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KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY – KUMASI

A COMPARATIVE ANALYSIS ON THE USE OF ORGANIC AND INORGANIC FERTILIZERS IN COCOA PRODUCTION AND THEIR IMPACT ON THE SOIL.

(A CASE STUDY OF SELECTED COCOA FARMS IN TAFO IN THE EAST-AKIM DISTRICT IN THE EASTERN REGION)

A THESIS SUBMITTED TO THE
DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY
IN FULFILLMENT OF THE REQIUREMENT FOR THE DEGREE OF MASTER OF SCIENCE

BY:

KORANTENG, VICTORIA ASIAMAH

JUNE, 2015

STUDENT'S DECLARATION

I hereby declare that this research work is original and the author's own undertaking under the supervision of Dr. M. G. Addo, a Senior Lecturer of KNUST and that it has neither been produced wholly nor partially for the award of a Master's Degree Certificate in this University or anywhere.

Materials from other works that have served as sources of information have been fully acknowledged by reference to them.

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ABSTRACT

In sustainable agricultural systems, recycling of nutrients is a major component of nutrient management. Cocoa as a perennial crop requires high nutritional supply for its proper growth and development. The continual uptake of nutrients from the soil by cocoa results in a likely degradation of soil nutrients overtime, hence there is the need to apply fertilizers in cocoa production to replenish the lost nutrients. A case study was conducted on ten cocoa farms in Tafo in the East-Akim District in the Eastern Region to investigate the use of organic and inorganic fertilizer application and their effects on soilphysico-chemical and biological properties and howthe effects impact cocoa production. Treatments included organic fertilization, inorganic fertilizer application and these were compared to control plots, which were plots of virgin forest. The treatments were fitted in a Completely Randomized, Design (CRD), each with five (5), replications. The inorganic farms showed increased levels of the plants' major nutrients such as available phosphorus, total nitrogen, exchangeable potassium (K^{+}) , Calcium (Ca^{2+}) and magnesium (Mg^{2+}) . However these farms recorded reduced values for soil pH, organic matter content and reduction in soil biofauna both in biomass and diversity. Soil from the organic farms on the other hand recorded increased values in soil pH, organic matter content and more soil microbes were contained in such farms both in diversity and in biomass. The organic farms recorded low levels of soil major nutrients such as nitrogen, phosphorus and exchangeable bases. The control plots (forests) on the other hand recorded the highest values in almost all the parameters considered. Additions of amendments did not significantly (p □□0.05) influence the levels of the major soil nutrients that were measured, however subsequent application of chemical fertilizers was likely to render the soil acidic on the bases of the results obtained for soil pH. There were also significant differences between the values recorded for all the species of bacteria and fungi and also some species of Nematodes, with the three treatments. Results of the study suggested that integrating organic and inorganic fertilizers would be effective in restoring the productivity of degraded soils and enhance the growth and development of Cocoa.

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LIST OF ABBREVIATIONS

AGRA	-	Alliance for a Green Revolution in Africa
CEC	-	Cation Exchange Capacity
CRIG	-	Cocoa Research Institute of Ghana
CSIR	-	Council of Scientific and Industrial Research
DOC	-	Dissolved Organic Carbon
FAO	-	Food and Agricultural Organization
LSD	-	Least Significant Difference
MA	-	MacConkey Agar
MPN	-	Most Probable Number
MSWC	-	Municipal Solid Waste Compost
PA	-	Pseudomonas Agar
PCA	-	Plate Count Agar
PDA	-	Potato Dextrose Agar
PGPR	-	Plant Growth Promoting Rhizobacteria
SMA	-	Salt Manital Agar
SOM	-	Soil Organic Matter

DEDICATION

This project is dedicated to my lovely daughters Thelma and Pascaline for whose reason I decided to undertake the Masters Degree Programme.

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Special thanks and appreciation go to Dr. Alfred Arthur, Dr. AduAcheampong, Dr. E. A. Dwomoh and the entire staff of the Soil Science Division of the Cocoa Research Institute of Ghana, New Tafo especially Brother Samuel and Killian, for their diverse support and encouragement as well as guidance in undertaking field and laboratory work which contributed to the successful accomplishment of this study. I would also like to express my profound gratitude to my husband Mr. Samuel Agbleke for his understanding and support to further my education.

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CHAPTER ONE

1.0 INTRODUCTION

Cocoa (Theobroma cacao), remains the major export crop in Ghana, and every year, revenue of millions of Ghana cedis is derived from dried cocoa beans. Its cultivation has gained prominence rapidly in Ghana such that statistics conducted in 2005 showed that Ghana produced 736,000 metric tons of cocoa beans, making Ghana to become the world‟s second largest producer of cocoa and the first in terms of quality beans. Apart from it providing revenue and job opportunities for most Ghanaians, the crop has been used in several researches in Ghana and several other countries such as Nigeria and India. It has been shown experimentally by the Cocoa Research Institute of Ghana (CRIG) that continuous cultivation of cocoa on the same farmland leads to appreciable decline in the level of nutrients in the soil (Ntiamoah and Afrane, 2007).

Cocoa production has, no doubt, contributed to the decline in soil fertility status. The mature tree has a taproot system of about 120-200 cm which grows deep into the soil together with an extensive system of lateral feeder roots most of which lie in the top 20cm of the soil, and where the humid layer is deep, they may extend to 40-50 cm. This implies that cocoa requires a high nutrient content and topsoil rich in organic matter (Opeke, 2005). This root system together with the fact that cocoa is a perennial crop and as such the soil nutrients in cocoa plantations are being mined annually via cocoa harvesting (Ogunlade et. al., 2009). Wessel (1991), reported that there is a steady decline in almost all the nutrients with continues cultivation of cocoa over a long period. Omotoso (1975), also showed that a crop of 1000 kg dry cocoa beans removes about 20 kg nitrogen (N), 4 kg phosphorus (P) and 10 kg potassium (K), and even where the pods are removed from the field, the amount of potassium removed is increased more than five folds.

In recent decades, unsustainable land cultivation practices such as continuous cultivation of crops on the same parcel of land for several seasons, has led to accelerated depletion of the natural soil base available for food production (Hossner and Juo, 1999). Soil productivity maintenance remains a major environmental issue in sub-Saharan African countries including Ghana (Oyetunji et. al.,(2001). Low soil

fertility inevitably leads to low cocoa productivity, since the growth and development of cocoa are fundamentally affected by the productivity level of land resources. Furthermore, unsustainable soil management activities including deforestation, indiscriminate vegetation removal, overgrazing, continuous cropping, etc. and the use of marginal lands for agricultural purposes often precede eventual degradation of soil resources and environmental damages (Henao and Baanante, 2006). Such poor cultivation practices have resulted in the decline of soil fertility, reduction in soil organic matter and increased occurrences of acidified soil (Aihou et al., 1998).

Decline in soil fertility as a result of land degradation decreases farmland productivity (Amede, 2003). Smaling (1993), estimated that annual net nutrient depletion rates per hectare exceed 30 kg nitrogen and 20 kg potassium in arable soil of several African countries including Ghana. Sustainable cocoa production incorporates the notion that land resource be used to increase agricultural output and income without depleting the natural resources base (Gruhn et. al., 2000).

Cultivated, highly weathered soils in Ghana have also been observed to commonly suffer from multiple nutrient deficiencies and nutrient balances are generally negative (Tandon, 1993; Mokwunye et. al 1996). Soil nutrient depletion and likely degradation have been considered serious threats to cocoa productivity, and has been identified as a major cause of decreased crop yields in general and the per capital food production in Ghana (Henao and Baanante, 2006).

This notwithstanding, Ghana‟s population growth rate has increased tremendously in recent times to an extent that is rather overwhelming. This has created an increased pressure on agricultural lands such that the former shifting cultivation system, where a parcel of land after being used for a number of seasons would have to be left to fallow, in order to regain its fertility, has significantly reduced, and at present rarely exceeds six years (Onyebinama, 2006). However, it is evident that fallow period shorter than ten (10) years will not allow the soil to recover adequately and the quality of the soil decreases with more frequent exploitation (Ewes, 1978). This has resulted in a diminishing fertility status of the soil due to shorter fallow periods, hence a reduction in the yield of crops in general to feed the ever increasing population (Agbeniyi et. al., 2010).

As a result it has become necessary to utilize the same piece of land for cultivation, season after season. Furthermore, the cocoa plant takes several years before "dying off" completely, implying that certain amount of nutrient is being used up year after year, causing a reduction in the total amount of nutrients in the soil, hence the need to apply fertilizers to replace the lost nutrients. Increased cocoa production largely relies on the type of fertilizers used to supplement essential nutrients available in the soil.

The nature and characteristics of nutrients released from organic, inorganic or bio-fertilizers are different and each type of fertilizer has its advantages and disadvantage with regards to crop growth and soil fertility. Sound management of fertilization must attempt to ensure both an enhanced and safeguarded soil quality.

In view of this there is the need to better understand the dynamics of employing various nutrient resources for the purpose of soil fertility improvement in order to keep a balance in the nutrient base available to crops, especially cocoa, whilst at the same time keeping in mind the natural state of the soil.

1.1 PROBLEM STATEMENT

Several studies have shown that excessive introduction of fertilizers especially the inorganic forms to the soil is rather more detrimental than being advantageous (Mbah and Onweremadu, 2009). For instance, the effects on ground water and other water bodies, the quality of crops as well as the impact on the soil cannot be overemphasized.

Chemical fertilizers have been shown to detrimentally affect the long term health of the soil by making it acidic and biologically unbalanced (Mbah and Onweremadu, 2009). The clearest example of biological imbalance is evident with algal blooms in water ways entirely driven by farm nutrient run-off. Secondly, plants are absolutely dependent on soil organisms for their health and ability to grow to productive capacity. They are unable to produce all the enzymes, hormones, vitamins and growth stimulants, and for these reasons they form symbiotic interactions with soil microbes to obtain these substances.

However, high concentrations of such chemical products destroy the soil organisms and may even cause their death. This notwithstanding, chemical fertilizers may cause rapid decomposition of organic matter and depletion of soil organic carbon, resulting in poor soil structure and high water run-off. Furthermore, nutrients are easily lost from the soil through leaching or gas emission and can lead to reduced fertility and soil efficiency.

Another problem resulting from the excessive application of these fertilizers is the fact that they reduce the colonization of plant roots by micorrhizae, inhibit symbiotic nitrogen fixation by Rhizobium, cause diminished intrinsic food nutritional content and the softening of plant tissue which results in plants that are more susceptible to diseases and pests.

It is sad to note that farmers tend to consider the fact that these fertilizers help to gain increased yield, forgetting about the fact that these gains are not sustainable. Also, if only chemical fertilizers are added, the soil gradually loses its organic matter and macrobiotic activity.As a result, and with time, the soil structure breaks down, becoming lifeless, compact and less able to hold water and nutrients.

The seriousness of the issue is that more fertilizers would have to be added before the farmer can produce his cocoa. In this case the cycling is perpetuated until the soil health becomes so compromised that the ability to produce cost-effectively collapses and the soil is abandoned for the purpose of agricultural production. The effect is that if the farmer is unable to apply the fertilizers due to increased cost, the land becomes abandoned as the soil loses its productive ability.

This is an issue which needs to be looked into and for that matter the present study seeks to compare the effects of organic and inorganic fertilizer application on cocoa farms, and to define a management system that will maintain the productive level of the soil without much negative consequences.

1.2 OBJECTIVES

1.2.1 General Objective

The goal of this research is to determine the effects of organic and inorganic fertilizer application on the soil and to establish a soil management system that will increase yield and quality of cocoa, with little or no negative impact on the soil.

1.2.2 Specific Objectives

1. To determine the physico-chemical properties of the soil in the selected farms.
2. To determine the amount of mineral elements in the organic and inorganic farms.
3. To identify the diversity of soil microbes and state their biomass in the selected farms.
4. To identify the effects of organic and inorganic fertilizer applciaiton on the soil in the selected farms.

1.3 Research Questions

1. What human activities and to what extent do they affect the soil in the selected cocoa-producing area?
2. How do the various soil components support growth and development of cocoa and what measures can be put in place to ensure the continual supply or existence of such soil components?
3. To what extent does the application of organic and inorganic fertilizer impact the soil?
4. What management system in terms of fertilizer application would be more effective in cocoa production?

1.4 Rational of the Study

A greater percentage of Ghanaian farmers are engaged in cocoa production. This has also created job opportunities for those who assist the farmers in working on their farms. The benefits derived from cocoa production by the government cannot be over-emphasized. Also the Cocoa Research Institute of Ghana (CRIG) has come out with several products derived from cocoa beans, which are being sold on the local as well as

the global market. These have also created job opportunities for several Ghanaians and generated more revenue for the government.

Increased cocoa production is dependent on the soil on which cocoa grows, and the ability of the soil to provide the cocoa plant with the necessary nutrients depends partly on natural systems that fix plant nutrients into the soil, and partly on management systems implemented by farmers. The quality of the soil on which cocoa grows, does not only impact on the yield but also the quality of the cocoa beans.

The introduction of fertilizers in cocoa production was intended to increase yield, and even though this objective has been achieved to some extent, the side effects cannot be over emphasized. For instance, the application of chemical fertilizers coupled with the use of weedicides to combat weeds is destroying or even killing the soil biofauna. Free-living nitrogen-fixing bacteria are dying off, and mycorrhizae are being broken. These allow nematodes and other soil pathogens to easily attack the crops. The nitrogen-fixing bacteria are now being replaced by denitrifying bacteria, since the chemical fertilizers have turned most soils acidic. Organic matter stored in plants labeled as "weeds", is completely destroyed as these plants are sprayed or treated with such chemicals.

It seems that we are rather creating a destruction of our farmlands, and most of these have been abandoned for the purpose of cocoa production. Most of our cocoa farmers are now losing interest in the production of cocoa since they have been running at a loss.The number of people employed to work at the various farms is now being reduced, rendering some people jobless.

Ghana cannot overlook the situation without finding solutions to the problem.

For this reason there is the need to investigate the two categories of fertilizers used on our cocoa farms, thus organic and inorganic, and to establish a soil management system in terms of fertilizer application, which will help maintain the natural resource base of the soil in support of cocoa production.

CHAPTER TWO 2.0 LITERATURE REVIEW

2.1 Causes of Soil Depletion

One of the Key factors involved in the potential for long-term productivity of terrestrial ecosystems is the availability of soil nutrients (Reich et. al., 2006). Indeed nutrient availability has been identified as the main limiting factor to net primary production stimulation under elevated CO_2 (Hungate et. al., 2006). Originally, the natural soil is labeled as a reservoir of plant food and every virgin forest is known to be made up of high quality soil in terms of agricultural production.

The productivity of any form of soil is a measure of its ability to continually support the growth and development of crops by supplying them with the needed nutrients they require over time. Thus soils contain natural reserves of plant nutrients. These mineral elements (nutrients) are "locked up" in rocks and as the rocks disintegrate by the process of weathering (weather physical, chemical or biological means) to form soil particles, the mineral elements are released to become part of the soil fragments.

Nutrient limitation in primary production and other ecological processes is widespread in terrestrial ecosystems, and nitrogen (N) and Phosphorus (P) are the most common limiting elements (Smithson, 1999). The principal factors affecting soil productivity potential of soil resources in Ghana involved human based and physico- climatic factors. It is generally believed that biological processes in many ecosystems on young soils may be limited by low supplies of nitrogen, whereas ecosystems with very old soils can become depleted in phosphorus (Walker and Syers, 1976). This phosphorus limitation occurs because P is derived from rock weathering, which means that farmlands begin their existence with a fixed complement of P from which even very small losses cannot readily be replenished (Vitousek et. al., 2010).

Agricultural production is obtained through the accumulation of biomass of the plants of biogenetic elements that have been taken from the soil. Due to the fact that after the crops have been harvested, only a part of the biogenetic element that have been extracted by the plant are returned, there can be problems in keeping the soil"s ecosystems balanced.

Human induced factors of soil degradation include Continuous cropping, where a parcel of land is used for cropping continuously for several seasons without adding fertilizer. This has been observed to cause significant decline in soil pH and exchange calcium and magnesium levels in soils. Decline in crop yield under continuous cultivation has

been attributed to factors such as acidification, soil compaction and loss of soil organic matter (Juo et.al., 1995).

Overgrazing: This renders the soil bare and makes it prone to soil erosion and the direct impact of the sun‟s heat causing evaporation and soil dryness, which intend causes starvation of soil animals and may lead to their death. It removes the native plants which would be replaced by less favourable plants. It does not help the land to hold rain water due to major run-off.

Deforestation: Uncontrolled removal and cutting down of natural vegetation have pronounced negative impact on soil system in Ghana. These comprise deterioration of soil physical structure and conditions through crusting and surface sealing, soil compacting and formation of restrictive layer in the soil profile.Such soils become more vulnerable to natural disasters such as wind and water erosion, which, if left unchecked, can lead to large-scale degradation of soils (Omotayo and Chukwuka, 2009).

Mining and Sand Winning: These practices remove the topsoil and subsoil, often resulting in permanent damage to soils and vegetation. Unfortunately, in most regions of the earth, the underground geological resources (minerals) are superimposed by above ground resources (forest). Hence mining operations necessarily involves deforestation, habitat destruction and biodiversity erosion. Therefore mining is essentially a destructive developmental activity where ecology suffers at the alter of economy. Scientific mining operations accompanied by ecological restoration and regeneration of mined wastelands and judicious use of geological resources, with search for eco-friendly substitutes and alternatives must provide sensational revelation to the impact of mining on human ecosystem (Surender, 2010).

Uncontrolled Bush Burning: Burning renders the soil bare, thus subjecting it to the intense heat from the sun. This causes evaporation of soil moisture, leading to soil dryness. Living organisms in the soil, which cause decomposition of organic matter and also enhance aeration are adapted to environment of low temperature. However, the fires increase the soil temperature which affects the growth and activities of the soil

organisms. These organisms may also be killed by fires. Soil nutrients such as nitrates, the form in which plants build up their proteins, may also become denatured as the properties of protein indicates that they are denatured by temperatures exceeding 60 ^{0}C. The formation of acid rain could also deteriorate plants, damage calcium in soils and also increase soil acidity. In a previous study, Edwin, (2006) observed that rampant bushfires cause significant damage in all the ecological zones and is most pronounced where the savanna vegetation predominate. Also, as the land becomes bare due to burning the soil becomes prone to erosion and leaching of nutrients to soil layers where plants‟ roots may not reach.

The Physico - climatic factors affecting soil quality may include climate change, increased carbon dioxide concentrations, edaphic factors such as topography and slope of land, mechanism of nutrient uptake and complex nutrient cycles.

Understanding the mechanisms involved in stabilizing and destabilizing soil Carbon (C) is essential to modeling the Earth‟s climatic system, as moderate changes in the biological cycling of C could cause substantial changes in the net flux of CO_2 to the atmosphere (Davidson and Janssens, 2006). The ecosystems most vulnerable to changes in soil C cycling are those near threshold conditions where modest shifts in environmental conditions could cause state changes that feed back to climate through changes beyond carbon-cycling to include heat exchanges, albedo and others (Field et. al., 2007; Chapin et. al., 2008). It should be noted however, that the activities of soil biota are responsible for much of small scale cycling of carbon (Lenoir et. al., 2001). For instance, the accumulation of organic matter in underground chambers or the deposition of waste materials in piles outside the colony, incidentally makes ant nests hot spots for nutrients to plant communities (Moutinho et. al., 2003, Sausa- Souto et. al., 2008, Sternberg et. al., 2007). The high content of organic matter and nutrients inside the colonies became hot zones for microbes which accelerate the mineralization and decomposition of the material (Farji-Brener, 2010). These activities affect the emission of carbon dioxide to the atmosphere, altering the balance of soil Carbon.

2.2 Farming Systems That Improve Soil Quality

Management practices to sustain crop yield are necessary to conserve or enhance soil quality (Aziz et. al., 2009; Countler et. al., 2009). A difference in management practices often results in a difference in biological, chemical and physical soil properties which in turn result in changes in functional quality of the soil (Islam and Weit, 2000).

