, 1988; Bouwman, 1990). However, an accurate estimate of how much CH_4 is produced from rice paddies have been difficult to obtain.

More than 60 % of all rice paddies are found in India and China where scientific data concerning emission rates are unavailable. Nonetheless, scientists believe that the contribution of rice paddies is large because rice production has more than doubled since 1950. Grazing animals release methane to the environment as a result of herbaceous digestion (enteric fermentation). Some researchers believe the addition of methane from this source has more than quadrupled over the last century (Bouwman, 1990; IPCC, 1997; Pidwimy, 2006).

Methane releases from combustion are associated with tropical forest clearing for agriculture and with burning of crop residues. Methane releases from rice paddies, enteric fermentation, and biomass burning are poorly quantified, but are estimated to total 20-150, 65-100, and 20-80 million tons per year, respectively (IPCC, 1992). Knowles, (1993) and Hao *et al.*, (2001) discovered that some soils can serve as a sink for methane, via bacteria known as methanotrophs (bacteria that are able to grow using methane). Since methanotrophs require oxygen, methane uptake tends to occur in moist rather than saturated or flooded soils, or at the boundary between aerobic and anaerobic conditions. Again, methane uptake by soils has been found in savanna and forest ecosystems. Globally, soils are estimated to remove from 15 to 45 million tons of atmospheric CH₄ per year (Schutz *et al.*, 1990). However, IPCC (1992) noted that agricultural development and nitrogen fertilization could diminish the sink capabilities of grassland soils and thereby lead to higher atmospheric concentrations of both methane and nitrous oxide.

2.3.1 METHANE PRODUCTION IN RICE PADDIES

Methane production depends on the ratio of oxidizing to reducing capacity of the flooded soil (Watanabe, 1984). The oxidizing capacity depends on the presence of O₂, NO₃⁻, Mn⁴⁺, and Fe³⁺. The reducing capacity depends on the presence of ammonium. Methanogenesis requires reduction-oxidation (redox) potentials of -150 to -190 mV (corrected to a pH of 7) (Neue *et al.*, 1990). After a soil is flooded and oxygen supply is cut off, bacteria decompose organic

matter anaerobically in a series of steps. The processes follow a thermodynamic sequence in which the soil's redox potential falls as the oxidized compounds are chemically reduced as shown in Table 2.4.

Table 2.4: Sequential reduction of oxidized soil compounds in a soil after inundation.

Redox reaction	pEo ⁷⁽¹⁾ (V) ²
$O_2 + 4H^+ + 4e \rightarrow 2H_2O$	13.8
$NO_3^- + H_2O + 2e \rightarrow NO_2^- + 2OH^-$	12.66
$MnO_2 + 4H^+ + 2e \rightarrow Mn^{2+} + 2H_2O$	6.80
$Fe(OH)_3 + 3H^+ + e \rightarrow Fe^{2+} + 3H_2O$	-3.13
$SO_4^{2-} + 10H^+ + 8e \rightarrow H_2S + 4H_2O$	-3.63
$CO_2 + 8H^+ + 8e \rightarrow CH_4 + 2H_2O$	-4.14

Source: Bouwman, 1991

1. pEo⁷ = -log (E_o)
2. Corrected for pH = 7

After the inorganic hydrogen acceptors have been exhausted, bacteria continue to oxidize the organic matter to form a mixture of CO₂ and CH₄. The relative amounts of the two gases produced depend on the degree of oxidation of the original organic material- that is, on the ratio of oxidizing capacity to reducing capacity. These processes may take place simultaneously in separate layers in paddy rice soil. The layers follow the values of redox

potentials given in Table 2.4, and consist of:

- i. A thin aerobic surface layer that is 0.5 to 10 mm thick. In this layer, consumption of methane produced in the reduced zone may occur.
- ii. The second layer is reduced with Fe^{3+} , Mn^{4+} , and NO_3^- still present.
- iii. The third layer is where sulfate reduction occurs.
- iv. The fourth layer is the main zone of methane generation (Bouwman, 1991).

Most methane is brought to the surface of rice paddies through diffusive transport in the rice plants themselves, rather than via rising bubbles and diffusion in the water (Cicerone and Shetter, 1981). Rice plants have tissues with elongated cells and large intercellular spaces, known as aerenchyma, that facilitate gaseous exchange and maintain tissue buoyancy. The root system of the rice plant is critical in methane processes: roots apparently can absorb methane independently of water uptake.

Factors affecting methane emissions from rice paddies vary with season, soil type, nutrients, redox potential, pH, and temperature. Other factors include agronomic practices such as irrigation and drainage, depth of water layer, cropping system, fertilization, and additions of manure or rice straw (Bouwman, 1991).

2.3.2. METHANE EMISSIONS FROM LIVESTOCK

Methane's post-emission residence in the atmosphere is over a decade (12-17 years). The concentration of methane in the atmosphere is 1.79 parts per million (Table 2.1).

Ruminant animals having compartments of stomachs (cattle, sheep, goats, camels, and

buffaloes) are primarily responsible for methane production via the process of enteric fermentation in the breakdown of cellulose (Crutzen *et al.*, 1986). This process generates methane, which is released into the air. Emissions of methane from domestic livestock and wild animals are estimated to be between 65 to 100 million t yr⁻¹ (about 15 % of total methane emissions) (Crutzen *et al.*, 1986, Lerner *et al.*, 1998; IPCC, 1992). Improving the accuracy of these estimates requires quantifying emissions rates per animal as affected by feeding habits and metabolism, as well as better data on animal populations around the world.

2.3.3. METHANE EMISSION THROUGH ENTERIC FERMENTATION

The methane produced as a result of enteric fermentation (86 million mt) accounts for about 18 % of the total methane production from anthropogenic sources (Bolle *et al.*, 1986). Ruminants give off methane as part of their normal digestive process. Ruminants have a special digestive system that enables them handle fibrous materials as crop residues. They have a resident microbial ecosystem (bacteria, fungi and protozoa) in the first and the largest stomach compartment, the rumen which aids the degradation or the enteric fermentation of fibrous feed into the production of organic acids. These acids are absorbed into the blood stream providing energy for utilization by the animal.

Resident also in the rumen is single-celled anaerobic bacteria called the methanogens, which are involved in metabolic production of methane, a by-product of enteric fermentation. Ruminants fed on fibrous or poor diet generates a lot of methane per animal and per unit product (Antwi *et al.*, 2009). Preston and Leng (1987) noted that straw-fermentation was

enhanced by supplementing the basal diet of straw with urea and by-pass proteins, methane production decreased by 82 % per unit kg meat. Monogastrics, pseudo ruminants and human as well, produce methane during digestion but their contribution to methane emission is relatively low, as they cannot handle fibrous feed to the same extent as ruminant animals. As a result, census on methane emission from enteric fermentation is primarily based on ruminant animals (LEAD, 2005).

Of the total emissions from enteric fermentation, beef cattle account for approximately 5 %, dairy cows 19 %, and sheep 10 % (Crutzen *et al.*, 1986; Lerner *et al.*, 1988). Dairy and beef cattle are most important, because of their high emission rates per animal (ranging between 35 and 55 kg CH₄ per animal per year) and their high populations worldwide.

According to FAO (1993), developed countries had 390 million head of cattle and 512 million sheep in 1992. In the developing countries, however, animal populations are much higher: about 895 million cattle and 600 million sheep in 1988. Livestock in Brazil, China, India, the former Soviet Union, and the United States are apparently responsible for about half the global methane emissions by domestic animals (Lerner *et al.*, 1988).

2.3.4. FACTORS AFFECTING METHANE EMISSIONS FROM LIVESTOCK

Livestock production in various parts of the world differs in type of animals, composition of feed with feed quality and amount, animal age, weight, genetic traits, activity, and enteric

ecology. When animals convert plant carbon to methane rather than to animal tissue or dairy product, a loss of efficiency ensues. Energy loss in the form of CH₄ varies from 3 to 8 % of gross energy intake for cattle, depending on the quality and quantity of feed. Overall, CH₄ emissions tend to be higher for heavier animals, greater amounts of feed, and diets high in cellulose forage (Burke and Lashof, 1990). Working (draft) animals tend to emit more CH₄ because they generally require more feed to produce energy for work, and some of the additional starch relative to cellulose. Thus, grain-fed cattle tend to emit less methane per unit of feed consumed, than range-fed cattle whose diet contains more cellulose (Burke and Lashof, 1990).

Methane emissions also vary directly with consumption level (i.e., the more feed consumed per animal the higher the emissions). At low consumption levels, a high-cellulose forage diet actually produces less methane than does a high-grain diet. On the other hand, at high consumption levels, a high-grain diet produces less methane than a high-cellulose diet (Baxter and Clapperton, 1965). This implies that the highest emissions occur with high-cellulose diets at high rates of consumption.

2.4.0 AGRICULTURAL EMISSIONS OF N₂O

Nitrous oxide is primarily produced in soil by the activities of microorganisms during nitrification, and denitrification processes. The ratio of N₂O to N production depends on oxygen supply or water-filled pore space, decomposable organic carbon, N substrate supply, temperature, and pH and salinity (IPCC, 1996; Rosenzweig and Hillel, 1998). N₂O production from soil is sporadic both in time and space, and therefore, it is a challenge to scale up the measurements of N₂O emission from a given location and time to regional and national levels (IPCC, 1996).

Nitrous oxide is a long-lived greenhouse gas (GHG), with a direct global warming potential 298 times higher than that of carbon dioxide over a 100-year period (IPCC, 2007; Mutegi *et al.*, 2010). Global anthropogenic emissions of N₂O presently amount to 4.5 ± 0.6 Tg N yr⁻¹, increasing atmospheric concentrations by approximately 0.25 % per year (Khalil and Rasmussen, 1992; Schlesinger, 1991; IPCC, 2007; Mutegi *et al.*, 2010). Agricultural land use may contribute up to 78 % of the anthropogenic N₂O source (USEPA, 2007). A number of agricultural activities add nitrogen to soils, thereby increasing the amount of nitrogen (N) available for nitrification and denitrification, and ultimately the amount of N₂O emitted. The emissions of N₂O that result from anthropogenic N inputs occur through both a direct pathway (i.e. directly from the soils to which the N is added), and through two indirect pathways (i.e. through volatilization as NH₃ and N₂O and subsequent redeposition, and through leaching and runoff) (IPCC, 2007).

Nitrous oxide is present in the atmosphere in even smaller quantities than methane. The current concentration is 0.31 ppm compared to 376 ppm for carbon dioxide and 1.79 ppm for that of CH₄ (Table 2.1), and its lifetime in the atmosphere is about 120 years. The average concentration of N₂O in the atmosphere is now increasing at a rate of 0.2 to 0.3 % per year (IPCC, 1996). Besides being a greenhouse gas, N₂O also plays another role in the atmosphere by oxidizing into NO in the stratosphere, where it acts to deplete the ozone.

Nitrous oxide emissions are part of the complex global nitrogen cycle by which various forms of nitrogen are both transported and transmuted in soils, plants, animals, and the atmosphere (Sprent, 1987; Brady, 1990; Schlesinger, 1991). There are large uncertainties in the estimation of N₂O emissions from both natural sources and human activities because of the high degree of spatial and temporal variations exhibited by many small sources. Human activities that contribute nitrous oxide emissions include the use of nitrogenous fertilizers (nitrate and ammonium fertilizers), biomass burning, conversion of forests to pastures in tropical regions, and the combustion of fossil fuels. Of these, agriculture plays a dominant role in fertilizer use, biomass burning, and land-use change (IPCC, 1992; 1995).

Surface burning of vegetation is estimated to release 0.2 to 1.0 million tons of nitrogen per year as N₂O (IPCC, 1992), and to lead to enhanced biogenic soil emissions of N₂O for an extended period (up to 6 months) subsequently (Anderson *et al.*, 1988). Tropical land-use, fertilizer and fossil-fuel use, are apparently contributors to atmospheric N₂O increases.

Estimates of N₂O emissions from fertilizer applications are highly uncertain, varying from 0.03 to 3.0 million tons per year out of an estimated total annual emission of 5 to 16 million tons N (IPCC, 1992). Uncertainties are due to lack of measurements of N₂O fluxes, the complexity of the biogeochemical interactions, and the heterogeneity of the land surface (IPCC, 1992).

2.4.1 NITROUS OXIDE EMISSIONS FROM SOILS

Nitrous oxide is released under natural conditions from water bodies and unfertilized soils via the sequential microbial processes of nitrification and denitrification, nitrate assimilation, and dissimilation (Sprenst, 1987). These processes are important stages in the global nitrogen cycle. Since plants cannot directly absorb the elemental nitrogen gas (N₂) that is abundant in the atmosphere, they must rely on certain bacteria in the soil and in aquatic systems to fix atmospheric nitrogen and convert it to ammonia or nitrate. It is in the nitrate forms that plants can absorb the nitrogen they need to synthesize proteins (Sprenst, 1987).

Nitrification is the biochemical oxidation of ammonium (NH₄⁺) to nitrate ions (NO₃⁻), predominantly by aerobic autotrophic bacteria. Denitrification is the biochemical reduction of nitrate ions, first to nitrite ions (NO₂⁻), and then to the gaseous compounds, nitric oxides (NO), nitrous oxide (N₂O), and nitrogen gas (N₂), by anaerobic microorganisms. Nitrous oxide is an intermediate stage of both nitrification and denitrification, but it is denitrification that constitutes the main process through which nitrous oxide is released from soils.

Under field conditions, denitrification produces both N_2O and N_2 . N_2O emission is favoured when there is ample nitrite ion (NO_2^-) present in the soil. Nitrous oxide emissions vary widely with soil conditions. Decomposable soil organic matter is generally needed for nitrification and denitrification processes to occur.

Other factors that affect N_2O emissions, besides soil organic matter, include soil moisture, available oxygen, temperature, of other chemicals, the amount of residual nitrogen present in the soil, tillage methods, irrigation practices, and crop rotation. Production of N_2O is generally stimulated by precipitation, although prolonged flooding inhibits it. Alternating wet and dry periods have been shown to increase emissions. Soil aeration diminishes emissions, because aerobic conditions promote complete nitrification and the production of nitrates as an end product rather than N_2O . Warmer temperatures also promote N_2O emissions. Denitrification has a temperature range of 25 to 65°C. N_2O production shows strong diurnal and seasonal cycles. Low pH values tend to arrest the denitrification process at the NO production phase before complete reduction occurs and forms N_2 gas. Therefore, soil acidity tends to promote N_2O emissions (Parker, 2009).

2.4.2 NITROUS OXIDE AND FERTILIZERS

Crops take up nitrogenous fertilizers, though often incompletely. The residues are either leached from the soil profile by downward percolation or volatilized following denitrification in the form of nitrous oxide. Significant amounts of nitrous oxide are emitted from agricultural soils, particularly from poorly aerated soils fertilized with organic manures or having high organic matter content (Sahrawat and Keeney, 1986; Coyne *et al.*, 1994).

Synthetic fertilizers also contribute to N₂O emissions. Nitrous oxide is released from soils during nitrification of ammonium and ammonium-producing fertilizers under aerobic conditions, as well as by denitrification of nitrates under anaerobic conditions (Bremner and Blackmer, 1978).

The use of synthetic fertilizers for agricultural crop production has grown widely since their advent in the late 1800s. Since the mid-1980s more than 70 million metric tons of nitrogen has been applied to crops each year (FAO, 1993). Nitrogenous fertilizer has been estimated to contribute between 0.14 to 2.4 million tons of the total annual N₂O emissions of 8 to 22 million tons (Lashof and Tirpak, 1990).

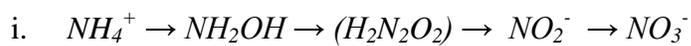
High rates of nitrogen fertilizer often exceed plant uptake and result in leaching of nitrates to groundwater or in run-off to surface waters. High nitrate levels in soils and water bodies provide a substrate for denitrification, the major process that releases N₂O to the atmosphere.

Both organic fertilizers and inorganic or synthetic fertilizers tend to promote N₂O production and release, but the differential impacts of the various types of N fertilization are yet undefined. Synthetic fertilizers are assumed to be the major sources of emissions, due to the often large quantities applied and the non-optimal timing and placement of the applications (Ehrlich, 1990), but fluxes from manured soils, especially after rain, can also be high (Coyne *et al.*, 1994).

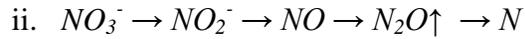
Attempts have been made to estimate the relative amounts of nitrous oxide emissions from various fertilizers. Eichner (1990) observed that daily average emissions of N₂O per kg N applied per ha are highest for anhydrous ammonia, followed by ammonium chloride and sulfate, ammonium nitrate, calcium, potassium, and sodium nitrates; and urea. Emissions tend to be higher when these fertilizers are applied in solution rather than in solid form. The average N₂O release from fertilized soils due to N fertilizer varied from about 0.1 to 1.5 % of applied nitrogen, with variations in release depending on soil type (Byrnes *et al.*, 1990).

2.5.0 GASEOUS LOSSES OF NITROGEN FROM SOIL

There are losses of nitrogen from soil in ways other than leaching and crop removal. Gaseous losses occur primarily as nitrous oxide (N₂O) and dinitrogen (N₂) during reductive (denitrification) and oxidative (nitrification) processes according to the following reactions:



↓



Other mechanisms leading to gaseous losses of nitrogen from soil include:

- a. Chemical decomposition of nitrite under aerobic conditions to form N_2 , NO plus NO_2 ; and small quantities of N_2O .
- b. Non-biological volatilization of free ammonia.

According to Tisdale *et al.*, (1985), denitrification of NH_4^+ does not take place, rather significant gaseous losses from ammonium and calcium nitrates could be obtained but no significant loss from ammonium sulphate.

2.5.1 DENITRIFICATION (REDUCTION PROCESS)

When soils become waterlogged, oxygen is excluded and anaerobic decomposition takes place. Some anaerobic organisms have the ability to obtain their oxygen from nitrates and nitrites with the accompanying release of nitrogen and N_2O . The most probable biochemical pathway leading to these losses is indicated in the equation below:



A few particular kinds of facultative aerobic bacteria are responsible for denitrification, and the active species belong to the genera *Pseudomonas*, *Bacillus*, and *Paracoccus*. A few species of *Chromobacterium*, *Corynebacterium*, *Hyphomicrobium*, and *Serratia* are implicated in

denitrification. Several autotrophs also capable of bringing about denitrification include *Thiobacillus denitrificans* and *Thiobacillus thioparus*.

There are large populations of these denitrifying organisms in arable soils and they are mostly numerous in the vicinity of plant roots. Carbonaceous exudates from actively functioning roots are believed to support growth of denitrifying bacteria in the rhizosphere. The potential for denitrification is immense in most field soils, but conditions must arise which cause these organisms to shift from aerobic respiration to a denitrifying type of metabolism involving use of NO_3^- as an electron acceptor in the absence of oxygen.

The magnitude and rate of denitrification are strongly influenced by several environmental factors, and these include the amount and nature of organic matter present, moisture content, aeration, soil pH, soil temperature, and level and form of inorganic nitrogen present. Bremner (1978) has established the fact that a supply of nitrate and / or nitrite in soil is a prerequisite for denitrification. Fertilizer nitrogen enters a labile “pool” of soil nitrogen that is subjected to continuous denitrification losses to the atmosphere. Since the earth’s atmosphere is largely N_2 while its oceans are virtually nitrate-free, denitrification is probably the process responsible for returning nitrogen to the atmosphere, thus offsetting gains from biological N- fixation.

The balance-sheet calculations, show that about 30 % of the applied nitrogen is lost through denitrification and leaching (Bremner, 1978). Higher part of the loss is attributed to denitrification.

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Therefore, the increased use of nitrogen fertilizers could substantially increase emissions of nitrous oxide from soils and thereby lead to partial destruction of the stratospheric ozone layer protecting the biosphere from biologically harmful ultraviolet radiation from the sun (Tisdale *et al.*, 1985).

Although there is evidence that denitrification of fertilizer-derived nitrate is responsible for emission of N_2O , contributions from nitrate produced by the natural transformations of soil organic matter and fresh crop residues have been largely ignored or discounted (Tisdale *et al.*, 1985).

2.5.2 CHEMICAL REACTIONS INVOLVING NITRITE

In addition to the volatilization of nitrogen by microbiological denitrification, nitrogen can also be released to the atmosphere by non-enzymatic decomposition of NO_2^- accumulated under apparently well-aerated conditions and from basic or alkaline soils. These gaseous losses of nitrogen occur while ammonium and ammonium-producing fertilizers are being nitrified (Christianson *et al.*, 1979).

The chemical reactions of NO_2^- are partly responsible for these fertilizer-induced emissions of nitrogen gases such as nitrous oxide and nitric oxide. Losses of nitrogen from NO_2^- by chemo-denitrification have been shown to increase with increasing organic matter content. The phenolic sites in soil organic matter are responsible for the reduction of nitrous acid to N_2 and N_2O , with nitrosophenols formed as intermediates.

The nitrosophenols are believed to tautomerize to quinine oximes, which subsequently reduce some of the nitrous acid to N_2O or N_2 (Christianson *et al.*, 1979). All the N_2O or N_2 evolved is thought to come entirely from the accumulated NO_2^- . Although, build up of NO_2^- in soil is favoured by high pH, its break down into gaseous forms of nitrogen is restricted by high soil pH (Tisdale *et al.*, 1985).

The nitrite loss mechanisms include:

- i. Decomposition of NH_4NO_2
- ii. Self-decomposition of HNO_2 at pH values below 5.0 with the resultant formation of NO plus NO_2^- .
- iii. Dissimilation of NO_2^- by reducing organic compounds.
- iv. Fixation of NO_2^- by soil organic matter and partial conversion of some N_2O , N_2 , and NO_2^- .

- v. Catalytic reaction of NO_2^- with reduced transitional metals such as Cu, Fe, and Mn.

The relative importance of these loss mechanisms varies among soils and the nitrogen management systems practised. In the transformation of NO_2^- in soil, part of the nitrogen becomes organically bound or fixed, while some nitrogen is concurrently evolved as N_2 , N_2O , and $\text{NO} + \text{NO}_2^-$. This fixation of NO_2^- and the associated release of nitrogen gases is significantly affected by soil pH and organic matter content. Nitrite fixed by soil organic matter is resistant to mineralization, because of the stability of the resultant heterocyclic compounds (Tisdale *et al.*, 1985).

2.5.3 FERTILIZER-INDUCED EMISSIONS INVOLVING NITROUS OXIDE

Breitenbeck *et al.* (1980) reported that small quantities of N_2O were generated in the course of nitrification of ammonium-forming fertilizers. They indicated that the fertilizer-induced emissions of N_2O with sulphate of ammonia, urea, and potassium nitrate amounted to between 0.11 and 0.18 % of the fertilizer nitrogen applied.

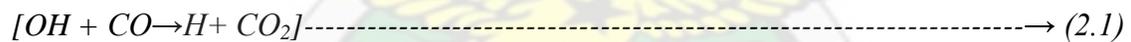
Further research by Breitenbeck *et al.* (1980) suggested that N_2O emissions are high when anhydrous ammonia is the nitrogen source. Thirty percent of the total N_2O emitted during the growing season in a Colorado study occurred from late June to the middle of July, a time when ammonia fertilization was being oxidized to nitrate by soil bacteria (Breitenbeck *et al.*, 1980). Apparently, N_2O was produced in the course of autotrophic nitrification of ammonia. If they are significant, it may be possible to modify fertilizer programs so that high concentrations of NH_4^+ in alkaline soil environments do not persist for extended periods (Fenn and Kissel, 1974).

2.5.4. NITRIFICATION (OXIDATION PROCESS)

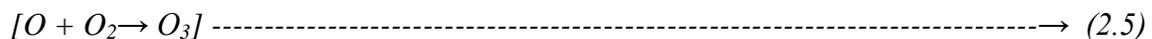
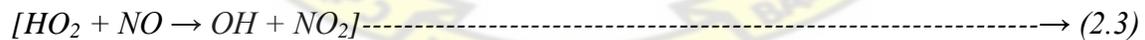
Nitrification is the biochemical oxidation of ammonium (NH_4^+) to nitrate ions (NO_3^-), predominantly by aerobic autotrophic bacteria. Similarly, the chemical reactions involved in tropospheric ozone formation are a series of complex cycles, in which carbon monoxide (CO) and volatile organic compounds (VOCs) are oxidized to water vapour and carbon

dioxide (Andreae *et al.*, 1988; Chatfield *et al.*, 1996; Thompson *et al.*, 1996; Chandra *et al.*, 2002).

The ozone formation starts with oxidation reaction of CO with hydroxyl radical. The hydrogen atom resulting from this then reacts rapidly with oxygen to give a peroxy radical HO_2 (Thompson *et al.*, 1996; Jenkins *et al.*, 1997).



