EFFECT OF ORGANIC AND INORGANIC FERTILIZERS ON SOIL PROPERTIES, STRIGA DENSITY AND MAIZE YIELD IN VIHIGA AND SIAYA COUNTIES, KENYA

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF SCIENCE IN SUSTAINABLE SOIL RESOURCE MANAGEMENT

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TECHNOLOGY, FACULTY OF AGRICULTURE,
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DECLARATION

I certify that this is my original work and has not been presented for award of a degree in any other University.

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DEDICATION

I dedicate this work to my dear husband, Moses Limuwa, my parents, Tancy and Winston Kamanga, my brothers, Mbuka and Blessings Kamanga and my sisters, Thokozile Shamuyarira and Wezi Blunt. Thank you all for your unconditional support throughout the duration of my masters programme. God bless you.

ACKNOWLEDGEMENTS

First I bow in grateful thanksgiving to Him whose name is above all names, our Lord Jesus Christ, for without Him, I would not have completed this piece of work, which is in fact a testimony of His faithfulness.

I wish to thank my supervisors, Dr. Richard Onwonga, University of Nairobi (UoN), for continuously keeping me on track, and helping me learn by putting into practice the knowledge and skills acquired during my education so that I could produce this valuable piece of work for others; Prof Shellemiah Keya, UoN, for his constructive criticism and intellectual advise, and Dr. Bernard Vanlauwe of the International Institute of Tropical Agriculture (IITA) for his commitment to seeing me through the whole period of this work and particularly for his efforts to get me attached to the Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT). I would also like to thank Dr Fredrick Baijukya of TSBF-CIAT for making resources available on time during my field research. Dr Samuel Guto is highly appreciated for linking me to Dr. Bernard Vanlauwe (of then) TSBF-CIAT without whom the research would not have been possible. I am also grateful to Professor Johan Six, University of California Davis (UCD) for his invaluable support in the physical soil analysis and imparting his knowledge and skills on the same to me.

Laboratory technical staff; Laban Nyambega, Evonne, Wilson Ngului, Nelson and Oba (TSBF-CIAT), Peninah, Kimotho (UoN), Elvis Weullow (World Agroforestry Centre), Josephine (Crop Nutrition) and Julian Herszage (UCD) for their technical and analytical support.

I am also greatly indebted to the Alliance for a Green Revolution in Africa (AGRA) for financially supporting my studies at UoN, TSBF-CIAT for providing additional field research funding, IITA for providing workspace and the Norman Borlaug Leadership Enhancement in Agricultural Program (LEAP) fellowship through the University of California Davis for providing further financial assistance towards completion of the field research.

To my parents, Winston and Tancy Kamanga, I thank them for constantly inspiring me to do more and to do it better. To my loving husband, Moses Limuwa, his overall support,

encouragement and sacrifice have been amazing. I thank him for continuously pushing me on when I wanted to give in and allowing me to visualize the land whilst I rode through the storm. Lastly I would like to thank my sister from another mother; Mtisunge Mngoli for being there for me through the highs and lows and to my friends; Lister Chapeta, Paulina Cebula, Yazan Elhadi, Beverly Liavoga and Maggie Munthali, who made this place bearable through nights of “30seconds” and “I have never”.

There are many more that l may have not mentioned by name or institutional affiliation, to all of you, your deserved contribution is highly acknowledged.

And to God be the Glory

GENERAL ABSTRACT

Continual soil fertility depletion and the increased infestation of weeds such as striga in small-holder farming systems are two of the main processes amplifying reduction in food production across Sub-Saharan Africa (SSA). These conditions are aggregated even further by the existence of soil fertility gradients in small-holder farmer fields resulting in varying crop yields in a single farm. Against this backdrop, this study aimed to assess the effects of fertilizer application on soil properties, striga density, and maize yield in small-holder farmer fields with existing soil fertility gradients. The study was conducted in Emusutswi in Vihiga County, and Nyabeda and Nyalgunga in Siaya County. Twelve farmers; four from each site were selected using Y frame sampling and their fields demarcated into low and high fertility status based on a previous study conducted by Tittonel et al 2005. The experiment was set in a completely randomized block design in a split plot arrangement. The fertility gradients were the main plots and the treatments; IR Maize (control), IR Maize+Manure and IR maize +Mavuno+ Manure were the sub-plots. The farmer fields were the replicates. The means of the four farmer fields explained the response of test crop (IR Maize) to applied treatments. The study was conducted during the short rains season. Soil was collected from all the treatments for the analysis of chemical properties- pH, cation exchange capacity (CEC), mineral nitrogen, total N, organic carbon, phosphorus, exchangeable bases (K, Ca and Mg), and biological properties - soil respiration and physical properties – soil fractionation. Striga weed was sampled at week 6, 8, 10 and 12 for striga emergence. Maize yield was determined at crop maturity by sampling from an area of $7.08m^2$. Results indicated that there were significant differences in P levels across treatment means, ($P<0.01$) and the mavuno+ manure treatment had the highest mean P levels (11.78%) showing superiority over the control and the manure only treatment. Organic Carbon showed significant differences across treatments and sites ($P<0.01$). Total N and pH showed significant differences across sites. Mineral N showed significant differences across treatments. Exchangeable bases potassium (K) and calcium (Ca) showed significant differences across treatments whilst Mg showed significant differences across sites. There were significant differences observed in CEC across treatments. There were however no significant differences in the measured soil chemical properties across fertility gradients. Soil respiration showed significant differences across fertility gradients but not across treatments and sites after 7 and 14 days of incubation. Elemental combustion showed significant differences in %C and %N in the fractions with the highest % C

(2.052) and % N (0.1816) found in the silt and clay fraction across treatments. Significant differences were further observed in the carbon fractions distributions across treatments and fertility gradients ($P<0.01$). Significant differences in striga density across treatments ($P<0.01$) were observed with the control (54,389 plants/ha) having the highest. There were no significant differences in striga density across sites and fertility gradients. Maize yields showed significant differences across sites and treatment means with the highest yield observed in Nyalgunga (mean =4330kg/ha) but no significant differences were observed across fertility gradients. Lack of significant differences in the measured parameters across fertility gradients may necessitate further investigation on the farmer perceived fertility status of their farms. Combined application of FYM and mavuno and the use of IR maize could enhance soil properties, reduce striga occurrence and increase maize yields.

ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CIMMYT	International Maize and Wheat Improvement Center
EC	Electrical Conductivity
FYM	Farm Yard Manure
ISFM	Integrated Soil Fertility Management
IR	Imazapyr Resistant
K	Potassium
KARI	Kenya Agricultural Research Institute
LSD	Least Significant Difference
N	Nitrogen
P	Phosphorus
pH	Potential Hydrogen
RCBD	Randomized Complete Block Design
SOC	Soil Organic Carbon
SSA	Sub-Saharan Africa;
TSBF - CIAT	Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture.
WSA	Water Stable Aggregates

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CHAPTER ONE: GENERAL INTRODUCTION

1.0 Background

Food production in Sub Saharan Africa (SSA) is moving at a far much slower pace than population growth, leading to continued declines in its already low food production per capita. The regions' agriculture is still heavily dependent on the natural soil fertility, terrain, climate and water availability (Breman & Debrah, 2003). Constraints, including diminishing land sizes and decline in inherent soil fertility have not only resulted in negative nutrient balances in most small-holder farming systems but also an increase in the infestation of invasive weeds like *Striga hermonthica* (Vanlauwe *et al.*, 2005). *Striga hermonthica* commonly known as the "witch weed" is a weed parasite that subsists on maize and other cereal grain plants, causing huge farm losses; and soil fertility depletion increases the occurrence of this weed; thus affecting crop yields (Gethi *et al.*, 2005). Western Kenya is one of the regions with high striga infestation. The striga problem in the area is made worse by its high adaptation to the climatic conditions of the region, its high fecundity, and longevity of its seed reserves in tropical soils (Ejeta & Gressel, 2005). Thus the growing conditions in western Kenya permit timely breaking of seed dormancy and conditioning of Striga seeds (Kanampiu *et al.,* 2001).

Various striga-coping mechanisms have been researched in Africa for over 50 years and most have proven to be foolproof, but the introduction of the imazapyr-coated herbicide-resistant maize (IR-maize) in recent years seems promising (Kanampiu *et al.,* 2001). The IR maize seed kills Striga before it damages the crop. For the IR maize seed to be most effective in improving crop yields and reducing striga weed, administering an integrated approach is recommended (Gethi *et al.,* 2005). The integrated approach includes the combination of high yielding varieties like IR maize with inorganic fertilizers so as to meet the increasing demand for food in Africa. This approach has however resulted in a greater use of chemical fertilizers (Gethi *et al.,* 2005) with resultant replacement of traditional practices such as recycling organic materials, and in many areas of SSA, application of organic resources has been abandoned (Sanginga & Woomer, 2009). Use of improved germplasm is another coping strategy but this method is costly to small-holder farmers hence most do not adopt it. Handpicking is another strategy farmers can use but it is laborious and time intensive. An integrated approach of organic and inorganic fertilizers plus use of high yielding varieties can therefore be an alternative.

The rapid depletion of soil nutrients such as N and P result in a complex pattern of soil fertility gradients[1] (Tittonell, 2007; Tittonell *et al.*, 2007). The existence of soil fertility gradients further exacerbates the variation in maize yields across individual farms. This results in the farm exhibiting both low and high fertility fields and thus farmers' fields under study were demarcated accordingly. The preferential application of resources also has an effect on soil carbon fractions as organic matter additions in the form of manure (either alone or in combination with chemical fertilizers), is more effective in maintaining and restoring organic matter in soils (Wu *et al.*, 2004). It was hypothesized in the current study that combined application of inorganic and organic fertilizers will enhance soil fertility, reduce striga density and increase maize yields.

1.1 Statement of the Problem

Diminishing land sizes and decline in inherent soil fertility in western Kenya have not only resulted in negative nutrient balances in most small-holder farming systems but also an increase in noxious weeds such as *Striga hermonthica* (Vanlauwe *et al.*, 2005). The non-use or use of sub-optimal levels of fertilizers, particularly P further accelerates the rate of soil fertility decline. This provides ideal conditions for Striga weed proliferation. Preferential application of fertilizers on the other hand has also led to development of fertility gradients on smallholder farms (Tittonell, 2003) and yet farmers continue to apply blanket fertilizer recommendations leading to variations in crop yields within a single farm (Tittonell *et al.*, 2006).

Further, there is scanty information on the effect of continued application of inorganic fertilizers on the soil chemical, biological and physical properties (Negassa *et al.*, 2005). Soil properties are bound to change, positively or negatively with applications of fertilizers to the soil. Different soil properties influence the soil's ability to respond to added fertilizers and hence affect the overall crop yield (Adeniyan *et al.*, 2011).

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[1] Soil fertility gradients are gradients of decreasing soil fertility found with increasing distance from the homestead within smallholder African farms, due to differential resource allocation (Tittonell *et al.,* 2005).

1.2 Justification

Striga weed thrives greatly in soils of low fertility that are common in the study area despite several strategies being implemented to reduce its effects on crop yields. The different strategies have varied degrees of success. Combined application of organic and inorganic fertilizers with improved crop varieties is a feasible approach as farmers can afford small quantities of inorganic fertilizers that can in turn be combined with organic fertilizers that are readily available. IR maize is an improved crop variety as it is coated with a imazapry herbicide that makes it resistant to striga attack. This is expected to enhance soil physical, chemical and biological properties and hence fertility improvement in general. With improved soil fertility, the striga infestation will subsequently be reduced. This will translate into increased maize yields, improved food security and enhanced social welfare.

1.3 Study Objectives

1.3.1 Overall Objective

To contribute towards soil fertility improvement, striga weed reduction and increased maize yield through combined application of inorganic and organic fertilizers.

1.3.2 Specific Objectives

The specific objectives of this study were to assess the effect of mavuno and manure fertilizers applied singly or in combination on;

1. Soil chemical and biological properties
2. Soil carbon fractions.
3. Striga density and IR maize yield

1.4 Hypotheses

Mavuno and manure fertilizers applied singly or in combination will;

1. improve soil chemical and biological properties
2. improve soil aggregate stability through improved distribution of organic carbon fractions
3. increase IR Maize yield and decrease striga weed infestation.

1.5 Thesis Outline

This thesis has 5 chapters and are as outlined: The general abstract gives the concrete synthesis of the study and highlights the study's key findings. Chapter 1 contains the general introduction that outlines the problem under study, the used significance and the objectives the study seeks to achieve. Chapter 2 contains literature review - surveying other studies conducted in relation to the current study including factors on how striga has been controlled in previous years, fertilizer influence on soil properties and how maize yields are affected with organic and inorganic fertilizer application. Chapter 3 is the materials and methods and gives a detailed description of the study area, the technique used in collecting data to achieve the objectives; specifically, how the maize yield data, striga density data, and the soil chemical, biological and physical data were collected. It also outlines the statistical packages used for the data analysis and subsequent data interpretation. Chapter 4 Results and discussion is divided into 3-sub chapters. Chapter 4.1 presents and discusses the results obtained from the evaluation of the effect of manure and mavuno on soil chemical and biological properties. Chapter 4.2 presents and discusses the results obtained from the assessment of the effect mavuno and manure on soil carbon fractions; and chapter 4.3 presents and discusses the results on the effect of manure and mavuno on striga density and maize yields. Chapter 5, the last chapter of this thesis - is on general conclusions and recommendations.

CHAPTER TWO: GENERAL LITERATURE REVIEW

2.0 Introduction to Literature Review

The continued increase in prices of inorganic fertilizers and the local availability of organic manures necessitates promotion of use of both fertilizers so as to improve, not only soil properties, but also to increase crop yields and reduce the occurrence of weeds such as striga. It has been reported by Sanginga & Woomer (2009) that higher benefits are obtained by overall improvement in soil physical, chemical and biological properties from recycling of organic materials in soil, and increase in the availability of plant nutrients. In support of Sanginga & Woomer (2009), the literature pertaining to the influence of organic manures like FYM and inorganic fertilizers like mavuno, the effects of striga weed and crop responsiveness to applied fertilizer are reviewed and presented in this chapter under the following sub-headings; Organic and inorganic fertilizers as a source of plant nutrients; effect of organic and inorganic fertilizers on soil chemical properties; effect of organic and inorganic fertilizers on soil biological properties; effect of organic and inorganic fertilizers on soil organic carbon fractions; *Striga hermonthica* problem in Sub-Saharan Africa and *Striga hermonthica* effects on crop yields.

2.1 Organic and Inorganic Fertilizers as a Source of Plant Nutrients

The use of inorganic fertilizers is indispensable in alleviating nutrient constraints and is central in integrated soil fertility management (ISFM) practices for improved crop production. The craft of ISFM involves making the best use of affordable fertilizers, available organic resources and accessible agro-minerals (Sanginga & Woomer, 2009). Inorganic fertilizers have a high concentration of nutrients that are rapidly available for plant uptake and they can be formulated to supply the appropriate ratio of nutrients to meet plant growth requirements. Today, a wide range of inorganic fertilizers are required to maintain soil fertility and sustainable agricultural systems. Farmers are aware that without inorganic fertilizers the productivity of their crops and pastures will drop and soil nutrient levels will decline rapidly (Waswa *et al.*, 2007).

On the other hand, throughout Africa, including Kenya, sufficient mineral fertilizers are not available at the right times during the year and this is attributed to high transaction costs and inefficiencies throughout the production – consumption chain (Nyamangara *et al.*, 2009).

Inorganic fertilizers also contribute to eutrophication (fertilization of surface waters), which results in explosive growth of algae resulting in disruptive changes to biological equilibrium (Scheren *et al.*, 2000).

According to Bhanuvally (2006), organic material in the form of FYM was the only recognized source of plant nutrients added to the soil before the introduction of chemical fertilizers in the middle of the 19th century. Dunjana *et al.* (2012) found a positive correlation between the application of cattle manure and inorganic N-fertilizer on soil organic carbon (SOC), bulk density, macro-aggregate stability and aggregate protected carbon and application of the cattle manure in combination with inorganic N fertilizer was necessary to increase maize yields. FYM is known to increase crop yield by its favourable effect on physical, chemical and biological factors that determines the productivity and fertility status of soil and supply nutrients in the readily available form to plants. For instance, 1 ton of high quality cattle manure can contain up to 23 kg of nitrogen, 11 kg of phosphorus and 6 kg of potassium as evidenced by Vasundhara (2006). Tennakoon & Bandara (2003), found the nutrient content of FYM to be between 1.2-1.8; 0.4-0.6 and 1.1-1.9 per cent of N, P, K respectively whereas Bhanuvally (2006) reports that FYM contains approximately 0.5, 0.2 and 0.5 per cent of N, P_2O_5 and K_2O, respectively.

Due to continued escalation of fertilizer prices, there is a great thrust to either supplement or replace mineral fertilizers with renewable and cheaper sources of nutrients like organic manures which are considered to be beneficial sources of plant nutrients in soil fertility management (Sanginga & Woomer, 2009). Organic resources are abundant in Africa because they are derived from both cultivated and natural lands, but their availability as nutrient sources is limited by their alternative uses as fuel, feed and fiber and the labour required to collect and process these materials. It is estimated that a zero grazing cow can produce up to 1.5 tons of manure per year. Hence two animals would be needed to supply a 2 ton maize crop, if the manure were of high quality, but eight animals would be required if the manure was of low quality (Siriri & Mwebaze, 2000).

Farmyard manure decomposes rapidly in moist and warm climates resulting in poor timing of nutrients release with crop demand. Tittonell *et al.* (2007) and Jagadeeswaran *et al.* (2005) reported that these organic residues most available to farmers have low nutrient concentrations with limited potential to improve crop yields when applied as the sole source of nutrients. Therefore, a combination of both organic and inorganic fertilizer may prove to be more effective than sole application.

At Uyole in Tanzania, application of low rates of NP fertilizers with FYM produced 7.10 t ha^{-1} of maize grain compared to 4.03 t ha^{-1} when the same rates of NP were used alone (Amede *et al.* 2004). Tittonell (2003) also reported that the use of organic inputs alone in small-holder farms of Western Kenya were less popular among farmers but there was evidence of combined use of organic manure and inorganic fertilizers on many of the fields. Negassa *et al.,* (2005) reported an increment of 0.47 t ha^{-1} in grain yield of maize due to application of FYM during the first year over no FYM, whereas increasing FYM applications from 0-20 t ha^{-1} increased wheat grain yield from 1.97 to 3.31 t ha^{-1}. In Western Oromia a study was conducted to introduce the culture of supplementing low rates of NP fertilizers with FYM in a maize based farming system and the results indicated that the application of FYM alone produced low average yields as compared to the integrated use of both FYM and NP fertilizers (Negassa *et al.,* 2005). The above cases clearly indicate that the potential of organic nutrient sources increases when used together with mineral fertilizers resulting in an improved soil status and hence increased crop yields.

2.2 Effect of Organic and Inorganic Fertilizers on Soil Chemical Properties

2.2.1 pH and Electric Conductivity

Brodruzzaman *et al.* (2010) showed that after 3 crop cycles, soil pH increased in plots applied with poultry manure but did not changed in fields applied with inorganic fertilizers and FYM. In contrast, Nalatwadmath *et al.* (2003) observed that the production of acids on decomposition of organic manure (FYM), and use of ammonical fertilizers reduced the pH from 8.9 to 8.7. Niwa *et al.* (2007), reported that large inputs of organic matter inputs (FYM) at 100 t ha^{-1} yr^{-1} and inputs from food factory sludge compost resulted in an increase in soil pH. The same study also observed that unlike pH, electric conductivity, (EC) of soil remained unaffected.