Soil quality has become a focal point for attempts to qualify modification in soil quality due to various soil management systems (Islam, 2006). Soil quality is, within natural and managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation. These conditions can be accomplished by preserving or improving the biological, chemical and physical properties of soil using farming systems such as crop rotation as a component of sustainable agricultural management practices (Aziz et. al., 2011), shifting cultivation/land rotation, alley cropping, mulching, soil inoculation and the application of organic and inorganic fertilizers. For the purpose of the study, attention would be focused on the use of organic and inorganic fertilizers. As indicated in the previous section, there are natural and managerial causes that lead to soil fertility decline. The decline may occur as a result of leaching, soil erosion and crop harvesting (Mbah and Onweremadu, 2009). Unless the nutrients are replenished through the use of organic or inorganic fertilizers, or partially returned through crop residues, or rebuilt more comprehensively through the traditional fallow system that allows restoration of nutrients and reconstruction of soil organic matter, the nutrient levels will continue to decline (Surender, 2010).

2.2.1 Chemical Fertilizers

Soil in Africa and for that matter Ghana is typically highly variable in fertility and in how they respond to inputs (Hossner and Juo, 1999; AGRA, 2007). The use of fertilizers in cocoa production started around the year 2003/2004, and the main chemical fertilizers used with their respective composition are as follows; "Asaasewura"- NPK, 0-22-18+9CaO+7S + 6MgO; Cocofeed - NPK, 0-30-20; Cocomaster - NPK, 1 - 21-19+9CaO + 6MgO + 1B; Nitrabor, another type of chemical fertilizer used in cocoa production, contains nitrogen in the form of nitrate. From the above chemical compositions it could be deduced that cocoa requires more phosphorus (P) than nitrogen (N).

The use of such chemical fertilizers has, without doubt, delivered tremendous increase in yields of cocoa. The use of chemical fertilizers in crop production may have the following advantages: nutrients are soluble and immediately available to the plants; therefore, the effect is usually direct and fast; the price is lower and more competitive

than that of organic fertilizers which makes chemical fertilizers more acceptable and often applied by farmers. They are quite high in nutrient content; only relatively small amounts are required for crop growth. However these gains are rather unsustainable and there have been significant unintended consequences such as:

Groundwater Pollution.

Chemical fertilizers that are highly soluble get absorbed by groundwater more rapidly than they are absorbed by the intended plants. Plants have the capacity to absorb only a given level of nutrition at a time leaving the rest of the fertilizer to leach. Leaching is hazardous to groundwater source, and the health of subsoil where these chemicals react with clay to create hard layers of soil known as hardpan. As a result of chemical fertilizer use the health of the soil and water is jeopardized.

Soil Friability Effect

The presence of a number of acids in the soil such as hydrogen chloride (HCl) and tetraoxosulphate (VI) acid (H_2SO_4), react to cause a damaging effect on the soil referred to as soil friability. The different acids in the soil dissolve the soil crumbs which help to hold the rock particles together. Soil crumbs result from the combination of humus with clay. These mineral rich soil crumbs are essential to soil drainage and greatly improve air circulation in the soil. As the chemicals in the chemical fertilizers destroy crumbs, the result is a highly compacted soil with reduced drainage and air circulation.

Destruction of Microbes.

The synthetic chemicals in such fertilizers adversely affect the health of naturally present soil micro-organisms by affecting the soil pH. These altered levels of acidity in the soil eliminate the microbes beneficial to plants and soil health but these increase the plants‟ natural defenses against pests and diseases. These useful microbes consist of antibiotic - producing bacteria, mycorrhizae and other fungi which are found in healthy soils. The use of chemical fertilizers also destroys the health of bacteria that fix the nitrogen –balance in the soil. These nitrogen - fixing bacteria are responsible for converting the atmospheric nitrogen into forms that can be used readily by plants.

Most of the chemical fertilizers do not provide trace elements, and also prevent the plant from absorbing them from the soil. This lack of absorption can be explained as follows: Minerals are transferred via colloidal humus particles found in healthy soil. These particles are negatively charged and attract positively charged elements, such as potassium (K), Sodium (Na), Calcium (Ca), Magnesium (Mg), Manganese (Mn), Aluminium (Al), Iron (Fe), Copper (Cu) and other metals. Large doses of sodium nitrate dumped into the soil will over time, radically change these humus particles. The result is that trace elements are crowded out because the humus particles become filled up with the excess Na. In essence, even though they may be present in the soil, they become unavailable to the plants Onyebinama, (2006).

Nitrate Pollution

Over supply of nitrogen – rich fertilizers leads to softening of plant tissue resulting in plants that are more sensitive to diseases and pests. The application of nitrogen fertilizers such as urea and ammonium sulphate to soils produces acids by two processes. Firstly, the natural process of oxidation of ammonium ions to nitrate ions release acid. Part of the acid produced is neutralized by alkaline ions released by plants during the subsequent uptake of the nitrate ions.Secondly, since nitrate ions are not strongly absorbed by the soil, they are liable to leach through the soil. The negatively charged nitrate ions carry positively charged basic cations such as Ca^{2+}, K^{+} , Mg^{2+} and Na^{+} in order to maintain the electric charge on the soil particles (Krough et. al., 2000). The processes involved in the conversion of soil nitrogen can be represented by the following chemical equations:

Urea hydrolysis:

$$CO(NH_2)_2 + H_2O \longrightarrow 2NH_3 + CO_2$$

Ammonification:

$$NH_3 + H_2O \longrightarrow NH_4^{+} OH^{-}$$

Nitrification:

$$2\,NH_4^{+} + 3O_2 \longrightarrow 2HNO_2 + 2H^{+} + 2H_2O \text{ (Nitrosomonas)}$$

$$2\,HNO_2 + O_2 \longrightarrow 2NO_3 + 2H^{+} \text{ (Nitrobacter)}$$

Net: $2NH_4^{+} + 4O_2 \longrightarrow 2NO_3^{-} + 4H + 2H_2O$

The nitrification process is mediated by autotrophic, obligately aerobic bacteria. Urea is decomposed by the enzyme urease or chemically hydrolysed into ammonia and carbon dioxide. Ammonia is converted by ammonium – oxidizing bacteria into ammonium. Ammonium is then

converted by nitrifying bacteria into nitrate. The nitrification of NH_4 to NO^+_3 occurs in the presence of bacteria to carry out the whole process. The process also requires soil temperature greater than 20 ^{0}C and pH of 5.5 – 7.5 and there should be sufficient availability of soil moisture and oxygen to enhance microbial activities. Ammonium may accumulate in the soil when this nitrogen conversion is limited or completely stopped if one or more of the following soil conditions are present (Mengel and Kirkby, 2001). According to their report, low pH conditions which implies increased acidity, subsequently depress microbial NH_4oxidation. Most of the putrefying bacteria that convert the nitrogen stored in dead plants and animals into ammonium compounds are aerobic and require oxygen for the production of energy. But the reduced pH conditions with its subsequent lack of oxygen as occurs in waterlogged soils, inhibit microbial activities.

Organic matter serves as the main carbon source for most bacteria, but in dry soils where the amount of organic matter might be low, there is the likelihood of such microbial activities being reduced. Low soil temperature depresses nitrification due to low soil micro-organism activity. Enzymes catalyse the activities of these soil microbes. The enzymes work with an optimum temperature and when this is reduced to low levels, the enzymes become inactive. Nitrification attains its optimum at 26 C,^{0} whilst the optimum for ammonification is as high as 50 ^{0}C. Thus in tropical soils, even under neutral pH conditions, ammonium may accumulate as a result of the low rate of nitrification.

Therefore a high nitrate concentration indicates likely presence of harmful bacteria as well. In conditions to high enrichment, NO_3 may produce a slate known as methamoglobinema (blue basics), which generally affects the infants under six months of age. Over use of N_2 fertilizers also lead to swindling of earth worms from the particular area which would imply loss of soil fertility.

These disadvantages of chemical fertilizers in simple terms imply that they detrimentally affect the long term health of the soil by making it acidic, saline and biological imbalance. This is evident with algal blooms in water ways entirely driven by surface run-off containing farm nutrient.

Also causing the destruction of soil microbes would mean that more of such fertilizers would be needed to maintain productivity. The cycling is perpetuated until the soil health is so compromised that the ability to produce cost- effectively collapses and the soil is abandoned for the purpose of agricultural production.

2.2. 2 Organic Fertilizers

Organic fertilizers refer to materials used to enrich the soil that occur regularly in nature usually as by – products or end products of naturally occurring processes. For instance the decomposition of organic materials results in the production of humus to enrich the soil.

Organic fertilizers, like any other fertilizer, typically provide the three major macro-nutrients required by plants i.e. nitrogen, phosphorus and potassium. These nutrients originate from sources such as bone, meat which release fertilizer slowly and are high in potassium and calcium. Poultry manure which is waste product from the chicken industry contains NPK. Fish emulsion is high in N P and trace elements.It is produced from the fluid remains of fish processed for fish oil and fish meal industrially. Fish meal is traditionally used as fertilizer prior to the advent of synthetic sources. It is rich in nitrogen (N) and phosphorous (P).

Apart from these, human excreta and other domestic as well as municipal wastes contain organic materials which can be used as fertilizers to replenish lost nutrients from the soil. Despite the magnitude of domestic and other municipal wastes generated daily and subsequent adverse effects on the environment, much serious attempts have not been made for their effective utilization or safe disposal. If these can be used as fertilizer to enrich the soil, then there is the need to utilise such substances rather than relying on chemical fertilizers with their numerous demerits.

Advantages of Applying Organic Fertilizers

The nutrient supply is more balanced, which helps to keep plants healthy and they enhance soil biological activity which improves nutrient mobilization from organic and chemical sources and decomposition of toxic substances. Organic fertilizers also enhance the colonization of mycorrhizae, which improves phosphorus supply.They increase the organic matter content of the soil, and therefore improve the exchange capacity of nutrients and increasing soil water retention, promoting soil aggregation and buffering the soil against acidity, alkalinity, pesticides and hazardous heavy metals.They also release nutrients slowly and contribute to the residual pool of organic

nitrogen and phosphorus in the soil, reducing N leaching loss and P fixation; they can also supply micro nutrients.Organic fertilizers provide food and promote the growth of beneficial microbes and earthworms.They help to suppress certain plant diseases, soil-borne diseases and parasites.

Despite the numerous advantages obtained from using organic fertilizers, they may, in a way, have some demerits, which include the fact that they are required in bulky volumes before providing enough nutrients for crop growth.The nutrient release rate is too slow to meet crop requirements in a short time, hence some nutrient deficiency may occur. Also the cost of using organic fertilizers is much higher as compared to inorganic fertilizers (Ntiamoah and Afrane, 2007).

Research comparing soils of organically and chemically managed farming systems has recognized the higher soil organic matter and total nitrogen (N) with the use of organic agriculture (Alverez et. al., 1988; Drinkwater et. al., 1995; Reganold, 1988). Soil pH becomes higher, plant available nutrient concentrations may be higher and the total microbial population increases under organic management (Clark et. al., 1998; Dinesh et. al., 2000; Lee, 2010).

Organic fertilizers which mainly come from agricultural waste residues such as cow and poultry manure, spent mushroom compost or municipal solid waste compost (MSWC) are often identified as suitable local organic fertilizers. These contain high levels of nutrients, eg N and P and high amounts of organic matter (Peyvast et. al., 2007; Olfati et. al., 2009; Shabani et. al., 2011). According to these studies the usage of MSWC can be an effective alternative to chemical fertilizers. However, the apparent deficiency of an adequate supply of plant available nitrogen (N) from organic fertilizer, resulting from a slow rate of mineralization, makes crop yields in fields treated with organic fertilizer lower than in those treated with chemical fertilizers (Blatt, 1991., Lee, 2010).

The minerization of organic matter in the soil is determined by many factors such as temperature, moisture, soil chemistry and microbial communities. Therefore, the prediction of nutrient at a specific period of time is generally hard (Owen et. al., 2008). However, when livestock manure is applied to the soil for many years, the incorporation

of manure P into the soil can lead to an increase in the amount of P available to the crop (Qian et. al., 2004). Since manure N:P ratio of most crops and the rates of manure application are based on crop N requirements, P can accumulate in the soil from excess manure P added over several years (Grossl and lnskeep, 1991). This may increase the risk of P loss from the soil system before it is used by subsequent crops (Sims et al., 2000; Qian et. al., 2004).

The type of poultry manure also determines its effects on soil pH and other properties because poultry feed contains varying amounts of calcium carbonate ($CaHCO_3$). All poultry rations contain some ground limestone. A survey of Alabama fescue pastures showed that fields that had received repeated application of poultry broiler litter over many years had an average surface soil pH of 6.3 ($^{+}$ 0.1), compared to fields receiving only chemical fertilizers. These latter fields had a surface pH of 5.8 ($^{+}$ 0.1) (Kingery et. al., 1993). Hue (1992) also showed that chicken manure was very effective in raising soil pH. He theorized that much of this pH increase was due to reactions of organic anions. Poultry litter can detoxifyaluminium (Al) by increasing soil pH, complexing soluble Al as it reacts with phosphorus in the litter.

Soil pH may increase substantially with application of hen manure because the amount of liming material added to the soil (which is contained in the feed) exceeds the amount of acidity released by the conversion of nitrogen.

Another organic manure which can be applied to soils in Cocoa production is compost. It is considered as one of the best overall soil amendment growers can use to increase the quality and the health of soil (Postma et. al., 2003). As compost decomposes in the soil, nutrients are released slowly. Compost generally will not supply all the nutrients required for optimum growth, but usually supplies most of the plant‟s micronutrients (Verma et. al., 2013) Good compost provides soil with nutrients, organic matter and beneficial microbes which can improve crop health, growth, quality and yields. It also improves soil structure and long – term nutrient availability, which helps plants better tolerate drought and suppress diseases (Rynk et. al., 1992).

In addition, compost induces benefits in soil bulk density macro-porosity, oxygen diffusion rate, shear vane strength and water filled pore space (Carter et. al., 2004).

Compost amendment significantly increases soil moisture by 7 to 10% (Edwards et. al., 2000) and water holding capacity (Lynch et. al., 2005). Compost applied as a soil amendment can improve soil organic matter content, nutrient retention in soils

susceptible to leaching and stabilize soil pH.The use of organic fertilizers can avoid or reduce the deleterious effects attributed to the use of chemical fertilizer (Kochakinezhad et. al., 2012).

2.3 Integrated Use of Organic and Inorganic Fertilizers

Organic fertilizers differ from chemical fertilizers due to the fact that they provide plants with the needed nutrients and at the same time build the soil structure. Soils with lots of organic material remain loose and airy, hold moisture and nutrients better, stimulate growth of soil organisms, and promote healthier root development. Organic fertilizers are made from plant and animal sources or from rock powders (Ogunlade et. al., 2009).

These materials need to be broken down by soil microbes in order for their nutrients to be released. Due to the fact that organic fertilizers work slowly, they provide long- term nutrition and steady growth.On the other hand, chemical fertilizers are composed of high concentrations of mineral salts, and as such are capable of killing many soil organisms that are responsible for the decomposition, and with time, formation. If only chemicals are added, the soil gradually loses its organic matter and microbiotic activity. As a result and with time, the soil structure breaks down, becoming lifeless, compact and less able to hold water and nutrients.

One of the main constraints for good yield in cocoa is its high nutritional requirements along with increased cost of fertilizers (Ghlove et. al., 2001). Similarly, spiraling prices coupled with inadequate availability of fertilizers and depletion of available nutrients and organic matter due to continuous cocoa cropping, necessitate the integrated use of organic and inorganic fertilizer resources (Kumar and Verma, 2002; Ibrahim et. al., 2008; Sarwar et. al., 2008;Khandagave, 2003).

Soil organic matter (SOM) plays a key role in the improvement of soil physical, chemical and biological properties (Quedraogo et. al., 2007). Also, the conservation of the quantity and quality of SOM is considered a central component of sustainable soil management and maintenance of soil quality (Doran et. al., 1996). Many studies have showed that balanced application of organic manure and inorganic carbon can maintain soil productivity (Blair et. al., 2006; Pawlson et. al., 2012). The application of organic manure in combination with chemical fertilizer has also been reported to increase

absorption of nitrogen, phosphorusand postassiumin sugarcane leaf tissue in the plant and ratoon crop, compared to chemical fertilizer alone (Bokhitar and Sakurae, 2005). Results from a field experiment on the combined application of organic and inorganic fertilizers by Chand et. al., (2006) indicated that integrated supply of plant nutrients through farmyard manure and fertilizers N P K, along with Sesbania green manuring, ensures sustainability in soil fertility and crop production. Dutta et. al., (2003), in their report based on the evaluation of soil quality indicators, also stated that the use of organic fertilizer, together with chemical fertilizer, compared to the addition of organic fertilizers alone, had higher positive effects on microbial biomass and hence soil health.

Kaur et. al., (2005), compared the change of chemical and biological properties in soils receiving farm yard manure, poultry manure and sugarcane filter cake alone or in combination with chemical fertilizers for seven years under a cropping sequence of pearl millet and wheat. Results showed that all treatments except chemical fertilizer application improved the soil organic carbon, total N, P and K status. Increase in microbial biomass, carbon and nitrogen was observed in soils receiving organic manures only or with the combined application of organic manures and chemical fertilizers, compared to soils receiving chemical fertilizers only.

This study showed that balanced fertilization using both organic and chemical fertilizers is important for maintenance of soil organic matter content and long – term soil productivity in the tropics where soil organic matter content is low.

Labile soil organic carbon pools like dissolved organic carbon (DOC), microbial biomass carbon, and particulate organic matter carbon are the fine indicators of soil quality which influence soil function in specific ways such as immobilization – mineralization, and are much more sensitive to changes in soil management practices (Saviozzi et. al., 2001; Xu et. al., 2011).

2.4 Diversity and Role of Soil Biofauna

Soil biofauna include Actinomycetes, Protozoa, Nematodes, Arthropods, Earthworms, Snails, Slugs and Rotifers. These are essential to efficient nutrient cycling, organic matter turn-over and maintenance of soil physical structure, production and ecosystem

carbon storage. The nutrients stored in the bodies of soil organisms prevent nutrient loss by leaching.

Microbial exudates act to maintain soil structure, and earthworms are important bioturbation.

Importance of Soil Macro – Fauna

They play key role in nutrient cycling as they help in the decomposition of complex materials or consume other organisms and by so doing help to convert nutrients from one form to another. Also they mix soil layers together to make the horizon less distinct, and at the same time adding organic matter to the different layers.

Soil Bacteria

These are grouped into:

Decomposers: Which break down organic matter to release the nutrients stored in them back into the soil. Eg. Bacillussubtitis sp. and Pseudomonas fluorescence. **Nitrogen Fixers:** Capable of converting atmospheric nitrogen into usable forms for plants. Some live freely in the soil and others form mutual association with leguminous crops such as groundnuts. Nitrogen – fixing bacteria includes Rhizobium in root nodules of legumes; Azotobacter, Azospirillum, Agrobacterium, Gluconobacter, Flavobacterium, Herbaspirillum and chlostridium.

Nitrifying bacteria: convert ammonia and ammonium compounds into nitrates, the form in which plants utilize nitrogen. They include Nitrosomonas and Nitrobacter. **Disease suppresses:** Eg. Bacillus megaterium, suppresses the diseases – causing fungus Rhizoctonia solant; Bacillus subtitis, used to suppress seeding blight of sun flowers and caused by Alterneria heltanthi.

Aerobic and Anaerobic bacteria:

Aerobic and Anaerobic bacteria live in well – drained soils and require oxygen for respiration. Anaerobes mainly dominate in wet, poorly drained soils and can produce toxic compounds that can limit root growth and predispose plants to root disease.