The peroxy radicals then react with NO to give NO_2 , which is photolysed to give atomic oxygen. This goes into reaction with oxygen and a molecule of ozone is produced, thus:



The net effect of these reactions is:

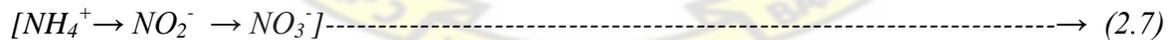


This cycle involving HO and NO is terminated by the reaction of OH with NO₂ to form nitric acid (HNO₃) or by the reaction of peroxy radicals with each other to form peroxides. The chemistry involving VOCs is much more complex but the same reaction of peroxy radicals oxidizing NO to NO₂ is the critical step resulting in the formation of ozone.

Nitrogen oxides (NO_x = NO + NO₂) contribute immensely to the oxidative capacity of the troposphere by the catalytic behavior of NO_x in the photochemical formation of ozone (O₃) (Graedel and Crutzen, 1993).

In the tropical Amazon Basin, sources of NO are mainly biomass burning (Andreae *et al.*, 1996) and biogenic emissions from the soil (Davidson *et al.*, 2000).

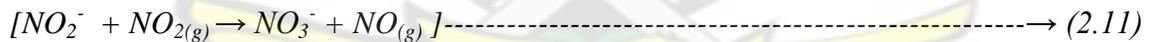
Production of nitric oxide (NO) in soil occurs both biologically (e.g. nitrification and denitrification) and chemically (chemo-denitrification). Nitrification is the oxidation of ammonium (NH₄⁺) to nitrate (NO₃⁻) (equation 2.7). Besides, heterotrophic bacteria have been found to oxidize NH₄⁺ and organic nitrogen species to NO₂⁻ and NO₃⁻ (heterotrophic nitrification).



Biological denitrification involves the reduction of NO₃⁻ to NO₂⁻, producing N₂O and N₂ (equation 2.8). Denitrification usually occurs under anaerobic conditions, although aerobic denitrifies and heterotrophic nitrifies have been found to denitrify NO₃⁻ under aerobic conditions (Parker, 2009).



Another pathway for NO production is through chemical reactions. Nitrite (NO_2^-) and nitrous acid (HNO_2) become chemically unstable in acid soils ($\text{pH} < 5.5$), especially in combination with a high organic matter content (Ludwig *et al.*, 2001). The concentrations of these species are generally low in soil. However, NO_2^- is produced as an intermediate product during both nitrification and denitrification, and hence can react chemically directly after its biological formation in acid and organic soils. Several chemical reactions are known to produce NO (as evidenced in equations 9, 10, and 11). These are generally referred to as chemo- denitrification.

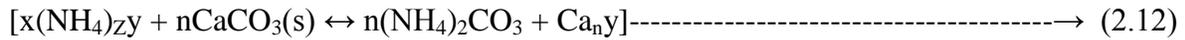


NO is also consumed in soil, and it is a substrate for denitrification and various other biological reduction and oxidation processes (Rudolph *et al.*, 1996).

Nitric oxide production and consumption occur simultaneously in soil. Research has proved that NO production generally exceeds consumption, resulting in net release of NO from soil to the atmosphere (Meixner and Eugster, 1999).

2.6.0 VOLATILIZATION OF AMMONIA

Ammonium-containing or ammonium-forming fertilizer reacts with CaCO_3 in soil to form $(\text{NH}_4)_2\text{CO}_3$ and calcium precipitates. The following general equations developed by Fenn and Kissel (1975) represent the reactions that take place.



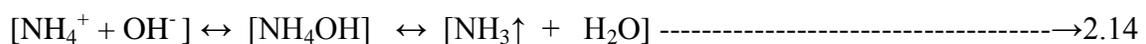
Where Y represents the ammonium anion and n, x, y and z depend on the valences of the anion and cation.

The final reaction product, $(\text{NH}_4)_2\text{CO}_3$ is unstable and decomposes thus:



The amount of NH_4OH formed in a given time would depend on the solubility of Ca_nY_x , and its rate of formation. If Ca_nY_x is insoluble, the reaction would proceed to the right causing more $(\text{NH}_4)_2\text{CO}_3$ and consequently more NH_4OH to be formed. If no insoluble precipitate is formed, no appreciable quantity of $(\text{NH}_4)_2\text{CO}_3$ will exist.

When $(\text{NH}_4)_2\text{CO}_3$ decomposes according to equation (2.13), CO_2 is lost from solution at a faster rate than NH_3 thereby producing additional OH^- ions and an increase in $[\text{OH}^-]$. Consequently, more NH_4^+ in solution becomes electrically balanced by OH^- , which would favour NH_3 loss as represented by the reaction:



If Ca_nY_x is soluble, then the NH_3 loss that occurs will be dependent upon the resultant pH value of the soil. The $\text{NH}_3\text{-NH}_4^+$ equilibrium is pH-dependent with lower pH values favouring the NH_4^+ forms (Tisdale *et al.*, 1985).

2.6.1 FACTORS INFLUENCING AMMONIA VOLATILIZATION

Many greenhouse and laboratory studies have shown that ammonia volatilization is influenced by soil factors such as pH, calcium carbonate content, cation exchange capacity, exchangeable cations, soil texture, temperature, soil moisture content, and species of ammonium-containing or ammonium-forming fertilizer salt (Parr and Engibous, 1966). Various aspect of fertilizer management, including rate of NH_4^+ application and depth of incorporation, also have important effects on ammonia losses. Results from numerous investigations conducted in the laboratory and under artificial conditions revealed that ammonia losses usually became greater with increases in soil pH, CaCO_3 content, temperature, and rate of NH_4^+ application. The percentage of free ammonia increases very rapidly with rising pH (Parr and Engibous, 1966).

Table 2.5: Relationship of pH to Percentage of Non-Ionized Ammonia

pH of Solution	Percentage of Non-ionized or Free Ammonia
6	0.1
7	1.0
8	10.0
9	50.0

Source: Parr and Engibous (1966)

The equilibrium equation for ionized and free ammonia is an integral part of the ammonia volatilization mechanisms as advanced by Fenn and Kissel (1975). Ammonia loss is thus favoured by naturally high soil pH or by reactions that raise it, even temporarily. Ammonia loss is greatest from ammonium fertilizer salts, which reacts with CaCO_3 to form precipitates of low solubility (Fenn and Kissel, 1975; Feagley and Hossner, 1978).

2.6.2 GASEOUS LOSS OF NO_3^-

It has also been suggested that there may actually be volatile losses of NO_3^- as nitric acid in soils containing appreciable amounts of KCl - exchangeable Al^{3+} plus H^+ . Under laboratory conditions greater losses of NO_3^- were observed on those soils with the greater amount of exchangeable acidity, and the losses increased with increases in temperature. The extent of such losses under field conditions is not known (Tisdale *et al.*, 1985).

The average nitrogen concentration in natural organics is typically between 1.0 and 13.0 %. Natural organic materials at one time were thought to release their nitrogen slowly, supplying the crop with its nitrogen requirement as needed, thereby avoiding excessive uptake and reducing potential losses of this element by leaching and denitrification. This was shown not to be the case; however, as more of the nitrogen that became available did so within the first three weeks. Under conditions optimum for nitrification at best only about half of the total nitrogen was converted to a form available to plants at the end of 15 weeks. In addition, of

the nitrogen (N) mineralized during the 15-week period, 80 % had been converted to NO_3^- at the end of the first three weeks (Cominco Ltd., 1979).

It is obvious that under warm, moist conditions, slow release of N from organic fertilizers is not effected and the amount becoming available to the crop is but a fraction of the total amount they contain (Beaton *et al.*, 1976).

2.6.3. CHEMICAL (SYNTHETIC) FERTILIZERS

Synthetic or chemical fertilizers are by far the most important sources of nitrogen. Anhydrous ammonia is the basic building block for almost all of these chemically derived N-fertilizer materials. Most of the ammonia in the world is produced synthetically by reacting N and H_2 gas, although some is still recovered as a by-product of coking coal. From the basic compound NH_3 , many different fertilizer N compounds are manufactured. A few materials do not originate from synthetic ammonia, but they constitute only a small percentage of the N-fertilizer tonnage used worldwide.

For convenience, the various N compounds are grouped into four (4) categories, namely: ammoniacal, nitrate, slowly available and others (Cominco Ltd., 1979). The composition of three (3) common chemical sources of N fertilizer used in Ghana is shown in Table 2.6.

Table 2.6: Fertilizer Use by Maize in Ghana

	Average fertilizer consumption(tones per	

Type of fertilizer	year)		Percent N content
	Bulk fertilizer	N consumed	
Ammonium Sulphate	8,620	1,810	21
Urea	1,925	886	46
Potassium nitrate	2,660	399	15
Total N nutrient consumption	-	3,095	-

Source: FAO Report, (2002)

2.6.4. AMMONIUM SULPHATE [(NH₄)₂SO₄]

This is one of the oldest sources of ammoniacal N, having been manufactured for many years as a by-product of the coking of coal. It now accounts for approximately 4 million tons of plant nutrient nitrogen worldwide.

In addition to the ammonium sulphate made available by recovery of coke-oven gas from the steel industry, it is also a by-product from metallurgical and chemical operations. Approximately ¼ of its world production stems from caprolactan manufacture, a raw material for the production of synthetic fibers (The Fertilizer Institute, 1973; IFDC, 1979).

The main advantages of (NH₄)₂SO₄ are low hygroscopicity, chemical stability and agronomic suitability. It is a good source of both N and S. The strongly acid-forming reaction of ammonium sulphate in soil can be undesirable in acidic soils already in need of liming. The

main disadvantage is its relatively low N concentration which when used solely for this nutrient will add substantially to packaging, storage, and transportation costs.

However, $(\text{NH}_4)_2\text{SO}_4$ can be an economical source of N when transportation cost are low, when it is a relatively inexpensive by-product, and when credit is given for its S content (Freney, 1967 ; The Fertilizer Institute,1973; IFDC, 1979).

2.6.5 UREA [$\text{CO}(\text{NH}_2)_2$]

Commercial production of urea first began in Germany in 1922, in 1932 in the U.S. and in 1935 in England. It was also manufactured as early as 1920 in eastern Canada (The Fertilizer Institute,1973; IFDC, 1979). Doubts about the agronomic suitability of urea impeded its adoption. Many agriculturists had reservations about using urea because of potential problems related to:

- i. Harmful effects of biuret, an impurity normally found at low concentrations, on germination and early growth of seedlings;
- ii. Phytotoxicity of urea to seed and seedlings due to locally high concentrations of ammonia released during the hydrolysis stage and/or the accumulation of nitrite during nitrification; and
- iii. N loss as ammonia from urea exposed on the soil surface particularly at high temperatures (IFDC, 1979).

According to IFDC (1979), practical experience with urea, so far, has shown that it is as good as any other N fertilizer if used properly. For efficient use of urea a higher degree of understanding of its properties and behavior in soil is necessary than for other N sources, such as sulphate of ammonia and potassium nitrate. There are, e.g. limits to the amount of urea that can be routinely placed with or near crop seeds. In addition, unfavourable climatic conditions, particularly high temperatures, should be avoided for broadcast applications of urea on bare surface soil and on grassland in humid areas (IFDC, 1979).

Urea is considered a slow-release fertilizer in the temperate region since it must undergo both hydrolysis and nitrification before it becomes abundantly available to most crops. These transformations proceed rapidly in warm, moist soils, such as prevalent particularly, in Ghana, and generally in West Africa. For paddy rice production, urea is preferable to nitrate-containing N fertilizers since nitrates tend to be denitrified and lost to the atmosphere when they are applied to flooded anaerobic soils. Also, the rice plant is fully able to utilize the ammonium form of N. The satisfactory properties of the physically improved granular urea plus favorable economics of manufacturing, handling, storage, and transportation have made urea a very competitive source of fertilizer N (IFDC, 1982).

2.6.6 ORGANIC FERTILIZERS (MANURES)

Organic fertilizers are soil enrichment substances that come directly from plant and animal sources. These may be partly processed by microorganisms, as is the case with animal manures and composts, or in pure form, as is the case with green manures (Awiti *et al.*, 2000).

2.6.7 ANIMAL MANURES

All types of animal manure can be used as fertilizers, but some are easier to collect and store than others. The most common sources of animal manure in Ghana are poultry, cattle, sheep and goats (Awiti *et al.*, 2000). Traditionally, the key sources of manure production for soil amendment and enrichment in Ghana are from cattle and poultry. Even though the population of sheep and goats is quite high, they are often tended in the field and the nature of their droppings, which are small in size, does not make them the key source of manure production (Bonsu, 2010). The population of cattle and poultry as well as their growth rate from 1996 to 2002 in Ghana are given in Table 2.7.

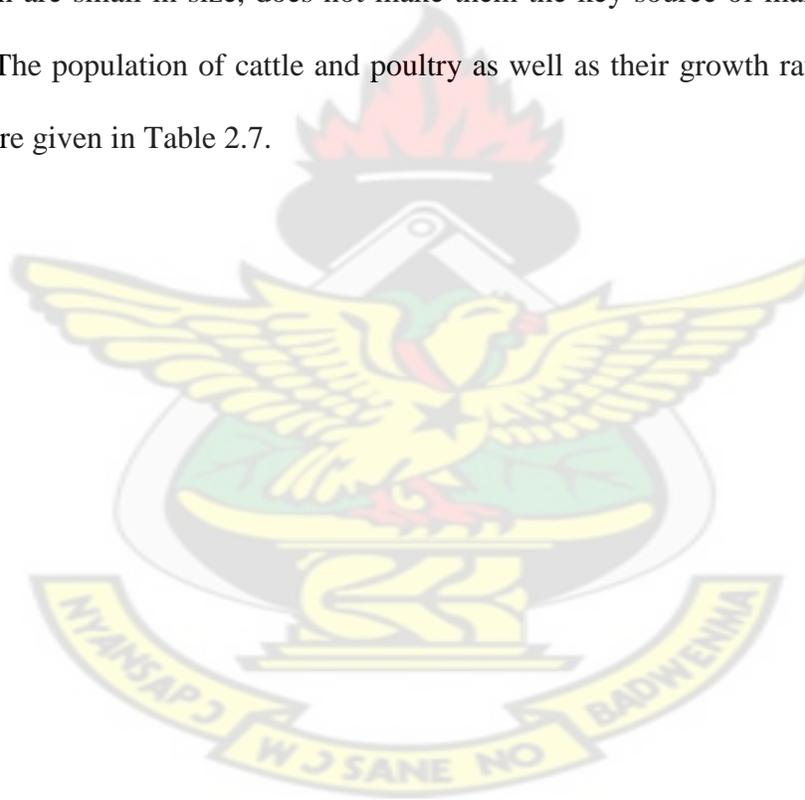


Table 2.7: The Population of Cattle and Poultry between 1996 and 2002.

YEAR	Cattle		Poultry	
	Population (‘000)	Growth Rate (%)	Population (‘000)	Growth Rate (%)

1996	1,248	-	14,589	-
1997	1,260	0.90	15,888	8.9
1998	1,273	1.04	17,302	8.8
1999	1,288	1.20	18,810	8.8
2000	1,302	1.10	20,472	8.8
2001	1,315	1.00	22,032	7.6
2002	1,330	1.15	24,251	9.6
Average	1,288	1.07	19,049	8.75

Source: ISSER, 2005.

The dung consists of undigested food parts, ground up and saturated with digestive juices. Dung will generally contain approximately one third of the nitrogen, one fifth of the potassium and nearly all phosphoric acid excreted by the animal. The large bacterial population present in the dung, up to 30 % of its mass, is important for its role as an activator in compost production (Awiti *et al.*, 2000; Bonsu, 2010). Efficient use of manure is possible by using appropriate collection, decomposition, storage and application techniques. Animal manure adds a concentrated, transportable and rapidly effective fertilizer to the nutrient cycle of the soil. It also provides a convenient way of applying nutrients to fields when and where they are needed.

Generally, animal manure has the following values and/or importance:

- i. *Provide a source of organic matter*
- ii. *Provide essential plant nutrients (NPK)*

- iii. *Provide essential micronutrients (Fe, Mn, Zn, Cu)*
- iv. *Improve soil-water storage capacity*
- v. *Improve soil structure*

Addition of animal manure to the soil results in an increase in humus as organic matter decomposes, as well as increasing the stability of soil structure and the ease with which roots can penetrate the soil.

Different livestock manures have different qualities of fertilizers due to differences in their nutrient and organic matter content. Within the same animal species, the composition of dung and urine varies according to what the animal eats (site, season) and water supplies, as well as the age of the animal and how it is used. For example, young animals and good milk-producing cows excrete less nitrogen than working or old animals because of their more efficient use of protein.

Except in the case of poultry, the proportion of soluble nitrogen in fresh dung is relatively low. In fresh cattle, horse or sheep manure, only some 10 % of the total nitrogen is immediately available (Awiti *et al.*, 2000). Storing and rotting the dung increases the content of available nitrogen, although the total nitrogen level may be reduced during the process by nitrate leaching and volatilization, implying some nitrogen losses into the atmosphere (Lekasi *et al.*, 1998).

Ruminants kept under smallholder conditions in the tropics (including Ghana), produce approximately 0.8 % of their live weight as faecal dry matter each day, and poultry 1.5-1.7 %

with adequate diets. Over the course of a year, this translates into 1022 kg per tropical livestock unit (250 kg) for ruminants. To obtain a similar weight of poultry faeces, 110-120 local poultry would be required (Barnard and Kristofferson, 1985).

Table 2.8: Estimate of Annual dung production from different livestock species.

Livestock type	Annual dung production (kg dry weight)
Cows	425-1445
Pigs	170-255
Sheep and Goats	85-170

Source: Barnard and Kristofferson (1985).

Associated with intensification of livestock operations is an increased amount of manure produced each year. In Ghana, the traditional practice is the direct application of cattle and poultry manure to farmlands. However, this has created environmental concerns such as nitrate leaching to the ground water, and contribution to emissions of greenhouse gases such as CO₂, CH₄, and N₂O (Chang and Janzen, 1996).

Eghball *et al.* (1997) observed N loss via NH₃ volatilization of 19 to 42 % of total N, and C loss as CO₂ between 46 and 62 % of total C during cattle feedlot manure in Nebraska. Nitrous oxide and CH₄ emission during the composting of municipal solid waste has also been reported (Hellmann *et al.*, 1997).

Nitrous oxide emissions varied between 0 and 0.33 g Nm⁻²d⁻¹ in a laboratory flow-through study simulating solid dairy manure storage (Brown *et al.*, 2000), and varied between 0 and 0.025 g Nm⁻²d⁻¹ during storage of solid pig manure (Petersen *et al.*, 1998). However, there is an apparent scarcity of quantitative information on GHG emissions during manuring and composting, especially in Ghana. This information is crucial for developing and assessing the potential for mitigating GHG emissions from cattle and poultry manure operations in Ghana.

2.7.0 GREENHOUSE GAS INVENTORIES FOR THE AGRICULTURAL SECTOR

This is based on the 2009 Ghana country report of the UNDP on capacity building for improving the quality of greenhouse gas inventories for the agricultural sector (Bonsu, 2010). This report generated the activity data of the population of livestock categories of cattle, sheep, goats, pigs, donkeys, horses, and poultry, between 1996 and 2002, obtained from the Directorate of Veterinary Services, MoFA, Accra, Ghana.

According to Bonsu (2010), the key sources of manure production in Ghana are from cattle rearing and poultry production under deep litter. Based on UNDP (2009) report, manure production, is estimated on the assumption that the average live-weight of cattle in Ghana is 250 kg and the daily feed requirement is 2.5 % of the live-weight (i.e. 6 kg per day). This amounts to 2190 kg per year feed requirement of average cattle. Effective digestibility of cattle in Ghana is 40 %, implying that feed intake that comes out as manure is 60 % of 2190 kg or 1314 kg per cattle per year. From this projection, future scenarios can be obtained by adjusting the current amounts by the average growth rate of 1.07 %.

The nitrogen content of cattle manure from confined animals in the kraal and that from droppings in the field has been estimated to be 1.41 % and 1.17 % of weight of manure, respectively (SRI-CSIR, 1999). The loss due to volatilization in the field accounts for 0.24 % of the total N lost, and the mean total N content of cattle manure from different locations in the savanna zone of Ghana was found to be 1.34 % (Bonsu, 2010).

Cattle manure management is a key source of emission of N_2O in Ghana, according to Bonsu (2010). With an average N content of 1.34 %, average annual cattle manure production of 1314 kg per animal and a total cattle population of 1.30 million, the total amount of N from cattle manure management can be estimated. Hence, the amount of N_2O emissions can be estimated using the conversion factor of 44/28 or 1.6 from the estimated N. Future projections or scenarios of N_2O emissions from cattle manure management can be obtained using the average growth rate of 1.07 %.

The average population of poultry within the period is estimated to be 19,049, with an annual growth rate of 8.75 %, the average bird-weight and feed intake of chicken in Ghana is about 1.4 kg, and 0.13 kg per day respectively, corresponding to a live-weight of 9.3 %. The total weight of poultry was 26.6 million kilograms, which translates into 47.45 kg of feed consumed per year. Therefore, in a year, the total weight of feed consumed by 9 million chicken will be approximately 901 million kilograms.

Effective digestibility of poultry in Ghana is assumed to be 40 %, hence, the total poultry manure is 60 % of the total feed intake, resulting in approximately 12 million kilograms per year. Again, future projections or scenarios are adjusted by considering the annual growth of 8.75 %. Therefore, the amount of N₂O produced by poultry is obtained using the conversion factor of 44/28 or 1.6. The average N content of poultry manure in Ghana is estimated to be about 2.2 % per kilogram.

The annual amount of synthetic fertilizer N applied is calculated using the assumption that the annual rate of synthetic fertilizer N consumed increases at a rate of 1.4 %. From this, the amount of N₂O emissions from synthetic fertilizers is estimated using a factor of 1.6. Future projections and /or scenarios can be estimated by adjusting the values by 1.4 % annually.

In Ghana, according to Bonsu (2010), the extensive system of livestock management whereby the animals are led out to graze in the field on undeveloped pastures and are brought back to be housed in kraals during the night is generally widely practised. Therefore, enteric fermentation is not the key source of methane emission. In this regard, the Tier 1 approach, in which the livestock population is used to estimate methane emissions from enteric fermentation, is applied. Bonsu (2010) reported that the annual mean growth rate of goats, sheep, and cattle are 4.7, 3.2, and 1.1 % respectively. With these growth rates, the activity data (in the form of livestock population) can be estimated and hence, methane emissions can be estimated using IPCC default factors.

2.8.0 EMISSION FACTOR (EF)

Emission factor is a coefficient that relates the activity data to the amount of chemical compound, which is the source of later emission. Emission factors are often based on a sample of measurement data, averaged to develop representative rate of emission for a given activity level under given set of operation conditions (IPCC, 1996).

Mathematically, the emission can be presented as:

$$[Emission = EF \times Activity\ data] \text{-----} \rightarrow 2.15$$

Activity data refers to data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time (Parker, 2009). According to IPCC, (1996), the Tier 1 Approach, which is consistent with good practice, prescribes that emission factors and activity data are developed according to the guidance presented below:

$$N_2O_{Direct-N} = [(F_{SN} + F_{AM} + F_{BN} + F_{CR}) \times EF_1] \times (F_{OS} \times EF_2) \text{-----} \rightarrow 2.16$$

where:

$N_2O_{Direct-N}$ = Emission of N_2O in units of Nitrogen

F_{SN} = Annual amount of synthetic fertilizer nitrogen applied to soils adjusted to account for the amount that volatilizes as NH_3 and NO_x

F_{AM} = Annual amount of animal manure nitrogen intentionally applied to soils adjusted to account for the amount that volatilizes as NH_3 and NO_x

F_{BN} = amount of nitrogen fixed by N-fixing crops cultivated annually

F_{CR} = Amount of nitrogen in crop residues returned to soils annually

F_{OS} = Area of organic soils cultivated annually

EF_1 = Emission factor for emissions from N inputs (kg N₂O-N/kg N input)

EF_2 = Emission factor for emissions from organic soil cultivation (kg N₂O-N/ha-yr)

Conversion of N₂O-N emissions to N₂O emissions for reporting purposes is performed by using the equation:

$$N_2O = N_2O-N \times 44/28, \text{ (IPCC, 2007)} \rightarrow 2.17.$$

The activity data to be generated include:

- i. Mass of poultry manure + 20 % of mass (fixed loss rate of nitrogen that volatilizes as NH₃ and NO)
- ii. Mass of cattle manure + 20 % of mass (fixed loss rate of nitrogen that volatilizes as NH₃ and NO)
- iii. Mass of urea + 10 % of mass (fixed loss rate of nitrogen that volatilizes as NH₃ and NO)
- iv. Mass of ammonium sulphate + 10 % of mass (fixed loss rate of nitrogen that volatilizes as NH₃ and NO) (IPCC, 1996).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY AREA

The study was done at the Soil Science Laboratory, Department of Crop and Soil Sciences, and Plantation Section, all of the Faculty of Agriculture, KNUST, Kumasi, and Soil Research Institute Experimental Field at Kwadaso, Kumasi, Ghana. All laboratory analysis on the soils, cattle manure and poultry manure and the experimental set up for the collection of the GHGs were done in the Soil Science Laboratory.