Patil *et al.* (2003) carried out a study to know the effect of FYM on soil pH and showed that there was decrease in pH from 7.99 to 7.65 and each increment of FYM reduced the soil pH significantly due to organic acid production during its decomposition. Rathod *et al.* (2003) reported that the pH of the sodic soil was reduced significantly by application of FYM at 5 tons per ha which was at par with the pH value that had been reduced by 50 per cent gypsum requirement. Similarly, electrical conductivity was reduced significantly by application of the FYM. On the other hand however, a study conducted in Kakamega in western Kenya to assess the effects of liming and inorganic fertilizers on maize yield revealed that a combination of lime with organic and inorganic fertilizers increased soil pH levels from ranges of 4.63 to 5.8 which were optimum ranges for maize yields and this resulted in an increase in maize yields (Mbakaya *et al.*, 2010).

2.2.2 Cation Exchange Capacity

The cation exchange capacity (CEC) gives an indication of the soils potential to hold plant nutrients. Increasing the organic matter content of any soil will help to increase the CEC since it also holds cations like the clays. Yilmaz and Alagöz (2010) and Dadhich *et al.* (2011) report that the application of farmyard manure resulted in significant increase in CEC and the increase was associated with rise in organic matter content. Another study conducted by Ovuka and Ekbom (2001) on the correlation between soil productivity, erosion status, land management and farm resource endowments among smallholders in the Central Kenya found that the action needed to achieve higher crop yields, improve soil properties such as CEC and sustainable agriculture differed depending on farmers' resource endowments and improved CEC levels were noted in farmers fields that had higher resources available.

Similarly, in a study conducted to compare the effect of organic manures and chemical fertilizers on soil properties, Adeniyan *et al.* (2011) reported that application of different organic manures enhanced CEC better than the NPK fertilizers. Boateng *et al.* (2009) concurred with these findings in a study to assess the effect of poultry manure on the chemical properties of the soil where he reported that CEC increased about four times when poultry manure was added as compared to addition of NPK fertilizers.

2.2.3 Exchangeable Bases

The amount of exchangeable bases is an important property of soils and sediments as they relate information on a soil's ability to sustain plant growth, retain nutrients, buffer acid deposition or sequester toxic heavy metals (Brix, 2008). Cation exchange occurs due to the negative charges carried by soil particles, in particular clay minerals, sesquioxides and organic matter. These negative charges are cancelled out by the absorption of cations from solution. The CEC can be estimated by summation of exchangeable bases (Ca, Mg, Na, K) and exchangeable Al. It is used as a measure of the soil's fertility, and in general the higher the exchangeable bases, the higher the CEC hence the higher the soil fertility. Factors favoring the formation of humus generally increases the exchangeable bases in the soil (Brix, 2008).

In a study conducted in Australia to analyze solonetzic soils from long term Kybybolite P plots indicated a close relation exists between organic matter increase and increases in CEC with associated increase in the level of exchangeable calcium and exchangeable hydrogen. Changes in exchangeable calcium were related to the amount and form of fertilizer or amendment applied. Therefore, the change in exchangeable bases in the soil is greatly dependent on the various amendments applied to the soil (Russell, 2001). In general, increasing the concentration of one cation species in soil solution can decrease levels of other cations in plants. This is shown in a study conducted to assess the effect of adding gypsum to unleached soil, and the effect of changing soil-exchangeable Ca/Mg ratios on corn root and shoot growth and nutrient concentrations. Results indicated that exchangeable Ca/Mg ratios did not substantially affect root and shoot growth in the leached soils, nor did gypsum addition to the unleached soil. On the other hand, there was less growth in the leached soils as compared to that in the unleached soils, probably because of removal of K in the leaching process. Thus the study concluded that an alteration in one of the exchangeable cations results in an increase or decrease on the other exchangeable bases (Favaretto *et al.*, 2008).

2.2.4 Soil Organic Matter

Soil organic matter (SOM), is any material produced originally by living organisms (plant or animal) that is returned to the soil and undergoes decomposition. It serves several functions as it acts as a revolving nutrient fund since it is formed mainly from plant residues and the residues contain essential plant nutrients. Therefore, accumulated organic matter is a storehouse of plant nutrients and the humus adsorbs and holds nutrients in a plant available form. Apart from acting as an agent to improve soil structure, SOM also maintains tilth and minimizes erosion. The rate of organic matter addition from crop residues, manure and other sources must equal the decomposition rate and also plant uptake rate and losses by leaching and erosion in order to maintain the nutrient cycling system. Where the rate of addition is less than the rate of decomposition, SOM declines and vice versa (Bot & Benites, 2005).

Soil organic matter (SOM) plays a major role in moisture retention and contributes to the physical, chemical and biological properties of the soil since the active and some of the resistant soil organic components, together with micro-organisms (especially fungi), are involved in binding soil particles into larger aggregates which is important for good soil structure, aeration, water infiltration and resistance to erosion and crusting. Studies indicate that soil physical, chemical and biological properties can sustainably be improved through the improvement of SOM like in the addition of FYM, vermicompost or poultry manure (Niwa *et al.*, 2007; Mtambanengwe & Mapfumo, 2005; Karunditu *et al.*, 2003; Adeniyan *et al.*, 2011). Apart from sole application of organic manures, a combination with inorganic fertilizers resulted in a general improvement in the SOM levels and hence an improvement in the soil fertility status. A 19-year long-term experiment was conducted to evaluate the effects of fertilization regimes on soil organic carbon (SOC) dynamics, soil physical properties, and wheat yield. The SOC content in the top 20cm soil layer remained unchanged over time under the unfertilized control plot whereas it significantly increased under both inorganic, NPK fertilizers and combined manure treatments (Yang *et al.,* 2011). Thus, considering improving SOM and soil-quality conservation and sustainable crop productivity, reasonably combined application of NPK and organic manure is a better nutrient-management option. An experiment carried out by Waswa *et al.* (2007) on the changes in SOM as influenced by organic residue management regimes in three selected sites in Kenya revealed that the soil carbon values were dependent on the amounts of the organic residues applied and the duration of application. The experiment indicated that organic residue management practices had a profound impact on the final contribution to the SOM pools and time of application of organic manures was also vital in the improvement in SOM.

An eleven-year study conducted to investigate the long-term effects of applied organic manures and inorganic fertilizers on yield and soil fertility in a wheat/rice cropping pattern indicated that percent SOM was reduced (19 to 13%) with inorganic fertilizers and increased (7 to 39%) with organic manures (Brodruzzaman *et al.*, 2010). Thus from the study we note the importance of combining inorganic fertilizers with organic manures so as to improve SOM concentrations and sole chemical fertilizer application has a negative impact on the SOM available in the soil.

2.2.5 Total and Available Nitrogen

Nitrogen (N) exists in the soils in two major forms, organic and inorganic N and total N is the sum of the inorganic and organic components of N. More than 90% of the N in soils is in the organic form e.g. amino acids, amino sugars and purine. The inorganic form of nitrogen in the soil is composed of NH_3-N; NH_4-N; NO_3-N, and NO_2-N and their concentrations may vary considerably depending upon a number of factors, including the application of N fertilizers. Thus plant available N is made up of the inorganic components of NH_4^+ or NO_3^-. Nitrogen is an essential nutrient for plant growth, chlorophyll and protein formation. Since soil N is mostly organic in nature, N concentrations in soil increase with increased organic matter contents (Camberato, 2001).

One study showed that continuous addition of manures for 20 years increased the soil total and available nitrogen content significantly from 0.05 to 0.083 per cent, while increase was only 0.005 per cent in N fertilizer applied plots as large portion of N was removed by the crop, and another observed a higher available nitrogen content in soil under continuous manuring with FYM over a period of 45 years in cotton–jowar rotation compared to the control (Blair *et al.*, 2006). Another study conducted in Turkey to compare the effects of composted tobacco waste (CTW) with FYM on soil physical and chemical properties and yield of lettuce, showed a significant increase in nitrogen in the FYM plots. The increase in N was also significantly correlated to the increased lettuce yield (Cercioglu *et al.*, 2012).

An experiment conducted to study the effect of long-term (20 years) fertilization and manuring on soil chemical and biological properties in vertisols at Akola in India, with treatments including NPK levels with and without FYM, indicated an increase in soil organic carbon and total nitrogen in treatments were 100% NPK + FYM at 10 tons/ha were applied as compared to control treatments and sole application treatments (Katkar *et al.*, 2011). A field experiment conducted for 6 years to assess the effect of the integrated use of FYM and inorganic fertilizers on soil chemical properties in Ethiopia, showed that NPK content of the soil increased with the level of FYM application Bayu *et al.* (2006). Another study conducted by Reddy *et al.*, (2008) to find out optimum level of farmyard manure (FYM) and nitrogen for improving productivity, quality, monetary returns of tobacco (*Nicotiana tabacum L*), and changes in soil fertility after tobacco, showed that application of FYM at 10 t/ha significantly increased the soil organic C, and available N by 0.08 and 6.6 respectively than that of no FYM application. Patil *et al.*, (2003) reported that inclusion of organic manures such as FYM enhanced the soil available nitrogen as compared to recommended dose of inorganic fertilizer alone. Whereas Brodruzzaman *et al.*, (2010) reports that percent total N was unchanged in organic matter applied plots, but reduced in those that were treated with chemical fertilizers. He further states that after 9 years, % total N was reduced further in inorganic treatments and increased in organic treatments. The above studies also outline that there are significant increases in both mineral and total nitrogen when inorganic fertilizers are applied in combination with organic manures as compared to sole applications.

2.2.6 Available Phosphorus (P)

Phosphorus is essential for plant growth and it exists in the soil in both organic and inorganic forms. P concentration in the soil is very variable and may range from zero to more than 2%. Its content increases with increased organic matter content and a positive linear regression exists between organic P and organic C content. Available P is the P in soil that is in a form that can be taken up by plants. The various soil fertility management practices implored have an effect on the available P. A field experiment was conducted to assess the effect of the integrated use of farmyard manure and inorganic fertilizers on soil chemical properties in NE Ethiopia. The results revealed substantial increases in available P (Bayu *et al.*, 2006). In another study by Adeniyan *et al.*, (2011), a pot experiment was conducted to compare different organic manures with NPK fertilizer for improvement of chemical properties of acid soil from farmer's fields and nutrient depleted soil from a research field Station. Results showed that application of different types of organic manures enhanced soil organic C, total N, available P, exchangeable K and CEC better than NPK fertilizer in both soils. This indicates that organic manures are better at enhancing soil chemical properties as compared with inorganic fertilizers. However an integrated approach to improve other factors such as yield is the best approach.

Another study conducted by Cercioglu *et al.* (2012) that compared the effects of composted tobacco waste with farmyard manure (FYM) on soil physical and chemical properties and yield of lettuce, showed that both organic inputs improved the soil physical and chemical properties and also lettuce yields. Dadhich *et al.* (2011), conducted a field experiment to study the direct effect of fertilizer P, FYM and bio-fertilizers alone and in combinations on soybean and their residual effect on subsequent wheat. Results showed that application of increasing levels of P, FYM and bio-fertilizers significantly enhanced the seed/grain yield of soybean and subsequent wheat. This study indicates that an integrated use of FYM and P fertilizers not only improves soil chemical properties and increases crop yields.

2.3 Effect of Organic and Inorganic Fertilizers on Soil Biological Properties

Soil biology refers to the organisms both animals (fauna/micro-fauna) and plants (flora/micro-flora). They are important in the overall quality, fertility and stability of the soil and are responsible for the formation of humus and formation of soil and its structural stabilization. Soil contains a vast number and wide range of organisms which are important in the myriad of biochemical reactions and intricate biological processes that take place within the soil (Bajracharya, 2011). Soil respiration is one such biological process.

2.3.1 Soil Respiration

Soil respiration refers to the carbon dioxide produced by organisms when they metabolize in the soil. This includes metabolism by plant roots, the rhizospheric microbes and fauna. Factors affecting soil respiration include temperature, moisture, rhizo-deposits and level of oxygen in the soil and these can produce extremely different rates of respiration. The rates can also be largely affected by human activity such as increased nitrogen fertilization. Soil respiration plays a significant role in global carbon cycling as well as other nutrient cycles and hence it is important to maintain sustainable rates of soil respiration. Gnankambary *et al.* (2008) conducted a study to investigate nutrient limitation and availability for soil microbial respiration after additions of glucose (C), in combination with nitrogen (N) and phosphorus (P) in soil. The results indicated that P limited the initial rate of respiration when added and hence P affects rates of microbial respiration. Thirukkumaran and Parkinson (2000) also conducted a study in order to elucidate the mechanisms by which N and P fertilizers affect below ground microbial processes. Ammonium nitrate was applied singly and in combination with triple super phosphate to pine materials under laboratory conditions and microbial variables were monitored over 120 days. Results indicated that ammonium nitrate significantly suppressed basal and substrate induced respiration when added singly or in combination with TSP. Changes in microbial indices as a result of fertilizer addition suggested that the present recommended rates of fertilizers suppressed microbial population (Thirukkumaran & Parkinson, 2000).

Another test was carried out by Ramirez *et al.*, (2010), to assess how amendments of different forms of nitrogen (N) affect microbial respiration rates by adding six different forms of N to three distinct soils. Results indicated that all inorganic N forms led to a net reduction in microbial respiration regardless of soil type and this led to a conclusion that the decreases in respiration rates were mainly a direct result of the increase in soil N availability. This however is in contrast to a study conducted to test the hypothesis that the variability in leaf litter quality produced by a highly diverse tree community determines the spatial variability of the microbial respiration process in the underlying soil in an undisturbed Amazonian rainforest. The microbial respiration process was assessed using substrate induced respiration (SIR) and results indicated that the variability of both litter quality and SIR rates was more important at large than at small scales. Total litter P and total litter N content correlated positively with SIR rates. The study showed that P and N concentrations in soil alter SIR accordingly (Fanin *et al.*, 2011).

Wang *et al.* (2003) carried out a study to assess the roles of microbial biomass and substrate supply as well as their interaction with clay content in determining soil respiration rate using a range of soils with contrasting properties. Results indicated that soil respiration was still closely correlated with the C availability indices in the pre-incubated soils, but poorly correlated with microbial biomass C. The observations suggested that soil respiration was principally determined by substrate supply rather than by the pool size of microbial biomass. The C:N ratio of the substrate is important in decomposition and hence in soil respiration. If the substrate is high in N and microbes satisfy their needs, additional quantities are not necessary and rate of degradation is high and if N in the substrate is low and microbes do not satisfy their needs, the N in the soil is immobilized by microbes and is not available to plants and hence there is also low soil respiration. Ramirez *et al.* (2010) in an experiment on how different forms of nitrogen affect microbial respiration rates revealed that all inorganic N forms led to a net reduction in microbial respiration.

Wood ash (WA) stimulated microbial respiration in a study were the effect of wood ash fertilization on microbial processes in the mineral top soil (0-5cm) of an acidic Norway spruce forest was assessed. After the addition of WA, various soil microbiological variables such as microbial biomass C (C_{mic}), basal respiration, *in situ* soil respiration as well as enzyme activities were determined. Soil chemical properties measured included pH, organic C and total N, and exchangeable cations. Results indicated that addition of WA resulted in a rapid change in the rate of CO_2 evolution and C_{mic}. It appeared that an increase in microbial activity in soil treated with WA was accompanied by an increase in the growth rate of soil microorganisms.

Increases in pH resulted in higher biomass and bioactivity (Zimmermann & Frey, 2002). Ilstedt and Singh (2005) carried out a study to investigate the nutrient limitations of microbial respiration over time after the addition of glucose (G), glucose-C-nitrogen (GCN) or glucose-C-phosphorus (GCP) in an acrisol and compared with those from compost. The experiment indicated that rate of respiration in the acrisol increased with P addition and in the treatment without N. Microbial respiration is also affected by the P-fixing properties of the soil, the fertilizer application time scale and the carbon availability.

2.4 Effect of Organic and Inorganic Fertilizers on Organic Carbon Fractions

Soil organic matter, (SOM), associated with particles of various sizes, differs in structure and function and an understanding of the form and function of SOM in soil is essential for sustainable crop production. Increasing soil amendments such as FYM that increase soil aggregation is therefore vital because most soils rely on aggregation of particles to maintain favourable conditions for soil microbial and faunal activity and plant growth. Whitbread (1995) reported that at higher levels of carbon, the stability of macro aggregates is increased presumably due to organic bonding mechanisms. Six *et al.* (2000) stated that, although total organic carbon of the soil declines due to cultivation, of particular concern is the decline in the more labile carbon fractions that are associated with soil nutrient dynamics. The effect of management upon SOM, specifically depended upon these labile components, and changes in soil structure were essential for the development of sustainable agricultural systems. A study conducted by Bell *et al.* (1998) investigated the role of active fractions of SOM in physical and chemical fertility of ferralsols. The results indicated that the most labile (easily oxidised) fractions of soil organic matter were very important key components of the chemical and physical fertility of ferrosols. Management practices that maintain adequate labile concentrations are essential for sustainable cropping.

Another study conducted by Dalal & Mayer (1986), investigating the long term trends in fertility of soils under continuous cultivation and cereal cropping and the distribution and kinetics of SOC in particle size fractions found that in the soil's original state no single particle size fraction was found to be consistently enriched compared to the whole soil and the largest proportion of organic C was in the clay size fraction. Once cultivated, the amounts in organic C declined from all particle size fractions except for the clay size that actually increased; inferring therefore that the clay fraction provides protection for the soil organic matter against microbial and enzymic degradation. Another study was conducted in 3 long-term fertility experiments on agricultural soils to examine the effect of cultivation and the application of inorganic and organic amendments on total soil organic carbon (TOC) and on the proportions of soil C fractions at these sites. The results indicated that the largest TOC contents were observed in NPK +FYM amended soils and the study concluded that fertilizer application and especially manure application had the potential to significantly increase SOC in agricultural soils.

2.5 *Striga hermonthica* problem in Sub-Saharan Africa

Striga hermonthica (Del.) Benth is a weed that attacks cereal crops mainly maize, rice and sorghum. It is one of the economically important weeds in Africa. Mohamed *et al.* (2001) describe 28 species of which six subspecies are from Africa. Of these, 22 species of striga are endemic and *Striga hermonthica* is one of the 11 that are most important and attacks crops. *S. hermonthica* originated from the Nuba Mountains of Sudan and Ethiopia and now is widespread in many parts of Africa, including western Kenya (Musselman, 1987), and it is steadily increasing its geographic domain and level of infestation. It is commonly referred to as the “witch weed” by local dwellers as the plant is known to debilitate plants it invades thereby greatly reducing crop yields. *S. hermonthica*, is an out-crossing species with purple flowers and it produces massive amounts of seed estimated at between 58 000 and 200 000 per plant (Hassan *et al.*, 1994). The seeds can remain viable in the soil for long periods of time resulting in continuous loss of cereal crops (Bebawi *et al.,*1984)

The Striga problem undermines the struggle to attain food security and economic growth in the continent as an estimate of roughly 300 million people in sub- Saharan Africa and up-to 50 million hectares of crop lands in the continent are adversely affected by Striga (Oswald & Ransom, 2002). This has resulted in areas of otherwise productive agriculture being abandoned and crops that were previously unaffected by striga, now showing serious infestation (AATF, 2006). Different coping strategies have been tested in attempt to reduce the effect of striga and these include some agronomic practices such as uprooting and burning Striga plants before flowering, field sanitation, crop rotation, intercropping, organic matter usage, improved fallows and push-pull system, host plant resistance (use of Striga-tolerant maize germplasm) and the application of herbicides (AATF, 2006).

