EVALUATION OF THE EFFECT OF MAVUNO PHOSPHORUS-BASED FERTILIZER AND MANURE ON SOIL ORGANIC CARBON AND MAIZE PRODUCTIVITY IN VIHIGA AND SIAYA COUNTIES OF WESTERN KENYA

By

LABAN ADERO NYAMBEGA

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SCHOOL OF ENVIRONMENT AND EARTH SCIENCES

MASENO

UNIVERSITY

ABSTRACT

Low soil organic carbon in western Kenya can be attributed to low soil fertility. The soils are predominantly phosphorus (P) fixing making the applied P-based fertilizers not to benefit target crops fully. Efforts to improve and maintain soil fertility through fertilization has been ongoing in western Kenya for years, despite this, soil degradation; the inability of soil to support plant growth associated with unfavorable soil conditions is still prevalent. Positive relationship between organic and inorganic fertilizers on soil properties has been suggested. Mavuno fertilizer provides more nutrients to plants than common fertilizers used in the region due to its additional chemical properties. Mavuno fertilizer has 10%N, 26%P_2O_5, 10%K_2O, 4%S, 8%CaO, 4%MgO, B, Zn, Mo, Cu and Mn. The main objective of this study was to assess the effect of Mavuno P-based fertilizer and manure on soil physical and chemical properties on degraded soils in Nyabeda, Nyalgunga (Siaya) and Emusutwi (Vihiga) sub-locations, western Kenya. Specific objectives were to: determine seasonal effect of Mavuno phosphorus-based fertilizer and manure application on SOC levels; determine residual Olsen-P attributed to their seasonal application; measure maize grain and stover yield following their application and assess levels of soil pH and bulk density. The study was carried out on CIAT-TSBF fields where Mavuno P-based fertilizer (20 $KgPha^{-1}$) and manure ($2tha^{-1}$) has been applied for 6 years. A randomized complete block design (RCBD) was used in the study. Soils were sampled from; control, manure, Mavuno and manure+Mavuno to a depth of 20cm, from eleven farms; 4 in Emusutswi, 4 in Nyabeda and 3 in Nyalgunga during the last 3 seasons. One thirty two soil samples were analyzed using standard methods for C%, Olsen-P ($mgPkg^{-1}$), soil pH and bulk density (g/cm^3). Mavuno P-based fertilizer and OM had no significant variation on SOC, Olsen-P and soil pH between treatments in both sites, however seasonal variation was observed; the soil bulk density was significant in Emusutswi and Nyabeda, but not in Nyalgunga. Mavuno resulted in remarkable increase in maize grain and stover yield, making it appropriate for low fertility and P-fixing soils. Mavuno has the potential of sustaining soil productivity, when adequate amount is applied thus managing soil acidity and lowering soil bulk density through improved SOM. Understanding the effect of continuous application of P-based fertilizers and manure is essential for sustaining soil productivity among small holder farms of western Kenya.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Soil degradation, the inability of soils to support crop production is on the rise in sub Saharan Africa and is the major cause of declining per capita food production (Sanchez *et al.* 1997, Hoeskstra and Corbert, 1995). Soils have deteriorated in terms of soil fertility attributed to low soil organic carbon an indicator of soil quality (Smaling, *et al.,* 1997). Farmers in western Kenya have made concerted efforts to address soil infertility to improve crop yield through intensification of agriculture through use of organic and inorganic fertilizers (Breman, 1998). Some of these interventions exacerbate further degradation by impacting negatively on soil physical and chemical properties (Tabu, 2003). Elsewhere, in temperate conditions it has been possible to increase organic C levels by sound fertilizer and plant residue management practices (Buol *et al*., 1990; Buol and Stokes, 1997). Even though soil organic carbon decline attributed to inappropriate use of common fertilizers have been documented, information is lacking on the effect of Mavuno P-based fertilizer on soil properties for Siaya and Vihiga.

Soils in western Kenya are inherently low in Olsen-P, the P form available for plant uptake, requiring major investment in P using appropriate P sources, this is important as the soils are predominantly P-fixing due to prevalence of higher levels of Aluminum (Al) and Iron (Fe) oxides that form complexes with P (Kifuko *et al*., 2007). Application of low rates of P-based fertilizers in such soils have been reported not to benefit crops as most of the applied P is sorbed leaving very little P in the soil solution (Opala *et al*., 2007) resulting in low crop yields. There is need to identify and test fertilizers which can enhance Olsen-P availability, benefit crops and reduce accumulation of available P in soils.

On the other hand, maize productivity has declined in western Kenya due to lack of sound fertilizer management options suitable for use in P-fixing soils of western Kenya. Common inorganic fertilizers like DAP have been tested for their potential in sustaining crop productivity in many agro-ecological zones of western Kenya (McIntire and Fussel, 1986). Farmers apply newly introduced fertilizers to increase crop yield due to their additional nutrient benefits without knowledge on the impact of such fertilizers on soil physical and chemical properties. There is need therefore to generate knowledge on the effect of new fertilizers on soil properties.

Phosphorus based fertilizers like TSP and SSP have no acidifying effect on soil when compared to other fertilizers with nitrogen component such as DAP (Smaling *et al.*, 1992; Kanyanjua *et al.*, 2002). Organic manure increases soil pH at time of application partly due to proton (H+) exchange between soil and the added manure. The increased soil organic matter turnover attributed to adequate fertilization and increased biomass yield resulted in improved soil physical properties, thus can probably have an impact on soil bulk density. Although soil degradation attributed to inappropriate fertilizer use is well documented information is lacking on the response of Mavuno P-based fertilizer on P-fixing soils of western Kenya. The present study was therefore to determine if Mavuno P-based fertilizer and manure have an effect on some soil physical and chemical properties and maize grain and stover yields following six years of use.

1.2 Statement of the Problem

Despite agricultural intensification adopting the use of organic and inorganic fertilizers to address soil fertility in western Kenya, crop productivity is still low in Siaya and Vihiga Counties. Soils have deteriorated due to inappropriate fertilizer application, negatively impacting on some soil properties on P-fixing soils. Mavuno fertilizer has additional chemical properties unlike fertilizers commonly used in the region; however, little has been done to analyze its effect on soil organic carbon and other soil properties in western Kenya. While the effect of organic and common inorganic fertilizers is well documented on their effect on maize grain and stover yields, the effect of Mavuno and manure on soil properties need to be established for Vihiga and Siaya. If the issue of low soil productivity is not addressed despite increased fertilizer use on P-fixing soils of western Kenya, then maize productivity will continue to decline resulting to food insecurity among small holder famers of Vihiga and Siaya Counties.

1.3 Objectives of the study

1.3.1. Main objective

The main objective of this study was to assess the effect of Mavuno P-based fertilizer and manure on soil physical and chemical properties on degraded soils in Vihiga and Siaya Counties of Western Kenya.

1.3.2. Specific objectives

1) To determine seasonal effect of Mavuno phosphorus-based fertilizer and manure application on soil organic carbon levels.
2) To determine residual Olsen-P attributed to seasonal application of Mavuno phosphorus-based fertilizer and manure.
3) To measure yields of maize grain and stover following application of Mavuno phosphorus-based fertilizer and manure.
4) To assess levels of soil pH and bulk density following seasonal application of Mavuno phosphorus-based fertilizer and manure.

1.4 Research hypotheses (null hypothesis)

1) Seasonal application of Mavuno phosphorus-based fertilizer and manure has no significant effect on soil organic carbon levels.

2) Residual Olsen-P is not affected by seasonal application of Mavuno phosphorus-based fertilizer and manure.

3) Application of Mavuno phosphorus-based fertilizer and manure has no significant effect on maize grain and stover yield.

4) Mavuno phosphorus-based fertilizer and manure seasonal application on soil has no significant effect on soil pH and bulk density.

1.5 Significance of the study

Soil organic carbon is an indicator of soil fertility and is important for the function of agro-ecosystems having a major influence on soil physical and chemical properties. Mavuno and manure application can promote fertilizer use efficiency especially in P-fixing soils of western Kenya which is lacking with common NPK fertilizers used in the region. Mavuno and manure can have an impact on SOC, influence soil pH and contribute to soil bulk density reduction. The findings of this study are useful in improving farmers understanding on the role of Mavuno planting fertilizer and manure on soil physical and chemical properties and crop yield in Vihiga and Siaya Counties of western Kenya.

1.6 Scope and limit of the study

This study was limited to CIAT-TSBF experimental fields where Mavuno P-based fertilizer and organic manure have been previously applied for six years in Emusutswi, Nyabeda and Nyalgunga sub-locations in western Kenya to evaluate within farm soil fertility gradients in western Kenya. Adjacent plots where manure and inorganic fertilizers have not been applied were used as control fields to establish changes in SOC, residual Olsen-P, maize grain and stover yields, soil bulk density and soil pH following Mavuno P-based fertilizer and manure application at the end of cropping season.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Past work on the effect of inorganic and organic fertilizers on soil properties presented here covers the effect of P-based fertilizers and organic manure on soil organic carbon (SOC), available phosphorus (Olsen-P). Also covered is the effect of P-based fertilizers and manure on maize grain and stover yield, soil pH and soil compaction (soil bulk density). Soil fertility depletion in small holder farms is the fundamental biophysical root cause for declining per capita food production in sub-Saharan Africa.

2.2. Phosphorus-based fertilizers and soil organic carbon

Studies by Vanlauwe (2004) reported that farmers in western Kenya face low soil fertility levels, severe decline in crop yields, low farm income and endemic food deficits. Studies by Bauer and Black (1994) have also reported decreased crop productivity associated with SOC content resulting from a concomitant loss in soil fertility. Higher rates of organic residues returned into the farming system can contribute to SOC build-up in soils (Gantzer *et al.*, 1987). There is much evidence for rapid decline of soil organic carbon levels with continuous cultivation in sub Saharan Africa (Bationo and Buerkert 2001; Bationo *et al.*, 1995). A study by Pieri (1989) in Senegal also showed that without adequate mineral fertilizer application, soil tillage increased the rate of annual SOC losses from 3.8 to 5.2%. The effects of mineral fertilizer application on SOC seem to depend on the type of fertilizer used (Odell *et al.*, 1982). NPK fertilizer applications was reported to reduce the depletion of soil carbon, fertilizer application resulted in a decline in annual losses from 5.2% without NPK to 3.9% with NPK (Pichot *et al.*, 1981). A study by Mucheru-Muna *et al.*, (2007); Sharma *et al.*, (2002) and Odell *et al.*, (1982) also reported that application of NPK fertilizers resulted in a significant increase in SOC even with continuous maize harvest. However, Gregorich *et al*., (1996) found a higher organic carbon in the top horizon in fertilized plots, and concluded that adequate fertilization increased crop yield leading to greater carbon storage in crops the soils.

It is well recognized that soil organic matter increases structural stability, resistance to rainfall impact, rate of infiltration and faunal activities (Roose and Barthes, 2001). Optimum management of the soil resource for provision of goods and services requires the optimum management of organic resources, mineral inputs and the SOC pools (Vanlauwe, 2004). Soil organic carbon is an index of sustainable land management (Woomer *et al*., 1994; Nandwa, 2001) and is critical in determining response to P fertilization.

Farmyard manure on the other hand, other than supplying soil organic matter (SOM) plays key roles in nutrient retention and availability, soil structure maintenance and soil water regime (Woomer et al., 1994). A study by (Sanchez, 1995) reported that increased SOC have positive environmental benefits and replenish soil fertility. It has been possible to increase soil organic carbon to their original levels by sound fertilizer and residue management practices in the temperate regions (Buol *et al*., 1990; Buol and Stokes, 1997) prompting similar studies under tropical conditions. Common inorganic fertilizers are not able to meet plant nutritional requirement especially in P-fixing soils of western Kenya (Kifuko *et al*., 2007). There is need to evaluate the potential of organic and new inorganic P-based fertilizers like Mavuno on their potential to contribute to SOC on P-fixing soils of western Kenya. Carbon sequestration in soils is a gradual process (Giller *et al*., 1997), and primarily occurs in the top soil restoring fertility of degraded soils (Fisher *et al*., 1994; Sanchez, 1995). Large improvement in SOC can be due to high crop biomass produced with improved nutrition, and therefore high amounts of root biomass, fallen leaves and stubble returned to soil after each harvest (Aulakh and Garg, 2007). Positive relationship has been found between SOC and plant available P (Olsen-P) present in the plough layer of different P treatments. Elsewhere a highly significant correlation coefficient (r = 0.880, P $\geq$ 0.01, n = 15) have been found implying an increasing accumulation of soil Olsen-P along with enhanced SOC which is reflected in increased crop yields.

While the potential of NPK fertilizers have been documented (Odell *et al.* 1982), their interaction with acidic soils of western Kenya could minimize their net benefits due to P fixation (Kifuko *et al.*, 2007). Mavuno due to its soil amendment chemical properties associated with calcium and magnesium oxides could offer additional benefits to crops and have an influence on SOC, however little is documented on the effect of Mavuno on SOC in western Kenya. Evaluation of seasonal application of low doses of blended P based fertilizer (20kg P ha^{-1}) and (2t ha^{-1}) organic manure on SOC is therefore important. More research should focus on the improvement of nutrient use efficiency in order to offer to smallholder farmer's cost-effective mineral fertilizer recommendations (Tiessen and Stewart, 1983, Nandwa, 2001).