3.2 SOILS, CATTLE MANURE AND POULTRY MANURE USED IN THE STUDY: SAMPLING AND SAMPLE PREPARATION

The soils used in the study were Kumasi series classified as Plinthi Ferric Acrisol (FAO / UNESCO, 1990) or Typic Plinthustult (Soil Survey Staff, 1998), and Bekwai Series classified as Orthi-Ferric Acrisol (FAO, 1988) or Plinthic Acrisol (WRB, 1998). The Kumasi series is a sandy loam soil and the Bekwai series is a loam soil.

The Kumasi series was taken at the Plantation Section of the Faculty of Agriculture, KNUST, Kumasi. This is located within 13 kilometers to the East of Kumasi City Center and lies within

longitudes $1^{\circ} 15' W$ and $1^{\circ} 52' W$ and latitudes $6^{\circ} 68' N$ and $6^{\circ} 69' N$ of the Greenwich Meridian in the semi-deciduous forest zone of Ghana. It has a bimodal rainfall pattern averaging about 1500 mm annually.

The Bekwai series was sampled near the uncultivated forest at the Soil Research Institute Experimental Field at Kwadaso, Kumasi. This is located about 8 km South-West of Kumasi City Centre. The area lies between latitudes $06^{\circ} .39' N$ and $06^{\circ}.43' N$ and longitudes $01^{\circ}.39' W$ and $01^{\circ}.42' W$ of the Greenwich Meridian in the semi-deciduous forest zone of Ghana. It has a bimodal rainfall pattern averaging about 1500 mm annually (Tetteh, 2004).

About 500 kg composite or bulked sample of each soil series was randomly collected at several locations at a depth of 0-20 cm using a spade and a pickaxe. The soils were air-dried and big stones were removed. Sub-samples of each soil series were taken and passed through 4 mm sieve. These were used for the organic C, total N, pH, and particle size distribution analyses, and the GHG emission experiment. Poultry manure and cattle manure materials were collected from the manure dump and cattle ranch sections, respectively of the Department of Animal Science, Faculty of Agriculture, KNUST.

3.3.0 ANALYTICAL METHODS

The soils were analyzed for organic C, pH, total N, and particle size distribution. The poultry manure and cattle manure were analyzed for pH, organic C, and total N. For each material,

three replicate samples were analyzed and the mean determined. Soil pH was determined in a 1:2.5 soil to distilled water ratio using the pH/Ion 510 Bench meter. The pH of the poultry manure and cattle manure were determined in a similar fashion (Rhoades, 1982).

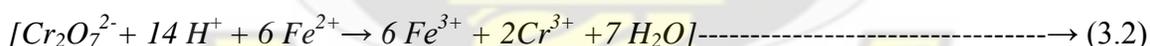
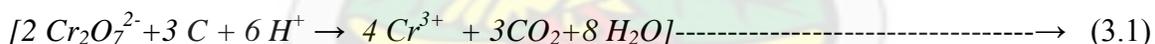
A blank reagent mixture was similarly treated alongside the soil. This was necessary to standardize the ferrous sulphate –a secondary standard which oxidizes gradually in the air.

KNUST

3.3.1 DETERMINATION OF SOIL ORGANIC CARBON

Organic C was determined by the modified Walkley-Black Wet oxidation method as outlined by Nelson and Sommers (1982). This procedure involves the oxidation of the organic C with potassium dichromate and the heat generated from the addition of conc. H₂SO₄. Addition of excess K₂Cr₂O₇ to a known weight of soil facilitates the oxidation of carbon in the soil and the excess titrated with 1.0 M ferrous sulphate.

Below are the summary equations of the reactions involved:



In this procedure, 2.00 g of soil was weighed into 250 ml conical flask and 10 ml of 0.166 M (1.0 N) K₂Cr₂O₇ solution added, followed by 20 ml conc. H₂SO₄ and allowed to cool on an asbestos material for 30 minutes. About 200 ml of distilled water was added followed by 10 ml of H₃PO₄ and then 1.0 ml of diphenylamine indicator solution. This mixture was then titrated with 1.0 M ferrous sulphate solution until colour changed from a blue-black coloration to a permanent greenish colour.

Calculation:

$$\% C = \frac{M \times (V_{bl} - V_s) \times 0.003 \times 1.33 \times 100}{g}$$

where,

M = Molarity of FeSO₄

V_{bl} = volume of FeSO₄ of blank titration (ml)

V_s = volume of FeSO₄ of soil sample titration (ml)

g = mass of soil taken in gram

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

1.33 = correction factor used to convert the Wet combustion C value to the true C value since the Wet combustion method is about 75 % efficient in estimating C value , (i.e. 100/75 = 1.33).

3.3.2 DETERMINATION OF TOTAL NITROGEN IN SOIL

Total N was determined using the Kjeldahl digestion method as outlined by Okelabo *et al.* (1993). Ten (10) grams of soil was weighed into a 500 ml Kjeldahl digestion flask and one spatula of copper sulphate, sodium sulphate and selenium mixture followed by 30 ml of concentrated H₂SO₄ was added. The mixture was heated strongly to digest the soil to a permanent clear green colour. The digest was cooled and transferred to a 100 ml volumetric flask and made up to the mark with distilled water. A 10 ml aliquot of the digest was transferred into a tector distillation flask and 20 ml of 40 % NaOH solution was added. Steam from a Foss Tecator apparatus was allowed to flow into the flask. The ammonium distilled was collected into a 250 ml flask containing 15 ml of 4 % boric acid with mixed indicator of bromocresol green and methyl red. The distillate was titrated with 0.1 M HCl solution. A blank

digestion, distillation and titration were carried out as a check against traces of nitrogen in the reagents and water used (Okelabo *et al.*, 1993).

Calculation:

$$\% N = \frac{(a-b) \times 1.4 \times M \times V}{S \times t}$$

where,

a = volume of HCl used for sample preparation (ml)

b = volume of HCl used for blank preparation (ml)

1.4 = $14 \times 10^{-3} \times 100$ % (14 = atomic weight of N)

M = molarity of HCl.

V = total volume of digest (ml)

S = mass of soil taken for digestion in grams

t = volume of aliquot taken for distillation (ml)

3.3.3 SOIL PARTICLE SIZE ANALYSIS

Soil particle size analysis was done using the Hydrometer method as per Anderson and Ingram (1993). A 51.0 g of air-dried soil was weighed into a plastic container and a dispersing agent solution (sodium hexametaphosphate) was added. This was shaken on a reciprocating shaker at 250 r.p.m. for 2 hours, then transferred to sedimentation cylinders, and made up to the 1000 ml mark with distilled water. A hydrometer was inserted into the solution and a hydrometer reading taken at 40 seconds and at 3 hours as well as corresponding temperatures of the solution (Okelabo *et al.*, 1993).

Calculation:

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

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

$$\% \text{ Silt} = 100 - (\% \text{ Sand} + \% \text{ Clay})$$

where,

H₁ = first hydrometer reading at 40 seconds

H₂ = second hydrometer reading at 3 ho

T₁ = temperature of suspension at first hydrometer reading at 40 seconds

T₂ = temperature of suspension at second hydrometer reading at 3 hours.

3.3.4 DETERMINATION OF TOTAL ORGANIC CARBON IN POULTRY MANURE AND CATTLE MANURE.

Organic C was determined using the modified Walkley and Black procedure as outlined by Nelson and Sommers (1982). The method and calculation used is the same as the one for the soil organic C determination.

3.3.5 DETERMINATION OF TOTAL NITROGEN IN POULTRY MANURE AND CATTLE MANURE.

Total N was determined using the Kjeldahl digestion method. Two (2.0) grams of sample was weighed into a 500 ml Kjeldahl digestion flask and one spatula of copper sulphate, sodium sulphate and selenium mixture followed by 30 ml of concentrated H₂SO₄ was added. The mixture was heated strongly to digest the sample to a permanent clear green colour. The digest was cooled and transferred to a 100 ml volumetric flask and made up to the mark with distilled.

A 10 ml aliquot of the digest was transferred into a tector distillation flask and 20 ml of 40 % NaOH solution was added. Steam from a Foss Tecator apparatus was allowed to flow into the flask. The ammonium distilled was collected into a 250 ml flask containing 15 ml of 4 % boric acid with mixed indicator of bromocresol green and methyl red. The distillate was titrated with 0.1 M HCl solution. A blank digestion, distillation and titration were carried out as a check against traces of nitrogen in the reagents and water used (Okelabo *et al.*, 1993).

Calculation:

$$\% N = \frac{\langle a - b \rangle \times 1.4 \times M \times V}{S \times t}$$

where

a = volume of HCl used for sample preparation (ml)

b = volume HCl used for blank preparation (ml)

1.4 = $14 \times 10^{-3} \times 100$ % (14 = atomic weight of N)

M = molarity of HCl.

V = total volume of digest

S = mass of sample taken for digestion in grams (2.0g)

t = volume of aliquot taken for distillation.

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3.4.0 EXPERIMENTAL DESIGN

Nine (9) airtight plastic containers made up of three (3) containers for each GHG (CO₂, CH₄ and N₂O) at the application rates of 4, 8 and 10 ton/ha of organic fertilizer were used in a completely randomized design. Six (6) kg of soil was weighed into each plastic container of dimensions 36 cm x 22 cm x 13 cm. Poultry manure and cattle manure were mixed with the soil at the following amounts: 32.0 g; 64.0 g and 80.0 g equivalent to 4.0, 8.0 and 10.0 ton/ha, respectively. A 90 kg N/ha urea and ammonium sulphate fertilizers was applied to the mixture in each plastic container.

Each of the soil and poultry manure or cattle manure mixture with the urea or ammonium sulphate set-up was thoroughly saturated with water equivalent to one-half the volume of the plastic container. This was repeated for each of the 72 set-ups.

Table 3.1: Rates of poultry manure and cattle manure applied

Rates of Application (ton/ha)	Mass of Poultry manure or cattle manure used (g)
4.0	32.0
8.0	64.0
10.0	80.0

Table 3.2: Rates of urea or ammonium sulphate applied

Rate (N kg/ha)	Mass (kg)
Urea : 90	0.5869
Ammonium sulphate : 90	1.2857

Table 3.3: Experimental set-up used

Treatment	Soil series	Organic fertilizer used at 4, 8, and 10 ton/ha	Inorganic fertilizer used at a rate of 90 kg N/ha
1	Kumasi	Poultry manure	Ammonium sulphate

2	Kumasi	Cattle manure	Ammonium sulphate
3	Kumasi	Poultry manure	Urea
4	Kumasi	Cattle manure	Urea
5	Bekwai	Poultry manure	Urea
6	Bekwai	Cattle manure	Urea
7	Bekwai	Poultry manure	Ammonium sulphate
8	Bekwai	Cattle manure	Ammonium sulphate

3.4.1 TRAPPING OF EMITTED GREENHOUSE GASES

Flexible rubber tubes were passed through the lid of the airtight plastic container and then connected to an enclosed receptacle (bottle) containing 50 ml of either of these reagents as in Figs.3.1-3.3:



Fig 3.1: Set up for collection of GHG: 4 ton/ha poultry manure or cattle manure



Fig.3.2: Set up for collection of GHG: 8 ton/ha poultry manure or cattle manure



Fig.3.3: Set up for collection of GHG: 10 ton/ha poultry manure or cattle manure

- i. 0.1 M NaOH for the collection of CO₂
- ii. 0.1 M NaCl for the collection of CH₄
- iii. Boric acid with mixed indicator for the collection of N₂O

This setup was agitated on daily basis.

3.5.0 DETERMINATIONS OF CO₂, CH₄, AND N₂O BY TITRATIONS

3.5.1. Carbon dioxide (CO₂)

The evolved CO₂ gas was passed through a bottle containing excess NaOH solution (0.1 M) where it was absorbed and converted into an equivalent amount of sodium carbonate solution. The emitted gas was collected over a 68-day period. The solution was then titrated with standard 0.1 M HCl. Titration to the first colourless phenolphthalein endpoint neutralizes the excess NaOH and converts all of the Na₂CO₃ into NaHCO₃. Continuation of the titration to the second methyl orange endpoint converts all of the NaHCO₃ to H₂O and CO₂. The difference in volume (ml) between the first and second endpoints was used to calculate the mass of CO₂ evolved from the sample.

Calculation:

Mass of CO₂ (g) = volume of HCl used × Molarity of HCl × molecular weight of CO₂ (Crosno et al., 1996).

Blank determinations were carried out in all to analyze the amount of contamination of the NaOH by atmospheric carbon dioxide.

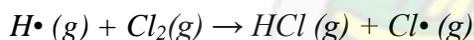
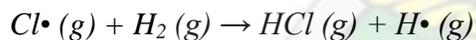
3.5.2 Methane (CH₄)

The evolved CH₄ gas was collected through flexible rubber tubing into a tight corked bottle containing excess NaCl where the methane was absorbed and converted into an equivalent amount of chloromethane (CH₃Cl). The emitted gas was collected over a 68-day period. The solution was then titrated with standard 0.1 M HCl.

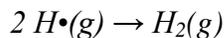
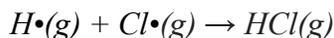
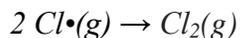
The light initiates a rapid photochemical reaction between hydrogen or methane and chlorine.

This mixture may explode with a loud bang, firing the cork into the air if precautions are not taken. Both reactions are radical chain reactions in which the initiation step is the absorption of a photon of visible light by a chlorine molecule. This causes the Cl-Cl bond to break, forming chlorine atoms, which are free radicals as they have an unpaired electron each.

The Cl-Cl bond energy is 243 kJ mol^{-1} . This energy corresponds to a wavelength of about 500 nm, in the blue-green region of the visible spectrum, so Cl-Cl bonds may be broken by radiation of wavelengths shorter than this. In the chlorine-hydrogen reaction, chain propagation steps follow this:

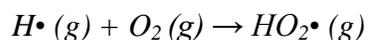


Chain termination takes place via a variety of reactions, such as:



which take place on the wall of the vessel to carry away excess energy.

Oxygen molecules can act as inhibitors via reactions such as:

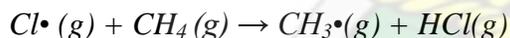


So the bottle was carefully filled and corked to prevent oxygen from entering.

Since, in the overall reaction, $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$, there is no increase in the number of moles of gas, the explosion must be due to the heat given out (93 kJ per mole of HCl), causing the gas mixture to expand rapidly.

The methane-chlorine reaction starts less readily, and proceeds less rapidly than the hydrogen-chlorine reaction. The first step will be the same – the production of two chlorine free radicals.

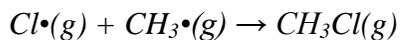
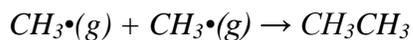
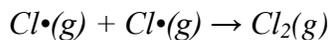
The first propagation step is likely to be:



The next likely step will then be:



Finally, several chain termination steps are possible:



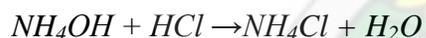
Calculation:

$Mass\ of\ CH_4\ (g) = volume\ of\ HCl\ used \times Molarity\ of\ HCl \times molecular\ weight\ of\ CH_4$

(Crossno *et al.*, 1996).

3.5.3 Nitrous oxide (N₂O)

The ammonium gas evolved was collected through flexible rubber tubing connected to a tight corked bottle containing 4 % boric acid with indicator of mixed bromocresol green and methyl red. The emitted gas was collected over a 68-day period. The absorption of the ammonium gas by the boric acid with the mixed indicator was exhibited by change in colour from pink to light green coloration after some time. The ammonium liberated was titrated with standard 0.1 M HCl. The endpoint colour was orange. The equation is shown below:



Calculation:

$Mass\ of\ N_2O\ (g) = volume\ of\ HCl\ used \times Molarity\ of\ HCl \times molecular\ weight\ of\ N_2O$

(Crossno *et al.*, 1996).

3.6.0 DETERMINATION OF CO₂, CH₄ AND N₂O IN THE SOILS BEFORE FERTILIZER APPLICATION

3.6.1 CONVERSION OF SOIL ORGANIC CARBON TO CO₂

In converting soil organic carbon to CO₂, use is made of the product of the average soil bulk density in Mg m⁻³ and soil depth of 0.20 m, and the soil organic carbon in kg ha⁻¹, all multiplied by the molar ratio of CO₂ (44/12 =3.67) (Bonsu *et al.*, 2011).

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Calculation:

$$CO_2 = \rho_b \times SOC \times Z \times 3.67$$

where,

3.67 = molar ratio of CO₂ (44/12)

ρ_b =bulk density in Mg m⁻³

SOC = fraction of soil organic carbon

Z = depth of sampling in meters [0.20 m]

3.6.2 CONVERSION OF SOIL ORGANIC CARBON TO CH₄

This was done by multiplying the fraction of the average soil organic carbon relative to the amount of soil by the soil bulk density and the depth (0.2 m) from which the soil was collected all converted to kg ha⁻¹ and then multiplied by molar ratio of CH₄ (16/12 =1.33) (Bonsu *et al.*, 2011).

Calculation:

$$CH_4 = \rho_b \times SOC \times Z \times 1.33$$

where,

1.33 = molar ratio of CH₄ (16/12)

ρ_b = bulk density in Mg m⁻³

SOC = fraction of soil organic carbon

Z = depth of sampling (m)

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3.6.3 CONVERSION OF SOIL TOTAL NITROGEN TO N₂O

In converting soil total nitrogen to N₂O, use was made of the product of the average soil bulk density in Mg m⁻³ and soil depth of 0.20 m, and the soil total nitrogen in kg ha⁻¹, all multiplied by the molar ratio of N₂O (44/28 =1.60) (Bonsu *et al.*, 2011).

Calculation :

$$N_2O = \rho_b \times SN \times Z \times 1.60$$

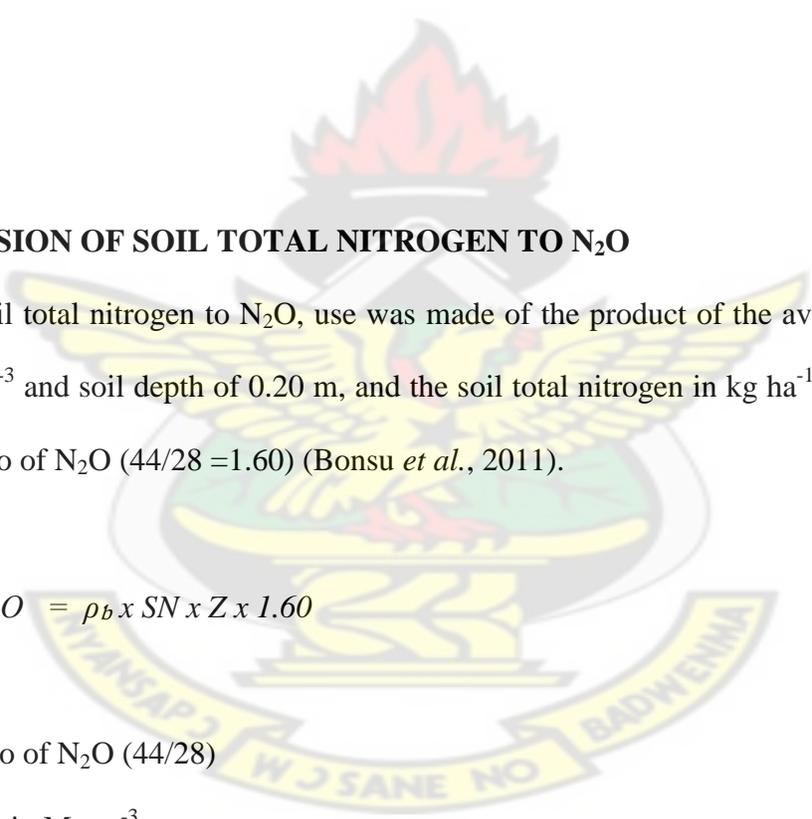
where,

1.60 = molar ratio of N₂O (44/28)

ρ_b = bulk density in Mg m⁻³

SN = fraction of soil total nitrogen;

Z = depth of sampling (m)



The outcome of this experiment was to help obtain the quantitative emissions of greenhouse gases resulting from the application of mineral and organic N-fertilizer sources, hence estimate the masses of CO₂, CH₄ and N₂O emissions from the decomposition of poultry manure and cattle manure. This was also to help evaluate the emission factors of CO₂, CH₄ and N₂O from the decomposition of N-based mineral and organic fertilizers-poultry manure and cattle manure.

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CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 CHEMICAL AND PHYSICAL COMPOSITION OF THE SOIL

The physical and chemical composition of the soils used in the study is presented in Table 4.1 below:

Table 4.1: Some chemical and physical parameters of the soils used for the study.

Parameters	Soil series							
	Kumasi		Average		Bekwai		Average	
pH(1:2.5 H ₂ O)	4.68	4.67	4.62	4.66	5.20	5.00	5.50	5.23
Total N (%)	0.17	0.14	0.15	0.15	0.31	0.28	0.29	0.29
Org. C (%)	0.94	1.04	1.00	1.00	1.50	1.60	1.40	1.50
ρ _b (Mg m ⁻³)	1.49	1.49	1.50	1.50	1.25	1.30	1.29	1.28

% Sand	72.50	76.50	70.60	73.20	41.18	37.25	37.25	37.25
% Silt	7.90	5.90	13.70	9.17	33.33	37.26	35.30	36.28
% Clay	19.60	17.60	15.70	17.63	25.49	25.49	27.45	26.47

Texture class

Sandy loam

Loam

The forest soil, Kumasi series with average pH of 4.66 was slightly acid (FitzPatrick, 1986) and contained 1.00 % organic carbon and 0.15 % N which is well below the 2.00 % C and slightly above the 0.11 % N being the critical levels for some Nigerian soils within the same climatic region as indicated by Adeputu *et al.* (1996).

On the other hand, the Bekwai series soil had pH 5.23 (moderately acid), 0.29 % total N, and 1.50 % organic C which agrees with Adu (1992) on the soils of Kumasi region. The average bulk densities of the Kumasi series and the Bekwai series soils were 1.50 and 1.28 Mg m⁻³, respectively. These values are within the ranges suggested by Biswas and Mukherjee (1994), 1.40-1.80 Mg m⁻³ for coarse-textured soils and 1.10 -1.30 Mg m⁻³, for fine-textured soils in the tropics.

4.2 CHEMICAL COMPOSITION OF POULTRY MANURE AND CATTLE MANURE USED IN THE STUDY

Table 4.2 presents the chemical parameters of the poultry manure and the cattle manure used in the study. The pH of the poultry manure was 5.45 whereas that of the cattle manure was 6.42, which are slightly acid and moderately acid, respectively. The poultry manure had 1.90 % N and 14.03 % C whereas cattle manure had 0.83 % N and 6.43 % C. Abekoe and Agyin-Birikorang (1999) noted that a well-decomposed poultry manure from the University of Ghana Research Station at Nungua had 2.30 % N, whilst Buri *et al.* (2004) found 2.60 % N and 23.08 % C in poultry manure in the Soil Research Institute, Kumasi. However, according to Bonsu (2010), cattle manure and poultry manure in different locations in the Savanna zone of Ghana had an average N content of 1.34 % and 2.20 %, respectively.

Table 4.2: Some chemical properties of the cattle manure and poultry manure used in the study.

Parameters	Cattle manure				Poultry manure			
				Av.				Av.
pH(1:5 H ₂ O)	6.38	6.34	6.54	6.42	5.43	5.41	5.50	5.45
Total N (%)	0.84	0.88	0.77	0.83	1.96	1.89	1.84	1.90
Org. C (%)	6.38	6.41	6.50	6.43	13.57	14.76	13.77	14.03

4.3 EMISSION FROM MIXTURE OF KUMASI SERIES SOIL, AMMONIUM SULPHATE FERTILIZER WITH CATTLE MANURE OR POULTRY MANURE WITH CORRESPONDING EMISSION FACTORS.

