EFFECTS OF LIME AND INORGANIC FERTILIZERS ON MAIZE YIELD AND STRIGA (*Striga hermonthica*) GROWTH IN ACID SOILS OF KAKAMEGA AND SIAYA COUNTIES, KENYA

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DECLARATION

Declaration by the Candidate

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DEDICATION

This Thesis is dedicated to Linet Nanjala Kisiangani, Rose Mukasia Mungahu and my children Diana Nasimiyu, Faith Nekesa, Defin Nelima, Glory Neema, Asaph Sipha and Abigail Afua for their encouragement, patience and understanding. The thesis is further dedicated to my surviving brother; Namukholi Mbakaya and sisters Ruth Werengekha and Perita Khasoa for their encouragement. It is also dedicated to my dear late father and mother Kepha Muse and Dina Namasindakusi respectively, brothers Luther Khaemba, Hebron Mbakaya and Francis Waswa, sister Sarah Nakhanu and maternal uncle Sikuku Wanakhoba, who passed on before enjoying the fruits of my achievement.

To God is all the glory forever.

ABSTRACT

Food insecurity is one of the major challenges in sub-Saharan Africa (SSA), Kenya included, and continues to pose a threat to the existence of millions of the inhabitants of the region. Yet a lot of research has been carried out and results have not changed the food security situation substantially. This could be attributed to the smallholder farmers in the region not adopting and / or scaling up the technologies. As a consequence, yield of maize hardly exceeds 0.5 t ha^{-1} at on-farm level compared to over 8.0 t ha^{-1} in research fields. These low yields are caused by multiple production constraints: low soil fertility (deficient nitrogen and phosphorus and soil acidity), *Striga* weed and high cost of inputs among other constraints. A study was conducted on 40 representative small holder farmers' fields for four consecutive seasons (2009 short rains to 2011 long rains season) in Kakamega and Siaya Counties to evaluate the effects of lime combined with fertilizers on soil characteristics, Striga infestation and maize yields. The design of the study was a randomized complete block (RCBD) with six treatments: Lime, Diammonium phosphate (DAP), Mavuno, Lime + DAP, Lime + Mavuno and control with maize as a test crop. Collected data was analyzed using GenStat and SPSS statistical packages. Results showed improvement in soil characteristics: pH from 4.91 to 5.23 (32%) and available phosphorus (1.88 to 7.88 ppm), maize yield (0.9 to 4.99 t ha^{-1} and a substantial *Striga* population reduction from 1,510,000 to 680,000 plants ha^{-1} (54.6%) in Lime with fertilizer treatment plots. Farmers overall rating of technologies based on maize yields at harvest was Mavuno + lime = Mavuno > lime + DAP > DAP > lime and control last. Yields from fertilizer based treatments with or without lime, were always more than 3 fold higher than those from the lime only and/or control. This was manifested by an increase of 3.5 and 3.7 t ha^{-1} for DAP and Mavuno fertilizers respectively compared to the control of 0.9 t ha^{-1}. Irrespective of the season maize yield from Mavuno was always higher than yield from DAP alone plots. A comparison between Mavuno plus Lime and Mavuno minus lime treatments for each season separately showed no significant difference. But in scenarios where DAP plus lime and DAP minus lime treatments, a significant difference ($p < 0.05$) was observed. It was observed that about 30% of SHF in the study sites acquires Mavuno fertilizer and lime yearly from local agro dealers for expansion of fields under lime on their farms. The study concludes that Mavuno fertilizer and liming technology have the best potential for optimizing maize yields and reduced Striga population. Therefore the study recommends that liming technology with Mavuno fertilizer be adopted in acidic soils in western Kenya in order to ameliorate soil acidity, improve food security and enhance economic growth and livelihoods of SHF. Lime and fertilizers maintained high maize yield while use of lime with fertilizer was economical and profitable than lime or fertilizer alone. The study also recommends that more research be conducted to come out with optimum rates, times and methods of lime application with nutrients inputs.

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LIST OF ACRONYMS AND ABBREVATIONS

AGMAK	Agricultural Marketing Association of Kenya
AGRA	Alliance for Green Revolution in Africa
ASI	Anthesis Silking Interval
DAP	Di-ammonium phosphate
BMP	Best management practice
CAN	Calcium Ammonium Nitrate
CBO	Community Based Organization
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GoK	Government of Kenya
HI	Harvest Index
ICIPE	International Center for Insect Pest Entomology
IFAD	International Fund for Agricultural Development
IITA	International Institute for Tropical Agriculture
ISFM	Integrated Soil Fertility Management
KALRO	Kenya Agricultural and Livestock Research Organization
MoA	Ministry of Agriculture
NGOs	Non-Governmental Organizations
WFP	World Food Programme
WRB	World Reference Base
SPSS	Statistical Packages for Social Sciences
SSA	Sub Saharan Africa

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Low agricultural productivity of less than 1 ton in Sub Saharan Africa (SSA), Kenya included is due to many constraints ranging from depletion of soil fertility (Sanchez and Jama 2002), weeds, pests, soil acidity and diseases. As observed by Sanchez *et al,* (1997), declining soil fertility is a major biophysical cause of low per capita food production in Africa. Over decades, smallholder farmers (SHF) have removed large quantities of nutrients from their soils without replenishment through continuous cropping. This has resulted in very high annual average depletion rate of 22 kg of nitrogen (N), 2.5 kg of phosphorus (P), and 15 kg of potassium (K) per hectare of cultivated land over the last 30 years in 37 African countries (Smaling *et al,* 1997). This annual nutrient loss is equivalent to US$ 4 billion in fertilizer equivalent (Van den Bosch *et al*., 1998, Sanchez, *et al.,* 1997). This loss is much higher than the estimated inorganic fertilizer use in Africa of 5 to 10 kg/yr (Heisey and Mwangi, 1996), emphasizing the need for soil fertility replenishment.

1.2 Constraints to Agricultural Production

1.2.1 Soil Fertility

Hanson (1992) reported that of the three billion hectares of arable land in tropical Africa, only 14.7% is considered to be free of physical or chemical constraints, 32.2% has physical constraints, 13.2% has limited nutrient retention capacity, 16.9% has high soil acidity, and 6.8% has high P fixation. Properly managed fertilizer, supports cropping systems that provide economic, social and environmental benefits. On the other hand, poorly managed nutrient applications can decrease profitability and increase nutrient losses and potentially degrading water and air. Therefore, best reward from use of fertilizers requires the implementation of best management practices (BMPs) that optimize the efficiency of fertilizer use through matching nutrient supply with crop requirements to minimize nutrient losses. The selection of BMPs varies with location, and those chosen for a given farm are dependent on local soil and climatic and crop management conditions and other site specific factors. Agronomic and conservation practices also play valuable roles in supporting nutrient use efficiency. Therefore, BMPs are most effective when applied with other practices (Jensen, 2010).

1.2.2 Soil acidification

Soil acidity is one of the major constraints to crop production in Africa. Acid soils are those characterized by pH which is (4.5 -5.5) to extremely acid (<4.5) values, a low cation-exchange capacity, low base saturation, plant mineral nutrient deficiencies and toxicities (Kanyanjua *et al*, 2002). Soil acidity can develop naturally, depending upon the nature of the parent material or leaching of bases from the soil profile (Bell and Edwards, 1991). Human activity can also aggravate it (van Straaten, 2007). In the World Reference Base (WRB) soil classification system, acid soils (as agricultural problem soils) mainly occur in the following soil groups: Acrisols, Arenosols, Ferralsols and Planosols with the widest distribution in Acrisols and Ferralsols, (WRB, 2006). African soils are highly susceptible to this phenomenon due to their inherent low buffering capacity. In Kenya acid soils cover 7.5 million hectares (13%) of high agricultural potential land of which 57,670 ha are in western Kenya (Kanyanjua *et al*,, 2002) (Figure 1.

Soil acidity has a negative effect on crop yields mainly through reduced phosphorus (P) availability due to P fixation by iron (Fe) and aluminum (Al) soil components (sesquioxides) and contributes to about 30% yield loss. Excess Al^{3+} ions, tend to accumulate in plant roots and hence prevent P translocation from the roots to other parts of the plant (Ligeyo and Gudu, 2005) leading to poor crop performance.

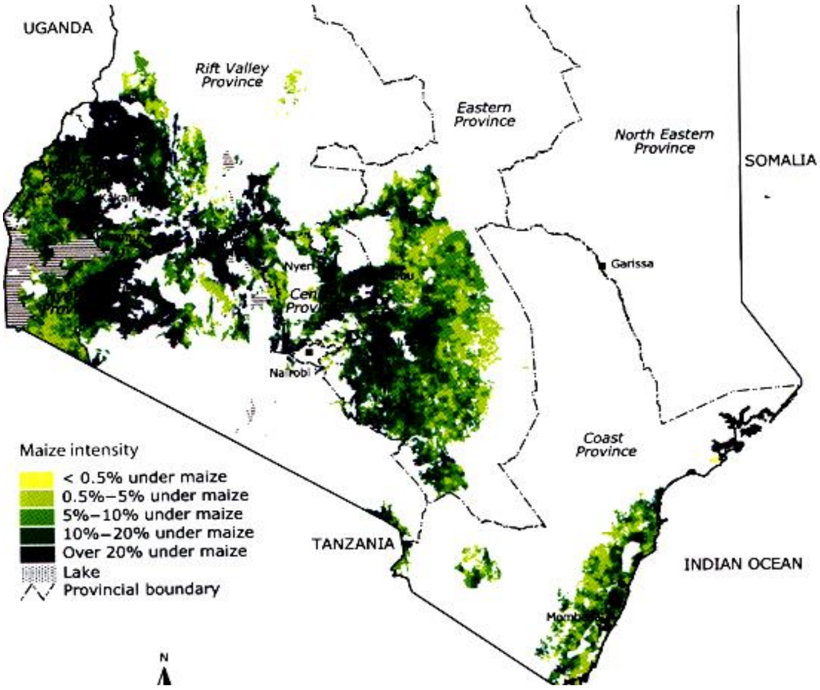

Figure 1 Map showing acid soils and maize growing areas in Kenya (Source: Muhammad and Underwood, 2004).

Additionally, excess H^+ ions affect plant root membrane permeability and therefore interfere with ion transport. Increasing soil pH by application of lime has a great potential for increasing availability of P and other nutrients, hence improving plant nutrition and crop yields. Lime is used worldwide to alleviate soil acidity but liming by SHF in sub Saharan Africa, western Kenya included, is not understood and therefore an overlooked component. This is because observations have shown that agricultural research scientists and extension staff have not sensitized the SHF the importance of lime in the region as they have done on the use of chemical fertilizers. A study conducted in the western Kenya region by (Odendo 2009) confirms this. Other causes that made lime use overlooked were practical issues related to lime availability, transport costs from manufacturers, bulkiness of lime and unknown application rates which are now being addressed.

1.2.3 *Striga* weed

Striga parasite belongs to the genus *Striga*, the family scrophulariaceae that comprises about 60 species, ranging from completely parasitic (*Striga gesnerioides*) to almost autotropic (*Striga angustifolia*). *Striga* is among the world's most tenacious, prolific and a destructive agricultural pest that has taken root throughout the continents of Africa and Asia, imparting extensive damage to staple cereal crops. *Striga hermonthica* (Del.) Benth, an obligate root hemi-parasite of several cereals, is the main constraint for food production in sub-Saharan Africa (SSA) (Sauerborn, 1991) as it infests 40% of the cereal producing areas of SSA regions.

The life cycle of *Striga* is mainly dependent on that of its host. Germination of *Striga* seeds is induced by exudates of many plants both the cereals and trap crops (Bouwmeester *et al*,, 2003). After germination, a series of chemical signals directs the radical to the host root where it attaches and penetrates. However, if the seedling does not attach to a host root within 3–5 days, the seedling perishes. Once penetration has occurred, an internal feeding structure (haustorium) is formed, and the parasite establishes host xylem connections (Cardoso et al 2010). The host photosynthate is diverted to the developing parasite, which also utilizes the host root system for water and mineral uptake. The *Striga* weed therefore survives by attaching itself to the root of the growing plant and sucks water and nutrients out of the host and uses these for its own growth. Initial symptoms of the host occur while the parasite is still subterranean.

Management of *Striga* weed is difficult because the most of its life cycle takes place below ground. If it is not detected before emergence, it is too late to reduce crop loss (Johnson, 2005). With every planting season, some of the dormant seeds, stimulated by crop exudates, germinate and infest the host crop while reproducing and increasing the *Striga* seeds in the soil thus escalating the problem.

1.2.4 Previous attempts to address low productivity and constraints to Integrated Soil Fertility Management (ISFM) uptake

Previous workers (Okalebo *et al,* 2006; Mbakaya, 2007; Nekesa 2007; Kisinyo 2011; Mbakaya, *et al*, 2011) attempted to address low agricultural production in western Kenya. Their attempts used of mineral fertilizers at recommended rates by split, banding and spot applications with no inorganic fertilizers to improve crop yields. While inorganic fertilizers are needed to maintain crop productivity, the workers therefore, lacked the integrated soil fertility management (ISFM) approaches such as use of mineral fertilizer with return of crop residues, use of other organic materials (manure) and minimum tillage that help maintain soil moisture, add organic matter.

1.2.5 Existing Gaps

Previous research approaches were not multidisciplinary thus they focused on single constraint amelioration without considering multi constraints to satisfy adverse soil conditions. Production on SHF farms is constrained by multiple factors. Past soil fertility research mainly focused on technical aspects of single technologies that add nutrients to agricultural land and showed that application of soil fertility improving inputs increases yields (KARI, 2003; Bationo, 2003). Other studies were rather monolithic where workers targeted one farm to conduct their testing to develop technologies without the involvement of the farmers. Such single solutions have been ineffective in addressing soil fertility problems in the region. The approach of this study was therefore to test the multiple technical solutions and also to understand the socio-economic factors needed to ensure greater success. It therefore used the multi-site and team based, hence offered an opportunity for SHF to understand better response of crops to inputs as well as the worker to understand the drivers of adoption/non-adoption of technologies when the recommendations of the technologies were later passed to the Ministry of Agriculture extension officers who in turn were to extend the same to the SHF.

This study represents a timely intervention due to continuous decline in soil fertility, increase in soil acidity and *Striga* weed infestation that have led to low and declining yields. It has been a major concern in the agricultural sector that food insecurity and levels of poverty have escalated in the recent years due to a number of exogenous and endogenous factors responsible for adoption and non-adoption of technologies. It is expected that there will be improved knowledge on the socio-economic factors that influence the adoption of technologies which will assist technology development agencies to adjust the research agenda setting process for SHF.

1.3 Statement of the problem

Western Kenya continues to experience serious food insecurity due to multiple factors; among them declining soil fertility (nutrient deficiencies of N and P), soil acidity and *Striga* weed infestation. Other factors are high cost of inputs, poor agronomic practices, and use of poor seed sources. Whereas there are opportunities for addressing some of the challenges, like use of lime to combat soil acidity and use of recommended fertilizer rates, observations show that transfer and adoption of technologies by SHF is limited. This study therefore addresses soil acidity and *Striga,* the agricultural production constraints to increase food production, reduce food importation and create awareness among smallholder farmers how to manage acid soils and *Striga* infestation.

1.4 Justification of the study

Increasing food production is a key priority for economic growth. The demand for maize, the traditional staple food for most Kenyans, continues to outstrip production, putting strain on the scarce foreign monetary reserve which has to be shifted to food importation (Tegemeo, 2009). Challenges identified affect vast areas of land relied on by the SHF in western Kenya. Therefore, these challenges have to be solved through research using participatory approaches for enhanced adoption of developed technologies for increased food security in Kakamega North sub County, Kakamega County and Ugenya sub County, Siaya County.

1.5 Overall objective

Evaluate synergies of fertilizers and lime to changes in soil characteristics and *Striga* infestation and their effects on maize production in smallholder farmers' fields (SHF) in Kakamega and Siaya counties of western Kenya.

1.6 Specific objectives

The specific objectives were:

1. To conduct baseline survey on socioeconomic, demographic characteristics and maize production constraints.
2. To evaluate changes in selected soil properties as a result of fertilizer and lime additions.

3. To evaluate the effect of combining lime with fertilizers on maize yields
4. To evaluate *Striga* weed infestation to lime and fertilizer use
5. Evaluate the potential adoption and economic profitability of the integrated soil fertility management (ISFM) technologies

1.7 Overall hypothesis

Use of lime in combination with multi nutrient fertilizers will improve soil characteristics, land productivity and manage *Striga* growth

1.8 Working hypotheses

The working hypotheses were:

1. Ho: There is no significant additive effect of combining lime with fertilizers on maize crop yield and Striga growth and on soil properties.

2. Ho: Economic benefits from use of lime and fertilizers will not significantly enhance potential adoption and profitability of the ISFM technologies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Agriculture in Kenya is propelled by smallholder farmers. It is the country's economic mainstay. This is confirmed by the fact that more than 80% of its population obtains its livelihood from this enterprise (Tegemeo 2009, Ominde 1988). The sector directly contributes 24 per cent (Ksh. 342 billion), of the country's gross domestic product (GDP) and another Kshs. 385 billion indirectly, accounts for two-thirds of Kenya's total exports and employs three in every four Kenyans in the rural areas (GoK Economic Survey, 2005, 2010). The importance of the sector in the economy is reflected in the relationship between its performance and that of the key indicators like gross domestic product (GDP) and employment. Therefore, SHF are a critical force in agriculture in Kenya and yet their central role in agricultural development and food security is largely ignored, particularly in policy aspects (GoK Economic Survey, 2010). These SHF grow maize as a staple food crop and whenever there is deficit of maize the Government imports to feed its people.

2.2 Importance of Maize (*Zea mays* L) in Kenya

Maize (*Zea mays*) is the third most important cereal crop worldwide in terms of area cultivated, after wheat and rice. It is the principle staple food crop in Kenya. As a major source of dietary requirements for the Kenyan people, maize supplies 40 – 45% of calories, 35 -40% of proteins and 75% of all the cereal quantity, consumed by the average Kenyan, (Ayaga 2003, GoK Economic Survey, 2003, 2005, and 2010).

Declining trends in maize productivity in the major maize growing areas have been cited by many authors (GoK Economic Survey, 2010, Ayaga 2003; Nekesa *et al*,, 1999). These negative trends are of major concern in western Kenya region where the bulk of maize that feeds most people in this country is produced (Ayaga 2003). The fluctuating trend in maize production is also a concern because; the country has to import increasing quantities of the commodity annually to satisfy growing demand (Ayaga 2003, GoK Economic Survey, 2005, 2006, 2010). The average maize consumption in this area is about 81 kg per person, 24 kg less than the estimated national consumption of 105 kg per person per year (Pingali, 2001). Various factors are cited as being responsible for low yields hence fluctuations in the overall maize production countrywide. Some of the factors cited include declining soil fertility due to continuous cropping with little /or no mineral fertilizer application, soil acidity, poor germplasms and limited adoption of new technologies. On low soil fertility, Smaling *et al,,* (1997) reported that N and P were being depleted at rates of 22 kg N and 2.5 kg P per hectare per year through cultivation without their return. In the cultivated sub Saharan African soils, N depletion is also through soil erosion, leaching, N removal through crop harvest and denitrification (Sanchez *et al,*., 1997).

The national average maize production per unit area in Kenya stands at about 2 tons per hectare while in research fields, yields over 8.0 tons per hectare have been achieved (Ligeyo and Gudu 2005). The annual average maize grain production in Kenya is about 2.8 million metric tons while consumption is 3.2 million metric tons which leaves a deficit of 0.4 million metric tons (Ligeyo and Gudu, 2005). As a result the country depends on food aid or importation to fill in the gap. For example in 2011, about 324, 000 tons of maize worthy 16.26 billion (based on the 2011 price of Kenya Shillings 15,555 per ton) was imported to bridge the gap (GoK Economic Survey, 2010). Table 1.

Table 1 National annual maize production and consumption of Kenya

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Area (ha)	1.62	1.80	1.89	2.01	2.31	2.15
Production (Tons)	2.93	2.37	2.44	3.47	3.1	3.0
Consumption (Tons)	3.07	3.,24	3.24	3.5	3.59	3.67

Note: Figures in millions **(Source: GoK Economic Survey 2013)**

2.3 Constraints in maize production

There are many constraints to maize production. Among the main ones are declining or low soil fertility especially deficient N and P, soil acidity, *Striga* weed and high cost of inputs (certified seeds and fertilizers) among other constraints as labour and land. However, as earlier cited in chapter one, soil fertility depletion is identified and accepted as the fundamental biophysical root cause for the low and declining per capita food production in SSA. Several decades of cultivation causing nutrient depletion have transformed the original fertile lands that yielded 2 – 4 tons per hectare of cereal grain into infertile ones yielding less than 1.0 ton per hectare, (Sanchez *et al,* 1997, Tegemeo, 2009). Thus one of the consequences of declining soil fertility is the contribution to increased *Striga* infestation as the presence of this weed has been used by farmers as an indicator of low soil fertility (Parker 2008; Mbwaga, 2002).

2.3.1 Nitrogen deficiencies in maize producing areas of Kenya

Nitrogen (N) is an integral part of all proteins, and is one of the main chemical elements required for plant growth and photosynthesis and when N is sub-optimal growth is reduced (Marschner, 1995). It may be in two forms: available and unavailable N. Only nitrogen in the form of ammonium ($NH^+{}_4$) and nitrate (NO_3^-) in the soil is available to plants. Plants acquire N from two principal sources: (a) the soil, through commercial fertilizer, manure, and/or mineralization of organic matter; and (b) the atmosphere through symbiotic N_2 fixation. However, about 98-99 percent of a soil's total N is in the unavailable organic form as part of humus (Serrem, 2006). Soil microbes gradually convert this unavailable organic N into ammonium and then nitrate. Most soils are too low in humus to supply N at a rapid enough rate for good yields. That is why N fertilizer is usually needed for non-legumes.