2.3. Phosphorus-based fertilizers and soil phosphorus levels

Soils in western Kenya are characterized by deficient levels of plant available P (Olsen P), arising primarily from either inherent low levels of soil P or depletion (Frossard *et al.*, 2000; Tiessen, 1991). Soil P stocks have decreased as increasing population has led to replacement of traditional systems of shifting cultivation to sedentary agriculture (Smalling *et al.*, 1997). The main source of phosphorus (P) in soils is through weathering of soil minerals, mineralization of organic matter, fertilizers and added organic materials (Buresh *et al.*, 1997). Phosphorus unlike nitrogen is not biologically fixed from air, and the P content of plant residues and manure are normally insufficient to meet the required P reserves (Palm, 1995). There is undisputable need to correct deficiency of soil P in Africa (Mokwunye, 1977, Sanchez *et al.*,1977), yet many small holder farmers in western Kenya lack appropriate and sufficient fertilizers to either correct inherent low levels of P or replace the P exported with harvested products (World Bank, 1994; Sanchez *et al.*, 1996, 1997). Numerous studies have shown that P fertilizers including phosphate rock (PR) and soluble sources such as triple super phosphate (TSP), single super phosphate (SSP) and ammonium phosphates can singly increase soil productivity through enhanced availability of Olsen P (Wild, 1973; Le Mare, 1984; Sale and Mokwunye, 1993). However some of these fertilizers do not benefit crops fully as most soils in western Kenya are P-fixing (Kifuko *et al.*, 2007). Relative small seasonal application of soluble P fertilizer can mitigate P deficiency in soils with low to moderate P sorption capacity, but large rates of P soluble fertilizers are required for soils with higher P sorption capacity like western Kenya (Palm, 1997), which most smallholder farmers cannot afford (World Bank, 1994).

The replenishment of soil phosphorus implies building soil P stocks to a level at which P is not limiting, after P is added into soil it can be sorbed onto clay or oxide surfaces or converted to organic P and then gradually released as plant available P (Sanchez and Palm, 1996). Replenishment of P capital can be achieved either rapidly through a one-time investment of large P application or gradually through seasonal application of P rates sufficient to increase P availability (Izac, 1997)

Organic manure can improve productivity of degraded soils in a number of ways; it increases CEC especially of light textured soils, and water holding capacity. During its oxidation P among other nutrients are released and may become plant available (Nziguheba *et al.*, 1998; Iyamuremye and Dick, 1996). Organic materials have the potential to increase the availability of P capital, application of 6t dry matter ha^{-1} of organic matter containing 3g P kg^{-1} can provide

18kg P ha^{-1} to sustain a 2 t ha^{-1} maize crop (Palm, 1995). According to Palm (1997) organic materials are restricted by their limited ability to supply P. Sufficient quantities of P-rich organic materials to meet the P requirements are simply not available at the farm level under smallholder farms therefore integrated use of inorganic P fertilizer sources with available organic materials is required to arrest and correct the depletion soil P occurring in many soils of Africa, resulting in gradual build up (Palm *et al.*,1997).

The application of Mavuno fertilizer by small holder farmers in western Kenya has steadily risen since 2003, due to its additional benefits (Chianu, N. J. *et al.* 2011; Muchena, F. N., *et al.* 2005). Field demonstration trials comparing Mavuno and DAP fertilizers in collaboration with farmers, agro-input dealers and Ministry of agriculture, showed that Mavuno fertilizer performed better depending on soil conditions (Muchena, F. N., *et al.* 2005). Relatively small rates of P fertilizer (10-25kg p ha^{-1}) particularly when mixed with soil in the planting hole can be attractive to small scale farmers on moderate P-fixing soils in the highlands of East Africa (Jama *et al.*, 1997; Opala *et al*,. 2007). Large one time application of soluble fertilizer can lead to losses of P through leaching especially in light textured soils, and surface runoff posing environmental problems therefore need to establish residual effect (Buresh *et al*, 1997).

Plants differ greatly in their ability to grow on soils with low P status and to respond to P inputs (Sanchez and Salinas, 1981). The solution P concentration required by plants for optimum growth varies among plants (Sanchez and Uhehara, 1980). The critical concentration of extractible P required for a given quantity for P uptake by plants decreases with an increase in P sorption. Cox (1994) showed that the critical P level with Mehlich-3 extractible P was 22mg P kg^{-1} for soils with low sorption, and 13mg P kg^{-1}. Residual P is very important in Olsen P management and build-up of P capital in soils as it has an impact on soil productivity and farm profitability (Eijk, 1997). Existing knowledge on immediate and residual effects of P fertilizer suggests that the gradual build up of soil P with seasonal applications of P can economically increase soil productivity through enhanced P-stocks (Jama *et al.*, 1997). Common fertilizers used in the region increase soil acidity due to their limited nutrient composition thus increasing P-sorption (Kifuko *et al.*, 2007).

2.4. Phosphorus-based fertilizers and soil productivity

According to Jama *et al.*, (1997) relatively small rates of P fertilizer (10 to 25kg P ha^{-1}) particularly when mixed with soils in the planting hole can increase crop yield and be financially attractive on moderately P fixing soils in the highlands of East Africa. Phosphorus (P) is crucial to life and is an essential major nutrient for plant growth and root development, increasing crop yield (Aulakh *et al.*, 1991). On many P-deficient soils in Africa, relatively moderate applications of 10 to 20 kg P ha^{-1} can dramatically increase crop yields (Buresh *et al.*, 1997). Such soils normally have low to moderate P-sorption capacity and no major constraint from Al saturation. Gradual replenishment of these soils could be achieved with seasonal P applications at sufficiently high rates to increase the availability of soil P (Rajan *et al.*, 1996).

Seasonal applications of P for gradual correction of P deficiency on soils with low to moderate P-sorption capacity will eventually result in greater build up of capital P (Cox *et al.*, 1981), and greater crop yields than a large, one time application of P. Gradual build up of soil P capital, however, will provide less immediate and cumulative crop yields than a relatively large corrective P application with subsequent maintenance application of P on moderate and high P-fixing soils (Rajan *et al.*, 1996).

Despite knowledge on soil fertility depletion and the need for P fertilizers, many small holder farmers in Africa have not adopted seasonal applications of sufficient P for the mitigation of soil P depletion (Sanchez *et al.*, 1977). Phosphorus is one of the major nutrients after Nitrogen limiting maize productivity in western Kenya soils (Traore, 1974). Various factors could be responsible for P availability to crop plants. These include the form of native soil P, the type of P applied to the soil, and soil reaction. Some work with phosphorus fertilizers has indicated positive response of maize to low rates of P (Amon, 1965; Amon and Adetunji, 1970). A study by Mokwunye, (1997) found that it is Olsen-P rather than total P which determines plant utilization and performance. Liming can reduce P-sorption thus increased utilization resulting to high maize yield. Organic and inorganic sources which have both macro and micro nutrients (Palm *et al.*, 1997; Giller *et al.*, 2002) are capable of reducing P-sorption due to their liming potential, thus increasing maize grain and stover yield (Gachengo *et al.*, 1998; Nziguheba *et al.*, 2000; Ikerra *et al.*, 2006). Common inorganic fertilizers can be applied to increase crop productivity but these often have negative impacts on soil due to their limited nutrient supply (McIntire and Fussel, 1986).

2.5. Phosphorus-based fertilizers and pH

Soil pH is an important soil attribute as it influences chemical and biological activities occurring in the soil (Vakalis *et al.*, 2005). Soil pH is determined by the amount of hydrogen ion activity [H^+] in soil solution and is influenced by climatic, biological and edaphic factors (Ulrich *et al.*, 1980). Soils become acidic due to leaching of basic cations Ca,Mg and K in the humid high rainfall areas, use of acid forming fertilizers such as DAP deposition of acid rains and microbial decomposition of organic manure which produces carbonic and other weak acids (Sumner *et al.*, 1991; Paul *et al.*, 2001; Bolan and Hedley, 2003). Aluminum and iron derived from soil minerals may be hydrolyzed and hence also contribute to soil acidity (Tisdale *et al.*, 1985). Harvest of high yielding crops accelerates soil acidification by removing basic cations that are responsible for counteracting the acidity developed by other processes from the soil system (Bolan and Hedley, 2003). Cation exchange capacity (CEC) can predispose soils to acidification; soils with low CEC are poorly buffered and thus are prone to abrupt acidification (Ulrich *et al.*, 1980). Phosphorus based fertilizers like TSP and SSP have no acidifying effect when compared to other fertilizers with ammonium component such as DAP (Smaling *et al.*, 1992; Kanyanjua *et al.*, 2002). Studies by Wong and Swift (1995) and (Wong *et al.*, 1998) found organic matter increased soil pH at time of application partly due to proton (H+) exchange between soil and the added manure, a study by Kapkiyai *et al.*, (1999) showed that increased soil organic matter turnover attributed to adequate fertilization and increased biomass yield resulting in improved soil physical properties, thus can probably have an impact on soil bulk density. Fertilization using nutrient option which replenish basic cations and release macro nutrients slowly enhancing crop yield like Mavuno could counter soil acidity bring added benefits to soils and the environment (Iyamuremye and Dick, 1996).

2.6 Conceptual framework

Efforts to increase soil productivity and enhance soil physical, chemical and biological properties in degraded environments are to some extent being achieved through soil amendments like inorganic and organic fertilizer use. NPK based fertilizers and manure are capable of influencing SOC levels, an indicator of sustainable soil management. Mavuno P based fertilizer and manure can influence SOC, Olsen P availability and use, soil pH and soil bulk density and impact on maize grain and stover yields (Figure 2.1).

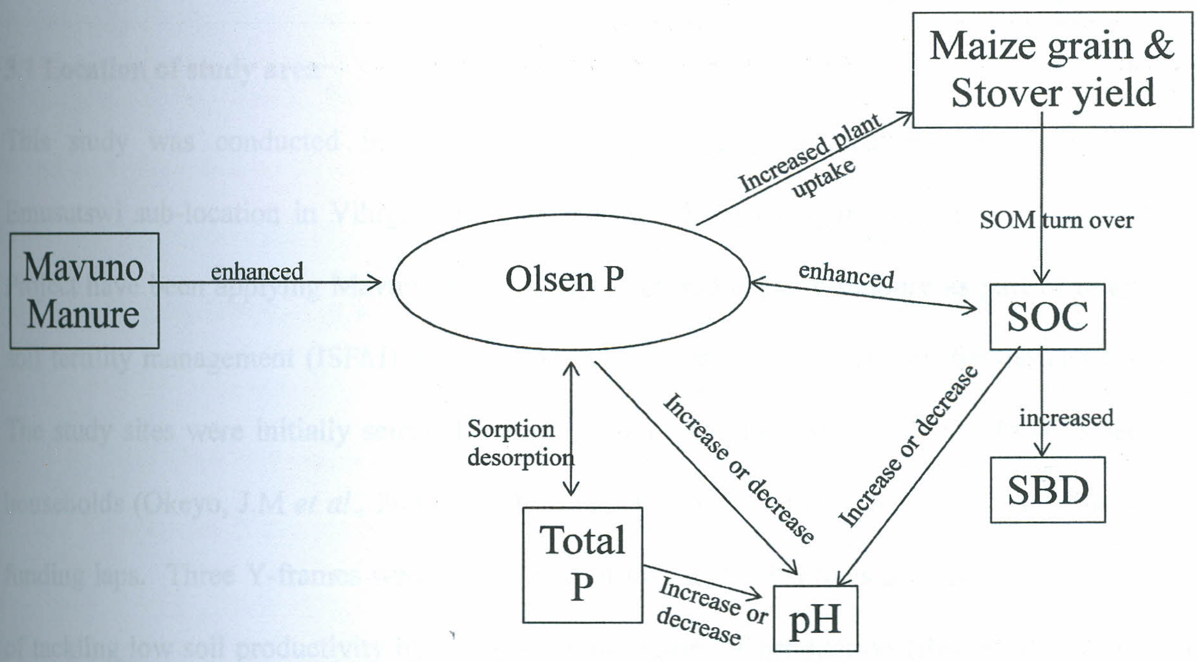

Fig 2.1. Effect of Mavuno and manure on soil organic carbon and maize yield, Phosphorus (P), soil organic carbon (SOC), soilbulk density (SBD), Carbon dioxide (CO_2), (Source: Conyers M.K. *et al.* 2009)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of study area

This study was conducted in Nyabeda and Nyalgunga sub-locations in Siaya County; Emusutswi sub-location in Vihiga County of western Kenya (Figure 3.3), where CIAT-TSBF Project have been applying Mavuno P-based fertilizer and organic manure as part of integrated soil fertility management (ISFM) interventions to address low soil fertility for the last 6 years. The study sites were initially selected using Y-frame sampling method to randomly select the households (Okeyo, J.M *et al.*, 2006). Each Y had 10 farms but then reduced to 4 farms due to funding laps. Three Y-frames were considered in this study. ISFM is a multi-faceted approach of tackling low soil productivity by addressing all factors of production (Rao *et al.*, 1999). The sites were selected to assess the state of the environment following six years of Mavuno P-based fertilizer and manure application. Soil samples taken for the last three seasons were used for this study.