They are capable of causing denitrification. Thus, they convert nitrates back into nitrogen gas. Certain anaerobic bacteria cause putrefaction of dead organic matter. **Actinobacteria:** Help to slowly break down humates and humic acids in soils. They dwell mainly in non-acidic soils and are mostly neutrophiles, dwelling in soils with pH

higher than 5 but less than 9. Examples include Actinomycetes which are Gram positive filamentous rod – shaped bacteria that often resemble fungi. They belong to the phylum Chlamydobacterial and the order Actinomycetales. Certain species are pathogenic for humans and other animals. However, in the soil they help in the decomposition of organic matter, and are also capable of producing antibiotics that aid in fighting root diseases. They are also responsible for producing the sweet earthly smell of soil.

Sulphuroxidisers: Many soil minerals contain sulfides but this form of sulfur is largely unavailable to plants. Thiobacillus can convert sulfides into sulphates which can be used by plants.

Fungi

These include moulds, yeasts and mushrooms. Fungi aid plants by breaking down organic matter or by releasing nutrients from soil minerals. They are quick in colonizing larger pieces of organic matter and causing decomposition. Some also produce plant hormones. Colletrotricum sp is an obligate symbiont to plants as endophytes. Though some are plant pathogens, others may have mutualistic relationship with hosts. Acosta-Rodriguez et. al., (2005), reported that Colletotrichum, lindemuthianum, a plant pathogen, spends part of its infection cycle as a biotroph, leaving off the host but not harming it, and the other part as a necrotroph, killing and obtaining nutrients from the host tissue. Trichoderma harzianum is also used as a fungicide in seed treatment and soil treatment for suppression of various diseases caused by fungal pathogens. It is used as biofertilizer, to speed up the rate of decomposition. Cuevas et. al., (2001), in their study explored the effectiveness of using two Trichoderma species (T. Parceramosum and T. pseudokoningii) in controlling Scleratium, ralfsii, a plant pathogen. Trichoderma has the potential as bio-control for diseases like damping off and seed blight (Cuevas et. al., 2001).

Mycorrhizae are fungi that live either on or in plant roots and act to extend the reach of root hairs into the soil. Thus they increase the uptake of water and nutrients.Roots colonized by mycorrhizae are less likely to be penetrated by root – feeding nematodes, since the pest cannot pierce the thick fungal network. Again they produce hormones and antibiotics that enhance root growth and provide disease suppression.

Fungi that infest cocoa include Moniliophthora roreri which causes frosty pod rot disease, one of the most serious problems for cocoa. This disease together with

„witches" broom disease caused by Moniliophthora pernicious and black pod disease caused by Phythophthora sp constitute the cocoa disease trilogy (Meinhardt et. al., 2008; Figueira et. al., 1993). Other fungi that affect cocoa include Ceratocystiscacao funesta (ceratocystiswilt), Verticilliumdahlia, Oncobasidium theobromae (vascular streak dieback) and Oomycetes.

Protozoa

These are unicellular, and mainly feed on soluble organic matter, bacteria and some fungi.

They release excess nitrogen as they feed on the bacteria. Protozoa are classified into 3, based on their shape or appearance.Species of Mastigophora or flagellates feed on bacteria and are the most numerous. Ciliophora (ciliates) are the largest and least numerous. They can consume thousands of bacteria within a day and by so doing they help in regulating bacteria populations.Sarcodina example Amoeba, reside in the rhizosphere and at the root surface where they graze on bacteria populations.

Protozoa play important role in mineralizing nutrients, making them available for plant use, and also to other soil organisms. They regulate bacteria and algae populations, thus help maintain ecological balance in the soil. They in turn, serve as food source for other soil organisms and help to suppress diseases by competing or feeding on pathogens.

Protzoa require water for movement, so moisture determines the biomass of protozoa that are active and present (Hoorman and James, 2011).

Nematodes

Nematodes use either a style or tooth to puncture and suck out cell contents or ingest cells whole. Depending on their diet, they are grouped into:

Bacteria Feeders: consume bacteria through a stoma, a large open channel. **Fungal feeders:** feed by puncturing the cell wall of fungi using a small slender stylet to suck out the internal content.

Predatory nematodes: feed on other nematodes.

Omnivorous nematodes: feed on variety of organisms including bacteria, fungi, protozoa and other nematodes.

Root feeders: Plant parasites that feed on roots.

Nematodes are very detrimental in cocoa and other crop production.Meloidogyne usually cause distinctive swellings called galls on the roots of affected plants (Mitkowski and Abawi, 2003). They burrow into the soft tissue of root tips and young roots and cause the nearby root cells to divide and enlarge. They exist in soils with low temperatures (Makumbi-Kidza et. al., 2000). Pratylenchus is another genius of nematodes commonly known as the lesion nematodes. They are migratory endoparasites that feed and reproduce in the root cortex, after which they move around.

In addition to host plant, soil type is also known to be a major factor that affects nematodes distribution. For example Melordogyne spp. occurs more frequently and more abundantly in sandy soils than in clay soils (Prot and Van Gundy, 1981, Dabire and Mateille, 2004). As invertebrate organisms that move through the soil porous space, the nematodes movements are determined greatly by soil physical and morphological properties (Neher et. al., 1999). It is well documented that well drained soils and macroporosity have been an influence on the higher population of plant parasitic nematodes (Bouwman and Arts, 2001; Avendano et. al., 2004).

Arthropods

These include soilbugs, beetles, mites, millipedes, centipedes and springtails. They are primary decomposers. They eat and break the large particles of plant and animal residues. Springtails eat fungi. Their waste is rich is plant nutrients after other fungi and bacteria decompose it. Dung beetles play valuable role in recycling of manure. Arthropods are detritivores. They feed and break down organic matter to some extent, to allow for thorough decomposition by bacteria and fungi.

Earthworms

Their burrows enhance water infiltration and soil aeration. Fields that were tilled by earthworms tunnels can absorb water at a rate 4 – 10 times more than that of fields lacking worm tunnels. This reduces water runoff, recharges ground water, and helps store more soil water for dry spells. Vertical earthworm burrows pipe air deeper into the soil, stimulating microbial nutrient cycling at those deeper levels.

Earthworms derive their nutrition from many forms of organic matter in the soil including decaying plant parts, decomposing remains of animals, and living organisms such as nematodes, protozoans, rotifers, bacteria and fungi. During the digestive

process, many insoluble minerals are converted to a plant – available soluble form and long – chain molecules such as cellulose are partially broken down by bacteria in the digestive tract. For this reason, investigations into earthworm castings show that they are several times richer in available nitrogen, phosphorus and potash than the surrounding topsoil. The analyses also reveals that the number of beneficial bacteria in the ejected worm castings is much higher than in the material ingested by the earthworm. The microbes contained in the castings are important in growing healthier plants, improving soil texture and providing water soluble nutrients to the plants.

2.5 The Cocoa Tree (Theobroma cacao)

2.5.1 Classification:

Kingdom	:	Plantae
Division	:	Angiospermophyta
Class	:	Eudicotidae
Subclass	:	Rosids
Order	:	Malvaceae
Genus	:	Theobroma
Species	:	T .cacao

Characteristics of Eudicotidae

Flowering plants with tricolphate pollen grains

Pollen grains are groove – structured

Pollen has three or more pores set infurrows called colpi.

Characteristics of Malvales

Have palmate leaves

Connate sepals

Cortex is fibrous, built of soft phloem layers.

Characteristics of Eudicotidae

Inflorescence – Both racemose and cymose types.

Flower is bracteates, bracteolate, varying in number from 3 to many.

Flower is actinomorphic, bisexual and hypogunouspentamerous.

Endospermic embryo curved.

2.5.2 Morphology of Cocoa Plant

There are about 22 species of Theobroma. The leaves are alternate, entire, unlobed, 10 – 40 cm (3.9 – 15.7 inch) long and 5 – 20 cm (2.0 7.9 inch) broad.

Flowers are produced in clusters directly on the trunk and older branches. This is known as cauliflony. The flowers are small, 1 – 2 cm (0.39 – 0.79 inch) in diameter, with pink calyx. Cacao flowers are mainly pollinated by tiny insects Forcipomyiamidges in the order Deptera.

The cocoa pod (fruit) is ovoid in shape, 15 – 30 cm (5.9 – 11.8 inch) long and 8 – 10 cm (3.1 – 3.9 inch) wide. It ripes yellow and weighs about 500g when ripe. The pod contains 20 to 60 seed, the "beans" embedded in a white pulp. The seeds are used to make chocolate, white pulp. The seeds are used to make chocolate, while the pulp is used to prepare refreshing juice, jelly and nata (Figueira, et al., 1993). The seeds contain significant amount of fat (40 50%) as cocoa butter. The most active constituent of the seeds is the theobromine, a compound similar to caffeine. In 2005, statistics showed that Ghana produced 736,000 metric tons of cocoa beans, the world"s 2nd largest producer.A tree begins to bear when it is four or five years old.

A mature tree may have 6000 flowers in a year, yet only about twenty pods.

CHAPTER THREE 3.0 MATERIALS AND METHODS

3.1 Study Area

3.1.1 Experimental Site

The study was conducted in Tafo in the East - Akim District in the Eastern Region. The East Akim Municipality is located in the central portion of the Eastern Region, with a total land area of approximately 725km ^{2}. Tafo, where the study was conducted is about 25km from the Eastern Regional Capital, Koforidua.

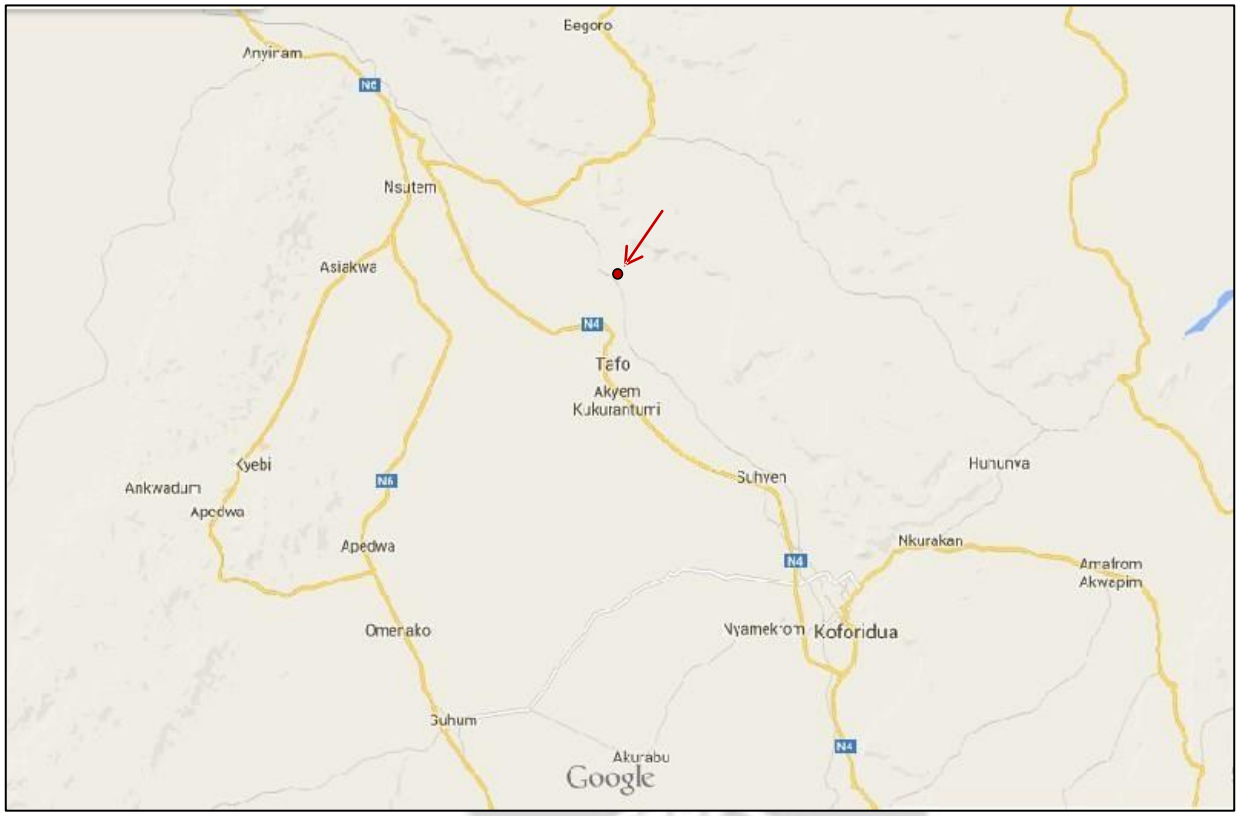

Fig. 1 Map of East Akim Municipal – Showing Tafo (Arrowed)

3.1.2 Vegetation: The district lies within the moist semi-deciduous forest. There are few forest reserves covering about 108.8 km ^{2} including part of the Atiwa forest. The forest reserves constitute about 15% of the entire surface area of the District. Some commercial species of trees contained in the forest are Odum, Wawa, Ofram, Mahogany, Kyenkyen (Atiwa District – Ghana Statistical Service).

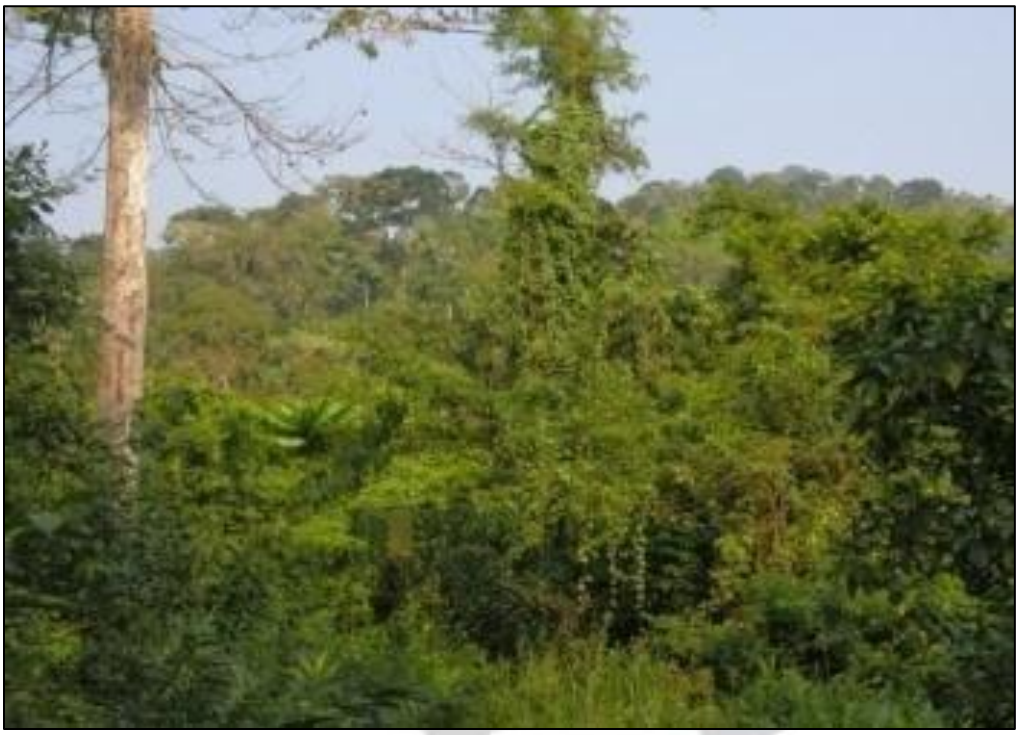

Plate 1. A picture of a portion of Atiwa Forest in East Akim

3.1.3 Geology and soil: The soil groups of Tafo series are mainly red, well drained, deep gravel - free silty loams and silty-clay (Atiwa District – Ghana Statistical Service). The soils are suitable for the cultivation of both food crops (cassava, plantain, yam, oil palm, citrus and cola) which are grown in the District. The land in this area is susceptible to very severe soil erosion if left bare without vegetation.

3.1.4 Climate: The District lies in the West semi - equatorial zone characterized by double rainfall maxima occurring in June and October; the first rainy season from May to June and the second from September to October. The mean annual rainfall is between 125 cm and 175 cm (Atiwa District – Ghana Statistical Service). The dry season (harmattan) is really distinct with the main season commencing in November and ending in Late February.Temperature is fairly uniform, ranging between 26 ^{0}C in August and 30 ^{0}C in March. Relative humidity is generally high throughout the year, ranging between 70% - 80% in the wet season.

3.1.5 Topography and drainage: The land is generally undulating and risesabout 240 metres to 300 metres above sea level with the highest point being the Atiwa ranges rising over 350 metres above sea level.There are several different types of rock formation giving the diff relief features ranging from flat bottom valleys to steep - sided highlands which are usually covered with iron pans, bauxite and kaolin.The underlying rocks are of the Birima main formation covering over three – forths of the closed forest zone.

Also found are masses of granite which occur in parallel belts. This rock group contains several mineral deposits including gold, diamond, bauxite and kaolin. The district is drained by rivers such as the Birim, Pra, Densu, Kua, Adenchensu and Merepong most of which have their catchment areas within the Atiwa and Apedwa forest ranges. Several other seasonal streams are found in the district. The pattern is largely dendritic flowing in the north - south direction.

3.2 Soil Treatments

Ten (10) cocoa farms were selected for the study. Five (5) of these farms had been treated with organic fertilizer, mainly poultry manure whilst the remaining farms had also been treated with inorganic fertilizers which included “Asaasewura”, Cocoa feed”, Nitrabor” and “Cocomaster”. The chemical compositions of the various fertilizers used have been given in the Literature review chapter. Aside these farms, five plots of virgin forest were also selected to be used as the control or baseline with which the selected farms were compared.

The farms had been treated with the respective fertilizers for the past ten (10) years. Treatments were conducted every two years on each farm for the ten year period. Each acre of farm was treated with three (3) of the fifty kilogram (50 kg) bag of fertilizer. (ie. 150 kg/ac).

3.3 Experimental Design and Management

Composite surface soil samples from each farm plot was collected using the following sampling tools: Earth chisel, for digging the earth plastic buckets in which the samples were collected, Hand trowel to pick the samples, polythene bags, blade scissors,

pencil, labels and twine rope to tie the samples in the poly-bags. From each farm plot, samples were taken from six different locations. This was done because the fertilizer might be more concentrated in a particular place than other areas. The collected samples were bulked together. By bulking, all the samples collected in a particular farm were mixed thoroughly, after which a representative sample was taken for the entire farm.

The earth was dug first up to 15cm deep after all debris had been removed from the surface. Sample was collected within the 15cm depth. The side walls of the hole created were pressed down with much force to make the soil compact. This was to ensure that samples from the topsoil (ie 0 - 15cm deep) did not mix with samples in the subsoil (15 – 30 cm deep). The earth chisel was again used to dig from the 15cm mark up to 30cm deep. Thus samples were also collected from the subsoil.

During the sampling process, the researcher avoided taking samples from the following locations: Eroded spots, which may include areas of gullies and rills or uniformly washed out of the topsoil. In addition, areas where fertilizers had leached or where there were heaps of cocoa podswere also not sampled. Waterlogged spots, areas where there were termiteria, as well as places where charcoal was being burnt or any other organic material, were also not sampled.

The reason being that, such areas do not give the true reflection of the amount of nutrients in the soil or the true soil properties. Either the sample taken from such places would have high nutrient content or less. For instance, areas where there are bent charcoal or heaped cocoa pods would contain more organic carbon than other places. Similarly, waterlogged areas might seem more acidic than the true pH value of the particular farm.

3.4 Soil Processing: This involved three stages.

Air drying: Samples were spread out and allowed to dry at room temperature for about one week.

Grinding: This was done using a pistle and mortar, till the samples turned into powder form.

Sieving: Samples were then sieved through a 2 mm mesh, rebagged and sent to the laboratory for the physico-chemical properties analysis.

Soil samples used to test for the biological properties, were stored in the refrigerator for about 1 week. This was to ensure that the samples were kept moist and more natural to ensure microbial development, growth and activities.

3.5 Determination of Physico - Chemical Properties of Soil Samples

3.5.1 Determination of Available Phosphorus.

This was done using the Troug method.