Available soil N can become tied up and unavailable when crop residues low in N are plowed into the soil. This is because the soil microbes that decomposes the residues need N to make body protein. Most crop residues like maize and sorghum stalks supply large amounts of carbon, which the microbes use for energy, but not enough N for the microbes' protein needs. The microbes make up for this shortage by taking ammonium and nitrate N from the soil. A crop may suffer a temporary N deficiency if planted under these conditions, until after the residues are decomposed and the tied up N released.

Maize is able to utilize either NH_4^+ or NO_3^- as N source and grows best when both are present (Schrader *et al*,, 1972). Therefore, deficiencies of N and P or inadequate availability of usable nitrogen (NH_4^+ or NO_3^-) are the most limiting soil factors of adequate growth (Kamprath, 1984). The production of high-quality, protein-rich food is extremely dependent upon availability of sufficient N.

The most practical way of application of any fertilizer is to broadcast it and incorporate it into the soil surface before planting. For nitrogen this procedure is efficient only if the NH4 $^{+}$ and NO3^{-} ions released stay in the root zone and are not leached or denitrified to a considerable extent. Since crop nitrogen requirements are low at early growth stages, the optimum timing is that which ensures a good nitrogen supply at the two critical growth stages of the maize at the lowest possible cost (Sanchez *et al,,* 1997). Plant N uptake has been shown to vary with the type of crop and stage of crop growth (Serrem, personal communication).

Nitrogen is a mobile element in the plant, meaning that crops relocate nitrogen from older tissue to younger tissue when deficiencies occur. This is why older plant leaves often show yellowing or other signs of nitrogen deficiency. The pattern of N accumulation in plant parts differs at various stages of growth (Serrem, 2006). Fertilizer N rate has been reported to affect the amount of N remobilized within a plant, with high N rates being inhibitory to the remobilization of vegetative N to the grains (Bulman and Smith, 1993). Nitrogen (N) deficiency severely affects many metabolic pathways and physiological progresses during maize growth and change of anthesis-silking interval (ASI) is one of the most serious consequences to yield (Serrem, 2006).

A number of experiments associated with increasing soil N availability, have documented increases in crop growth rates and yields (Esilaba, 2006, Odhiambo, 1989). However, due to low concentration of mineral nitrogen in acid soils, N uptake is limited and hence affects crop yields (Alexander, 1977). Nitrogen is important in increasing maize yields but the abundance of Al, Fe, and exchangeable H^{+} in acid soils lead to poor N mineralization hence low yields (Serrem et al, 2008). Previous studies in western Kenya have reported that soils in the region are severely depleted of nitrogen (N) and phosphorus (P) (KARI, 2000; Nyambati *et al*, 2003). The soil fertility improvement research by these authors mainly focused on single technologies of adding fertilizers to improve yields (KARI, 2003; Bationo, 2003 (Plate 1).

Plate 1 N-deficiency in maize and beans intercrop, Got Nanga, Ugenya sub County, Siaya County (Source: Author, 2009).

2.3.2 Phosphorus availability and deficiencies in maize producing areas of Kenya

Like nitrogen, phosphorus (P) is an essential part of the process of photosynthesis (FAO, 2006). P is one of the major essential elements in maize production. It is the most commonly limiting nutrient element in the tropics after water and nitrogen. The P is taken up from the soil in $H_2PO_4^-$ and HPO_4^{2-} ionic forms by plants, and unless the soil contains adequate P or it is supplied from external sources, plant growth is restricted. However, P losses through leaching and crop removal are generally small compared to N (Tisdale *et al.*, 1990).

The plant uses phosphorus for photosynthesis and energy/nutrient transport. Insufficient supply may cause green and purple discoloration, wilting and small fruits (Kamprath, 1984; Bekunda *et al.*,, 1997). Phosphorus, when combined with water, breaks into separate ions ($H_2PO_4^-$ and HPO_4^{--}) that can be absorbed by the plant's root system. Phosphorus (P) is present in the soil as mineral or organic and inorganic P forms in amounts ranging from 0.1% to 0.4% total P. However, Okalebo (1987) reported values up to 0.7% total P in some arable soils in East Africa. The amount of P in plants ranges from 0.05% to 0.30% of total dry weight (Bieleski, 1973). The concentration gradient from the soil solution to the plant cell exceeds 2,000-fold, with an average free P of 1 μM in the soil solution (Bieleski, 1973). The largest P requirement occurs after flowering and during ripening periods (Serrem, 2006). During grain formation, translocation of P to the grain is smaller compared to that of N. At maturity, about 75% of the total P in the above ground parts of the plant should be in the grain (Keulen, 1983). Under P deficiency, the amount available to the plant during grain formation definitely influences the P content of the grain.

Residual phosphate from a fertilizer application not used by a crop continues to be of value to succeeding crops, although the uptake each year is usually less than that of the first year Russell (1973). Anderson and Ingram, (1993) found that P fertilization can markedly affect P concentration in the soil solution by influencing competition for adsorption sites between organic P compounds and orthophosphates. Evans (1985) reported that competition between inorganic and organic P for soil sorption sites could take place and presumably result in the increase of dissolved organic phosphorus directly after fertilizer application.

Earlier studies by Obura, (2008) reported that P can be fixed up to 80% by free aluminum (Al) and iron (Fe) oxides. Consequently decrease nitrate uptake, that consequently limit crop yields by 30 – 55% (Parentoni *et al.*, (2010) as plants absorb P from the soil as inorganic orthophosphate (Pi) ion (Plate 2).

In Kenya, low P reserves in the soil are consequences of weathering, intensive leaching and poor land management resulting in soil erosion (Okalebo, 2009). In addition, human activities that induce P depletion are known to contribute to food insecurity (Sanchez *et al*, 1997). At low pH, large quantities of Al and Fe hydroxides, which have the ability to adsorb P onto their surfaces, are present in soil. Thus much of the added P is fixed and not readily available for crop uptake. However, as the pH increases, the acidity decreases with P solubility. The optimal pH for P availability ranges between 6.0 and 8.0. Above the pH of 8.0, the ions of metals as Ca and Mg, as well as their carbonates, tend to precipitate the added P and its availability decreases.

While N inputs can be supplemented from sources such as biological nitrogen fixation, there is no biological replenishment of P. This means external sources of P need to be applied in order to improve the soil P status to enhance plant growth. Currently, the global food supply is dependent on continual inputs of artificial phosphate fertilizer to maintain soil fertility and to compensate for uptake by the harvested crops. In the developing world, farmers are becoming increasingly aware that use of inorganic fertilizer increases crop production (Okalebo *et al.*, 2006, Sanchez, *et al.*, 1997).

Plate 2 P deficiency in young maize leaves, Machemo, Kakamega North sub County, Kakamega County (Source: Author, 2010).

The plant uses P for photosynthesis and energy/nutrient transport. In the maize plant, P principally stimulates early root formation and growth, hastens crop maturity and affects the grain yield (Marschner, 1995). Adequate P promotes early plant growth and root formation through its role in the division and organization of cells. It is also essential to flowering and fruiting and the transfer of hereditary traits. Crop yield on 40% of the world's arable land is limited by P availability. In plant nutrition, extractable P thus taken up by plants is more important than total P. On the contrary, insufficient supply of P is visible through defficiency symptoms that include: slow growth and stunting of plants, purplish coloration on foliage of some plants, dark green coloration with tips of leaves wilting and/or dying, delayed maturity and poor fruit or seed development (Kamprath, 1984a; Bekunda *et al*,, 1997).

2.3.3 Soil acidity and its impacts in the world

Acid soils occur in the tropics and subtropics as well as in moderate climates occupying about 4 billion hectares of the total world soils (von Uexkull and Mutert, 1995) with 58% of the land area suitable for agricultural production, inhabited by 73% of the worlds’ population (Fig.2). In Sub Saharan Africa, acid soils occupy 29% of the total land area. They are characterized by low pH and low mineral base saturation, plant mineral nutrient deficiencies, and, for most of the cases, mineral toxicities. The widest distributions of acid soils are Acrisols and Ferralsols, (WRB 2006).

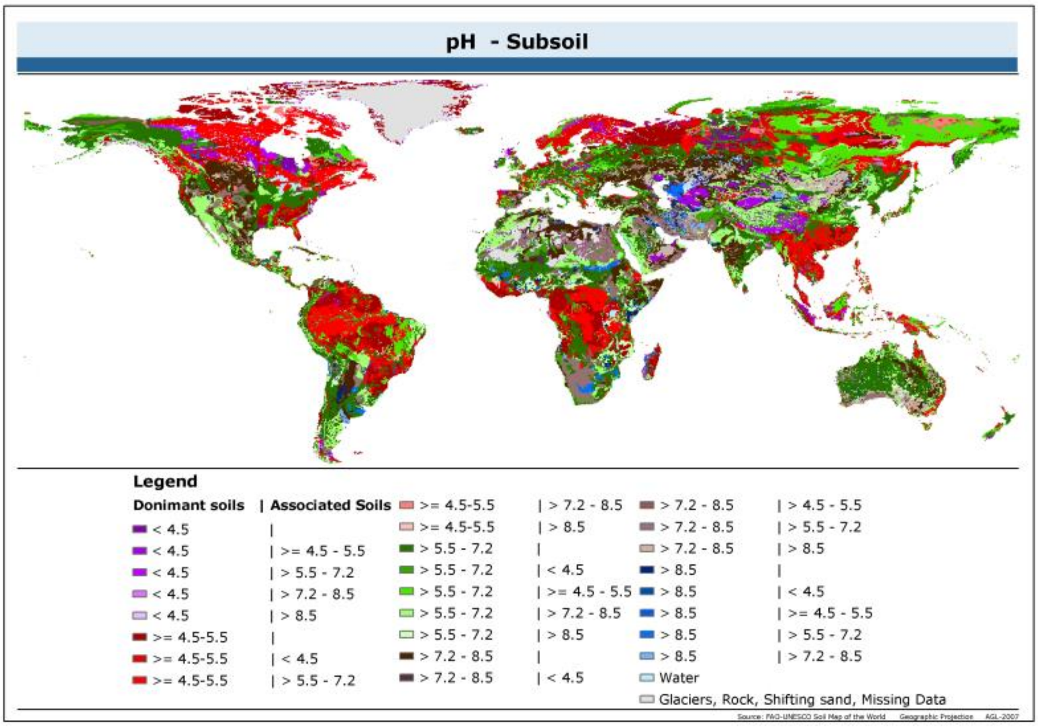

Figure 2 Acid soils of the world (Source: FAO Soil map of the world Geographic Projection, 2007)

The process of soil acidification is a potentially serious land degradation issue. Without treatment, soil acidification will have a major impact on agricultural productivity and sustainable farming systems. Acidification can also extend into subsoil layers posing serious problems for plant root development and remedial action.

The formation of acid soils depends on specific conditions of climate, topography, vegetation, parent material and time for soil formation. Human activity can also aggravate soil acidification leading to low productivity of crops due to toxic levels of aluminum (Al) and the concomitant phosphorus (P) deficiency that hinder plant growth. The macronutrients tend to be less available in soils with low pH while micronutrients tend to be less available in soils with high pH.

Soil acidity has a negative effect on crop yields mainly through reduced phosphorus (P) availability via P fixation in soils whereby the iron (Fe) and aluminum (Al) soil components (sesquioxides) fix sizeable quantities of P. Excess Al^{3+} ions tend to accumulate in plant roots and hence prevent P translocation from the roots to other parts of the plant (Ligeyo and Gudu, 2005) leading to poor crop performance. Additionally, excess H^+ ions affect plant root membrane permeability and therefore interfere with ion transport.

In Kenya, acid soils occupy about 13% (7.5 million hectares) of high agricultural potential land, of which 57,670 ha are in western Kenya, (Kanyanjua *et al*,, 2002). These soils have high Al, low N and P that are responsible for low maize productivity. The Al levels are between 4 – 67% Al saturation with N<0.2% and P< 5mg P/kg (bicarbonate P) (Gudu *et al*, (2005). The Al toxicity more than 20% Al saturation negatively affects maize growth.

Several approaches have been used to manage soil acidity to improve crop output from these acid soils. These include use of soil amendments that counteract the effects of soil acidity e.g. application of lime in combination with nitrogenous and phosphatic fertilizers, and addition of organic manure, (Atiwag 1992) or using crops tolerant to high level of exchangeable Al, use of mulch from agroforestry tree species, burning of sites to produce ash and use of animal wastes such as poultry manure. Woomer *et al*,, (2003) noted that in most cases these materials are too bulky, variable in quality and always not available in adequate amounts required. Okalebo, (2009) reported that Lime, Phosphate Rock (PR) and fertilizers that contain Ca and Mg have a liming potential which have not been tapped. Therefore there is need to demonstrate the usefulness of these materials to farmers.

Increasing soil pH by application of lime has a great potential for improving availability of P and other nutrients, hence improving plant nutrition and crop yields. Apart from correcting soil pH, lime does not supply key nutrients required for plant growth. It is therefore important to understand that application of lime, in combination with fertilizers improves crop yields and profitability at the farmers' level. Apart from lack of agreement on the level of yield increase as a result of lime application, recent studies, have failed to show significant lime effect on crop yield in scenarios where lime is combined with P fertilizers. Therefore blanket recommendations and conclusions on effect of lime cannot be applied with confidence (Kisinyo, 2011).

Communities in areas with acid soils see the direct impacts of soil acidity as lost productivity and reduced income from acid sensitive crops like maize. Soil acidity may permanently cause the degradation of the soil when the acidity leaches to a depth where it cannot be practically or economically corrected. Soil pH has also an effect on the availability of nutrients to crops. Nutrients are available at different pH levels. For example below pH of 5.5 might result in reduced crop yields like maize, because under these low pH, conditions for availability of micronutrients such as manganese, aluminum and iron increases and toxicity problem occurs. At low pH, availability of other nutrients, such as K, Ca and Mg is decreased and result in deficiencies. Previous studies have reported that soil acidity causes retarded plant growth through H^+ and Al^{3+} ionic effects, mineral ion toxicity or by indirectly interfering with mineral availability (Table 2).

Often many soils with pH <5.5 have high exchangeable aluminum and outright toxicity to most crops (Carver and Ownby, 1995) as aluminium ions occupy the negatively charged cation exchange capacity (CEC). This negative charge is due to the chemical makeup of the soil clay and organic matter and this means that it can attract positively charged ions. The exchangeable aluminium is in equilibrium with dissolved aluminium in the soil solution and reacts with water to form hydrogen ions in the solution: (Equation 2.1)

$$Al^{3+} + H_2O \longleftrightarrow Al\,(OH)^{2+} + H^{+} \quad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (2.1)$$

The larger the percentage of exchange sites occupied by aluminum, the greater the amount of hydrogen formed, the lower the pH and the higher the acidity of the soil (Crozier and Hardy, 2003). Over time, soils become more acid due to the leaching of calcium and magnesium mainly. The loss of these basic cations is permanent if they are leached out of the root zone.

Table 2 Effect of soil pH on nutrient availability to crops

Element	**pH effect**
Nitrogen (N)	Fully available at pH of 6.0-8.0. Availability decreases below pH 6.0 and above pH 8.0
Phosphorus (P)	Fully available at pH of 6.5-7.5. Availability decreases at pH of 6.0- 6.5, becoming too low below pH 6.0.
Potassium and sulphur (K & S)	Fully available at pH of 6.0-10.0. Availability decreases below pH 6.0.
Calcium and Magnesium (Ca & Mg)	Fully available at pH of 7.0-9.0. Availability decreases below pH 7.0 and above pH 9.0.
Aluminium (Al)	Available increases below pH 5.5. Availability decreases above pH 6.5. Note: *Liming to pH 5.5 is recommended to avoid toxicity at pH from 8.5.*

(Source: Landon, 1984)

Strong soil acidity is associated with aluminum (Al), hydrogen (H), Iron (Fe), and manganese (Mn) toxicities to plants in the soil solution and corresponding deficiencies of the available phosphorus (P), molybdenum (Mo), calcium (Ca), magnesium (Mg) and potassium (K) (Giller and Wilson, 1991). Other causes of soil acidity include: humus or organic matter, aluminosilicate clays, hydrous oxides of Al and Fe, soluble salts and carbon dioxide (Tisdale *et al*, 1990). The presence of exchangeable Al^{3+} ions combined with one or more of the following factors: depletion of basic cations such as Ca, Mg, K and Na by leaching and crop removal; organic residues decomposition; application of acid forming fertilizers particularly ammonium based such as diamonium phosphate (DAP), calcium ammonium nitrates (CAN), urea and atmospheric sources (e.g. acid rain) (Tisdale et al,., 1985), acidifies the soil (van Straaten 2007). The ammonium and urea based fertilizers during their oxidation to form nitrates release H^+ ions that lead to soil acidification.

2.3.4 Effect of soil acidity on maize productivity

Nutrient solubility, and thus availability to plants, varies with soil pH. Some nutrients may reach toxic levels, while others become unavailable leading to deficiencies (Sanchez, 2011). The increased availability of aluminium in the soil solution associated with low pH is an example of this, where aluminium toxicity becomes a major problem for crop growth in acid soils. Other production losses may occur where acidity reduces the activity of beneficial soil micro-organisms. It is recognized that the nitrogen fixation by Rhizobia spp. on legume roots is retarded in acid soils, resulting in lower nitrogen availability and reduced production.

2.3.5 Factors contributing to Soil acidity

Soils are not homogenous and the pH can vary considerably from one spot in the field to another. It also varies with soil depth. The use of both chemical and organic fertilizers may eventually make the soil more acid. Hydrogen is added in the form of ammonia-based fertilizers (NH_4^+), urea-based fertilizers [$CO\ (NH_2)_2$], and as proteins (amino acids) in organic fertilizers. Transformations of these sources of nitrogen (N) into nitrate (NO_3^-), release H^+ to create soil acidity. Therefore, fertilization with ammonium based fertilizers or even adding large quantities of organic matter to a soil will ultimately increase the soil acidity and lower the pH, (Equation 2.2)

$$NH_4^+ + 2O_2 \longrightarrow \text{bacteria} \longrightarrow NO_3^- + \mathbf{2H^+} + H_2O \ldots\ldots\ldots\ldots \quad (2.2)$$

Source: Nutrient Management Concepts: pH and Nutrient Formulation, University of Hawaii Cooperative Extension Services Hilo Jul 25 2006.

2.3.6 The Buffer pH

The soil pH measures the amount of acidity in the soil solution and indicates whether liming is necessary for crop production. This measure does not indicate the amount of reserve acidity held on the clay and organic matter particles in the soil, which dictate how much lime is needed. Different amounts of reserve acidity mean that two soils at the same pH value need different amounts of lime to raise the pH to the desired level. The reserve acidity is measured in a separate test: the buffer pH. The greater the amount of reserve acidity, the lower the buffer pH and the more lime required to raise the pH. In general, the lime requirement of a soil increases with the content of clay and organic matter (Sanchez, 1976).

2.3.7 Justification for liming soils

Soil acidity is corrected by adding a liming material to reduce the hydrogen ion (H+) concentration and increase the level of alkaline/basic cations (positively charged ions) in the soil thus increase the pH. Acid-producing hydrogen ions are adsorbed on exchange sites or present in soil solution. These hydrogen ions are in equilibrium between adsorbed and solution states. The (H+) adsorbed to the cation exchange sites serves as a reservoir for neutralizable/reserve acidity that rapidly replaces the (H+) ions in the soil solution that are neutralized by lime. A soil pH test tells how acidic a soil is, but it does not measure the neutralizable/reserve acidity. Thus, to determine how much lime is required to raise the pH, the soil must be tested for neutralizable acidity. This is done in soil testing labs by measuring buffer pH. In general, the lime requirement of a soil increases with the content of clay and organic matter (Sanchez, 1976).

The amount of lime needed to achieve a certain pH depends on (i) the pH level of the soil and (ii) the buffering capacity of the soil. The buffering capacity is related to the cation exchange capacity (CEC). The higher the CEC, the more exchangeable acidity (hydrogen and aluminum) is held by the soil colloids. As with CEC, buffering capacity increases with the amounts of clay and organic matter in the soil. Soils with a high buffering capacity require larger amounts of lime to increase the pH than soils with a lower buffering capacity. Lime reduces soil acidity (increases pH) by changing some of the hydrogen ions into water and carbon dioxide (CO_2). A Ca^{++} ion from the lime replaces two H^+ ions on the cation exchange complex. The carbonate (CO_3^-) reacts with water to form bicarbonate (HCO_3^-). These react with H^+ to form H_2O and CO_2. The pH increases because the H^+ concentration has been reduced. In addition to other effects, increasing pH facilitates release of fixed P from the colloidal complex allowing plants to access and use it for their own nutrition. Lime also supplies calcium and magnesium contents and stimulates biological activity in soils.

2.4 Liming Materials

Liming materials used in agriculture all over the world include: calcite/ calcium carbonate ($CaCO_3$), dolomite ($Ca Mg(CO_3)_2$), burnt quick lime/ calcium oxide (CaO), calcium hydroxide/ hydrated lime $Ca(OH)_2$), marl (unconsolidated deposits of $CaCO_3$) and slags (Tisdale *et al,,* 1990). Choice of the material depends on the availability, transport, reactivity and cost. Reaction mechanisms of liming materials in acid soils are complex. However, when liming materials are added to acid soils, whether carbonates, hydroxides or oxides, the chemical reaction is to produce the bicarbonate forms (Table 3).

Table 3 Liming materials used to manage acid soils

Liming material	**Composition**	**Relative neutralizing value (%)**
Calcium carbonate	$CaCO_3$	100
Calcitic limestone	$CaCO_3$ + Impurities	50 to 100
Dolomitic limestone	$CaCO_3 + MgCO_3$ + Impurities	90 to 109
Quick (burned) lime	CaO	150 to 180
Hydrated (slaked) lime	$Ca(OH)_2$	115 to 135

(Source: Muse and Mitchell, 1995)

The most common liming materials are calcitic ($CaCO_3$) or dolomitic ($CaCO_3$ + $MgCO_3$) limestones. These are natural products made by finely grinding natural limestone. Since natural limestone is relatively insoluble in water, limestone must be very finely ground so that it is thoroughly mixed with the soil and allowed for a period of not less than two months to react with the soil's acidity.