3.1.1 Siaya

The trials were located in Nyabeda and Nyalgunga sub-locations in Siaya County. Nyabeda had four farms - Maria A Otao farm (E34 24 17.5, N0 08 01.2, 1347m), Yala Division, North Gem location, Nyabeda village; Jane Oyoo farm (E34 24 21.2, N0 08 02.8, 1360m) Yala Division, North Gem location, Nyabeda village; Anastasia Okello farm (E34 24 29.5, N0 07 42.9, 1323m) Yala Division, North Gem location, Nyabeda village; Chrispin Bodi farm (E34 24 10.8, N0 07 50.5, 1333m) Yala Division, North Gem location; while Nyalgunga had three farms, Leonida A Otieno farm (E34 18 21.8, N0 04 50.1, 1300m), Boro division, North Alego Sublocation, Nyakongo village; Pitalis Ogunga farm (E34 18 19.1, N0 04 42.6, 1335ml), Boro division, North Alego Sublocation, Ogwato village; Rabar Kobondo farm (E34 13 17.5, N0 04 56.9, 1312m) Boro division, North Alego Sublocation, Nyakongo village; The fouth farm Joseph Ogutu farm (E34 17 53.3, N0 05 05.4, 1310m) was discarded due to severe livestock damage. Siaya receives a bimodal annual rainfall of 800 - 1600mm (Figure 3.4): March – July (long rains) and September – November (short rains) (Rao *et al.*, 1999.). The soils are developed mostly on basic igneous rocks (Sombroek *et al.*, 1982). Nyabeda and Nyalgunga have Eutric Nitisols (Figure 3.1). The soils are well drained, very deep, red to dark red, friable to firm clay; in some places moderately deep over petro-plinthite. Nyalgunga soils have variable fertility with low levels of available Phosphorus, Nitrogen and soil carbon (Jaetzold and Schmidt, 1982, Rao *et al.*, 1999). The annual average temperature is about 21.5°C. Population density is about 188 people per square km, with an average of 5.25 persons per household; the average land ownership stands at 0.39ha per household (Rao *et al.*, 1999).

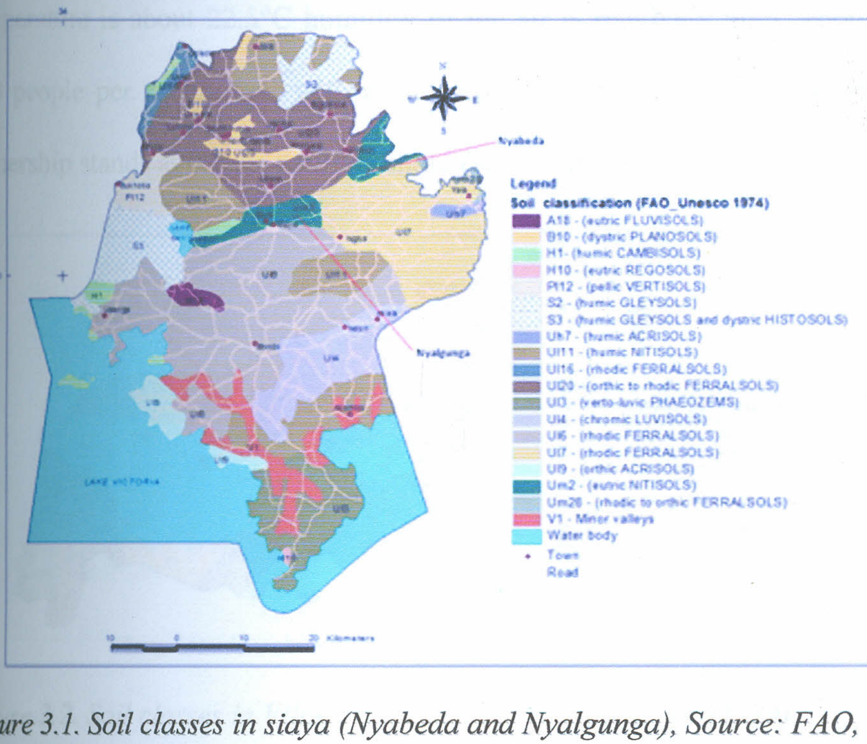

Figure 3.1. Soil classes in siaya (Nyabeda and Nyalgunga), Source: FAO, (1974).

3.1.2 Vihiga

In Vihiga the four farms were located Emusutswi sub-location- Kesia Atito farm (E34 40 46.2, N0 07 36. 0, 1510m), Ikolomani Division, Ikaluni location, Makata village; Lawi Angote farm (E34 40 26.0, N0 07 23. 2, 1503m) Emuhaya Division , North East Bunyore location, Kilingili village; Patrick K Karatasi farm (E34 40 11.9, N0 07 30.0, 1470m) Emuhaya Division , North East Bunyore location, Kilingili village; Josephine Omukhamasi farm (E34 40 17.2, N0 07 39.1, 1528m) Emuhaya Division , North East Bunyore location, Kilingili village. Vihiga receives a bimodal rainfall of 1000 - 1800mm (Figure 3.4), in long rains (March – July) and short rains (September – November) and average altitude of 1500m. Emusutswi has Orthic Acrisols, developed on granites (Figure 3.2). The soils are well drained, very deep, dark red to yellowish red, friable to firm, sandy clay to clay, with acid humic topsoil. The soils have low levels essential plant nutrients, particularly exchangeable bases and P, and high levels of exchangeable Al. (Sombroek *et al.*, 1982, Jaetzold and Schmidt, 1982, Rao *et al.*, 1999). The annual average temperature is about 22.5°C humidity of the air is relatively high. Population density is about 500 people per square km, with an average of 8.25 persons per household; the average land ownership stands at 0.19ha per household (Rao *et al.*, 1999).

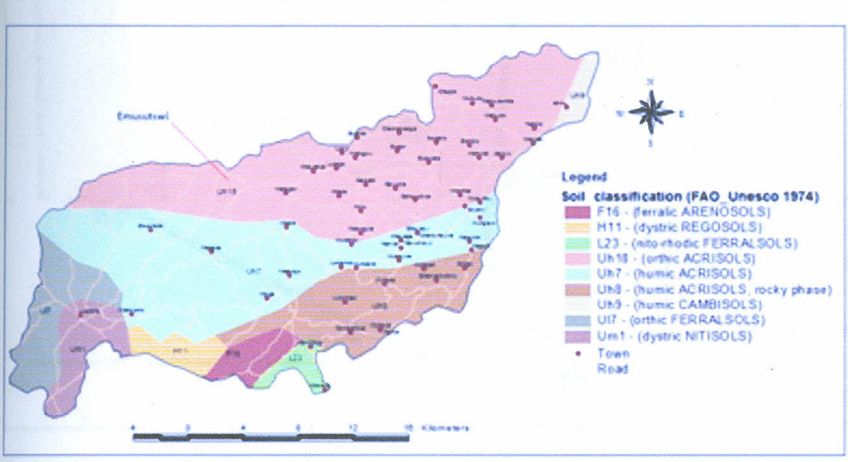

Figure 3.2. Soil classes in Vihiga (Emusutswi), Source: FAO, (1974).

Fig 3.3. Trial locations in Western Kenya, Source: Jaetzold and Schmidt,(1982).

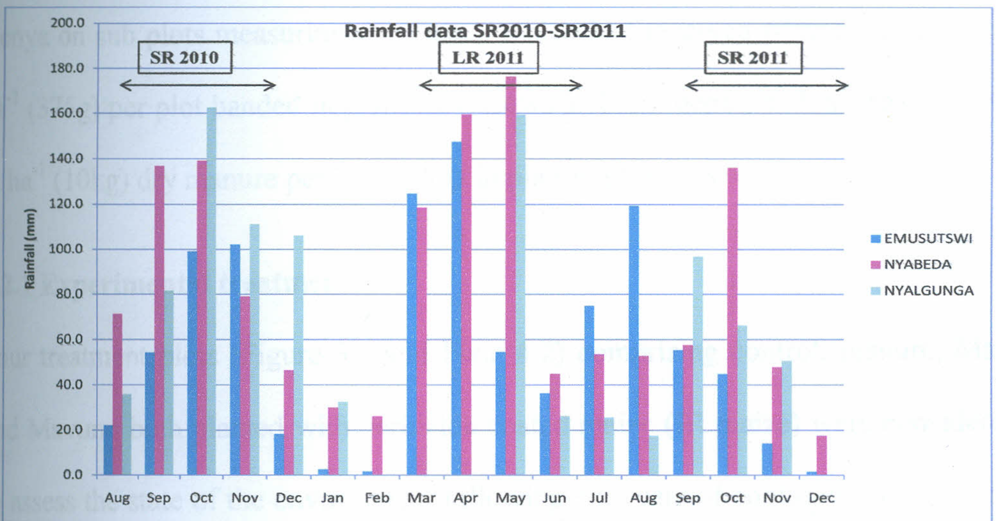

Fig 3.4. Rainfall received at Emusutswi, Nyabeda and Nyalgunga during the experimental period.

3.2 Study design

A randomized complete block design (RCBD)[1] was used to study the effect of *Mavuno* phosphorus based fertilizer and manure on soil physical and chemical properties in western Kenya, where low soil fertility associated with low soil organic carbon and phosphorus has been pointed out as the major factor limiting crop productivity, resulting to low crop yield. The study investigated changes in soil organic carbon, available phosphorus (Olsen P), maize yield ,soil pH and soil bulk density on fields where Mavuno P based fertilizer and manure have been used continuously for 6 yrs by sampling and analyzing three season's soils samples.

= observed response for treatment *j* in block *i*

= mean value for block *i*

= treatment effect for treatment *j*, and

= represents the random unit variation within a block

The study was carried out using soils randomizely collected from three sub-locations of western Kenya on sub plots measuring $25m^2$ each which had received Mavuno fertilizer rate of 20kg P ha^{-1} (375g) per plot banded in planting furrows at 10cm depth, and or organic manure applied at 2t ha^{-1} (10kg) dry manure per $25m^2$ plots in planting furrows.

3.2.1 Experimental treatments

Four treatment plots (Figure 3.5 and Plate 4.2) comprising control, manure, Mavuno+ manure and Mavuno both planted with herbicide coated maize (IR maize) were considered in this study to assess the state of the environment following six years of continuous use on soil physical and chemical properties. IR maize is a herbicide coated maize to combat parasitic cereal weed *Striga hermonthica*, IR maize is suitable for striga prone areas of western Kenya was used to test treatment responses. A control plot which has not received any treatment provided a basis for comparison on the effects of Mavuno and manure on SOC, Olsen P, maize yield, pH and soil bulk density. This multi-location study was replicated at sub-location level with 4 fields in Nyabeda, 4 in Emusutswi and 3 in Nyalgunga. A total of 132 soil samples were analyzed using standard methods to establish SOC, Olsen phosphorus, pH and soil bulk density as affected by Mavuno P-based fertilizer and manure application.

T1 IR Maize (control - no fertilizer added)

T2 IR Maize + Mavuno

T3 IR Maize + Manure

T4 IR Maize + Mavuno + Manure

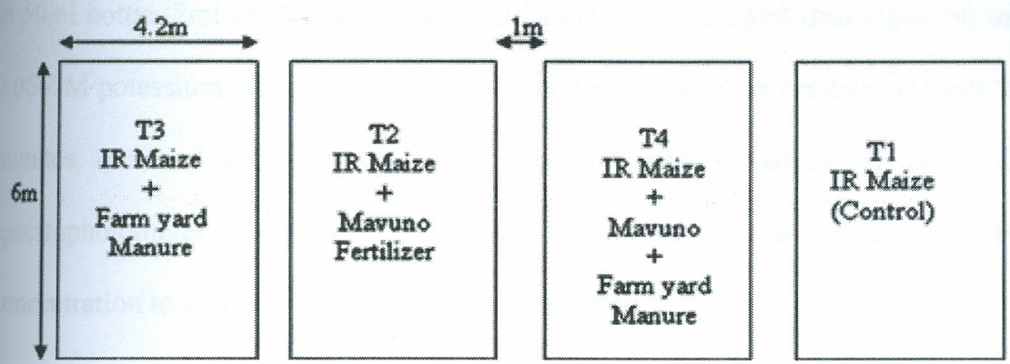

Fig 3.5. Field layout at farm level

3.3 Sampling and analytical procedures

3.3.1 Determination of changes in soil properties

Three composite top-soil (0–15 cm) samples collected adopting the W-sampling design at 9 positions for each treatment using a 5cm diameter soil auger (Okalebo *et al*, 2002) at household level and analyzed to determine changes in soil properties following Mavuno and manure application. Air dried and sieved soil samples were subjected to soil carbon, olsen P, and pH analyses. Soil organic carbon was determined using (Walkley and Black 1934; Rhoades, 1982) method. Olsen P analyzed using Olsen method (Olsen *et al.*, 1954, Okalebo *et al*, 2002).