Tables 4.3a and 4.3b present the emissions of CO₂, CH₄ and N₂O from Kumasi series soil and ammonium sulphate fertilizer treated with cattle manure and poultry manure, respectively. At 4 ton/ha, the treatment with poultry manure released more CO₂ (5902 kg ha⁻¹), CH₄ (120 kg ha⁻¹) and N₂O (182 kg ha⁻¹) (Table 4.3a) compared to 3121 kg CO₂ ha⁻¹, 92.3 kg CH₄ ha⁻¹ and 114 kg N₂O ha⁻¹ emitted by the mixture treated with cattle manure (Table 4.3b), respectively. At 8 ton/ha, the gases released are respectively 7730 kg CO₂ ha⁻¹, 147.7 kg CH₄ ha⁻¹ and 207 kg N₂O ha⁻¹ as against 5017 kg CO₂ ha⁻¹, 110.8 kg CH₄ ha⁻¹ and 148 kg N₂O ha⁻¹. The 10 ton/ha treatment for poultry manure emitted 9566 kg CO₂ ha⁻¹, 170.8 kg CH₄ ha⁻¹ and 262 kg N₂O ha⁻¹ whereas 6691 kg CO₂ ha⁻¹, 136.9 kg CH₄ ha⁻¹ and 203 kg N₂O ha⁻¹ were released by the cattle manure treatment. The rates of CO₂, CH₄ and N₂O emissions from all the treatments were low during the first 24 days after the set-up except N₂O emission from Bekwai series soil + CO(NH₄)₂ + poultry manure treatment which peaked around the 23rd day after the set up as indicated by Fig. 4.5c.

This trend may be attributed to increased soil organic matter and N mineralization from the organic and mineral fertilizers, which stimulated N₂O production as a result of elevated oxygen consumption rates (Mutegi *et al.*, 2010).

Results of greenhouse gas emissions from CO₂, CH₄ and N₂O are presented in Figs.4.1a-4.8c. Despite differences in treatments, emissions of CO₂, CH₄ and N₂O followed a similar trend

and responded similarly to various increases in the rates of poultry manure and cattle manure applications.

The poultry manure treatments released higher amount of gases in all cases than the cattle manure treatments confirming earlier studies by Bonsu (2010), and Buri *et al.* (2004) that poultry manure in different locations in the Savanna zone of Ghana had higher C and N contents. This, no doubt accounted for the higher GHG emissions in all the poultry manure treatments.

Table 4.3a: Emissions and EF of CO₂, CH₄ and N₂O from mixture of Kumasi series (KS) soil with (NH₄)₂SO₄ fertilizer and poultry manure (PM) at 4, 8 and 10 ton/ha.

Treatments	Gas (kg/ha)	Emissions	
		CO ₂	CH ₄
4 ton/ha	5902(23.67)	120.0(1.32)	182(1.70)
8 ton/ha	7730(31.00)	147.7(1.63)	207(1.94)
10 ton/ha	9566(38.72)	170.8(1.88)	262(2.45)
LSD (5%)	1878.4	40.59	110.9
*SE	654.9	14.15	38.7
CV (%)	30.5	34.9	64.2

*SE = Standard errors of means. Emission factors (EF) is in parenthesis.

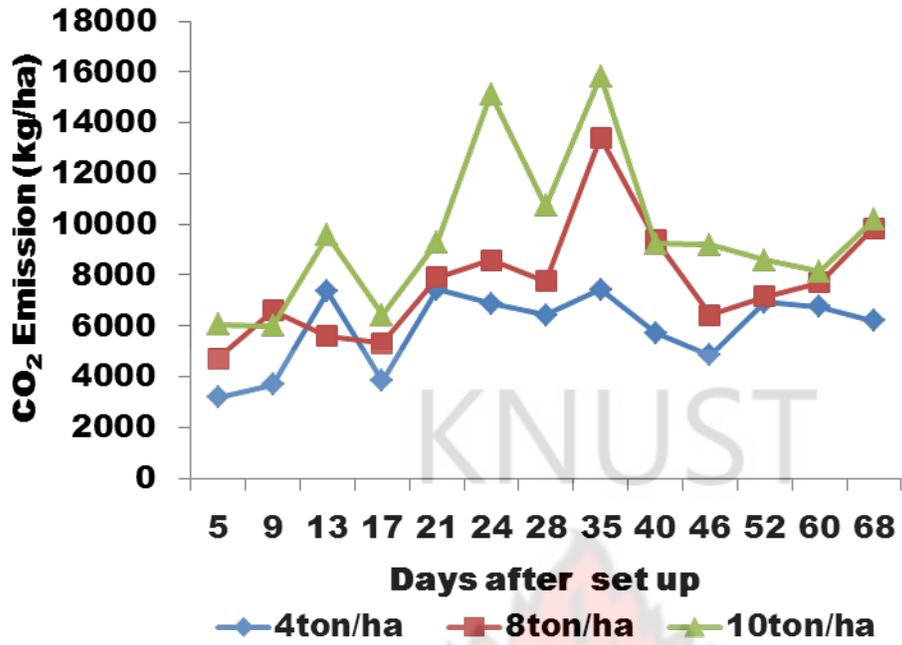


Fig. 4.1a: CO₂ emission from KS, (NH₄)₂SO₄ fertilizer and poultry manure.

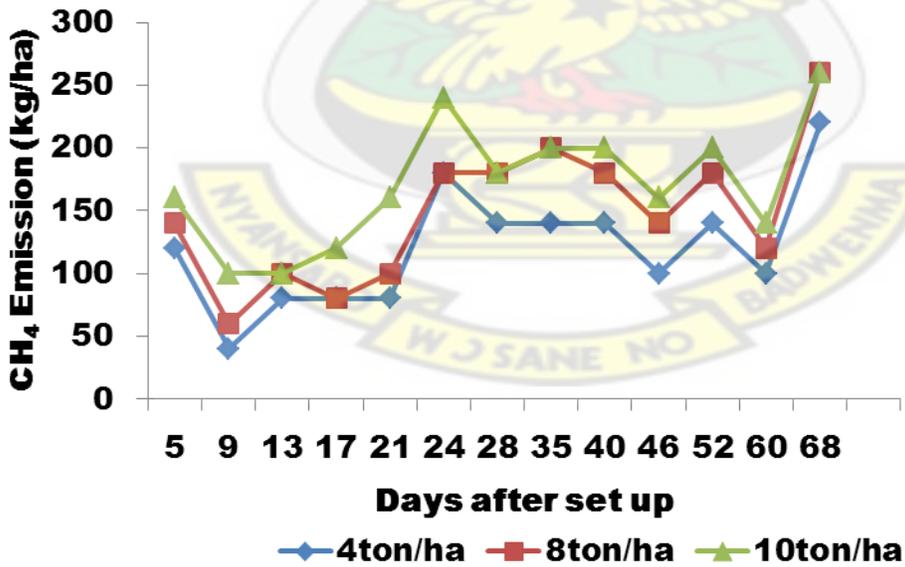


Fig. 4.1b: CH₄ emission from KS, (NH₄)₂SO₄ fertilizer and poultry manure.

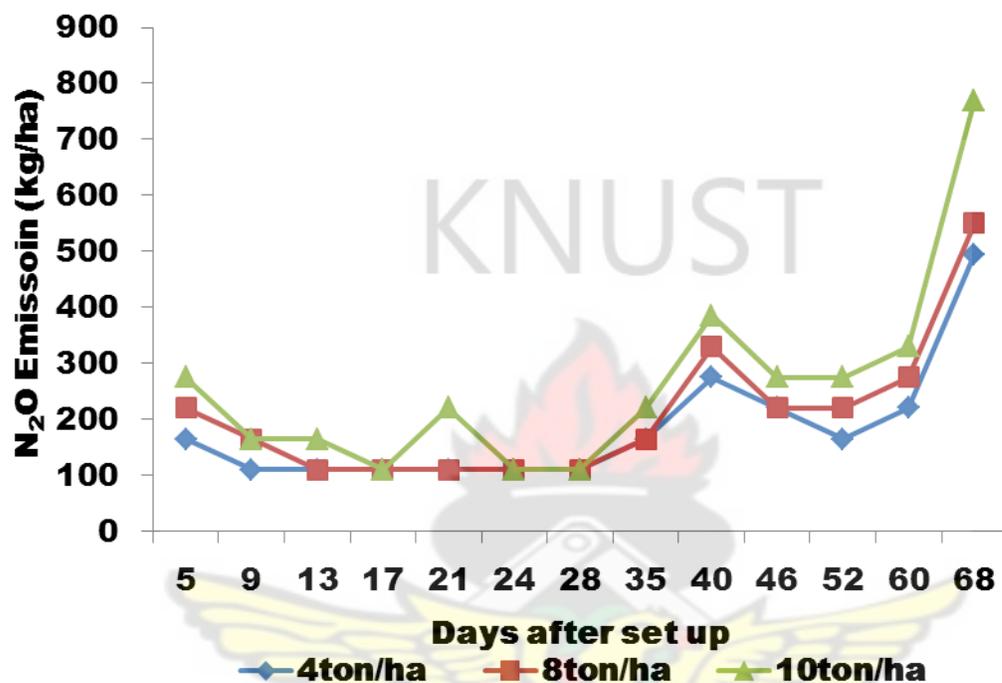


Fig. 4.1c: N₂O emission from KS, (NH₄)₂SO₄ fertilizer and poultry manure.

Table 4.3b: Emissions and EF of CO₂, CH₄ and N₂O from mixture of Kumasi series (KS) soil with (NH₄)₂SO₄ fertilizer and cattle manure (CM) at 4, 8 and 10ton/ha.

Treatments	Gas Emissions (kg/ha)		
	CO ₂	CH ₄	N ₂ O
4 ton/ha	3121(12.52)	92.3(1.02)	114(1.07)
8 ton/ha	5017(20.12)	110.8(1.22)	148(1.39)
10 ton/ha	6691(26.84)	136.9(1.51)	203(1.90)
LSD (5%)	1742.3	37.69	90.6
*SE	607.5	13.14	31.6
CV (%)	44.3	41.8	73.4

*SE =Standard errors of means. Emission factors (EF) is in parenthesis

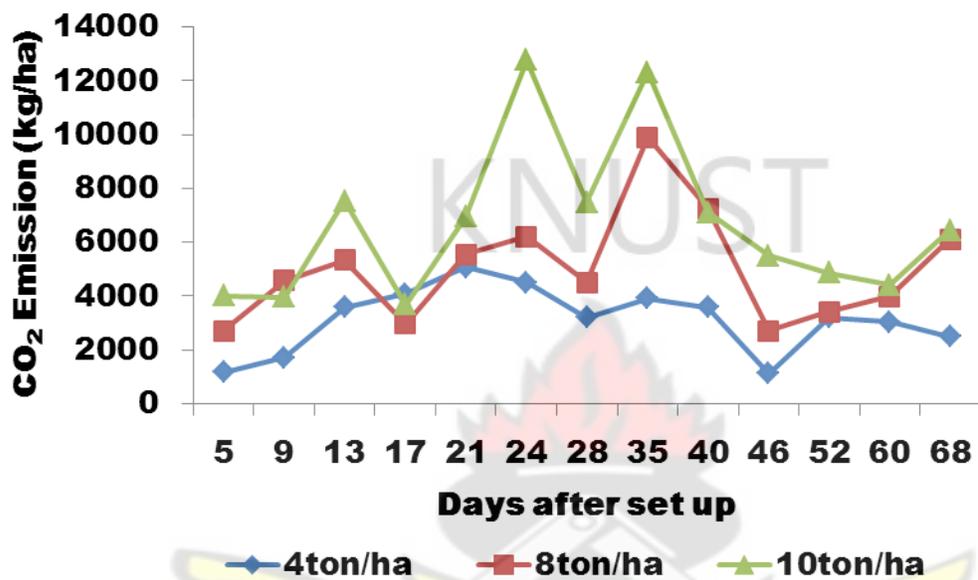


Fig. 4.2a: CO₂ emission from KS, (NH₄)₂SO₄ fertilizer and cattle manure

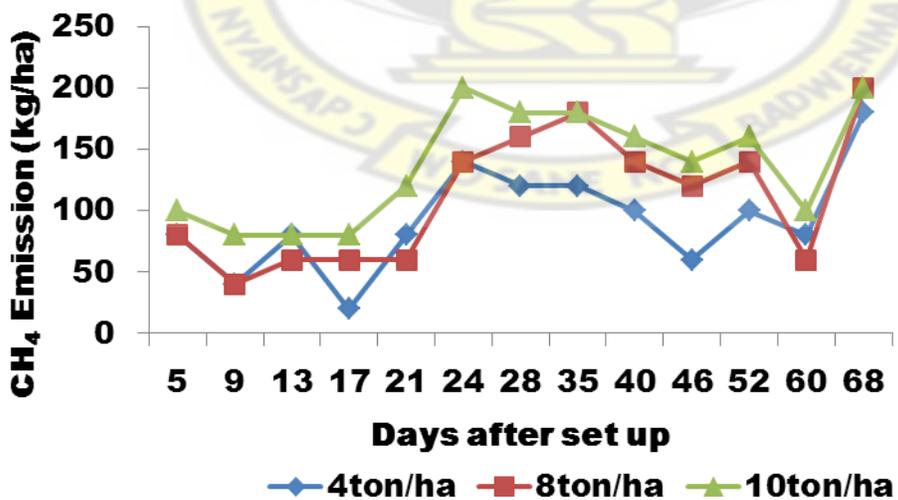


Fig. 4.2b: CH₄ emission from KS, (NH₄)₂SO₄ fertilizer and cattle manure

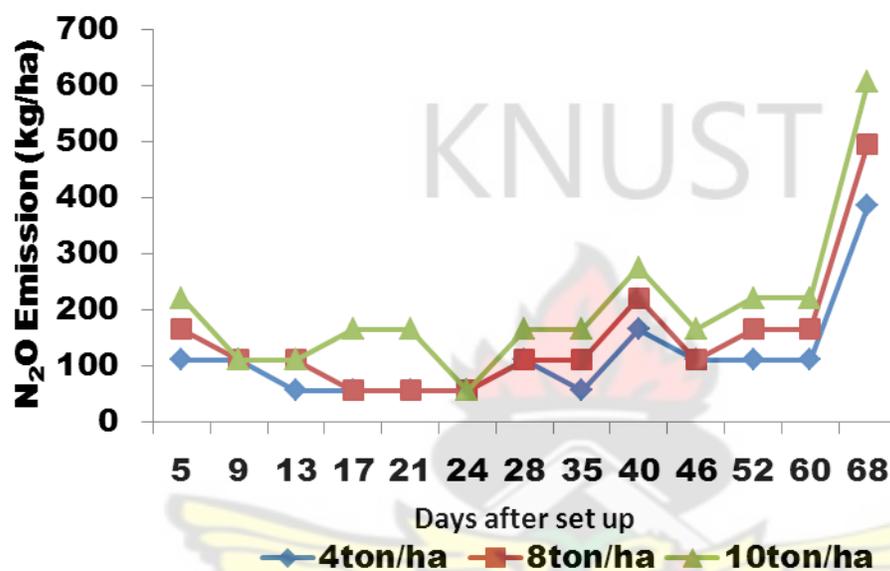


Fig. 4.2c: NO emission from KS, (NH₄)₂SO₄ fertilizer and cattle manure

4.4 EMISSION FROM MIXTURE OF KUMASI SERIES (KS) SOIL, UREA FERTILIZER WITH CATTLE MANURE OR POULTRY MANURE WITH CORRESPONDING EMISSION FACTORS

Table 4.4a: Emissions and EF of CO₂, CH₄ and N₂O from mixture of Kumasi series (KS) soil with CO(NH₄)₂ fertilizer and poultry manure (PM) at 4, 8 and 10 ton/ha.

Treatment	Gas Emission (kg/ha)		
	CO ₂	CH ₄	N ₂ O
4 ton/ha	8587(34.44)	104.7(1.15)	199(1.86)
8 ton/ha	9020(36.18)	116.3(1.28)	249(2.33)

10 ton/ha	9725(39.00)	171.0(1.89)	470(4.40)
LSD(5%)	1858.3	21.34	69.4
*SE	913.4	7.42	24.1
CV (%)	24.6	19.7	27.3

*SE = Standard errors of means. Emission factors (EF) is in parenthesis

The emissions of CO₂, CH₄ and N₂O from Kumasi series soil and urea fertilizer treated with cattle manure and poultry manure respectively are presented in Tables 4.4a and 4.4b. Even though the emissions observed from the poultry manure treatments are high compared to that of the cattle manure due mainly to the reasons given by Bonsu (2010), and Buri *et al.* (2004) that poultry manure in different locations in the Savanna zone of Ghana had higher C and N contents, the CO₂ emissions from the 4 ton/ha, 8ton/ha and 10 ton/ha treatments were not significantly different P<0.05 with a very high standard error (SE). On the other hand, CH₄ and N₂O emissions were significantly different and higher in the PM treatments than in the cattle manure treatments.

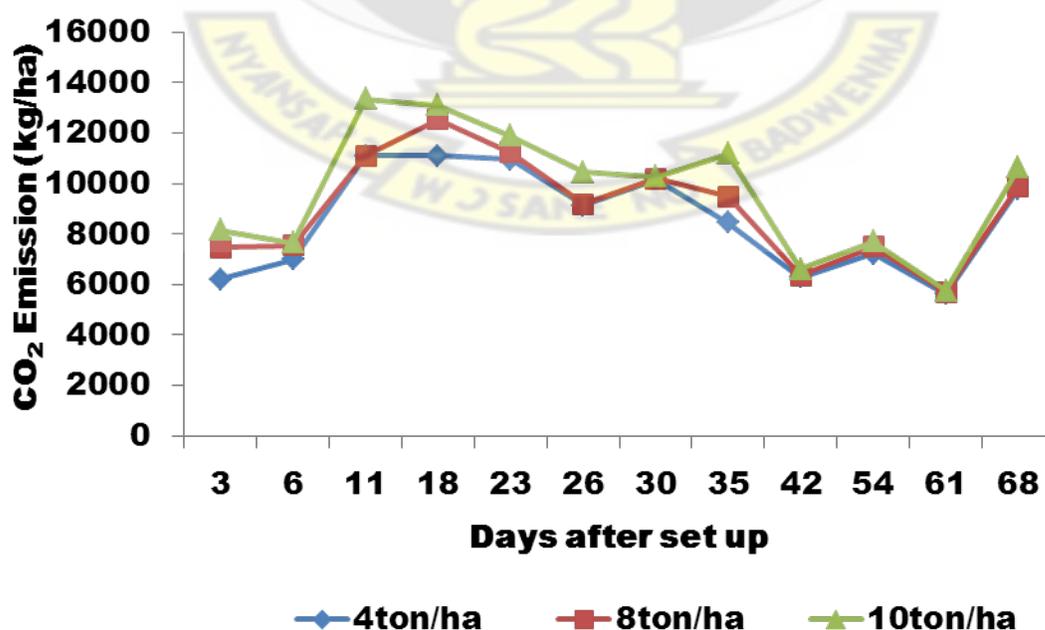


Fig. 4.3a: CO₂ emission from KS, CO(NH₄)₂ fertilizer and poultry manure

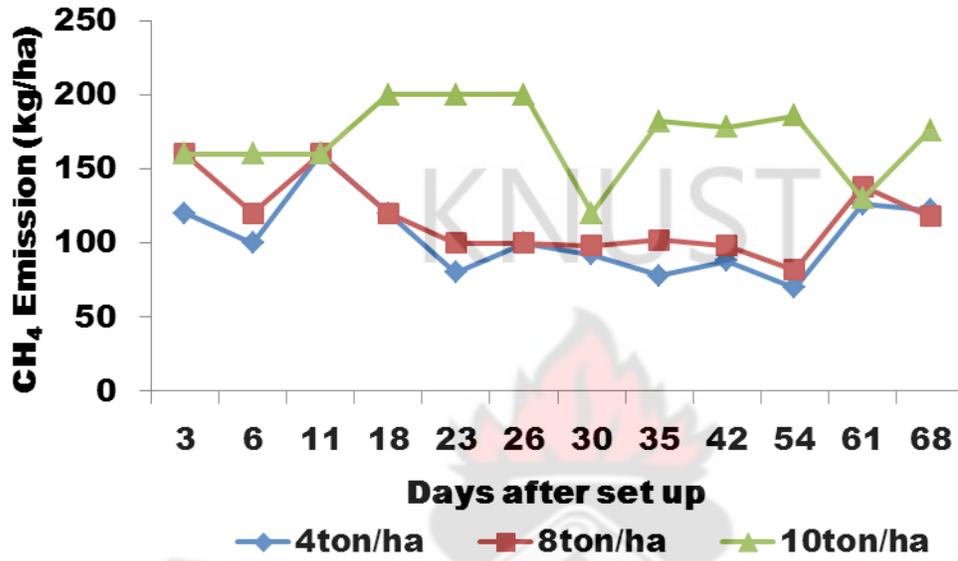
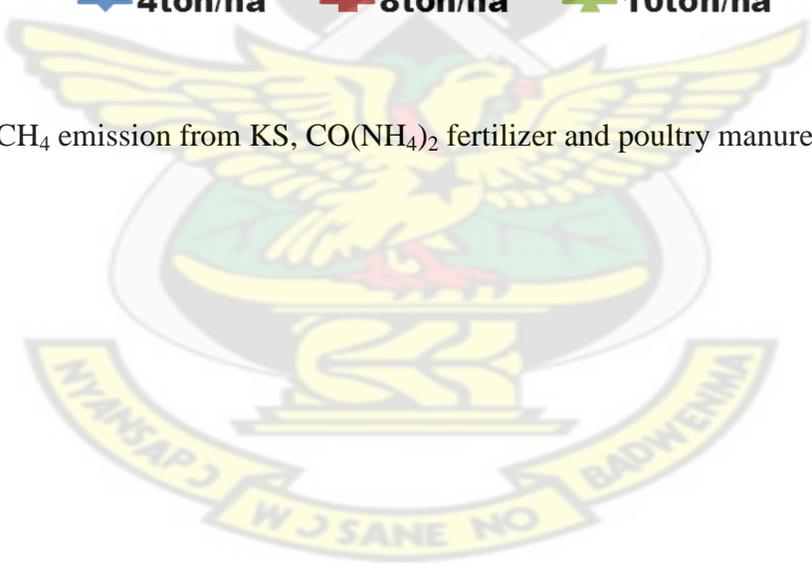


Fig.4.3b: CH₄ emission from KS, CO(NH₄)₂ fertilizer and poultry manure



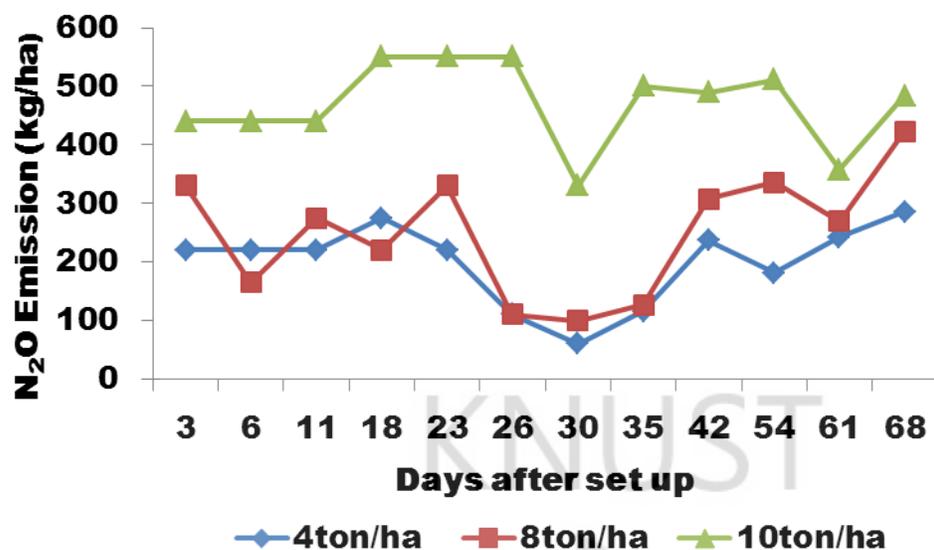


Fig. 4.3c: N₂O emission from KS, CO(NH₄)₂ fertilizer and poultry manure

Table 4.4b: Emissions and EF of CO₂, CH₄ and N₂O from mixture of Kumasi series (KS) soil with CO(NH₄)₂ fertilizer and cattle manure (CM) at 4, 8 and 10 ton/ha.