Procedure:

5.0gm of air-dried samples were weighed into shaker bottles. 100ml of 0.2 N H_2SO_4 were added to the samples in the shaker bottles, which were then shook for 2 hours on a mechanical shaker. Shaking causes the extractant (i.e 0.2 NH_2SO_4) to extract the phosphate ions from the soil surface into the solution. The shook samples were filtered through Whatman № 42 filter papers into 100ml volume volumetric flasks. 10ml aliquot of the sample solution in the 100 ml volumetric flasks. 4ml of "Reagent „B" were added to the sample solution, followed by distilled water to the 25ml mark and then shook by hand to mix well. Blank solutions were also prepared with 4ml Reagent B and distilled water. This served as a control set up to verify whether or not colour change was due to the availability of phosphorus in the sample solution. UV visible Cecil spectrophotometer (CE 7400 model) was calibrated using phosphorus standards of known concentrations at a wavelength of 882nm. Upon blue colour development, absorbance readings of the samples were taken on the spectrophotometer at the same wavelength. The absorbance readings (nm) were then used to calculate for the available phosphorus in the samples, using the formula below:

Available Phosphorus (űg / g) = Absorbance (G.F) × DF × vol of extractant (100 ml)
Weighted of soil (5.0 g)

Where; G.F is Graph factor $= \frac{\Sigma \text{ of Absorbance readings of Phosphorus Standards}}{\Sigma \text{ of Concentration of PhosphorusStandards}}$

DF is Dilution factor = $\frac{\text{Vol. of volumetric flask used (25ml)}}{\text{Vol. of aliquot used (10ml)}}$

The regents used were prepared as follows:

0.2N H_2SO_4 in 2 litres: 11ml of conc. H_2SO_4 was added to some distilled water in a 2 litre volumetric flask. The flask was well shake by hand and allowed to cool under fume chamber. The volume was made to the 2 litre mark with distilled water and the flask labeled.

'Reagent A':12.0g of Ammonium molybdate [$(NH_4)6\ Mo_7O_{24}.\ 4H_2O$] was dissolved in about 250 ml distilled water. 0.2908 g of Antimony potassium tartrate ($KSbO.\ C_4H_4O_6$) was also dissolved in about 100 ml distilled water. Both of the dissolved reagents were added to a litre of 5N H_2SO_4 (135.98 ml conc. H_2SO_4 / litre). The reagent was mixed thoroughly and made to 2 litres. The prepared reagent was then stored in Pyrex glass bottle in dark, cool compartment.

Reagent B': 1.056 g of L-Ascorbic acid was dissolved in 200ml reagent A. The flask was shaken by hand to mix the reagents well, and then labeled.

3.5.2 Determination of Organic Carbon in Soils by Walkley - Black (1934) Method and Subsequent Estimation of Organic Matter

Procedure:

1.0 g of air-dried soil samples were weighed into 500ml conical flasks, and were placed under fume chamber. 10ml of Potassium dichromate were added to the samples in the flasks, followed by 20 ml of Concentrated Sulphuric acid (Conc. H_2SO_4). The flasks were swirled vigorously for one minute and were allowed to stand for 30 minutes 200 ml of distilled water were added, followed by 10 ml of Orthophosphoric acid (H_3PO_4). 10 drops of diphenylamine indicator were added to the contents in the flask and were swirled to mix well. The samples were then titrated with standard Ferrous Ammonium Sulphate until the solutions were purple or blue Small lots of the Ferrous Ammonium Sulphate were added to the solutions until the colour flashed to green. Exactly 0.5 ml of standard Potassium dichromate was added to give an excess and then titrated drop

by drop with the Ferrous Ammonium Sulphate until the blue colour just disappeared. Blank titrations were carried out in an identical way using the same reagents, but omitting the soil. The percentage organic carbon in the soil samples were then calculated using the formula below:

% Organic Carbon = [Dichromate used - (Factor × Titra value of sample)] × Soil factor.
Where; Dichromate used = 10.5

Factor equals Dichromate used divided by the Mean Blank titre value.

Soil factor = 0.39
% OrganicMatter (OM) was calculated by multiplying the % Organic Carbon (OC) value by a factor of 1.724 (van Bennelen factor). Thus % OM = %OC X 1.724 The reagents used were prepared as follow:

Ferrous Ammonium Sulphate - $(NH_4)_2Fe(SO_4)2.\ 6H_2O$ in 1L: 196.07 G of solid Ammonium iron (II) sulphate was weighed and dissolved with distilled water into 1 litre volumetric flask. 15 ml of concentrated H_2SO_4 was added. The volume was made up to the 1 litre mark with more distilled water and mixed well. The flask was labeled.

Potassium dichromate - $K_2Cr_2O_7$ in 1L: 49.04 g of solid K_2CrO_7 was weighed and dissolved with distilled water into 1 litre volumetric flask. The volume was made up to the 1 litre mark with more distilled water and mixed well. The flask was labeled.

Diphenylamine indicator - $(C_6H_5)2\ NH$: 0.5 g of solid Diphenylamine was weighed into a beaker. 20ml of distilled water followed by 100 ml of conc. H_2SO_4 were added and mixed well. The prepared indicator was transferred into 250 ml volumetric flask and labeled. Some quantity was poured into indicator bottle for use.

Note: The potassium dichromate oxidizes the active forms of carbon in the soil samples. The reaction, which is exothermic was enhanced by heat of dilution. i.e The heat produced when concentrated sulphuric acid is added to potassium dichromate.

At that stage, the heat produced is of a temperature of over 150 ^{0}C that is able to cause the complete oxidation by wet combustion. Because of the heat generated, the contents

were cooled with distilled water to bring the temperature to optimum room temperature which is suitable for the continuation of the whole analysis. The othophosphosric acid is therefore added to reduce any form of iron (ii) ions that were present to inhibit the actual titration.

3.5.3 DETERMINATION OF TOTAL NITROGEN BY KJELDAH METHOD AS PROPOSED BY BREMNER (1965).

Procedure:

2.5g of air-dried soil samples were weighed into digestion tubes, after which about 0.5g of catalyst was added to the samples in the tubes. 12ml of conc. H_2SO_4 of Nitrogen free were added to the samples under fume chamber. The tubes were put in a digestor under fume chamber, and the samples were digested for 2 hours at 350 ^{0} C (the temperature and time were increased when samples were not well-digested). Well-digested samples were either white or colourless. The digested samples (digests) in the tubes were allowed to cool under fume chamber until there were no fumes evolving. The smaller tubes containing the digests were washed and rinsed about three times with distilled water into bigger tubes for distillation. The distilled samples (distillates) which contained the ammonia compounds were then collected in receiver flasks and titrated with 0.02N H_2SO_4 which had previously been standardized with borax (Boric acid), till just a colour change was observed (from green to blue). The percentage Nitrogen in the samples was then calculated using the formula below:

$$\% \text{ Nitrogen} = \frac{\text{Titre value of sample (ml)} \times \text{Normality of acid (0.02)} \times 1.401}{\text{Weight of sample (g)}}$$

The reagents used were prepared as follow:

0.02N H_2SO_4 in litre: 0.54 ml of conc. H_2SO_4 was added to some distilled water in a 1 litre volumetric flask. The flask was well shaken by hand and allowed to cool under fume chamber. The volume was made to the 1 litre mark with distilled water and the flask labeled.

40% Sodium hydroxide (NaOH) in liter: 400.0 g of solid NaOH was weighed into a

1 litre beaker and completely dissolved with distilled water. The solution was then poured into a 1 litre volumetric flask and made to volume with distilled water. The flask was labeled.

2% Boric acid (H_3BO_3) in litre: 20.0 g of solid H_3BO_3 was weighed into a litre beaker and completely dissolved with distilled water. The solution was then poured into a litre volumetric flask and made to volume with distilled water. The flask was labeled.

Indicator: 1.0 g each of methyl blue and methyl red were dissolved in 50 ml of 95% alcohol.

Catalyst: 1:5:25 g Selenium (Se), Copper sulphate ($CuSO_4$), Potassium sulphate (K_2SO_4) ratio, prepared by grinding separately 4 g Se, 20 g $CuSO_4$, and put together in a catalyst container.

During digestion the sulphuric acid with the help of the catalyst convert the organic nitrogen in the soil to ammonium sulphate. ie

N (soil) $\longrightarrow$ $(NH_4)_2SO_4$

At the neutralization stage the solution in the digestion flask is made alkaline by adding sodium hydroxide which converts the ammonium ion to ammonia gas with the help of the boric acid, the ammonia gas was collected from the digestion flask into the receiving flask, which turned the solution "green".

$(NH_4)_2SO_4 + Na\ OH \longrightarrow NH_3 + H_2O + Na_2SO_4$

3.5.4 Determination of Exchangeable Bases in soils by Ammonium Acetate Method of Hanway and Heidel (1952)

The exchangeable Bases analysed were Potassium (K^+), Magnessium (Mg^{2+}) and Calcium (Ca^{2+})

Procedure:

5.0 g of air-dried soil samples were weighed into shaker bottles. 25ml of 1 Molar Ammonium acetate (1 M NH_4OAC) solution were added to the samples in the shaker bottles, which were then shaken for 10 minutes on a mechanical shaker. The shook samples were filtered through Whatman No. 42 filter papers into 50ml volumetric

flasks. The sample solutions (filtrates) were analyzed for the concentrations of the various elements on the Atomic Absorption Spectrometer (Specter AA 220 FS model, Varian Brand). The extraction solution was prepared by weighing 77.08 g of solid NH_4OAC into a litre beaker and completely dissolved with distilled water. The solution was then poured into a litre volumetric flask and made to volume with distilled water. The flask was labeled.

The Ammonium acetate displaces K^+, Mg^{2+} and Ca^{2+} and releases them into solution. The ammonia in the Ammonium acetate then replaces the position of those cations, by way of exchanging them at the exchange site on the soil surface or on the clay lattice of the soil. The reaction is enhanced by shaking the contents (soil + Ammonium acetate mixture) for sometime. This is to exert a force between the two. The mixture was filtered and the leachate obtained contains the various concentrations of the required cations which were read on the Atomic Absorption Spectrometer.

3.5.5 Determination of Soil pH Using Glass Electrode / pH Meter, and 1:2.5 Soil - Water Suspension.

Procedure:

10.0 g of air-dried soil samples were weighed into 100 ml beakers. 25 ml of distilled water were added to the samples. The beakers containing the samples were stirred and left to stand for 30 minutes. (This was to make sure that the hydrogen ions have been extracted). Before taken any measurements or readings, the pH meter was standardized as follows: A buffer solution of pH 4 was measured by dipping the electrode into the solution and adjusting the meter to read the pH of 4. The electrode was rinsed with distilled water and wiped gently with tissue paper. A buffer solution of pH 7 was measured in the same manner after which the electrode was rinsed again with distilled water and wiped gently. The test samples were then measured, making sure the electrode dipped into the solution properly, after which the pH of the samples read on the pH meter and recorded.

3.5.6 Mechanical Analysis (Particle Size and Soil Texture Determination) This was done using the hydrometer method of Bouyoncos (1951).

Procedure:

52.0 g of air-dried soil samples were weighed into 250 ml beakers. 20 ml of 20% Hydrogen peroxide (H_2O_2) were added to samples in the beakers, and were left to stand until they got wet, after which they were dried on a hot plate and grinded. The H_2O_2 kills organisms present in the soil, and reduces amount of soil to 50g. 100 ml of 5% Sodium hexametaphosphate / Calgon $(NaPO_3)_6$ were added and mixed thoroughly, after which they were left to stand for between 15 - 20 hours.

The CALGON helps to separate the soil particles into layers according to their sizes with the aid of a dispenser. The contents in the beakers were then washed into soil cup with distilled water, and were stirred with dispensing machine for 2 minutes. The cup was disconnected then the contents washed into 1 litre soil cylinders and were filled to the litre mark with distilled water. The mouths of the cylinders were closed with rubber stoppers and turned completely upside down and back about 20 times. Few drops of Amyl alcohol ($C_5H_{11}OH$) were quickly added on top of the suspension to dissipate froths where they appeared. Hydrometer was gently placed in the soil suspensions and first reading taken within 40 seconds.

The hydrometer was removed and washed with distilled water. After exactly 2 hours of continuous sedimentation, the second reading was taken with the hydrometer. The hydrometer was removed and washed with distilled water. The relative amounts of sand, silt and clay were then calculated using the formula below:

% Sand = 100 - 2 (X + 2.88); % Clay = 2 (Y + 2.88); %Silt = 100 - (A + B)

Where; X = First corrected hydrometer reading = 1st Hyd. Read - 6.5

A = % Sand; B = % Clay

Once the relative amounts of sand, silt and clay were known, the soils‟ textural classes were determined by using a soil textural triangle.

The reagents used were prepared as follow:

20% Hydrogen peroxide (H_2O_2) in 1 litre: 200 ml H_2O_2 was measured into a 1 litre volumetric flask and made to volume with distilled water. The flask was labeled.

5% Sodium hexametaphosphate $(NaPO_3)6$ in 1 litre: 50.0 g of solid $(NaPO_3)$ was weighed into a 1 litre beaker and completely dissolved with distilled water. The solution was then poured into a 1 litre volumetric flask and made to volume with distilled water.

3.6. DETERMINATION OF DIVERSITY AND BIOMASS OF SOIL MICROBES

3.6.1 Determination of Diversity and Biomass of Soil Bacteria Procudure:

Serial dilutions of 10^{-1} to 10^{-4} were prepared by diluting 1g of each soil sample into 10ml of sterilized distilled water. 1 ml aliquot from each of the dilutions was inoculated into Petri dishes with already prepared PCA. The plates were then

incubated at 35^0 C for 24 hours. After incubation all white spots or spread were counted and recorded as total viable counts using the colony counter. Thus total viable counts were obtained by the pour plate method.

Identification of Soil Bacteria

A drop of culture from TVC plate was placed on a slide, spread with a flamed sterile loop, allowed to dry and fixed the bacteria by passing the slid two times through a Bunsen flame. The Bacterial smear was stained with dilute 0.5% crystal violet for 2 minutes. It was then stained with dilute iodine for 2 minutes.

The crystal violet and iodine solution form a purple / black complex inside the bacterial cell. Absolute alcohol was carefully dropped onto the smear and allowed to run off. This was repeated three times and washed off with water.

The alcohol dissolves the lipid layer surrounding the gram negative cells and allows the crystal violet and iodine complex to wash out. It was counter stained with 1% safranine for 2 minutes, washed and allowed the slide to dry. The slides were observed under the microscope.

Observation

Some of the cell stained purple or black, others stained light pink.

Inference

Purple or black stained cells indicate gram positive cells and those that stained light pink indicate gram negative cells.

Types of Bacteria obtained from the Soil samples

A. Organic Farms

The bacterial types obtained in the organic farms include: white circular colony: these were identified as Gram positive shot rods. i.e Bacillus sp. White Spread colony were identified as Gram positive Bacillus sp. with spore forms. Also present were white fern type colony, and were identified as Gram positive Bacillus sp.with spore forms in chains. Cream and yellow colonies were also identified as Pseudomonas sp. and Staphylococcus

B. Inorganic Farms

The bacterial types obtained in the inorganic farms include: white circular colony these were identified as Gram positive Bacillus sp. with spore forms. White spread colony were identified as Gram positive, Bacillus sp. and white fern type were identified as Gram negative short rods (ie. Escherichia coli).

Determination of Biomass of Staphylococcus

Staphylococcus were isolated and enumerated by Pour Plate Method and growth on Salt Monital Agar (SMA). Serial dilutions of 10^{-1} to 10^{-4} were prepared and 10g of soil sample was added into 90mls of sterilized distilled water and pulcified for 15 seconds. One milliliter aliquots from each of the dilution were inoculated into petri dishes with already prepared SMA. The plates were then incubated at 35 ^{o}C for 24 hours.

Observation

Yellow arrow spots or spread were observed and were counted and recorded as Staphylococcus count using the colony counter.

Determination of Biomass of Pseudomonas

Pseudomonaswere isolated and enumerated by Pour Plate method and growth on

Pseudomonas Agar (PA). Serial dilutions of 10^{-1} to 10^{-4} were prepared and 1g of soil sample was added into 10mls of sterilized distilled water. One millilitre aliquots from each of the dilution were inoculated into petri dishes with already prepared PA. The plates were then incubated at 44 ^{o}C for 24 hours. After incubation Pseudomonas were counted and recorded using the colony counter.

Determination of Biomass of Escherichia coli

Escherichia coli were isolated and enumerated by Pour Plate method and growth on MacConkey Agar (MA). Serial dilutions of 10^{-1} to 10^{-4} were prepared and 10g of soil sample was added into 90mls of sterilized distilled water and pulcified for 15 seconds. One millilitre aliquots from each of the dilution were inoculated into petri dishes with already prepared MA. The plates were then incubated at 35^{o} C for 24 hours.

Observation

Pink arrow spots were identified and these were counted and recorded as E. coli counts using the colony counter.

Determination of Biomass of Total and Faecal coliforms

The Most Probable Number (MPN) method was used to determine total and faecal coliforms in the soil samples. Serial dilutions of 10^{-1} to 10^{-4} were prepared by taking 10g of the sample into 90 mls of sterilized distilled water and pulcified for 15 seconds. One millilitre aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth with inverted tubes and incubated at 35 ^{o}C for total coliforms, and 44^{o} C for faecal coliforms for 18 – 24 hours. Tubes showing colour change from purple to yellow were collected and identified as positive for both total and faecal coliforms. Counts per 100ml were calculated from the Most Probable Number (MPN) tables.

3.6.2 Determination of Diversity and Biomass of Soil Fungi using the Pour Plate Method.

Serial Dilution of 10^{-1} to 10^{-4} prepared by diluting 1g of each soil sample into 10ml of sterilized distilled water. 1ml aliquots from each of the dilution were inoculated into petri dishes with already prepared PDA. The plates were then incubation all white spot or spread were counted and recorded as mould using the colony counter.

Identification of Soil Fungi

A smear of the culture from the PDA was placed on a slide and a drop of methylene blue was added onto the smear and covered with cover slip.

These were observed under the microscope to identify the various soil fungi. Species of Fungi obtained from the soil samples include Fusarium sp., Tricholderma sp., Aspergillus flavus., Aspergillus niger., Colletotrichum sp and Penicillum sp.

3.6.3 Determination of Diversity and Biomass of Nematodes Using the Extraction Tray Method

Procedure:

Using a coarse sieve, remove stones and debris from soil and break up soil lumps. In a plastic container (basin, bucket) thoroughly mix the soil sample. Remove a measure of soil (100 ml) Place tissue paper in the plastic sieve (placed on a plastic plate) ensuring that the base of the sieve is fully covered by the tissue. Place the soil measure on the tissue in the sieve. It is important that the soil remains on the tissue paper - spill-over results in dirty extractions. Add water to the extraction plates. Take care to gently pour water into the plate (dish) and not onto the tissue paper or soil (between the edge of the mesh and the side of the tray). Add a set volume to each dish to wet but not cover the soil, ensuring there is sufficient not to dry out dd more lately if necessary. Leave (preferably in the dark) undisturbed for a set period (48 hours if possible). Nematodes from the soil will move through the tissue paper into the water below, resting on the tray/plate. Remove the sieve and dispose of soil. Pour the water from the plate into a labeled beaker (or cup), using a water bottle to rinse the plate. Leave samples to settle for 24 hours. For counting the nematodes in the extraction, reduce the volume of water by gently pouring off or siphoning the excess (taking care not to lose nematodes and sediment). Transfer the extraction into a graduated cylinder and raise to a known volume (50 ml) by adding water. Pipette a known volume (1 ml) into the counting tray and mount on a microscope. With the aid of the tally counter, counts identify and count

nematodes in the tray. The total number of each nematode in the 50 ml is the number in 1 ml multiplied by 50. Since the 50 ml was derived from the 100 ml soil, the number of each genus in 100 ml soil is the number in the 50 ml extraction.

CHAPTER FOUR

4.0 RESULTS

4.1 Physico-chemical Properties of the Various Treated Soils

In all the parameters considered, thus soil carbon, nitrogen and cation exchange capacity (K^+, Ca^{2+}, and Mg^{2+}) the inorganic farms recorded higher values than the organic farms for both the topsoil and the subsoil except for soil pH in which the organic farms recorded higher value than the inorganic farms. Nonetheless soil from the control plots recorded the highest values as compared to the inorganic and organic farms. (Table 1 and 2).