3.3.2 Determination of Soil Organic Carbon (SOC)

Soil organic carbon was determined using Walkley and Black (1934) oxidation method. This method involves complete oxidation of soil organic carbon using concentrated sulphuric acid (H_2SO_4) and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture (Nelson and Sommers, 1975). Thus to determine soil organic C, 40g of wet soil was weighed into 250ml bottle, and 150ml of 0.5M K_2SO4 added placed on horizontal position shaker for 1hour at 150 reciprocations per minute. The solution was then filtered through Whatman No. 5 filter paper and the filtrate stored in 50ml bottle. 2ml of sample extract/standard were transferred into digestion tube then 1ml of 0.0667M potassium dichromate added and the tubes placed in pre-heated block at 150°C for 30 minutes, removed and allowed to cool. The concentration of carbon in mg C was read on spectrophotometer at 600nm. The mean blank value was subtracted from the sample concentration to give a corrected concentration value.

Calculation

$$TOC = \frac{(SCCONC - SCBLNK) \times 0.1}{SCSOLWT} \text{------------------------} (2)$$

Where;

SCCONC = soil concentration in mg C

SCBLNK = carbon content of blank (mg C)

SCSOLWT = dry weight of soil sample (g)

TOC = total soluble carbon

Source: Okalebo, et al., (2002).

3.3.3 Determination of Olsen P (available phosphorus)

Available P was determined using the phosphomolybdate method (Olsen *et al*, 1954). In this method phosphate and ammonium molybdate form a complex, which is reduced with ascorbic acid to produce a blue complex in solution whose intensity is measured using a spectrophotometer. Soil extraction was done by weighing 2.5g of air dried soil passed through 2mm sieve into 150ml polythene shaking bottle and adding 50ml of Olsen extracting solution (0.5M $NaHCO_3$ at pH 8.5) to each bottle. This bicarbonate extractant decreases the concentration of Ca in the solution by precipitating Ca as $CaCO_3$ in the calcareous, alkaline or neutral soils containing calcium phosphate, resulting in an increase of the P concentration the solution (Sibbensen, 1978). The bottle was stoppered well and shaken on an electrical mechanical shaker for 30 minutes and the suspension filtered through No. 42 Whatman paper. Phosphate standard solutions were prepared from 250ppm P standard phosphate stock solution. Working standards in $NaHCO_3$ extracting solution (0, 1, 2, 4 and 5mg P/L); made using Ependorf multipette, pipette 0, 1, 2, 4 and 5 of the 50mg P/L solution into labeled 50ml volumetric flasks, then made to volume with the $NaHCO_3$ extracting solution mixed well. 1ml of each P standard solution was pipetted together with each 10ml of each sample filtrate and two reagent blanks into 50ml volumetric flasks. 5ml of 0.8M boric acid was added to each flask to suppress interference from fluorides and sulphates. Beginning with the standards and blanks, 10ml of ascorbic acid (ammonium molybdate/antimony potassium tartate/5N H_2SO_4/ascorbic acid) was added to each flask and the contents made up to the mark with distilled water. Contents were stoppered, shaken well, and after one hour, the absorbance (blue colour intensity) was measured at a wavelength setting of 880nm on a spectrophotometer, and correction made for blank P concentrations.

Calculation

$$\text{P concentration mg P kg} - 1 = \frac{(\text{EXPCONC} - \text{EXPBLNK})(\text{EXPVOL})}{\text{EXKSOLWT}} ---------(3)$$

Where;

EXPCONC = Phosphorus concentration for sample (mg P L^{-1})

EXPBLNK = Phosphorus concentration for blank (mg P L^{-1})

EXPVOL = Volume of extracting solution (ml)

EXKSOLWT = Weight of dry weight soil extracted (g)

Source: Okalebo, et al., (2002).

3.3.4 Maize grain yields assessment

Maize grain yield data for three seasons at the same sampling time, harvested from net plots of 7.08m^2 calculated by leaving out the outer rows and end plants of each row of a 12.5m^2 plot were used to calculate grain yield to get an indication of SOC effect on maize productivity. Maize was harvested at physiological maturity and grain yield calculated at 12% moisture content. Plants from the effective area were counted and cob removed from the husks in the standing plants. The cobs were counted and put in labeled bags and their fresh weight taken. Six cobs representing all cob sizes were sub-sampled and their fresh weights taken (Okalebo *et al*,. 2002). The difference between the dry weights and fresh weights was used as a conversion factor for determining the dry grain yields on a hectare basis using the following formula[6]:

$$\text{Grain yield ha}^{-1} = \frac{\text{grain sample dry wt.}}{\text{cob sample fresh wt.}} \times \frac{\text{cob fresh weight from net plot}}{\text{plot size}} \times 1000 - (6)$$

Formula in (Okalebo et al, 2002)

3.3.5 Maize stover yields assessment

Maize stover yield data for three seasons at the same sampling time, cut from net plots of 7.08m^2 calculated by leaving out the outer rows and end plants of each row of a 12.5m^2 plot were used to calculate biomass yield to get an indication of SOC effect on maize productivity. Four stovers were randomly picked after cob separation, chopped into small pieces then parked in brown bags for drying after taking sample fresh weight (Okalebo *et al*,. 2002). The maize stover sub-samples were oven-dried at 70^{0}C for 48 hours and dry weights taken. The difference between the dry weights and fresh weights was used as a conversion factor for determining the dry stover yields on a hectare basis using the following formula[7]:

$$\text{Stover yield ha}^{-1} = \frac{\text{stover sample dry wt.}}{\text{Stover sample fresh wt.}} \times \frac{\text{stover fresh weight fro net plot}}{\text{plot size}} \times 1000 - (7)$$

Formula in (Okalebo et al, 2002)

3.3.6 Soil pH measurement

Twenty five milliliters of distilled water was added to 10g air dried soil passed through 2mm sieve. The mixture was stirred for 30 minutes using a 33-place stirrer and allowed to stand for 20 minutes after which the soil suspension was stirred again for 2 minutes. Soil pH was measured on 2.5:1 water to soil suspension using pH meter on a glass electrode as also reported by Okalebo *et al*, (2002).

3.3.7 Soil bulk density determination

Soil bulk density samples were taken using a 5cm diameter core inserted carefully in a level soil surface after scraping 1-2 cm from the soil surface. The core was then excavated and excess soil removed from both ends using a sharp knife, the soil collected using a known volume core[4] was then dried in an oven at 105°C for 2 days and weight recorded as also reported by Okalebo *et al*, (2002). The soil bulk density was calculated using the formula below[5].

$$Core\ volume = \pi r^2 ------------------------------------ (4)$$

$$\text{Bulk density (g cm} -3) = \frac{\text{Soil sample dry weight (g)}}{\text{Volume (Cm3)}} ----------------(5)$$

3.4 Statistical data analysis

Data was analyzed using the Genstat 14.1 package. Two way Analysis of variance (ANOVA) was performed to test for significant treatment difference and seasonal variation on soil properties and maize yield. Soil analysis data for dependent variables; soil organic carbon (%), Olsen P (mg kg^{-1}) , soil pH and soil bulk density (g cm^{-3}) data were analyzed and treatment means tested for significance to evaluate if they are influenced by Mavuno phosphorus-based fertilizer and manure application in three sites in western Kenya. Mean maize and stover yield (Kg ha^{-1}) data for the three sites were also analyzed and tested for significance to evaluate if they are influenced by Mavuno phosphorus-based fertilizer and manure application using Genstat at 95% confidence interval (P=0.05) and means separated by LSD (Mead and Curnow, 1983; Gomez and Gomez, 1984).

CHAPTER FOUR

RESULTS

4.1 Introduction

Soil laboratory analysis results and maize yield data presented shows the effect of Mavuno phosphorus-based fertilizer and manure applied separately or in combination on soil organic carbon, Olsen-P, maize grain and stover yield, soil pH and soil bulk density, at the end of 6 years of continuous application in Emusutswi,Vihiga County and Nyabeda and Nyalgunga in Siaya County.

4.2 Effect of treatments on Soil organic carbon (SOC)

Soil organic carbon results for Emusutswi based on treatments are presented in Table 4.1. Soil organic carbon did not show any significant variation among treatments (P = 0.056) however there was a significant seasonal variation (P=<0.001) with SOC decreasing with seasonal Mavuno and manure application (Figure 4.1). Mavuno (20kg P ha^{-1}) had the highest mean soil carbon level 2.4±0.23, while control plot had the lowest mean SOC level of 2.0±0.15 , manure (2t ha^{-1}) and Mavuno+manure plot had 2.2±0.15 and 2.1±0.15 mean carbon levels, respectively.

Table 4.1. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil organic carbon (%) in Emusutswi, Vihiga

Treatment	Season			Mean SOC
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	2.2±(0.17)	2.3±(0.16)	1.5±(0.22)	2.0±(0.15)
Manure	2.6±(0.13)	2.3±(0.17)	1.6±(0.09)	2.2±(0.15)
Mav+Man	2.3±(0.31)	2.2±(0.13)	1.7±(0.14)	2.1±(0.15)
Mavuno	3.3±(0.18)	2.2±(0.1)	1.7±(0.18)	2.4±(0.23)
LSD(Season)	0.250**			
LSD (Treatment)	0.289NS			

In Nyabeda (Table 4.2), no significant variations were observed in soil organic carbon under different treatments (P =0.115). However, the Mavuno plot had the highest mean soil carbon level 1.9±0.16 followed by control plot 1.9±0.12. Manure and Mavuno+manure fields had mean soil organic carbon levels of 1.7±0.11 and 1.7±0.12 respectively. Seasonal SOC variation was highly significant (P=<0.001), with seasonal decline in SOC levels from short rains 2010 to short rains 2011 (Figure 4.1).

Table 4.2. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil organic carbon (%) in Nyabeda, Siaya

Treatment	Season			Mean soil organic carbon
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	2.2±(0.03)	1.9±(0.27)	1.6±(0.19)	1.9±(0.12)
Manure	2.0±(0.13)	1.7±(0.05)	1.3±(0.05)	1.7±(0.11)
Mav+Man	2.0±(0.19)	1.8±(0.02)	1.4±(0.14)	1.7±(0.12)
Mavuno	2.3±(0.10)	2.0±(0.04)	1.3±(0.04)	1.9±(0.16)
LSD (Season)	0.179**			
LSD (Treatment)	0.206 NS			

Table 4.3. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil organic carbon (%) in Nyalgunga, Siaya

Treatment	Season			Mean soil organic carbon
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	2.4±(0.32)	2.1±(0.16)	1.3±(0.19)	1.9±(0.20)
Manure	1.9±(0.08)	2.2±(0.14)	1.5±(0.06)	1.9±(0.13)
Mav+Man	2.0±(0.13)	2.1±(0.11)	1.5±(0.17)	1.9±(0.13)
Mavuno	2.0±(0.36)	2.0±(0.14)	1.7±(0.19)	1.9±(0.12)
LSD (Season)	0.223**			
LSD (Treatment)	0.257 NS			

Just like in Emusutswi and Nyabeda, no significant variations were observed in soil organic carbon between different treatments in Nyalgunga sub location (P = 0.906) as presented in

(Table 4.3). Manure plot had soil organic carbon of 1.9±0.13, Mavuno+manure plot 1.9±0.13, control plot 1.9±0.20 and Mavuno added plot 1.9±0.12. The seasonal variation was highly significant (P=>0.001) with a general decline in SOC over the season (Figure 4.1).

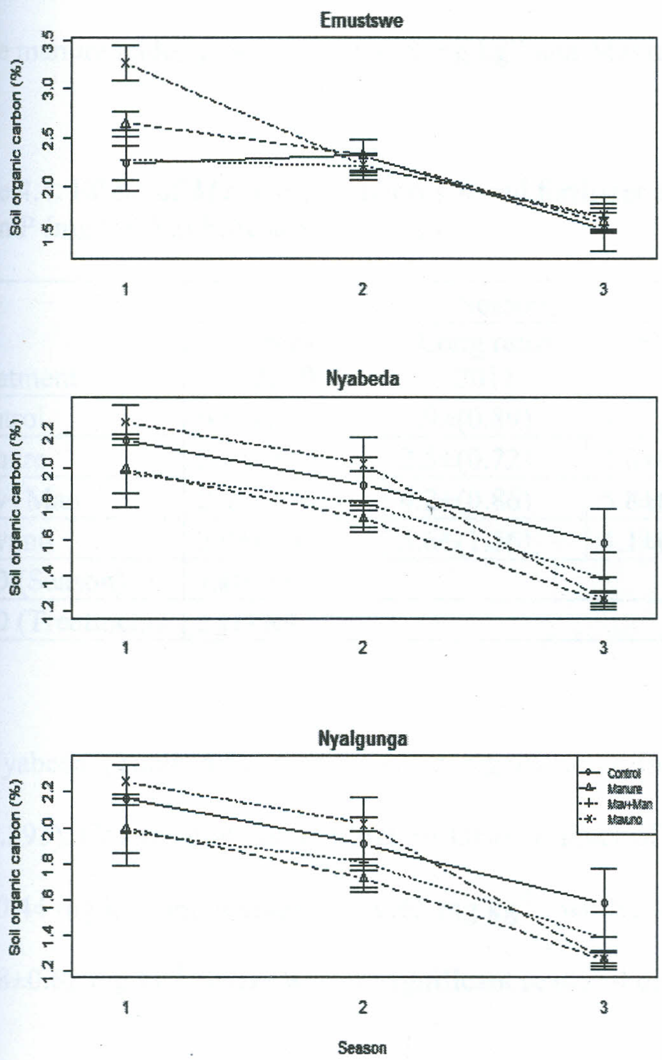

Fig 4.1. Seasonal trend for mean soil organic carbon (%) for Emusutswi, Nyabeda and Nyalgunga, short rain season 2010 -short rain season 2011.