2.6 Effects of *Striga hermonthica* on crop yields

Over 21 million ha of cereal crop have been affected by S. hermonthica in sub-Saharan Africa and farmers lose 20 to 80% of their yield, which translates to 4.1 million tons of grain per year. This affects livelihoods of approximately 100 million people (Kanampiu *et al.*, 2002). It is estimated that 76% of land planted with maize in western Kenya is infested with striga. Annual losses due to striga are estimated to be $40.8 million in the region (Hassan *et al.*, 1994; Kanampiu *et al.*, 2002).

Two studies were conducted in western Kenya, one to assess the effect of transplanting maize and sorghum on grain yield and striga parasitism (Oswald *et al.*, 2001) and the other to determine whether maize varieties with different maturity periods and susceptibility to striga parasitism respond similarly to transplanting (Oswald & Ransom, 2002). In both cases, the author noted that transplanting clearly reduced striga emergence for all varieties of maize. However in the earlier experiment, in transplanted sorghum, striga emergence was not reduced. Transplanting maize in both experiments also significantly increased grain yield compared to direct seeding. Transplanting is therefore a striga-reduction strategy in some crops but may not be easily adopted due to its high labor requirement.

Imazapyr and pyrithiobac-coated Imidazolinone-resistant (IR) maize is maize that is coated with the imazapyr herbicide. The herbicide allows the maize to attack the striga and kill it before it damages the crop. IR maize is a striga control option for small-holder farmers in Africa as research documents that coating maize prior to planting at rates of 30 to 45g/ha provide near season long control of striga. There is also evidence that it has the potential of increasing maize yields three to fourfold if supplied with fertilizer (Ransom *et al.*, 2011). Another striga adoption strategy is the use of fertilizer to reduce striga incidence. The results of the strategy indicated that N applications resulted in up to 93% reduction in the incidence of striga but the maize height was unaffected by N. On the other hand, K applications led to a more than 4 fold increase in striga incidence and P had no significant effect. These results indicate that increasing N and maintaining levels of P and K applications will directly cause a decrease in striga density (Farina *et al.*, 2006).

In another experiment to assess the effects of N, P and K on *Striga* seed germination and infestation of sorghum, sorghum plants were grown in pots and N was applied at varied rates. Results indicated that with an increase of soil N, *Striga* infestation as well as the sorghum shoot dry matter losses due to infestation, decreased. Presence of N in the growth medium considerably reduced the effectiveness of the stimulating substance for striga growth produced by sorghum roots, whereas K promoted stimulant activity only in the absence of N. The presence or absence of P in the growth medium did not affect germination of *striga* seed concurring with the findings of (Farina *et al.*, 2006; Raju *et al.*, 2006).

CHAPTER 3: GENERAL MATERIALS AND METHODS

3.1 Experimental Site and Selection of Farmers

The study was conducted on small-holder farms in Western and Nyanza Provinces of Kenya bordering Uganda and parts of Lake Victoria. The Western Province is located west of the Eastern Rift Valley and is inhabited mainly by the Luhya people with Kakamega as the provincial capital. Nyanza province is located in the southwest part of Kenya also around Lake Victoria**.** The Luo people inhabit it predominantly and its provincial capital is Kisumu.

Twelve farmer fields in 2 counties, Vihiga and Siaya, were selected. Farmers were selected using a Y- shaped sampling frame (Tittonell *et al.*, 2010). The sampling frame was designed to include those characteristics considered to occur at random such as elevation, parent material, climate, landscape and position and 'fixed effects' considered under farmers' control such as soil management and land use history. One farm was located at the centre of the 'Y' and three in each of the randomly oriented arms separated at constant distances from the central farm at 100, 300 and 900 m (Tittonell *et al.*, 2010). The study therefore selected 12 farmers from the three sites, 8 in Siaya (Nyalgunga -4 and Nyabeda - 4) and 4 in Vihiga (Emusutswi). The Y-frames were prepared using ARC–GIS software to obtain the exact geographical location of each farm (Fig. 1) and farms were geo-referenced using a global positioning system (GPS) device (Table 1).

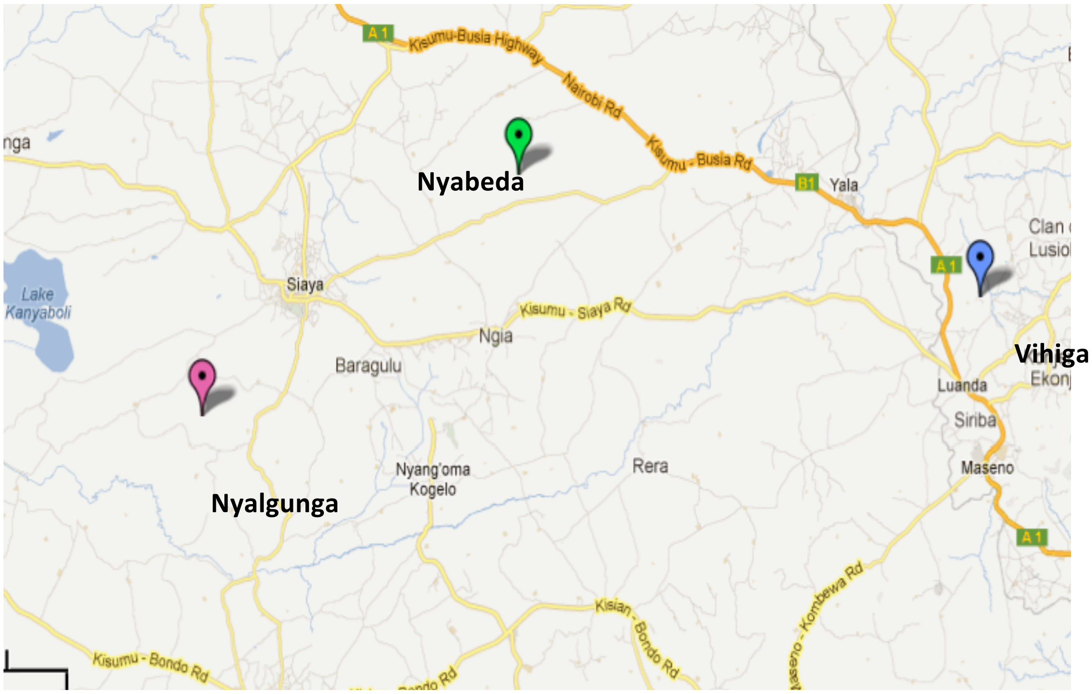

Figure 1: Map showing Emusutswi, Nyabeda and Nyalgunga

Table 1: Location of Experimental Sites

District	Farm	Site	Northing	Easting	Elevation (m a.s.l)
Vihiga	1	Emusutswi	0º07’39.1”	34º40’17.2”	1528
	2	Emusutswi	0º07’23.2”	34º40’26.0”	1503
	3	Emusutswi	0º07’30.0”	34º40’11.9”	1470
	4	Emusutswi	0º07’36.2”	34º40’46.2”	1510
Siaya	1	Nyalgunga	0º04’42.6”	34º18’19.1”	1335
	2	Nyalgunga	0º04’50.1”	34º18’21.8”	1300
	3	Nyalgunga	0º05’05.4”	34º17’53.3”	1310
	4	Nyalgunga	0º04’56.9”	34º13’17.5”	1312
	1	Nyabeda	0º07’42.9”	34º24’29.5”	1323
	2	Nyabeda	0º07’50.5”	34º24’10.8”	1333
	3	Nyabeda	0º08’02.8”	34º24’29.5”	1360
	4	Nyabeda	0º08’01.2”	34º24’17.5”	1347

Rainfall in Western Kenya averages over 2000 mm per annum and it is bimodal in distribution. The average received during the experimental period (Fig 2) was 187mm.

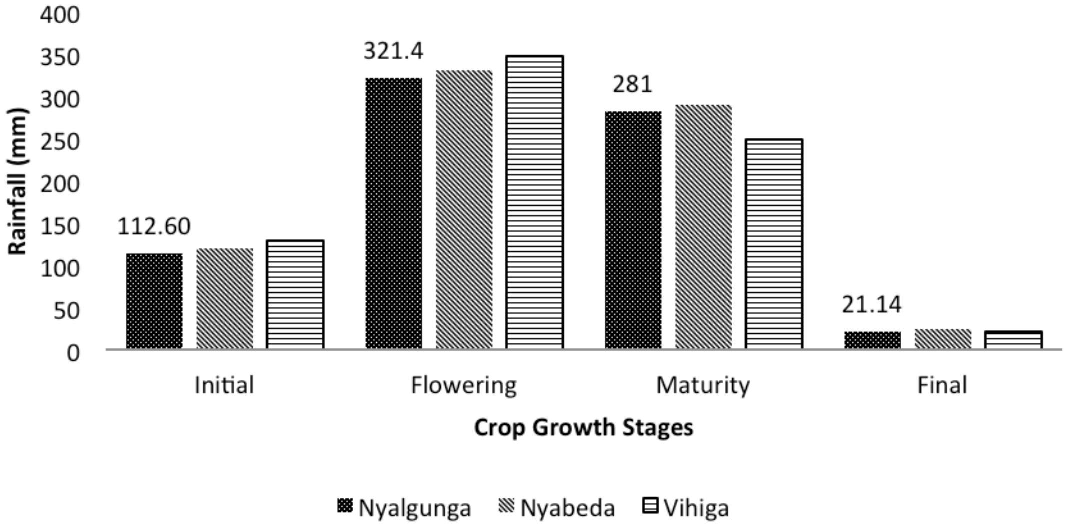

Figure 2: Rainfall distribution during crop growing stages

Temperatures in the region can go up to as high as 35°C between January and February the hottest months (Cheserem, 2012a). Siaya District has a tota area of approximately 2530 km² and a population density of 333 people/km^2 (Cheserem, 2012b). Farms in Siaya are larger, 0.5–5ha, compared to Vihiga, 0.3–2ha, due to the much higher population density in Vihiga, 1,045 people/km^2, over a much lesser total area of 531km^2 (Cheserem, 2012a). The climate of the region is mainly tropical, with variations due to altitude. Kakamega District, the provincial capital, is mainly hot and wet most of the year, while the hilly Vihiga District is the coldest. Rainfall distribution across the whole region is bimodal, characterized by a long and short rainy seasons that allow two cropping seasons per year. The long rains fall between March and June with a peak in April and May and the short rains begin in September- October and begin to subside in November – December. The humidity is relatively high with mean evaporation being between 1800 mm to 2000 mm in a year (Cheserem, 2012b).

Farming is the main economic activity across the two provinces. Maize is grown for subsistence together with sorghum and pearl millet whilst tea and sugarcane plantations in Vihiga and

Bungoma respectively are largely produced commercially. Dairy farming is also widely practiced in Vihiga. In Siaya, fishing and fish trade is a growing economic activity in the province. The poverty rates for Siaya and Vihiga are 35.3% and 41.8% respectively.

The soils in the study area are mainly humic nitosols and ferralsols in Vihiga, and ferralsols and acrisols in Siaya. Humic nitosols are developed from volcanic rocks and have better chemical and physical properties than other tropical soils: Most are acidic (pH < 5.5) due to the leaching of soluble bases but are the best agricultural soils found in the region (Gachene & Kimaru, 2003).

Ferralsols occur on gently undulating to undulating topography such as that in Siaya district. The ferralsols are made up of acidic parent rocks and have high quartz amount. They are very old, highly weathered and leached soils, and therefore with a poor fertility, which is restricted to the top soil, as the subsoil has a low cation exchange capacity. Ferralsols are rich in Aluminium (Al) and Iron (Fe) but Phosphorous (P) and Nitrogen (N) are always deficient (Okalebo *et al.*, 2005). Acrisols on the other hand occur on undulating to hilly topography. They show an increase of clay content in the sub-soil (B-Horizon) often resulting in a low porosity sub soil hence impeding root penetration. In wet areas, Acrisols have a low pH (acid), Al and Mn toxicities and low levels of nutrients and nutrient reserves. The above soil types all require organic and inorganic fertilizers to improve crop production. The soils respond well to fertilizers (especially N, P and K) and to the use of soil organic matter (Gachene & Kimaru, 2003).

3.2 Treatments and Experimental Design

Farmers' fields were demarcated into two fertility gradients, low and high. Fields classified as having low fertility had sparser crops, approximately 30% less plants/ m^2, and higher weed infestation levels than those fields classified as high fertility fields. 12 farmers were selected, 4 from each of the sub-locations Nyabeda, Nyalgunga and Emusutswe. Three treatments were applied to each of the 12 farms namely;

T1	IR Maize (control- no fertilizer added) – IR maize was the test crop
T2	IR maize + Manure
T3	IR maize + Mavuno + Manure

IR maize was the test crop and it is maize coated with a herbicide that makes it resistant to striga weed. Mavuno fertilizer 50 kg Net, N-P-K 10:26:00 contains 10% ammonic, 26% P_2O_5, 14% CaO, 4% MgO and 4% S and trace elements Bo, Mn, Zn, Na and Cu. Mavuno fertilizer was applied at the rate of 375 g per plot (6m x 4.2m) and FYM was applied at a projection of 2 tons per ha that is 10kg dry manure per plot.

Agronomic Practices:

The experimental setup was a completely randomized block design with a split plot arrangement replicated four times in each site. The blocks were the farmers, the main plots were the fertility gradients and the sub plots were the treatments (T1 – T3). The study was multi-locational and was carried out in one season with the application of similar organic and inorganic nutrient sources. Total quantity of P and half of N was applied as basal at the time of sowing of maize crops.

Field 1						Field 2					
Low fertility			High fertility			Low fertility			High fertility		
T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3

Figure 3: Field Layout

3.3 Soil, Plant Sampling and Analysis

3.3.1 Soil Sampling and Analysis

Soil samples were collected from the 12 farms' low and high fertility plots. Within each plot, the IR+ Mavuno +Manure, IR+Manure and control treatments were sampled after the experiment. Soil samples were collected using a 5 cm diameter auger to a depth 0-20 cm. 1.5 kg soil was bulked from 5 points within one treatment plot and collected in a sampling bag. A 200 g portion of soil was collected from the bulk sample and placed in a cool box and later transferred to a freezer below 2°C for mineral N and soil respiration determination.

Soil pH was determined both in KCl using a 1:2.5 soil/ solution ratio and read using a pH meter according to methods described by (Johnson & Davis, 1978)For CEC and exchangeable bases, soil samples were extracted using ammonium ethanoate and 1*M* KCl. The samples were then titrated for exchangeable bases using HCl and Ca and Mg were determined by atomic absorption spectrometry. P was extracted using the Mehlich 1 (double acid method) containing 0.05N HCl and 0.025N H_2SO_4.. Exchangeable K was determined by the flame photometer and P calorimetrically (molybdenum blue) (Nelson & Sommers, 1996). The Kjeldhal (1961) method was used in the determination of total N by digestion with sulphuric acid and a mixed catalyst containing potassium sulphate (K_2SO_4) and copper sulphate ($CuSO_4$). The Walkley-Black (1934) procedure was used for the determination of organic C calorimetrically by H_2SO_4 dichromate oxidation. For CO_2 respiration, samples were incubated for 3, 7 and 14 days and titrated against 0.25 *N* HCl. Organic carbon fractions were determined using the aggregate fractionation protocol as described by Six (2011).

3.3.2 **Plant sampling and analysis**

Maize yield and striga density per plot were recorded for each season. In all plots maize was harvested over a total area of 7.08m^2. The numbers of maize plants and ears were recorded and the fresh weight of the stalks, ears and grains recorded. The moisture content (MC) of the shelled grains was determined using a grain moisture meter. Grain sample fresh and dry weights were also recorded. Maize yield were calculated using the formula.

$$Maize\ yield\ (kg/ha) = \frac{Ear\ whole\ fresh\ weight * \left(\frac{Grains\ sample\ dry\ weight}{grains\ sample\ fresh\ weight}\right)}{area\ harvested\ (m^2)} * 10000$$

Striga plants were counted at weeks 6, 8, 10 and 12 after maize planting. Striga density per plot was calculated using the formula;

$$Striga\ density (plants/ha) = \frac{Total\ striga\ plants\ at\ (6 + 8 + 10 + 12)\ wks}{plot\ area\ (m^2)}$$

3.4 Statistical Analysis

Striga density data and maize yield data was subjected to ANOVA using GENSTAT statistical package. The hypotheses were tested at a 95% confidence interval and the means were compared using least significant difference (LSD) test.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 EFFECT OF MAVUNO AND FARM YARD MANURE FERTILIZERS APPLIED SINGLY OR IN COMBINATION ON SOIL CHEMICAL AND BIOLOGICAL PROPERTIES

Abstract

The present study was undertaken to evaluate the effect of organic and inorganic fertilizer application on soil chemical and biological properties. This is in view of the fact that soil properties are bound to change, positively or negatively with applications of fertilizers. The study was conducted on-farm in Siaya and Vihiga counties. The experiment was set up in a randomized complete block design with a split plot arrangement. The main plots were the fertility gradients and the sub-plots were the treatments, IR+ mavuno, IR+ mavuno + manure and no fertilizer. IR maize was the test crop. Soil pH, organic carbon (OC), phosphorus (P) and total nitrogen (N) were analyzed at initial planting, flowering and at crop maturity. Mineral N, exchangeable bases and CEC were analyzed at crop harvest. Organic carbon respiration was recorded at days 3, 7 and 14 of incubation. There were significant differences in P levels between treatment means with mavuno + manure treatment recording the highest mean P levels (11.78mg/kg) at crop maturity. Soil organic C and total N showed significant differences across sites and treatments prior to planting and at harvest ($P<0.01$). There were significant differences in soil pH across sites prior to planting. The mineral nitrogen showed significant differences across treatments. Exchangeable bases; K and Ca and CEC showed significant differences across treatments whilst Mg showed significant differences across sites. Soil respiration showed significant differences across fertility gradients after 7 and 14 days of incubation but no significant differences were noted between sites or treatments. A combination of both organic and inorganic fertilizers enhanced both soil biological and chemical properties. Further studies are recommended on dynamics of soil microbial biomass across fertility gradients in smallholder farms.