Table 1: **Physico-chemical Properties of Soil Samples for the Topsoil (0-15 cm)**

TREATMENT	pH	Available Phosphorus (µg/g)	Organic Carbon (%)	Total Nitrogen (%)	Cation Exchange Capacity (meq / 100 g)		
					K^+	Ca^{2+}	Mg^{2+}
ORGANIC FARMS (T_1)	6.8	27.6	1.73	0.14	0.24	2.70	1.68
INORGANIC FARMS (T_2)	6.7	58.4	0.95	0.23	0.41	5.44	2.47
CONTROL PLOTS (T_3)	6.9	65.0	3.12	0.35	1.17	5.48	5.21

Table 2: Physico-chemical Properties of Soil Samples for the Subsoil (15-30 cm)

TREATMENT	pH	Available Phosphorus (µg/g)	Organic Carbon (%)	Total Nitrogen (%)	Cation Exchange Capacity (meq / 100 g)		
					K^+	Ca^{2+}	Mg^{2+}
ORGANIC FARMS (T_1)	6.5	8.8	0.67	0.09	0.23	1.76	0.84
INORGANIC FARMS (T_2)	5.9	34.0	0.41	0.11	0.30	2.53	0.71

CONTROL PLOTS (T_3)	7.1	27.4	1.22	0.18	1.17	3.28	1.69

4.1.1 Soil pH of the Treated Plots.

The control plots recorded the highest pH value of 6.9, followed by the organic farms with the mean value of 6.8 while the inorganic farms obtained the value 6.7. A similar trend was observed with regards to the sub-soil, where the control plots had the highest pH followed by the organic farms and then the inorganic farms recorded the least with the mean values being 7.1, 6.5 and 5.9 respectively (Table 1). Subjecting the results to statistical analysis gave no significant difference between the values.

The least significant difference (LSD) value at $p<0.05$ was 0.4438 (Appendix 1a).

4.1.2 Soil Available Phosphorus (µg/g) and Nitrogen (%) content.

The control plots and the inorganic farms showed appreciable recorded values for the two of the major soil nutrients which were nitrogen and phosphorus. With regards to the top-soil the mean values for the control plots and inorganic farms were 0.35% N and 58 µg/g av. P respectively. The organic farms on the other hand recorded least values for nitrogen and phosphorus contents and are comparable to the two aforestated treated plots with the mean values 0.14% N and 27.6 µg/g available phosphorus (Table 1).

Even though the control plots had the highest value for the amount of phosphorus in the top-soil, there seem to be a rather higher value for the inorganic farms than the control plots in the case of the sub-soil. The inorganic farms rather recorded 34.0 µg/g av. P. while the control plots read mean av. P of 27.4 µg/g. however there was not change in trend regarding the values for nitrogen content, as the control plots as usual recorded highest value of 0.181 & followed by the inorganic farms and then the organic farms will their respective vales being 0.105& and 0.097%. Statistically the difference in the values recorded for nitrogen content of the subsoil is significant (LSD < 0.05) = 0.029 (Appendix $2B_3$). But there is no significant difference between the values in the topsoil (LSD at $p<0.05=0.06$); neither is there any significant difference for the values obtained for phosphorus in the sub-soil (LSD at 5% probability = 9.6).

4.1.3 Carbon Content of the Treated Soils.

There was more carbon and for that matter, more organic matter in the organic farms than the inorganic farms. The recorded mean values for the two treated farms with respect to carbon were 1.73% and 0.95% for organic and inorganic farms respectively. The control plots contained about twice the amount of carbon as much as contained in the inorganic farms and even more than three times as contained in the inorganic farms, with the mean recorded value of 3.12% (Table 1).

These results, as obtained from the top-soil are not statistically different, since the LSD value for the carbon content in the top-soil $p < 0.05$ gave 0.563 (Appendix $2A_2$). The sub-soil showed a similar trend for the amount of carbon in the various treated soils where the control plots recorded the highest value followed by organic and then the inorganic farms, with their respective mean values being 1.22%, 0.67% and 0.41%. Statistically there was no significant difference between the values. The LSD valued at $p<0.05$ was 0.183.

4.1.4 Cation Exchange Capacity (Meq / 100g) of the Treated Soils.

The various cations measured were potassium ions (K^+), Calcium ions (Ca^{2+}) and Magnesium ions (Mg^{2+}). The experimental results showed that in all the three variables, the control plots recorded the highest values, followed by the inorganic farms and then the organic farms for both the top-soil and the sub-soil. There seemed to be very slight difference between the amount of Calcium ions contained in T3 and T2 for the top-soil with the mean values of 5.48 and 5.44. As the control plots recorded 1.17 for K^+ the inorganic farms recorded only 0.41 whiles the organic farms recorded 0.24. Also with regards to magnesium ions, as the control plots recorded a mean value of 5.21, the inorganic farms recorded 2.47 thus the control plots obtained about twice the value of inorganic farms and almost three times the value of the organic farms (Table 1).

However, statistical analysis revealed that the differences are not significant, since the calculated LSD values at 5% probability showed that K^+ had 0.163, Ca^{2+} had 2.19 and Mg^{2+} gave 0.71 for the top-soil (Appendix $2A_5$, $2A_6$ and $2A_7$).

Regarding the subsoil, again the control plots recorded higher value as compared to the mean values for inorganic and organic farms for all the cations measured. For instance, as the control plots recorded 1.17 for K^+, inorganic farms recorded only 0.30. Thus the control plots recorded about five (5) times the value of inorganic farms. Also in the case of magnesium ions the control plots recorded about twice the value of inorganic farms. And for the first time in almost all the chemical properties measured, the organic farms had a greater value than the inorganic farms, and that is for the mean values for magnesium ions. The organic farms recorded 0.84 while the inorganic farms recorded 0.71(Table 2).

However, despite all these clear differences, the statistical analysis indicated that the differences were not significant. The LSD values obtained at 5% probability gave values as 0.0996, 0.91 and 0.251 for K^+, Ca^{2+} and Mg^{2+} respectively.

4.2 Biological Properties of the Treated Soils.

The soil microbes considered for the purpose of the study were bacteria, fungi and soil Nematodes. Though there were several other organisms living in the soil, the researcher selected these three to serve as bases for representing both beneficial and harmful microbes in crop production. For instance, most fungi and bacteria are beneficial as they help in nutrient cycling by causing decomposition. Nematodes, on the other hand, were used to represent the role of harmful microbes in the soil. Considering all microbes in the soil would cause a deviation from the main topic and objective for the study.

The control plots (forest) contained more of these microbes both in terms of diversity and biomass, than the organically treated farms as well as the inorganic farms (Tables 3, 4, 5, 6, 7 and 8).

4.2.1 Diversity and Biomass of Bacteria in the Treated Soils.

Several species of bacteria were obtained from the various soils and these included Bacillus subtiles, Pseudomonas fluorescens, Azospirillum, Agrobacterium, Azotobacter, Flavobacterium, Bacillus megaterium, Escherichia coli, Staphylococcus

sp., total cauliform, faecal cauliformand Actinobacteria just to mention a few. Some of these appeared as white circular colonies, white spread or white fern types. There were also species with spore forms in chains, cream colonies and yellow colonies.

Table 3: Bacteria Biomass of the Treated Farms for the Topsoil (0-15 cm)

Treatment	sp.	sp.	coli	Coliform	Coliform
Organic Farms	$1.7x10^{5}$	$2.8x10^{5}$	$9.8x10^{4}$	$1.4x10^{10}$	$2.3x10^{5}$
Inorganic Farms	$4.0x10^{4}$	$2.8x10^{4}$	$1.8x10^{4}$	$3.1x10^{8}$	$5.1x10^{4}$
Control Plots	$1.5x10^{5}$	$1.7x10^{5}$	$1.6x10^{5}$	$1.1x10^{10}$	$3.4x10^{5}$
	Staphylococcus	**Pseudomonas**	**Escherichia**	**Total**	**Faecal**

Table 4: Bacteria Biomass of the Treated Farms for the Subsoil (15-30 cm)

Treatment	sp.	sp.	coli	Coliform	Coliform
Organic Farms	$8.3x10^{4}$	$3.4x10^{4}$	$3.2\ x10^{4}$	$2.7x10^{9}$	$2.1x10^{5}$
Inorganic Farms	$3.9x10^{3}$	-	$5.3\ x10^{3}$	$6.3x10^{8}$	-
Control Plots	$9.1x10^{4}$	$1.8x10^{4}$	$4.8x10^{4}$	$5.1x10^{9}$	$8.7x10^{4}$
	Staphylococcus	**Pseudomonas**	**Escherichia**	**Total**	**Faecal**

Results of the topsoil showed that the organic farms recorded greater counts of Staphylococcus, Pseudomonas and total coliforms as compared to the biomass of these bacteria species obtained for the control plots and inorganic farms (Table 3).

The organic farms recorded a mean count of 1.7 x 10^5 cfu of Staphylococcus as against 1.5 x 10^5 cfu recorded for the controlplots and 4.0 x 10^4 for the organic farms. The differences in the number of Staphylococcus counts as recorded for the three treatments are statistically significant. The LSD value at $p < 0.05$ was calculated as

0.01 (Appendix 7). Similarly, as the organic farms recorded 2.8 x 10^5 cfu of Pseudomonas, the control plots and inorganic farms respectively. Statistically the difference in values is significant. The LSD at 5% probability gave 0.01.

The biomass of total coliforms recorded for the organic farms was 1.4 x 10^{10} cfu. This was followed closely by the control plots while the inorganic farms recorded the least with their respective values being 1.1 x 10^{10} cfu and 3.1 x 10^8 cfu. The difference between the values is statistically significant since the LSD value at $p < 0.05 = 0.02$. The control plots recorded the greatest counts for Escherichia coli and the biomass of faecal coliforms. The mean value of E. coli counts for the control plots was recorded as 1.6 x 10^5 cfu. The organic farms recorded 9.8 x 10^4 cfu and the inorganic farms again recorded the least count of 1.8 x 10^4 cfu. The p- value at 5% probability was calculated as 0.01. Thus there was significant difference between the values recorded for the biomass of E. coli in the treated farms.

The control plots again recorded the greatest value for the biomass of faecal coliforms with a mean count of 3.4 x 10^5 cfu. The inorganic farms recorded the least count in all the bacteria isolated and enumerated. The biomass of faecal coliforms recorded for the inorganic farms was 5.1 x 10^4 cfu as against 2.3 x 10^5 cfu recorded for the organic farms. These values obtained for the three treatments for faecal coliform biomass are significantly different. (LSD at $p < 0.05 = 0.00$).

The highest mean value of the biomass of E. coli in the subsoil was recorded for the control plots and this was followed by the organic farms and then the inorganic farms, with their respective values being 4.8 x 10^4 cfu; 3.2 x 10^4 cfu and 5.3 x 10^3 cfu respectively. Statistically the differences are not significant (LSD at $p < 0.05 = 0.57$) There was vast significant difference between the values of total coliforms recorded for the three treatments. The LSD values at 5% probability gave 0.00. The mean values of their biomass were recorded as 2.7 x 10^9, 6.3 x 10^8 and 5.1 x 10^9cfu for the organic, inorganic and control plots respectively.With regards to the number of colonies of faecal coliforms in the subsoil enumerated for the three treatments, the organic farms

recorded the highest count of 2.1 x 10^5 cfu. This was followed by the control plots with the mean value of 8.7 x 10^4 cfu whilst the inorganic farms recorded no count of faecal coliforms. Statistically these values are significant since the LSD value at 5% probability was calculated as 0.00.

4.2.2 Diversity and Biomass of Mycoflora in the Treated Soils.

The species of fungi contained in the selected farms were Fusarium sp; Trichoderma sp; Aspergillus flavus, A. niger, Colletotrichum sp. and Penicillum sp. (Table 5). The number of Fusarium colonies contained in the topsoil of the control plots were five (5) as against four (4) for the organic farms while the inorganic farms recorded only one (1). There was significant difference between the values obtained for the number of colonies of Fusarium. The calculated p- value was obtained as 0.02 (Appendix 8). For Trichoderma sp; as the control plots recorded five (5), the organic farms recorded three (3) and there was only one (1) colony counted from the inorganic farms. These values are significantly different since the LSD at p- 0.05 gave 0.00. There was no Colletotrichum sp. in the inorganic farms, but the organic and control plots counted two (2) and three (3) respectively. It was also observed that more Penicillum sp. was contained in the control and organic farms but only one colony was counted from the inorganic farms.

Statistically there were significant differences between the biomass of Colletotrichum sp. and also Penicillum sp. in the treated farms. The LSD at $p < 0.05 = 0.00$ for each of the two species of fungi. The colonies of Aspergillus Flavus and A. niger were also significantly different since the p- value for each of the species for the three treatments was calculated as 0.00 (Table 5).

Table 5: Soil Mycroflora in the Treated Farms for the Topsoil (0 – 15 cm).

	Fusarium sp.	**Trichoderma sp.**	**Aspergillus flavus**	**Aspergillus Niger**	**Colletotrichum sp**	**enicillum sp**
Sample	**No. of Colonies**	**No. of Colonies**	**No. of Colonies**	**No. of Colonies**	**No. of Colonies**	**No. of Colonies**
Organic Farms	4	3	3	4	2	4
Inorganic Farms	1	1	1	2	0	1
Control Plots	5	5	5	6	3	7

Table 6: Soil Microflora in the Treated farms for the Subsoil (15 -30 cm)

	Fusarium sp.	Trichoderma sp.	Aspergillus flavus	Aspergillus Niger	Colletotrichum sp	Penicillum sp
Sample	**No. of Colonies**	**No. of Colonies**	**No. of Colonies**	**No. of Colonies**	**No. of Colonies**	**No. of Colonies**
Organic Farms	1	1	1	1	1	1
Inorganic Farms	0	0	0	1	0	0
Control Plots	2	2	2	2	1	3

Regarding the subsoil, it was observed that no fungal colony was counted in the inorganic farms with the exception the Aspergillus niger in which one colony was counted in the inorganic farms. However both the control and organic farms contained colonies for all the species observed (Table 6). The organic farms counted one Fusarium colony while the control plots counted two. The difference between the mean values of Fusarium counts in the subsoil is significant. The LSD at 5% probability was calculated as 0.026 (Appendix 8). There was one colony each for Trichoderma, Aspergillus flavus, Aspergillus niger, Collectotrichum and Penicillum in the organic farms. The control plots also counted two colonies for each of Fusarium, Trichoderma, Aspergillus flavus and Aspergillus niger. There was only one Collectotrichum sp and three Penicillum coloniesin the control plots. Again there was significant difference between the mean values of Trichoderma, Aspergillus flavusand
A. niger. The p- values were calculated as 0.00 for Trichoderma; 0.049 for A. flavus and 0.007 for A. niger.

No colonies were counted for Penicillum and Colletotrichum in the subsoil of the inorganic farms. But the organic farms recorded one (1) count for each of the species while the control plots recorded one colony count for Colletotrichum and three (3) for Penicillum. Statistically the difference between these values is significant since the LSD value at 5% probability gave 0.001 for Colletotrichum, and 0.000 for Penicillum.

4.2.3 Diversity and Biomass of Nematodes Contained in the Treated Soils. More nematodes were contained in the control plots than the organic farms in all the species

considered for the study, with reference to both the topsoil and subsoil. The inorganic farms contained least number of nematodes (Table 7 and 8).

Table 7: Biomass of Nematodes per 100 ml of soil in the Treated farms for the Topsoil. (0 – 15 cm).

Treatment	Root-knot Nematode	Pratylenchus	Helicotylenchus	Monochus	Free-living
Organic farms	150	110	70	40	180
Inorganic farms	20	0	30	10	80
Control plots	420	220	160	90	320

Table 8: Biomass of Nematodes per 100ml of Soil in the Treated Farms for the Subsoil (15 – 30 cm).

Treatment	Root-knot Nematode	Pratylenchus	Helicotylenchus	Monochus	Free-living
Organic farms	100	20	50	20	70
Inorganic farms	10	10	0	0	20
Control plots	110	40	70	20	80

The species of Nematodes contained in the sampled soils were Root-Knot nematode, Pratylenchus, Helicotylenchus, Monochus and Free-living nematodes.Results of the topsoil show that there were as many as 420 Root knot nematodes per 100ml of soil in the control plots, while the organic farms counted a mean of 150. The inorganic farms contained only 20 for the same species. The difference between the mean values of root-knot Nematodes is statistically significant (LSD at $p < 0.05 = 0.008$). The inorganic farms contained no Pratylenchus,but the organic farms contain 110 which is half the number contained in the control plots (i.e. 220). There was vast significant difference between the values since the LSD value at $p < 0.05$ was calculated as 0.003.

Also the control plots recorded 160 per 100 ml of soil of Helicotylenchus, while the organic farms recorded 70, a value which is a bit less than the number contained in the

control plots. There were only 30 of the same species of nematodes counted in the inorganic farms. This is far less than the number contained even in the organic farms. For both Monochus and Free-living Nematodes the control plots contained greater numbers while the organic farms recorded about half the number contained in the control farms, but the inorganic farms counted for far less numbers than the two previous treated plots. There seem to be differences between the biomass of Helicotylenchus, Monochus and free-living Nematodes contained in the topsoil of the three treatments. However the differences are not statistically different. The p- values for the three species of Nematodes were obtained as 0.14 for Helicotylenchus; 0.081 for Monocus and 0.166 for free-living Nematodes.

In the sub-soils the numbers contained in the organic farms were much closer to those of the control plots, but the inorganic farms still counted the least values for all the Nematodes observed, and even for Helicotylenchus and Monochus, no count was made in the sub-soil. (Table 8).

We can say that in totality the control plots contained more number of nematodes for both the topsoil and subsoil and was followed closely by the organic farms but the inorganic farms did not only record least numbers but also some species were completely extinct from the inorganic farms.We can also say that there was a wider margin between the number of nematodes contained in the control and organic farms with regard to the topsoil but for the subsoil the gap between the two treatments was rather very close. However, in both cases the inorganic farms attained very low levels.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Physico-Chemical Properties of the Treated Soils.

The results of the study showed that treating depleted soil with inorganic fertilizers releases enormous amounts of nutrients into the soil, which are readily made available to crops. But when such soils are treated with organic fertilizers, the nutrients are released at a slower rate, and therefore the required amount of nutrients may not be readily available to the crops. Although the inorganic fertilizers release the nutrient fast, excessive doses may cause poor physical structure of soil, and also retention of the nutrients, since the nutrients would be released in excess. This soil retention has the

consequence of rendering the soil acidic over time, and this would adversely affect the growth and development of cocoa. In Nigeria, inorganic fertilizer application is a major input in crop production processes, and its use is the most adapted agricultural technology by farmers. Chude (1999) reported that the quality of cocoa exported by Nigerians is very low.

5.1.1 pH of the Treated Soils.

The study recorded pH values of 6.9 for the control plots, 6.8 for organic farms and 6.7 for the inorganic farms with regards to the topsoil. The Council for Scientific and Industrial Research (CSIR), and the Soil Research Institute (SRI) grade soils with pH values ranging from 6.6 to 7.0 as neutral (www. wikipedia.org). This implies that the topsoil of all the selected farms could be labeled as neutral. However, moving down the soil profile to the subsoil, the control plots recorded the highest pH mean value of 7.1; this was followed by the organic farms which recorded 6.5, while the inorganic farms recorded a lower pH value of 5.9.

The CSIR and SRI grading system indicates that soils with pH ranging from 6.6 to 7.0 are neutral (www. wikipedia.org)., which implies that the control plots still had neutral soils even when moved down the soil profile. The organic farms also recorded 6.5, and this value falls within the range 6.1 to 6.5 which is described by CSIR and SRI as slightly acidic. Thus the subsoil of the organic farms is still very close to neutral. But the value recorded for the inorganic farms (5.9), falls within the range 5.6 to 6.0, which is graded as moderately acidic.