Treatments	Gas emissions (kg/ha)		
	CO ₂	CH ₄	N ₂ O
4 ton/ha	7684(30.82)	64.7(0.71)	163(1.53)
8 ton/ha	8395(33.67)	79.8 (0.88)	225(2.11)
10 ton/ha	9540(38.26)	126.0(1.39)	395(3.70)
LSD (5%)	1887.2	19.50	72.5
*SE	655.9	6.78	25.2
CV (%)	26.6	26.0	33.5

*SE = Standard errors of means. Emission factors (EF) is in parenthesis

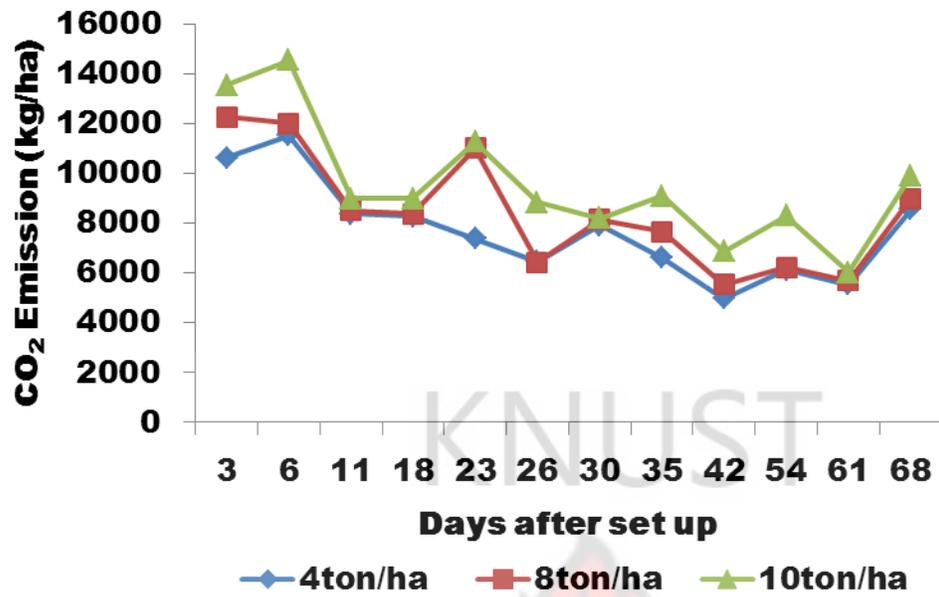
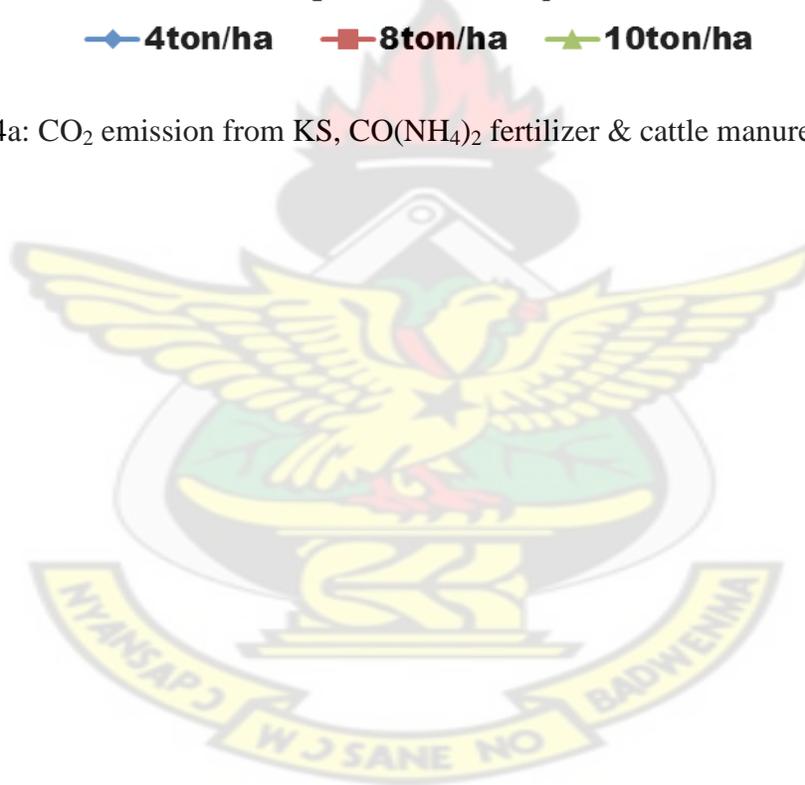


Fig. 4.4a: CO₂ emission from KS, CO(NH₄)₂ fertilizer & cattle manure.



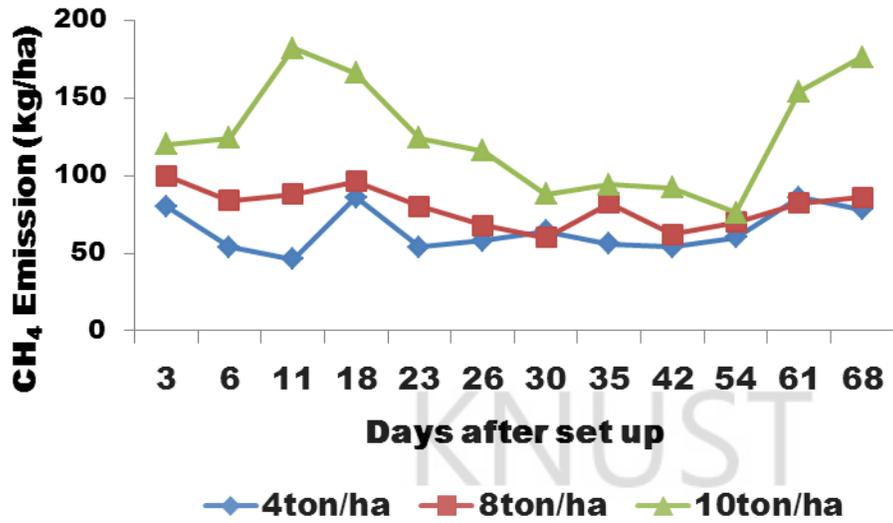


Fig.4.4b: CH₄ emission from KS, CO(NH₄)₂ fertilizer & cattle manure.

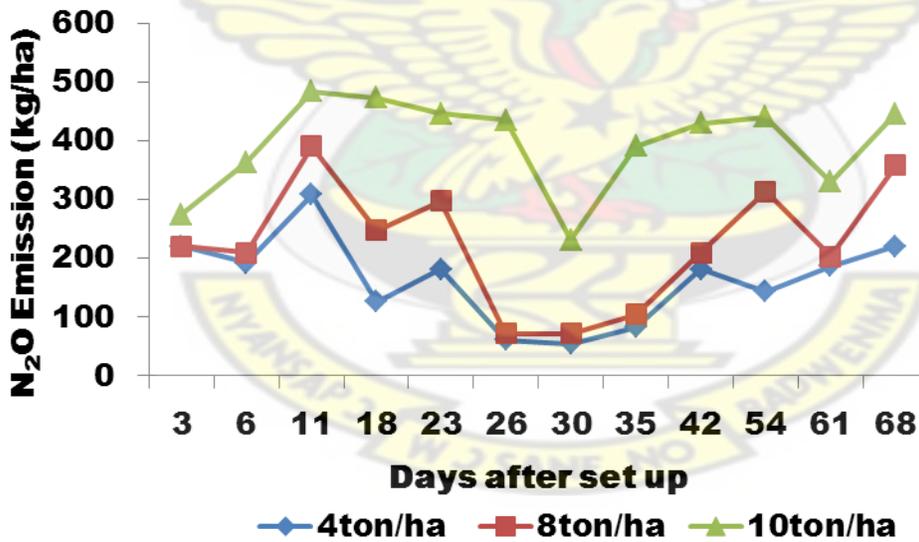


Fig. 4.4c: N₂O emission from KS, CO(NH₄)₂ fertilizer & cattle manure.

4.5 EMISSION FROM MIXTURE OF BEKWAI SERIES (BS) SOIL, UREA FERTILIZER WITH CATTLE MANURE OR POULTRY MANURE WITH CORRESPONDING EMISSION FACTORS.

Table 4.5a: Emissions and EF of CO₂, CH₄ and N₂O from mixture of Bekwai series (BS) soil with CO(NH₄)₂ fertilizer and poultry manure (PM) at 4, 8 and 10 ton/ha

Treatment	Gas emissions (kg/ha)		
	CO ₂	CH ₄	N ₂ O
4 ton/ha	4587(18.40)	132.0(1.46)	227(2.12)
8 ton/ha	5940(23.82)	188.0(2.07)	260(2.43)
10 ton/ha	6956(27.90)	280.0(3.09)	462(4.32)
LSD (5%)	1471.7	45.21	87.6
*SE	515.7	15.84	30.7
CV (%)	34.3	30.7	37.6

*SE = Standard errors of means. Emission factors (EF) is in parenthesis.

Tables 4.5a and 4.5b give the emissions from Bekwai series soil and urea fertilizer with poultry manure and cattle manure. The CO₂ emissions in both the poultry manure and cattle manure in all three treatments (4 ton/ha, 8 ton/ha and 10 ton/ha) increased as the mass of manure increased but were not significantly different (P<0.05). The results were as follows: 4587 kg CO₂ ha⁻¹; 5940 kg CO₂ ha⁻¹; and 6956 kg CO ha⁻¹ for the 4, 8 and 10 ton/ha respectively for the poultry manure, whereas cattle manure released 3513 kg CO₂ ha⁻¹, 4631 kg CO₂ ha⁻¹ and 5581 kg CO₂ ha⁻¹. Methane and nitrous oxide emissions also increased as the mass of manure increased, but, unlike CO₂, were significantly different (P<0.05) in the poultry manure and cattle manure treatments. The amount of emissions for poultry manure were 132 kg CH₄ ha⁻¹, 188 kg CH₄ ha⁻¹ and 280 kg CH₄ ha⁻¹; and 227 kg N₂O ha⁻¹, 260 kg N₂O ha⁻¹ and 462 kg N₂O ha⁻¹ for the 4, 8 and 10 ton/ha, respectively. Again, the amount of emissions for cattle manure were 84 kg CH₄ ha⁻¹, 126.7 kg CH₄ ha⁻¹ and 185.3 kg CH₄ ha⁻¹; and 121 kg N₂O ha⁻¹, 139 kg N₂O ha⁻¹, and 301 kg N₂O ha⁻¹, respectively.

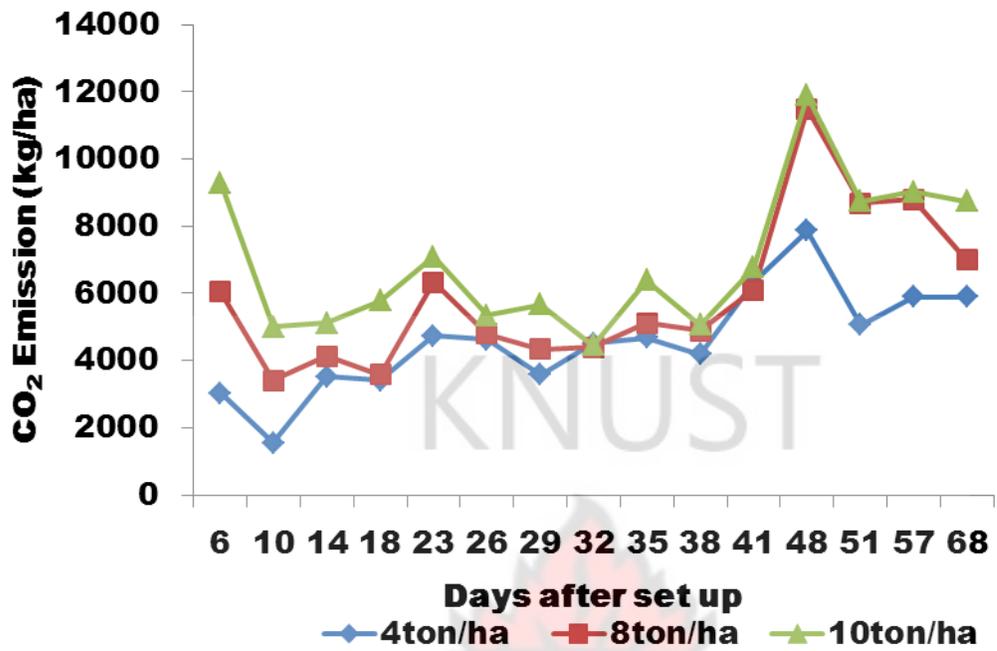


Fig. 4.5a: CO₂ emission from BS, CO(NH₄)₂ fertilizer & poultry manure.

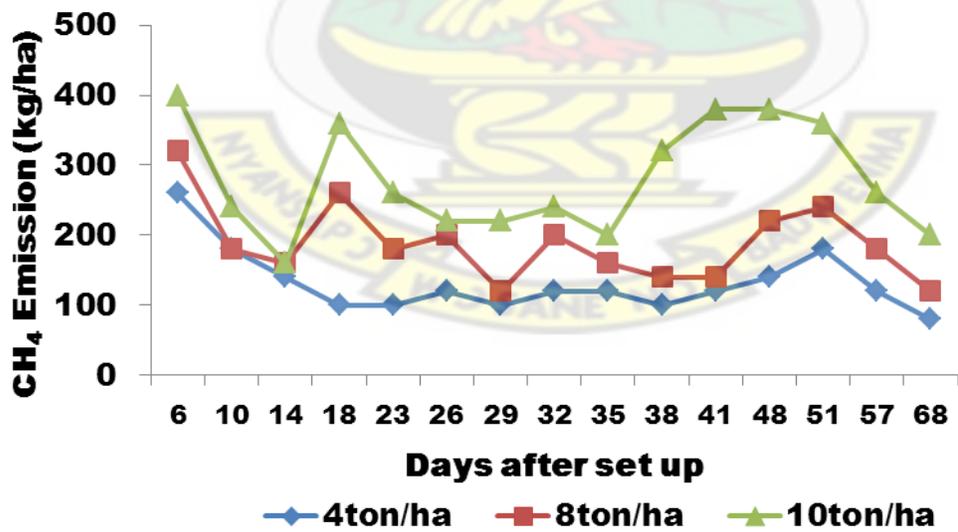


Fig. 4.5b: CH₄ emission from BS, CO(NH₄)₂ fertilizer & poultry manure.

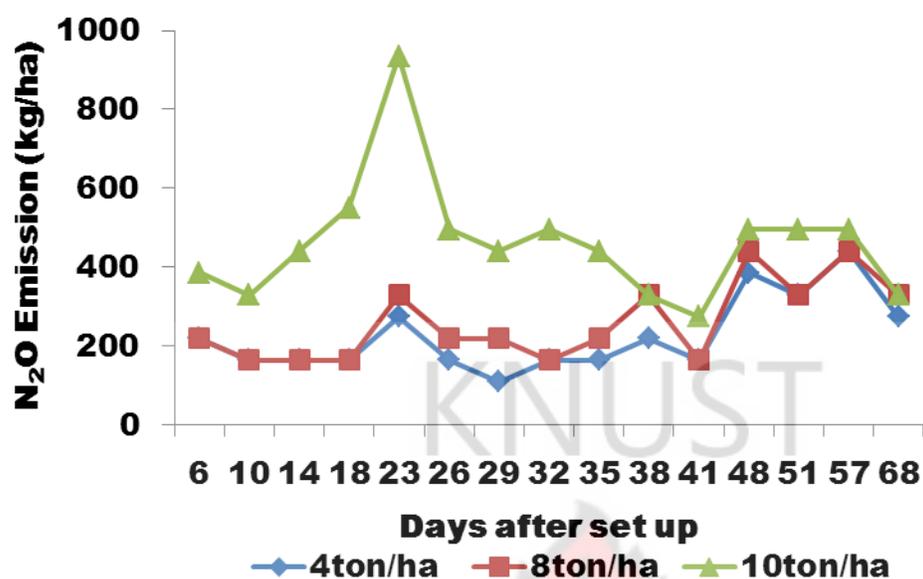


Fig. 4.5c: N₂O emission from BS, CO(NH₄)₂ fertilizer & poultry manure.

Table 4.5b: Emissions and EF of CO₂, CH₄ and N₂O from mixture of Bekwai series (BS) soil with CO(NH₄)₂ fertilizer and cattle manure (CM) at 4, 8 and 10 ton/ha

Treatment	Gas emissions (kg/ha)		
	CO ₂	CH ₄	N ₂ O
4 ton/ha	3513(14.09)	84.0(0.93)	121(1.13)
8 ton/ha	4631(18.57)	126.7(1.40)	139(1.30)
10 ton/ha	5581(22.38)	185.3(2.04)	301(2.82)
LSD (5%)	1173.3	23.71	65.6
*SE	411.1	8.31	23.0
CV (%)	34.8	24.4	47.6

*SE = Standard errors of means. Emission factors (EF) is in parenthesis

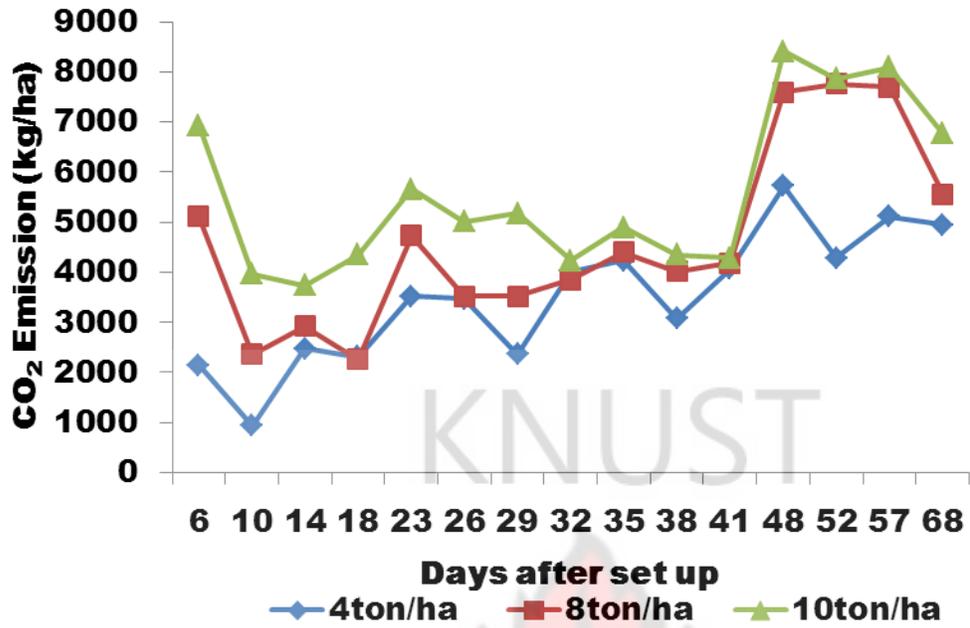


Fig. 4.6a: CO₂ emission from BS, CO(NH₄)₂ fertilizer & cattle manure.

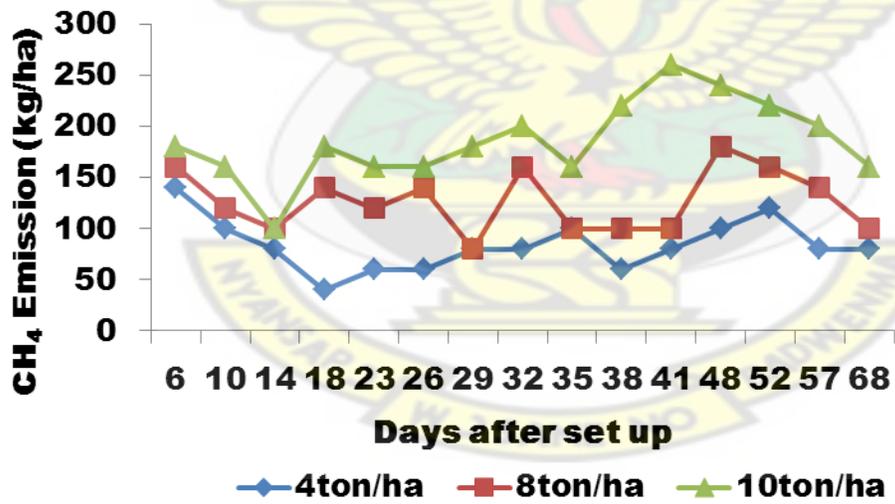


Fig. 4.6b: CH₄ emission from BS, CO(NH₄)₂ fertilizer & cattle manure

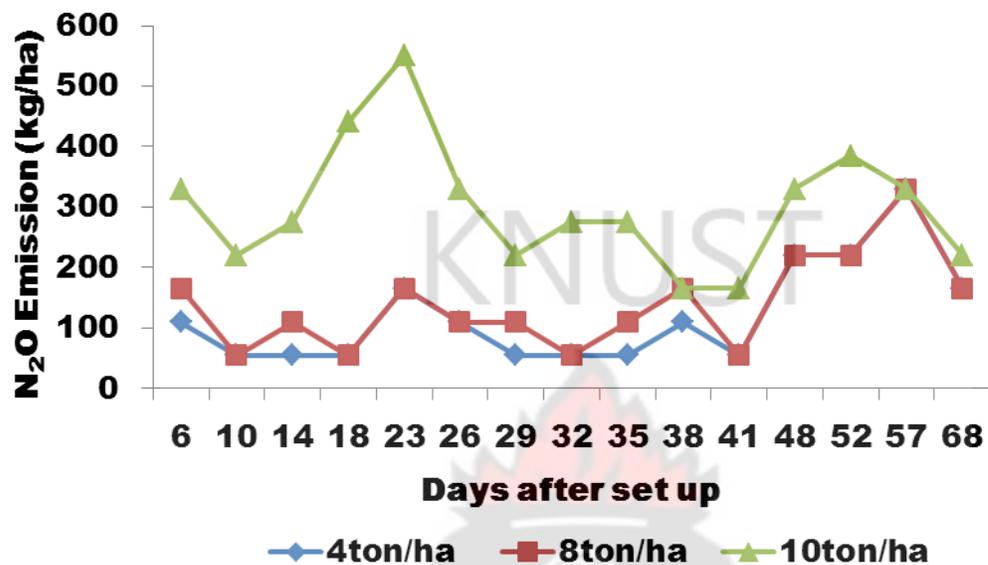


Fig. 4.6c: N₂O emission from BS, CO(NH₄)₂ fertilizer & cattle manure.

4.6 EMISSION FROM MIXTURE OF BEKWAI SERIES (BS) SOIL, AMMONIUM SULPHATE FERTILIZER WITH CATTLE MANURE OR POULTRY MANURE WITH CORRESPONDING EMISSION FACTORS.

Table 4.6a: Emissions and EF of CO₂, CH₄ and N₂O from mixture of Bekwai series (BS) soil with (NH₄)₂SO₄ fertilizer and poultry manure (PM) at 4, 8 and 10 ton/ha

Treatment	Gas emissions(kg/ha)		
	CO ₂	CH ₄	N ₂ O
4 ton/ha	5964(23.92)	113.3(1.25)	153(1.43)
8 ton/ha	8568(34.36)	135.6(1.50)	226(2.11)
10 ton/ha	10597(42.50)	200.0(2.21)	318(2.98)
LSD (5%)	8121.1	43.43	69.1
*SE	2782.3	14.88	23.7
CV (%)	99.7	29.8	30.6

*SE = Standard errors of means. Emission factors (EF) is in parenthesis.

The emissions resulting from the mixture of Bekwai series soil, ammonium sulphate fertilizer and poultry manure and cattle manure are shown in Tables 4.6a and 4.6b. Carbon dioxide emissions were not significantly different ($P < 0.05$) in both the poultry manure and cattle manure treatments with values of 5964 kg CO₂ ha⁻¹, 8568 kg CO₂ ha⁻¹ and 10597 kg CO₂ ha⁻¹; and 4767 kg CO₂ ha⁻¹, 6789 kg CO₂ ha⁻¹ and 8562 kg CO₂ ha⁻¹ for the 4, 8 and 10 ton/ha, respectively. Methane and nitrous oxide emissions in poultry manure treatments were all significantly higher ($P < 0.05$) than cattle manure treatments. The methane obtained for the three levels in respect of poultry manure and cattle manure were 113.3 kg CH₄ ha⁻¹, 135.6 kg CH₄ ha⁻¹, 200.0 kg CH₄ ha⁻¹; and 64.4 kg CH₄ ha⁻¹, 86.7 kg CH₄ ha⁻¹ and 157.8 kg CH₄ ha⁻¹, respectively. For N₂O, the emissions were 153 kg N₂O ha⁻¹, 226 kg N₂O ha⁻¹, and 318 kg N₂O ha⁻¹; and 61.1 kg N₂O ha⁻¹, 110.0 kg N₂O ha⁻¹ and 213.9 kg N₂O ha⁻¹, respectively for poultry manure and cattle manure.