Key words: Fertility gradients; Inorganic fertilizer; Organic fertilizer; Soil respiration

4.1.1 Introduction

Soil fertility management practices by small-holder farmers mainly depend on application of farm-yard manure (FYM) since it is cheap. Sufficient mineral fertilizers are not available at the right times during the year due to high transaction costs and inefficiencies throughout the production-consumption chain (Nyamangara *et al.*, 2009). Mavuno (10-26-00) is a mineral fertilizer that is being advanced in western Kenya. It is formed from the combination of important macro-nutrients N and P with locally granulated minerals of gypsum and dolomitic limestone, muriate of potash and micro-nutrients B, Zn, Mn, Mo and Cu (Poulton *et al.,* 2006). The use of local minerals makes mavuno blends less expensive than other mineral fertilizers and therefore readily available to small-holders in western Kenya. However continual use of mineral fertilizers has led to the development of fertility gradients in a single farm with pronounced variations in the soil chemical and biological properties. On the other hand, Western Kenya is heavily infested with *striga* weed that thrives greatly in low-fertility soils. The existence of the fertility gradients therefore enhances the occurrence of this weed, since fertility gradients occur due to preferential fertilizer application within one farm. This results in some parts of the field exhibiting low fertility and hence are easily attacked by striga. Farmers in Siaya and Vihiga use IR maize in their fields to minimize the effects of *striga* on their crops. IR maize is a herbicide coated maize that makes it resistant to attacks by *striga.* Fertilizer manufacturing and blending is shifting to ensure that fertilizers not only have the major macronutrients but also the secondary and micro-nutrients (Sanginga & Woomer, 2009). It is therefore important to carry out research not focusing only on NPK but other elements as well, hence the importance of the study. Like the major macronutrients, both the secondary and the micro-nutrients also play a vital role in enhancing the soil's dynamic properties.

Soil is made up of dynamic and relatively static properties. Dynamic physical properties change with change in management whilst static properties are naturally occurring and cannot easily be altered by human interventions (Doran & Zeiss, 2000). Soil Properties such as organic C, mineral and total nitrogen, pH, CEC, N and P levels and organic carbon respiration are dynamic and change with the practices employed (Doran & Zeiss, 2000). Soil properties also act as possible early-warning indicators of changes in plant and microbial community and changes in nutrient cycling and energy flow processes (Chiurazzi, 2008). The above have an effect on the quality and quantity of crops produced in any particular field and is therefore important to constantly assess integrated soil fertility management technologies employed in farmer fields and come up with conclusions on whether the technologies are detrimental or beneficial. It is vital to study soil dynamic properties as this gives us additional information on current and future conditions of the soil. This allows us to come up with better management strategies aimed at maximizing the available resources whilst maintaining or improving the soil health and quality. The study was therefore conducted to assess the effects of application of mavuno and manure fertilizers applied singly or in combination on soil biological and chemical properties in small-holder farmer fields in Siaya and Vihiga.

4.1.2 Materials and Methods

4.1.2.1 Site description and farmer selection

Fertility trials were conducted on- farm in 3 locations; Nyalgunga and Nyabeda in Siaya County and Emusutswi in Vihiga County all in Western Kenya. Vihiga County has an annual average rainfall of between 1,800mm and 2,000 mm with an average temperature of 24.00 ^{0}C. Siaya county on the other hand, has an annual rainfall of between 1,170 mm and 1,450 mm with a mean annual temperature of 21.75 ^{0}C and a range of 15 ^{0}C and 30 ^{0}C (Cheserem, 2012b). The two main soil types in Emusutswi are humic nitosols and ferralsols and Nyabeda and Nyalgunga have ferralsols and acrisols (Gachene & Kimaru, 2003). Maize is grown for subsistence together with sorghum in Siaya and Vihiga counties. Tea and sugarcane are largely produced commercially and dairy farming is widely practiced in Vihiga (Cheserem, 2012b). In Siaya, fishing and fish trade is a growing economic activity in the county (Government of Kenya, 2002). From the three sites, 12 farmers were selected, 4 from each site, using Y frame sampling procedure that selects farmers according to characteristics considered to occur at random and those considered under farmers' control such as soil management and land use history. One farm was located at the center of the 'Y' and three in each of the randomly oriented arms separated at constant distances from the central farm at 100, 300 and 900 m (Tittonell *et al.*, 2010). Farms were demarcated into low and high fertility gradients based on a study conducted by Tittonell *et al.,* (2005) were fields classified as having low fertility had sparser crops (30% less plants /m^2) and had higher weed infestation levels than those classified as fertile, leading to important differences in maize yield (0.9 versus 2.4 t /ha).

4.1.2.2 Experimental Design and treatments

A randomized complete block design with a split plot arrangement replicated 4 times (with each farmer acting as a replicate) was used to test the effect of fertilizer application on soil chemical and biological properties. The main plots were the fertility gradients (high and low) and the subplots were the fertilizer treatments; control, manure and manure+ mavuno. IR maize was used as the test crop.

Agronomic Practices

Mavuno was applied at a rate of 20kg P per ha and FYM was applied as a projection of 2 tons N per ha. IR maize was planted at a spacing of 30cm x 75cm in a plot of size 6mx4.2m. The plots were weeded twice during the growing season.

4.1.2.3 Soil sampling and analysis

Soil sampling was done at intial, flowering and maturity stages of crop growth. Soil samples were collected using a soil auger at a depth of 0-20 cm at 5 points using W-sampling procedure as described by Peters *et al.* (2008). The soil was composited, then divided into four equal parts and a 500g sample obtained and bagged in polythene bags for pH, P, total N, organic C, CEC and exchangeable bases analysis. Another 200 g of the composite sample was collected and put in polythene bags and kept in a cooler box for mineral N and organic carbon respiration analysis.

Soil pH was measured using a soil to water ratio1:2.5. The exchangeable bases K, Ca and Mg were extracted using 1M Ammonium Acetate (NH_4OAc) at pH 7. From the extract Ca and Mg were determined using the Atomic Absorption Spectrophotometer (AAS). The wet digestion method and the Kjedahl method were used in the determination of organic carbon and total N. Ammonium-nitrogen (NH_4-N) and nitrate-nitrogen (NO_3-N) were determined by extraction with 2Normality potassium chloride (KC1) followed by steam distillation with added magnesium oxide (MgO) and Devarda's alloy used to reduce NO_3 to NH_4. The Mehlich 1 method was used to extract soil P. The methods used for the soil analysis are those described by Okalebo *et al.* (2002). Organic carbon respiration was measured using passive CO_2 absorption in an alkali trap incubated for 3, 7 and 14 days as described by Jensen *et al.* (1996).

4.1.2.4 Data Analysis

Analysis of variance to assess the effects of site, treatment, fertility gradients and their interactions on soil chemical properties was conducted using GENSTAT 14th Edition. The Least Significant Difference (LSD) was used to separate means of significant differences.

4.1.3 Results and Discussion

4.1.3.1 Soil Chemical Properties

The initial soil analysis parameters; pH, %N, %OC and P varied across sites with the highest pH (6.2) and P (11.66mg/kg) recorded in Nyalgunga and the highest %OC (2.51) and %N (0.21) in Nyabeda both in the high fertility fields (Figs 4, 5, 6 and 7. Both Nyabeda and Nyalgunga are in Siaya County and have same similar soil types when compared to Emusutswi in Vihiga County. The variation therefore may have resulted due to the inherent soil properties and the rainfall distribution in the different sites. The experimental plots in Siaya lie on gently undulating topography and experiences less rainfall when compared to plots in Vihiga that lie on sloppy topography. Nutrient leaching is less likely to occur in Siaya than Vihiga, thus the resultant higher pH, N and P levels (Figs.4, 5 and 7). This is in line with the findings of Lehman and Schroth (2003) who reported that inherent soil properties such as clay content, length and steepness of slope and soil depth were correlated to nutrient availability in soils.

At flowering stage, there were no significant differences observed across sites, fertility gradients and treatments in pH, %N, %OC and P (Figs. 4, 5, 6 and 7). This could be attributed to the addition of the organic and inorganic amendments that allowed an improvement in Vihiga soils to show similar characteristics as those experienced in Siaya. This is in line with Achieng *et al.*(2010) who reported that addition of organic and inorganic fertilizers have the potential of improving soil chemical and biological properties.

At harvest, the %OC showed significant differences ($P<0.01$) across sites and treatments and there were significant differences in P across treatments. The differences observed in %OC may be attributed to the fact that FYM applied in the 3 sites was dependent on the number of cattle and the quantity and quality of food the cattle were fed on. It also depended on the crop residues available in each site. Farmers in Siaya owned larger farms and more cattle as compared to those in Vihiga and hence they had more crop residues and animal waste which translated to larger quantities of

FYM available for their farms. Siriri and Mwebaze (2000) reported that a zero grazing cow could produce up to 1.5 tons of manure per year. Hence two animals would be needed to supply a 2 ton maize crop, if the manure were of high quality, but eight animals would be required if the manure was of low quality depending on the feed for the cattle.

There were however no significant differences observed across sites, treatments and fertility gradients in pH and % N at the maturity stage. This can be attributed to the soil's inherent properties. Both ferralsols and acrisols are heavily leached soils and exchangeable cations are replaced by Al and H resulting in the soil becoming more and more acidic. The soils are also usually depleted of N and it would therefore require large amounts of N added to the soil for both plant uptake and soil replenishment before a significant increase in soil N can be observed. The results are similar to those of Kihanda and Warren (2011), who observed no change in soil N when a low quality N substrate (saw dust) was added to a maize growing field and an increase in soil N when a high quality N substrate was added to the same field.

Mineral N, CEC, exchangeable Ca, K and soil respiration (Tables 2, 3 and 4) showed significant differences across treatments with the highest being mavuno +manure treatment at harvest. The addition of FYM resulted in the creation of favourable conditions for microbial activity hence microbes broke down nutrients into forms readily available for plant uptake. Also the FYM improved the soil structure, enabling the soil to readily exchange cations thus an increase in the CEC of the soil and the exchangeable bases in the order control< IR +manure< IR +mavuno + manure (Tables 3 and 4). This is in agreement with Krishnakumar *et al.* (2005) who reported that among the organic N sources, application of FYM registered maximum population of bacteria, fungi and actinomycetes in a study conducted to assess the effect of various fertilizer sources on microbial populations. Krishnakumar *et al.* (2005) further attributed this to the enhanced organic carbon content to the soil that improved soil physical properties such as structure and hence CEC and microbial population.

Soil pH

There were significant (P<0.01) differences in initial soil pH across sites (Fig. 4). The highest pH was observed at flowering of the crop. There was a general decrease in soil pH from flowering to harvest stages.

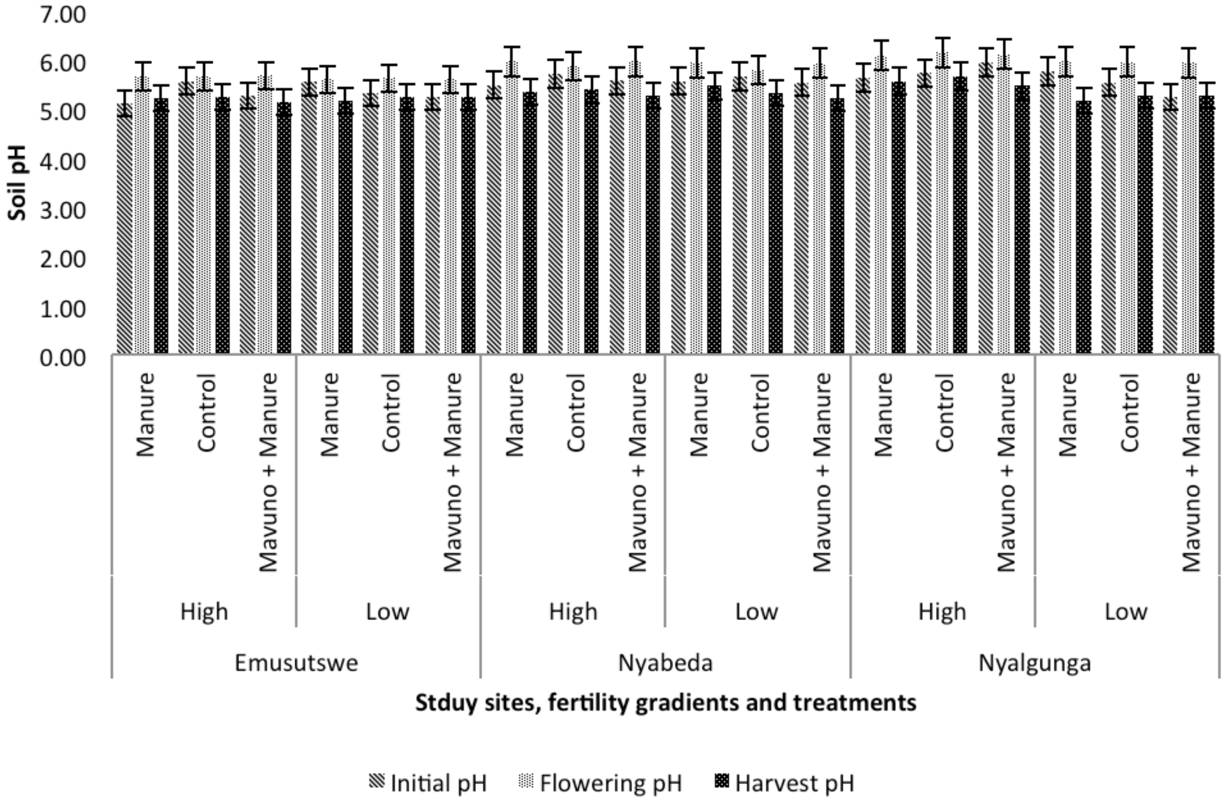

Figure 4: Effects of different fertilizer treatments on soil pH between two fertility gradients at different sites depending on maize phenological stages.

The differences across sites may be due to the variations in soil types and rainfall distribution across sites. Emusutswi is in Vihiga and Nyabeda and Nyalgunga are in Siaya. Vihiga receives higher rainfall resulting in leaching of cations and accumulation of Al^+ and H^+ ions hence making the soils more acidic. This is in line with Basu *et al.* (2011) who found that inorganic fertilizer treatments had an acidifying effect and hence reduced soil pH. The pH ranged from 5.1-6.0 in all the fields before the maize crop was planted. During the flowering stage there was a slight increase in pH ranging from 5.6 -6.1 and when the crop had matured pH ranged from 5.2 to 5.7 (Fig.4`). The slight decrease in pH from initial to maturity may be attributed to the manure added to the soil and high rainfall during the growing season. When microbes decompose manure added to the soils they produce acids in the process and if these acids are in large amount, a significant decrease in pH is observed. These results are similar to those of Nalatwadmath *et al.* (2003) who recorded an increase in production of acids on decomposition of organic manure (FYM) that resulted to decreases in soil pH.

The results also showed higher decreases in soil pH in the IR+mavuno+manure treatment when compared to treatment with manure alone treatment, indicating that mineral fertilizers can cause soil acidity. This view is also supported by the findings of Thomas *et al.* (2007) who reported that soil pH decreased with increased doses of N fertilizer from pH of 7.5 to 7.2.

Phosphorus

There were highly significant differences in P levels between treatment means (P<0.01) at all stages of crop growth. The P levels across sites and treatments were highest at the flowering stage and reduced at maturity (Fig. 5) in Nyabeda and Nyalgunga. This may be due to plant uptake of the nutrient during the flowering stages as P is a critical element in root development, flower initiation, and seed and fruit development. This findings are the same as those of Uchida (2000) who found reduction in P during the flowering stages of the crop and in later stages observed a slight increase.

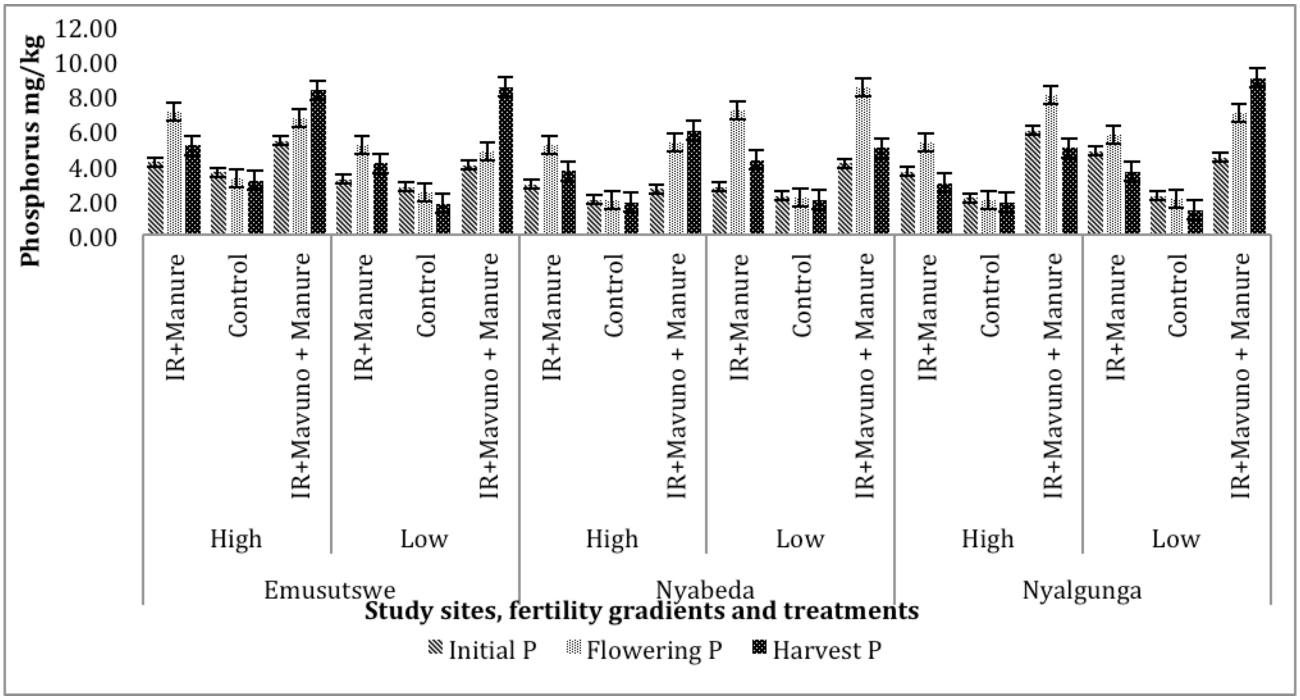

Figure 5: Effects of different fertilizer treatments on soil phosphorus between two fertility gradients at different sites depending on maize phenological stages.

The IR+ mavuno+manure treatment had the lighest P (9.00 mg/kg) at maturity stage as observed in Nyalgunga in the high fertility field compared to 1.41 and 3.61 (mg/kg) for the control and manure respectively. Mavuno is a P fertilizer and contains 26% P_2O_5 that improved the soil's mineral components. On the other hand FYM, may have improved the soil's structure and hence its ability to hold nutrients. Thus the mavuno+ manure treatment created an ideal environment for nutrient uptake by the plant and retention in the soil matrix. These results indicate that a combination of both organic and inorganic fertilizers is better at improving soil P compared to their sole applications. These results are in agreement with those reported by Kathuku *et al.* (2011) where there was an increase in yield and soil nutrients in soil that were supplied with mineral N fertilizer combined with manure when compared to manure only applications.

The IR + mavuno+manure treatment registered higher levels of phosphorus compared to the manure only treatment. The sites and fertility gradients were not significantly different in P content and this is due to the nature of the soils (ferralsols, nitosols and acrisols) across sites, which are acidic and heavily leached. Gachene & Kimaru (2003) support these findings and reported that the nature of ferralsols and nitosols are that they are usually deficient of N and P due to heavy leaching. If pH is lower than 6, P starts forming insoluble compounds with iron (Fe) and aluminium (Al) and if pH is higher than 7.5 P starts forming insoluble compounds with calcium (Ca) (Abaye *et al.*, 2006).