At the moment much concern might not be raised about the slight difference in the results. This is because the differences in pH values for the three treatments are statistically not significant. The LSD value at 5% probability was 0.44. Besides the International Cocoa Organization recommend soils of pH ranging from 5.5 to 7.7 in 1:2.5 water as suitable for cocoa production. So the pH values obtained for all the three treatments fall within the recommended range. However since cocoa is a deep- rooted crop threats could result if care is not taken to check the rate at which inorganic fertilizers are applied.

The reduction in the pH value of the sub-soil of the inorganic farms could be due to the fact that plants have the capacity to absorb only a given level of nutrition at a time. For that matter the excessive application of chemical fertilizers which contain greater

amounts of readily available nutrients, would cause the plants to absorb only given levels of the nutrients, leaving the rest of the fertilizer to leach, thereby causing the lower layers of the soil to become more and more acidic which could result in reduced productivity.

This is in line with the suggestion made by Smithson (1999), that soil acidity and phosphorus deficiencies limit crop production in many tropical soils. Kingery et al; (1993), applied chemical fertilizers and paoultry border litter to the soil and showed that soil that had received repeated application of poultry border litter over many years had an average surface soil pH of 6.3 (+ 0.1), compared to fields receiving only chemical fertilizers. These latter fields were shown to have a surface pH of 5.8 (+ 0.1).

The high pH value recorded in the organic farms could result from the reacition of organic anions contained in the organic fertilizers. Hue (1992), in his study showed that chicken manure was very effective in raising soil pH. He theorized that much of this pH increase was due to reactions of organic anions. Soil pH may also increase substantially with application of hen manure because the amount of liming materials added to the soil which is contained in the "feed" exceeds the amount of acidity released by the conversion of nitrogen. Clark et al; (1998); Dinesh et. al.,(2000) and Lee, (2010), also reported that soil pH becomes higher under organic management.

The high pH recorded for the organic farms could also be due to the fact that during microbial decomposition of incorporated organic manure, organic acid might have been released, which neutralized the alkalinity of the organic manure. This caused an increase in the pH of the organically treated soil and rendered it much closer to neutral, which is favourable for a good crop (cocoa) production. Somani and Totawat (1996), observed a similar result in their study on organic amendments in alkaline soils.

5.1.2 Soil Available Phosphorus (µg/g) Content.

The control plots recorded the greatest amount of available phosphorus (av. P) with a mean value of 65.0. This was followed closely by the inorganic farms with av.P value 58.4, while the organic farms recorded only 27.7 for the topsoil. The difference

between the values was not statistically significant. The LSD value at 5% probability gave 19.2.With regards to the sub-soil; the inorganic farms recorded the highest amount of available P with the mean value of 34.0. This was followed by the control plot while the organic farms recorded the least with their respective mean value being 27.4 and 8.8 respectively. Similarly, there was no significant difference between the values for the subsoil since the LSD value at $p<0.05$ was obtained as 9.64. But the increased value in the inorganic farms for both top and subsoil could be that the nutrients contained in the chemical fertilizers are soluble and readily available to crops; therefore the effect is usually direct and fast.

Nnabude and Mbagwu (2001), reported that the application of 100% NPK with the help of available organic carbon in the soil, help to increase phosphorus status of soil. Though the forest plots recorded higher values in almost all the parameters, the inorganic farms with regards to the sub-soil had a higher available P value than the control. This means that more nutrients in the inorganic farms might have leached to the subsoil. Therefore the increased available P value might be due to residual effect.

The available P limitation in the organic farms corroborates the findings of Qian et al., (2004). They reported that when manure (organic fertilizer) is applied to the soil for many years, the incorporation of manure P into the soil can lead to an increase in the amount of P available to the crops. However, since manure N: P ratio is often smaller than the N: P uptake ratio of most crops, and the rate of manure application are based on N requirement, P can accumulate in the soil over several years (Grossl and Inskeep, 1991; and Sims et. al., 2000). This they reported may increase the risk of P loss from the soil system before it is used by subsequent crops. Vitousek et. al., (2010), also reported that phosphorus is derived from rock weathering, which means that farmland begin their existence with a fixed complement of P and for that matter even very small losses cannot readily be replenished.

Therefore if the fertilizer used (organic) could not readily provide the needed amount of P, there would certainly be deficiency. Blatt, (1991); Lee, (2010) and Bakayoko et. al., (2009), attributed the low levels to the slow rate of mineralization of organic fertilizers. But is should be noted that since cocoa requires more P for proper growth and development, its deficiency would definitely limit cocoa production (Smithson, 1999).

5.1.3 Nitrogen Content of the Treated Soils.

The results for the topsoil showed the highest value in total nitrogen for the control plots with a mean value of 0.35%. This was followed by the inorganic farms and then the organic farms with their respective values being 0.23% and 0.14% (Table 1). Subjecting these values to statistical analysis gave no significant difference between the values. LSD at $p<0.05$ was obtained as 0.059 (Appendix $2A_3$). The control plots also recorded the highest amount of Nitrogen for the subsoilwith the mean value of 0.18%. The inorganic farms follow closely and recorded 0.11%, while the organic farms again recorded the least value of the nitrogen content with the mean value of 0.09%. Though the values for the three treatments seemed very close, statistically the difference between the values was significant since the LSD value at 5% probability was calculated as 0.029 (Appendix $2B_3$).

Comparing these values with the grading system as recommended by CSIR and SRI, one can say that the control plots are high in nitrogen while the organic and inorganic farms contain moderate amount of total nitrogen (Appendix 6).Though the organic farms are rated as moderate, they recorded the least value, and this could result from, crop uptake, immobilization by microorganisms and nitrogen loss through volatilization (Defoer et. al., 2000; Filter and Hay, 2002).

The high nitrogen content as recorded in the control plots could be as a result of increased organic matter content. Soil organic matter content largely determines the nitrogen supply capacity of soils because organic matter releases nitrogen into the soil. The forest is noted to consist of bulk volumes of dead decaying matter which could result in the increased supply of nitrogen. The activities of soil biota in the forests could also result in the high levels of nitrogen. Farji-Brener (2010), proposed that the high content of organic matter and nutrients inside the colonies became hot zones for microbes which accelerate the mineralization and decomposition of the material.On the other hand the low levels of nitrogen in the organic and inorganic farms may be due to the comparatively reduced organic matter content recorded and crop uptake (Mbah and Onweremadu, 2009). The organic farms recording the least N value could also be attributed to the slow rate at which nutrients are released from organic fertilizers (Bakayoko et. al., 2009).

The value recorded for the organic farms that is 0.14 is not detrimental to cocoa production. This is because the Food and Agriculture Organization (FAO) had indicated that cocoa plant require more phosphorus than nitrogen for its growth and development. Besides, the value 0.14 falls within the range 0.1 - 0.2 which is described as moderate. This is good enough for effective cocoa production. This not withstanding, other researchcomparing soils of organically and chemically managed farming systems obtained similar values and these were recognized as appreciable amounts of total N with the use of organic fertilizers. Also a study conducted by Peyvast et. al.,(2007) recorded 0.25% nitrogen to show the effect of organic fertilizers on the soil. Olfati et. al.,(2009); and Shabani et. al., similarly recorded 0.38% and 0.35% nitrogen respectively, which showed that organic fertilizers have positive effect on the nitrogen content of the soil. Organic fertilizers have beneficial effect on soil structure and the nitrogen (N) availability (Thy and Buntha, 2005). They reported that the organic fertilizer help to maintain the nitrogen content and also increase yield and quality of crops.

5.1.4 Organic Matter Content of the Treated Soils.

For both topsoil and subsoil, the control plots recorded the highest amount of carbon which implies greatest amount of organic matter with the mean organic carbon (%C) values being 3.12 for the topsoil and 1.22 for the subsoil. This was followed by the organic farms while the inorganic farms recorded the least values with their respective mean values being 1.73; 0.67 (organic farms) and 0.95; 0.41 (for inorganic farms). There was no significant difference between the values for both the topsoil and subsoil. The LSD value at 5% probability gave 0.56 for the topsoil and 0.18 for the subsoil.

The Council for Scientific and Industrial Research (CSIR) and SRI have the following grading system for the organic matter content of soils. Soils with organic matter <1.5 are described as low; 1.6 to 3.0 are labeled as moderate and those with organic matter > 3.0 are described as high (Appendix 6).

The organic fertilization allowed tremendous increase in the soil organic matter content in the organic farms. That was due to the fact that the organic fertilizer provided higher organic carbon by mineralization (Fan et al., 2004; Wuest et. al., 2005). These results are similar to those of Wang et al., (2006), who observed that cattle manure increased the concentration of organic matter significantly. The increase in the organic matter as induced by the organic fertilizer was due to the role played by such fertilizers, (1) protection of the soil against erosion and (2) increase in the activities of earthworms and other soil microbes which reduced water runoff and leaching (Hole et. al., 2005; Parfitt et. al., 2005)

The results are in agreement with conclusions of other researchers (Thuries et. al., 2000), who observed that manure allowed significant increase in the carbon content of the soil. Similar results were obtained by Bado (2002), when he applied manure to soil of Farakô-Ba in Burkina-Faso.

The results confirmed the fact that organic materials improve the physical properties of soils that allow profitable crop (cocoa) production (Somani and Totawat, 1996). Also Gutierrez-Miceli et al.,(2007); Peyvast et.al., (2008); Shabani et al., (2011) and Ayyobi et al., (2013), reported that the use of compost, organic manure in agricultural soils had positive effects on soils and in the production of vegetables.

The results are also in accordance with the report given by Harris (2002), who pointed out the importance of manure as a nutrient source in raising the organic matter content. Greenhouse and felid studies have examined the effects of vermicompost, another organic fertilizer on crops (Ayyobi et. al., 2014; Kochakinezhad et. al., 2012; Chatterjee et. al., 2014). These investigations confirmed that organic manure has beneficial effects on plant growth.The inorganic farms recording the least amount of organic matter content could be due to the reduction in biomass and diversity of soil biota recorded for such farms. This is because the synthetic chemicals in chemical fertilizers affect the health of naturally present soil microbes by reducing soil pH. These altered levels of acidity in the soil eliminate the microbes beneficial to plants and soil health as they increase the plants‟ natural defenses.

5.1.5 Cation Exchange Capacity (CEC) of the Treated Soils (meq/100g).

The results of the topsoil showed that for all the CEC measures, thus K^{+}, Ca^{2+} and Mg^{2+}, the control plots recorded the highest values for K^{+}, Ca^{2+} and M^{2+} with theirrespective mean values being 1.17, 5.48 and 5.21, while the values for the inorganic farms were 0.41, (K^{+}); 5.44 (Ca^{2+}) and 2.47 (Mg^{2+}). Again the organic farms recorded the least values for CEC as 0.24 (K^{+}), 2.770 (Ca^{2+}) and 1.68 (Mg^{2+}). Statistically the differences between the values at 5% probability were not significant.

The $p<0.05$ value for Ca^{2+} was 2.19; K^{+} had 0.16 and that of Mg^{2+} was 0.71. The values obtained for the subsoil gave a similar trend where the control plots recorded the highest values for all the three parameters, followed by the inorganic farms and the organic farms recorded the least. But in the case of Magnesium ions (Mg^{2+}), the organic farms recorded a higher value than the inorganic farms in the subsoil. The organic farms recorded 0.84 while the inorganic farms recorded 0.71. Again, the difference between the values was statistically insignificant. The LSDat $p<0.05$ was recorded as 0.91 (Ca^{2+}); 0.09 (K^{+}) and 0.25 (Mg^{2+}).

The grading of soils as proposed by the Council for Scientific and Industrial Research (CSIR) and the Soil Research Institute (SRI), with respect to exchangeable potassium indicates that soils with values < 0.2 are graded as low; those ranging from 0.2 to 0.4 are labeled as moderate and soils having $K^{+} > 0.4$ are regarded as high. Similarly, CSIR and SRI regard soils as low when the calcium content is < 5; as moderate when > 10 the soil is regarded as high. With these specifications, one can say that the control plots are very high in K^{+} while the organic and inorganic farms are moderate with regards to K^{+}. Similar observation was made for the subsoil.With regards to calcium; the inorganic farms had a much closer marking with the control plots, with their respective mean values being 5.44 and 5.48. Thus soils of both fields are said to be moderate, since the values range between 5 and 10. The organic farms recorded a mean value of 2.7 which is rather very low. Krough et. al., (2000), are of the opinion that soils differ in their CEC depending on clay and organic matter content. So the difference in CEC of the various treated fields could be comparable to the values recorded for their organic matter content (Table 2).

This is in line with the studies conducted by Hepper et. al., (2006); Gogo and Pearce (2009) and Parfitt et al., (1995), who stated that CEC is influenced by the amount of acidity of clay mineralogy, organic matter content and soil reaction or pH. The control

plots which recorded the highest CEC value also recorded same for organic matter, and high organic matter content implies that such soils are much cramped together and so can hold considerable amount of water and nutrients without them being leached easily. Thien and Graveel (1997), asserted that soils with high CEC present management problems associated with high clay content.

On the other hand, Sahrawat (1980), observed that soils with low CEC are easier to cultivate than soils with high CEC. This implies that the inorganic farms which recorded high value of CEC would require more frequent lime and fertilizer, unlike the organic farms which do not need to be treated with lime or more fertilizer.

However, Hao and Chang (2002), from a different perspective reported that organic fertilizer help to increase the sum of the exchangeable Cations (Ca^{2+}, Mg^{2+}, K^{+}). This is in agreement with conclusions drawn from the research conducted by Thuries et. al., (2000), that manure allowed significant increase in CEC of the soil.

5.2. Biological Properties of the Treated Soils.

The results of the study showed that treating farmlads with organic fertilizersstimulates the growth and development of soil microbes and ensures the health of the soil. In all the three parameters considered, that is soil bacteria, fungi and Nematodes, the control and organic farms recorded greater counts than the inorganic farms in terms of biomass and diversity.

With respect to soil bacteria, as the organic plots recorded 1.7×10^{5} cfu of staphylococcus, the control plots recorded 1.5×10^{5} cfu while the inorganic farms recorded only 4.0×10^{4} cfu (Table 3). These values gave significant difference beween the threetreatments with a p-value of 0.01. Similarly there were significant differences between the mean values recorded for other soil bacteria such as Pseudomonas, E. coli, total coliforms and faecal coliforms with their respective p-values being 0.01, 0.01, 0.02 and 0.00 respectively. These significant differences resulted from the tremendous values obtained for the control and organic farms as compared to the low values recorded for the inorganic farms (Table 3). These results could be due to the fact that treating farmlands with organic fertilizers promoted the growth and activities of the soil

bacteria which were present unlike the inorganic fertilizers which rather inhibited their growth. It was also realized that there were no counts for the biomass of Pseudomonas and faecal coliforms in the subsoil of theinorganic farms (Table 4).

However the organic and control plots recorded high values for these two bacteria species with mean values of 3.4 x 10^4cfuas recorded for the organic farms and 1.8 x 10^4 as recorded for the control plots (for Pseudomonas). The organic farms recorded 2.1 x 10^5 cfu of faecal coliforms and the control plots recorded 8.7 x 10^4 cfu. The inorganic farms recording zero count for Pseudomonas and faecal colifom might have resulted from the fact that the chemical fertilizers killed such species to the extent of rendering them extinct from the farms treated with chemical fertilizers.

A similar trend was observed in the biomas of fungi in the topsoil and subsoil of the treated farms, where the control and organic farms recorded greater counts of fungi much more than the inorganic farms. For instance, as the organic farms recorded 4 colonies of Fusarium in the topsoil the control plots recorded 5 but the inorganic farms recorded only 1. Also the organic farms recorded 4 colonies of Penicillum while the control plots recorded 7 but the inorganic farms recorded only 1. These significant differences ($p<0.05 = 0.002$ for Fusarium and 0.000 for Penicillum), could be as a result of the organic matter content of the various farms, since fungi are saprotrophs and mainly depend on dead decaying matter, rich in organic matter for nourishment. But it was realized that the organic matter content of the inorganic farms was rather low and this could not support the growth of fungi in the inorganic farms, hence the least counts recorded for such farms.

The results on soils Nematodes were no different as the control and organic farms recorded maximum values than the inorganic farms. Similarly, the low counts recorded for the inorganic farms (Tables 7 and 8), might have resulted from the chemical fertilizers destroying the soil nematodes and thus causing a reduction in the numbers.

In totality, it was deduced that the low counts recorded for the inorganic farms for all the soil microbes could result from the fact that the synthetic chemicals in chemical fertilizers adversely affectedthe health of the naturally present soil microbes by affecting soil pH. The reduced levels of soil pH recorded for the inorganic farms (Table 1), making the soil moderately acidic might have caused the elimination of microbes

beneficial to plants and soil health. Some of these microbes increase the plants‟ natural defenses against pests and diseases.

Mengel and Kirkby (2001), showed that low soil pH conditions substantially depress microbial NH_4^+ oxidation. In Malaysia, Asy Syura and Tsan (2010), also reported on the fact that application of inorganic fertilizers in oil palm production had a negative impact on soil biota unlike organic fertilizers which promoted the growth and activities of soil microbes.

The increased microbial strength in the control and organic farms could be due to the fact that the bulk volumes of organic manure applied to the organic farms, and also the increased amounts of organic matter recorded in the control and organic farms, served as “food” for the various soil microbes which helped in enhancing their activities (decomposition of organic matter), thereby aiding their multiplication.

The study revealed that fields treated with organic fertilizers enhance microbial growth unlike chemical fertilizers which have proven to be detrimental to microbial growth and activities. This could be supported by findings obtained in the study conducted by Verma et. al.,(2013), that compost, an organic manure, though will not supply all the nutrients required for optimum plant growth, but usually provides soil with organic matter and beneficial microbes which can improve crop health, growth, quality and yield. Kochakinezhad et. al., (2012), are of the opinion that organic fertilizers can avoid or reduce the deleterious effects (such as destruction of soil organisms), attributed to the use of chemical fertilizers. Clark et. al., (1998); Dinesh et. al., (2000) and Lee, (2010), also proved that when fields are under organic management, the total microbial population increases.

In China, (Ren et. al., 1996; Sun, 2003; and Lv et. al., 2005), showed that organic fertilizers enhance microbial activity such as improving activity of soil enzymes and increasing soil microbial biomass. Harris (2002), also pointed out the importance of manure as a nutrient source not only to crops, but also the soil organisms in the nutrient balances of two farming systems, thus organic and inorganic.Though some soil microbes are destructive (eg. Nematodes), the importance of beneficial soil microbes cannot be overemphasized. Some researchers have indicated that plant growth

promoting rhizobacteria (PGPR) will often have multiple modes of action. Ratti et. al., (2001) found that a combination of the arbuscular mycorrhizal fungi, Glomas aggregatum, the PGPR Bacillus polymyxa and Azospirillum brasilense maximized biomass and phosphorus content of the aromatic grass palmarosa (Cymbopogon martini).

Bennett (2010), reported that Aspergillus flavus produces aflatoxin which is both a toxin and carcinogen and can contaminate foods such as nuts. However, beneficial fungi such as Trichoderma which occur naturally in cocoa peat, works in symbiosis with plant roots to protect them from pathogenic fungi such as Fusarium oxysporum. The study conducted by Cuevas et. al., (2001), also explored the effectiveness of using two Trichoderma species (T. parceramosum and T. pseudokoningii) in controlling Scleratium ralfsii a plant pathogen.

These studies imply that the low levels of microbial strength recorded for the inorganic farms aredeleterious to the soil health. In Nigeria, Chude (1999) reported that inorganic fertilizer is a major input in crop production processes, and its use is the most adopted agricultural technology by farmers. For this reason he stated that the quality of cocoa exported by Nigeria is low, and managing soil health is much of a problem. The results of this study have shown that organic fertilizers have positive effects on soil microbes, but inorganic fertilizers have negative impact on microbial strength.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Efficient plant nutrition management should ensure both enhanced and sustainable agricultural production and safeguard the environment. Cocoa as a perennial crop requires increased amounts of soil nutrients for its proper growth and development. As Olfati et. al., (2012), indicated if the appropriate amounts of fertilizers are not applied

during production, physiological symptoms of deficiency can occur in crops.Organic or inorganic fertilizer application has its advantages and disadvantages in terms of nutrient supply, soil quality and crop growth.