2.4.1 Purity of Lime

One factor affecting the ability of lime to neutralize soil acidity is the amount of calcium and magnesium carbonates it contains and expressed as calcium carbonate equivalent (CCE). The minimum calcium carbonate equivalent (CCE) to qualify as ground limestone is 80%. This means that at least 80% of the material could dissolve and neutralize soil acidity. Some dolomitic limestone that is very pure and contains significant amounts of magnesium carbonate can have a CCE greater than 100%. This is because magnesium carbonate can neutralize more acidity than calcium carbonate (Tisdale et al 1990). Clay, sand, organic matter, or other minerals present in limestone rock dilute its purity, leading to low CCE lime.

2.4.2 Fineness of Lime

Fineness of lime is determined by sieving it through screens of known mesh size (mesh is rated according to the number of openings per linear inch of the screen). Good quality lime should be ground fine enough that 90% will pass through a 10-mesh sieve and 35% through a 50-mesh sieve. Since limestone rock is slow to dissolve, it must be ground to be effective as a liming material for soil. In order to effectively neutralize soil acidity, all lime should be fine enough to dissolve within four years after application. Coarse lime particles react more slowly than very fine particles. Therefore, using very finely ground limestone and thoroughly mixing it with soil, is necessary to achieve the desired soil pH change within a shorter period than using coarse material.

The amount of lime needed to raise the pH of a soil by a given amount (say 1 pH unit) depends on the amount of humus and clay the soil contains. This relates to the ways lime works. For example Calcium carbonate ($CaCO_3$) dissolves slowly in the soil solution to release calcium and bicarbonate ions (Sanchez 2011).

2.4.3 Sources of Lime in Kenya

Kenya is endowed with large deposits of lime at Koru in Kisumu County and Athi River in Machakos County. Other unexploited deposits where commercial mining has not yet started are found in Kapenguria in Pokot County and Mount Elgon in Bungoma County respectively. Two companies that produce lime in Kenya are: Homa Lime Company, Koru and Athi River Mining Company, Nairobi are keen to increase production. Lime deposits in Koru are mined and processed by Homa Lime Company Limited to produce burnt lime which contains about 21% CaO as one of the by-products which is used for liming acid soils. The deposits at Athi River are mined by Athi River Mining Company Limited that contains about 38% CaO. The factory price of burnt lime at Homa Lime Co. Ltd was Kshs. 5,400 ($ 67.5) per ton in July 2009 and Kshs. 7,000 ($ 87.5) in August 2012, (personal communication).

2.4.4 Application and Placement of Lime

There are two important factors that should be observed when applying lime to achieve best results. These are the ideal time to apply and placement of lime.

2.4.4.1 Time of application of lime in the year.

Lime may be applied at any time of the year. However for best results, applying prior to land preparation when rainfall is expected is usually the most convenient as it needs moisture for the chemical process to occur. Thus as soon as moisture is present, the lime will begin to react (Sanchez, 2011). The Ca^{2+} ions provided by Lime replace acid cations on the exchange complex and do not move readily down the profile. It is therefore recommended to apply lime at least two months before planting the crop (Sanchez, 2011).

2.4.4.2 Placement of lime.

Solubility of lime is relatively low, so if it is applied only to the soil surface, it will probably affect only the top layer of the soil, not more than a few centimeters deep. Therefore the most important consideration is lime placement. Lime will not move into the soil like water-soluble fertilizers. It is therefore advisable to thoroughly mix the recommended amount of lime with the top 15 to 20 cm of soil and be given time to react with soil to be effective (Sanchez, 1997, Brady and Weil, 2004).

Although liming is an initial expensive pH correction investment, it is the most effective solution for soil acidity problem (Malhi *et al*, 1998). An important consideration in the economics of liming is the period of time the effect will last. However, the residual liming effect is dependent on the soil's buffer capacity (organic matter and texture) and management practices, especially the use of ammonium based fertilizers and removal of cations (calcium) from the top soil by leaching and crop harvesting (Beckie and Ukrainetz, 1996). Nekesa (2007) reported that lime increased soil pH > 5.5 and maintained it to almost same values for two cropping seasons with positive effects that resulted in good yields. A study by Kisinyo (2011) showed that reapplication of 2 tha^{-1} lime was necessary after a period of about 2 years, because at this time the pH levels had dropped below the critical level of 5.5.

2.5 Aluminium in the soil

Aluminium is the most abundant metal and the third most common element comprising of about 7% of the earth's crust (Foy *et. al*., 1978). In soils, large amounts of Al are locked up in aluminosilicates or Al oxides of the clay fractions where they do not pose toxicity hazards. However, upon acidification, a fraction of these Al oxides becomes soluble and potentially toxic to plants (Viterello *et. al*., 2005). As Al solubility is pH dependent, Al toxicity occurs only at pH values below 5.5 and is more severe in soils with low base saturation, poor in Ca and Mg (von Uexkull and Mutert, 1995). At soil pH < 5.0, Al minerals hydrolyze to form octahedron hexahydrate Al^{3+}) and mononuclear hydroxides Al (OH) $^{2+}$ and Al (OH)$^{2+}$)$_2$ which are phytotoxic (Kochian, 1995) and responsible for reduced crop production. Aluminum stress is one of the major constraints to crop production on acid soils as most of these soils contain aluminium minerals that become soluble at low pH, thus releasing the Al^{3+} into soil solution.

2.5.1 The effect of aluminium (Al) toxicity

Aluminium in the soil solution causes most of the problems associated with acidic soils. The principal effects on plant growth from aluminium in the soil solution are: reduced root mass and its function, observed in the field as stunted, club shaped roots that reduce their ability to extract moisture and nutrients from the soil and tying up phosphorus. Soluble aluminium immobilizes phosphorus in the soil causing symptoms of phosphorus deficiency, manifested in young leaves as dark-green or occasionally purple coloration. The symptoms become more pronounced as the aluminium level increases. Very high levels of aluminium in the soil also reduce the uptake and utilization of calcium and magnesium (Sanchez, 2011).

2.6 *Striga* weed

The parasitic weed belonging to the genus *Striga* that belongs to the family *scrophulariaceae* and comprises of about 60 species, ranging from completely parasitic (*Striga gesnerioides*) to almost autotropic (*S. angustifolia*) are among the world's most tenacious, prolific and destructive agricultural pests (Plate 3)

Plate 3 Two different *Striga* varieties in Africa

(Source: *Striga* Research Methods - A manual 2nd Edition June, 1997 (Eds) D.K. Berner, D.K., M.D. Winslow, A.E. Awad, K.F. Cardwell, D.R. Mohan Raj and S.K. Kim).

This noxious root parasite has a wide geographical distribution causing severe damage to a broad range of hosts including many graminoaceous crops. *Striga* species have taken root throughout the continents of Africa and Asia, imparting extensive damage to staple cereal crops (Kanampiu and Friesen 2004). *Striga hermonthica* (Del.) Benth, an obligate root hemi-parasite of several cereals, is the main constraint for food production in sub-Saharan Africa (SSA) (Kanampiu and Friesen 2004). as it infests about 40% of the cereal producing areas of SSA regions. It infests an estimated two thirds of the 73 million hectares devoted to cereal crops in Africa, resulting in crop losses especially maize among subsistence farmers between 30 –100% (Kanampiu and Friesen 2004, Vanlauwe *et al,*, 2008), a setback valued at approximately US $1 billion per year. This causes substantial pre- and post-harvest food grain losses that have made food situation to remain insecure and unpredictable leading to high levels of cyclic famine and poverty throughout sub-Saharan Africa (SSA) (Vanlauwe *et al,*, 2008).

The buildup of *Striga hermonthica* (Delite) Benth, in SSA has been associated with declining soil fertility (Gacheru and Rao 2001, Vanlauwe *et al,*, 2008,) as a result of continuous cropping without fertilizer inputs; (Ransom, 2000; Tittonel *et al,* 2005), a common phenomenon in densely populated areas such as western Kenya (Vanlauwe *et al*, 2005). In western Kenya, *Striga* has infested over 210,000 ha of otherwise high potential cropland, (Vanlauwe *et al,* 2005) driving households into extreme poverty and placing the food security at risk. The *Striga* menace is expanding in the Lake Victoria basin of western Kenya largely due to declining soil fertility (Gacheru and Rao, 2001) and monocropping of cereals, which has created a conducive environment for its infestation increase.

Work by Lendzemo *et al,* (2005), indicates that of all the factors favoring *Striga* development and infestation, the most important ones are related to the soil base. Crops growing in nitrogen deficient soils are often more severely damaged by *Striga* than those growing in soils well supplied with N. Researchers who have worked on *Striga* attribute the effect of soil nitrogen to the reduced production of *Striga* stimulant by the host plant (Gacheru and Rao 2001), inhibiting germination of *Striga* seeds and their subsequent attachment on the host plant. Soil nitrogen also promotes vegetative growth of the host plant, helping it to escape severe Striga parasitism (Gacheru and Rao 2001).

Adaptation of *Striga* to parasitism includes not only dependence upon a host plant for metabolic inputs such as water, minerals, and energy, but also for developmental signals. In this way parasite and host development are highly integrated. The early host-derived chemical signals *Striga* requires for seed germination and for initiation of the haustorium by which it attaches to host roots, are exuded from host roots into the soil. After *Striga* penetrates the host root, subsequent developmental signals are apparently exchanged directly, through vascular tissue. Germination stimulants for most *Striga* hosts have been identified as strigol-type compounds (strigolactones) (Ejeta 1993). Sorghum genotypes which produce extremely low amount of stimulants are resistant to Striga (Ejeta 1993)

2.6.1 Life cycle of *Striga*

The life cycle of *Striga spp.* is composed of five stages: germination, haustorium initiation, penetration of host tissue, physiological compatibility and parasite growth and maturation. Apart from normal seed germination requirements, *Striga* spp. requires a chemical stimulant for germination to occur and a second chemical signal to initiate haustorium, which connects *Striga* roots to its host for resource acquisition (Cardoso, *et al*, 2010). The fact that germination stimulants are also found in non-host plants suggests that induction of germination in absence of a host root can be used to reduce *Striga* populations via suicidal germination (Rugutt, 1990). Although trap plants release chemicals that stimulate *Striga* seed germination they neither produce haustorial initiation signals, nor are they attacked by the parasite (Eplee, 1992).

Symptoms of *Striga* parasitism such as scorched, severe stunting, drought-like symptoms and leaf margin curling in the life cycle are broadly similar, regardless of the host-parasite combination, although there are some minor variations as they are mainly dependent on that of its host (Appendix 12). Initial symptoms occur while the parasite is still subterranean; they are evident in water soaked leaf lesions, chlorosis, and eventual leaf and plant desiccation and necrosis. With time the maize slowly begins to be stressed. When maize is stressed at flowering due to deficit of water, light and nutrients, ear growth slows in relation to tassel growth and the anthesis-silking interval (ASI) increases. Anthesis is largely unaffected, resulting in an increased anthesis-silking interval (ASI) (Edmeades *et al*, 2000). Selection for reduced ASI has been used successfully to increase the drought tolerance of maize, Hassan, *et al*, (2008).

Individual *Striga* plant produces roughly 50,000 to 500,000 microscopic and dormant seeds per plant and they are viable up to 20 years in the soil (Berner *et al* 1995). The Striga plant flowers 4 weeks after emergence, after 4 more weeks the seeds are mature. The seeds are about 200^{-5} microns wide by 300 microns long (Worsham, 1987). Their germination is induced by exudates of many plants both the cereals and trap crops (Bouwmeester *et al*, 2003). The latter plants stimulate Striga germination but without becoming infected by the root hemi-parasite, as subsequent attachments only take place on true hosts (Ejeta and Butler, 1993; Olivier, 1995).

After germination, a series of chemical signals directs the radical to the host root where it attaches and penetrates (Figure 3). However, if the seedling does not attach to a host root within 3–5 days, the seedling perishes. Once penetration has occurred, an internal feeding structure (haustorium) is formed, and the parasite establishes host xylem connections (Cardoso et al 2010). The host photosynthate is diverted to the developing parasite, which also utilizes the host root system for water and mineral uptake. As the host matures, the parasites emerge and begin to produce chlorophyll and photosynthesize. After emergence, host symptom development is intensified.

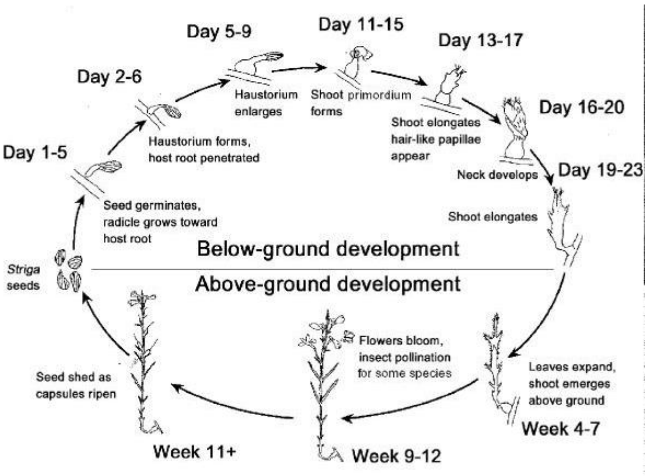

Figure 3 General life cycle of *Striga* species (courtesy E.I Aigbokhan)

(Source: *Striga* Research Methods — A manual 2nd Edition (June, 1997) *(Edited by* D.K Berner, M.D. Winslow, A.E. Awad, K.F. Cardwell, D.R. Mohan Raj, and S.K. Kim)

Reproductive schemes vary from autogamy to obligate allogamy, depending on species (Musselman, 1987). *Striga hermonthica* and *Striga aspera* are the only two species known to be obligately allogamous and require insect pollinators. Following reproduction, seeds are dispersed and the cycle is reinitiated. The relative success of each stage of the life cycle governs the volume of seed production. At each stage, there is a potential opportunity for control. However, successful sustained control will depend on eliminating the *Striga* spp. seed reserves in the soil and preventing parasitism at the early crop growth stages.

After dispersal, seeds may remain dormant for several months; during this time, seeds will not germinate even if conditions are ideal. This period is termed after-ripening (Vallance, 1950), and it may be an evolutionary adaptation to prevent germination during the last rains of the season, when there are no hosts around. Studies have indicated that the length of the after-ripening period is different for different *Striga* species and for seed samples collected from different geographical areas (Van Mele, *et al,* 1992). It may be anywhere from a few days to 2 years. After this period, seeds will germinate only under conditions of favorable moisture and temperature (free moisture adequate for seed imbibitions and at temperatures between 20 and 33^0 C) and only in the presence of a germination stimulant, usually exuded from plant roots.

2.6.2 *Striga* weed on food production and its economic importance.

In sub-Saharan Africa agriculture is characterized by subsistence farming of cereals in small land holdings, Striga is an ever increasing scourge, infesting an estimated 21 million hectares of crop land in the region with an estimated US$ 331 million annual loss in cereals production (Suaerborn 1991). More than 48 million ha currently devoted to cereals production are threatened by Striga and livelihoods of some 300 million people affected by the problem (AATF, 2006) (Tables 4 and 5).

In western Kenya Striga *hermonthica* is increasingly becoming more of a problem escalating both in severity and spread (Hassan and Ransom, 1998, Frost 1994). Over 39% of the farmers lose more than 50% of their maize crop to *S. hermonthica* (Hassan and Ransom, 1998).

Table 4 Area covered by *Striga* and its economic loss of maize in sub-Saharan Africa (SSA)

Total Maize Area in SSA	**25,375,000 ha**
Total Maize Area with *Striga*	6,122,000 ha
% SSA Area infested with *Striga*	24%
Value of Maize in SSA	US$ 10 billion
Value of Maize lost due to *Striga*	US$ 1.2 billion
Total Area with *Striga* in Kenya	246,000 ha

(Source: Unlock Cereal Production Potential in East Africa by Eliminating the Striga threat AATF, 2006)

Table 5 Estimated maize area under *Striga* in Eastern Africa

Country	Maize Area (ha)	% Maize Area under *Striga*	*Striga*- infested Maize Area (ha)
Kenya	1,665,000	15	246,000
Uganda	750,000	5	38,000
Tanzania	2,000,000	33	660,000
Total Area	4,415,000	17.7	944,000

(Source: Unlock Cereal Production Potential in East Africa by Eliminating the Striga threat AATF, 2006)

2.6.3 Impact of Striga weed on Maize production

The symptoms of Striga attack on Maize caused by lack of water (drought), like wilting and curling of leaves at an early stage are difficult to distinguish. The infected plant may also show stunting and a pronounced burning of the leaf borders a symptom of phosphorus deficiency. The leaves are 'burnt' when the parasitic weed dominates over the maize plant (Kanampiu, and Friesen 2004).

Striga may attach as early as two weeks after maize germinates. By the time Striga appears on the surface and flowers, it has already done damage to maize. When *Striga* attaches to the root of the growing plant, it starts to suck water and nutrients out of the host and uses these for its own growth as a consequence the host becomes stunted. The maize loss due to *Striga* attack is estimated between 20-80 per cent (Esilaba, 2006). As few as three plants per square metre can completely prevent grain production.

2.6.4 Control and Management of Striga weed

The technologies range from simple cultural practices such as intercropping maize with legumes, rotating maize with soybean (soybean stimulates the Striga to germinate but it later dies in the absence of a maize host to latch onto) to deploying a “push-pull’ technology that involves intercropping cereals with specific Striga-suppressing desmodium forage legume (Kanampiu and Friesen 2004).

The strong survival mechanism of *Striga* including seed dormancy, long lasting viability even up to 20 years and attacking susceptible host plants render mechanical control ineffective owing to the damage that is done to the crops before the weeds even emerge from the ground level. Traditional hand weeding or inter cultivation does little to reduce the damage. Physical removal of *Striga* shoots by hand is not useful since shoots resprout soon from its crown buds which are located up to 15 cm below the soil level (Kanampiu and Friesen 2004).

The use of crop rotation, trap crops and nitrogenous fertilizer prevent or delay *Striga* germination and establishment for sufficiently long periods (Schulz *et al*, 2002, De Groote et al, 2010). Nitrogen not only provides good protection to the host from the parasite but also improves the performance of the infected crop in such a way that when heavy dose of nitrogen is applied, it is likely to bring in a more intensive utilization of *Strigol*, root exudates of sorghum responsible for *Striga* germination (Noggle and Fritz, 1977, Gacheru and Rao, 2011). In spite of this, if *Striga* germinates; it will not survive because of increased nitrogen concentration of the host and a decreased osmotic pressure gradient towards parasite. This reduction in osmotic pressure gradient decreases the ability of the parasite to stay alive. Improvement in the soil fertility is said to discourage *Striga* incidence (Esilaba 2006).

Striga is difficult to control because each fully mature plant produces between 50,000 and 500,000 seeds. In the soil, mature seeds remain dormant for 6 months to 20 years so routine field sanitation is insufficient to eradicate *Striga* once it becomes well established. *Striga* emerges in spotty, unpredictable pattern and it does most harm to the host prior to its emergence, (Odhiambo and Ransom 1994). Clearly, *Striga* poses an ominous obstacle to a continent struggling with food insecurity and rural stagnation. These losses are often quite severe because the weeds are able to develop underground while attacking crops causing much damage without being noticed (De Groote *et al*,, 2008). This ability of underground development also, makes their control difficult compared to other common weeds as it emerges after most other weeding operations have been completed. *Striga* is very difficult to control and all the various methods have their challenges. Therefore the key to sustainably manage this weed is to combine various technologies.

Current *Striga* control measures include chemical control, rotation with trap crop, soil fertility amendments, hand pulling, and intercropping (Kabambe *et al*,, 2008). Search for resistant crop varieties is underway and promising. Most of these measures do not offer complete control and may require several seasons for substantial *Striga* reduction. An integrated approach to *Striga* control is considered most feasible for low input production of most developing countries. The approach incorporates tolerant genotypes, agronomic practices to delay or reduce emergence, minimize seed return to soil, avoid maximum damage to the soil, and general enhancement of crop growth (Kabambe *et al*, 2008). One of the recommended options is the use of trap crops either in sole stands to decrease the *Striga* seed bank in the soil or as intercrops in maize to reduce attachment to the host and suppress emerged *Striga*.

With every planting season, some of the dormant seeds, stimulated by crop exudates, germinate and infest the host crop while reproducing and increasing the *Striga* seeds in the soil thus escalating the problem. *Striga* management should therefore include a reduction in *Striga* seed bank from heavily infested soil and preventing further seed multiplication (Ramaiah, 1983). Rotating or intercropping maize with trap crops such as beans, ground nuts, sunflower and cowpeas may help reduce the number of Striga seed in the soil. However these technologies have not been widely adopted because of the mismatch between technologies and farmers socio economic conditions (Debrah *et al,* 1998).

2.7 Combined impact of soil acidity and Striga weed on maize production

The combined impact of soil acidity and *Striga* may render the land unproductive unless the situation is corrected. Soil acidity has negative effects as it generally affects the availability of nutrients some nutrients such as N, P and K which result in limiting plant growth that consequently cause yield loss of about 30%. On the other hand *Striga* weed infestation leads to degradation of agricultural land that may lead upto 100% crop loss (Abunyewa and Padi, 2003. This may also discourage the farmers who may no longer care for those fields (Abunyewa and Padi, 2003) and some studies claim that problems caused by *Striga* continue due to loss of soil fertility since low soil fertility would benefit Striga (Parker, 2008). According to Parker (2008) problems with *Striga* are generally caused by low economic resources and poor soil fertility.