Organic Carbon

Soil organic C showed significant differences across sites at the initial soil sampling (P<.0.01) and the highest mean (2.19%) observed in Nyabeda which was significantly different from Nyalgunga (1.87%) and Emusutswi (1.84%) (Fig. 6).

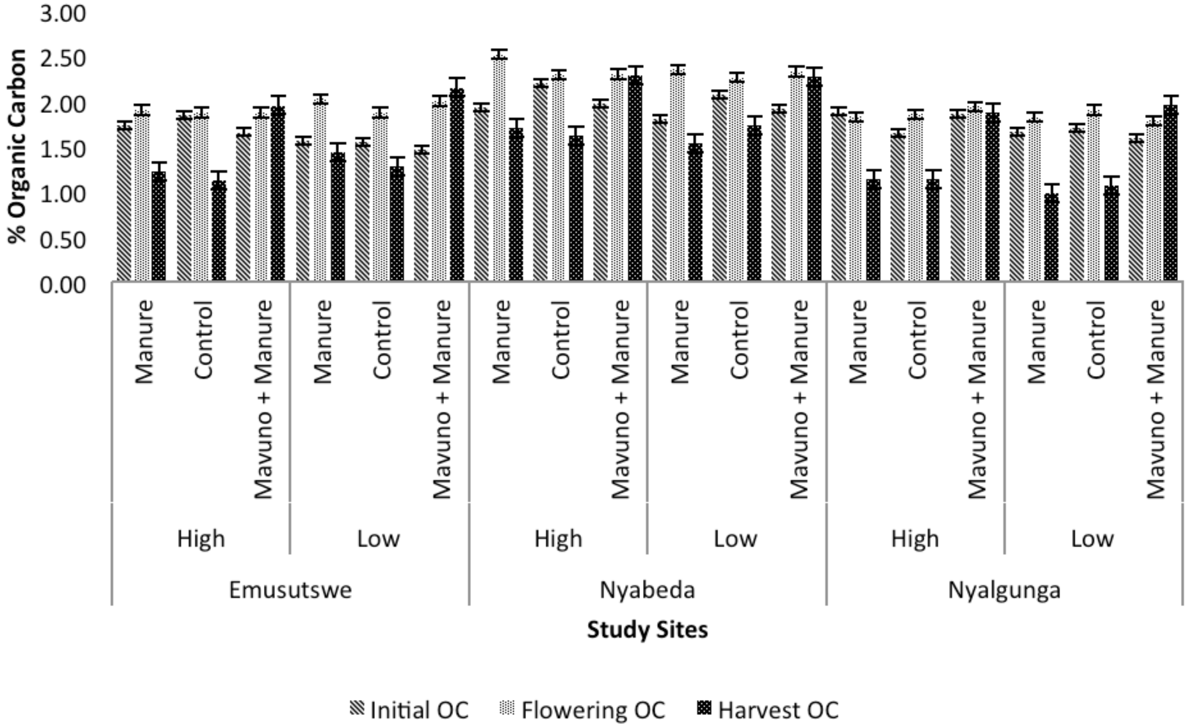

Figure 6: Effects of different fertilizer treatments on soil organic carbon between two fertility gradients at different sites depending on maize phenological stages.

At the flowering stage, there were no significant differences across sites, treatments or fertility gradients in %OC. Percent C was higher at the flowering stage across several treatments than at initial and final sampling. This may be attributed to high precipitation during the flowering stage (Fig. 2) that resulted in an increase in soil organic carbon. This is due to the moist environment and moderate temperatures created when it rains that allow soil microbes to become active and hence breakdown organic residues thus increase the soil carbon. This is also suggested by Alvarez and Lavado (1998) that soil organic carbon increased with higher precipitation and decreased with higher temperature. Consequently, the organic carbon content in the top 0–20 cm soil layer is positively correlated with the precipitation/temperature ratio.

There were significant ($P < 0.01$) differences observed at the maturity stages of growth across sites and treatments (Fig. 6). The differences across sites may be attributed to the clay content in the soils of the different sites. The higher the clay content a soil has, the higher the %OC it contains due to the stability of clay colloids. Results in the work of Feller and Beare (1997) support the argument and reported that organic carbon generally increased with the clay content. The treatments had an influence on the %OC as hypothesized when a combination of organic and inorganic amendments were added and not manure only application.

The control and the manure treatments were not significantly different from each other and this could be due to low quality (P<10mg/kg and %OC <5%) manure added to the soil that really did not make significant contributions in altering the carbon content of the soil. The FYM used in the above study may have been of a lower quality with low N content and therefore high C:N ratio (>30:1) resulting in large volatilization of CO_2 into the atmosphere hence loss in carbon. In support to this Dadhich *et al.* (2011) reported that application of organic inputs such as FYM, in the required amounts significantly increased organic carbon but if these organic inputs are of low quality this can cause a reduction in the soil. The quantity and quality of organic inputs will affect rate of decomposition hence more organic inputs with high N content the higher the decomposition rate.

Total Nitrogen

The % N showed (P<0.01) significant differences in the sites at the initial stages of the growing season. All sites were significantly different from one another with the highest %N observed in Nyabeda (0.195%) and the lowest in Emusutswi (0.161%) (Fig 7).

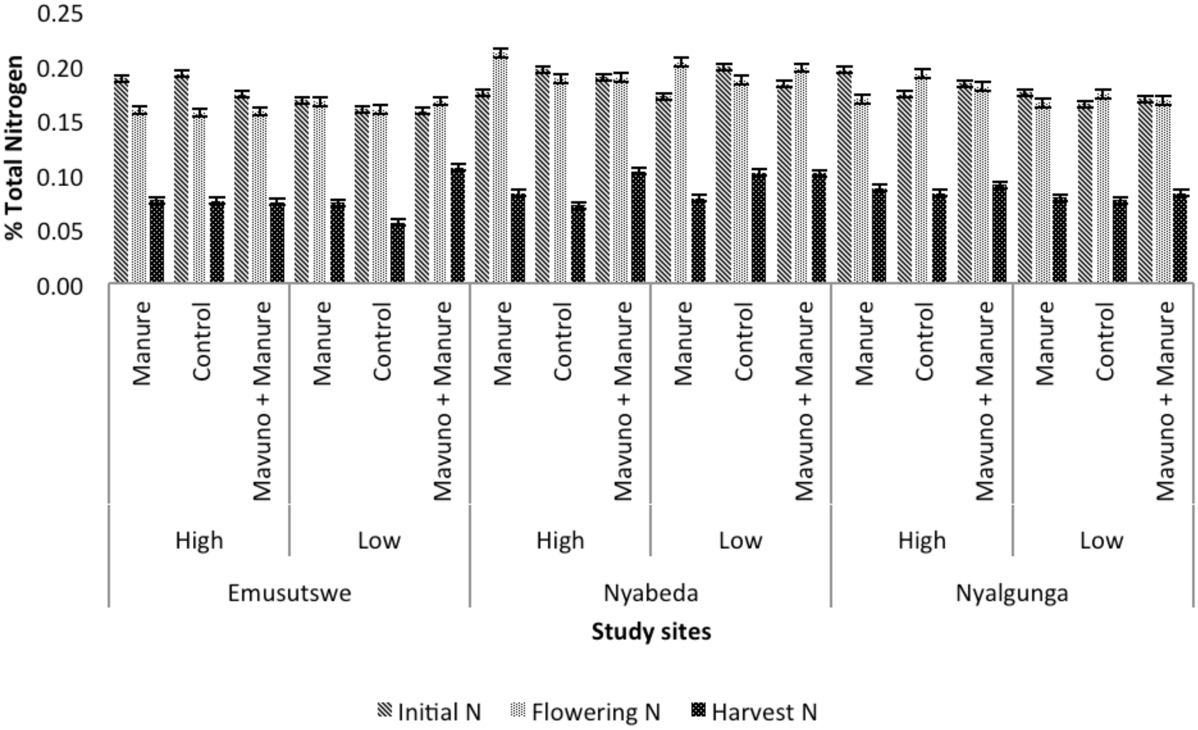

Figure 7: Effects of different fertilizer treatments on soil nitrogen between two fertility gradients at different sites depending on maize phenological stages.

This can be attributed to previous cropping systems practiced by the farmers prior to the experiment. Farmers in Siaya grew legumes which may have fixed nitrogen and hence resulted in a significant differences being observed across sites in %N at initial soil sampling. The findings are the same as those reported by Oriola and Bamidele (2012) that the cropping systems have effects on soil elements, fertility status and has implications for agricultural productivity.

There were no significant differences in %N across treatments, sites and fertility gradients at flowering and maturity stages as hypothesized. This may be attributed to the low N content of the FYM (P<10mg/kg and %OC <5%) added and Mavuno which contains 10% N and also to manure's slow release of nutrients. This is supported by Johnson, *et al.*(1987) that a substrate with low N and hence a high C:N ratio results in a disappearance of nitrates from the soil due to great demand from microbes for reproduction. Nutrient leaching is also evident as the treatments showed no significant differences. The types of soils under study require large fertilizer amendments in order to make a significant N increase in the soil to cater for N uptake by plants and also N leaching since nitrogen is the most mobile nutrient in the soil due to its ability to exist in various forms.

There was however a decrease in %N in most of treatments across the three sampling stages in the order initial < flowering < maturity (Fig.7). This could be attributed to maize uptake and development. This is in line with the findings of Lelei *et al.* (2009) that N was taken up by maize throughout the growing season with maximum uptake recorded at 10 days before to 25 to 30 days after tasselling. N losses can also be attributed to leaching down the soil profile due to heavy rains, microbial immobilization and or denitrification. Hoeft (2004) supports the findings and reports that excessive rainfall is an effective agent for removing basic cations resulting in losses in agricultural nutrients.

Mineral Nitrogen

Mineral nitrogen, showed significant differences ($P<0.01$) between treatments at maturity stage of crop growth (Table 2). The highest was recorded in the mavuno+ manure treatment, 11.29mg/kg and 10.72mg/kg for NH_4^+ and NO_3^- respectively. The lowest was recorded in the control plots 5.64mg/kg and 3.76mg/kg for NH_4^+ and NO_3^- respectively. There were no significant differences observed across sites and fertility gradients.

Table 2: Mineral N across treatments, fertility gradients and Sites (values followed by the same letter in a row are not significantly different)

Mineral N (mg/kg)	Site	Fertility	Control	Manure	Mavuno+Manure
NH_4^+	Emusutswi	High	6.70^b	9.52^a	10.66^a
		Low	5.65^a	8.59^b	11.29^c
	Nyabeda	High	6.70^a	8.71^a	8.57^a
		Low	6.08^a	8.12^a	9.84^b
	Nyalgunga	High	6.36^a	8.43^{ab}	11.26^b
		Low	7.53^a	9.44^a	9.09^a
SED =1.253					
LSD= 2.511					
NO_3^-	Emusutswi	High	5.15^a	9.52^b	9.68^b
		Low	3.46^a	9.65^b	8.30^b
	Nyabeda	High	7.62^a	6.17^{ab}	9.52^a
		Low	4.89^a	8.84^b	9.22^b
	Nyalgunga	High	7.28^a	8.94^a	8.29^a
		Low	7.98^a	8.26^a	10.72^b
SED = 1.219					
LSD = 2.443					

The significant differences across treatments can be attributed to the overall increase in N due to addition of both mavuno which contains 10% N and manure which improved soil structure and hence aggregate stability. This resulted in improving the soils' CEC and hence its ability to retain cations. This is supported by the findings of Nyamangara *et al.* (2009) who reported that organic resources were poor and inadequate sources of N but were to be supplemented with mineral N to reduce N immobilization but they had the potential to improve the soil physical environment.

CEC and **Exchangeable bases** There were significant differences across treatments in CEC (P<0.01) with the highest CEC recorded in mavuno+ manure treatment. Sites and fertility gradients were not significantly different from each other (Table 3).

Table 3: Mean CEC in different Treatments (Values followed by the same letter in a row are not significantly different**)**

Site	**Fertility**	**Control cmolc/kg**	**IR+Manure cmolc/kg**	**IR+Mavuno+Manure cmolc/kg**
Emusutswi	High	25.50^{a}	29.50^{ab}	36.87^{b}
	Low	24.88^{a}	19.25^{a}	42.12^{b}
Nyabeda	High	32.38^{a}	23.13^{a}	43.75^{b}
	Low	30.50^{a}	20.00^{b}	47.88^{c}
Nyalgunga	High	30.00^{a}	26.25^{a}	44.50^{b}
	Low	29.37^{a}	19.62^{a}	44.37^{b}
SED= 4.88				
LSD =9.80				

The exchangeable bases, Ca and K showed significant differences across treatments and Mg across sites (Table 4).

Table 4: Exchangeable bases across sites fertility gradients and treatments (values followed by the same letter in a row are not significantly different**)**

Ex. Base (cmolc/kg)	**Site**	**Fertility**	**Control**	**IR+Manure**	**IR+Mavuno+manure**
Ca	Emusutswi	High	0.58^{a}	1.47^{a}	3.13^{b}
		Low	0.54^{a}	1.75^{ab}	2.94^{b}
	Nyabeda	High	0.62^{a}	2.24^{b}	3.35^{b}
		Low	0.75^{a}	2.30^{b}	4.53^{c}
	Nyalgunga	High	0.68^{a}	2.85^{b}	3.71^{b}
		Low	0.67^{a}	1.68^{a}	3.19^{b}
SED=0.694					
LSD=1.391					
K	Emusutswi	High	0.11^{a}	0.74^{b}	0.18^{a}
		Low	0.07^{a}	0.78^{b}	0.18^{c}
	Nyabeda	High	0.16^{a}	0.83^{b}	0.34^{c}
		Low	0.09^{a}	0.81^{b}	0.25^{a}
	Nyalgunga	High	0.35^{a}	0.76^{b}	0.61^{ab}
		Low	0.09^{a}	0.88^{b}	0.39^{a}
SED=0.181					
LSD=0.363					
Mg	Emusutswi	High	0.30^{a}	0.25^{a}	0.31^{a}
		Low	0.31^{a}	0.30^{a}	0.28^{a}
	Nyabeda	High	0.46^{a}	0.42^{a}	0.43^{a}
		Low	0.41^{a}	0.45^{a}	0.33^{a}
	Nyalgunga	High	0.57^{a}	0.48^{a}	0.50^{a}
		Low	0.47^{a}	0.46^{a}	0.37^{a}
SED=0.088					
LSD=0.177					

The CEC and exchangeable bases such as Ca and K vary according to the soil type and amendments added to the soil. The CEC of soils also depends on the amount and composition not only of clay minerals but also of soil organic matter (SOM). The higher the organic matter content in a soil the higher the CEC that soil has and hence the higher its exchangeable bases. This explains the significant differences observed in CEC and exchangeable Ca and K across treatments. These findings are supported by Kaiser *et al.,*(2008) and Brix (2008) who report increase in CEC and exchangeable bases in treatments where both mineral and organic fertilizers were added. The manure treatments exhibited lower CEC values compared to the control. This could be attributed to the low quality of the FYM that results in little or no change in the soil's structure and hence its ability to attract cations. This is also reported by Jagadeeswaran *et al.* (2005) that organic residues most available to farmers have low nutrient concentrations with limited potential to improve soil properties when applied as the sole source of nutrients.

Soil respiration

Soil Respiration showed no significant differences ($P<0.01$) in treatments means after 3 days of incubation but higher respiration rates were noted from IR+ Mavuno+Manure treatment (Fig. 8). There were no significant differences across sites. Soil samples from the manure treatment were not analyzed due to non-refrigeration soon after sampling and therefore results for the same are not indicated.

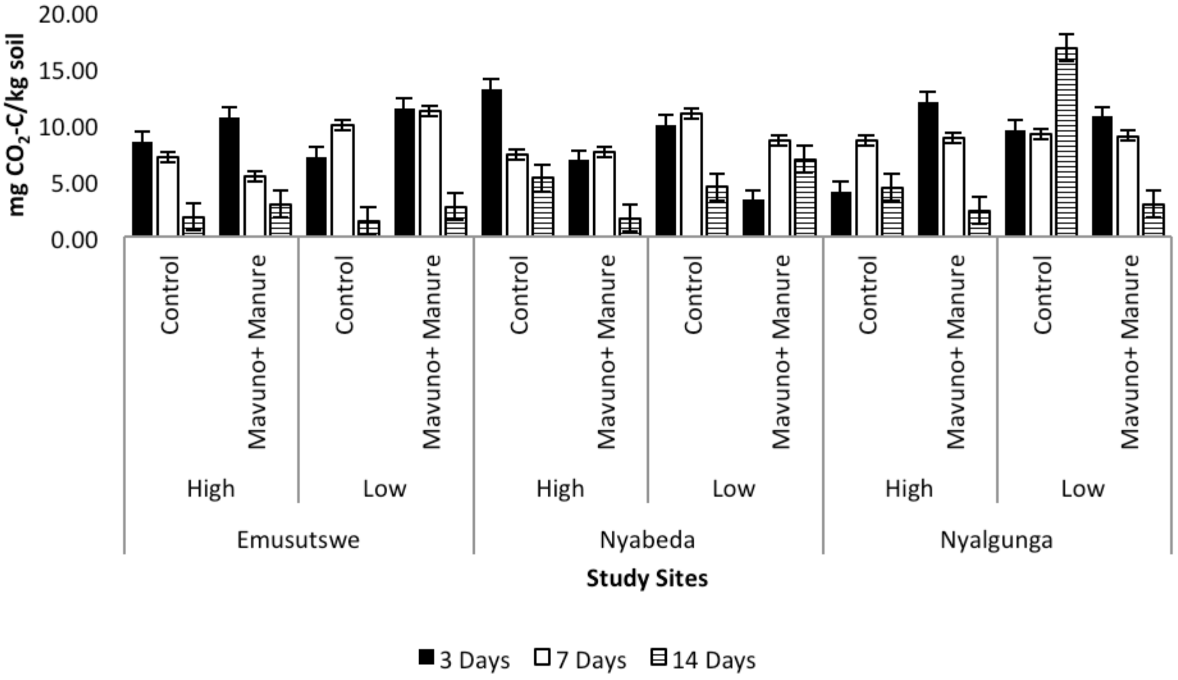

Figure 8: Effects of different fertilizer treatments on soil respiration between two fertility gradients at different sites at 3, 7 and 14 days of incubation

The higher respiration rates in the IR+mavuno+mavuno treatments could be attributed to higher organic matter present in fertilizer-amended plots hence a higher activity in microbes as opposed to the control plots. After 7 days and 14 days of incubation, the low and high fertility plots were significantly different ($P<0.01$). Treatments were however not significantly different with respect to soil respiration after 7 and 14 days of incubation. Organic carbon respiration is a reflection of the microbes present in the soil under study. The IR+mavuno +manure treatment and the manure only treatment provided organic matter to the soil a source of energy for the microbes in the soil. In degrading the organic matter the microbes respired resulting in higher respiration rates observed in the treatments. The control plot however did not have any organic matter added to it implying that very little microbial activity was present in the soil. This therefore resulted in lower respiration rates being observed. This is in line with the findings of Fanin et al. (2011) who reported that microbial respiration rates were affected by composition of organic matter in the soil.