In view of resurgence of interest, the results of the study revealed that the application of inorganic fertilizers has proven to release soil nutrients very fast into the soil and these are made readily available to crops and most especially cocoa with its high demand for nutrients. Even though chemical fertilizers work faster than organic fertilizers, in my opinion the nutrients are released too quickly and in greater amounts which creates a great deal of upper growth of weeds at a much faster rate than the roots of crops are able to absorb the nutrients. Also, because they are so rich the synthetic chemicals can easily be over-applied and that may “burn” roots or creates toxic concentrations of salts. Such fertilizers are composed of high concentration of mineral salts, and these are capable of killing off many of the soil microbes that are responsible for decomposition and soil formation. The results also showed that applying inorganic fertilizers to farmlands would cause a reduction in soil microbes both in terms of biomass and in diversity. Applying only inorganic fertilizers in highly weathered soils or in cocoa farms would cause poor physical structure, soil acidification and nutrients retention characteristics which would adversely affect the growth of cocoa and crops in general.

Organic farming can be considered to be a sound and viable option in crop production. Organic fertilizers have beneficial effects on soil structure and nutrient availability. Such fertilizers maintain quantity and quality of yield and are less costly than synthetic fertilizers (Olfati et. al., 2012; Thy and Buntha, 2005; Ayyobi et. al., 2014). Organic farming would act as a catalyst in triggering interest in the organic agricultural systems even across the world. The system considers important aspects of farming such as sustainability of natural resources and the environment as a whole. The system favours maximum use of organic legumes, farms wastes, bio-pesticides and discourages the use of synthetically produced agro-inputs for maintaining soil productivity and fertility. The results of the study showed that organic fertilizers support the activities of soil microbes and therefore enhance soil health.

However, there are certain demerits in the use of organic fertilizers such as harbouring of pests and pathogens, bulkiness, which demands large storage space and high

transportation and labour cost. Also the rate of nutrient release from organic fertilizers is rather too slow and cocoa with its high nutritional requirement may not flourish well when only organic fertilizers are used in its production, nonetheless the organic system can be described as suitable and poses no long term negative effects.

6.2 Recommendations

Based on the conclusion drawn from the study, the researcher would like to recommend the combined use of organic and inorganic fertilizers as this would improve the soil health better than applying only chemical or organic fertilizer alone. With the combined use of the two fertilizer types, the soil health is assured and also, the negative impact, which would be caused by only chemical or organic fertilizer, would also be remedied.

This recommendation is also based on several other research works which corroborate the findings of this study.Tiwari et. al., (2002), suggested that combination of inorganic fertilizer with organicmanure will not only sustain crop production but also will be effective in improving soil health and enhancing the nutrient use efficiently. A study conducted by Kaur et. al.,(2005), showed that balance fertilization using both organic and chemical fertilizers is important for maintenance of soil organic matter content and long-term soil productivity in the tropics where soil organic matter content is low.

A similar research work could be conducted to investigate into the impact of the two fertilizer types on other cash crops such as cashew, coffee or citrus etc and their effects on other soil organisms such as earthworms, Arthropods and Protozoan. Further studies can also be conducted to investigate the impact of combined application of organic and inorganic fertilizers in cocoa production.

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APPENDICES

Appendix 1A: Raw Data for Mineral Elements (Topsoil)

TREATMENT	PLOT	pH	Available P	% C	% N	K^{+}	Ca^{2+}	Mg^{2+}
Organic farms	1	6.12	20.8	1.21	0.146	0.218	2.037	1.194
Organic farms	2	6.86	26.9	1.7	0.141	0.227	2.196	1.696
Organic farms	3	6.86	13.9	2.5	0.138	0.23	2.299	1.951
Organic farms	4	7.01	48.8	1.21	0.164	0.294	3.992	2.039
Organic farms	5	6.98	27.5	2.01	0.129	0.251	2.963	1.511
Inorganic farms	1	6.33	64.7	0.98	0.158	0.291	6.071	1.761
Inorganic farms	2	6.79	25.9	0.86	0.227	0.3	5.849	2.755
Inorganic farms	3	7.48	62.9	0.84	0.318	0.733	8.423	3.643
Inorganic farms	4	6.53	63.2	1.2	0.175	0.331	2.939	1.764
Inorganic farms	5	6.6	75.1	0.86	0.27	0.374	3.921	2.424
Control Plots	1	6.89	64.1	3.38	0.343	1.195	6.677	5.407
Control Plots	2	6.69	64	3.08	0.359	1.177	6.076	5.141
Control Plots	3	6.91	66.9	3.18	0.356	1.172	5.724	5.2
Control Plots	4	6.92	64.6	3.06	0.336	1.179	4.601	5.226
Control Plots	5	6.91	65.2	2.9	0.334	1.147	4.307	5.097

Appendix 1B: Raw Data for Mineral Elements (Subsoil)

TREATMENT	PLOT	pH	Available P	% C	% N	K^{+}	Ca^{2+}	Mg^{2+}
Organic farms	1	5.96	7.7	0.63	0.11	0.218	1.602	0.844
Organic farms	2	6.94	8.6	0.65	0.087	0.193	1.422	0.965
Organic farms	3	6.51	7	0.83	0.098	0.197	1.984	0.87
Organic farms	4	6.47	10.2	0.4	0.106	0.282	2.096	0.903
Organic farms	5	6.61	10.3	0.82	0.082	0.251	1.707	0.61
Inorganic farms	1	5.39	47.4	0.43	0.111	0.309	2.255	0.533
Inorganic farms	2	6.07	28.8	0.28	0.123	0.432	2.527	0.853
Inorganic farms	3	6.54	17.1	0.45	0.123	0.333	3.677	1.111
Inorganic farms	4	5.59	37.2	0.47	0.051	0.215	1.176	0.427
Inorganic farms	5	5.93	39.4	0.4	0.117	0.228	3.032	0.618
Control Plots	1	7.07	26.1	1.17	0.178	1.196	3.749	1.671
Control Plots	2	6.98	27.6	1.3	0.186	1.14	3.498	1.635
Control Plots	3	7.11	27.4	1.21	0.185	1.191	3.242	1.714
Control Plots	4	7.17	28.2	1.23	0.179	1.126	3.004	1.687
Control Plots	5	7.1	27.8	1.17	0.179	1.195	2.882	1.718

APPENDIX 2A$_1$: ANALYSIS OF VARIANCE

Variate: pH 0-15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	0.61951	0.15488	1.67	
REPS.xUnitsx stratum					
TREATMENT	2	0.03988	0.01994	0.22	0.811
Residual	8	0.74085	0.09261		
Total	14	1.40024			

Tables of means

Variate: pH

Grand mean 6.792

TREATMENT	Forest	Inorganic	Organic
	6.864	6.746	6.766

Standard errors of means

Table TREATMENT

rep. 5 d.f. 8

e.s.e. 0.1361

Standard errors of differences of means

Table TREATMENT
rep. 5 d.f. 8
s.e.d. 0.1925

Least significant differences of means (5% level)

Table TREATMENT
rep. 5 d.f. 8
l.s.d. 0.4438

APPENDIX 2A$_2$: ANALYSIS OF VARIANCE

Variate: % Carbon 0-15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	0.2355	0.0589	0.39	
REPS.xUnitsx stratum					
TREATMENT	2	12.1102	6.0551	40.57	<.001
Residual	8	1.1939	0.1492		
Total	14	13.5396			

Tables of means

Variate: %_C

Grand mean 1.931

TREATMENT	Forest	Inorganic	Organic
	3.120	1.726	0.948

Standard errors of means

Table TREATMENT

rep. 5 d.f. 8

e.s.e. 0.1728

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 0.2443

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 0.5634

APPENDIX 2A$_3$: ANALYSIS OF VARIANCE

Variate: % Nitrogen 0-15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	0.005343	0.001336	0.80	
REPS.xUnitsx stratum					
TREATMENT	2	0.102760	0.051380	30.65	<.001
Residual	8	0.013413	0.001677		
Total	14	0.121516			

Tables of means

Variate: %_N

Grand mean 0.240

TREATMENT	Forest	Inorganic	Organic

0.346 0.230 0.144

Standard errors of means

Table TREATMENT

rep. 5 d.f. 8

e.s.e. 0.0183

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 0.0259

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 0.0597

APPENDIX 2A$_4$: ANALYSIS OF VARIANCE

Variate: Available Phosphorous 0-15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	720.8	180.2	1.04	
REPS.xUnitsx stratum					
TREATMENT	2	3980.4	1990.2	11.48	0.004
Residual	8	1386.8	173.3		

Total 14 6088.0

Tables of means

Variate: Av_P

Grand mean 50.3

TREATMENT	Forest	Inorganic	Organic
	65.0	58.4	27.6

Standard errors of means

Table TREATMENT
rep. 5 d.f. 8
e.s.e. 5.89

Standard errors of differences of means

Table TREATMENT
rep. 5 d.f. 8
s.e.d. 8.33

Least significant differences of means (5% level)

Table TREATMENT
rep. 5 d.f. 8

l.s.d. 19.20

Appendix $2A_5$: Analysis of variance

Variate: Calcium (Ca^+) 0-15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	6.618	1.655	0.74	
REPS.xUnitsx stratum					
TREATMENT	2	25.421	12.711	5.65	0.030
Residual	8	17.997	2.250		
Total	14	50.036			

Tables of means

Variate: Ca

Grand mean 4.54

TREATMENT	Forest	Inorganic	Organic
	5.48	5.44	2.70

Standard errors of means

Table TREATMENT rep.

5

d.f. 8

e.s.e. 0.671

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 0.949

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 2.187

APPENDIX 2A$_6$: ANALYSIS OF VARIANCE

Variate: Potassium (K^+) 0-15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	0.04287	0.01072	0.86	
REPS.xUnitsx stratum					
TREATMENT	2	2.46868	1.23434	98.67	<.001
Residual	8	0.10008	0.01251		
Total	14	2.61164			

Tables of means

Variate: K

Grand mean 0.608

TREATMENT	Forest	Inorganic	Organic
	1.174	0.406	0.244

Standard errors of means

Table TREATMENT

rep. 5 d.f. 8

e.s.e. 0.0500

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 0.0707

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 0.1631

APPENDIX 2A$_7$: ANALYSIS OF VARIANCE

Variate: Magnessium (Mg^{2+}) 0-15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	1.1078	0.2769	1.18	
REPS.xUnitsx stratum					
TREATMENT	2	34.4387	17.2194	73.41	<.001
Residual	8	1.8765	0.2346		
Total	14	37.4230			

Tables of means

Variate: Mg

Grand mean 3.12

TREATMENT	Forest	Inorganic	Organic
	5.21	2.47	1.68

Standard errors of means

Table TREATMENT

rep. 5 d.f. 8

e.s.e. 0.217

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 0.306

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 0.706

APPENDIX 2B$_1$: ANALYSIS OF VARIANCE

Variate: pH 15-30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	0.64463	0.16116	1.93	
REPS.xUnitsx stratum					
TREATMENT	2	3.49284	1.74642	20.90	<.001
Residual	8	0.66849	0.08356		
Total	14	4.80596			

Tables of means

Variate: pH

Grand mean 6.496

TREATMENT	Forest	Inorganic	Organic
	7.086	5.904	6.498

Standard errors of means

Table TREATMENT
rep. 5 d.f. 8
e.s.e. 0.1293

Standard errors of differences of means

Table TREATMENT
rep. 5 d.f. 8
s.e.d. 0.1828

Least significant differences of means (5% level)

Table TREATMENT
rep. 5 d.f. 8
l.s.d. 0.4216

APPENDIX 2B$_2$: ANALYSIS OF VARIANCE

Variate: % Carbon 15-30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	0.03109	0.00777	0.49	
REPS.xUnitsx stratum					
TREATMENT	2	1.71033	0.85517	54.35	<.001
Residual	8	0.12587	0.01573		
Total	14	1.86729			

Tables of means

Variate: %_C

Grand mean 0.763

TREATMENT	Forest	Inorganic	Organic
	1.216	0.666	0.406

Standard errors of means

Table TREATMENT

rep. 5 d.f. 8

e.s.e. 0.0561

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 0.0793

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 0.1829

Appendix 2B3: Analysis of variance

Variate: % Nitrogen 15-30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	0.0010627	0.0002657	0.64	
REPS.xUnitsx stratum					
TREATMENT	2	0.0218309	0.0109155	26.35	<.001
Residual	8	0.0033137	0.0004142		
Total	14	0.0262073			

Tables of means

Variate: %_N

Grand mean 0.1277

TREATMENT	Forest	Inorganic	Organic
	0.1814	0.1050	0.0966

Standard errors of means

Table TREATMENT

rep. 5 d.f. 8

e.s.e. 0.00910

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 0.01287

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 0.02968

Appendix 2B4: Analysis of variance

Variate: Available_Phosphorous 15-30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	193.39	48.35	1.11	
REPS.xUnitsx stratum					
TREATMENT	2	1712.13	856.06	19.60	<.001
Residual	8	349.44	43.68		
Total	14	2254.96			

Tables of means

Variate: Av_P

Grand mean 23.4

TREATMENT	Forest	Inorganic	Organic
	27.4	34.0	8.8

Standard errors of means

Table TREATMENT

rep. 5 d.f. 8

e.s.e. 2.96

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 4.18

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 9.64

Appendix $2B_5$: Analysis of variance

Variate: Calcium (Ca) 15-30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	1.1568	0.2892	0.74	
REPS.xUnitsx stratum					
TREATMENT	2	5.7221	2.8611	7.32	0.016
Residual	8	3.1282	0.3910		
Total	14	10.0071			

Tables of means

Variate: Ca

Grand mean 2.52

TREATMENT	Forest	Inorganic	Organic
	3.28	2.53	1.76

Standard errors of means

Table TREATMENT

rep. 5 d.f. 8

e.s.e. 0.280

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 0.395

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 0.912

Appendix $2B_6$: Analysis of variance

Variate: Potassium (K) 15-30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	0.003931	0.000983	0.21	
REPS.xUnitsx stratum					
TREATMENT	2	2.736986	1.368493	293.34	<.001
Residual	8	0.037322	0.004665		

Total 14 2.778239

Tables of means

Variate: K

Grand mean 0.567

TREATMENT	Forest	Inorganic	Organic
	1.170	0.303	0.228

Standard errors of means

Table TREATMENT

rep. 5 d.f. 8

e.s.e. 0.0305

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 0.0432

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 0.0996

Appendix $2B_7$: Analysis of variance

Variate: Magnessium (Mg) 15-30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REPS stratum	4	0.14170	0.03542	1.19	
REPS.xUnitsx stratum					
TREATMENT	2	2.81230	1.40615	47.37	<.001
Residual	8	0.23745	0.02968		
Total	14	3.19144			

Tables of means

Variate: Mg
Grand mean 1.077

TREATMENT	Forest	Inorganic	Organic
	1.685	0.708	0.838

Standard errors of means

Table TREATMENT
rep. 5 d.f. 8
e.s.e. 0.0770

Standard errors of differences of means

Table TREATMENT

rep. 5 d.f. 8

s.e.d. 0.1090

Least significant differences of means (5% level)

Table TREATMENT

rep. 5 d.f. 8

l.s.d. 0.2513

Appendix 3A: Raw Data of the Number of Bacteria per 100ml of Soil (Topsoil)

Treatment	Staphylococcus	Pseudomonas	Eschenchia coli	Total Coliform	Faecal Coliform
Organic F1	$1.8x10^{5}$	$3.3x10^{5}$	$7.1x10^{4}$	$2.4x10^{10}$	$2.3x10^{5}$
Organic F2	$1.5x10^{5}$	$3.7x10^{5}$	$5.9x10^{4}$	$2.4x10^{10}$	$3.3x10^{5}$
Organic F3	$1.7x10^{5}$	$1.0x10^{5}$	$1.3x10^{5}$	$9.2x10^{9}$	$2.3x10^{5}$
Organic F4	$1.2x10^{5}$	$3.9x10^{5}$	$1.9x10^{5}$	$4.2x10^{9}$	$2.6x10^{5}$
Organic F5	$2.2x10^{5}$	$2.0x10^{5}$	$3.8x10^{4}$	$7.3x10^{9}$	$9.0x10^{4}$
Inorganic F1	$1.2x10^{4}$	$2.1x10^{4}$	$2.3x10^{4}$	$4.3x10^{8}$	$2.3x10^{4}$
Inorganic F2	$1.1x10^{5}$	$4.3x10^{4}$	$2.7x10^{4}$	$2.4x10^{8}$	$4.0x10^{4}$
Inorganic F3	$3.4x10^{4}$	$3.7x10^{4}$	$1.1x10^{4}$	$2.1x10^{8}$	$4.0x10^{4}$
Inorganic F4	$2.6x10^{4}$	$1.5x10^{4}$	$1.9x10^{4}$	$2.4x10^{8}$	$5.0x10^{4}$
Inorganic F5	$1.7x10^{4}$	$2.3x10^{4}$	$9.5x10^{3}$	$4.3x10^{8}$	$1.0x10^{5}$
Control P1	$1.1x10^{5}$	$5.2x10^{5}$	$2.2x10^{5}$	$9.2x10^{9}$	$2.3x10^{5}$

Control P2	$1.2x10^{5}$	$2.1x10^{5}$	$5.7x10^{4}$	$9.2x10^{9}$	$4.3x10^{5}$
Control P3	$1.2x10^{5}$	$2.2x10^{5}$	$1.9x10^{5}$	$9.1x10^{9}$	$4.3x10^{5}$
Control P4	$2.5x10^{5}$	$2.2x10^{5}$	$1.7x10^{5}$	$1.3x10^{10}$	$3.8x10^{5}$
Control P5	$1.3x10^{5}$	$1.4x10^{5}$	$1.7x10^{5}$	$1.2x10^{10}$	$2.5x10^{5}$

Appendix 3B: Raw Data of the Number of Bacteria per 100ml of Soil (Subsoil)

Treatment	**Staphylococcus**	**Pseudomonas**	**Eschenchia coli**	**Total Coliform**	**Faecal Coliform**
Organic F1	$9.9x10^{4}$	$9.5x10^{3}$	$4.9x10^{4}$	$4.2x10^{9}$	$4.0x10^{4}$
Organic F2	$8.3x10^{4}$	$3.3x10^{4}$	$1.9x10^{4}$	$2.1x10^{9}$	$3.1x10^{4}$
Organic F3	$1.1x10^{5}$	$4.5x10^{4}$	$3.4x10^{4}$	$2.3x10^{9}$	$3.3x10^{4}$
Organic F4	$6.7x10^{4}$	$5.5x10^{4}$	$4.3x10^{4}$	$1.5x10^{9}$	$2.6x10^{4}$
Organic F5	$5.8x10^{4}$	$2.7x10^{4}$	$1.4x10^{4}$	$3.4x10^{9}$	$2.5x10^{4}$
Inorganic F1	$1.0x10^{4}$	-	$3.2x10^{3}$	$1.1x10^{9}$	-
Inorganic F2	-	-	$8.3x10^{3}$	$8.2x10^{8}$	-
Inorganic F3	-	-	$5.8x10^{3}$	$4.3x10^{8}$	-
Inorganic F4	$4.8x10^{3}$	-	$4.5x10^{3}$	$4.3x10^{8}$	-
Inorganic F5	$4.5x10^{3}$	-	$4.9x10^{3}$	$3.7x10^{8}$	-
Control P1	$9.9x10^{4}$	$1.5x10^{4}$	$5.8x10^{4}$	$4.4x10^{9}$	$9.0x10^{4}$
Control P2	$9.5x10^{4}$	$1.5x10^{4}$	$5.8x10^{4}$	$4.1x10^{9}$	$9.2x10^{4}$
Control P3	$8.7x10^{4}$	$2.3x10^{4}$	$6.1x10^{4}$	$5.4x10^{9}$	$8.7x10^{4}$
Control P4	$8.0x10^{4}$	$2.0x10^{4}$	$7.9x10^{3}$	$5.6x10^{9}$	$8.5x10^{4}$
Control P5	$9.3x10^{4}$	$1.5x10^{4}$	$1.2x10^{4}$	$5.8x10^{9}$	$8.2x10^{4}$