2.8 Economic analysis of the use of lime and fertilizers on *Striga* attack

The economic evaluation of new innovations is done to assess suitability, acceptability, potential adoption and profitability under farmers' environment, economic and managerial conditions with the aim of adapting the innovation to make it more sustainable with the farmers' conditions and thus facilitate wide adoption (Kipsat, 2002). After testing the agronomic viability of several treatment combinations, an economic analysis is carried out to determine the treatment combinations that yield the greatest benefits and which provide the basic elements for adoption (CIMMYT 1993). The method used for economic analysis of treatment combinations is the costs and returns analysis method. Costs include labour, land, inputs such as fertilizers, certified seeds, pesticides etc. The method determines the impact of a new innovation (Barlow *et al*,, 1983). Some of the parameters used in economic analysis include gross margins, returns to land, labour and capital and value to cost ratios. Gross margin is used to make evaluation of ongoing or existing projects and is defined as gross output less variable costs and is also used to determine profitability of enterprises produced under alternative innovations or treatments. Returns to land, labour and capital are measures of land, labour and capital productivities respectively, and are used as measures of performance of innovations. Value to cost ratio refers to the ratio of total revenue and total variable costs. It is often used as a measure of performance of innovations, particularly when capital is a constraint. Net change in income is a technique used in evaluation of costs and benefits that varied from control.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials, Sites; Background information

The study was carried out in two counties (Kakamega and Siaya) located in western Kenya and as described below: (Fig. 4).

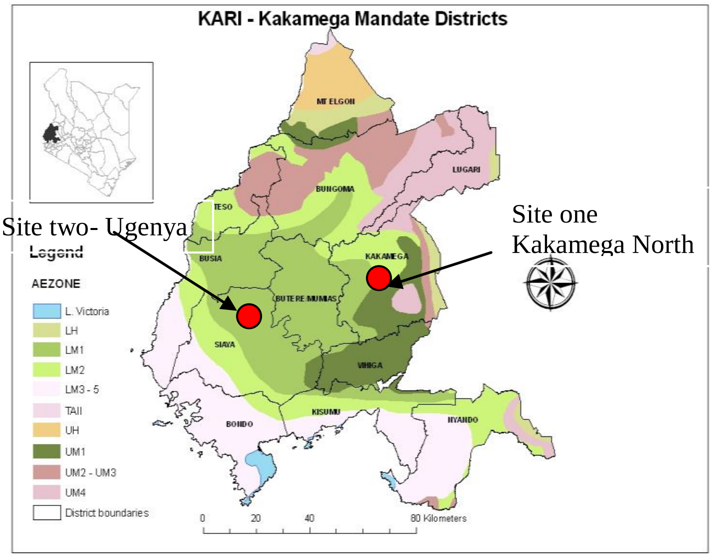

Figure 4 Study sites (Source: Kenya Soil Survey 2005)

● **Study sites: Ugenya and Kakamega North in Kakamega and Siaya Counties respectively**

3.1.1 Kabras, Kakamega North sub county in Kakamega County

The location of the trial was Kabras East Location in Kakamega North sub County, Kakamega County lies between latitude 0° 25.3'S and longitude 34° 04' E. The mean altitude is 1,200 meters above the sea level. The annual mean rainfall ranges from 1,200-2,200 mm (Figure 5) and is received in two rainy seasons, the long rains begins from March to June while the short rains from September – November, (Jaetzold et al, 2007). The 60% reliability of the length of the growing periods ranges from 365 days in Upper midlands (UM) 1 to about 230 days in UM 4. In the eastern part of the County (UM 0, 1, 2 and UM 3-4) the annual mean temperature is between 18 and

21°C. Due to the wet climate evapotranspiration is not high, between 1,600 –1,800 mm per year. The soils are well drained, deep to very deep and vary from dark red Nitisols and Ferralsols to dark brown Acrisols (Jaetzold et al, 2007).

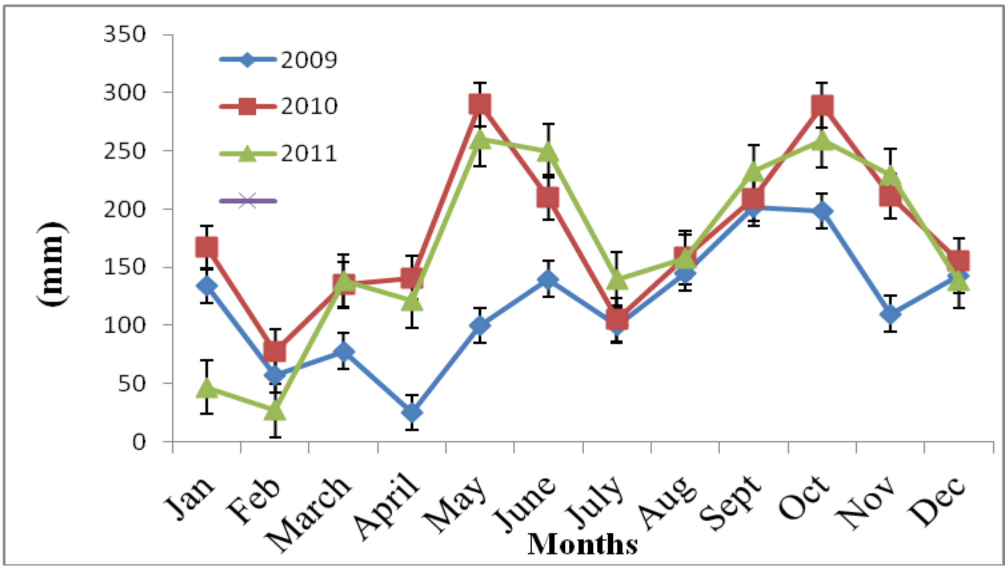

Figure 5 Total mean monthly rainfall, 2009-2011, Kabras, Kakamega County

3.1.2 Got Nanga, Ugenya Sub County in Siaya County

The location of the trial was Got Nanga in Ugenya North East Location in Ugenya sub County of Siaya County lies between latitude 0° 30'S and 0° 20' S and longitude 34° and 34° 30' E. The altitude ranges between 1,140 and 1,400 m above the sea level. The annual average rainfall ranges from 800 - 1800 mm received in two rainy seasons; the long rains (LR) from March to June and short rains (SR) from September to December (Figure 6) (Jaetzoid et al,, 2007). The mean annual temperatures ranges between 15° and 27°C while mean minimum temperature ranges from between 15° and 17°C, while the mean maximum range from between 27° and 30°C. The soils are developed from basalt volcanic rocks. They are well drained, deep to very deep and friable; however some areas are shallow with petroferric phase i.e. murrum. They vary from dark red Nitisols and Ferralsols to dark brown Acrisols (Jaetzold et al, 2007).

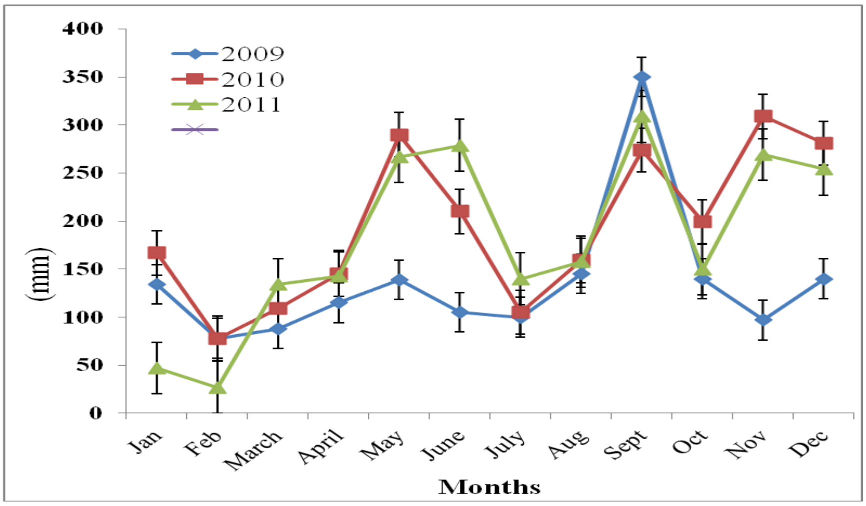

Figure 6 Total mean monthly rainfall, 2009-2011, Got Nang, Siaya County

3.1.2 Baseline survey methodology in study sites.

The selection of farmers was through two stages. The Ministry of Agriculture staff mobilized farmers to attend a sensitization meeting where objectives and criteria of selecting participating farmers were explained. After the sensitization meeting two days were set aside one per County for the Ministry of Agriculture extension staff to select representative farmers from each of the two Counties to participate in the baseline survey.

A baseline survey was conducted to establish socioeconomic and demographic characteristics of households and their livelihood assets, using a structured questionnaire with an overall objective of evaluating the status of households' livelihood strategies that would form benchmark indicators that would be used to determine the success of the study in the study sites.

The specific objective was to conduct baseline survey on socioeconomic characteristics and production constraints. The sampling design and data collection relied on two complementary data sources: primary and secondary. The relevant literature of secondary data was reviewed first followed by primary data through conducting informal and formal surveys. Informal survey involved four focus group discussions (FGDs), two in each study site, comprising 6 to 10 male and female farmers and interviewing 20 key informants using a checklist. The key informants included experienced male and female farmers, community leaders, government extension officers and non-governmental service providers. The information gathered during informal survey together with the secondary literature was important for refining the questionnaire for the formal survey.

A multi-stage sampling technique (IFAD, 2003) was used to identify the survey households that were representative of the farming population in the two counties. In the first stage, two locations, namely Kabras East in Kakamega North sub County, Kakamega County and Ugenya North East Location in Ugenya sub County, Siaya County were selected for the study because they were amongst the key locations with soil acidity, *striga* infestation and overall low maize yields. The sample size of households per study site was determined by using Equation (3.1) as per Wonnacott and Wonnacott (1990):

$$N = \frac{Z^2 P(1-P)}{\Phi^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (3.1)$$

where; N = required sample size, Z = confidence level at 95% (standard value of 1.96), p = estimated proportion of an attribute, which was estimated at 85% due to the fact that about 85% of the rural population in Kenya are employed in farming activities (CBS, 2001) and Φ = margin of error at 5% (standard value of 0.05). Therefore, using Equation (3.2), N was determined.

$$N = \frac{1.96^2(0.85)(1-0.85)}{(0.05)^2} = 195.92 \quad \ldots\ldots\ldots \qquad (3.2)$$

The sample size of 160 households, comprising 80 from Kakamega County and 80 from Siaya County were selected and interviewed. The 160 respondents included men and women aged between twenty fine to seventy years The standard questionnaire (Appendix 1) was used to gather information on: household demographic characteristics (members of the household, their number and relation to the head of the household, age, sex, education level), resource endowments, major livelihood strategies, types of crops grown, availability of labour and its utilization, agronomic practices applied and yields obtained, farmers' perceptions of soil fertility depletion and adoption of soil management practices. The other data included household access to different institutions that focus on improving agriculture such as extension and credit, membership in local groups. The collected data was analyzed by the use of Statistical Package for Social Sciences (SPSS) software version 17 2010.

3.1.3 Soil Classification and characterization of study sites

Soils have many different chemical and physical characteristics based on various prevailing conditions. The soil profile is an important tool in nutrient management. By examining a soil profile, one gains valuable insight into soil fertility. As the soil weathers and/or organic matter decomposes, the profile of the soil changes (Serrem – personal communication). For instance, a highly weathered, infertile soil usually contains a light-colored layer in the subsurface soil from which nutrients have leached away. On the other hand, a highly fertile soil often has a deep surface layer that contains high amounts of organic matter. With clues provided by soil profile, one can begin to predict how a soil will perform under certain nutrient management conditions. Therefore it was important to characterize the study sites to better understand them by knowing their chemical and physical characteristics.

The objective to classify and characterize study sites was also to later assist to determine the effects of agricultural lime and fertilizers on mainly soil pH changes and P availability over time. Four profile pits were dug, two in Kakamega County and the other two in Siaya. The depth of each pit depended on width of the horizons and accessibility of the parent material. In addition to the profile pits, soil samples were collected across farmlands using soil auger to a depth of 20 cm based on procedures described by Okalebo *et al.,* (2002) from 20 farms from each study site.

3.1.4 Soil sampling strategy

Soil has many physical, chemical and biological properties that affect the growth of plants. The degradation of the physical soil properties has considerable consequence on plant growth, yield and quality of crops, regardless of the soil plant nutrient. Degraded physical soil properties take considerable time and cost to correct. The way the farm is managed has substantial effects on the soil which strongly influence the long term profits. To understand the soils in the study sites soil sampling was carried out. Using the protocol of Okalebo *et al..* (2002), the first sampling was carried out prior to the installation of the study and was repeated every planting season for four consecutive seasons. The data was to monitor the responses and changes in soil characteristics over time due to lime and other macro nutrients application. The collected soil samples were thoroughly mixed and a sub sample of composite soil, properly labeled and taken to KARI Kakamega laboratory for physical and chemical analysis (soil texture, soil pH by water method, available phosphorus, soil particle size, soil organic carbon content) as described by Okalebo *et al.*. (2002) and some of the results were used to produce soil texture, acidity and available phosphorus maps. The soil pH (w) was determined in the field by using the colour chart and later verified through laboratory analysis (Appendix 2).

For quick determination of soil pH in the field that was later verified in KALRO Kakamega laboratory, a Munsell Colour chart used (Figure 4).

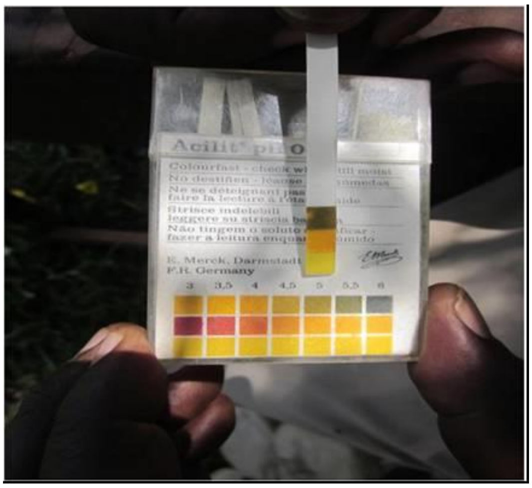

Plate 4 Munsell Colour chart used to determine pH in the field

3.1.5 Soil analysis procedures

Several methods were used in the analysis of physical and chemical properties. These were hydrometer method for physical properties, (soil particle size - texture). Soil samples are air dried, ground and sieved in a 2mm sieve. pH (1:2.5, soil: H_2O, water method), Olsen method for available P, 1.0 M ammonium acetate (NH_4OAc) method for the exchangeable bases, atomic absorption spectrometer (AAS) for extractable cations, Walkley – Black method for organic carbon and Kjeldahl distillation method for total N. The detailed procedures of these methods are in Okalebo *et al.*, (2002) protocol.

3.2 Field Experiments

3.2.1 Experimental Design

For field experimentation, twenty farms were further selected from the earlier 80 representative farmers for the field trials in terms of similar soil pH, terrain, soil type, *Striga* infestation. Each farmer's field was a block measuring 64 by 43 metres that comprised of six trial treatments plots each measuring 20 by 20 m. The experiment was set up in a randomized complete block design (RCBD) where the farmer was a replicate with six treatments. One maize variety HB513 preferred in both study sites, due to its early maturing characteristic, was used as the test crop. The statistical model for the design was

$$y_{ij} = \mu + t_i + b_j + \varepsilon_{ij}$$

where y_{ij} is the individual observation in the *ith* treatment in the block, μ is the overall mean, t_i is the effects of the *ith* treatment, b_j is the effect of the *jth* block, and ε_{ij} is th usual NID (0, σ) random error term.

Experiment unit one included six treatments: Lime (CaO) (2.0 t ha^{-1}), Diamonium phosphate (75 kg ha^{-1}) from MEA Ltd Company, Nakuru; Mavuno 26 kg ha^{-1} P) a fertilizer blend from Athi River Mining Company (ARM), Lime (2.0 t ha^{-1} plus Diamonium phosphate (DAP 75 kg ha^{-1}), Lime (2.0 t ha^{-1}) plus Mavunos26 kg ha^{-1} P) Mavuno (26 kg ha^{-1}) and the conventional farmers practice (FP) as the control (Table 6). In the sub experiment unit two (Table 7), included two application rates of 0 and 2 MT ha^{-1} of lime from Koru, Mavuno only 75kg (N) +26kg (P)) Kg ha^{-1} , 2 MT ha^{-1}. (CaO 21%) + Mavuno 75kg (N) +26kg (P)) Kg ha^{-1}, DAP only 75kg (N) +26kg (P)) Kg ha^{-1}, 2 MT ha^{-1}. (CaO 21%) + DAP 75kg (N) +26kg (P)) Kg ha^{-1} the objective was to determine the yield increases of maize resulting from addition of lime with and without fertilizers. In sub experiment unit three (Table 8) consisted of three treatments: sterilized sand + no agricultural lime + no fertilizer + no host; agricultural lime + host; and agricultural lime + fertilizer + host. The main idea in this sub experimental unit was to assess the *Striga* germination counts. The basis of selecting 2.0 t ha^{-1} was a recommendation within the project (Kiplagat 2013).

Table 6 On farm Experimental treatments in Kakamega and Siaya Counties

Sub experimental unit 1 - Lime, Lime with multi nutrient fertilizers and control as check

Treatment	Description	Treatment code
1	Lime alone	L
2	Diamonium phosphates alone	DAP
3	Mavuno alone	MVN
4	Lime plus Diamonium phosphates	LDAP
5	Lime plus Mavuno	L MVN
6	Control (No inputs	C

Table 7 On farm Experimental treatments in Kakamega and Siaya Counties

Sub experimental unit 2 - Rates of Application (MT ha^{-1}) of agricultural lime

Treatment	Rates of application	Treatment code
1	0 MT ha^{-1}. (CaO 21%)	0 L
2	2 MT ha^{-1}. (CaO 21%)	2 L
3	Fertilizer 75kg (N) +26kg (P) Kg ha^{-1} Mavuno	Mavuno

4	2 MT ha^{-1}. (CaO 21%) + Fertilizer 75kg (N) +26kg (P) Kg ha^{-1} Mavuno	2 L + Mavuno
5	2 MT ha^{-1}. (CaO 21%) + Fertilizer 75kg (N) +26kg (P) Kg ha^{-1} DAP	2 L + DAP
6	Fertilizer 75kg (N) +26kg (P) Kg ha^{-1} DAP	DAP

Table 8 On farm Experimental treatments in Kakamega and Siaya Counties

Sub experimental unit 3 –Monitor germination rates of Striga in the laboratory.

Treatment	Description	Treatment code
1	Incubate 50 seeds of *Striga* in sterilized soil with no lime and fertilizer.	0L
2	Incubate 50 seeds of *Striga* in 2 t ha^{-1} lime with no fertilizer.	2L
3	Incubate 50 seeds of *Striga* in 2 t ha^{-1} lime with fertilizer.	2 L + Fertilizer

In all lime treatment plots, lime was applied two months before planting prior to short rains of 2009. Both Mavuno and DAP were applied at planting in each of the four seasons. The Mavuno plots were top dressed with Mavuno top-dress fertilizer (N=26, CaO=10, S=5) from (ARM) while DAP plots were top dressed with CAN (N=26) from (MEA Ltd) when the crop was four weeks after germination. The nutrient contents for each of these soil amendments used in the trial are shown in (Table 9).

Table 9 Nutrient content% of fertilizers used for planting and top dressing

Fertilizer	**…..Macronutrients…..**			**………… Micronutrients………..**						
	N	P	K_2O	S	CaO (%)	Mg	B	Zn	Mn	Cu
DAP	18	46	0	0						
Mavuno planting	10	26	10	4	10	4	++	++	++	++
CAN	26	-	-	-	-	-	-	-	-	-
Mavuno-top dress	26	-	-	5	10	-	-	-	-	-
Lime	-	1.24	-	0.1	21	0.3	-	-	-	-

(Source: MEA Ltd, Athi River Mining Company Nairobi and Homa Lime Company Koru).

3.2.2 Selection of crop trial sites in Kakamega and Siaya Counties

The selection of the trial sites was first preceded by a visit in each of the two Counties. A sensitization meeting was held with the objective of explaining the criteria used to select farmers that were to host the trials. The farms were selected based on the following criteria:

(i) that the farmer should be willing to allocate a half hectare of his/ her land for trial for three continuous years

(ii) that the location of the farmer’s land was be accessible by other farmers as it will serve as a learning site

(iii) that based on soil analysis results the soils pH value was be less than 5.5, the value indicative for liming.

(iv) that the farmer was to show interest and willingness to work with the research team on the agricultural lime trials for three years

3.2.3 Land preparation and layout of field experiments

The seedbeds for farms selected for the research trials were prepared two months prior to start of the respective rain season. Each participating household participated in the clearing and preparation of land measuring 64 x 43 m to accommodate six treatments. Most SHF prepared the experimental plots using the traditional manual methods with hand hoes. Few SHF used ox-plough to prepare experimental plots. After the initial experimental plots were prepared, six trial plots (each 20 m × 20 m) were marked out and separated by one meter wide spaces to allow for movement around the plots. This layout permitted farmers to view and clearly assess the performance of treatments (Figure 8).

3.2.4 Lime application and planting the test crop

After establishing the plots at each site, one month prior to the planting of the test crop, lime was applied by broadcast method at the rate of 2 t ha^{-1} as recommended in earlier studies (Kisinyo, 2011) and well incorporated into the soil to allow for adequate time for lime to react with the soil (Appendix 3). Of the six trial plots only three were limed. The remaining three, one was the control, the other two, one received DAP only and the other Mavuno only at planting.