The soil respiration rates across treatments and sites were generally below 9.5 mgCO_2/kg/day (fig. 9) indicating that there is very low soil activity. This is a sign that the soil is much depleted of available organic matter and has little biological activity. Apart from this temperature and soil moisture content also affect soil respiration rates. Higher respiration rates were observed in the mavuno+ manure treatment (Fig. 8). These findings are in line with Yuste *et al.* (2007) who reports that the higher the carbon inputs added to the soil the higher the soil respiration. The results however also observed an abnormality in Nyalgunga were higher soil respiration rates were obtained in the control treatment as opposed to the fertilizer amended one. Soils in this treatment has a medium soil activity indicating that the soil could be approaching or declining from an ideal state of biological activity (United States Department of Agriculture, 2001).This could be due to exposure of organic matter to organisms and oxygen following tillage (Stoyan *et al.,*2000).

4.1.4 Conclusions

Soil chemical and biological properties were improved in fields applied with both mavuno and manure. Manure application improved soil properties but not as much as the combined application of manure and mavuno. Soil fertility gradients did not differ significantly in chemical and biological properties.

4.2 COMBINED EFFECT OF MAVUNO AND MANURE FERTILIZER ON SOIL ORGANIC CARBON FRACTIONS

4.2.1 Abstract

A soil's ability to resist erosion and maintain good levels of C and N rests in the distribution of its fractions. Soil management practices alter organic carbon fraction distribution and hence the ability of the soil to sequester carbon or resist erosion. The study's main objective was to look at the influence of organic (FYM) and inorganic fertilizer (Mavuno) fertilizer on C fractions in soils from Siaya and Vihiga Counties of Western Kenya. The treatments applied were no fertilizer added (control), IR + manure, and IR +mavuno+ manure with IR maize as the test crop. Soils were wet sieved to separate into 4 carbon fractions; large macro-aggregates (LM), small-macro-aggregates (sM), micro-aggregates (m) and silt and clay (S+C). The results indicated that there were significant differences in the carbon fraction distributions in different soils but no significant differences in the LM, sM, m and S+C fraction proportions in different sites, treatments and fertility gradients. Elemental combustion was carried out and significant differences in %C and %N organic C fractions were observed across treatments with the highest % C (2.052) and % N in (0.1816) in the silt and clay fraction. A combination of both manure and mavuno increased %N and %C in carbon fractions. The treatments, fertility gradients and sites had no effect on the carbon fraction distribution.

Key word; organic carbon fractions, mavuno, farm-yard manure

4.2.2 Introduction

Soil organic carbon (SOC) is the carbon stored within soil and is part of the soil organic matter (SOM). SOC is composed of fractions and the knowledge of the type of organic carbon fraction present is important as this greatly impacts soil productivity. The four biologically significant fractions of soil organic carbon identified by Baldock (2010) are crop residues, particulate organic carbon, individual pieces of plant debris that are smaller than 2 mm but larger than 0.053 mm, humus which are less than 0.053 mm and are dominated by molecules stuck to soil minerals and recalcitrant organic carbon which is biologically stable and typically in the form of charcoal. The fractions do not only differ in size but also in material compositions and have different chemical and physical properties and decomposition rates (Yang *et al.*, 2005).

SOC fractions have different functions depending on the fractions' relative stability and biological availability. The amount of each carbon fraction varies significantly across soil types and some fractions can be altered by management practices (Six *et al.*, 2000).

Farmers in Siaya and Vihiga manage their maize fields by application of mavuno and FYM as these are cheap and readily available methods. There is however preferential application of these fertilizers resulting in the formation of fertility gradients within one farm. It is therefore important to analyze the effects of these fertilizers on carbon fraction distribution so as to make informed decisions on the potential for the soils in the study area to sequester carbon or resist erosion based on the different sites, the fertility gradients and the treatments applied. The study therefore grouped the carbon fractions identified by Baldock (2010) into large macro-aggregates (LM) >2000mm; small macro aggregates (sM) 250 - 2000mm; micro aggregates, (m) 53-250mm; and silt and clay (S+C) <53mm (Six, 2011).

It is important to differentiate aggregate size classes within the soil as this gives a measure of the soil stability and therefore differentiate a more resistant soil to one that is prone to soil erosion (Stewart *et al.,* 2009). A soil that has more macro aggregates, has a better soil structure and therefore more resistance to soil erosion. The soil matrix affects microbial activity, nutrient cycling and carbon sequestration and in this regard macro aggregates are not important in C sequestration because they are less stable and therefore more dynamic when compared to micro aggregates. They are however important as a temporary nutrient sink and source, thus are critical for soil fertility. Micro aggregates on the other hand, are more stable and less dynamic and form an ideal microenvironment for microorganisms. In micro-aggregates a bit of carbon is stabilized creating a long-term pool for carbon. The silt and clay fractions are a non-aggregated fraction containing lot of older carbon that is stabilized within the silt particles (Six *et al.*, 2000).

4.2.3 Materials and Methods

4.2.3.1 Site Description and farmer selection

Fertility trials were conducted on- farm in 3 locations, Nyalgunga and Nyabeda in Siaya County and Emusutswi in Vihiga County all in Western Kenya. The area receives rainfall averaging over 2000mm per annum and temperatures are as high as $35^{o}C$ (Cheserem, 2012b). The two main soil types in Emusutswi are humic nitosols and ferralsols and Nyabeda and Nyalgunga have ferralsols and acrisols (Gachene & Kimaru, 2003). From the three sites, 12 farmers were selected, 4 from each site, using Y frame sampling procedure (Tittonell *et al.*, 2010). Farms were demarcated into fertility gradients as perceived by farm owners.

4.2.3.2 Experimental Design and treatments

A randomized complete block design with a split plot arrangement replicated 4 times (with each farmer acting as a replicate) was used to test the effect of fertilizer application on soil carbon fractions. The main plots were the fertility gradients (high and low) and the subplots were the fertilizer treatments; control, IR + manure and IR + manure+ mavuno. IR maize was used as the test crop and mavuno was applied at a rate of 20kg P per ha whilst FYM was applied as a projection of 2 tons per ha. IR maize was planted at a spacing of 30cm X 75cm in a plot of size 6mX4m, weeded twice and top dressed with mavuno.

4.2.3.3 Soil sampling and analysis

Soil samples were collected using a soil auger at a depth of 0-20 cm at 5 points using W-sampling procedure as described by Peters *et al.* (2008). The soil was composited, and then divided into four equal parts and a 200g sample obtained and placed in labeled plastic containers. The soils were then passed through an 8mm sieve to homogenize the sample and break apart other larger soil particles. The method for separating soil into different stable aggregates used was adopted from Six (2011). The procedure has four parts (Fig. 1) but for this experiment only one part, Part A, was of interest, which is the wet sieving of the soil. After wet sieving the soil aggregates were further analyzed using the Costech ECS 4010 elemental combustion system to analyze the amount of C and N in the different soil fractions

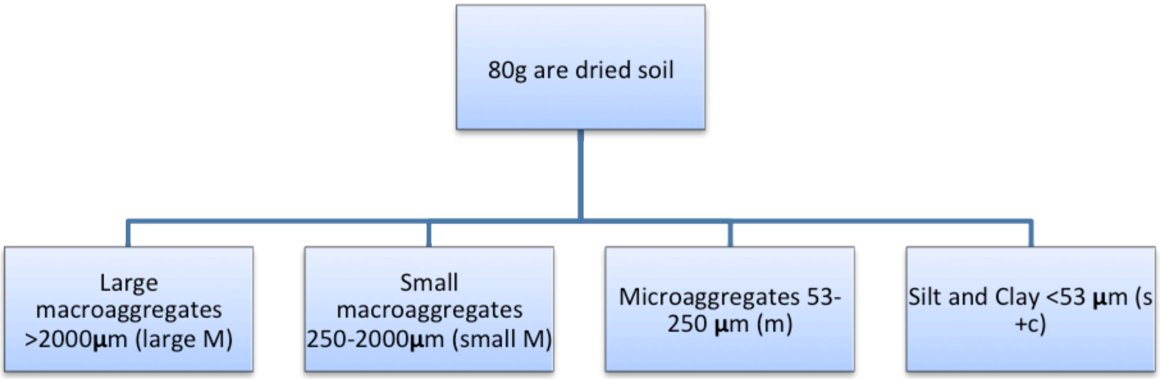

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Figure 9: Procedure for Soil Organic Carbon Fractionation as modified from Six (2011)

4.2.3.4 Wet-sieving of soil.

80 g of a subsample from air dried whole soil was weighed using a digital balance. A white 30cm diameter and 8cm deep basin was filled with water and a 2000 mm sieve-mesh placed into it. The soil subsample was sprayed evenly on the sieve and allowed to soak for 5 minutes. The soil was then sieved through the mesh for 2 minutes by moving the sieve 50 times up and down with a slight angle ensuring that water and small particles went through the mesh. The >2000 mm aggregates, that is large macro aggregates were backwashed into a pre-weighed small drying pan. Floating litter was also decanted into a drying pan. The sieving procedure was repeated but using 250 mm mesh (small macro aggregates), 53 mm mesh (micro aggregates), and the aggregates were all placed in pre weighed drying pans. The remaining particles < 53 mm particles (silt + clay) were also transferred into a drying pan.

The experiment aimed to separate the soil into different water stable aggregate size fractions in order to look at the stability of the soils as well as the carbon and nitrogen stabilized in the fractions as affected by organic and inorganic fertilizers. When the soil sample soaks for five minutes, it mimics the field situation. The water goes into the aggregate from the outside and pressure builds up within the aggregate. For an unstable aggregate, when the pressure becomes too much that the aggregate cannot withstand it, the aggregate breaks unless if that aggregate is very stable then it can actually handle that pressure and so does not break up. It is therefore basically the process of slaking and pressure build up that determines if an aggregate is stable versus an aggregate that is not stable (Six, 2011). The study hypothesizes that organic and inorganic amendments influence soil stability by affecting the quantity and quality of organic fractions. At the end of the wet sieving of each subsample there were 5 drying pans each with soil fractions. All the drying pans with soil fractions were then transferred into a 60°C forced air dry oven. After the soil samples in the pans had dried, the pans were re-weighed and the soil weight was calculated as follows;

$$Soil\ Weight = (Pan + soil\ weight) - \ empty\ pan\ weight$$

4.2.3.4.1 Elemental Combustion

The different soil fractions collected from the wet sieving, silt+clay (S+C), micro aggregates (m) and macro-aggregates (sM+ LM) were passed through the elemental combustion system. A sample of between 19- 20 mg soil was weighed using a microbalance and placed in aluminium weigh tins. The soil samples were then transferred into the Costech ECS4010 elemental combustion system that was responsible for detecting N and C levels of the different fractions.

4.2.3.4.2 Data Analysis

Analysis of variance to assess the site effect, treatment effect, fertility gradient effect and their interactions on soil carbon fractions and the C and N content of the fractions was conducted using GENSTAT 14th edition. The Least Significant Difference (LSD 5%) was used to separate means of significant differences.

4.2.4 Results and Discussion

4.2.4.1 Proportions of Soil Organic Carbon Fraction

There were no significant differences in the weight of LM, sM, m and S+C fraction proportions across sites, treatments and fertility gradients (Fig. 10). The transportation, storage and handling of soil samples may have resulted in breakage of the aggregates and hence affecting their proportions in the soil across treatments, sites and fertility gradients. Farmer fields in the study area are heavily infested with striga weed thus the continuous soil turnover during the growing season in order to control weeds may also have contributed to the breakdown of soil aggregates. This however is in contrast to the findings of Lee *et al*. (2009) who reported a significant difference in the carbon fraction proportions in long term fertilized fields. The differences could be attributed to the long term aspect in their experiment compared to the current study.

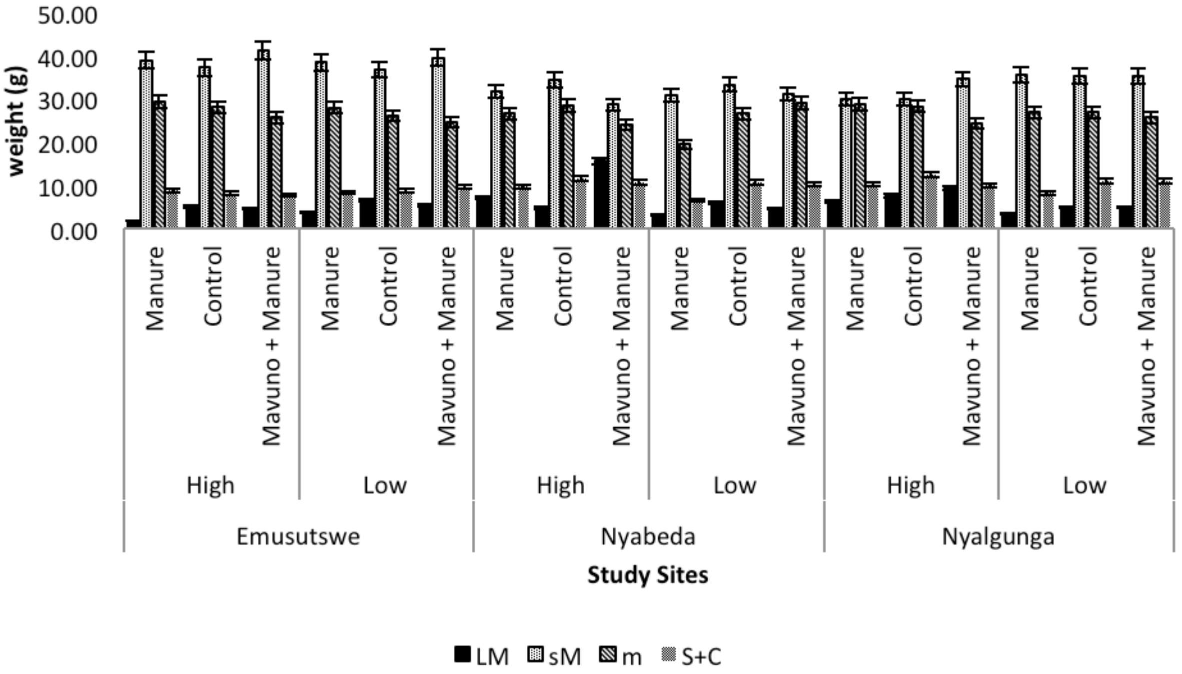

Figure 10: Effects of different fertilizer treatments on soil fractions between two fertility gradients at different sites.

The large proportion of sM can also be attributed to the breakdown of the LM (>2000 µm) during soil sampling, handling and transportation. In a similar study conducted by Six *et al*., (2000), results indicated that the proportion of macro aggregates (LM and sM) accounted for 85% of the dry soil weight and was similar across management treatments.

Low proportions (<10%) of the LM (>2000 µm) fraction in all treatments were also observed. This can be attributed to high decomposition rates of organic materials by microbes in the farmer fields as a result of high temperatures and available organic material on the soil surface. These findings are in line with those of Lee *et al.* (2009) who found the SOC proportion of LM fractions to be less than 3% in compost only fields. On the other hand, fraction breakup during sampling and storage cannot be entirely ruled out.

4.2.4.2 C and N composition in organic fractions

% Organic Carbon: Significant differences (P<0.01) were observed in the %C composition in the macro-aggregates (M), micro-aggregates (m) and the silt and clay (s+c) fractions across sites but not across treatments or fertility gradients (Fig. 11).

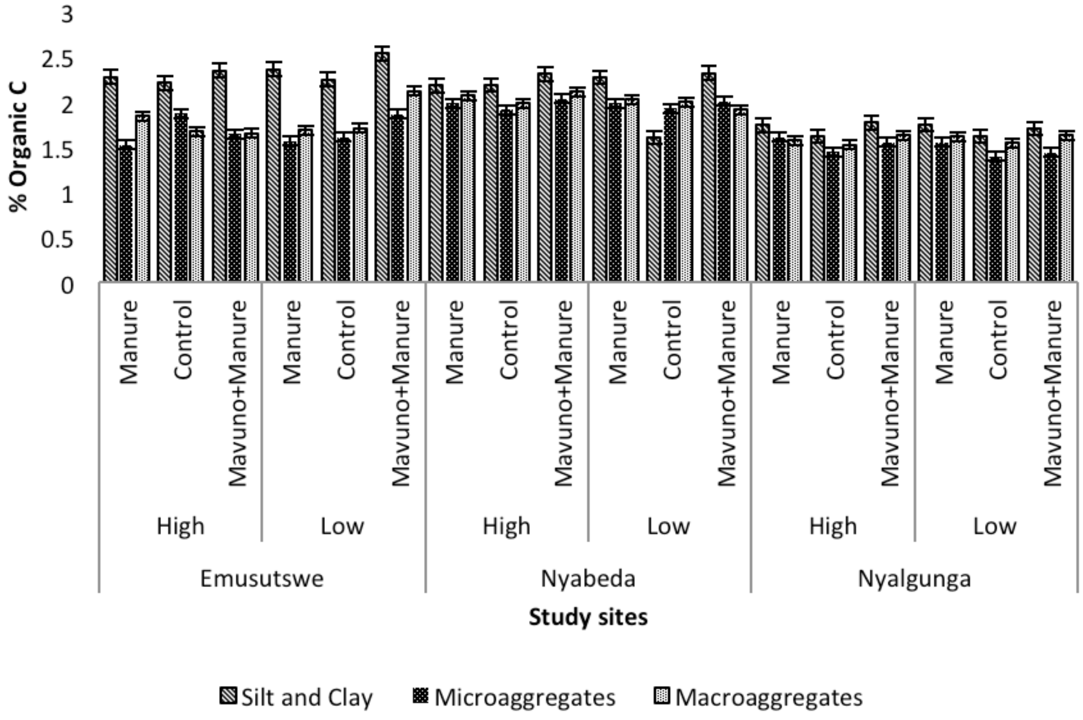

Figure 11: Effects of different fertilizer treatments on % carbon in soil fractions between two fertility gradients at different sites

SOM added to the soil in the form of FYM contributes to the quality of carbon fractions formed. The FYM added to the farmers' fields was specific to the sites and dependent on the quantity of organic residues and cattle manure the farmers had within their locality. This therefore may have resulted in the formation of SOM of different quality. The FYM added resulted in an increase in microbial populations in the soil that enhanced breakdown of organic material and hence resulted in significant differences in %OC in the aggregates formed across sites. The addition of mavuno did not influence the soil's physical properties but the chemical properties. After crop harvest, farmers in the study sites would leave crop residues in the field thus also causing no significant differences between the fertilizer amended plots and the control plots. The results are similar to those reported by Lee *et al.* (2009) that total SOC concentration was significantly increased by continuous addition of compost, but continually decreased with the chemical (NPK) and no fertilization (the control). In the NPK and control treatments, most of the SOC was supplied through the plant root biomass, because the aboveground part was removed at the harvesting stage.