4.3 Changes in available Phosphorus (Olsen P) as influenced by treatments

The Olsen P results for Emusutswi are presented in table 4.4, there was no significant difference in Olsen P between treatments (P=0.122) and between seasons (P=0.951). Mavuno applied plot and control plot had had a mean Olsen P of 4.9±0.78 mg kg^{-1} and 4.9±0.72 mg kg^{-1} respectively, while manure added plot had 2.7±0.38 mg kg^{-1} and Mavuno+manure 4.3±0.72 mg kg^{-1}.

Table 4.4. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil Olsen P (mg kg^{-1}) in Emusutswi, Vihiga

Treatment	Season			Mean Olsen P
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	6.6±(2.08)	3.9±(0.89)	4.3±(0.28)	4.9±(0.78)
Manure	2.9±(0.75)	2.5±(0.72)	2.6±(0.69)	2.7±(0.38)
Mav+Man	2.9±(0.56)	4.2±(0.86)	5.8±(2.68)	4.3±(0.94)
Mavuno	5.0±(1.40)	5.6±(1.56)	4.1±(0.93)	4.9±(0.72)
LSD (Season)	1.830 NS			
LSD (Treatment)	2.113 NS			

In Nyabeda (Table 4.5), there was no significant difference in Olsen P between treatments (P=0.293). Control plot had the highest Olsen P level of 6.4±0.62 mg kg^{-1} followed by Mavuno 5.5±0.44 mg kg^{-1} and manure 5.3±0.65 mg kg^{-1} while, Mavuno+manure had the lowest Olsen P of 4.8±0.62 mg kg^{-1}. There was no significant seasonal deference between the seasons (P=0.701).

In Nyalgunga (Table 4.6), there was a significant difference between treatments under study (P=0.029) with Mavuno+manure having the highest mean Olsen P of 6.4±0.82 mg kg^{-1}, followed by Mavuno added plot 5.5±1.22 mg kg^{-1}. Control and manure added plot Olsen P of 4.1±0.32 mg kg^{-1} and 3.6±0.31mg kg^{-1} respectively. There was no significant difference (P=0.564) between sampling seasons.

Table 4.5. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil Olsen P (mg kg^{-1}) in Nyabeda, Siaya

Treatment	Season			Mean Olsen P
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	7.0±(0.76)	6.1±(1.45)	6.1±(1.18)	6.4±(0.62)
Manure	3.9±(0.87)	6.5±(1.57)	5.4±(0.56)	5.3±(0.65)
Mav+Man	5.8±(1.13)	4.1±(0.54)	4.4±(1.45)	4.8±(0.62)
Mavuno	6.6±(0.67)	5.0±(0.79)	4.9±(0.65)	5.5±(0.44)
LSD (Season)	1.490 NS			
LSD (Treatment)	1.721 NS			

Table 4.6. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil Olsen P (mg kg^{-1}) in Nyalgunga, Siaya

Treatment	Season			Mean Olsen P
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	3.5±(0.26)	4.1±(0.87)	4.6±(0.33)	4.1±(0.32)
Manure	3.3±(0.73)	3.5±(0.44)	4.0±(0.56)	3.6±(0.31)
Mav+Man	7.3±(1.33)	4.5±(1.47)	7.3±(1.29)	6.4±(0.82)
Mavuno	6.2±(2.25)	5.3±(2.53)	4.9±(2.41)	5.5±(1.22)
LSD (Season)	1.665 NS			
LSD (Treatment)	1.923*			

4.4 Effect of treatments on maize grain yield

Mean maize grain yield results for Emusutswi are presented in table 4.7. There was a significant difference in maize grain yield between treatments (P=<0.001). Mavuno+manure added field had the highest mean grain yield of 1994±397.9Kg ha^{-1}, followed by manure field 1250±272.5Kg ha^{-1}, Mavuno field had 1223±295.4Kg ha^{-1} and control field which did not received external fertilizers had the lowest mean grain yield of 345±118.8Kg ha^{-1}. There was a significant difference between seasons (P=<0.001) with long rains 2011 yielding higher than short rains 2010 and 2011.

Table 4.7. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean maize grain yield (Kg ha^{-1}) in Emusutswi, Vihiga County

Treatment	Season			Mean maize grain yield
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	83±(55.8)	638±(283.8)	314±(140.5)	345±(118.8)
Manure	485±(194.4)	2079±(448.8)	1185±(390.4)	1250±(272.5)
Mav+Man	900±(327.3)	3551±(558.1)	1530±(209.8)	1994±(397.9)
Mavuno	535±(245.5)	2217±(540.3)	917±(298.9)	1223±(295.4)
LSD (Season)	364.9**			
LSD (Treatment)	421.3**			

In Nyabeda, (Table 4.8), there was significant difference between treatments (P=<0.001). Mavuno field had the highest mean grain yield of 2287±326.9 Kg ha^{-1}, followed by combined Mavuno+manure treatment 2093±271.6 Kg ha^{-1} then manure field 1999±276.6 Kg ha^{-1}. Control plot had the lowest mean grain yield of 1113±202.8Kg ha^{-1}. Significant variation was observed between seasons (P=<0.001), with long rains 2011 yielding higher than both short rains 2010 and 2011 just like in Emusutswi. (Figure 4.2).

Table 4.8. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean maize grain yield (Kg ha^{-1}) in Nyabeda, Siaya County

Treatment	Season			Mean maize grain yield
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	998±(314.9)	1308±(481.1)	1035±(320.2)	1113±(202.8)
Manure	1736±(357.3)	2599±(515.4)	1661±(516.6)	1999±(276.6)
Mav+Man	1635±(389.5)	2626±(315.9)	2017±(627.1)	2093±(271.6)
Mavuno	1909±(692.2)	3189±(455.2)	1764±(280.7)	2287±(326.9)
LSD (Season)	463.5**			
LSD (Treatment)	535.2**			

In Nyalgunga (Table 4.9), there was a significant difference between treatments (P=<0.001). Mavuno field had the highest mean grain yield of 3006±316.4 Kg ha^{-1}, followed by manure+Mavuno field 2758±578.9 Kg ha^{-1} and manure added field 1940±544.8 Kg ha^{-1}.

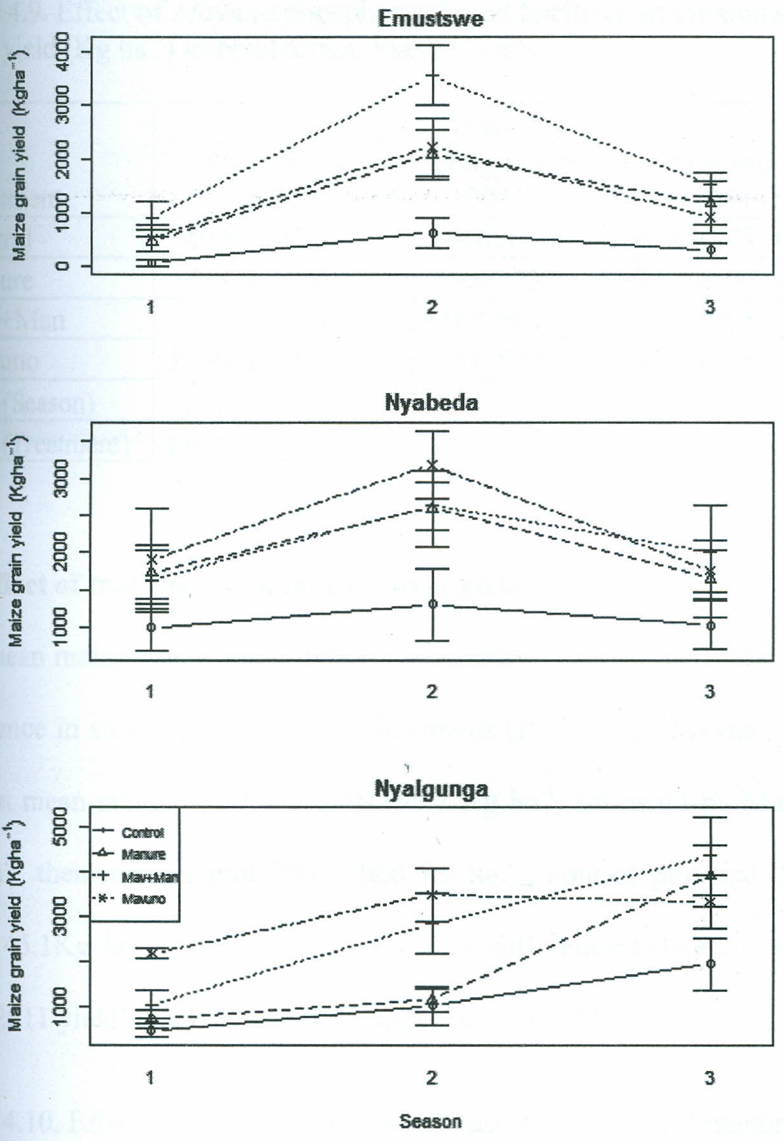

Fig 4.2. Seasonal trend for mean maize grain yield (Kg ha^{-1}) for Emusutswi, Nyabeda and Nyalgunga, short rain season 2010 - short rain season 2011

Control plot had the lowest mean grain yield of 1169±301.2 Kg ha^{-1}. Significant variation was observed between seasons (P=<0.001), with long rains 2011 yielding higher than both short rains 2010 and 2011 as seen in both Emusutswi and Nyabeda (Figure 4.2).

Table 4.9. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean maize grain yield (Kg ha^{-1}) in Nyalgunga, Siaya County

Treatment	Season			Mean maize grain yield
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	492±(143.3)	1046±(428)	1968±(573.9)	1169±(301.2)
Manure	738±(188.4)	1168±(273.2)	3915±(692.5)	1940±(544.8)
Mav+Man	1062±(315.4)	2848±(664.5)	4364±(865.3)	2758±(578.9)
Mavuno	2199±(108.4)	3483±(592.5)	3338±(586.4)	3006±(316.4)
LSD (Season)	731.2**			
LSD (Treatment)	844.3**			

4.5 Effect of treatments on maize stover yield

The mean maize stover yield data for Emusutswi is given in Table 4.10. There was a significant difference in stover yield between treatments (P=<0.001). Mavuno+manure added field had the highest mean stover yield of 1340±190.7 Kg ha^{-1}, followed by Mavuno added field 846±103.4 Kg ha^{-1}, then manure plot 796±128.6 Kg ha^{-1} , control plot had the lowest mean stover yield 537±145.1Kg ha^{-1}. There was a significant difference between seasons (P=<0.001), with long rains 2011 yielding more than short rains 2010 and 2011.

Table 4.10. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean maize stover yield (Kg ha^{-1}) in Emusutswi, Vihiga County

Treatment	Season			Mean maize stover yield
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	336±(116.4)	894±(383.7)	380±(81.2)	537±(145.1)
Manure	684±(207.8)	1068±(90.5)	635±(304.8)	796±(128.6)
Mav+Man	996±(249)	2035±(307)	989±(50.4)	1340±(190.7)
Mavuno	701±(222)	1169±(95.6)	668±(114.7)	846±(103.4
LSD (Season)	303.8**			
LSD (Treatment)	350.8**			

In Nyabeda (Table 4.11), There was a significant difference in stover yield between treatments (P=0.034). Mavuno added field had the highest mean stover yield of 1431±162.2 Kg ha^{-1}, followed by Mavuno+manure added field 1299±129.5 Kg ha^{-1}, then manure plot 1155±161.8 Kg ha^{-1} , control plot had the lowest mean stover yield 986±124.9 Kg ha^{-1}. There was a significant difference between seasons (P=<0.001), with long rains 2011 yielding more than short rains 2010 and 2011 as seen in Emusutswi.

Table 4.11. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean maize stover yield (Kg ha^{-1}) in Nyabeda, Siaya County

Treatment	Season			Mean maize stover yield
	Long rains 2011	Short rains 2011	Short rains 2010	
Control	749±(152.6)	885±(269.3)	1324±(124.9)	986±(124.9)
Manure	876±(155.6)	1344±(444)	1244±(161.5)	1155±(161.8)
Mav+Man	837±(110.9)	1689±(189.4)	1372±(111.9)	1299±(129.5)
Mavuno	820±(123.2)	1793±(269.3)	1680±(113)	1431±(162.2)
LSD (Season)	264.1**			
LSD (Treatment)	305.0*			

While in Nyalgunga (Table 4.12), there was no significant difference in stover yield between treatments (P=0.108). Mavuno+manure added field had the highest mean stover yield of 1545±365.5 Kg ha^{-1}, followed by Mavuno added field 1282±229.6 Kg ha^{-1}, then manure plot 1140±270.3 Kg ha^{-1} , control plot had the lowest mean stover yield of 998±206.6 Kg ha^{-1}. There was however a significant difference between seasons (P=<0.001) with long rains 2011 yielding more than short rains 2010 and 2011 (Figure 4.3).