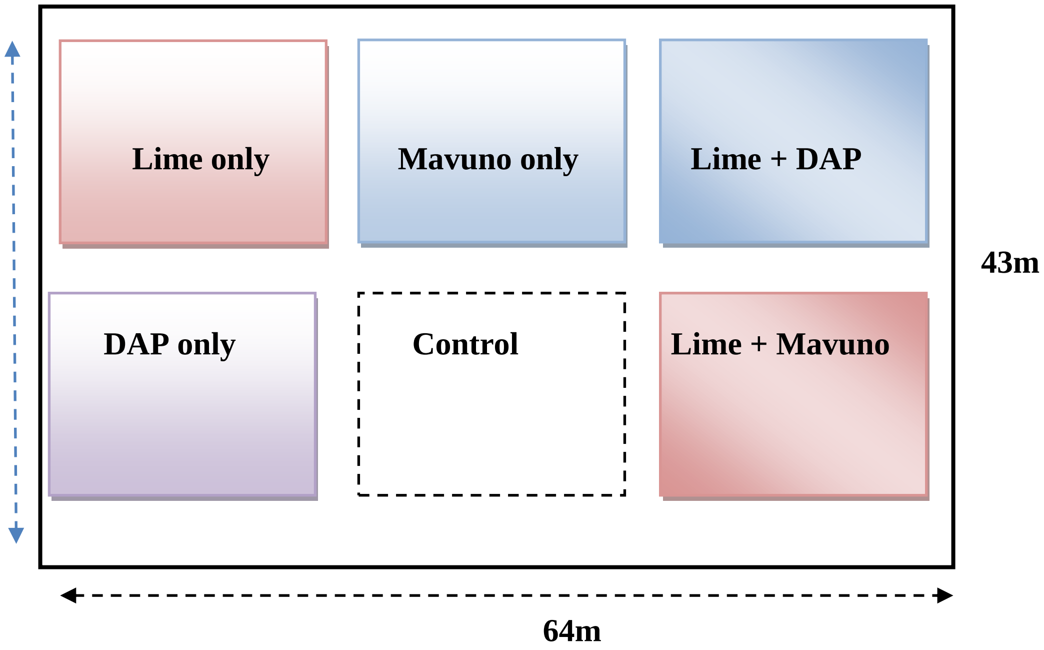

Figure 7 On farm layout of a block with six trial plots in Kakamega and Siaya Counties

3.2.5 Effects of lime with fertilizer on Striga growth and survival in the laboratory and field.

A study was conducted to evaluate the effects of lime only and lime with fertilizer on *Striga* germination/ emergence. The study was carried out both under the laboratory and field conditions in KALRO Kakamega laboratories. Sand was collected and sterilized. Sterilized sand was put in seven pots. The treatments were as follows: Pot 1 (control) sterilized sand, no host, no lime and no multi nutrients; pots 2, 3 and 4 a mixture of sterilized sand with 10 g of agricultural lime plus a host (Maize) and pots 5, 6 and 7 a mixture of sterilized sand with 10 g of agricultural lime, 10 g of multi nutrient fertilizer plus a host (maize). 50 seeds of *Striga hermonthica* were planted in each pot. *Striga* emergence counts per treatment were recorded at ten days after planting.

Fields with no *Striga* weeds were identified and lime applied to the trial plots using broadcast method at two rates 0 t ha^{-1} (control) and 2 t ha^{-1} at least one month before planting the maize crop. The plots were demarcated and Striga seeds broadcast and incorporated into the soil. Holes were dug in rows following the recommendation spacing of 75 by 30 cm and one maize seed per hole was planted using the recommended quantities of fertilizers (DAP, Mavuno planting, CAN and Mavuno top dressing) at planting and topdressing respectively. The crop was allowed to grow to physiological maturity for harvesting time.

The field and laboratory observations included a) *Striga* emergence in terms of number of *Striga* plants per plot per treatment. Uprooted maize plants were submerged in a series of buckets of water to remove the soil from the host root and count the *Striga* plants that had emerged (is green), and count the number of underground *Striga* plants whose sum of the two gives the total number of attached *Striga* plant. Several observations were made on: *Striga* population per treatment in field trial plot and converted into population per hectare at silking stage of maize, growth parameters: plant height, yield and yield components.

The objective was to evaluate *Striga hermonthica* weed infestation, the most devastating of all *Striga* species in Kenya (Kanampiu and Fresian 2004). A field study consisted of six treatment plots each measuring 5 m by 5m as follows, plot one (control) neither received lime (0 t h^{-1}) nor fertilizer, plot two received only lime equivalent of 2 t ha^{-1} at planting, plot three received lime equivalent of 2 t ha^{-1} with Mavuno equivalent of 75 kgh^{-1} N and 26 kg P h^{-1} at planting, plots four received Mavuno equivalent of 2 t ha-1 at planting, plot five received lime equivalent of 2 t ha^{-1} with DAP equivalent of 75 kgh^{-1} N and 26 kg P h^{-1} at planting and plot six received only DAP an equivalent of 75 kgh^{-1} N and 26 kg P h^{-1} at planting. Plots three to six which received fertilizer at planting also received an equivalent of 75 kgh^{-1} N as top-dress.

Striga population counts were taken thrice (before first weeding, tasseling and at harvesting using a 0.5 by 0.5 m quadrat. The Striga plants per quadrat were converted to plants per hectare. The Striga emergence trial was conducted in the laboratory with three treatments: sterilized sand with no maize (host), sterilized sand mixed with lime and maize and sterilized sand mixed with lime and fertilizer with maize.

3.2.6 **Crop monitoring for appraising treatments at different plant growth Stages**

The research trial plots were regularly monitored by farmers. The germination rates were measured in each treatment two weeks after planting of maize. At weeding and tasselling the crop in each trial plots was monitored and evaluated for nutrient deficiency symptoms, obnoxious weeds, disease and any pest incidences. Close to harvesting the crop was monitored and assessed for maize physiological maturity. Student supervisors and top managers from University of Eldoret and Kenya Agricultural Research Institute Headquarters monitored the trial plots prior to harvesting to appraise each treatment. The objective of crop monitoring was mainly to appraise treatments at different plant growth stages (Plate 5).

Plate 5 Visit by KALRO and University of Eldoret staff on Jowi's farm Got Nanga, Ugenya, Siaya County (Source: Author 2010)

Harvesting of maize was done at physiological maturity from the net plot area of 256 m^2. The number of maize plants per net plot was counted to determine the survival rate. All plants in the net-plot were cut at ground level and the total fresh weight taken. Ten cobs and ten stover sub samples were randomly taken and weighed to get fresh weight for each plot. A sub sample of stover was taken, while still in the field, stover sub sample was cut into small portions 1 – 3 cm, packed in polythene bags, well labelled and taken to KALRO Kakamega laboratories for analysis according to Okalebo *et al* (2002) methodology. The ten cobs were air dried, grain was shelled from the cobs and weighed to determine extrapolated grain and core yields per hectare. Part of the sub samples were sent to Plant and Crop Nutrition laboratory Nairobi for comparison and quality control purposes.

The harvest index (HI) was calculated to determine the ratio of harvested grain to total shoot dry matter, and HI was used as a measure of reproductive efficiency for each treatment, Pennington, 2013. Therefore HI as a predictor of maize stover yield, is defined as kilograms of grain divided by the total kilograms of above ground biomass (stover plus grain).

Harvest index = kg of grain / (kg stover + kg grain), Pennington, 2013.

3.2.7 Economic analysis of the suitability and profitability of the treatments.

Economic performance has a direct bearing on people's food security and nutritional status which corresponds with the impact on improved standards of living in the study sites. The objective of carrying out an economic evaluation was to assess suitability and profitability of the new innovations. The commonest used method for economic analysis of treatment combinations includes the costs and returns analysis method which was used to determine the impact of a new innovation (Barlow *et al*., 1983).

The objective of carrying out the economic analysis in this study was to evaluate economics, assess suitability, acceptability, potential adoption and profitability of liming and fertilizers, a new integrated soil fertility management (ISFM) innovation. Two analyses were done. These were the economic analysis and cost benefit analysis to enable understand the benefits of using agricultural lime and multi nutrient fertilizers based on source of inputs location and seasonal maize prices.

3.2.8 Statistical analysis on the field data collected

Data regarding social factors was analyzed by SPSS software version 17, 2010 and the grain yields analysis was analyzed by use of GenStat Release 7.22 TE (2010). Analysis of variance (ANOVA) (Table 10) was used to test the hypothesis that liming soil and those additive interactions for including multi nutrient fertilizers could enhance maize crop yield. Protected least significant difference (LSD) at $p \leq 0.05$ was used to separate them.

Table 10 Outline of Analysis of Variance (ANOVA)

Source of Variance	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**Computed F**	**Tabular F5%**
Replication	1				
Treatments	5				
Error	5				
TOTAL	11				

CHAPTER FOUR

RESULTS

4.0 Baseline Survey on Socio economic characteristics of smallholder farmers in Kakamega and Siaya counties.

4.1 Socio economic and demographic characteristics

Demographic and socio economic characteristics play a key role in determination of livelihoods of farm households of rural people in Kakamega and Siaya Counties. The mean age of the household heads was 50 years with a standard deviation of 14. The household heads were significantly older in Kakamega County than Siaya County ($p<0.01$) (Table 4.1). With regard to sex of the household heads, most households (81%) were male headed, being significantly higher in Siaya County than Kakamega County ($p<0.01$) (Table 11).

The household sizes in both Counties were about 6 persons and were highly significant ($p<0.01$) in Kakamega County than Siaya County respectively. The level of education of household heads in both Counties was low. Majority of them (62%) ad attended school up to primary School level.

4.2 Household assets

4.2.1 Physical capital

Physical capital comprises the basic infrastructure required to support livelihoods in a given environment. The physical capitals for agriculture are land and agricultural tools such as hoes, machetes, wheelbarrows etc. Physical capital is often used as social indicators of wealth. Land size and access to land are essential determinants for application of agricultural practices. Land ownership and tenure systems are shown in (Table 12)

Table 11 Mean demographic and socioeconomic characteristics of the sample households (160) in sampled areas in Kakamega and Siaya counties

Characteristics	**All (N=160)**	**Siaya (N=80)**	**Kakamega(N=80)**	**Test-statistic** [a]
Age of household head (years)	49.6 (13.6)	52.5 (13.6)	47.0 (13.2)	2.928***
Sex household head (male) (%)	80.6	87.6	73.3	6.777***
Household size (number)	6.1 (2.5)	5.8 (2.3)	6.3 (2.6)	1.70*
Education levels (%)				
None	9.2	15.8	2.9	
Primary	62.1	61.9	62.4	
Secondary	22.8	17.8	27.6	
College	5.8	4.0	7.6	
Marital status (%)				
Single	2.4	2.9	1.9	
Monogamous	61.5	44.7	78.1	
Polygamous	13.9	19.4	8.6	
Widowed	21.6	32.0	11.4	
Divorced	0.5	1.0	0.0	

[a] Chi-square and t-tests for percentages and means between the two divisions, respectively. * and *** indicate significant differences at 0.05 and 0.001 respectively

Table 12 Mean farm sizes (ha), land tenure % and acquisition (%)

Characteristics	**All (N=160)**	**Siaya County (N=80)**	**Kakamega County (N=80)**
Farm size (Acres)	1.6	2.1	1.2
Land tenure (%):			
Freehold with the title	47.1	43.7	50.5
Freehold without title	65.4	71.8	59.0
Leasehold	13.0	13.6	12.4
Communal	1.0	1.9	0.0
Method of land acquisition (%)			
Inherited	94.2	97.1	91.4
Bought	17.3	18.5	16.2
Rented in	13.9	13.5	14.3

The mean farm size for the whole sample was 1.6 acres (0.73 hectares) and was significantly ($p<0.05$) lower in Kakamega than in Siaya County respectively. The study also investigated land ownership rights. Land rights are essential in enhancing or reducing investment on land. About 65% of the households had freehold land ownership without title deeds, while nearly half (47%) had freehold land ownership with title deeds, whilst 94% of the households inherited the land they owned. With regard to ownership of agricultural tools, most widely owned was hand hoes (Table 13).

Table 13 Percent house hold ownership of agricultural tools in Kakamega and Siaya Counties

Asset	Siaya (N=80)	Kakamega County (N=80)
Hand hoe	98.1	100.0
Wheel barrow	39.8	23.8
Ox-plough	3.9	34.3
Ox-cart	0.0	0.2

Another important indicator of wealth was the type of housing. Two types of house roofs were identified: corrugated iron sheets (66% for Kakamega and 49% for Siaya Counties respectively); while grass thatched (34% for Kakamega and 51% for Siaya) (Table 14). Burnt bricks were found, 19% of households in Siaya and 51% in Kakamega County.

Table 14 Materials in percent for main household houses in Kakamega and Siaya Counties

Materials	Siaya County (N=80)	Kakamega County (N=80)
Roof:		
Iron sheets	49	66
Grass	50	34
Wall:		
Bricks/Blocks	19.4	49.6
Mud	80.6	50.4

4.2.2 Financial capital

This is a form of asset that could contribute to both production and consumption in the household. Components include cash and cash related property. For example, smallholders often maintain stocks of animals they could rely on in periods of scarcity. These non-working livestock are life-supporting assets to the poor. They form part of the financial capital that enhances the quality of life as they have the potential to generate quick cash to owners when there is an urgent need for money; they can feed humans with meat/milk and add manure to the soil. They are also a source of security to the smallholders who depend heavily on such assets during periods of unexpected partial or total crop failure. In addition, they are symbols of social recognition. The most common types of livestock assets were chicken (owned by 94% and 72%, cattle (76%) and 61%, and small ruminants (41% and 52%) of the households in Kakamega and Siaya Counties respectively.

4.2.3 Human capital

This analysis showed that family labour represented the major source of power in the studied systems. Nearly 75% of the households cited household labour as the most important source of agricultural labour, followed by hired (23%) and pooled (2%) labour sources. The importance of family labour as a source of labour supply could be attributed to low incomes of smallholder farmers that constrain financial liquidity for hiring labour. Therefore, lack of adequate labour accompanied by inability to hire labour could seriously hamper the adoption of technologies.

4.2.4 Social capital

Membership in community associations offered tremendous opportunities to boost agricultural production by providing various forms of support to farmers. The respondents (160) pointed out that they belonged to diverse community associations, some belonging to only one while others belonging to more than one association. Overall, 85% (160) of the households had at least one member who belonged to a group. Most frequently cited groups were religious (33%), savings /merry go round (17%) and community social welfare (14%).

4.2.5 Household livelihood strategies

The major source of livelihood for 69% of households in the study sites was in farming, followed by a private sector wage employment, and casual non-agricultural employment (Table 15). Other non-farm income generating activities that were of importance were business and teaching. The number of households involved in these activities was higher in Siaya compared to Kakamega County.

4.3 Farmers awareness of crop production constraints

Most of the respondents in the two Counties were aware of the soil fertility constraint but not the soil acidity problems as a result most farmers were passively willing to participate in the demonstration trials involving the promotion of lime. However the few farmers from Kakamega County who had some prior knowledge of lime (Mbakaya, 2007), accepted their farms to be used for demonstrations but farmers from Siaya County who had no prior knowledge preferred multi nutrients fertilizers over lime which they thought was rejected cement collected from Mombasa port and that this could spoil their farms.

Table 15 Percentage of most important occupations of the household members in Kakamega respondents (N=80) and Siaya (N=80) Counties

Livelihood strategy indicators	Siaya County (%)	Kakamega County (%)
Farming	68.9	77.1
Private sector employee	10.7	4.7
Casual labor in non-agriculture	9.7	2.9
Petty businesses	3.9	5.7
Teaching	1.9	3.8
Casual labor in agricultural sector	1.9	3.8
Civil servant	1.0	2.0

Notes: *Strategies were listed independently; hence the total % does not sum to 100*

With the farmers limited knowledge on soil acidity; it was noted that the need for sensitizing the communities and wide scale soil testing to determine the acidity levels and ranges to identify farms that qualify for liming was essential. The survey team also observed that the promotion of lime with multi-nutrient fertilizers would best be carried out as part of a ‘holistic’ program to improve agricultural production. The approach includes use of improved seed, recommended rates of fertilizer application, and adherence to sound agronomic practices.

Realizing that the strategic stakeholders, Agro dealers, farmer associations, Non-Governmental Organizations (NGO’s) and other extension agents are instrumental in influencing the farming activities of the small-scale farmers, the team proposed that they be incorporated. In particular the activities of the strategic stakeholders would include; stocking of agricultural inputs (e.g. fertilizer, seed and pesticides), training farmers in agronomic practices (e.g. crop rotation, diversification, and crop management and soil conservation), post-harvest technologies (e.g. grain storage) and facilitation and formation of farm groups/co-operatives.

4.3.1 Farmers' indicators for soil fertility depletion

Farmers have their own indicators for judging soil fertility status. Amongst the farmers who perceived soil fertility depletion, the most frequently cited indicators were visual, including low crop yields, presence of indicator weeds; especially witch weed (*Striga hermonthica)*, poor crop growth vigour, and soil colour (Figure 9). The finding of this study with regard to farmers' soil fertility indicators is consistent with the findings of similar studies (Mairura et al, 2008).

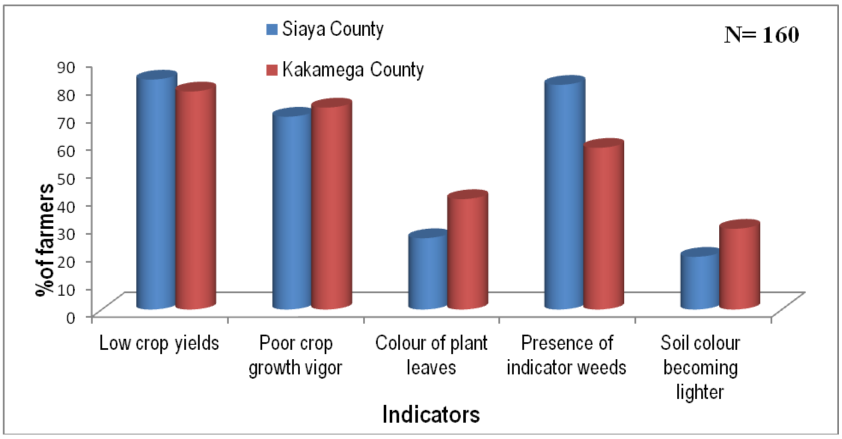

Figure 8 Indicators of low soil fertility in western Kenya

There were some convergences between farmers' and scientists' indicators of soil fertility with regard to visual indicators such as soil colour and crop performance parameters (e.g., Moges and Holden, 2007). Recent studies (e.g., Moges and Holden, 2007), have invariably shown that farmers' perceptions of soil fertility status match with laboratory measurements. Indeed, Moges and Holden (2007) contend that farmers' reliance on crop yields as a key indicator of soil fertility is consistent with current soil science paradigms which use yield as one of the best proxies for soil fertility. Thus, although few farmers in the study areas benefit from formal soil testing, they appear to have reasonably accurate appraisals of soil fertility based on local indicators.

The fundamental divergence between scientists’ and farmers’ indicators of soil fertility is based on how the indicators are derived and a range of parameters used. Whilst scientists conduct physical and chemical analyses to objectively measure soil nutrient levels, types of different soil nutrients, soil physical characteristics and other soil conditions such as acidity, farmers subjectively evaluate soil fertility status. Thus, soil fertility indicators from scientific testing are very important in deciding how to address specific soil deficiencies. Farmers’ perceptions of soil fertility are also holistic as they include factors they feel influence the soils and crop growth.. Therefore, the finding on farmers’ indicators underscores the value of taking into consideration farmers’ indigenous knowledge in soil fertility management studies as an important initial step in diagnosis of soil fertility problem. Moreover, the indicators could also be used as one of the definition tools for planning and formulating of research and extension agenda.

4.3.2 Farmers’ perception on causes of soil fertility decline

Farmers’ perceptions of causes of soil fertility depletion are presented in Figure 4.2. Lack of crop rotation due to land shortage, i.e small farm sizes was the most frequently cited as the cause of soil fertility depletion by 64% of the respondents. Other important causes included inadequate cash to buy mineral fertilizer (55%), soil erosion (43%) and inadequate supply of animal manure (43%). Incidentally, only 2.4% of the respondents did not know any cause of soil fertility decline.

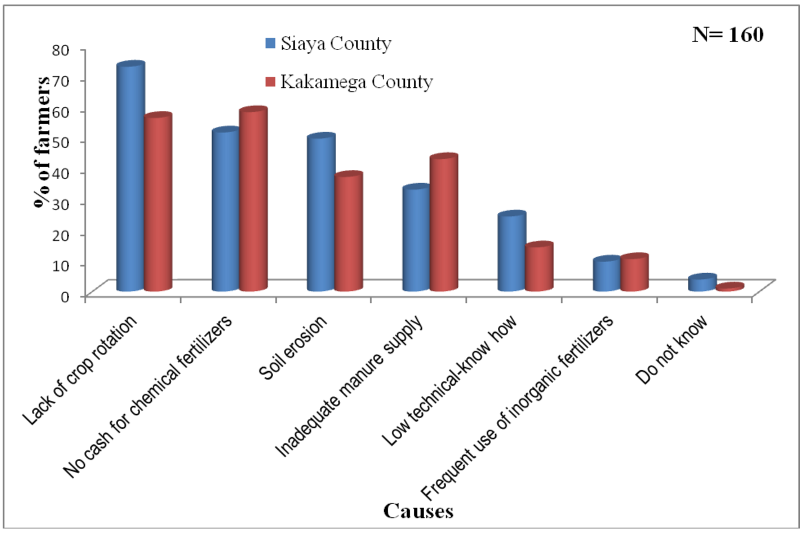

Figure 9 Perception of percent causes of low soil fertility in Kakamega and Siaya Counties

Note: Due to multiple independent responses, % does not add to 100.

4.3.3 Farmers' awareness and use of agricultural inputs

The study focused on adoption or use of crop-productivity enhancing inputs, mainly seed and organic and inorganic fertilizers. Farmers adopted various soil management strategies on their crops, especially maize. Knowledge of innovation was necessary in the first stage in the adoption process. It consisted of an individual becoming aware of a problem or developing a need to solve a problem, and then gaining knowledge of existence and workings of an innovation that might lead to problem resolution (Figure 11).