Most of the SOC was accumulated in the particulate organic carbon (53 μm <sM <2000 μm) fraction that occupied over 75% of the total SOC in the control, manure and mavuno+manure treatments. This was the largest proportion of SOC because at harvest farmers leave crop residues in the plots forming a conducive microclimate for microbial activities. Microbes quickly act on the organic substrates and breakdown the crop residues into individual plant debris forming the particulate organic carbon. The highest OC (2.53%) was recorded in the silt and clay fraction. The silt and clay fraction is composed of decomposed materials that are dominated by molecules stuck to soil minerals. It also has recalcitrant organic carbon which is biologically stable thus resulting in all the carbon broken down from the macro and micro-aggregates, stabilized in the silt and clay fraction hence the highest OC recorded thereof. This is in line with Lee *et al.* (2009) who reported that after continuous addition of NPK fertilizers, NPK + compost and sole compost to the soil and testing for organic carbon in the various fraction, most of the SOC was accumulated with the organo-mineral fraction (<0.053 mm) which occupied 83%, 84%, 73% and 78% of the total SOC in the control, NPK, NPK + Compost, and Compost, respectively. The stability of the OC in the silt and clay fraction makes the silt and clay fraction a potential carbon sink in the long term (Six, 2011).

Total Nitrogen

Significant differences (P<0.01) were observed in %N in the silt and clay fraction across treatments and sites but not across fertility gradients (Fig. 12). The silt and clay fraction contains a high CEC due to the presence of humus which is the end product of decomposed organic matter. Organic matter colloids have large quantities of negative charges which are essential in attracting soil nutrients such as nitrogen (NH_4^+) resulting in higher nitrogen being observed in the silt and clay fraction compared to the macro and micro aggregates. The significant differences in %N observed across sites can be attributed to the soil's mineralogy across the sites. Siaya has ferralsols which are made up of acidic parent rocks with high quartz amount whilst Vihiga soils are humic nitosols that are developed from volcanic rocks. The clay particles of the sites therefore also differ. Loerch *et al.*(2012) reports that CEC varies according to the type of clay and is highest in montmorillonite clay, found in chocolate soils and black puggy alluvials.

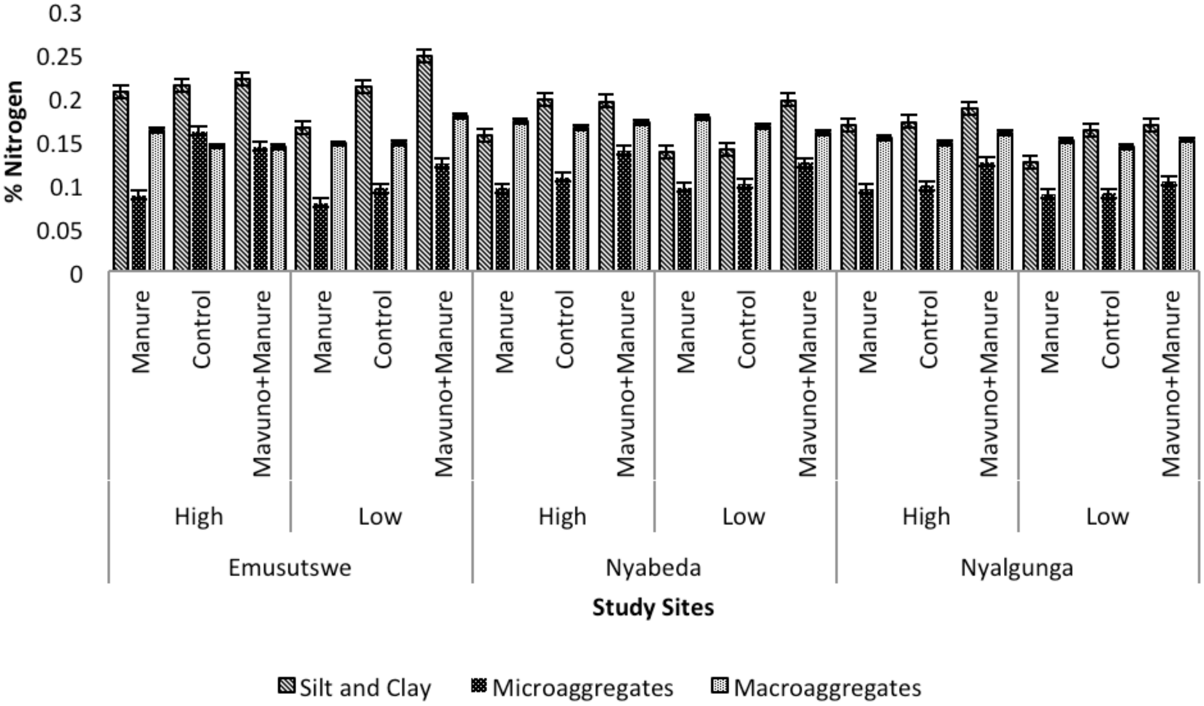

Figure 12: Effects of different fertilizer treatments on % nitrogen in soil fractions between two fertility gradients at different sites

It is lowest in heavily weathered kaolinite clay, found in ferralsols, and slightly higher in the less weathered illite clay. The significant differences in %N of the silt and clay fractions across treatments can be explained by the improvement of soil structure upon addition of FYM in the IR+manure and IR+mavuno+manure treatments. Soil particles are held together in a better aggregation and decreases soil loss hence nutrient loss resulting in %N being maintained in the soil in the biologically stable aggregates. This is supported by Krull *et al.* (2003) who reported that FYM played a critical role in improving the soil's structure and also added nutrients to the soil that were acted upon by microorganisms, resulted in the formation of humus that was more stable.

No significant differences were observed in %N in the macro and micro aggregate fractions across sites fertility gradients or treatments. The macro and micro aggregates are less stable when compared to the silt and clay fractions. They act as temporary nutrients sources for the time in which they are able to hold the nutrients before they are taken up by plants. Thus at the time of sampling, plants had reached maturity and had been harvested and hence nutrients were mined in the process leaving the macro and micro aggregates mined of nutrients.

4.2.5 Conclusions

Organic carbon fraction distribution was not affected by site, application of mavuno and manure or fertility gradients. The %OC in the silt and clay fractions were affected by the treatments applied with the mavuno and manure treatments exhibiting higher %OC. The macro and micro aggregates were not affected by the site treatments or fertility gradients. %N was affected by the sites and the treatments applied but not the fertility gradients and the highest %N was in the silt and clay fraction in the mavuno +manure treatment. It is therefore recommended that similar studies to be carried out with better care and handling of the samples.

4.3 EFFECT OF MAVUNO AND MANURE FERTILIZER APPLIED SINGLY OR IN COMBINATION ON STRIGA DENSITY AND MAIZE YIELD.

4.3.1 Abstract

The on-farm study to assess the effect of organic and inorganic fertilizers on striga density and Imazapyr Resistant (IR) maize yield was conducted in Vihiga and Siaya districts of Western and Nyaza provinces in Kenya respectively. The hypothesis was that maven and manure fertilizer application would improve soil fertility and hence decrease the occurrence of striga weed and increase IR Maize yields. The experiment was set up in a completely randomized block design with a split plot arrangement. The main plots where the fertility gradients and the sub-plots were the treatments, without fertilizer -control; IR+manure; IR+mavuno+ manure. IR maize (WS303) was the test crop. FYM was applied at a rate of 60kg N per ha and mavuno at a rate of 20kg P/ha. Maize yield was determined at maturity and striga density data were collected during the growing season. Significant differences in maize yields were observed across sites and treatments (P<0.01) with the highest maize yields observed in Nyalgunga (4833 kg/ha) in the high fertility field with mavuno +manure treatment. The lowest maize yields were observed in Emusutswi (263kg/ha) in the control treatment of the low fertility field. Results also indicated that the treatment was highly significant (P<0.01) in striga density with the highest striga density observed in the control (54,379 plants/ha). Integration of both organic and inorganic fertilizer in the plots reduced striga density and showed higher maize yields than plots the control and manure only treatments.

Key words: Farmyard manure, Mavuno, *Striga hermonthica,* Soil fertility

4.3.2 Introduction

Maize is a principal crop for smallholder farmers not only in western Kenya, but in most countries across sub-Saharan Africa (Sanginga & Woomer, 2009). Maize yield has however been greatly reduced by striga weed (Ejeta & Gressel, 2005). There are many species of striga weed and the most important of 11 species that attack crops are *Striga asiatica, Striga gesnerioides* and *Striga hermonthica* which is the most common and notorious in Western Kenya (Gethi *et al.*, 2005).

Striga hermonthica commonly known as the witch weed is an invasive weed that has shown great resistance in smallholder farms in western Kenya. *S. hermonthica* is thought to have originated from the Nuba Mountains of Sudan and Ethiopia and it is now widespread in many parts of Africa. It is an out crossing species with purple flowers (Photo 1) and produces huge amounts of seed estimated at between 58 000 and 200 000 per plant which can remain viable in the soil for a long period of time (Karaya *et al.*, 2010). *Striga* seeds, after germination attach to the host crop's roots through an organ known as the haustorium (Haussmann *et al.*, 2000). The striga parasite then sucks water and nutrients from the roots resulting in the crop showing symptoms of stunting chlorosis and in severe cases death. (Photo 2).

Photo 1: *Striga hermonthica* in maize field

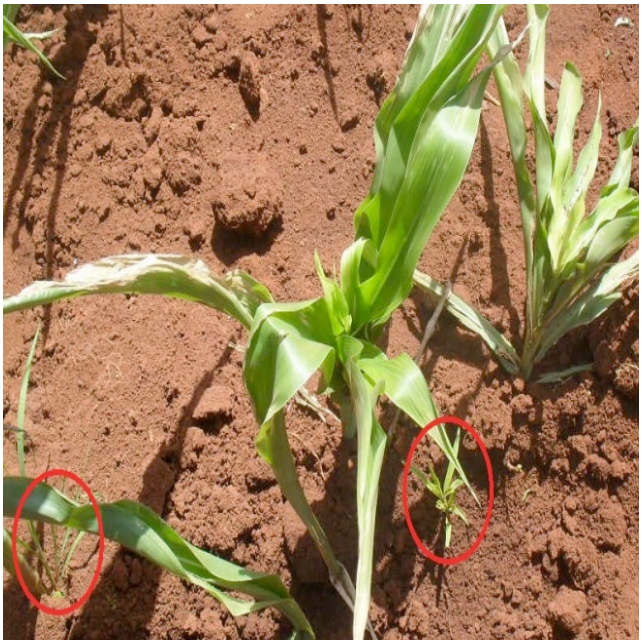

Photo 2: Maize stunting and chlorosis after striga attack

IR maize is maize seed that kills striga before it damages the crop. The seed is resistant to imazapyr herbicide, which is used a coating around the seeds. After absorption by the crop roots, the herbicide is exuded and kills attaching or attached striga seedlings as well as its nearby non-germinated striga seeds in soil (Kanampiu *et al.*, 2002). Losses resulting from striga can range from slight to total crop failure in heavily infested areas (Dugje *et al.*, 2006) and Ransom *et al.* (2011) reports that losses in cereal production are as high as US$311 million annually. This affects livelihoods of approximately 100 million people (Kanampiu *et al.*, 2002). In western Kenya, it is estimated that 76% of land planted to maize (*Zea mays L.*) and sorghum (*Sorghum bicolour L.*) Moench) is infested with *S. hermonthica*, causing annual losses of an estimated at US$40.8 million (Kanampiu *et al.*, 2002). According to Noubissie *et al.* (2012), the most effective way to control *Striga* is to use resistant crop varieties. This is a cheap and potentially durable control strategy suitable for small-holder famers like those in western Kenya. Resistance to *striga* has been found to be controlled by both major and minor genes (Haussmann & Hess, 2001). Hence an introduction of IR maize as a resistant variety can help in the reduction of the weed. Over the years, scientists have come up with various mechanisms such as handpicking, intercropping with legumes and use of Imazapyr resistant herbicide-coated maize (IR maize) to help reduce the occurrence of striga (Kanampiu *et al.*, 2002).

The low soil fertility is another constraint in western Kenya and it has been reported to contribute to the increases in striga occurrence (Vanlauwe *et al.*, 2008). The current study therefore hypothesizes to improve the fertility status of the soils through addition of both organic and inorganic fertilizers with use of resistant maize varieties could reduce the occurrence of *striga* and subsequently increase maize yields.

4.3.3 Materials and Methods

4.3.3.1 Site Description and selection of farmers

Fertility trials were conducted on- farm in 3 locations, Nyalgunga and Nyabeda in Siaya County and Emusutswi in Vihiga County all in Western Kenya (see Section 4.1.2, sub-section 4.1.2.2). The area receives rainfall averaging over 2000mm per annum and temperatures are as high as 35^{o}C (Cheserem, 2012b). The two main soil types in Emusutswi are humic nitosols and ferralsols and Nyabeda and Nyalgunga have ferralsols and acrisols (Gachene & Kimaru, 2003). From the three sites, 12 farmers were selected, 4 from each site, using Y frame sampling procedure (Tittonell *et al.*, 2010). Farms were demarcated into fertility gradients as perceived by farm owners.

4.3.3.2 Experimental Design and treatments

A randomized complete block design with a split plot arrangement replicated 4 times (with each farmer acting as a replicate) was used to test the effect of fertilizer application on striga density and maize yield. The main plots were the fertility gradients (high and low) and the subplots were the treatments; control, manure and manure+ mavuno. IR maize was used as the test crop and mavuno was applied at a rate of 20kg P per ha whilst FYM was applied as a projection of 2 tons per ha. IR maize was planted at a spacing of 30cm x 75cm in a plot of size 6m x 4m and weeded twice.

4.3.3.3 Plant sampling and analysis

Striga counts were carried out manually at weeks 3, 6, 9 and 12 after planting and uprooted each time after counting. Striga density was estimated as follows;

$$\text{Striga density plants /ha}=\frac{Total\ number\ of\ striga\ plants\ counted\ \ at\ weeks\ 3{,}6{,}9\ and\ 12}{Area\ of\ plot}$$

Maize was harvested over a total area of 16.8m^2 in the control, manure and mavuno+ manure treatments. Plant and ear counts were carried out and the fresh weight of the stalks, ears and grains were recorded. The moisture content of the shelled grains was determined using a grain moisture meter. The fresh weight of a sample of 4 stover was recorded and the stover were air dried for 2 weeks and the dry weight recorded. Grain sample fresh and dry weights were also recorded. Maize yield was calculated as follows;

$$Maize\ yield\ (kg/ha) = \frac{Ear\ whole\ fresh\ weight * \left(\frac{Grains\ sample\ dry\ weight}{grains\ sample\ fresh\ weight}\right)}{area\ harvested} * 10000$$

Results for striga density and maize yield were extrapolated to plants/ha and kg/ha respectively.

4.3.3.4 Data Analysis

Analysis of variance (ANOVA) to assess the effect of fertilizer application on maize yield and striga density across treatments, fertility gradients and sites was conducted using GENSTAT 14th edition. The Least Significant Difference (LSD 5%) was used to separate means.

4.3.4 Results and Discussion

4.3.4.1 Striga Density

The highest striga density was observed in the control plots (54,379plants/ha) and was significantly different from the other treatments (Fig. 13). No significant differences were however observed across sites or fertility gradients. Highest striga infestation was observed in Emusutswi in the low fertility treatment (Fig.13). Except for the high fertility field in Emusutswi, all treatments showed a decrease in striga density in the order; IR+manure + mavuno < IR+mavuno < control (Fig. 13). Results correspond to those reported by Raju *et al.* (2006) that with an increase of soil N, striga infestation decreased.

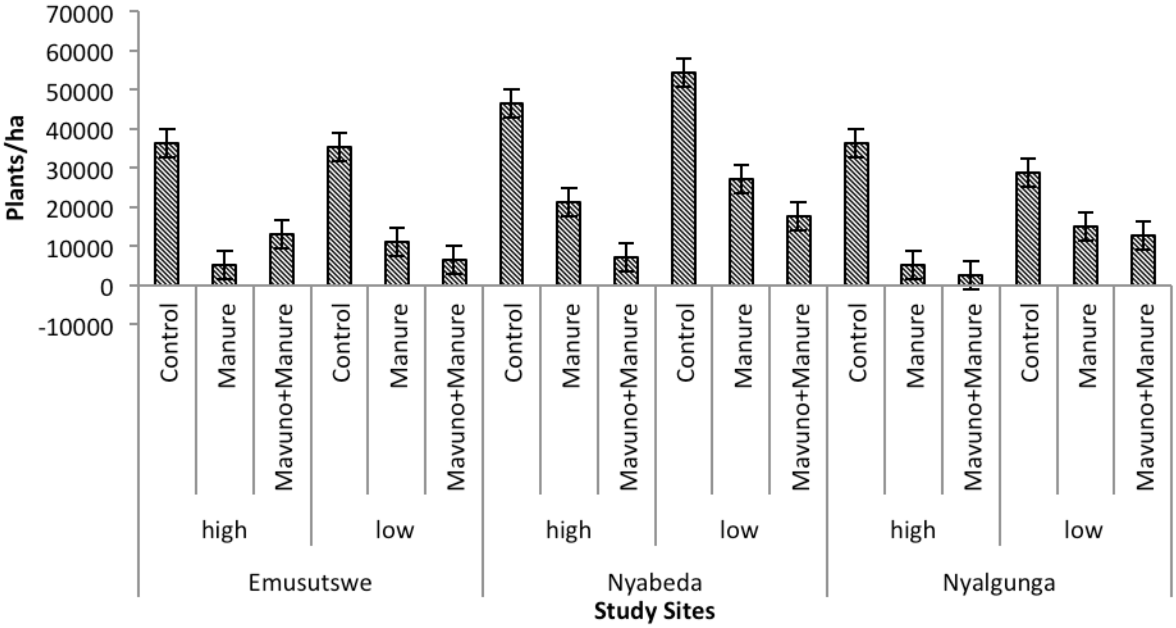

Figure 13: Effects of fertilizer treatments on striga density between two fertility gradients at different sites

Though higher striga was observed in the control plots, the presence of IR maize also caused the striga density to be lower than that which famers normally experienced (>200,000plants/ha) killed the striga seed before they germinated thus reducing its density within the plot. This is in line with

Noubissie *et al.*(2012) who reported that the most effective way to control *Striga* is to use resistant crop varieties. It is evident therefore that IR maize reduces striga infestation as striga was reduced by 76%. Comparing the IR+mavuno+manure treatment with the IR+manure treatment results showed that both treatments reduced striga infestation. , though their combination yielded more reduced levels of striga..

4.3.4.2 Maize Yields

In all three sites, the control treatment, IR Maize, produced lower yields compared to the other two treatments. Maize yields increased in the different treatments in the following order control < IR+Manure < IR + mavuno + manure (Fig. 14).