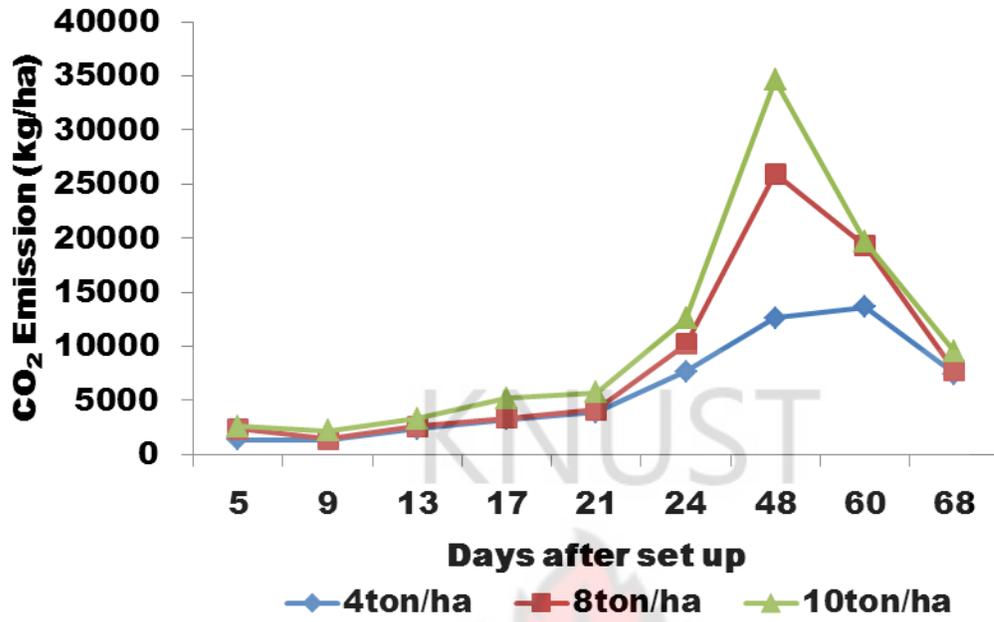


Fig. 4.7a: CO₂ emission from BS, (NH₄)₂SO₄ fertilizer & poultry manure

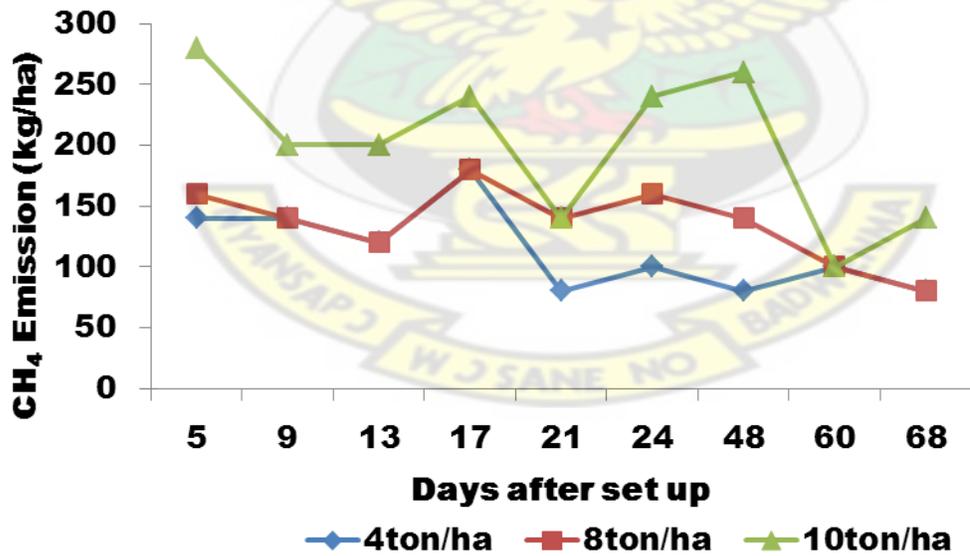


Fig. 4.7b: CH₄ emission from BS, (NH₄)₂SO₄ fertilizer & poultry manure.

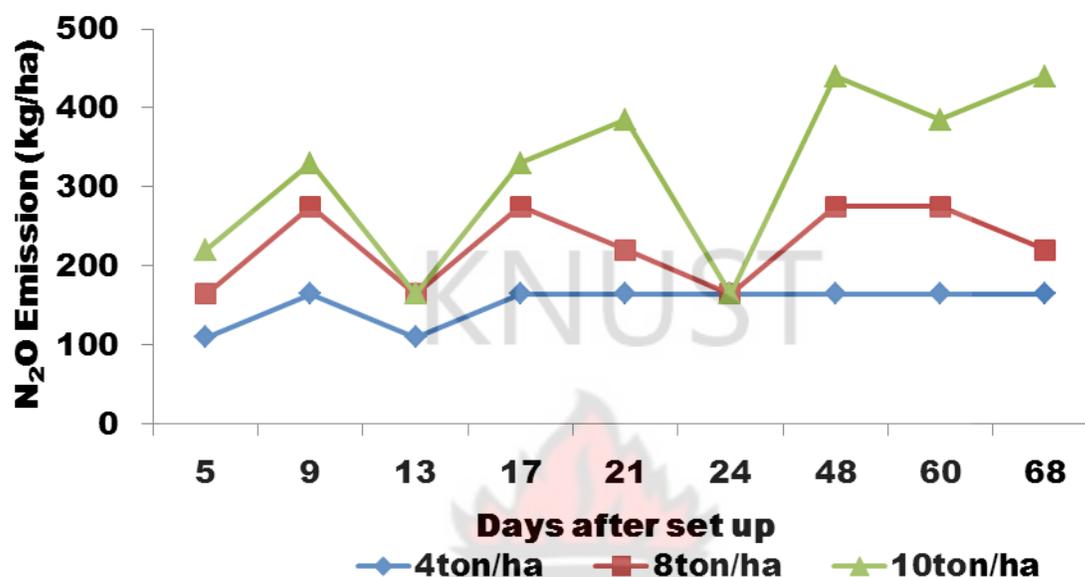


Fig. 4.7c: N₂O emission from BS, (NH₄)SO₄ fertilizer & poultry manure

Table 4.6b: Emissions and EF of CO₂, CH₄ and N₂O from mixture of Bekwai series (BS) soil with (NH₄)₂SO₄ fertilizer and cattle manure (CM) at 4, 8 and 10 ton/ha

Treatment	Gas emissions(kg/ha)		
	CO ₂	CH ₄	N ₂ O
4 ton/ha	4767(19.12)	64.4(0.71)	61.1(0.57)
8 ton/ha	6789(27.23)	86.7(0.96)	110.0(1.03)
10 ton/ha	8562(34.43)	157.8(1.74)	213.9(1.99)
LSD (5%)	6747.3	36.50	48.58
*SE	2311.7	12.51	16.64
3CV (%)	103.4	36.4	38.9

*SE = Standard errors of means. Emission factors (EF) is in parenthesis.

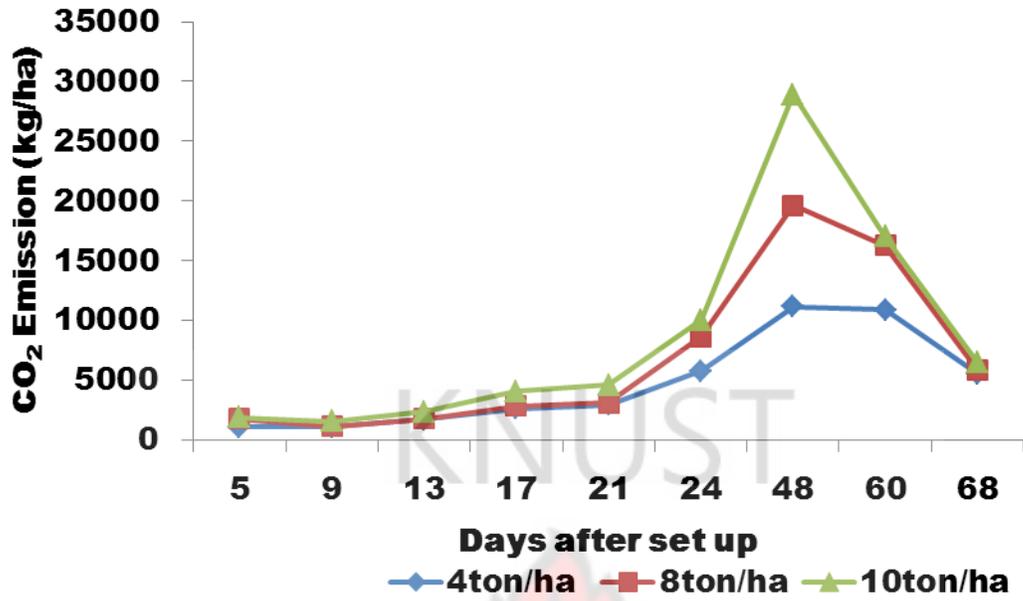


Fig. 4.8a CO₂ emission from BS, (NH₄)SO₄ fertilizer & cattle manure

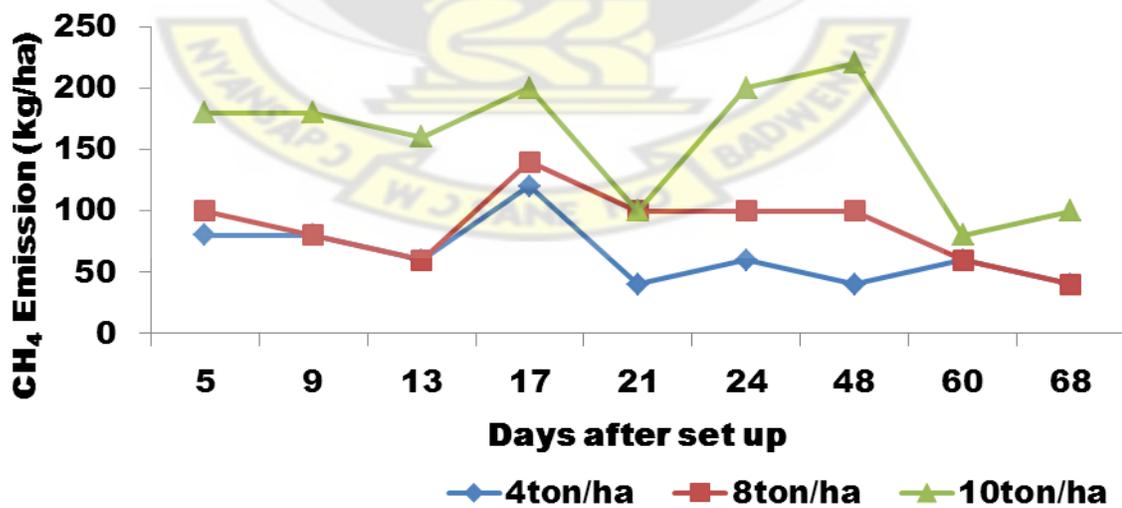


Fig. 4.8b: CH₄ emission from BS, (NH₄)SO₄ fertilizer & cattle manure

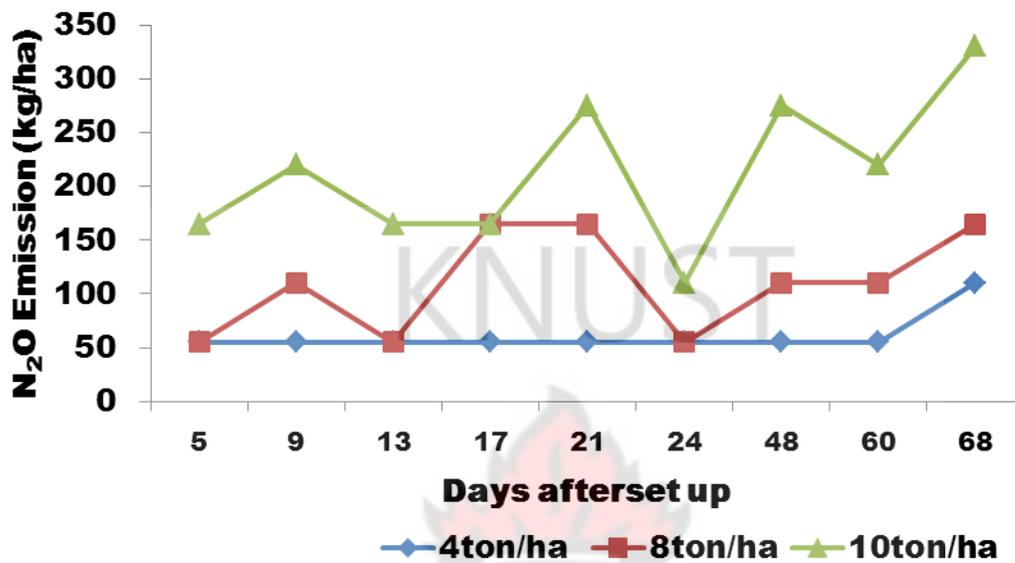


Fig. 4.8c: N₂O emission from BS, (NH₄)SO₄ fertilizer & cattle manure.

4.7.1 CO₂ EMISSIONS

Carbon dioxide (CO₂) was estimated to be the highest GHG released. The result ranged from 10597.0 kg CO₂ ha⁻¹ to a low value of 3121 kg CO₂ ha⁻¹. The descending order of emission was observed to be:

Bekwai series soil + (NH₄)₂SO₄ + PM; Kumasi series soil + CO(NH₄)₂ + PM; Kumasi series soil + CO(NH₄)₂ + CM, Kumasi series soil + (NH₄)₂SO₄ + PM; Bekwai series soil + (NH₄)₂SO₄ +

CM; Bekwai series soil + $\text{CO}(\text{NH}_4)_2$ + PM; Kumasi series soil + $(\text{NH}_4)_2\text{SO}_4$ + CM; Bekwai series soil + $\text{CO}(\text{NH}_4)_2$ + CM.

Carbon dioxide emission dynamics were characterised by high peaks resulting from poultry manure treatments. The study showed that CO_2 emissions were high in all poultry manure treatments and the highest emission occurred in Fig. 4.7a, Bekwai series soil with ammonium sulphate fertilizer and poultry manure.

The high CO_2 emissions observed in Fig. 4.7a was most likely a function of the soil with increased soil organic matter from the soil, poultry manure and the mineral fertilizer which stimulated CO_2 production due to elevated oxygen consumption rates (Mutegi *et al.*, 2010).

Low CO_2 emissions were observed in most of the cattle manure treatments and the lowest emission was observed in the Bekwai series soil + $\text{CO}(\text{NH}_4)_2$ + cattle manure treatment as depicted in Fig.4.5a.

4.7.2 CH_4 EMISSIONS

Methane emissions estimated ranged from a mean of $64.4 \text{ kg CH}_4 \text{ ha}^{-1}$ to $280 \text{ kg CH}_4 \text{ ha}^{-1}$. The descending order of emissions in terms of the treatment with organic and inorganic fertilizers and soil type was observed to follow the trend shown below:

Bekwai series soil + $\text{CO}(\text{NH}_4)_2$ + PM; Bekwai series soil + $(\text{NH}_4)_2\text{SO}_4$ + PM; Kumasi series soil

+ $(\text{NH}_4)_2\text{SO}_4$ + PM; Kumasi series soil + $\text{CO}(\text{NH}_4)_2$ + PM; Bekwai series soil + $\text{CO}(\text{NH}_4)_2$ + CM; Kumasi series soil + $(\text{NH}_4)_2\text{SO}_4$ + CM; Bekwai series soil + $(\text{NH}_4)_2\text{SO}_4$ + CM; Kumasi series soil + $\text{CO}(\text{NH}_4)_2$ + CM.

Methane emission was low in Kumasi series soil + $\text{CO}(\text{NH}_4)_2$ + cattle manure treatment as indicated in Fig.4.4b due mainly to oxidation of CH_4 toward the container surface where there was high O_2 concentrations as reported by Hao *et al.* (2001). High CH_4 emission occurred in the Bekwai series soil + $\text{CO}(\text{NH}_4)_2$ + poultry manure treatment shown by Fig.4.5b as a result of increased soil organic matter in the Bekwai series soil as against the Kumasi series soil (Hao *et al.*, 2001). Although CH_4 constituted a much smaller amount of the total emissions, its impact cannot be neglected since its global warming potential (GWP) is 72 times that of CO_2 over 20 years or 25 times that of CO_2 over 100 years (IPCC, 1997).

Hao *et al.* (2001) and Knowles (1993) reported that there was virtually no CH_4 emission when raw manure was applied directly to agricultural land as agricultural soil is regarded as a sink for CH_4 . This explains why CH_4 emissions were virtually low both in the poultry manure and the cattle manure treatments.

4.7.3 N_2O EMISSIONS

The decreasing order of emission was observed to follow the pattern:

Bekwai series soil + $\text{CO}(\text{NH}_4)_2$ + PM; Kumasi series soil + $\text{CO}(\text{NH}_4)_2$ + PM; Kumasi series soil + $\text{CO}(\text{NH}_4)_2$ + CM; Bekwai series soil + $(\text{NH}_4)_2\text{SO}_4$ + PM; Kumasi series soil + $(\text{NH}_4)_2\text{SO}_4$ +

PM; Bekwai series soil + $\text{CO}(\text{NH}_4)_2$ + CM; Kumasi series soil + $(\text{NH}_4)_2\text{SO}_4$ + CM; Bekwai series soil + $(\text{NH}_4)_2\text{SO}_4$ + CM.

Fig.4.5c indicates the highest N_2O emission from Bekwai series soil and poultry manure. Chemo-denitrification may play an important role in the high N_2O production and emissions (Hao *et al.*, 2001). On the other hand, Fig.4.8c represents low N_2O emission from Bekwai series soil and cattle manure treatments from the study. This result, therefore support earlier observations by Elmi *et al.*(2003), Chatsikh and Olesen (2007) and Rochette (2008) that light textured soils (soils rich in clay) mixed with cattle manure has a potential for reducing N_2O emissions.

The emissions of N_2O recorded for all the treatments under the study were higher than CH_4 and ranged from $61.1 \text{ kg N}_2\text{O ha}^{-1}$ to $470 \text{ kg N}_2\text{O ha}^{-1}$. This is contrary to the view that CH_4 is the second highest GHG after CO_2 , globally (IPCC, 2006). The primary reasons that could be attributed to the enhanced N_2O emissions from soils amended with organic and inorganic fertilizers, according to IPCC (1996), are, increased N inputs by mineral fertilizers, animal wastes (organic manure) and biological N fixation.

4.8 EMISSION FACTORS (EF)

Emission factor is a coefficient that relates the activity data to the amount of chemical compound being the source of emissions. Emission factors are dependent on a sample of

measurement data, averaged to develop a representative rate of emission for a given activity level under given set of operational conditions (IPCC, 1996).

Emission of GHG is given as:

$$[Emission = Emission\ factor\ (EF) \times Activity\ data]$$

where, Activity data refers to data on the magnitude of human activity, which give rise to emissions or removals occurring during a given period of time.

In this study, the activity data generated were:

- i. Mass of poultry manure + 20 % of mass (fixed loss rate of nitrogen that volatilizes as NH₃ and NO)
- ii. Mass of cattle manure + 20 % of mass (fixed loss rate of nitrogen that volatilizes as NH₃ and NO)
- iii. Mass of urea + 10 % of mass (fixed loss rate of nitrogen that volatilizes as NH₃ and NO)
- iv. Mass of ammonium sulphate + 10 % of mass (fixed loss rate of nitrogen that volatilizes as NH₃ and NO) (IPCC, 1996).

$$\text{Hence, } EF = \frac{Emission}{\sum [Activity\ data\ generated\ for\ GHG]}$$

Ward *et al.* (1991) indicates that emission factors are used to quantify the mass of a particular species emitted into the atmosphere during decomposition and mineralization to the mass of

gas released. Tables 4.3a-4.6b indicate the emission factors (in parenthesis) estimated for the GHG species emitted from the experimental set-ups. The mean emission factors observed in the study for CO₂, CH₄ and N₂O are summarised in Table 4.7:

Table 4.7: Mean Emission factors

Gas	Emission factor
CO ₂	28.0
CH ₄	1.47
N ₂ O	2.11

The emission factors for CH₄ and N₂O were 1.47 and 2.11 respectively. These values are in tandem with the mean emission factor proposed by IPCC (1997) which stipulates a range of 0.1 to 5.0 and a recommended constant figure of 1.25 for global and national emissions from fertilized soils. Again, the emission factor for CH₄ is similar to that of Andreae and Merlet (2001) stipulated as CH₄ 2.3 ± 0.9. The emission factor for CO₂ was observed to be 28.0.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATION

5.1 SUMMARY

Agricultural practices contribute largely to emissions of the GHGs especially, CO₂, CH₄ and N₂O, which potentially affect climate change mainly through the absorption and reflection of terrestrial radiation into the atmosphere. This study was aimed at determining the emissions of these three important GHGs released from two different agricultural soil types, two organic and two inorganic fertilizers known to potentially contribute to GHG emissions and hence, global climate change.

Rates of emissions of CO₂, CH₄ and N₂O increased similarly to increasing amounts of poultry manure as well as cattle manure. The poultry manure treatments released higher amount of gases in all cases than the cattle manure treatments confirming earlier studies that poultry manure in different locations in the Savanna zone of Ghana had higher C and N contents. This, no doubt contributed to the higher GHG emissions in all the poultry manure treatments as compared to the cattle manure treatments.

It was observed in the study that emissions of GHGs followed the descending order of CO₂, N₂O and CH₄. This, certainly, is contrary to the general notion that CH₄ is the second highest GHG that has a dramatic effect on climate change. The results observed from this study demonstrate the important contribution of N₂O emissions from soils, organic and inorganic fertilizers to the total GHG emissions.

The overall contribution of N_2O might have actually been underestimated in this research, since indirect emissions induced by NO_3^- -leaching and NH_3 volatilization were not accounted for. Carbon dioxide was the highest greenhouse gas emitted and the values ranged from 3121 $\text{kg CO}_2 \text{ ha}^{-1}$ to 10597 $\text{kg CO}_2 \text{ ha}^{-1}$. The second highest was nitrous oxide which was estimated to be in the range of 61.1 $\text{kg N}_2\text{O ha}^{-1}$ to 470 $\text{kg N}_2\text{O ha}^{-1}$.

Methane, the third in terms of emission was estimated to range from a mean of 64.4 $\text{kg CH}_4 \text{ ha}^{-1}$ to 280 $\text{kg CH}_4 \text{ ha}^{-1}$.

The emission factors relevant in the estimation of emission of greenhouse gases were determined as well. The determined emission factors were found to be in the descending order of CO_2 , N_2O and CH_4 . The emission factors for CH_4 and N_2O were 1.47 and 2.11 respectively. This study has added to knowledge the rate of GHG emissions, emission factors and the emission patterns of CO_2 , CH_4 and N_2O from poultry manure and cattle manure mixed with inorganic fertilizers. The study has also confirmed findings of other researchers that poultry manure mixed with inorganic fertilizers emit high N_2O , light textured soils mixed with cattle manure produce low N_2O emissions and that the emissions increase with increasing quantities of poultry manure and cattle manure.

5.2 CONCLUSIONS

The rate of emissions of CO₂, CH₄ and N₂O corresponds with the quantity of poultry manure and cattle manure applied and follows a pattern of direct correlation. Increasing quantities of poultry manure and cattle manure yielded high levels of CO₂, CH₄ and N₂O. Poultry manure mixed with either Kumasi series soil or Bekwai series soil yields higher rates of CO₂, CH₄ and N₂O emissions than the corresponding cattle manure.

Emission factors help in the estimation of greenhouse gas emissions when enough activity data have been generated and the emission factors generated in this study confirm the values of other researchers including what IPCC have obtained.

Finally, the null hypothesis was rejected because decomposition of manures mixed with N-based fertilizers releases greenhouse gases into the atmospheric environment.

5.3 RECOMMENDATION

There is a need for further research on the emission of greenhouse gases-CO₂, N₂O and CH₄ from organic and mineral fertilizer applications to crops in the field. More research work must be done on nitrous oxide emissions to establish its current status in Ghana in view of its high global warming potential (GWP) and subsequent harmful contribution to the climate change phenomenon.

More research work must be done on the emission of GHGs (CO₂, N₂O and CH₄) from organic and inorganic fertilizer application to crop field.

Caution should also be exercised in the excessive use of poultry manure and nitrogen fertilizers in integrated soil fertility management programmes.