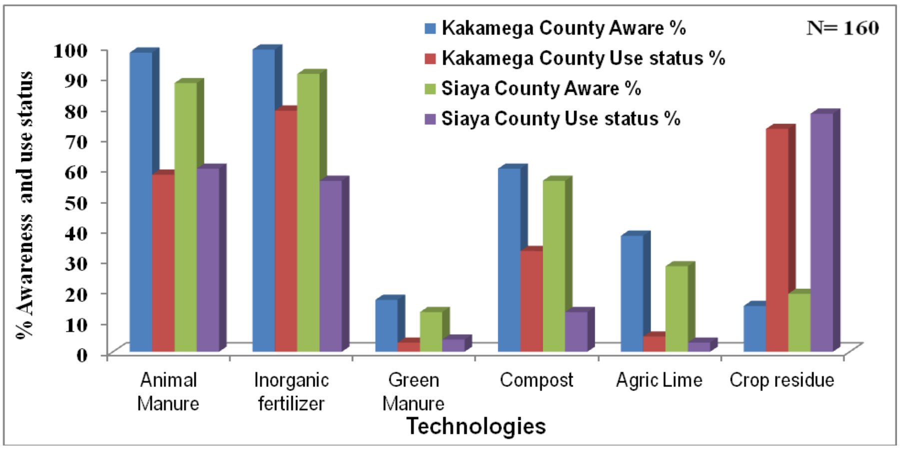

Figure 10 Awareness and use status of soil fertility management practices

From figure 4.3 above, it was observed that over 99% of the 80 the households in Kakamega County were aware of inorganic fertilizer in 2009; however, in Siaya County, 56% of the 80 households reported using inorganic fertilizer during the 2009 long rains. A relatively larger percentage of households (79%) in Kakamega County applied inorganic fertilizer, especially to maize. A few types of inorganic fertilizers were commonly used. The most frequently used basal fertilizer was Diamonium phosphate (DAP) whilst calcium ammonium nitrate (CAN) and Urea were the most widely used N topdressing fertilizers in maize and sugar cane respectively (Figure 12). Green manure was the soil fertility management practice farmers were least aware of.

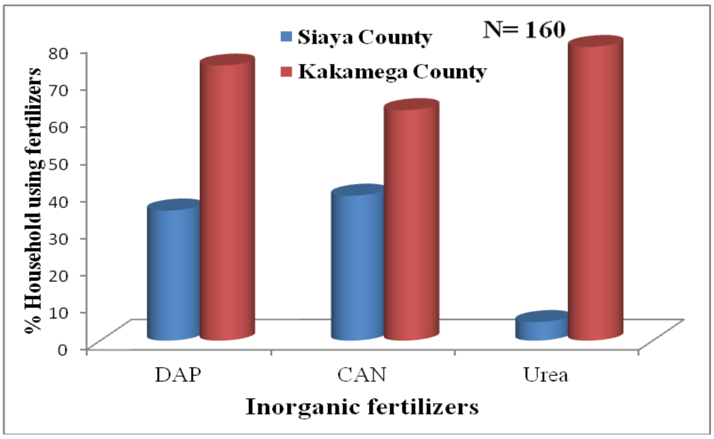

Figure 11 Percent households using different inorganic fertilizers in LR 2009

The rates of DAP fertilizer applied were not very low compared to the recommendation rates fertilizer use research project (FURP 1994): about 73 kg of fertilizer per ha for Siaya and 134 kg of fertilizer per ha in Kakamega County. The higher rate of Urea in Kakamega was due supply of it to contracted sugar cane farmers by Butali sugar company Similarly, the rate of CAN applied as top dress was low (Figure 13). Given that maize often requires rates of 90 to 120 kg N/ha to expect good yields of about 4–6 tons/ha, therefore the quantities applied by farmers in western Kenya were not as per the recommended rates (FURP 1994) but just symbolic where the farmers apply any amount as low as 25 kg per ha of fertilizer they could afford to purchase.

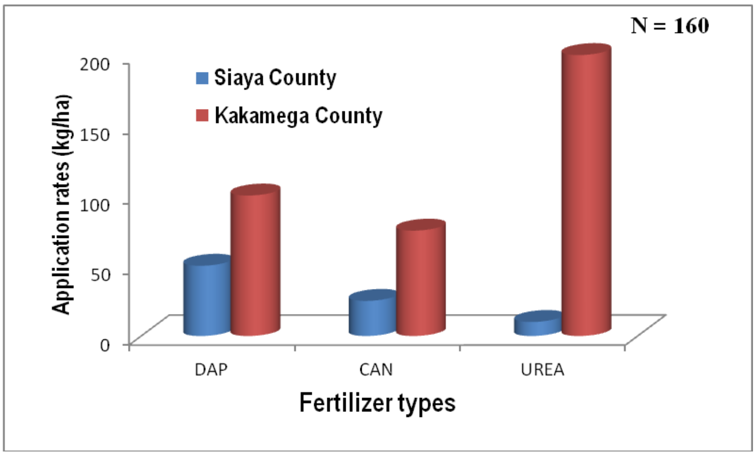

Figure 12 Application rates of inorganic fertilizer in Kakamega and Siaya Counties

4.3.4 Farmers use of improved seed in Kakamega and Siaya Counties

Seed was an important input in agriculture, and compared to fertilizers and labor, seed was the cheapest. However, farmers’ access to improved seed was constrained by availability of the right seed at the right time and price. With regard to maize varieties generally grown, about 66% of the whole sample mainly planted improved maize seed with the remaining planting local seed maize varieties (Figure 4.6). The improved seed refers to certified seed, particularly of maize and beans sold legally on the market. The results also suggest that most households (93%) in Kakamega County used improved maize seed varieties while about 46% of the households in Siaya County used improved maize seed varieties. This variability explains why more households in Siaya County frequently face food shortages every year than households in Kakamega County. Estimated uptake of improved seeds, fertilizers and lime progressively increased from 2008 to 2012 in both Counties (Table 16).

Table 16 Estimated uptake of improved seeds, fertilizers and lime 2008-2012 in Kakamega and Siaya

Variable	2008	2010	2012	% Change 2008-2012
Number of agro- dealers*	1	2	8	500
Improved seeds access by farmers (tons)	105	708	1,706	300
Fertilizer access by farmers (tons) **	584	1,356	3,078	400
Lime access by farmers (tons)	74	6,000	28,500	>1000
Areas under fertilizer (ha)	4, 672	8,580	26,664	470
Area under lime (ha)	75	3,768	15,476	>1000

**Number of agro dealers stocking lime; **sum of the amount of fertilizer applied during planting and topdressing; 2008 values are based on baseline survey carried out in July-August 2009*

In Kakamega County, it was observed that there were many Agro dealers closer to the SHF who at the same time provided advisory services. This was contrary to Siaya County which had limited/ no agro dealers. The few that were there did not provide advisory services to SHF. They were basically business people. With regard to crop varieties generally grown, about 66% of the whole sample mainly planted improved maize seed with the remaining planting local seed maize varieties (Figure 14).

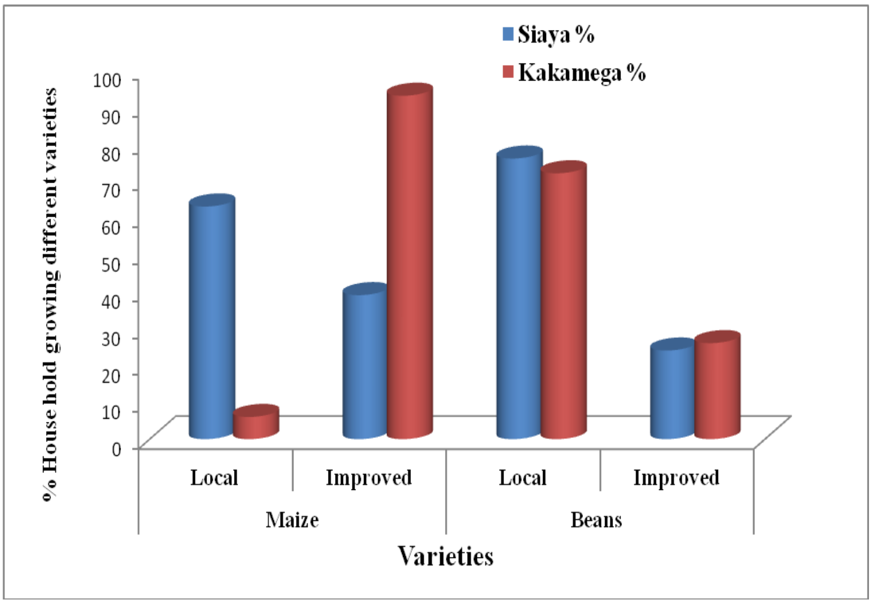

Figure 13 Percentage households growing different varieties of maize and beans in 2010 LR

The demand for lime resulted in agro dealers' start stocking lime and large quantities of other farm inputs as fertilizers and seeds. This demand was as a result of the awareness created through capacity building of farmers and expansion of hectares under lime use. More agro dealers stocking farm inputs made it possible for more farmers access improved seeds, lime and fertilizers.

4.4 Major crops in study sites.

A wide range of crops is grown in western Kenya. Maize and beans are grown by most households in both Counties; while sorghum and cassava are predominant in Siaya. Maize was grown by almost all the surveyed households, with an exception of sugar cane 85% in Kakamega County only, beans by 82%, and sweet potato by 59%. Others were cassava (53%) and sorghum (39%) (Table 17). Maize is the staple food in western Kenya and this most probably explains its high prevalence.

Table 17 Six major crops in Kakamega and Siaya Counties

Crop	% reporting of respondents		
	All (N=160)	Siaya (N=80)	Kakamega (N=80)
Maize	97	100	99
Beans	82	90	76
Sugar cane	81	5	92
Sweet potato	59	52	66
Cassava	53	78	30
Sorghum	39	78	2

(N stands for number of households per site)

4.5 Food availability

Frequency of food shortages in the households is a good indicator for measuring household vulnerability. It projects the extent to which households are exposed to other risks such as the need to dispose assets as a coping strategy. The frequency of food shortages during the year is given by the number of months that farmers experience food shortages. A large proportion of farmers reported that they experience food shortages in their households (Figures 15 and 16). In Siaya County 69.6% of the households while 49.8% in Kakamega County reported that they experienced food shortages every year.

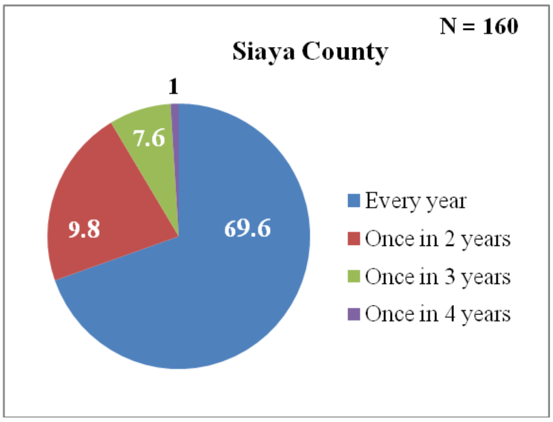

Figure 14 Frequency of households facing food shortages in, 2004-2009 in Siaya County

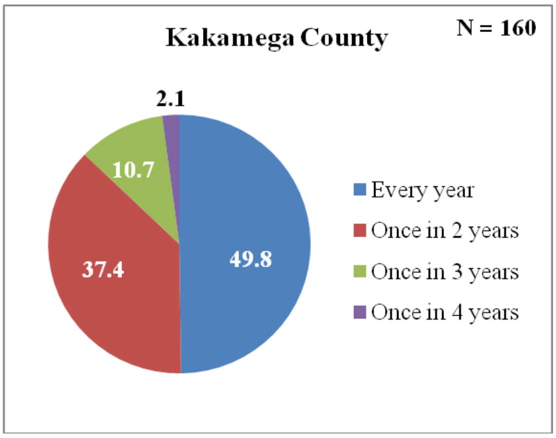

Figure 15 Frequency of households facing food shortages, 2004-2009 in Kakamega County

During focus group discussions, SHF attributed food shortages to different constraints among the major ones as *Striga*, low soil fertility, lack of funds to buy inputs, termites, moles, stem borer in maize, bean root rot and unreliable rainfall. When the SHF was asked to rank the constraints, they ranked the constraints as shown in (Table 18), with *Striga* being the major constraint in Siaya County only.

Farmers were asked how they solved some of the constraints they faced, especially with regard to low soil fertility and Striga. Farmers are aware of some technologies to manage *Striga* and soil fertility improvement like hand uprooting of the weed, application of manure, use of inorganic fertilizers, use of improved seed variety KSTP94 maize, and use of terraces to control soil erosion. However, the use of animal manure was low because of few livestock. Likewise the rate of inorganic fertilizers use was low in both study sites because of liquidity constraints.

Another opportunity was that several organizations collaborated with farmers in the study sites in order to increase agricultural productivity. These include KALRO-

KAPP, Ministry of Agriculture - Extension Services, AGMARK (NGO), Church and Provincial administration. The Church and Provincial administration were two groups mainly identified with farmers in the area. These groups could play a central role in sensitizing and disseminating soil acidity management technologies in the study sites. In addition, climatic conditions have a high to moderate agricultural productivity potential, thus favoring moderate crop productivity to help reduce hunger and alleviate poverty.

Table 18 Ranking of constraints to increased agricultural productivity Kakamega and Siaya Counties in Western Kenya

Constraints	**Ranking by respondents**	
	Siaya County (N=80)	**Kakamega County (N=80)**
Striga	1	**-**
Low soil fertility	2	1
Lack of funds to buy inputs	3	2
Termites	5	5
Moles	6	4
Stem borer in maize and bean root rot	7	6
Unreliable rainfall	4	3

5.0 Site characterization and synergies or additive effects of combining lime with fertilizers on soil properties

5.1 Site morphology and characterization

The understanding of the nature, properties, dynamics and functions of the soil as part of landscapes and ecosystems is a basic requirement in any soil. The availability of reliable information on soil morphology and other characteristics obtained through examination and description are important. Thorough soil description serves as the basis for soil classification. A good soil description and the derived knowledge on the genesis of the soil are powerful tools to guide, help explain and regulate the costly laboratory work.

5.1.1 Description of soil profile No.1: Kakamega County

The pit was excavated on Atsango's farm, Chemoroni area, about 5 km east of Malava Township in Kakamega County. Chemoroni lies between latitude 00° 26' and 00° 52' N and longitude 34° 52' and 34° 59' E at a mean elevation of 1,200 metres above the sea level. The soils of this area had varying parent materials, geologically formed from Kavirondian shales (Sombroek, *et al*, 1982), Jaetzold and Schmidt, (1983).

The key site characteristics included: physiography thus the sloping end of the western side of Nandi hills. The surrounding landform was the gentle slope towards westwards with a potential drainage density of 0 -25. The meso- relief was part of Nandi hills complex slope with gradient of 2 – 3%. The area is located in Agro-climatic zone Upper Midland one (UM1) to transition Lower Midland one (LM1). The main land use is subsistence farming and local livestock keeping. Cultivated crops include maize, finger millet, bananas, sweet potatoes, cassava, sugar cane and assorted fruit trees. In addition to cultivated food crops, the land cover composes of native and exotic Eucalyptus trees from South African and Cyprus trees. After following the protocol for site characterization (Appendix 4) the soil in the area was classified as Ferralo Humic, Acrisol, (Serrem, personal communication).

5.1.2 Description of soil profile No.2: Kakamega County

The pit was excavated in Tumbeni area on Indombela’s farm, about 3 km south east of Malava Township, Kabras East location in Kakamega County of western Kenya. Tumbeni lies between latitude 00° 26' and 00° 52' N and longitude 34° 52' and 34° 59' E at a mean elevation of 1,100 metres above the sea level.

The site characteristics included: physiography thus the sloping end of the western side of Nandi hills. The surrounding landform was flat/ level land to gentle slope sloping southwards with a potential drainage density of 0 -25. The meso- relief was the flat part of a complex end of Nandi escarpment with gradient of less than 1%. Generally the area is located in Agro-climatic zone Lower Midland one (LM1), with the Kavirondian shales as parent material. The main land use is subsistence farming and local livestock keeping. Cultivated crops include maize, finger millet, bananas, sweet potatoes, cassava, sugar cane and assorted fruit trees. In addition to cultivated food crops, the land cover composes native and exotic Eucalyptus trees from South Africa. After following the protocol for site characterization (Appendix 5) the .general soil in the area was classified as Ferralo Humic Acrisol, (Serrem, personal communication).

5.1.3 Description of soil profile No.3: Siaya County

The profile was in Nyangela village on Isaac Okwanyi’s farm in North Ugenya location, Ugenya sub County, Siaya County. The pit was about 600 metres south west from Got Nanga centre along Busia-Kisumu road. It was at an elevation of 1250 m ASL and at latitude of 0^0 03^1 N and longitude of $34^0 25^1$ E. The general area had an undulating topography.

The site characteristics included: physiography of the area was gently sloping southwards towards a dry valley. The surrounding landform was level to gentle slope sloping southwards. The meso- relief was a gentle slope southwards towards the dry valley with a general gradient of 3 - 4%. Generally the area is located in Agro-climatic zone Lower Midland one (LM1), with the basalt (past volcanic activity). The main land use is crop farming and local livestock keeping. Cultivated crops include maize, finger millet, bananas, sweet potatoes, cassava, local vegetables, tomatoes and assorted fruit trees like Avocados and pawpaw. In addition to cultivated food crops, the land cover composes native grass and trees. After following the protocol for site characterization (Appendix 6), the general soil in the area was classified as Orthic Acrisol, (Serrem, personal communication).

5.1.4 Description of soil profile No.4: Siaya County

This profile pit on John Owoko's farm was located in Got Nanga area about 400 m south of Got Nanga market along Busia – Kisumu road in Ugenya sub County, Siaya County. The area lies between latitude 0^0 03' N and longitude of 34 ^{0}25' E at an altitude of 1240 metres above sea level. The site characteristics included: physiography of the area was slightly undulating westwards. The surrounding landform was generally undulating. The meso- relief was a gentle slope westwards with a general gradient of 1 - 2%. Generally the area is located in Agro-climatic zone Lower Midland one (LM1), with Kavirondian shales. The main land use is crop farming and local livestock keeping. Cultivated crops include maize, ground nuts, finger millet, sorghum, sweet potatoes, cassava, local vegetables, tomatoes and assorted fruit trees like oil palm, avocados and pawpaw. In addition to cultivated food crops, the land cover composes native grass and trees. After following the protocol for site characterization (Appendix 7), the general soil in the area was classified as Orthic Acrisol, (Serrem, personal communication).

5.2 Soil Analysis

5.2.1 Soil Analysis results of Kakamega and Siaya Counties

The mean physical and chemical characteristics are presented in (Table 19). The results revealed that the soils in the study sites were predominantly acidic in nature, the Acrisols and Ferralsols. Based on soil texture (hydrometer method), sand was the dominant proportion (Appendices 8a and b). Based on soil texture results, soils in Kakamega County site were classified sandy loam and in Siaya County sandy clay loam

Results of soil pH analysis by 1:2.5, soil: water method showed that mean soil pH values were 5.01 in Kakamega and 4.91 in Siaya. These pH values indicate that soil acidity was significantly higher in Siaya County than in Kakamega County. It was noted that 94% of the 160 farms sampled (80 in Kakamega County and 80 Siaya County), recorded strongly acidic pH (pH 4.91- 5.23) with only 6% of those 160 farms recording moderate to moderately acidic (pH 5.23- 5.46) soils. A clear pattern of soil pH and hence soil acidity was evident in the study areas, (Figure 17) especially in cultivated fields that regularly receive inorganic fertilizer (Appendix 8c).

Table 19 Mean physical and chemical characteristics of soils in the study sites in Kakamega and Siaya Counties (0 – 20 cm depth)

Parameters	**Sampling sites**	
	Kakamega County	Siaya County
Soil pH (w) (1:25)	5.01	4.91
Available P (ppm) (Olsen)	5.23	3.01

Organic Carbon (%)	1.86	1.25
N (%)	0.19	0.14
Ca (Cmol/kg)	2.89	2.75
Mg (Cmol/kg)	1.16	1.10
K (Cmol/kg)	0.55	0.45
Al (cmol/kg)	1.85	1.67
% Al saturation	55.3	43.2
Sand (%)	70	60
Clay (%)	10	30
Silt (%)	30	10
Textural Class	Sandy Loam	Sandy Clay Loam
Soil Class	Orthic Acrisol	Ferralo Humic Acrisol

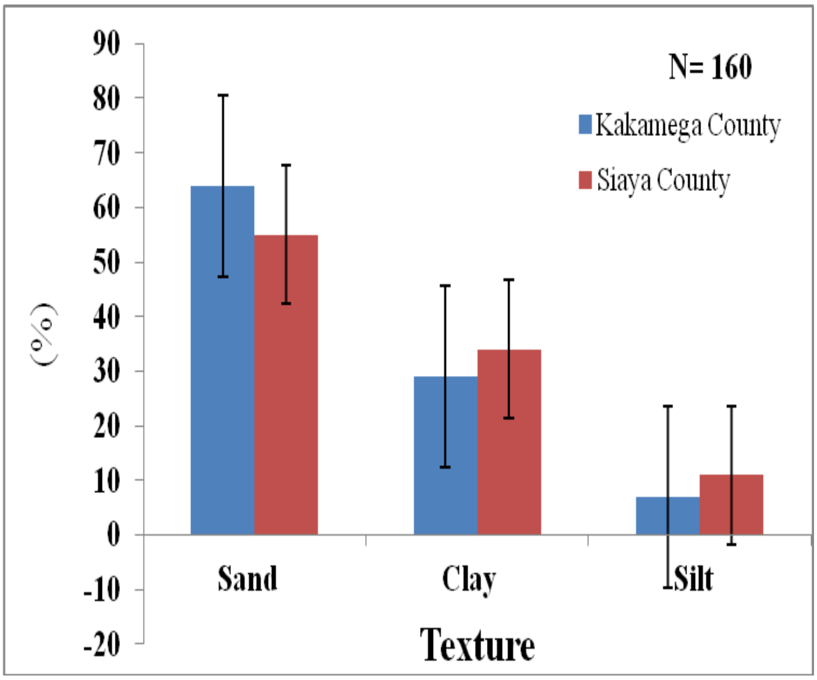

Figure 16 Soil texture in Kakamega and Siaya Counties

5.2.2 Soil total organic carbon (TOC) and nitrogen (TON)

High variation in soil total carbon was observed across Kakamega County study site (Figure 18). The values ranged from 1 to 5.9%. A critical look at the carbon variation showed that 17% and 37% of the farms sampled (Table 20) in Kakamega and Siaya respectively had low (<2.0%) TOC levels, corresponding to less than 2.0% soil organic matter (SOM). Despite variation in trend of different types of soils, scientists generally agree that 2% soil organic carbon (SOC) (ca. 3.4% SOM) is a critical threshold below which potentially serious decline in soil quality will occur (Pretty, 1998). The observations were in line with the findings of earlier researches by Pretty, (1998). Considering the above threshold, about 55% and 88% of farms in Kakamega and Siaya Counties respectively were considered having SOM below the critical level, hence are at a threat of soil degradation if not well managed.