Table 4.12. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean maize stover yield (Kg ha^{-1}) in Nyalgunga, Siaya County

Treatment	Season			Mean maize stover yield
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	443±(100.5)	990±(114.8)	1559±(420.8)	998±(206.6)
Manure	584±(186.6)	758±(94.2)	2078±(406.6)	1140±(270.3)
Mav+Man	410±(74.9)	1608±(271.2)	2617±(550.2)	1545±(365.5)
Mavuno	651±(48.1)	1273±(103)	1921±(465.6)	1282±(229.6)
LSD (Season)	392.9**			
LSD (Treatment)	453.7 NS			

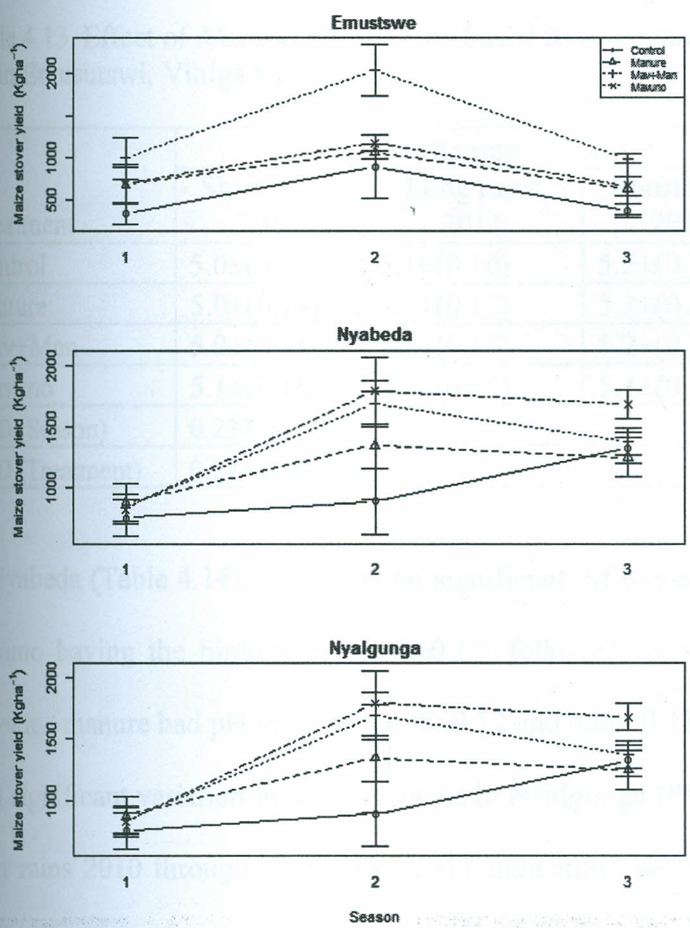

Fig 4.3. Seasonal trend for mean maize stover yield (Kg ha^{-1}) for Emusutswi, Nyabeda and Nyalgunga, short rain season 2010 - short rain season 2011

4.6 Effect of treatments on soil pH

The soil pH data as affected by treatments for Emusutswi is presented in Table 4.13. There was no significant difference between treatments in Emusutswi (P=0.711). Combined Mavuno+manure plot had the highest mean soil pH 5.15±0.09, Control plot which had not received any input for 6 years had mean pH of 5.12±0.12, manure plot had a pH 5.04±0.11, while mavuno used singly had the lowest pH of 5.02±0.08. The was no significant seasonal variation for pH in Emusutswi sub-location (P=0.272).

Table 4.13. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil pH in Emusutswi, Vihiga County.

Treatment	Season			Mean soil pH
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	5.0±(0.13)	5.1±(0.16)	5.2±(0.30)	5.12±(0.12)
Manure	5.0±(0.14)	4.9±(0.17)	5.2±(0.26)	5.04±(0.11)
Mav+Man	5.0±(0.11)	5.2±(0.13)	5.2±(0.20)	5.15±(0.09)
Mavuno	5.1±(0.16)	4.8±(0.15)	5.1±(0.11)	5.02±(0.08)
LSD (Season)	0.237 NS			
LSD (Treatment)	0.274 NS			

In Nyabeda (Table 4.14), there was no significant difference between treatment (P=0.794), with Mavuno having the highest pH 5.02±0.12, followed by manure 5.04±0.12. Control plot and Mavuno+manure had pH values of 4.98±0.12 and 4.96±0.13 respectively. There was however a high significant variation between seasons in Nyalgunga (P=<0.001), with an upward trend from short rains 2010 through short rains 2011 indicating use of Mavuno and manure reduced soil acidity with time (Figure 4.4).

Table 4.14. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil pH in Nyabeda, Siaya County.

Treatment	Season			
	Short rains 2010	Long rains 2011	Short rains 2011	Mean soil pH
Control	4.6±(0.12)	5.0±(0.18)	5.3±(0.11)	4.98±(0.12)
Manure	4.6±(0.14)	5.1±(0.12)	5.4±(0.12)	5.04±(0.12)
Mav+Man	4.6±(0.08)	4.9±(0.05)	5.4±(0.07)	4.96±(0.13)
Mavuno	4.8±(0.15)	4.9±(0.19)	5.4±(0.10)	5.02±(0.12)
LSD (Season)	0.1514**			
LSD (Treatment)	0.1748 NS			

In Nyalgunga (Table 4.15), there was no significant difference between treatments under study (P=0.923). Control had the highest pH 5.14± 0.12 followed by Mavuno+manure 5.12± 0.10, Manure 5.09± 0.07 and Mavuno added plot 5.07± 0.10. However there was significant seasonal variation (P=<0.001) in pH values rising with seasonal fertilization using both manure and mavuno or their combinations (Figure 4.4).

Table 4.15. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil pH in Nyalgunga, Siaya County.

Treatment	Season			
	Short rains 2010	Long rains 2011	Short rains 2011	Mean soil pH
Control	4.8±(0.05)	5.2±(0.12)	5.5±(0.16)	5.14±(0.12)
Manure	4.8±(0.04)	5.3±(0.09)	5.2±(0.06)	5.09±(0.07)
Mav+Man	5.0±(0.45)	5.1±(0.04)	5.3±(0.06)	5.12±(0.10)
Mavuno	4.8±(0.07)	5.2±(0.12)	5.2±(0.21)	5.07±(0.10)
LSD (Season)	0.2028**			
LSD (Treatment)	0.2342 NS			

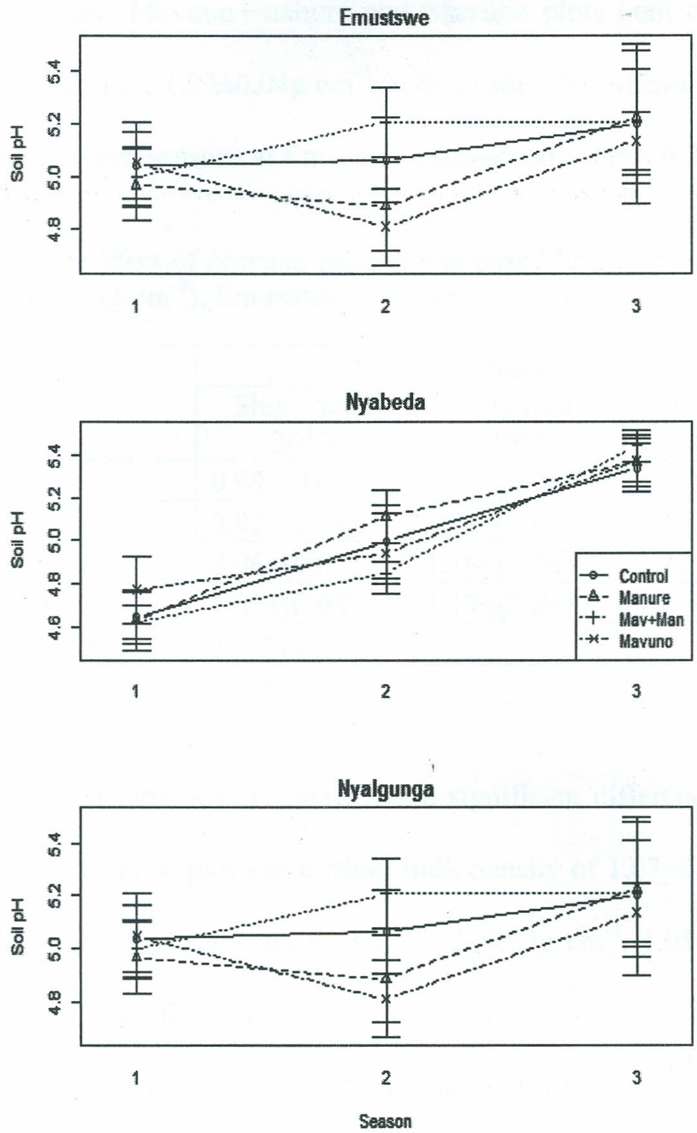

Fig 4.4. Seasonal trend for mean soil pH for Emusutswi, Nyabeda and Nyalgunga, short rain season 2010 - short rain season 2011

4.7 Effect of treatments on Soil Bulk Density (SBD)

The soil bulk density data as affected by treatments for Emusutswi is presented in Table 4.16. There was no significant difference between treatments in Emusutswi (P=0.165). Control plot which had not received inputs for 6 years had the highest mean soil bulk density of 1.13±0.04g

cm^{-3}, Manure, Mavuno+manure and Mavuno plots both had a bulk density 1.09±0.04g cm^{-3}, 1.07±0.04g cm^{-3}, 1.09±0.04g cm^{-3} in that order. Significant variations was observed in soil bulk density between seasons at Emusutswi sub-location (P=<0.001).

Table 4.16. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil bulk density (g cm^{-3}), Emusutswi, Vihiga

Treatment	Season			Mean soil bulk density
	Short rains 2010	Long rains 2011	Short rains 2011	
Control	0.99±(0.07)	1.25±(0.06)	1.16±(0.06)	1.13±(0.04)
Manure	0.97±(0.04)	1.21±(0.07)	1.11±(0.05)	1.09±(0.04)
Mav+Man	0.96±(0.07)	1.16±(0.04)	1.10±(0.05)	1.07±(0.04)
Mavuno	1.00±(0.08)	1.17±(0.04)	1.10±(0.04)	1.09±(0.04)
LSD (Season)	0.04793**			
LSD (Treatment)	0.05534 NS			

In Nyabeda (Table 4.17), There was a significant difference between treatments in Emusutswi (P=0.037). Control plot had a mean bulk density of 1.07±0.02g cm^{-3}, Manure, Mavuno+manure and Mavuno plots had bulk density 1.03±0.03g cm^{-3}, 1.01±0.03g cm^{-3} and 1.02±0.03g cm^{-3} in that order. Significant variations was observed in soil bulk density values between seasons at Nyabeda sub-location (P=<0.001) with an upward trend in soil bulk density (Figure 4.5).

Table 4.17. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil bulk density (g cm^{-3}), Nyabeda, Siaya

Treatment	Season			Mean soil bulk density
	Short rains 2010	Long rains 2011	Short rains 2010	
Control	0.98±(0.02)	1.08±(0.02)	1.14±(0.03)	1.07±(0.02)
Manure	0.95±(0.03)	1.04±(0.03)	1.09±(0.04)	1.03±(0.03)
Mav+Man	0.97±(0.03)	1.02±(0.03)	1.02±(0.02)	1.01±(0.03)
Mavuno	0.97±(0.04)	1.01±(0.02)	1.09±(0.03)	1.02±(0.03)
LSD (Season)	0.03675**			
LSD (Treatment)	0.04243*			

The soil bulk density data as affected by treatments for Nyalgunga is presented in Table 4.18. There was no significant difference between treatments in Nyalgunga (P=0.169). Control plot which had not received inputs for 6 years had the highest mean soil bulk density of 1.10±0.02g cm^{-3}, Manure, Mavuno+manure and Mavuno plots had a bulk density of 1.05±0.03g cm^{-3}, 1.05±0.02g cm^{-3}, and 1.05±0.04g cm^{-3} in that order . Seasonal variation was observed in soil bulk density values for Nyalgunga sub-location (P=0.001).