Appendix 4A: RAW DATA FOR SOIL MYCOFLORA (TOPSOIL)

	Fusarium sp.	Trichoderma sp.	Aspergillus flavus	Aspergillus niger	Colletotrichum sp	Penicillum sp
Treatment	No. of Colonies	No. of Colonies	No. of Colonies	No. of Colonies	No. of Colonies	No. of Colonies
Organic farm 1	2	2	4	4	2	4
Organic farm 2	6	4	2	6	1	5
Organic farm 3	5	4	4	3	3	3
Organic farm 4	4	3	1	4	2	2
Organic farm 5	2	4	3	3	3	4
Mean	4.2	3.4	2.8	4.0	2.2	3.6
Inorganic farm 1	-	-	1	3	-	-
Inorganic farm 2	1	1	1	2	-	1
Inorganic farm 3	1	2	1	2	-	2
Inorganic farm 4	2	1	-	-	1	1
Inorganic farm 5	1	-	1	1	-	1
Mean	1.0	0.8	0.8	1.6	0.2	1.0
Control plot 1	6	5	6	6	3	9
Control plot 2	4	4	5	7	3	5
Control plot 3	6	5	6	7	4	8
Control plot4	5	6	4	6	2	7

Control plot5	5	5	4	5	4	7
Mean	5.2	5.0	5.0	6.2	3.2	7.2

Appendix 4B: RAW DATA FOR SOIL MYCOFLORA (SUBSOIL)

	Fusarium sp.	Trichoderma sp.	Aspergillus flavus	Aspergillus niger	Colletotrichum sp	Penicillum sp
Treatment	No. of Colonies	No. of Colonies	No. of Colonies	No. of Colonies	No. of Colonies	No. of Colonies
Organic farm 1	-	1	1	1	1	2
Organic farm 2	1	1	1	-	1	-
Organic farm 3	2	-	2	1	1	1
Organic farm 4	1	1	-	-	1	1
Organic farm 5	1	1	1	1	1	1
Mean	1.0	0.8	1.0	0.6	1	1
Inorganic farm 1	-	-	-	1	-	-
Inorganic farm 2	-	-	1	-	-	-
Inorganic farm 3	-	-	-	1	-	1
Inorganic farm 4	1	-	1	-	-	-
Inorganic farm 5	-	-	-	-	-	-
Mean	0.2	0.0	0.4	0.6	0.0	0.2
Control plot 1	2	2	2	3	1	3
Control plot2	-	1	3	2	-	2

Control plot3	2	1	1	2	1	2
Control plot4	3	2	2	-	1	3
Control plot5	2	2	1	3	1	3
Mean	1.8	1.6	1.8	2.0	0.8	2.6

APPENDIX 5A: RAW DATA OF BIOMASS OF NEMATODES (TOPSOIL)

Treatment	Root-knot Nematode	Pratylenchus	Helicotylenchus	Monochus	Free-living
Organic farm 1	150	100	-	-	-
Organic farm 2	-	-	100	50	-
Organic farm 3	150	200	-	-	250
Organic farm 4	250	150	250	100	400
Organic farm 5	200	100	-	50	250
Mean	150	110	70	40	180
Inorganic farm 1	50	-	100	-	200
Inorganic farm 2	50	-	50	-	100
Inorganic farm 3	-	-	-	-	-
Inorganic farm 4	-	-	-	-	50
Inorganic farm5	-	-	-	50	50
Mean	20	0	30	10	80
Control plot 1	650	300	200	100	400

Control plot 2	550	100	250	100	500
Control plot 3	-	250	250	150	200
Control plot 4	600	350	100	-	500
Control plot 5	450	100	-	100	-
Mean	450	220	160	90	320

APPENDIX 5B: RAW DATA OF BIOMASS OF NEMATODES (SUBSOIL)

Treatment	Root-knot Nematode	Pratylenchus	Helicotylenchus	Monochus	Free-living
Organic farm 1	100	100	-	50	-
Organic farm 2	-	-	100	-	-
Organic farm 3	-	-	-	50	150
Organic farm 4	200	-	100	-	100
Organic farm 5	200	-	50	-	100
Mean	100	20	50	20	70
Inorganic farm 1	50	-	-	-	50
Inorganic farm 2	-	-	-	-	-
Inorganic farm 3	-	50	-	-	-
Inorganic farm 4	-	-	-	-	50
Inorganic farm 5	-	-	-	-	-

Mean	10	10	0	0	20
Control plot 1	200	-	50	-	200
Control plot 2	-	100	100	50	100
Control plot 3	100	-	100	-	-
Control plot 4	100	50	50	-	100
Control plot 5	150	50	50	50	-
Mean	110	40	70	20	80

APPENDIX 6

SOIL NUTRIENT (MINERAL) GRADING SYSTEM

Nutrient	Rank/Grade
Soil pH (Distilled H_2O method)	
< 5.0	Very acidic
5.0 – 5.5	Acidic
5.6 – 6.0	Moderately acidic
6.1 – 6.5	Slightly acidic
6.6 – 7.0	Neutral
7.1 – 7.5	Slightly alkaline
7.6 – 8.5	Alkaline
> 8.5	Very alkaline
Organic Matter (%)	
< 1.5	Low
1.6 – 3.0	Moderate
> 3.0	High
Nitrogen	
< 0.1	Low
0.1 – 0.2	Moderate
> 0.2	High
Phosphorus P(ppm) – Bray‟s No. 1	
< 10	Low
10 – 20	Moderate
> 20	High
Potassium, K. (ppm)	
< 50	Low
50 – 100	Moderate
> 100	High
Nutrient	Rank/Grade

Calcium Ca(cmol(+) kg $^{-1-}$)/Mg = 0.2Ca

< 5	Low
5 – 10	Moderate
> 10	High

Exchangeable Potassium (cmol(+) kg $^{-1}$)

< 0.2	Low
0.2 – 0.4	Moderate
> 0.4	High

ECEC (cmol(+) kg $^{-1}$)

< 10	Low
10 – 20	Moderate
> 20	High

Source: Council of Sceintific and Industrial Research (CSIR) APPENDIX 7A: ANALYSIS OF VARIANCE FOR SOIL BACTERIA (TOPSOIL)

VARIATE: Staphylococcus

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	4.700E+10	2	2.350E+10	7.97	0.01
Plot	2.071E+09	4	5.177E+08	0.18	0.94
Error	2.357E+10	8	2.947E+09		
Total	7.264E+10	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound

Organic	1.68E+05	2.43E+04	1.12E+05	2.24E+05
Inorganic	3.98E+04	2.43E+04	-1.62E+04	9.58E+04
Control	1.46E+05	2.43E+04	9.00E+04	2.02E+05

VARIATE: Pseudomonas

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	1.96E+11	2	9.81E+10	8.90	0.01
Plot	6.15E+10	4	1.54E+10	1.40	0.32
Error	8.82E+10	8	1.10E+10		
Total	3.46E+11	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	2.78E+05	4.69E+04	1.70E+05	3.86E+05
Inorganic	2.78E+04	4.69E+04	-8.05E+04	1.36E+05
Control	2.62E+05	4.69E+04	1.54E+05	3.70E+05

VARIATE: Eschenchia coli

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	5.17E+10	2	2.58E+10	11.00	0.01
Plot	1.21E+10	4	3.02E+09	1.28	0.35
Error	1.88E+10	8	2.35E+09		
Total	8.26E+10	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	9.76E+04	2.17E+04	4.76E+04	1.48E+05
Inorganic	1.79E+04	2.17E+04	-3.21E+04	6.79E+04
Control	1.61E+05	2.17E+04	1.11E+05	2.11E+05

VARIATE: Total Coliform

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	4.91E+20	2	2.46E+20	6.85	0.02
Plot	9.06E+19	4	2.26E+19	0.63	0.65
Error	2.87E+20	8	3.59E+19		
Total	8.69E+20	14			

Table of Means

Treatment	**Mean**	**Std. Error**	**95% Confidence Interval**	
			Lower Bound	**Upper Bound**
Organic	1.37E+10	2.68E+09	7.56E+09	1.99E+10
Inorganic	3.10E+08	2.68E+09	-5.87E+09	6.49E+09
Control	1.05E+10	2.68E+09	4.32E+09	1.67E+10

VARIANCE: Faecal Coliform

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	2.18E+11	2	1.09E+11	21.72	0.00
Plot	3.16E+10	4	7.90E+09	1.57	0.27
Error	4.02E+10	8	5.03E+09		
Total	2.90E+11	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	2.28E+05	3.17E+04	1.55E+05	3.01E+05
Inorganic	5.06E+04	3.17E+04	-2.25E+04	1.24E+05
Control	3.44E+05	3.17E+04	2.71E+05	4.17E+05

APPENDIX 7B: ANALYSIS OF VARIANCE FOR SOIL BACTERIA (SUBSOIL)

VARIATE: Staphylococcus

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	2.323E+10	2	11616612667	69.514	0.000
Plot	8.179E+08	4	204472666.7	1.224	0.373
Error	1.337E+09	8	167112666.7		
Total	2.539E+10	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	83400.000	5781.222	70068.477	96731.523
Inorganic	3860.000	5781.222	-9471.523	17191.523
Control	90800.000	5781.222	77468.477	104131.523

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Organic	Inorganic	79540.00	8175.883	.000	60686.38	98393.62
	Control	-7400.00	8175.883	.392	-26253.62	11453.62
Inorganic	Organic	-79540.00	8175.883	.000	-98393.62	-60686.38
	Control	-86940.00	8175.883	.000	-105793.62	-68086.38
Control	Organic	7400.00	8175.883	.392	-11453.62	26253.62
	Inorganic	86940.00	8175.883	.000	68086.38	105793.62

Multiple Comparisons

VARIATE: Pseudomonas

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	2874433333.333	2	1437216666.667	16.072	.002
Plot	552000000.000	4	138000000.000	1.543	.278
Error	715400000.000	8	89425000.000		
Total	4141833333.333	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	33900.000	4229.066	24147.756	43652.244
Inorganic	6.366E-012	4229.066	-9752.244	9752.244
Control	17600.000	4229.066	7847.756	27352.244

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Organic	Inorganic	33900.00	5980.803	.000	20108.24	47691.76
	Control	16300.00	5980.803	.026	2508.24	30091.76
Inorganic	Organic	-33900.00	5980.803	.000	-47691.76	-20108.24
	Control	-17600.00	5980.803	.019	-31391.76	-3808.24
Control	Organic	-16300.00	5980.803	.026	-30091.76	-2508.24
	Inorganic	17600.00	5980.803	.019	3808.24	31391.76

Multiple Comparisons

VARIATE: Escherichia coli

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	2142841333.333	2	1071420666.667	4.176	.057
Plot	2310569333.333	4	577642333.333	2.252	.153
Error	2052458666.667	8	256557333.333		
Total	6505869333.333	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	31800.000	7163.202	15281.626	48318.374
Inorganic	11100.000	7163.202	-5418.374	27618.374
Control	39380.000	7163.202	22861.626	55898.374

Multiple Comparisons

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Organic	Inorganic	20700.00	10130.298	.075	-2660.51	44060.51
	Control	-7580.00	10130.298	.476	-30940.51	15780.51
Inorganic	Organic	-20700.00	10130.298	.075	-44060.51	2660.51
	Control	-28280.00	10130.298	.023	-51640.51	-4919.49
Control	Organic	7580.00	10130.298	.476	-15780.51	30940.51
	Inorganic	28280.00	10130.298	.023	4919.49	51640.51

VARIATE: Total Coliform
ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	4.913×10^{19}	2	2.457×10^{19}	35.826	.000
Plot	1.931×10^{18}	4	4.827×10^{17}	.704	.611
Error	5.486×10^{18}	8	6.857×10^{17}		
Total	5.655×10^{19}	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	2.7×10^9	3.703E+08	1.846E+09	3.554E+09
Inorganic	6.3×10^8	3.703E+08	-2.240E+08	1.484E+09
Control	5.06×10^9	3.703E+08	4.206E+09	5.914E+09

VARIATE: FaecalColiform

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	2.051E+10	2	1.025E+10	622.087	0.000
Plot	1.529E+08	4	3.823E+07	2.320	0.145
Error	1.319E+08	8	1.648E+07		
Total	2.079E+10	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	31000.000	1815.673	26813.052	35186.948
Inorganic	-9.322E-12	1815.673	-4186.948	4186.948
Control	89200.000	1815.673	85013.052	93386.948

APPENDIX 8A: ANALYSIS OF VARIANCE FOR SOIL MYCOFLORA (TOPSOIL)

Variate :Fusarium

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	45.733	2	22.867	14.144	.002
Plot	4.667	4	1.167	.722	.601
Error	12.933	8	1.617		
Total	63.333	14			

Table of Means

Fertilizer	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	3.800	.569	2.489	5.111
Inorganic	1.000	.569	-.311	2.311
Control	5.200	.569	3.889	6.511

VARIATE: Trichoderma

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
treatment	44.933	2	22.467	35.474	.000
plot	2.933	4	.733	1.158	.397
Error	5.067	8	.633		
Total	52.933	14			

Fertilizer	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	3.400	.356	2.579	4.221
Inorganic	.800	.356	-.021	1.621
Control	5.000	.356	4.179	5.821

VARIATE: Aspergillusflavus

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
treatment	44.133	2	22.067	55.167	.000
plot	8.400	4	2.100	5.250	.023
Error	3.200	8	.400		
Corrected Total	55.733	14			

Table of Means

Fertilizer	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	2.800	.283	2.148	3.452
Inorganic	.800	.283	.148	1.452
Control	5.000	.283	4.348	5.652

VARIATE: Aspergillus niger

Table of Means

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
treatment	52.933	2	26.467	33.083	.000
plot	7.600	4	1.900	2.375	.139
Error	6.400	8	.800		
Corrected Total	66.933	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	4.000	.400	3.078	4.922
Inorganic	1.600	.400	.678	2.522
Control	6.200	.400	5.278	7.122

VARIATE: Colletotrichumsp

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	23.333	2	11.667	23.333	.000
Plot	2.400	4	.600	1.200	.381
Error	4.000	8	.500		
Total	29.733	14			

treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	2.200	.316	1.471	2.929
Inorganic	.200	.316	-.529	.929
Control	3.200	.316	2.471	3.929

VARIATE: Penicillumsp

ANOVA TABLE

Source	Sum of Squares	df	Mean Square	F	Sig.
treatment	96.933	2	48.467	28.233	.000
plot	2.267	4	.567	.330	.850
Error	13.733	8	1.717		
Total	112.933	14			

Table of Means

treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	3.600	.586	2.249	4.951
Inorganic	1.000	.586	-.351	2.351

Table of Means

Control	7.200	.586	5.849	8.551

APPENDIX 8B: ANALYSIS OF VARIANCE FOR SOIL MYCOFLORA (SUBSOIL)

VARIATE: Fusarium

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
treatment	6.400	2	3.200	6.000	.026
plot	3.333	4	.833	1.562	.274
Error	4.267	8	.533		
Corrected Total	14.000	14			

Table of Means

			95% Confidence Interval	
Fertilizer	Mean	Std. Error	Lower Bound	Upper Bound
Organic	1.000	.327	.247	1.753
Inorganic	.200	.327	-.553	.953
Control	1.800	.327	1.047	2.553

VARIATE: Trichoderma

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
treatment	6.400	2	3.200	27.429	.000

plot	1.067	4	.267	2.286	.149
Error	.933	8	.117		
Corrected Total	8.400	14			

treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	.800	.153	.448	1.152
Inorganic	-3.454E-17	.153	-.352	.352
Control	1.600	.153	1.248	1.952

VARIATE: Aspergillusflavus

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	4.933	2	2.467	4.485	.049
plot	1.600	4	.400	.727	.598
Error	4.400	8	.550		
Total	10.933	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound

Table of Means

Organic	1.000	.332	.235	1.765
Inorganic	.400	.332	-.365	1.165
Control	1.800	.332	1.035	2.565

VARIATE: Aspergillusniger

ANOVA tABLE

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	7.600	2	3.800	9.913	.007
Plot	5.333	4	1.333	3.478	.063
Error	3.067	8	.383		
Total	16.000	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	.600	.277	-.039	1.239
Inorganic	.400	.277	-.239	1.039
Control	2.000	.277	1.361	2.639

VARIATE: Colletotrichum sp

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	2.800	2	1.400	21.000	.001

Plot	.267	4	.067	1.000	.461
Error	.533	8	.067		
Total	3.600	14			

treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	1.000	.115	.734	1.266
Inorganic	1.605E-16	.115	-.266	.266
Control	.800	.115	.534	1.066

VARIATE: Penicillumsp

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
treatment	14.933	2	7.467	24.889	.000
plot	1.600	4	.400	1.333	.337
Error	2.400	8	.300		
Total	43.000	15			
Total	18.933	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval

Table of Means

			Lower Bound	Upper Bound
Organic	1.000	.245	.435	1.565
Inorganic	.200	.245	-.365	.765
Control	2.600	.245	2.035	3.165

APPENDIX 9: ANALYSIS OF VARIANCE FOR SOIL NEMATODES

VARIATE:Root-knot Nematode

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	486333.333	2	243166.667	9.552	.008
Plot	109333.333	4	27333.333	1.074	.430
Error	203666.667	8	25458.333		
Total	799333.333	14			

Table of Means

			95% Confidence Interval	
Fertilizer	Mean	Std. Error	Lower Bound	Upper Bound
1	150.000	71.356	-14.547	314.547
2	20.000	71.356	-144.547	184.547
3	450.000	71.356	285.453	614.547

Multiple Comparisons

(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Organic	Inorganic	130.00	100.913	.234	-102.70	362.70
	Control	-300.00	100.913	.018	-532.70	-67.30
Inorganic	Organic	-130.00	100.913	.234	-362.70	102.70
	Control	-430.00	100.913	.003	-662.70	-197.30
Control	Organic	300.00	100.913	.018	67.30	532.70
	Inorganic	430.00	100.913	.003	197.30	662.70

VARIATE: Pratylenchus

ANOVA Table

Source	Sum of Squares	df	Mean Square	F	Sig.
Treatment	121000.000	2	60500.000	13.570	.003
Plot	39333.333	4	9833.333	2.206	.158
Error	35666.667	8	4458.333		
Total	196000.000	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	110.000	29.861	41.141	178.859
Inorganic	1.235E-14	29.861	-68.859	68.859
Control	220.000	29.861	151.141	288.859

VARIATE: Helicotylenchus

ANOVA table

Source	Sum of Squares	df	Mean Square	F	Sig.
treatment	44333.33	2	22166.67	2.51	0.14
plot	32333.33	4	8083.33	0.92	0.50
Error	70666.67	8	8833.33		

Total	147333.33	14			

Table of Means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	70.000	42.032	-26.925	166.925
Inorganic	30.000	42.032	-66.925	126.925
Control	160.000	42.032	63.075	256.925

VARIATE: Monochus

ANOVA Table

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
treatment	16333.333	2	8166.667	3.500	.081
plot	2333.333	4	583.333	.250	.902
Error	18666.667	8	2333.333		
Total	37333.333	14			

Table of means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	40.000	21.602	-9.815	89.815
Inorganic	10.000	21.602	-39.815	59.815
Control	90.000	21.602	40.185	139.815

VARIATE: Free-living

ANOVA Table

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
treatment	145333.333	2	72666.667	2.268	.166
plot	77666.667	4	19416.667	.606	.670
Error	256333.333	8	32041.667		
Corrected Total	479333.333	14			

Table of means

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Organic	180.000	80.052	-4.600	364.600
Inorganic	80.000	80.052	-104.600	264.600
Control	320.000	80.052	135.400	504.600