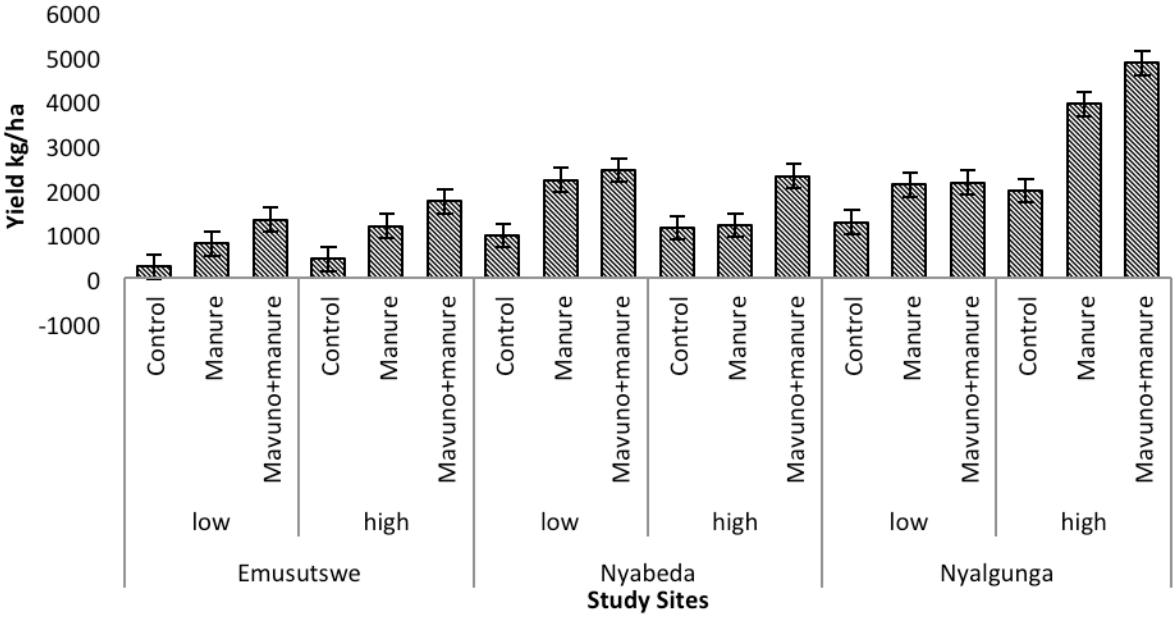

Figure 14: Effects of fertilizer treatments on maize yield between two fertility gradients at different sites

Significant differences in maize yields were observed in sites and treatments (P<0.01) with the highest maize yields observed in the IR+mavuno+manure treatment in Nyalgunga (mean =4833kg/ha) in the high fertility fields. The lowest maize yields were observed in the control treatment (IR Maize) with dwindling mean yields of 263kg/ha in the low fertility field of Emusutswi. The findings are in line with those found by Nalatwadmath *et al.*(2003) who reported significant grain yields when both FYM and NPK fertilizers were used in combination as compared to their single applications and control treatments. In the high and low fertility gradients in different sites, maize yields were not significantly different.

The sites mean yield of maize were significantly different from one another and the manure only treatments were not significantly different from each other but were both significantly different from the control treatment. This implies the possibility of replacing chemical fertilizers for organic only fertilizers in places were organic fertilizers are plenty and of high quality. This is supported by Prasad & Sinha (2000), that FYM could substitute 50% NPK for wheat production. This is also in line with Adeniyan *et al.* (2011), who also found significant yield increases in inorganic and organic fertilizer applications when compared to manure applications only.

4.3.5 Conclusions

The higher the striga density the lower the maize yields. A combination of both manure and mavuno fertilizers reduced striga yields and increased maize yields. Application of manure alone reduced striga density significantly, but did not increase maize yields significantly thus combining both mavuno and manure gave better results. Adoption of an integrated approach encompassing high yielding Striga resistant and/or tolerant crop varieties combined with use of organic and inorganic fertilization may provide a cheap and easy to apply method for striga control under low-input farming systems therefore

CHAPTER 5: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 DISCUSSION

The study established some likely causes of nutrient losses in the different sites. Organic carbon and nitrogen showed reduced values after crop harvest an indication that the soil had been depleted of its original nutrient status. Losses due to organic carbon may be attributed to the fact that after harvest the crop stover were removed from the field as feed for the cattle and not left as litter on the field. Nzuma *et al.*(1998) reported that stover aids in trapping nutrients from urine particularly the nitrogen portion that could otherwise be lost through runoff or volatilization. Nitrogen added to the soil from the manure was not enough to sustain the crop growth as levels of the nitrogen in the soil after harvest clearly indicated a deterioration. Nitrogen may have volatized or immobilized due to low N sources as suggested by Nyamangara *et al.* (2009). Application of the manure too early before the rains to ensure timely land preparation and planting may also lead to nutrient losses. This is because the manure is exposed to the hot, dry and windy conditions prevalent during January and February months in Kenya and therefore nutrients, especially nitrogen may be lost by volatilization. On the other hand, the farmers in the 3 sites heaped their manure without turning for periods of time prior to field application and Wanjekeche *et al.* (2000) reports that the practice of heaping manure without turning is likely to encourage seeping and leaching of liquids from the manure which contain soluble nutrients readily available for plant uptake. Also, heaping manure triggers aerobic decomposition, which causes a net immobilization of nutrients in the first eight weeks after application as, indicated by most nutrients in the above study at maize harvest. Nitrogen leaching may have occurred down the profile as suggested by Camberato (2001), due to low levels in anion exchange capacity in the soil, nitrate moves with the percolating water leading to loss of nitrate from the root zone.

The soil pH in the above study played a critical role in nutrient availability. Low pH levels indicating acidic conditions were observed in all sites and this resulted in low dissolved N availability and insoluble P. In order for nutrients like N and P to be available for plants in the soil,

soil pH must be in ranges between 6.0 and 7.5 for maize crops. Lower pH values in the study area indicates that some chemical elements like P formed insoluble compounds with Fe and Al making it unavailable for plant uptake (Achieng *et al.*, 2010) (Waldrip *et al.*, 2012). Though fertilizers like mavuno applied at a rate of 20kg P per ha were added to the fields, pH effects were greater.

Organic carbon respiration is an indication of the microbes available in the soil and the higher the respiration, the higher the decomposing organisms and the OM. The FYM applied to the field exhibited low organic carbon respiration rates in most of the treatments. According to Dadhich *et al.* (2011), application of organic inputs such as FYM, in the required amounts significantly increased organic carbon respiration. However, if these organic inputs are of low quality, this can cause a reduction. The quantity and quality of organic inputs will affect rate of decomposition, hence more organic inputs higher decomposition rate. The study indicated very low soil activity, a sign that the soil is depleted of available organic matter and has little biological activity. Soil temperature and soil moisture content also affect soil respiration rates (Yuste *et al.* 2007). Practices like mulching can help increase both moisture and temperature hence can be adopted in the study area. Though chemical and biological functions showed a general decrease in the different stages of the crop cycle, there was increase in the level of nutrients from the treatments in the following manner, control< IR maize+manure<IR maize +manure+mavuno. This indicates the potential of improving soil chemical and biological properties through an integrated approach of applying both organic and inorganic fertilizers.

Soil can be separated into different aggregate size classes that possess different functions in the soil as undertaken in the study. The proportions of the aggregates show the measure of the soil's stability and tell us whether the soil is easily eroded or is highly resistant. It also affects microbial activity, nutrient cycling and carbon sequestration. The above study indicated a larger proportion of macro-aggregates compared to micro-aggregates in soil; an indication that the soils under study had a better soil structure and more resistant to soil erosion, but are less stable than the micro-aggregates and therefore not important in carbon sequestration but instead as a temporary nutrient source and sink (Six *et al.*, 2000). Higher macro-aggregates were especially noted in the (mavuno +manure) treatment, showing the potential of organic and inorganic fertilizers in improving soil structure and improving its resistance to erosion (Six *et al.*, 2000) (chapter 4.3). Soil sampling, handling and storage are crucial when soils are to be tested for aggregate stability as when the soils mishandled; aggregates breakdown and hence results in higher micro aggregates formed. The micro aggregates formed about 30% of the soils in the study area, which are more stable and less dynamic, thus form a micro environment for micro-organisms. The higher the micro aggregates, the higher the microorganisms and hence organic respiration. This directly shows that since the soils under study had less micro aggregates (30%), less organisms were present in the soil hence less decomposition rates as observed in chapter 4.2. the micro aggregates also act as a longer term pool for carbon when compared to the macro aggregates (Wu *et al.*, 2004). The silt and clay made up about 10% to 15% of the soil, indicating the older carbon in the soil. This also acts as a sink for carbon**.**

Within the study period, it is noted that fertilizer application reduced striga production and increased maize yields. It was also observed that the use of improved crop varieties like IR maize resulted in higher maize yields. This clearly indicates the potential for increasing crop yield using organic and inorganic fertilizers in striga-infested fields and by using improved crop Striga density increased in the following order IR+ manure+ mavuno< IR+manure<control (IR alone) indicating the potential for IR maize as a striga reduction strategy. Though IR maize has a potential to reduce striga infestation in field, the strategy should not be done in isolation. Other strategies should be integrated in order to get the maximum returns (Chapter 4.4) including addition of both organic and inorganic amendments. Farmers in the area should also aim to increase their soil fertility by addition of amendments since one of the major causes of striga increase is the existence of low fertile soils. From the results we also note that long-term fertilizer amendments cause increase in maize yields when the right rates are applied. An integrated approach of soil fertility management can therefore improve soil properties, reduce striga density and hence increase maize yields.

5.2 CONCLUSIONS

Combined application of mavuno and FYM improved soil properties over sole manure application. Alternative approaches for soil pH amelioration such as liming and intensive use of organic inputs are imperative in order to improve the soil chemical, physical and biological properties.

Site, application of fertilizers and fertility gradients had no effects on organic carbon fraction distribution. The %OC in the silt and clay fractions were increased by the application of mavuno and manure treatments whereas the macro and micro aggregates were not affected by the site, treatments and fertility gradients. %N was affected by the sites and the treatments applied but not the fertility gradients and the highest %N was in the silt and clay fraction in the mavuno +manure treatment.

A combination of both manure and mavuno fertilizers reduced striga yields and increased maize yields. An integrated approach involving use of inorganic and organic fertilizers seem to be a viable strategy in improving soil fertility, subsequent reduction of striga and ultimately enhanced maize yields.

5.3 RECOMMENDATIONS

1. pH levels highly affected the availability of nutrients to plants hence liming should be done in the study area to increase pH values to optimum levels.
2. Crop stover should be left in the field to increase organic carbon and hence improve %C in the soil respiration and soil organic carbon fractions.
3. Farmers can benefit from the integrated use of both FYM and mavuno as this will enable them to save money in procurement of inorganic fertilizers.
4. Improvement of the management of the FYM is encouraged in order to improve its quality.

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Appendices

Appendix 1:ANOVA for Phosphorus

Source of Variation	d.f	s.s	m.s	v.r	F pr.
Site	2	30.57	15.28	1.50	0.232
Fertility Status	1	71.72	71.42	7.01	0.011
Treatment	2	11142.38	571.19	56.05	<.001
Site.fertility status	2	20.37	10.19	1.00	0.375
Site x treatment	4	28.85	7.21	0.71	0.590
Treatment x fertility status	2	76.75	38.38	3.77	0.029
SitexFert tatusxTreat	4	45.79	11.45	1.12	0.355
Residual	54	550.31	10.19		
Total	71	1966.45			

Appendix 2: ANOVA for Organic Carbon

Source of Variation	d.f	s.s	m.s	v.r	F pr.
Site	2	3.07354	1.53677	22.41	<.001*
Fertility Status	1	0.02920	0.02920	0.43	0.517
Treatment	2	8.99084	4.49542	65.55	<.001*
Site.fert status	2	0.19694	0.09847	1.44	0.247
Site x treatment	4	0.20639	0.05160	0.75	0.561
Treatment x fertility status	2	0.06467	0.03233	0.47	0.627
Site. Fert status.Treat	4	0.08737	0.02194	0.32	0.864
Residual	54	3.70338	0.06858		
Total	71	16.35233			

Appendix 3:ANOVA for pH

Source of Variation	d.f	s.s	m.s	v.r	F pr.
Site	2	0.4544	0.2272	1.41	0.254
Fertility Status	1	0.2006	0.2006	1.24	0.270
Treatment	2	0.0936	0.0468	0.29	0.750
Site.Fert-status	2	0.4678	0.2339	1.45	0.244
Site x treatment	4	0.0839	0.0210	0.13	0.971
Treatment x fertility status	2	0.0353	0.0176	0.11	0.897
Site.Fert status.Treat	4	0.0889	0.0222	0.14	0.968
Residual	54	8.7200	0.1615		
Total	71	10.1444			

Appendix 4:ANOVA for Total Nitrogen

Source of Variation	d.f	s.s	m.s	v.r	F pr.
Site	2	0.0019053	0.0009527	1.8	0.175
Fertility Status	1	0.0000184	0.0000184	0.03	0.853
Treatment	2	0.0033806	0.0016903	3.19	0.049
Site.fertility status	2	0.0007620	0.0003810	0.72	0.491
Site x treatment	4	0.0011836	0.0002959	0.56	0.693
Treatment x fertility status	2	0.0005124	0.0002562	0.48	0.619
Site.Fert status.Treat	4	0.0037591	0.0009398	1.78	0.147
Residual	54	0.0285748	0.0005292		
Total	71	0.0400963			

Appendix 5: ANOVA for Mineral NH_4^+

Source of Variation	**d.f**	**s.s**	**m.s**	**v.r**	**F pr.**
Site	2	7.897	3.949	1.77	0.179
Fertility Status	1	0.129	0.129	0.06	0.811
Treatment	2	1431.442	715.721	321.48	<.001*
Site x fertility status	2	1.133	0.566	0.25	0.776
Site x treatment	4	27.326	6.832	3.07	0.024
Treatment x fertility status	2	2.815	1.408	0.63	0.535
Site. Fert status.Treat	4	13.765	3.441	1.55	0.202
Residual	54	120.224	2.226		
Total	71	1604.731			

Appendix 6: ANOVA for NO_3^-

Source of Variation	**d.f**	**s.s**	**m.s**	**v.r**	**F pr.**
Site	2	1.516	0.758	0.34	0.717
Fertility Status	1	0.546	0.546	0.24	0.625
Treatment	2	1308.513	654.256	289.22	<.001*
Site x fertility status	2	3.285	1.642	0.73	0.488
Site x treatment	4	8.237	2.059	0.91	0.465
Treatment x fertility status	2	0.276	0.138	0.06	0.941
Site x Fert statusxTreat	4	16.380	4.095	1.81	0.140
Residual	54	122.157	2.262		
Total	71	1460.909			

Appendix 7: ANOVA for CEC

Source of Variation	d.f	s.s	m.s	v.r	F pr.
Site	2	144.11	72.06	1.51	0.231
Fertility Status	1	42.78	42.78	0.90	0.348
Treatment	2	5241.47	2620.73	54.84	<.001*
Site x fertility status	2	15.08	7.54	0.16	0.854
Site x treatment	4	230.18	57.55	1.20	0.320
Treatment x fertility status	2	287.44	143.72	30.1	0.058
Sitex Fert statusxTreat	4	69.92	17.48	0.37	0.832
Residual	54	2580.44	47.79		
Total	71	8611.41			

Appendix 8: ANOVA for Ca

Source of Variation	d.f	s.s	m.s	v.r	F pr.
Site	2	3.9808	1.9904	2.07	0.137
Fertility Status	1	0.0180	0.0180	0.02	0.892
Treatment	2	96.5827	48.2914	50.13	<.001*
Site x fertility status	2	3.1683	1.5841	1.64	0.203
Site x treatment	4	1.6525	0.4131	0.43	0.787
Treatment x fertility status	2	0.5916	0.2958	0.31	0.737
SitexFert statusxTreatment	4	2.5244	0.6311	0.66	0.626
Residual	54	52.0166	0.9633		
Total	71	160.5349			

Appendix 9:ANOVA for K

Source of Variation	**d.f**	**s.s**	**m.s**	**v.r**	**F pr.**
Site	2	0.40421	0.20211	3.08	0.054
Fertility Status	1	0.07447	0.07447	1.31	0.292
Treatment	2	5.65998	2.82999	43.08	<.001*
Site x fertility status	2	0.02641	0.01320	0.2	0.819
Site x treatment	4	0.15788	0.03947	0.60	0.664
Treatment x fertility status	2	0.12763	0.06382	0.97	0.385
Site x Fert statusxTreatment	4	0.08089	0.02022	0.31	0.872
Residual	54	3.54752	0.06569		
Total	71	10.0789			

Appendix 10:ANOVA for Mg

Source of Variation	**d.f**	**s.s**	**m.s**	**v.r**	**F pr.**
Site	2	0.42952	0.21476	13.83	<.001*
Fertility Status	1	0.02559	0.02559	1.65	0.205
Treatment	2	0.02771	0.01386	0.89	0.416
Site x fertility status	2	0.02486	0.01243	0.8	0.454
Site x treatment	4	0.01546	0.00386	0.25	0.909
Treatment x fertility status	2	0.03387	0.01693	1.09	0.343
Site x Fert statusxTreatment	4	0.00211	0.00053	0.03	0.998
Residual	54	0.83828	0.01552		
Total	71	1.39140			

Appendix 11: ANOVA for %C in Soil Organic Carbon Fractions

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Site	2	7.8805	9403	8.08	<.001
Treatment	2	0.7006	3503	3.39	0.036
Fraction	2	4.6649	2.3325	22.54	<.001
Site.Treatment	4	0.2597	0.0649	0.63	0.644
Site.Fraction	4	2.1338	0.5334	5.16	<.001
Treatment.Fraction	4	0.2809	0.0702	0.68	0.608
Subloc.Treatment.Fraction	8	0.3543	0.0443	0.43	0.903
Residual	189	19.5568	0.1035		
Total	215	35.8314			

Appendix 12: ANOVA for %N in soil Organic carbon Fractions

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Site	2	0.0168156	0.0084078	8.47	<.001
Treatment	2	0.0251757	0.0125879	12.68	<.001
Fraction	2	0.1980910	0.0990455	99.80	<.001
Site.Treatment	4	0.0023384	0.0005846	0.59	0.671
Site.Fraction	4	0.0214471	0.0053618	5.40	<.001
Treatment.Fraction	4	0.0135280	0.0033820	3.41	0.010
Sub-locat.Treatment.Fraction	8	0.0039031	0.0004879	0.49	0.861
Residual	189	0.1875709	0.0009924		
Total	215	0.4688699			

Appendix 13: ANOVA for Striga Density

Source of Variation	**d.f**	**s.s**	**m.s**	**v.r**	**F pr.**
Location	2	8.922E+11	4.2611E+11	2.15	0.119
Fertility Status	1	6.019E+11	6.019E+11	2.94	0.088
Treatment	4	4.577E+12	1.144E+12	5.52	<.001*
Location x fertility status	2	5.747E+11	2.874E+11	1.39	0.252
Location x treatment	8	1.686E+12	2.107E+11	1.02	0.425
Treatment x fertility status	4	9.746E+11	2.436E+11	1.18	0.323
Location x Fert status x Treatment	8	1.083E+12	1.354E+11	0.65	0.732
Residual	210	4.354E+13	2.074E+11		
Total	239	5.394E+13			

Appendix 14: ANOVA for Maize Yields

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Site	2	68396203.	34198101.	28.62	<.001
fertility_status	1	1833038.	1833038.	1.53	0.218
Treatment	7	50831335.	7261619.	6.08	<.001
Site.fertility_status	2	8505926.	4252963.	3.56	0.031
Site.Treatment	14	11492022.	820859.	0.69	0.784
fertility_status.Treatment	7	3372704.	481815.	0.40	0.899
Site.fertility_status.Treat	14	4542900.	324493.	0.27	0.996
Residual	144	172055072.	1194827.		
Total	191	321029200.			