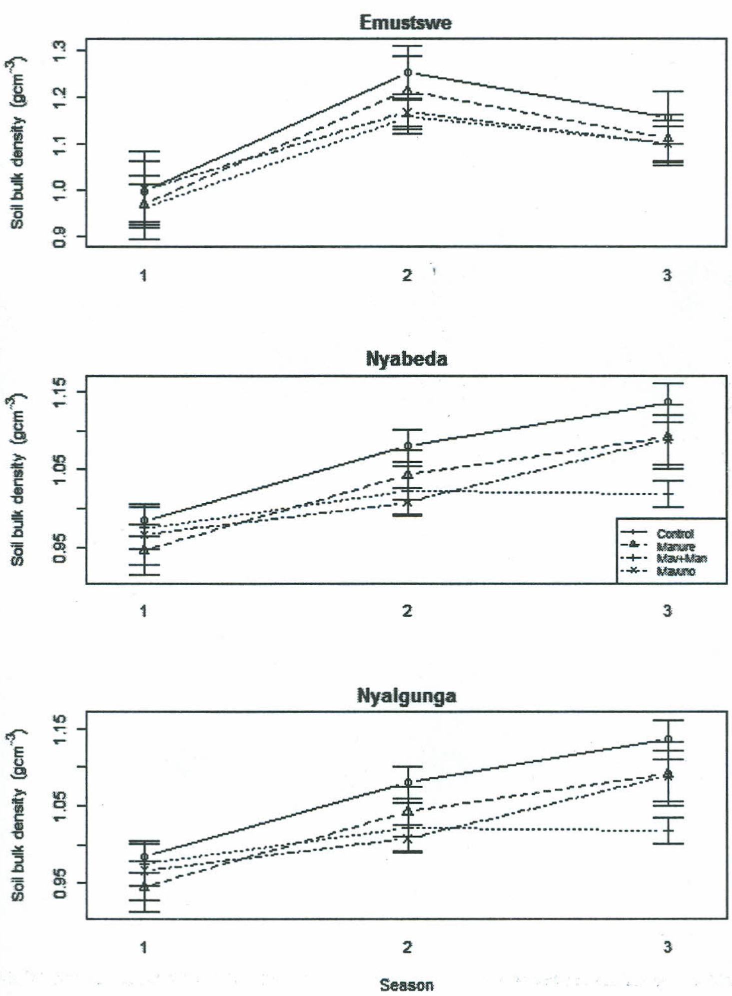

Fig 4.5. Seasonal trend for mean soil bulk density (g cm^{-3}) for Emusutswi, Nyabeda and Nyalgunga, short rain season 2010 - short rain season 2011

Table 4.18. Effect of *Mavuno* phosphorus-based fertilizer and manure application on mean soil bulk density (g cm^{-3}), Nyalgunga, Siaya County

Treatment	Season			Mean soil bulk density
	Short rains 2010	Long rains 2011	Short rains 2010	
Control	1.03±(0.00)	1.16±(0.03)	1.10±(0.03)	1.10±(0.02)
Manure	1.00±(0.02)	1.10±(0.02)	1.05±(0.04)	1.05±(0.03)
Mav+Man	1.04±(0.01)	1.09±(0.03)	1.02±(0.02)	1.05±(0.02)
Mavuno	1.04±(0.04)	1.02±(0.05)	1.02±(0.04)	1.05±(0.04)
LSD (Season)	0.04500**			
LSD (Treatment)	0.05197 NS			

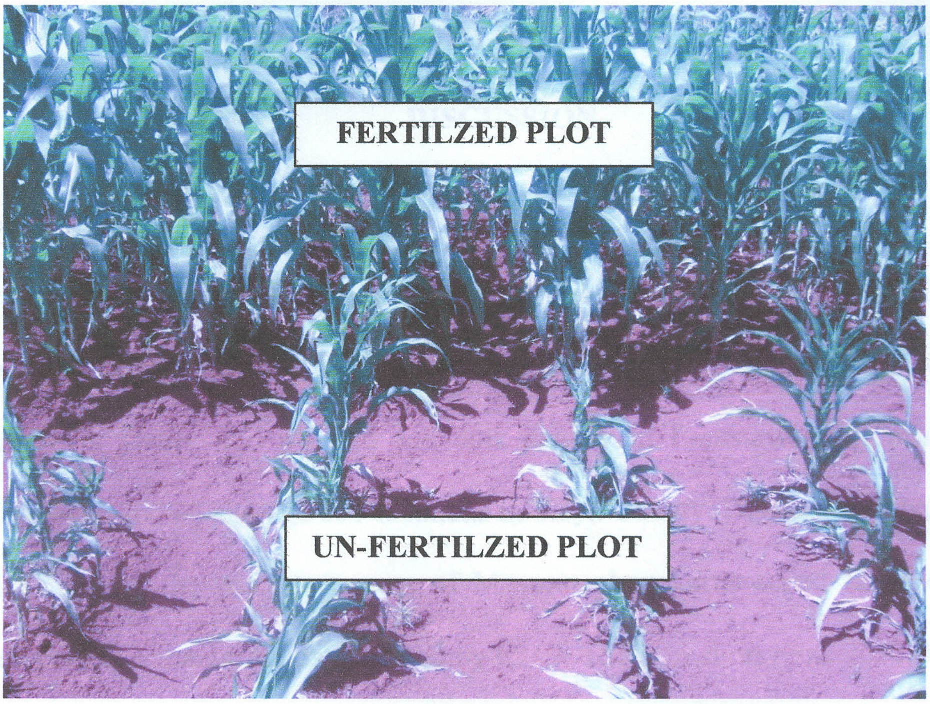

Plate 4.1. Shows crop performance for unfertilized (control) and fertilized (treatment plot) at Nyabeda experimental site in Siaya County 2011 (*Photo by Author)*.

Plate 4.2. Shows treatments under study with IR maize: (1) control, and susequent improvement in growth for treatments (2) Manure, (3) *Mavuno* and best growth where both manure and *Mavuno* have been applied (4) at Nyalgunga experimental site 2011. (*Photo by Author)*

CHAPTER FIVE

DISCUSSION

5.1 Introduction

Soil characteristics discussed here reflects the impact of 6 years application of Mavuno (20kg P ha^{-1}) phosphorus-based fertilizer and manure (2t ha^{-1}) on soil organic carbon, Olsen P, maize grain and stover yields, soil pH and soil bulk density in Emusutwsi sub-location in Vihiga County; Nyabeda and Nyalgunga sub-locations in Siaya County. Discussion is based on soil and maize yield data at the end of 6 years of Mavuno phosphorus based fertilizer and manure application on experimental fields managed by CIAT-TSBF in short rains 2010, long rains 2011 and short rains 2011 (Figure 4.6).

5.2 Effect of treatments on Soil Organic Carbon (SOC)

Soil organic carbon was not significantly affected by application of Mavuno phosphorus based fertilizer (20kg P ha^{-1}) and manure (2t ha^{-1}) for the three season under study in Emusutswi P= 0.056 (Table 4.1) Nyabeda P=0.115 (Table 4.2) and Nyalgunga P=0.906 (Table 4.3). This is in contrast to many studies that have indicated that application of NPK fertilizers resulted in a significant increase in soil organic carbon even with continuous maize harvest (Mucheru-Muna *et al.*, 2007; Sharma *et al.*, 2002; Odell *et al.*, 1982; Pieri 1989). However there are study findings that agree with results in this study confirming that rapid decline in soil organic carbon levels with continuous cultivation in sub Saharan Africa (Bationo and Buerkert 2001; Bationo *et al.*, 1995). The apparent contradictions of the effect of fertilization on SOC are partly attributed to rate of Mavuno and manure application and duration of application (Giller *et al.*, 1997). While most studies have indicated that consistent application of mineral and organic based resources contributed to soil organic carbon build up (Buol *et al.*, 1990; Buol and Stokes, 1997), the insignificant results from this study can be attributed to fertilizer use duration, this is confirmed by a study by Giller *et al.*, (1997) which reported that carbon sequestration is gradual and would require long term consistent use of adequate mineral and organic resources to realize substantial increase. Gregorich *et al.*, (1996) found a higher organic carbon in the top horizon in fertilized plots, and concluded that adequate fertilization increased crop yield leading to greater carbon storage in the soils. This confirms that the 6 year period being evaluated in this study was not enough hence need for more time and higher rates of Mavuno and manure application, as found also by (Giller *et al.*, 1997,Fisher *et al.*, 1994 and Sanchez, 1995).

The significant variation between seasons in all sites (Emusutswi, Nyabeda and Nyalgunga) can bes attributed to nutrient depletion overtime to meet crop nutrition requirement. A study by Murwira, (1996) pointed that soil organic matter acts as a reservoir of plant nutrients such as N, P and S and modifies the effect of toxic elements; hence in nutrient depleted soils SOM is mineralized to release nutrients for plant use resulting to low SOC. This is in agreement with a study by Lal *et al.* (1995) which found that the loss of top soil organic carbon associated with soil nutrient depletion resulted in additional CO_2 emissions to the atmosphere from decreasing soil and plant C stocks. All sites Emusutswi, Nyabeda and Nyalgunga showed a declining trend with seasonal application of Mavuno and manure (Figure 4.1). The downward trend is attributed to low soil fertility and crop nutrient demand requiring large investments in P, especially in western Kenya where soils are P fixing (Kifuko *et al.*, 2007).

This study therefore confirms that Mavuno (20kg P ha^{-1}) and manure (2t ha^{-1}) is not adequate to meet plant nutrient demand in P deficient and P fixing soils coupled with low soil fertility leading to a decline in SOC with seasonal tillage. Studies by Pieri (1989) reported that without adequate mineral fertilizer application, soil tillage increased the annual rate of SOC losses from 3.8% (with manual tillage) to 4.7% and 5.2% following light and heavy tillage respectively. Balesdent et al. (1990) also found that conventional tillage practices promoted soil organic matter loss due to increased soil aeration, thus concurring with the seasonal decline experienced both in Emusutswi, Nyabeda and Nyalgunga in western Kenya.

5.3 Changes in residual Olsen P as influenced by treatments

Seasonal application of Mavuno phosphorus based fertilizer (20kg P ha^{-1}) and manure (2t ha^{-1}) did not have a significant change on residual Olsen P in Emusutswi P= 0.122 (Table 4.4) and Nyabeda P=0.293 (Table 4.5). The low rates of Mavuno and manure are probably not sufficient to meet crop requirement and contribute to residual Olsen P. This had been confirmed by studies done by Frossard *et al.*, (2000) and Tiessen, (1991) which pointed out that soils in western Kenya are inherently low in extractable P and would require large rates of P soluble fertilizers to meet crop P demands for soils with higher P sorption capacity like Emusutswi and Nyabeda in western Kenya (Palm, 1997).

Studies by Nziguheba *et al.*, (1998) and Iyamuremye and Dick, (1996) confirmed that incorporation of manure increases P use efficiency and during its oxidation P and other nutrients become plant available reducing their concentration in soil. A study by Opala *et al*,.(2007) also found no response to low P rates in western Kenya. This is consistent with the findings of this study which did not find significant levels of residual P between treatments. Mavuno P based fertilizer due to its chemical properties have a liming properties on acidic soils of western Kenya due to Calcium and Magnesium oxides reversing the P sorption characteristic of soils in the study area, enhancing P availability to crops as pointed out by Cox (1994).

Mavuno enhances Olsen P release and uptake by plant due to its additional chemical properties on P sorbing soils. A study by Buresh (1997) concluded that whereas strongly sorbed non labile P also referred to as reserve capital is composed of less soluble P pools, sodium hydroxide extractable inorganic and organic P (NaOH-P_i and NaOH-P_o) and hydrochloric acid extractible P (HCL-P_i) that gradually becomes plant available over many cropping seasons is only slowly released and made available to plants lowering its concentration towards the end of cropping season.

Addition of manure improves soil conditions making the inherent P available to crops thus reducing its concentration in soil solution through improved uptake by plants. Manure alone has a low potential of supplying the required P for plant growth however it enhances P-availability. A study by Guppy *et al.*, (2005b) have proposed mechanisms for increasing P availability as a result of OM application. During OM decomposition and mineralization Olsen-P is increased (Nziguheba *et al.*, 2002, Guppy *et al.,* 2005a and Palm *et al.*, 1997). Studies by Fox and Searle (1978) and Iyamuremye *et al.*, (1996a) have also reported increased P availability through liming of P-fixing acid soils. A study by Lindsay and Stephenson (1959) also showed that as SOM decomposes in the soil, carbon compounds are produced through microbial action that may react directly with sorption sites in the soil, potentially increasing the solution P concentration. In this study sampling soils at the end of cropping season showed low residual available P in the soil due to enhanced P availability to crops. Application of Mavuno singly or in combination with manure resulted in enhanced Olsen P thus promoting P uptake by plants. Study by Othieno, (1973) revealed that organic anions produced during decomposition of organic materials may compete with P for the same adoption sites and thereby increase P availability for plant uptake as witnessed in this study.

In Nyalgunga significant variation between treatments was observed P=0.029 (Table 4.6), with Mavuno in combination with manure contributing to high residual Olsen P followed by Mavuno

No significant difference was observed for residual Olsen P between seasons in Emusutswi (P=0.951), Nyabeda (P=0.701) and Nyalgunga (P=0.564). An indication that application of low dose of Mavuno and manure do contribute to residual Olsen P and climatic variations have no effect on available P especially when low doses which doesn't meet plant P requirements are applied on P fixing soils of western Kenya.

5.4 Effect of treatments on maize grain yield

Application of Mavuno phosphorus based fertilizer (20Kg P ha^{-1}) and manure (2t ha^{-1}) had a significant effect on maize grain yield in Emusutswi during the study period (P=<0.001). Mavuno in combination with manure or when applied singly resulted in high mean grain yield (Table 4.7), while control field which had not received external fertilizers had the lowest mean grain yield. This clearly indicates that application of Mavuno and manure can greatly improve maize yield in Emusutswi. Mavuno and manure besides the direct benefit of nutrient supply, have an effect on soil properties which influence nutrient acquisition and plant growth (Palm *et al.*, 1997; Giller *et al.*, 2002). Poor maize growth was observed on control treament (plate 4.1and4.2) which translated into low grain yield of control plot. Manure and additional nutrients in Mavuno increseas P availability and use efficiency (Nziguheba *et al.*, 1998; Ikerra *et al.*, 2006; Gachengo *et al.*, 1998), leading to high maize grain yield.