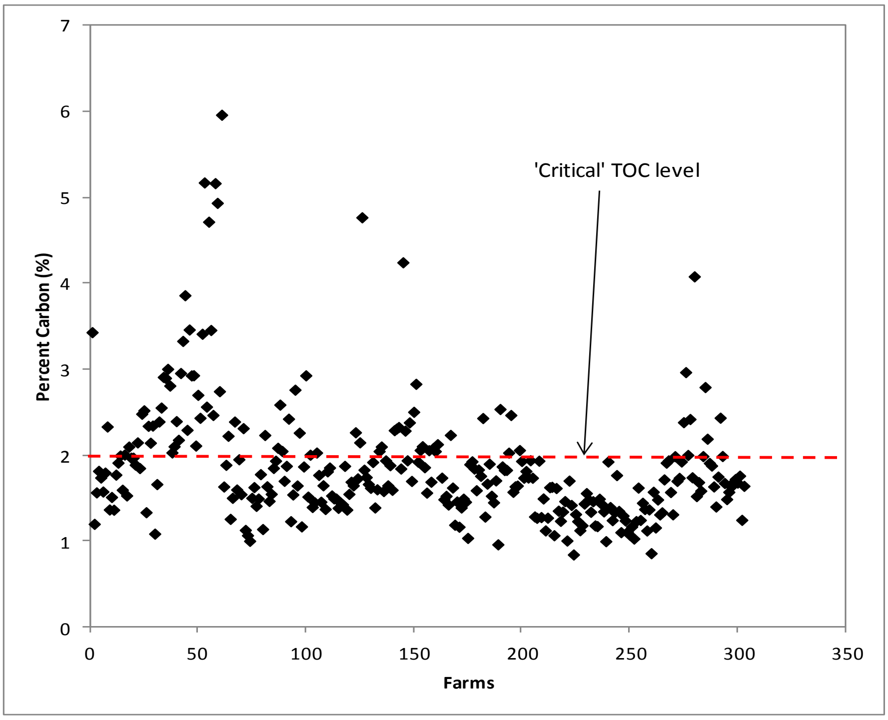

Figure 17 Total Soil Carbon (TOC) variation across farms in Kakamega County

Table 20 Total Organic Carbon (TOC) ratings across farms in Kakamega and Siaya Counties (N=160)

Total Organic Carbon (TOC)	Carbon Rating	Proportion of farms (%)	
		Kakamega County	Siaya County
>3%	High	8	1
2.0 – 3.0%	Moderate	55	42
< 2.0%	Low	17	37
Total		80	80

SOC also varied with land use. In Kakamega County for example, forest or areas adjacent to forests (north- Malava Forest) recorded the highest TOC up to 4% compared to 1.9% TOC for most cultivated areas. The pattern of TOC varied depending on other factors such as soil type, pH, CEC among others (Appendix 8d).

5.2.3 Effect of lime application on soil pH in Kakamega and Siaya Counties

The initial soil analysis results of September 2009, showed that in all plots before lime was applied, the soils were strongly to medium acidic ranging from as low as pH 4.91 to as high as 5.23. On average, the soil pH was 5.01 in Kakamega County and 4.91 in Siaya County. Thereafter, soil pH was analysed at four month intervals with the last soil analysis being carried out in August 2011, two years from the start of the experiment (Figure 19). The soil pH results in those plots which received 2 tons of lime had gone up to mild acid of pH value of 5.59 in Kakamega and 6.45 in Siaya by April 2010, eight months after lime application, an improvement of 19% in Kakamega and 32% in Siaya County. Overall, liming increased soil pH by approximately 0.58 to 1.34 units in eight months before it started dropping. On the other hand, pH in plots that were not limed in 2009, their soil pH minimally improved by 4.5% in Kakamega County and by 0.22% in Siaya County respectively.

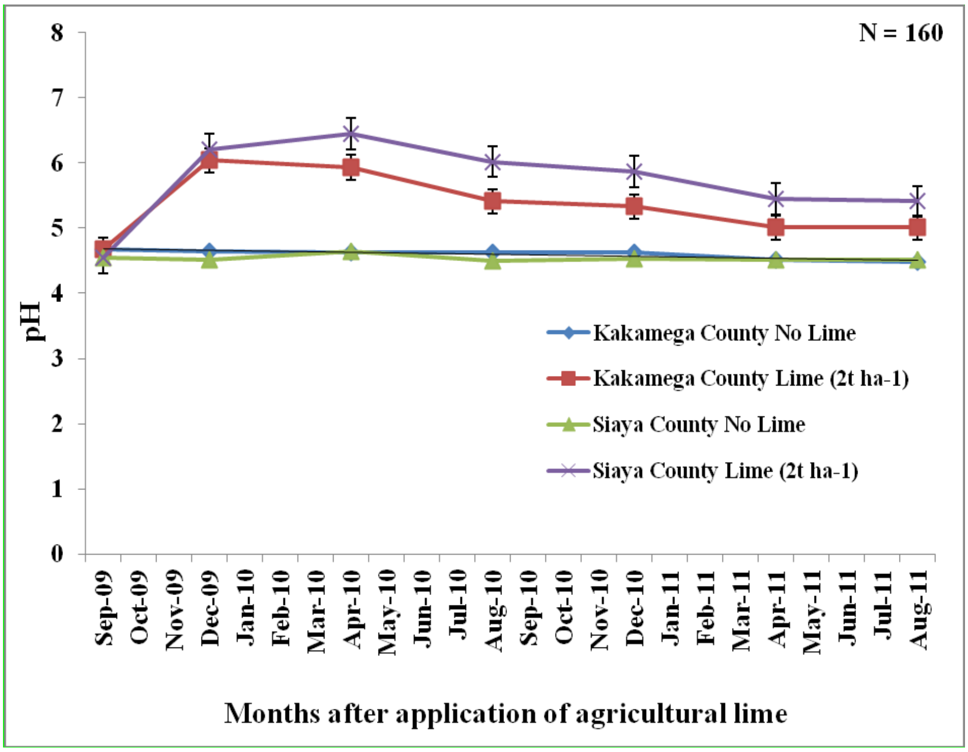

Figure 18 Soil pH changes over time after the application of lime in Kakamega and Siaya Counties

5.2.4 Effects of lime on Organic carbon changes in Kakamega and Siaya Counties.

Most of the farms in the study sites had Organic carbon content ranging from 1.01 to 1.88%, with an average of 1.86% which was inadequate at the start of the study in 2009. On average, soil Organic carbon was 1.86% in Kakamega County and was 1.24% in Siaya County. All trial plots had received 2 tons ha^{-1} of lime. Two years later in 2011, it was observed that in the plots that lime was applied and crop residues left in the plots, the soil organic carbon had gone up to 3.88% an increase of 1.52% in Kakamega County and 4.34% increase of 3.09% as shown in (Figure 20).

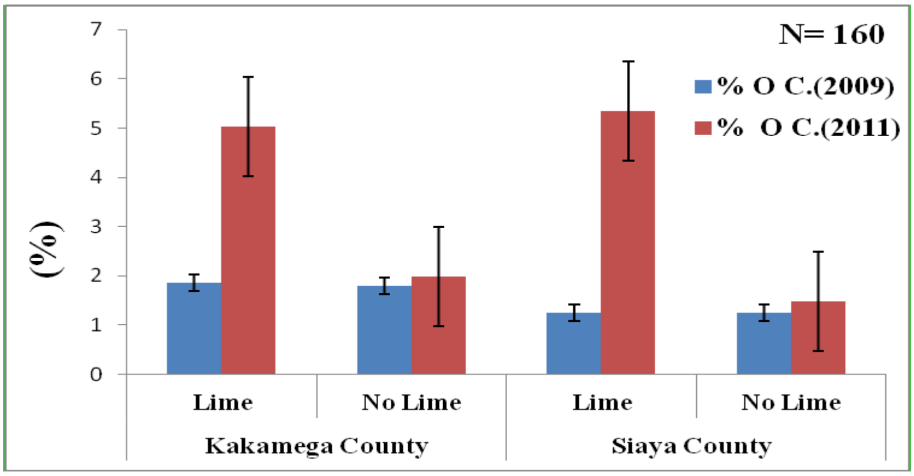

Figure 19 Effects of lime on organic carbon in Kakamega and Siaya Counties

5.2.5 Effects of lime on available phosphorus content in soils in Kakamega and Siaya Counties.

Most of the farms in the study sites had soil phosphorus (P) ranging from 1.03 to 1.87 ppm which was inadequate at the beginning of the study in 2009. All trial plots received 2 tons ha^{-1} of lime and crop residues left in the plots except the control plots which also had no application of P prior to the start of this trial in September 2009. Two years later in August 2011, it was observed that in the plots that received 2 tons ha^{-1} of lime and crop residues left in the plots the soil P had gone up from 5.23 to 7.88 ppm, an increase of 2.63 ppm in Kakamega County (Appendix 8c) and 3.01 to 5.20 ppm an increase of 2.19 ppm in Siaya county (Figure 21)However, studies elsewhere reported conflicting views on the effects of liming on P availability in highly weathered acidic soils. Some found Agricultural liming increased (Dalal, 1986), decreased (Anjos and Rowell, 1987) or had no effect (Miranda and Rowell, 1987) on the extractability or availability of soil P. These authors further reported that effects of lime on P availability therefore depended on the extent to which P was sorbed by reactions with exchangeable Al and absorbing surfaces and soil type.

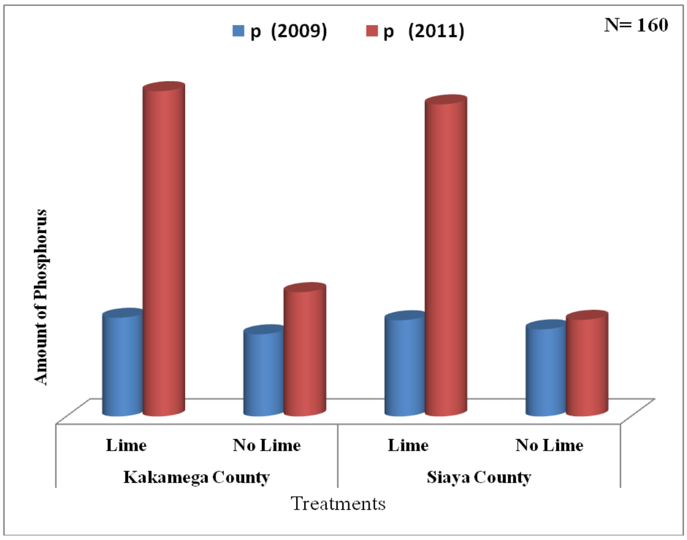

Figure 20 Effects of lime on phosphorus in Kakamega and Siaya Counties

6.0 Effects of combined lime and inorganic fertilizers on maize production in Kamega and Siaya counties

6.1 Maize grain size by weight

Grain weight was a measure of the extent to which individual grains accumulate dry matter. This was calculated by weighing 200 maize seeds from each treatment per site. There was a positive improvement in the grain weight with fertilizers and lime use. In Siaya County the best grain weight was 112g per 200 seeds where lime plus fertilizer had been applied. The same scenario was in Kakamega County where the best grain weight was 121g per 200 grain from lime plus fertilizer plots.

The differences in weights could have been due to soil fertility and pH variation. The supply of nitrogen and phosphorus by DAP increased crop yield, but even a better crop yield was observed in plots where Mavuno was used. It is important to note that, plants require both macro and micro nutrients for healthy growth. The most commonly used fertilizers by SHF like DAP and CAN (top dress) contain only 2 macro nutrients. In contrast, Mavuno contains 11 nutrients both macro and micro nutrients. As soils become acidic and deficient in K, Ca, Mg, S and other micro nutrients, it is important that all these deficiencies are corrected, for better plant nutrition when soil pH is increased to pH ranges of 5.5 to 6.5. The ability of Mavuno to simultaneously supply a variety of nutrients (basic cations included) explains the better crop performance under Mavuno relative to DAP application.

6.1.1 Stover yield per season in Kakamega and Siaya Counties

The results of stover yield of maize showed that both Kakamega County and Siaya County had the lowest mean stover yield in 2009 short rain season and highest in 2011 long rain season, (Figure 22).

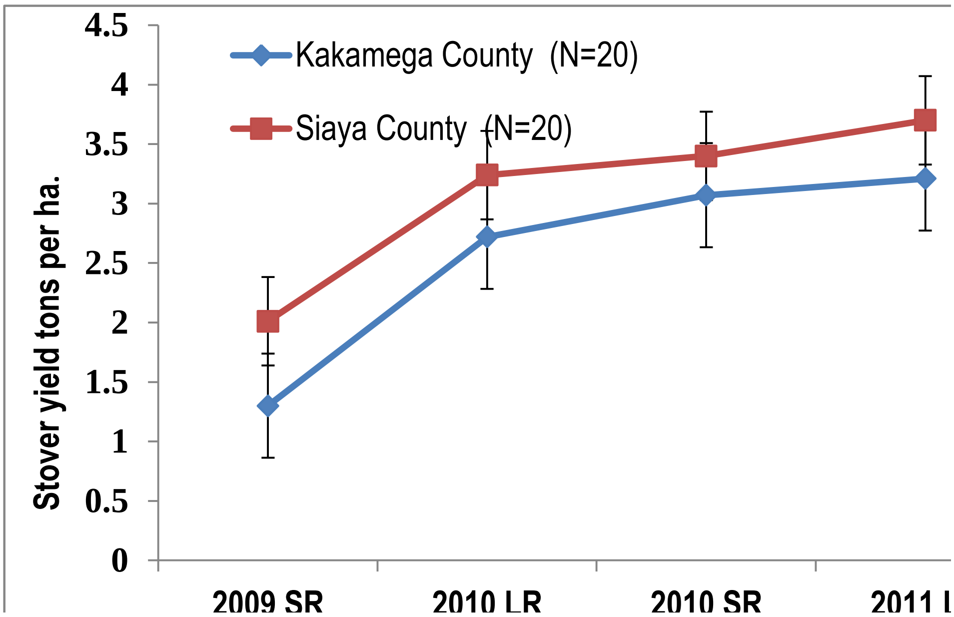

Figure 21 Mean stover yield, 2009 short rains -2011 long rains in Kakamega and Siaya Counties

Key: SR09 – Short rains, 2009; LR10 – Long rains, 2010, SR10 – Short rains, 2010 and LR11 – Long rains 2011

The low stover yield was attributed to low pH, low and poor rainfall distribution in 2009. Low pH affect intake of nutrients. Application of lime in 2009, there was progressive increase in stover yields with cropping seasons. This was mainly due to improvement of some soil characteristics which enhanced soil fertility. For example, two years after one season application of lime in the short rains of 2009, soil pH improved from pH 4.91 to 6.45. This improved pH enhanced the availability and accessibility of plant nutrients like P for better maize growth resulting in increased stover yield. Also there was fair to good rainfall both in amount and distribution in 2010 and 2011 which was above the long term normal long rain season in the two counties, (Sections 3.11 and 3.12 (Figures 3.2 and 3.3). However, on average Kakamega county had significantly lower stover yields than Siaya County ($p<0.05$) throughout the study period.

6.1.2 Maize grain yield in Kakamega County

From Figure 23, maize grain yields from control treatment plots were significantly different ($p<0.05$) from other treatments in Kakamega County. Based on treatments; Mavuno and DAP remained high and control the lowest. In comparison among the seasons, yields progressively increased with subsequent seasons. The yields were lowest during short rains of 2009 that ranged between 0.5 and 0.9 t ha^{-1} and highest in long rains of 2011; that ranged between 1.2 to 4.9 t ha^{-1}. For all the four seasons, maize yield was lowest in the control treatment relative to all the other treatments. The maize yields in the control plots never exceeded 0.9 t ha^{-1}. Incorporating lime in the plots with no additional amendments enhanced maize crop yield increase by approximately 0.32 and 1 t/ha. Maize yield from Mavuno fertilizer plots was always higher than yield from DAP plots. Yields from fertilizer based treatments (i.e. Mavuno and DAP either with or without lime application) were always more than 3 folds higher than yield from the control and lime only in the four seasons. This was manifested by an increase of up to 3.5 and 3.7 t ha^{-1} for DAP and Mavuno fertilizer respectively relative to the control (Appendices 9). A comparison between fertilizer plus lime and fertilizer minus lime treatments for each season separately and across the seasons suggested no significant effect due to lime application where either Mavuno fertilizer or DAP was applied together with lime. Although maize yield increases in DAP and DAP with lime did not attain statistical significance, from SHF point of view, there was an increase in maize yield from DAP plus lime plots compared to DAP alone plots.

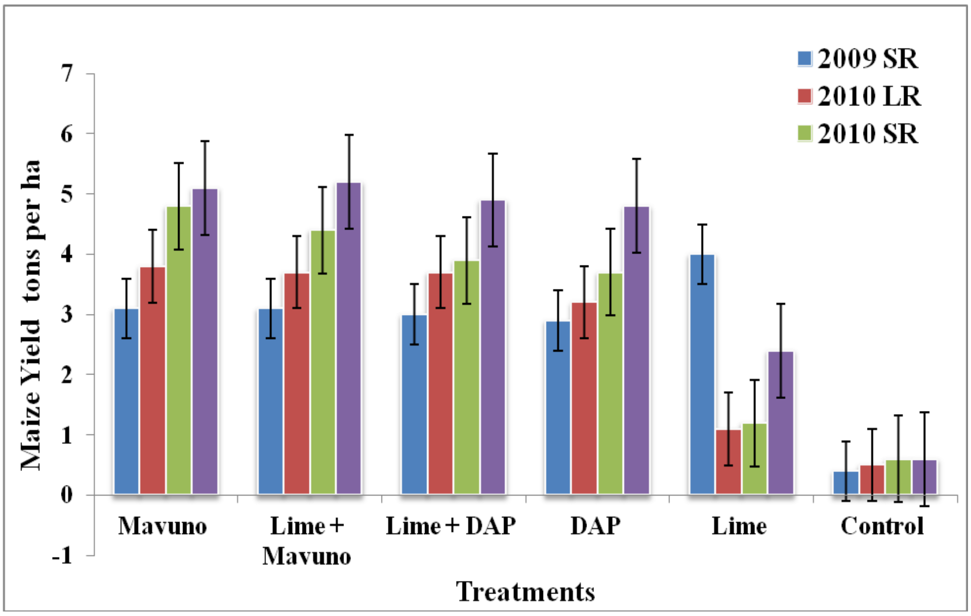

Figure 22 Mean maize yields (t/ha) grown under various fertilizer and lime, 2009 short rains to March 2011 long rains cropping seasons in Kakamega County

Key: SR09 – Short rains, 2009; LR10 – Long rains, 2010, SR10 – Short rains, 2010 and LR11 – Long rains 2011

6.1.3 Maize grain yield in Siaya County

The treatment and season effects on maize grain yields in Siaya County were significantly ($p<0.05$), Figure 24. Based on treatments Mavuno and DAP remained high and control the lowest, while maize grain yields progressively increased with subsequent seasons. The grain yields were lowest during the short rains of 2009 that ranged between 0.4 and 0.8 t ha^{-1} and highest in the long rains of 2011; that ranged between 1.64 and 4.8 t ha^{-1}. For all the four seasons, maize yield was lowest in the control treatment compared to all the other treatments. The maize yields in the control plots never exceeded 0.8 t ha^{-1}. Incorporation of lime in the plots with no additional amendments enhanced maize crop yield increase by approximately 0.32 and 1 t/ha. Irrespective of the seasons, maize yield from Mavuno fertilizer was always higher than the yield from DAP plots. Yields from the fertilizer based treatments (i.e. Mavuno and DAP either with or without lime application) were always more than 3 folds higher than yield from the control and lime only in each of the four seasons after lime application. This was manifested by an increase of up to 3.3 and 3.5 t ha^{-1} for DAP and Mavuno fertilizer respectively relative to the control. A comparison between multi nutrients fertilizer + lime and multi nutrients fertilizer (without lime) treatments for each season separately and across the seasons suggested no significant lime effect in scenarios where either Mavuno fertilizer or DAP was applied together with lime. Although maize yield increases in DAP only and DAP with lime did not attain statistical significance, from SHF point of view, there was an increase in maize yield from DAP plus lime plots compared to DAP alone plots. This was also demonstrated by the maize performance during 2011 long rain seasons. (Appendices 10) show the performance of maize grown under various fertilizer and lime and maize cobs increase in size as a response to liming with addition of multi nutrients fertilizers. However the performance of maize grown under various fertilizers and lime and increase in size as a response to agricultural liming with addition of fertilizers was not as dramatic where lime alone was applied compared to control.

The implications of the improved production on maize yields hence household food security and incomes were as a result of the adoption of fertilizer (Mavuno and DAP) with lime. Seasonal yields for each of the two study sites and their annual on-farm yield were 4.99 tons ha^{-1} in Kakamega County and 4.8 tons ha^{-1} in Siaya County for Mavuno fertilizer with lime plots. Compared to farmer practice, where annual yields were between 0.9 and 1.2 tons ha^{-1}, the maize yield increase attributable to Mavuno fertilizer and lime was more than 300%.