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APPENDICES

DAYS AFTER SET UP/DAYS	CO ₂ (mL)	CH ₄ (mL)	N ₂ O (mL)
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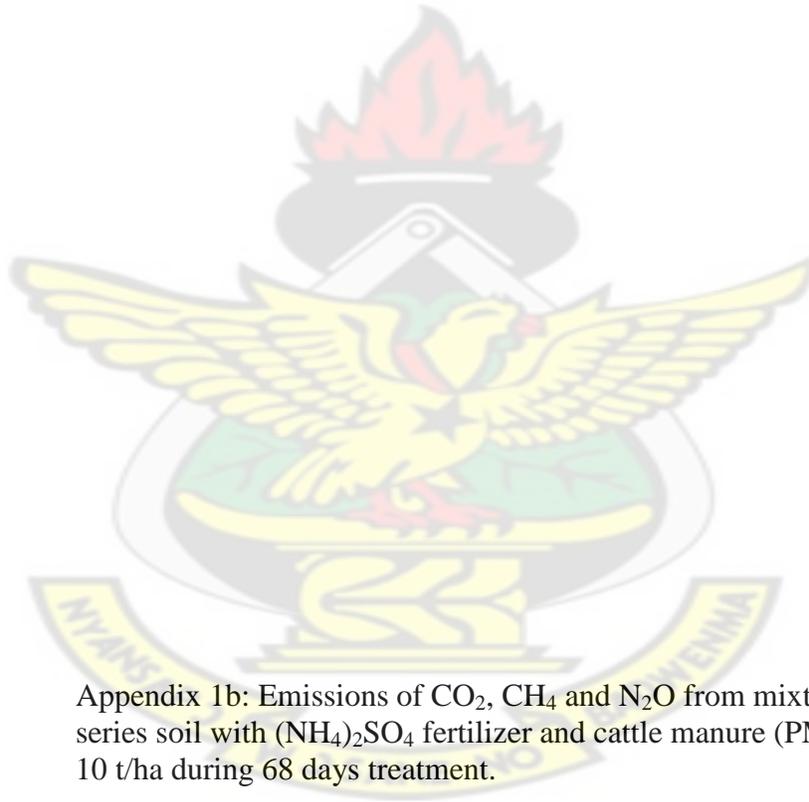
KNUST



Appendix 1a: Emissions of CO₂, CH₄ and N₂O from mixture of Kumasi series soil with (NH₄)₂SO₄ fertilizer and poultry manure (PM) at 4, 8 and 10 t/ha during 68 days treatment.

	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
5	5.80	8.60	11.00	0.60	0.70	0.80	0.30	0.40	0.50
9	6.70	12.00	10.90	0.20	0.30	0.50	0.20	0.30	0.30
13	13.40	10.20	17.40	0.40	0.50	0.50	0.20	0.20	0.30
17	7.00	9.70	11.70	0.40	0.40	0.60	0.20	0.20	0.20
21	13.50	14.40	16.90	0.40	0.50	0.80	0.20	0.20	0.40
24	12.50	15.60	27.50	0.90	0.90	1.20	0.20	0.20	0.20
28	11.70	14.10	19.50	0.70	0.90	0.90	0.20	0.20	0.20
35	13.50	24.40	28.80	0.70	1.00	1.00	0.30	0.30	0.40
40	10.40	17.10	16.80	0.70	0.90	1.00	0.50	0.60	0.70
46	8.80	11.70	16.70	0.50	0.70	0.80	0.40	0.40	0.50
52	12.60	13.00	15.60	0.70	0.90	1.00	0.30	0.40	0.50
60	12.30	14.00	14.80	0.50	0.60	0.70	0.40	0.50	0.60
68	11.30	17.90	18.50	1.10	1.30	1.30	0.90	1.00	1.40
TOTAL	139.50	182.70	226.10	7.80	9.60	11.10	4.30	4.90	6.20

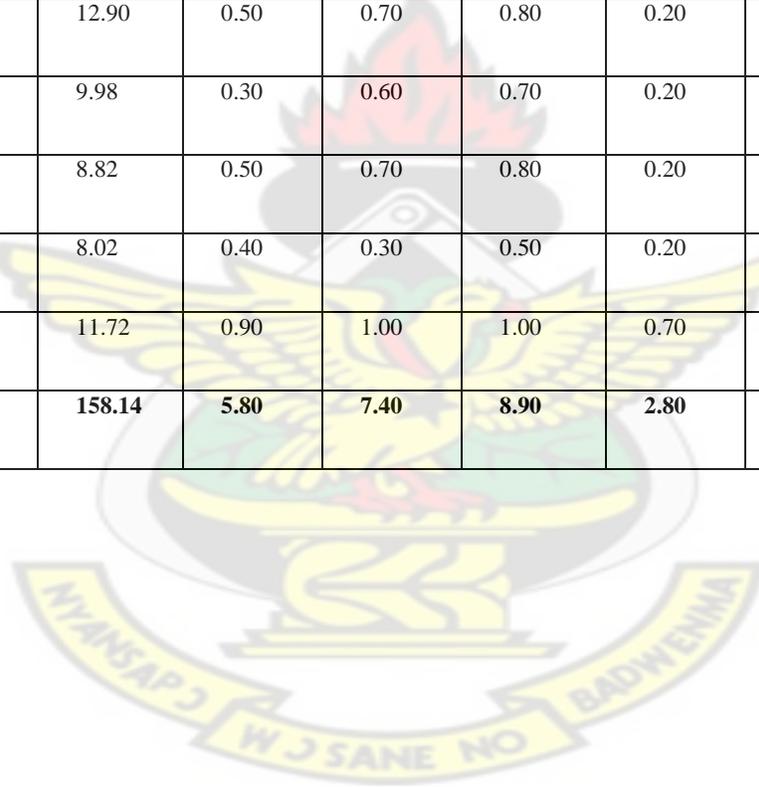
KNUST



Appendix 1b: Emissions of CO₂, CH₄ and N₂O from mixture of Kumasi series soil with (NH₄)₂SO₄ fertilizer and cattle manure (PM) at 4, 8 and 10 t/ha during 68 days treatment.

DAYS AFTER SET UP (DAS)	CO ₂ (mL)			CH ₄ (mL)			N ₂ O (mL)		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
5	2.10	4.90	7.30	0.40	0.40	0.50	0.20	0.30	0.40

9	3.10	8.30	7.20	0.20	0.20	0.40	0.20	0.20	0.20
13	6.50	9.70	13.70	0.30	0.40	0.40	0.10	0.20	0.20
17	5.40	7.40	6.70	0.10	0.30	0.40	0.10	0.10	0.30
21	9.20	10.10	12.60	0.30	0.40	0.60	0.10	0.10	0.10
24	8.20	11.30	23.20	0.70	0.70	1.00	0.20	0.20	0.30
28	5.80	8.20	13.60	0.60	0.80	0.90	0.10	0.20	0.30
35	7.10	18.00	22.40	0.60	0.90	0.90	0.30	0.40	0.50
40	6.50	13.20	12.90	0.50	0.70	0.80	0.20	0.20	0.30
46	2.02	4.92	9.98	0.30	0.60	0.70	0.20	0.30	0.40
52	5.82	6.22	8.82	0.50	0.70	0.80	0.20	0.30	0.40
60	5.52	7.22	8.02	0.40	0.30	0.50	0.20	0.30	0.40
68	4.52	11.12	11.72	0.90	1.00	1.00	0.70	0.90	1.10
TOTAL	71.78	120.58	158.14	5.80	7.40	8.90	2.80	3.70	4.90



DAYS AFTER SEED	CO ₂ (mL)	CH ₄ (mL)	N ₂ O (mL)
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KNUST

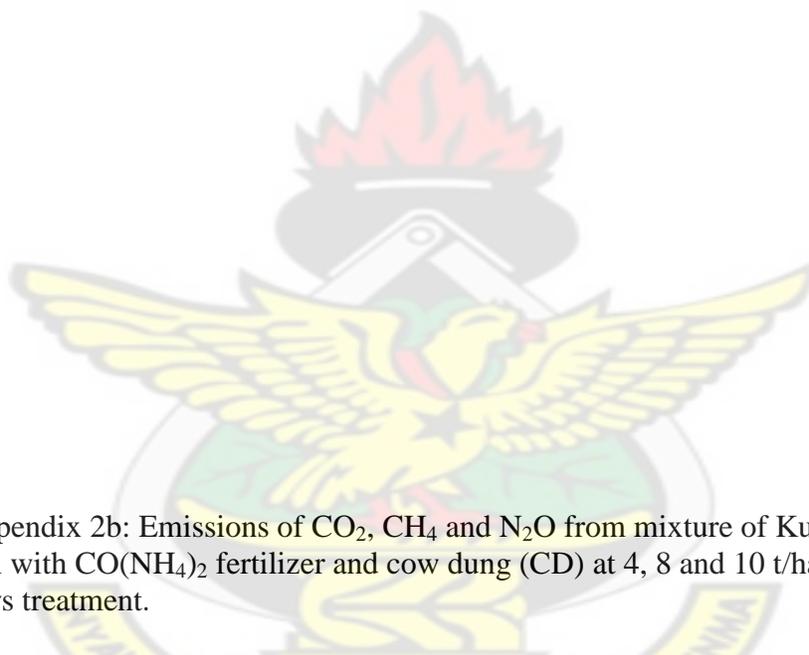


Appendix 2a: Emissions of CO₂, CH₄ and N₂O from mixture of Kumasi series soil with CO(NH₄)₂ fertilizer and poultry manure (PM) at 4, 8 and 10 t/ha during 68 days treatment.

	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
3	11.30	13.60	14.80	0.60	0.80	1.10	0.40	0.60	0.80
6	12.70	13.70	13.90	0.50	0.60	0.90	0.40	0.30	0.80
11	20.20	20.20	24.30	0.80	0.80	1.10	0.40	0.50	0.80
18	20.20	22.80	23.80	0.60	0.60	0.90	0.40	0.50	1.00
23	19.90	20.40	21.60	0.40	0.50	0.70	0.40	0.60	1.00
26	16.60	16.70	19.00	0.50	0.50	0.80	0.20	0.20	1.00
30	18.49	18.56	18.70	0.46	0.49	0.52	0.11	0.18	0.60
35	15.38	17.24	20.31	0.39	0.51	0.58	0.21	0.23	0.91
42	11.43	11.58	12.01	0.44	0.49	0.61	0.43	0.56	0.89
54	13.14	13.63	14.00	0.35	0.41	0.44	0.33	0.61	0.93
61	10.21	10.37	10.44	0.63	0.67	0.81	0.44	0.49	0.65
68	17.81	18.01	19.33	0.61	0.59	0.92	0.52	0.77	0.88
TOTAL	187.36	196.79	212.19	6.28	6.96	9.38	4.24	5.54	10.26



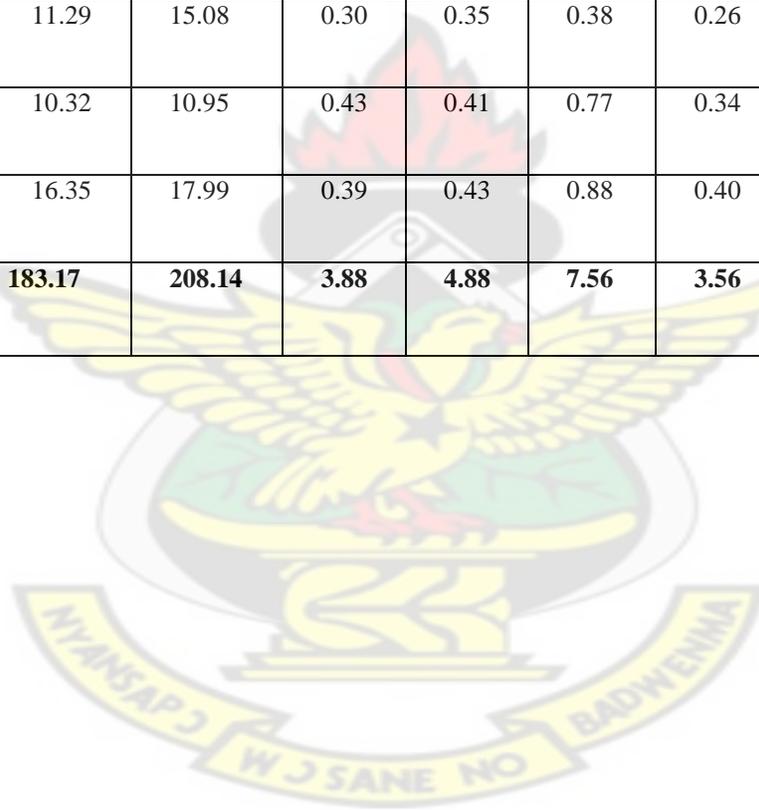
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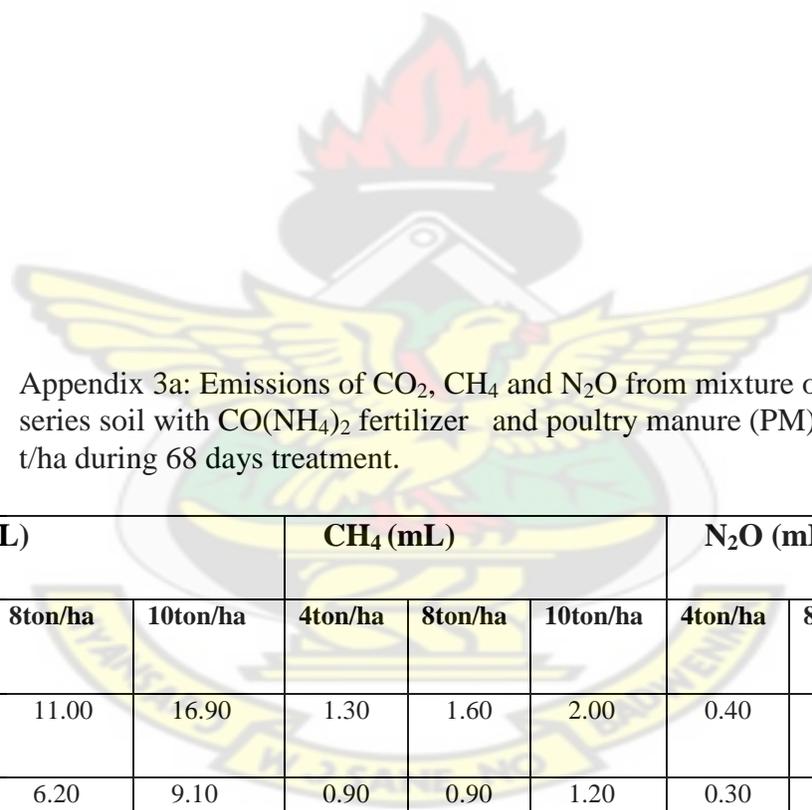
Appendix 2b: Emissions of CO₂, CH₄ and N₂O from mixture of Kumasi series soil with CO(NH₄)₂ fertilizer and cow dung (CD) at 4, 8 and 10 t/ha during 68 days treatment.

DAYS AFTER SET UP(DAS)	CO ₂ (mL)			CH ₄ (mL)			N ₂ O(mL)		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
3	19.30	22.30	24.60	0.40	0.50	0.60	0.40	0.40	0.50
6	20.93	21.81	26.43	0.27	0.42	0.62	0.35	0.38	0.66
11	15.21	15.43	16.32	0.23	0.44	0.91	0.56	0.71	0.88

18	15.01	15.23	16.35	0.43	0.48	0.83	0.23	0.45	0.86
23	13.39	20.01	20.45	0.27	0.40	0.62	0.33	0.54	0.81
26	11.71	11.67	16.07	0.29	0.34	0.58	0.11	0.13	0.79
30	14.38	14.79	14.89	0.32	0.39	0.44	0.10	0.13	0.42
35	12.01	13.92	16.53	0.28	0.41	0.47	0.15	0.19	0.71
42	9.03	10.05	12.48	0.27	0.31	0.46	0.33	0.38	0.78
54	11.11	11.29	15.08	0.30	0.35	0.38	0.26	0.57	0.80
61	10.03	10.32	10.95	0.43	0.41	0.77	0.34	0.37	0.60
68	15.53	16.35	17.99	0.39	0.43	0.88	0.40	0.65	0.81
TOTAL	167.64	183.17	208.14	3.88	4.88	7.56	3.56	4.90	8.62



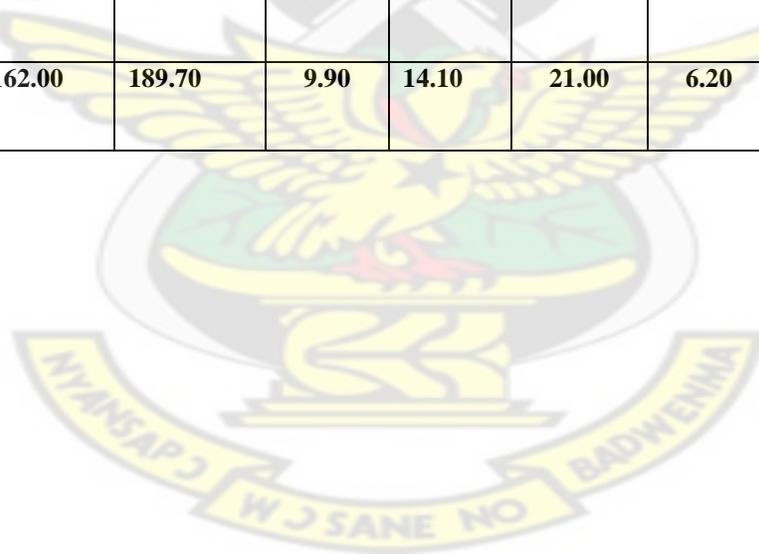
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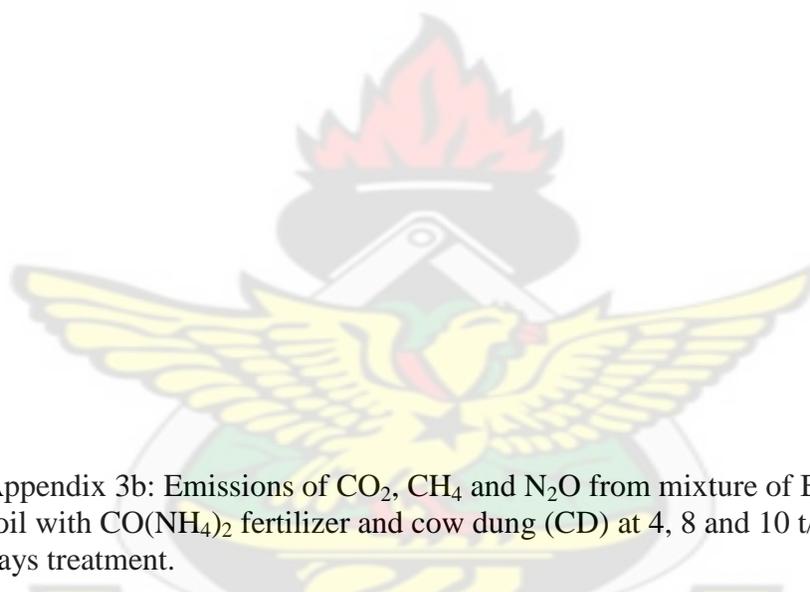
Appendix 3a: Emissions of CO₂, CH₄ and N₂O from mixture of Bekwai series soil with CO(NH₄)₂ fertilizer and poultry manure (PM) at 4, 8 and 10 t/ha during 68 days treatment.

DAYS AFTER SET UP(DAS)	CO ₂ (mL)			CH ₄ (mL)			N ₂ O (mL)		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
6	5.50	11.00	16.90	1.30	1.60	2.00	0.40	0.40	0.70
10	2.80	6.20	9.10	0.90	0.90	1.20	0.30	0.30	0.60
14	6.40	7.50	9.30	0.70	0.80	0.80	0.30	0.30	0.80
18	6.20	6.50	10.50	0.50	1.30	1.80	0.30	0.30	1.00
23	8.60	11.50	12.90	0.50	0.90	1.30	0.50	0.60	1.70

26	8.40	8.70	9.70	0.60	1.00	1.10	0.30	0.40	0.90
29	6.50	7.90	10.30	0.50	0.60	1.10	0.20	0.40	0.80
32	8.20	8.00	8.10	0.60	1.00	1.20	0.30	0.30	0.90
35	8.50	9.30	11.60	0.60	0.80	1.00	0.30	0.40	0.80
38	7.60	8.90	9.20	0.50	0.70	1.60	0.40	0.60	0.60
41	11.50	11.10	12.30	0.60	0.70	1.90	0.30	0.30	0.50
48	14.30	20.90	21.60	0.70	1.10	1.90	0.70	0.80	0.90
52	9.20	15.80	15.90	0.90	1.20	1.80	0.60	0.60	0.90
57	10.70	16.00	16.40	0.60	0.90	1.30	0.80	0.80	0.90
68	10.70	12.70	15.90	0.40	0.60	1.00	0.50	0.60	0.60
TOTAL	125.10	162.00	189.70	9.90	14.10	21.00	6.20	7.10	12.60



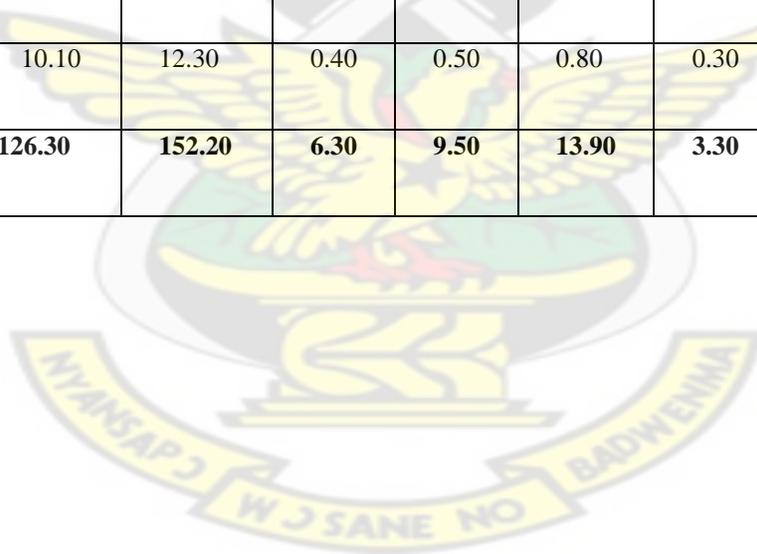
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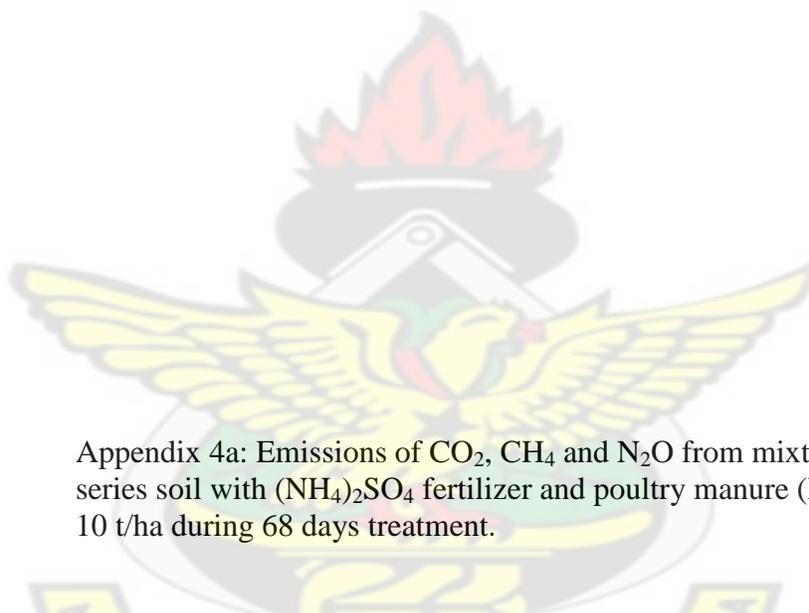
Appendix 3b: Emissions of CO₂, CH₄ and N₂O from mixture of Bekwai series soil with CO(NH₄)₂ fertilizer and cow dung (CD) at 4, 8 and 10 t/ha during 68 days treatment.

DAYS AFTER SET UP(DAS)	CO ₂ (mL)			CH ₄ (mL)			N ₂ O (mL)		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
6	3.90	9.30	12.60	0.70	0.80	0.90	0.20	0.30	0.60
10	1.70	4.30	7.20	0.50	0.60	0.80	0.10	0.10	0.40
14	4.50	5.30	6.80	0.40	0.50	0.50	0.10	0.20	0.50
18	4.20	4.10	7.90	0.20	0.70	0.90	0.10	0.10	0.80

23	6.40	8.60	10.30	0.30	0.60	0.80	0.30	0.30	1.00
26	6.30	6.40	9.10	0.30	0.70	0.80	0.20	0.20	0.60
29	4.30	6.40	9.40	0.40	0.40	0.90	0.10	0.20	0.40
32	7.30	7.00	7.70	0.40	0.80	1.00	0.10	0.10	0.50
35	7.70	8.00	8.90	0.50	0.50	0.80	0.10	0.20	0.50
38	5.60	7.30	7.90	0.30	0.50	1.10	0.20	0.30	0.30
41	7.40	7.60	7.80	0.40	0.50	1.30	0.10	0.10	0.30
48	10.40	13.80	15.30	0.50	0.90	1.20	0.40	0.40	0.60
52	7.80	14.10	14.30	0.60	0.80	1.10	0.40	0.40	0.70
57	9.30	14.00	14.70	0.40	0.70	1.00	0.60	0.60	0.60
68	9.00	10.10	12.30	0.40	0.50	0.80	0.30	0.30	0.40
TOTAL	95.80	126.30	152.20	6.30	9.50	13.90	3.30	3.80	8.20



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Appendix 4a: Emissions of CO₂, CH₄ and N₂O from mixture of Bekwai series soil with (NH₄)₂SO₄ fertilizer and poultry manure (PM) at 4, 8 and 10 t/ha during 68 days treatment.