In Nyabeda, just like Emusutswi, there was significant difference between treatments (P=<0.001). Mavuno added field had the highest mean grain yield, while control plot had the lowest mean grain yield (Table 4.8). In Nyalgunga(Table 4.9), there was a significant difference between treatments (P=<0.001) with Mavuno field having the highest mean grain yield and control plot the lowest mean grain yield. The high significant differences in mean maize grain yield is in agreement with a study by Qureshi (1991) which reported that inorganic and organic fertilizers when combined or used singly gave maize grain yields above 3000 kg ha^{-1} with good crop husbandry whereas control plot gave only 462 kg ha^{-1}. Improved crop growth and yield is essential for the build-up of soil organic carbon necessary for maintenance of soil structure, water holding capacity of soil and nutrient availability to crops.

Farmyard manure (FYM) is a useful source of N, P, and K (Russell, 1973). In Emusutswi, Nyabeda and Nyalgunga sub-locations Mavuno phosphorus based fertilizers resulted to doubling of maize grain yield compared to control plots. Similar results have been witnessed by Qureshi, (1991) and Swift *et al*., (1994) in their previous studies. In Emusutswi application of Mavuno resulted in a yield increase of 255% above control; Nyabeda 105% above control; and Nyalgunga 157%. The ability of Mavuno to improve P availability to crops among others contributes to a remarkable yield increase owing to its additional nutritional benefits compared to ordinary fertilizers used in the region. Continuous croping without nutrient addition results in nutrient mining leading to low soil fertility as can be seen with control plots having the lowest mean grain yield consistently at all sites.

The mean maize grain yield for Emusutswi, Nyabeda and Nyalgunga sub-locations showed significant seasonal variation (P=<0.001). Short rains 2010 and short rains 2011showed the lowest yield, while long rains 2011 had the highest mean grain yield across all treatment. The seasonal variation can be attributed to rainfall distribution and amount during the study period (Figure 3.4).

5.5 Effect of treatments on maize stover yield

Just like maize grain yield, there was a significant variation in maize stover yield in Emusutswi ($P=<0.001$) as shown in table 4.10, the high stover yield exhibited when Mavuno is combined with manure or used singly is an indication that fertilization with Mavuno enhances plant growth resulting to increased biomas production. This is achieved due to addition of Mavuno fertilizer and manure, which other than supplying macronutrients has other benefits of supplying micronutrients required for optimum crop growth in acidic soils of western Kenya. Control plot had consistently low stover yield in Emusutswi compared to other treatments under study. The result is comparable to studies by Qureshi (1987) which reported that in low fertlity fields, maize yield can decline by about 30% in the absense of fertilizers and or manure application.

A study by Gregorich *et al.*, (1996) found a higher organic carbon in the top horizon in fertilized plots, and concluded that adequate fertilization increased biomas yield leading to greater carbon storage in the soils. This supports the need for integrated soil fertility management for enhanced biomass productivity and reduction of environmental degradation through incorporation both inorganic fertilizer like Mavuno and manure. A study by Han *et al.* (2006) and Wang *et al.* (2006) found that chemical fertilizers combined with organic manure increased nutrient availability contributing to soil organic carbon build up in soils through increased soil organic matter turnover in soils. Odell *et al.*, (1982) reported that application of NPK fertilizers resulted in a significant increase in soil organic carbon over time and this is linked to increased crop vigour. There was a significant variation between the seasons in Emusutswi ($P=<0.001$). The high maize stover yield in long rains 2011 and low maize stover yield in both short rain season 2010 and 2011 confirms that rainfall amount and distribution equally have an effect on maize growth and yield.

In Nyabeda (Table 4.11) just like Emusutswi there was a significant variation between treatments (P=0.034), with Mavuno used singly or in combination with manure giving the highest maize stover yield and control plot the lowest stover yield. The enhanced soil physical, chemical and biological properties following addition of Mavuno phosphorus-based fertilizer and organic manure resulted into high stover yield in both Mavuno and manure plots. Campbell *et al*., 1986, Palm *et al*., 1997, Nziguheba *et al*., 2002 and Guppy *et al*.,2005a, reported increased mineralization caused by addition of manure.There was a significant difference between season in Nyabeda (P=<0.001) showing long rains season yielding more mean maize stover than both short rainy season under study. In Nyalgunga unlike Emusutswi and Nyabeda there was no significant treatment differences following 6 years application of Mavuno P based fertilizer and manure (Figure 4.12). This can be linked to low and poorly distributed rainfall received in Nyalgunga during the study period (Figure3.4). FAO soil classification for Siaya also confirms that Eutric Nitisols of Nyalgunga have variable fertility. However there were significant variation between seasons under study P=<0.001), confirming rainfall distribution and pattern had an effect on maize growth in Nyalgunga (Figure 4.6).

5.6 Effect of treatments on soil pH

In Emusutswi (Table 4.13), application of Mavuno and manure had no significant effect on soil pH (P=0.711), this indicates that Mavuno and manure application have no effect on soil pH. This can be attributed to the buffering capacity of Mavuno due Mg^{2+} and Ca^{2+} ions which have a liming effect on soils, this is consistent with findings of Anetor and Akinrinde (2007) which showed that fertilizer sources with Mg^{2+} and Ca^{2+} have a potential for sustaining soil productivity by raising pH of acidic soils. Their buffering potential increases nutrient availability to crops hence no negative impact on soil, this is confirmed by non significant difference between seasons in Emusutswi in this study (Figure 4.4).

In Nyabeda (Table 4.14), just like Emusutswi application of Mavuno and manure had no significant effect on soil pH (P=0.794. The buffering potential of both Mavuno and manure are beneficial in maintaining soil properties for enhanced nutrient release and utilization in P-fixing soils. A study by Buresh, (1997) reported 80% of soils in western Kenya are P deficient (<5 mg P kg ha^{-1}), therefore application of low doses Mavuno and manure would have no effect on soil pH in Nyabeda, similar results were reported by Kifuko *et al.,* (2007) and Palm, *et al.,* (1997). There was no significant difference in soil pH between seasons under study in Nyabeda (Figure 4.4).

In Nyalgunga (Table 4.15), just like Emusutswi and Nyabeda application of Mavuno P based fertilizer and manure did not have a significant effect on pH. The low phosphorus levels and high P-fixing capacity of soils in the Nyalgunga led to low impact realized from application of low levels of organic manure (2t ha^{-1}) and inorganic phosphorus (20kg P ha^{-1}) on soil pH. However there was a significant variation in soil pH in Nyalgunga. This can be attribted to poor distribution of rains and low intensity (Figure 3.4). Low soil moisture lead to high concentration of minerals in soils causing seasonal fluctuations based rainfall availability.

5.7 Effect of treatments on soil bulk density

There was no significant treatment difference in soil bulk density in Emusutswi (P=0.165) with low doses of Mavuno and manure application (Table 4.16). The low soil fertility in western Kenya results in low soil organic matter turnover in soils through crop yield. Low soil fertility leads to mineralization of accumulated SOC to release nutrient for plant growth hence no biomass effect on soil bulk density. Studies by Tittonel (2005) in Eastern Uganda and Western Kenya also revealed compaction in top soil profile attributed to continuous tillage with little organic and inorganic inputs; this is consistent with the results of this study showing addition of low doses of Mavuno fertilizer and manure in low fertility and P-fixing soils had no significance effect on soil bulk density. However seasonal variation was significant between study seasons showing soil bulk density varied with seasonal rainfall availability and distribution P=<0.001). Roose and Barthes, (2001) have reported that high rainfall and poor soil cover leads to soil compaction.

Unlike Emusutswi, there was a significant treatment difference in soil bulk density levels in Nyabeda (P=<0.001) as shown in (Table 4.17). Mavuno and manure improves soil microbial function by promoting crop growth leading to improved shoot and root biomas in soils (Bauer and Black, 1994). Combining Mavuno and manure has synergistic effects resulting to low soil bulk density, improved aeration, nutrient availability and use efficiency (Bationo et al., 1996). Seasonal variation was significant between study seasons (P=<0.001), the high soil bulk density found in control plot is linked to low maize and stover yields resulting to low soil organic turnover in soils in Nyabeda.

While in Nyalgunga (Table 4.18), just like Emusutswi, there was no significant effect between treatments (P=0.169). This is confirmed by lack of significance in maize stover yield in Nyalgunga which is the main contributor to soil organic matter. Crop biomass returned in soil contribute to soil organic carbon resposible for improvements in soil bulk density, Hagan *et al.*, (2010) reported accumulation of SOM due to increased biomass production. Low and poor rainfall dirtibution in Nyalgunga (Figure 3.4) resulted in low biomass production thus little benefit to SOM and bulk density in Nyalgunga. However seasonal variation in soil bulk density was noted in Nyalgunga (Figure 4.6).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Mavuno phosphorus based fertilizer (20kg P ha $^{-1}$) and organic manure (2t ha $^{-1}$) continuous application in Emusutswi, Nyabeda and Nyalgunga after 6 years did not have an effect on soil organic carbon. Soils in western Kenya are P-fixing; therefore application of Mavuno and manure which have buffering capacity due to Calcium and magnesium oxides enhances nutrient availability, thus application of Mavuno and manure didn't contribute to residual Olsen P. Additional chemical properties offered by Mavuno results in a remarkable increase in maize grain and stover yield, making it appropriate for low fertility soils in western Kenya, Mavuno has the potential of sustaining soil productivity, when adequate amount is applied thus having no effect on soil acidity and lowering soil bulk density through improved plant growth.

6.2 Conclusions

After 6 years of fertilization with Mavuno phosphorus based fertilizer (20kg P ha $^{-1}$) and organic manure (2t ha $^{-1}$) there was no effect on soil organic carbon both in Emusutswi, Nyabeda and Nyalgunga. Due to low soil fertility, soil organic matter attributed to maize stover is mineralized to release nutrients for plant growth resulting in no effect on soil organic carbon. Seasonal variability evident in all study sites shows soil organic carbon is affected by rainfall amount and distribution.

There were no changes in residual extractable phosphorus (Olsen P) following application of Mavuno planting fertilizer (20Kg P ha $^{-1}$) and manure (2t ha $^{-1}$) in Emusutswi and Nyabeda except Nyalgunga. Mavuno and manure due to their soil buffering properties enhances P availability for plant use, therefore no P accumulation was observed. The significant residual Olsen P levels in Nyalgunga is attributed to low rainfall received slowing P dissolution and use.

Mavuno (20Kg P ha^{-1}) when applied alone or in combination with manure (2t ha^{-1}) was more effective in increasing maize grain and stover yields due to improved soil conditions compared to control plots in both sites. The use of Mavuno and manure also resulted to doubling of mean maize grain and stover yield through increased biomas production. Mavuno planting fertilizer has both *macro* and *micro* nutrients important for maize growth and improved soil conditions due to its Ca^{2+} and Mg^{2+} components. Seasonal differences in rainfall amout affected maize grain and stover yield except in Nyalgunga where season had no effect on stover yield due to low precipitation.

Application of Mavuno planting fertilizer (20Kg P ha^{-1}) and manure (2t ha^{-1}) had no effect on soil pH. Soils in the study are are generally P-fixing, therefore addition of Mavuno and manure which have soil buffering potential enhanced nutrient use without affecting soil pH. Seasonal fluctuations were experience in Nyabeda and Nyalgunga but not in Emusutswi. Soil bulk density was affected by Mavuno and manure application in Nyabeda but not the other study sites. Season variation was also evident in all sites studied.

6.3 Recommendations

Mavuno (20Kg P ha^{-1}) when applied alone or in combination with manure (2t ha^{-1}) have no effect on soil organic carbon but can be important in P fixing soil of western Kenya due to its buffering potential thus enhancing soil productivity.

To reduce phosphorus accumulation in soils and promote its availability to crops Mavuno can be applied in combination with manure for improved phosphorus utilization and crop yield in western Kenya which generally has low Olsen-P and the soils are P-fixing due to high levels of Al^{2+} and Fe^{2+} oxides.

Application of Mavuno phosphorus based fertilizer and manure results in remakable yield increase therefore Mavuno can be applied in P-fixing soils of western Kenya for increased maize yield.

Due to its buffering capacity Mavuno phosphorus based fertilizer and manure can be used in acid soils in western Kenya without affecting soil pH.

Mavuno phosphorus based fertilizer and manure by increasing maize stover yield, can increase soil organic matter turnover thus having positive effect on soil bulk density, through increased SOC and improved porosity.

6.4 Areas for further study

Other parameters contributing to high significant maize grain and stover yield need to be investigated as the soil parameters investigated were not affected by treatments under study, following Mavuno P-based fertilizer and manure use.

There is need to study the effect of varying Mavuno phosphorus based fertilizer and manure rates on soil chemical properties in P-fixing soils of western Kenya, to have an indication of the optimal levels to address crop P requirements.