DAYS AFTER SET UP(DAS)	CO ₂ (mL)			CH ₄ (mL)			N ₂ O(mL)		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
5	2.50	4.30	4.70	0.70	0.80	1.40	0.20	0.30	0.40
9	2.50	2.60	4.00	0.70	0.70	1.00	0.30	0.50	0.60
13	4.30	4.70	6.00	0.60	0.60	1.00	0.20	0.30	0.30
17	5.90	6.10	9.50	0.90	0.90	1.20	0.30	0.50	0.60

21	7.10	7.50	10.40	0.40	0.70	0.70	0.30	0.40	0.70
24	14.00	18.60	22.90	0.50	0.80	1.20	0.30	0.30	0.30
48	23.00	47.20	62.90	0.40	0.70	1.30	0.30	0.50	0.80
60	24.80	35.10	35.70	0.50	0.50	0.50	0.30	0.50	0.70
68	13.50	14.10	17.30	0.40	0.40	0.70	0.30	0.40	0.80
TOTAL	97.60	140.20	173.40	5.10	6.10	9.00	2.50	3.70	5.20



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Appendix 4b: Emissions of CO₂, CH₄ and N₂O from mixture of Bekwai series soil with (NH₄)₂SO₄ fertilizer and cow dung (CD) at 4, 8 and 10 t/ha during 68 days treatment.

DAYS AFTER SET UP(DAS)	CO ₂ (mL)			CH ₄ (mL)			N ₂ O (mL)		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
5	2.00	3.20	3.40	0.40	0.50	0.90	0.10	0.10	0.30
9	2.00	2.10	2.90	0.40	0.40	0.90	0.10	0.20	0.40
13	3.10	3.20	4.30	0.30	0.30	0.80	0.10	0.10	0.30
17	4.80	5.20	7.40	0.60	0.70	1.00	0.10	0.30	0.30
21	5.40	5.70	8.40	0.20	0.50	0.50	0.10	0.30	0.50
24	10.50	15.70	18.30	0.30	0.50	1.00	0.10	0.10	0.20
48	20.30	35.70	52.60	0.20	0.50	1.10	0.10	0.20	0.50

60	19.80	29.60	30.90	0.30	0.30	0.40	0.10	0.20	0.40
68	10.10	10.70	11.90	0.20	0.20	0.50	0.20	0.30	0.60
TOTAL	78.00	111.10	140.10	2.90	3.90	7.10	1.00	1.80	3.50

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Appendix 4.3.1: Cumulative emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Kumasi series soil with (NH₄)₂SO₄ fertilizer.

	Gas emissions (kg/ha)								
	CO ₂			CH ₄			N ₂ O		
Manure type	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
Poultry manure	76725.0	100485.0	124355.0	1560.0	1920.0	2220.0	2365.0	2695.0	3410.0
Cow dung	39478.75	66318.75	86977.50	1160.0	1480.0	1780.0	1540.0	2035.0	2695.0

Appendix 4.3.2: Cumulative emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Kumasi series soil with CO(NH₄)₂ fertilizer.

	Gas emissions (kg/ha)
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Manure type	CO ₂			CH ₄			N ₂ O		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
Poultry manure	103047.5	108235.0	116705.0	1256.25	1392.50	1876.25	2332.50	3047.50	5642.0
Cow dung	92202.5	100743.75	114477.5	776.25	976.25	1512.50	1957.50	2695.00	4741.25

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Appendix 4.3.3: Cumulative emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Bekwai series soil with CO(NH₄) fertilizer.

Manure type	Gas emissions (kg/ha)								
	CO ₂			CH ₄			N ₂ O		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
Poultry manure	68805.00	89100.00	104335.0	1980.0	2820.0	4200.00	3410.00	3905.00	6930.00

Cow dung	52690.00	69465.00	83710.00	1260.0	1900.0	2780.00	1815.00	2090.00	4510.00
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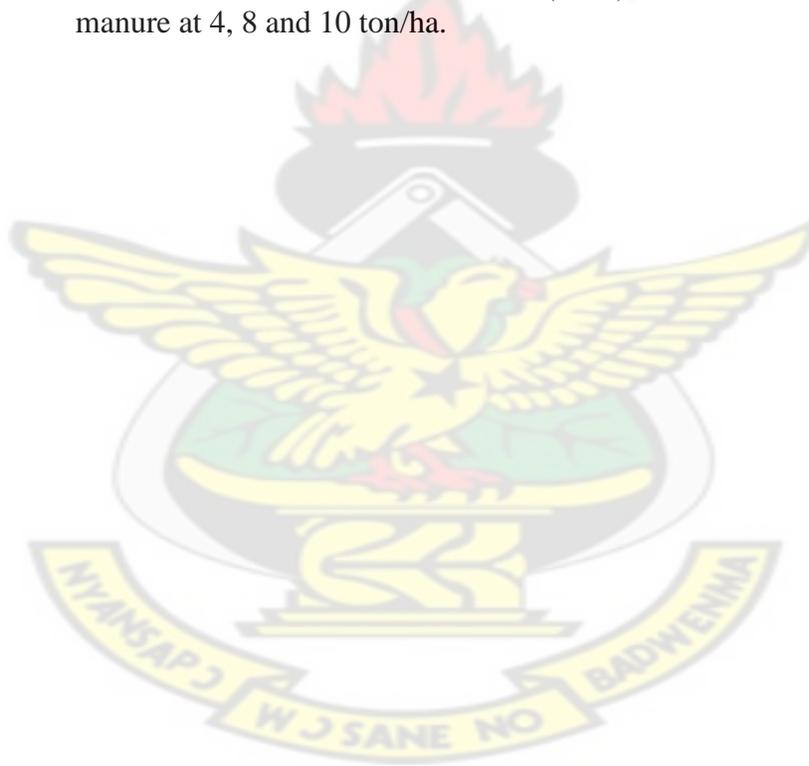
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Appendix 4.3.4: Cumulative emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Bekwai series soil with (NH₄)₂SO₄ fertilizer.

	Gas emissions (kg/ha)								
	CO ₂			CH ₄			N ₂ O		
Manure type	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
Poultry manure	53680.00	77110.00	95370.00	1020.0	1220.0	1800.00	1375.00	2035.00	2860.00
Cow dung	42900.00	61105.00	77055.00	580.00	780.00	1420.00	550.00	990.00	1925.00

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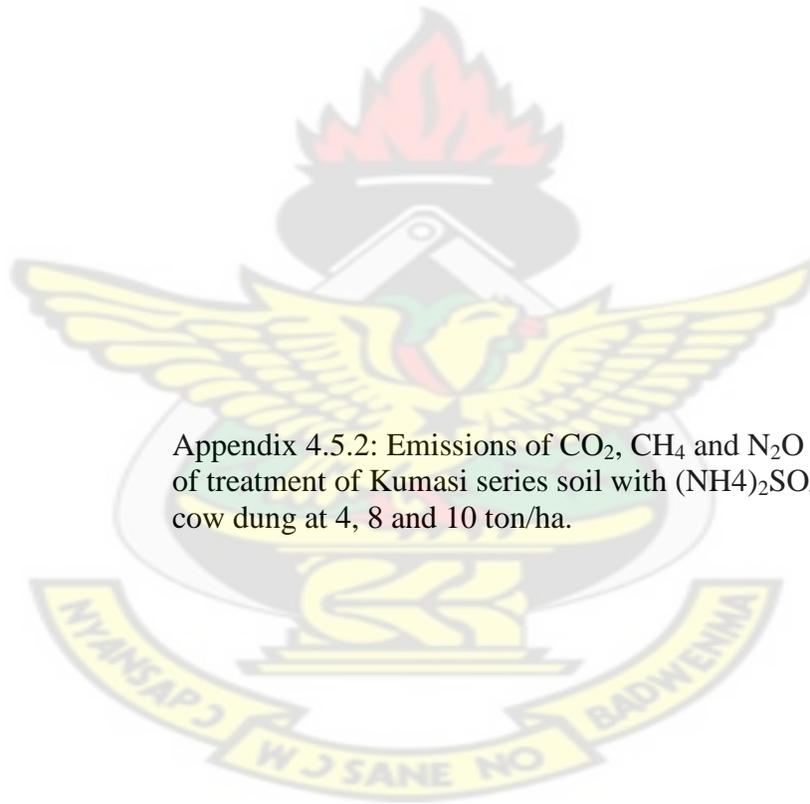
Appendix 4.5.1: Emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Kumasi series soil with (NH₄)₂SO₄ fertilizer and poultry manure at 4, 8 and 10 ton/ha.



GAS EMISSION (kg/ha)

DAS	POULTRY MANURE								
	CO ₂			CH ₄			N ₂ O		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
5	3190	4730	6050	120	140	160	165	220	275
9	3685	6600	5995	40	60	100	110	165	165
13	7370	5610	9570	80	100	100	110	110	165
17	3850	5335	6435	80	80	120	110	110	110
21	7425	7920	9295	80	100	160	110	110	220
24	6875	8580	15125	180	180	240	110	110	110
28	6435	7755	10725	140	180	180	110	110	110
35	7425	13420	15840	140	200	200	165	165	220
40	5720	9405	9240	140	180	200	275	330	385
46	4840	6435	9185	100	140	160	220	220	275
52	6930	7150	8580	140	180	200	165	220	275
60	6765	7700	8140	100	120	140	220	275	330
68	6215	9845	10175	220	260	260	495	550	770

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Appendix 4.5.2: Emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Kumasi series soil with (NH₄)₂SO₄ fertilizer and cow dung at 4, 8 and 10 ton/ha.

GAS EMISSION (kg/ha)

DAS	COW DUNG								
	CO ₂			CH ₄			N ₂ O		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
5	1155	2695	4015	80	80	100	110	165	220
9	1705	4565	3960	40	40	80	110	110	110
13	3575	5335	7535	80	60	80	55	110	110
17	4070	2970	3685	20	60	80	55	55	165
21	5060	5555	6930	80	60	120	55	55	165
24	4510	6215	12760	140	140	200	55	55	55
28	3190	4510	7480	120	160	180	110	110	165
35	3905	9900	12320	120	180	180	55	110	165
40	3575	7260	7095	100	140	160	165	220	275
46	1111	2706	5489	60	120	140	110	110	165
52	3201	3421	4851	100	140	160	110	165	220
60	3036	3971	4411	80	60	100	110	165	220
68	2486	6116	6446	180	200	200	385	495	605

GAS EMISSION (kg/ha)

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Appendix 4.5.3: Emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Kumasi series soil with CO(NH₄) fertilizer and poultry manure at 4, 8 and 10 ton/ha.

DAS	POULTRY MANURE								
	CO ₂			CH ₄			N ₂ O		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
3	6215	7480	8140	120	160	160	220	330	440
6	6985	7535	7645	100	120	160	220	165	440
11	11110	11110	13365	160	160	160	220	275	440
18	11110	12540	13090	120	120	200	275	220	550
23	10945	11220	11880	80	100	200	220	330	550
26	9130	9185	10450	100	100	200	110	110	550
30	10169.5	10208	10285	92	98	120	60.5	99	330
35	8459	9482	11170.5	78	102	182	115.5	126.5	500.5
42	6286.5	6369	6605.5	88	98	178	236.5	308	489.5
54	7227	7496.5	7700	70	82	186	181.5	335.5	511.5
61	5615.5	5703.5	5742	126	138	130	242	269.5	357.5
68	9795.5	9905.5	10631.5	122	118	176	286	423.5	484



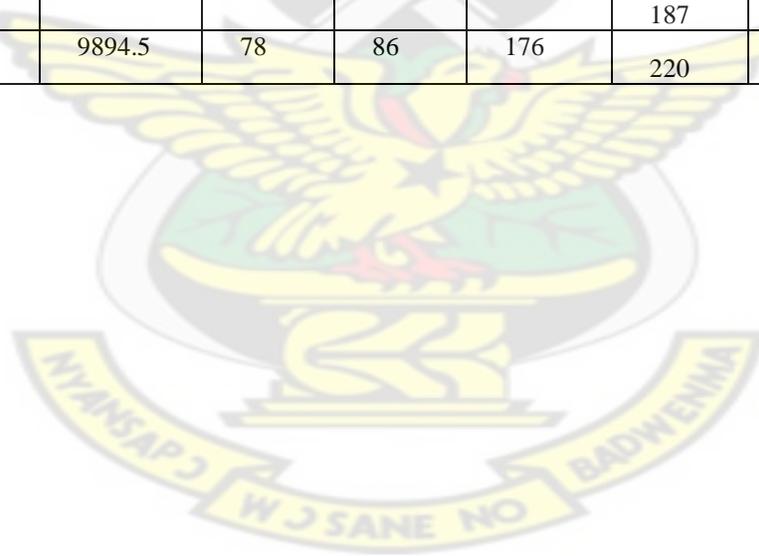
GAS EMISSION (kg/ha)

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Appendix 4.5.4: Emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Kumasi series soil with CO(NH₄) fertilizer and cow dung at 4, 8 and 10 ton/ha

DAS	COW DUNG								
	CO ₂			CH ₄			N ₂ O		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
3	10615	12265	13530	80	100	120	220	220	275
6	11511.5	11995.5	14536.5	54	84	124	192.5	209	363
11	8365.5	8486.5	8976	46	88	182	308	390.5	484
18	8255.5	8376.5	8992.5	86	96	166	126.5	247.5	473
23	7364.5	11005.5	11247.5	54	80	124	181.5	297	445.5
26	6440.5	6418.5	8838.5	58	68	116	60.5	71.5	434.5
30	7909	8134.5	8189.5	64	60	88	55	71.5	231
35	6605.5	7656	9091.5	56	82	94	82.5	104.5	390.5
42	4966.5	5527.5	6864	54	62	92	181.5	209	429
54	6110.5	6209.5	8294	60	70	76	143	313.5	440
61	5516.5	5676	6022.5	86	82	154	187	203.5	330
68	8541.5	8992.5	9894.5	78	86	176	220	357.5	445.5



GAS EMISSION (kg/ha)

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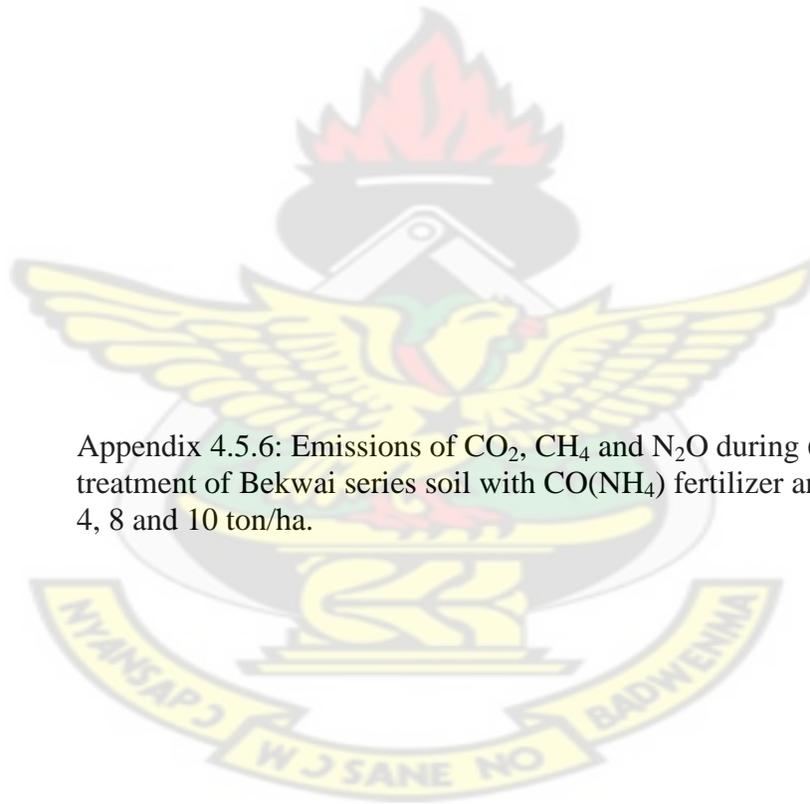


Appendix 4.5.5: Emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Bekwai series soil with CO(NH₄) fertilizer and poultry manure at 4, 8 and 10 ton/ha.

DAS	POULTRY MANURE								
	CO ₂			CH ₄			N ₂ O		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
6	3025	6050	9295	260	320	400	220	220	385
10	1540	3410	5005	180	180	240	165	165	330
14	3520	4125	5115	140	160	160	165	165	440
18	3410	3575	5775	100	260	360	165	165	550
23	4730	6325	7095	100	180	260	275	330	935
26	4620	4785	5335	120	200	220	165	220	495
29	3575	4345	5665	100	120	220	110	220	440
32	4510	4400	4455	120	200	240	165	165	495
35	4675	5115	6380	120	160	200	165	220	440
38	4180	4895	5060	100	140	320	220	330	330
41	6325	6105	6765	120	140	380	165	165	275
48	7865	11495	11880	140	220	380	385	440	495
51	5060	8690	8745	180	240	360	330	330	495
57	5885	8800	9020	120	180	260	440	440	495
68	5885	6985	8745	80	120	200	275	330	330



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Appendix 4.5.6: Emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Bekwai series soil with CO(NH₄) fertilizer and cow dung at 4, 8 and 10 ton/ha.

GAS EMISSION (kg/ha)

DAS	COW DUNG								
	CO ₂			CH ₄			N ₂ O		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
6	2145	5115	6930	140	160	180	110	165	330
10	935	2365	3960	100	120	160	55	55	220
14	2475	2915	3740	80	100	100	55	110	275
18	2310	2255	4345	40	140	180	55	55	440
23	3520	4730	5665	60	120	160	165	165	550
26	3465	3520	5005	60	140	160	110	110	330
29	2365	3520	5170	80	80	180	55	110	220
32	4015	3850	4235	80	160	200	55	55	275
35	4235	4400	4895	100	100	160	55	110	275
38	3080	4015	4345	60	100	220	110	165	165
41	4070	4180	4290	80	100	260	55	55	165
48	5720	7590	8415	100	180	240	220	220	330
51	4290	7755	7865	120	160	220	220	220	385
57	5115	7700	8085	80	140	200	330	330	330
68	4950	5555	6765	80	100	160	165	165	220

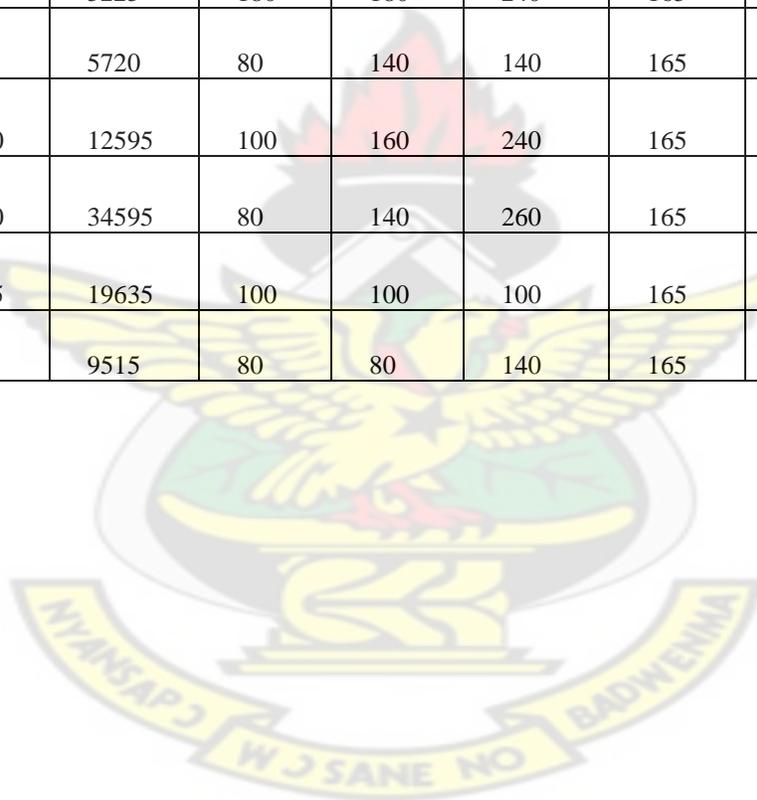
GAS EMISSION (kg/ha)

KNUST

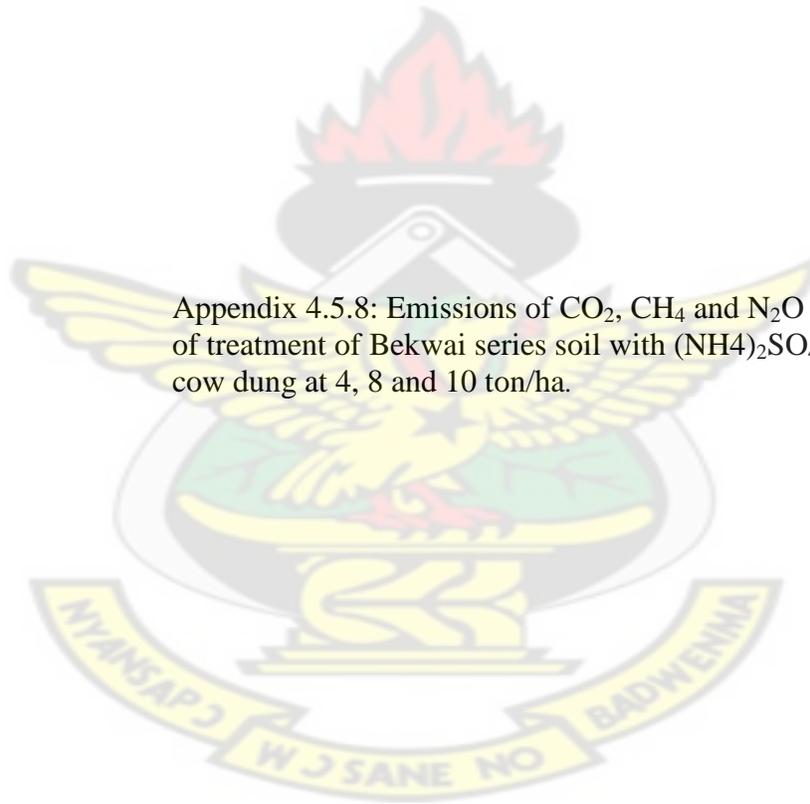


Appendix 4.5.7: Emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Bekwai series soil with (NH₄)₂SO₄ fertilizer and poultry manure at 4, 8 and 10 ton/ha.

DAS	POULTRY MANURE								
	CO ₂			CH ₄			N ₂ O		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
5	1375	2365	2585	140	160	280	110	165	220
9	1375	1430	2200	140	140	200	165	275	330
13	2365	2585	3300	120	120	200	110	165	165
17	3245	3355	5225	180	180	240	165	275	330
21	3905	4125	5720	80	140	140	165	220	385
24	7700	10230	12595	100	160	240	165	165	165
48	12650	25960	34595	80	140	260	165	275	440
60	13640	19305	19635	100	100	100	165	275	385
68	7425	7755	9515	80	80	140	165	220	440



KNUST



Appendix 4.5.8: Emissions of CO₂, CH₄ and N₂O during 68 days of treatment of Bekwai series soil with (NH₄)₂SO₄ fertilizer and cow dung at 4, 8 and 10 ton/ha.

GAS EMISSION (kg/ha)

DAS	COW DUNG								
	CO ₂			CH ₄			N ₂ O		
	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha	4ton/ha	8ton/ha	10ton/ha
5	1100	1760	1870	80	100	180	55	55	165
9	1100	1155	1595	80	80	180	55	110	220
13	1705	1760	2365	60	60	160	55	55	165
17	2640	2860	4070	120	140	200	55	165	165
21	2970	3135	4620	40	100	100	55	165	275
24	5775	8635	10065	60	100	200	55	55	110
48	11165	19635	28930	40	100	220	55	110	275
60	10890	16280	16995	60	60	80	55	110	220
68	5555	5885	6545	40	40	100	110	165	330