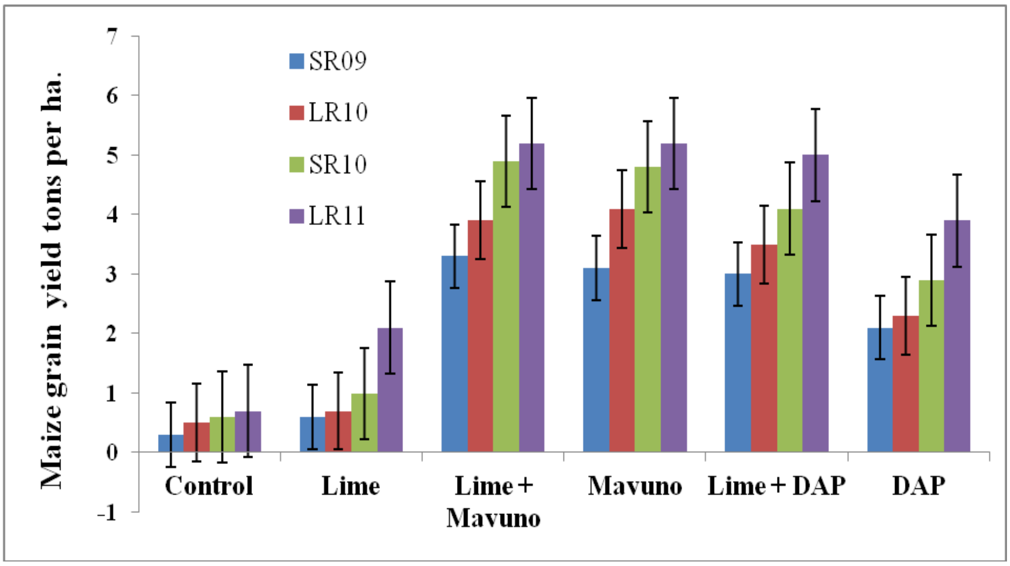

Figure 23 Mean maize yields (t/ha) grown under various fertilizer and Lime, 2009 short rains to 2011 long rains cropping seasons in Siaya Counties

Key: SR09 – Short rains, 2009; LR10 – Long rains, 2010, R10 – Short rains, 2010 and LR11 – Long rains 2011.

6.1.4 Harvest index (HI)

It was noted that there was wide variation in the harvest index (HI) that ranged from 0.36 to 0.76) (Table 21) among the treatments in Kakamega and Siaya Counties. Work elsewhere by Pennington, (2013) showed that in normal years, the harvest index was generally around 0.50. With application of lime with DAP or Mavuno fertilizers, higher crop yields were achieved resulting in highest harvest index. Within the same year, variations in the harvest index were recorded from the two Counties. The variations were due to the variability in soil types, rainfall distribution and amounts and management of the maize crop.

Table 21 Mean harvest index (HI), 2009 to 2011 in Kakamega and Siaya Counties.

Year	Location	Grain (T ha^{-1})	Grain + Stover (T ha^{-1})	Harvest index (Grain + Total Biomass)
2009 SR	Kakamega	1.1	2.62	0.42
2009 SR	Siaya	0.6	1.67	0.36
2010 LR	Kakamega	1.67	2.79	**0.60**
2010 LR	Siaya	1.17	2.09	0.56
2010 SR	Kakamega	3.11	4.09	**0.76**
2010SR	Siaya	2.58	3.74	**0.69**
2011 LR	Kakamega	4.0	6.25	**0.64**
2011 LR	Siaya	3.77	6.18	0.61

7.0 To evaluate striga weed growth response to lime and fertilizer use in Ugenya sub county

7.1 Striga population counts in the field

The results of the of *Striga* counts per treatment showed remarkable variations. The mean *Striga* counts from control plot had the highest counts followed by plot two (lime alone) and was significantly different with all other plots except plot two (lime only (p=0.05). Mean *Striga* counts from fertilizer based plots (plots 3,4,5 and 6) were not significantly different ($p<0.05$) from each other though some variations were observed Plate 6.

Plate 6 Taking Striga counts in the field

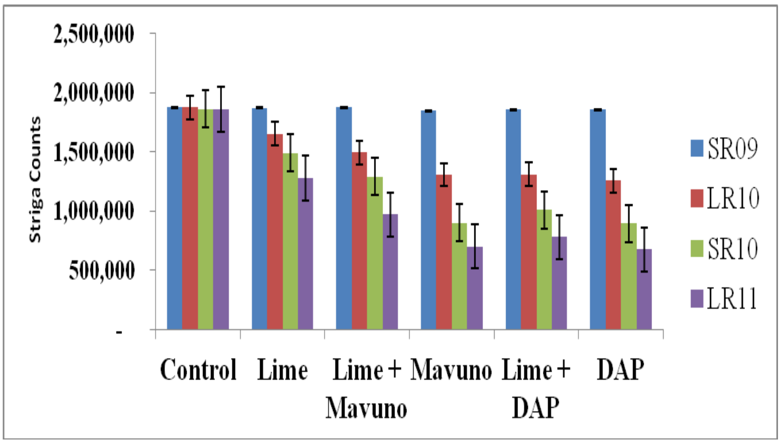

Figure 24 Mean *Striga hermonthica* counts per treatment per hectare

These differences could be attributed to the nitrogen and phosphorus from fertilizers and calcium from calcium oxide (CaO) that may have enhanced the vigorous growth of maize. Since *Striga* depends on the host for its growth, the application of CaO may have caused a micro environment that led to a change in *strigol* chemical compound that was not recognized by *Striga*. Also the vigorous growth of maize in plots that received fertilizers may have suppressed *Striga* causing a delay in the *Striga* emergence and growth. The decline in *Striga* infestation with lime and fertilizer application observed in this study could be related to the suppressive N effect on *Striga* growth and development. The results were comparable and in agreement with the past findings (Esilaba, 2006) that reported that *Striga* infestation declined with increasing N availability.

The excitement of SHFs' was associated with observed *Striga* reduction in limed plots (back part of plate 7). Striga infestation could cause maize yield losses as high as 100% in highly-infested fields in the region (Vanlauwe et al, 2008). In the case of this study, the *Striga* counts were lower by approximately 57% in limed plots with fertilizer relative to unlimed control plots. The mechanism by which this happened is now a subject of future studies. The project supported by Alliance for Green Revolution in Africa (AGRA) is currently supporting an MSc student to do research on the mechanisms lime uses to reduce *Striga* population.

Plate 7 Limed plot 95% cover of good maize (back) and unlimed plot less than 30% cover of poor stunted maize in (front) due to *Striga* on Owoko's farm, Got Nanga, Siaya County. (Source: Author, 2010)

7.1.1 Striga germination counts in KARI Kakamega Laboratory

The laboratory results of the three treatment showed that pot (1) the control had least *Striga* germination. The mixture of sterilized sand, 10 g of lime + host (Maize) pots (2, 3 and 4) had the highest *Striga* germination/ emergency. The mixture of sterilized sand, 10 g of lime and 10 g of multi nutrient fertilizer with host pots (5, 6 and 7) had average *Striga* emergency. This could be attributed vigorous growth of maize that did not favour Striga attachment (table 22).

Table 22 Percentage germination of *Striga* hermonthica in the Laboratory

Reps	**Treatments**						
	Sterilized sand, no host, no lime and no multi nutrients	Mixture of sterilized sand, 10 g of lime + host (Maize)			Mixture of sterilized sand, 10 g of lime and 10 g of fertilizer with host		
			Pots				
	1	2	3	4	5	6	7
Rep 1	0	33	31	34	23	26	22
Rep 2	2	37	36	37	25	24	24
Total	2	70	67	71	48	50	46
Mean	1	35	34	36	24	25	23
Grand mean	1	35			24		
% Germination	2%	70%			48%		

7.2 Effect of Striga on maize growth parameters

7.2.1 Effect of Striga on maize height

It was observed that in all non-lime treatments; the maize leaves were small, scorched, (plate 8) and severe stunting and drought-like symptoms (Plate 9) such as leaf margin curling also indicate *Striga* infection (Parkinson, *et al*, 1985), compared to the lime with multi nutrients fertilizer added treatment, (plate 10). The lime and non-lime (control) treatments showed earlier flowering with significant reduction in maize stem height due to *Striga* infestation (Appendix 11). The observation was similar to the findings by Khan *et al*,. (2007) who conducted field trials during the long (March-August) and short (October-January) rainy seasons of 2003 and 2004 at the International Centre of Insect Physiology and Ecology (ICIPE), Thomas Odhiambo Campus, Mbita point in Hama Bay County, on the eastern shores of lake Victoria shores.

Plate 8 Scorched maize leaves a characteristic of *Striga hermonthica* infection (Source: Author, 2010)

Plate 9 Stunted maize due to *Striga* infestation on control plots, Jowi's farm Ugenya Sub County 2010. (Source: Author, 2010)

Plate 10 Good maize with no *Striga* where 2 t/ha of lime was incorporated and multi nutrients fertilizer on Achieng's farm, Ugenya, Siaya County
(Source: Author, 2010)

7.2.2 Effect *of Striga* on yield and yield components

In this study it was observed that *Striga hermonthica* attaches to maize roots and start sucking nutrients, resulting in crop yield loss ranging from 15 to 100% per cent depending upon severity of infestation. Similar results were obtained by Lagoke *et al,* (1991). Rao *et al,* (1989a) also quoted the yield losses in rain fed crops in western Kenya varied from 30 to 80 per cent depending upon the severity of *Striga* infestation.

Generally the results of this study also revealed that *Striga* significantly reduced grain yield and all other yield components considerably see plates 7.3 and 7.4.

In treatment plots that lime was applied with addition of fertilizers, the yield of maize was not affected (see Section 6.4.1, Figure 6.3). The maize grew vigorously and the *Striga* emerged to the soil surface when the maize crop was at the silking stage. The *Striga* therefore had no chance to affect maize (Plate 7.5) because it emerged when maize was at silking stage.

When Striga attaches itself to the maize roots at the ninth leaf of maize growth, it starts drawing water and nutrients (Appendix 12). With time the maize begins to be stressed. When maize is stressed at flowering because of deficits of water, light and nutrients, ear growth slows in relation to tassel growth and the anthesis-silking interval (ASI) increases. This appeared to be a general response by the plant in control plots to a reduction in photosynthate formed during this growth stage. This finding was similar to that of Edmeades, *et al*, 2000. Therefore, the growth and emergence of maize silks has a considerable importance in the determination of yield of stressed maize crop under water deficit and nutrient deficient. Thus when soil water deficit occurs before flowering, silk emergence out of the husks is delayed while anthesis is largely unaffected, resulting in an increased anthesis-silking interval (ASI) (Edmeades *et al*, 2000).

8.0 An economic evaluation to assess suitability, potential adoption and profitability of integrated soil fertility management (ISFM)

8.1.1 Economic Analysis

A cost benefit analysis showed that the benefits of using lime varied depending on location, maize prices, and the acidity of the soil. Small-scale farmers living close to the source of their inputs, farming highly acid soils and can realize a high price for their maize; will see the greatest increase in their incomes. Farmers living a long distance from the source of their inputs, farming moderately acid soils and could only realize a low price for their maize would have greater costs and a smaller increase in their income.

In general, the study findings show that: the application of lime was highly profitable except where there was little response to liming of the soil and the farmers were remote from markets. In a good season, where the maize prices reached US$200 per ton, the use of lime was worthwhile even on the less acidic soils.

8.1.2 Cost Benefit Analysis

The use of lime could lead to maize yield increases in the range of 3 to 5 tons per hectare (section 6.4.3 tables 6.3 and 6.4). The economic benefits to SHF's were summarized as the Value Cost Ratio (VCR). The VCR was determined by subtracting the cost of using lime with multi-nutrient fertilizers from the value of the additional crops grown. The VCR was a simple method of evaluating the economic benefits of using lime with multi-nutrient fertilizers.

The economic benefits to the small-scale farmer which were visualized by use of Benefit/Cost procedures while assuming an exchange rate of 1 dollar = Ksh 80 was summarized as the Value Cost Ratio (VCR). The VCR was determined by subtracting the cost of using lime with multi nutrient fertilizers from the value of the increased yield and cultivation of other crops varieties grown as a result of improved soil pH and other nutrients.

The cost of lime was Kenya Shillings Six thousand (Ksh. 6,000) (US$ 75) per ton. Income generated through the sale of surplus yields was at least double the cost spent on using lime. Where a farmer realized a relatively high price for the additional maize yields bought lime and expanded the area, he/she earned up to 12 times the cost incurred in buying the lime and multi-nutrient fertilizers. Conversely, the farmers' income from farms where the farmers did not apply lime with multi-nutrient fertilizers, the earnings from the sale of maize continued to reduce. Therefore, use of lime with multi-nutrient fertilizers was found to be economically beneficial to the small-scale farmer in the study sites.

Although there was a demonstrable economic benefit in the use of lime with multi-nutrient fertilizers, its use ultimately depended on the small-scale farmer's purchasing power, knowledge and the perceived profitability, closeness and availability of lime in sufficient amounts. Therefore, an important criterion in the decision to establish rural agro-dealers in the villages to stock lime depends on these factors.

8.1.3 Value Cost Ratios

The benefits of using lime varied greatly. Small-scale farmers who lived closer to the source of their inputs, farming acid soils could realize high price for their maize and would realize greatest increase in their incomes. But farmers living a long distance from the source of their inputs, farming acid soils could only realize a low price for their maize as greater transportation costs led to smaller increase in their income. The VCRs of the first farmer would be higher than those achieved by the second farmer. Therefore the application of lime was highly profitable except where there was little response to liming of the soil and the farmer was remote from markets. In good seasons, where the maize prices are high, the use of lime was worthwhile.

8.1.4 Financial performance of various treatment options

Financial analysis was conducted for all the four seasons' data (Table 23) and Gross financial returns were highest in Mavuno-based treatments, intermediate for DAP-based treatments, low for lime and lowest in the control. Lime + Mavuno, Mavuno and DAP + Lime treatments were approximately 2 times more expensive than sole lime. Due to less input and labour costs, control was the cheapest treatment. Notwithstanding the low cost, the benefit/cost ratio of the control was less than 1 indicating that farmers would not be able to meet the cost of production if they continued using the farmers' practice. On the other hand, the benefit/cost ratio of Lime was only 1.1, implying that by application of lime without inclusion of fertilizer, farmers would meet the cost of production, but not make profits. Land owners would make the highest profits of Shillings 60 per every Shilling they invested by adopting multi nutrient fertilizers like Mavuno that has 25% CaO and lime with DAP.

Table 23 Effect of various soil amendments on maize production and house hold financial performance, 2009-2011 cropping season in Kakamega and Siaya Counties

Treatment	TR (Ksh)	TVC (Kshs.)	NPV (Kshs)	B:C ratio
(Mavuno)	211031	85068	125963	2.2
2 tha^{-1} Lime + Mavuno)	202432	94049	108383	2.2
2 tha-^{1} Lime + DAP	178357	94339	84018	2.0
DAP	183212	98830	84381	1.9
2 tha-^{1} lime	83780	75659	8121	1.1
Control	60236	70433	-10198	0.9

Key: TR= Total revenue TVC= Total Variable Costs NPV= Net profit Value B: C=Benefit Cost ratio

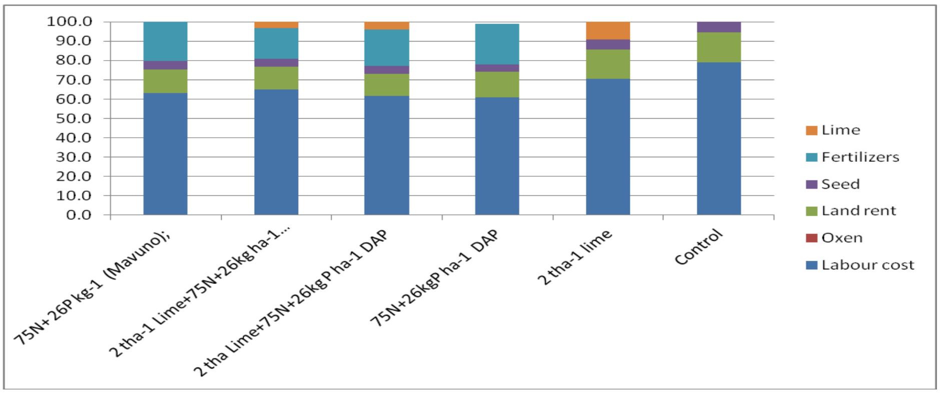

Figure 25 Percentage share of treatment cost components (Labour: 36-49%, Fertilizer: 20-29%, Seed: 5.5-8.2%, Lime: 3.8-5.7%)

CHAPTER FIVE

DISCUSSION

5.1 Baseline Survey on Socio economic characteristics of smallholder

Demographic and socioeconomic characteristics play a key role in the determination of livelihoods of farm households of rural people in Kakamega and Siaya Counties. With the farmers' limited knowledge on soil acidity, it was noted that the need for sensitizing the communities and wide scale soil testing to determine the acidity ranges and levels to identify farms that qualify for liming was essential. The survey team also observed that the promotion of lime with multi-nutrient fertilizers would best be carried out as part of a 'holistic' program to improve agricultural production. The approach includes use of improved seed, recommended rates of fertilizer application, and adherence to recommended agronomic practices.

The fundamental divergence between scientists' and farmers' indicators of soil fertility is based on how the indicators are derived and a range of parameters used. Whilst scientists conduct physical and chemical analyses to objectively measure soil nutrient levels, types of different soil nutrients, soil physical characteristics and other soil conditions such as acidity, farmers subjectively evaluate soil fertility status. Thus, soil fertility indicators from scientific testing are very important in deciding how to address specific soil deficiencies. Farmers' perceptions of soil fertility are more holistic as they include factors they feel influence the soils and crop growth than those of researchers. Therefore, the finding on farmers' indicators underscores the value of taking into consideration farmers' indigenous knowledge in soil fertility management studies as an important initial step in diagnosis of soil fertility problem. Moreover, the indicators could also be used as one of the definition tools for planning and formulating of research and extension agenda.

5.2 Site characterization and synergies or additive effects of combining lime with fertilizers on soil properties

The results showed changes in soil properties as a result of fertilizer and lime additions. The soil pH had increased from 4.91 in September 2009 to 5.23 after two years of lime application. A clear pattern of soil pH was observed an evidence of pH improvement in the study areas. Generally phosphorus (P) in soil increased from 1.38ppm to 6.55ppm in Kakamega and from 1.45ppm to 4.1ppm in Siaya respectively in two years (2009 – 2011) with lime application. The same scenario was observed with soil organic carbon which increased from 1.86% to 3.88% % in Kakamega and from 1.24% to % to 4.34 in Siaya in two years (2009 – 2011). The results disapproved our hypothesis that stated that there could be no significant additive effect of combining lime with fertilizers changes to soil characteristics.

5.3 Effects of combined lime and inorganic fertilizers on maize production in Kakamega and Siaya counties

In this study the use of 2 t ha^{-1} lime to improve soil pH and use of multi nutrient fertilizers that enhance crop yields had different results from what was expected. However, liming at a rate of 2 t ha^{-1} maintained high maize yield for two years after one application during 2009 short rain season. These results agree with findings by Singh, Pal and Arora (1987) at Kontagora and Yandev Nigeria. The supply of nitrogen (75kg) and phosphorus (26kg P) by DAP increased crop yield, but even a better crop yield was observed where Mavuno equivalent of nitrogen (75kg) and phosphorus (26kg P) fertilizer was applied because the micro nutrients it had.

The variation was observed as plants require adequate macro and micro nutrients for their healthy growth (Miriam 2012). In acid soils, some nutrients such as phosphorus are fixed. The most commonly used fertilizer by SHF in the study sites was DAP that contains only 2 macro nutrients N and P of which P is fixed. In contrast, use of Mavuno that contains some lime and 11 nutrients both macro and micro nutrients benefit the soil. In acid soils micro nutrients frequently become deficient so use of Mavuno fertilizer blend corrects the deficiencies for better plant nutrition. Also with continuous use of Mavuno, soil pH is improved. Therefore in this study, the addition of lime enhanced increases of soil pH that made the fixed P available to the maize hence improved yields. Therefore the ability of Mavuno fertilizer to simultaneously supply a variety of nutrients (basic cations included) explains the observation of a better crop performance under Mavuno relative to DAP application by the farmers though there were not significantly different ($p<0.001$).

Soil acidity and associated problems such as aluminium (Al) toxicity, phosphorus (P) and nitrogen (N) deficiencies can reduce yields. In this study the control and lime alone without addition of multi nutrients, the yields remained significantly low and this concurs with the findings of Kanyanjua *et al*, (2002).

Despite the magnitude of the soil acidity problem and the observed responses from the application of lime in western Kenya, the use of lime is still low. This is mainly due to its unavailability, lack of awareness of its importance and mode of application by the farmers as well as limited extension messages reaching the SHFs'. Lime application should be viewed as high capital investment but with high returns in the future. Combined interventions, including some public subsidy and greater awareness creation in the use of lime are essential. Creating demand among the SHF is therefore essential in stimulating the agro-dealers to invest and stock this valuable resource so that SHF can easily access it.

Liming increased soil pH ranging between 0.9 and 1.46 units in both sites. Inclusion of lime, as a soil amendment and other nutrients increased maize crop yield ranging between 1.9 and 3.5 t ha^{-1}. Although such yield response may appear small, farmers were nevertheless excited by this effect especially in plots that previously yielded very little.

5.4 Evaluation of Striga weed growth response to lime and fertilizer use in Ugenya sub county

The application of 2 t ha $^{-1}$ lime in combination with fertilizers significantly suppressed *Striga* germination and or emergence. T*he Striga* population per treatment differed. But there was significant difference $p< 0.05$ between control and all other treatment except lime only ($p < 0.5$). The Striga population reduction in no lime and fertilizer, lime only, lime + Mavuno fertilizer, Mavuno only, Lime + DAP and DAP only was (0.8%), 42%, 54.6%, 48.2%, 50.2% and 49.1% respectively. Lime changed pH level disorienting the growth pattern of *Striga* and disrupting chemical composition of exudates from maize that trigger the germination of Striga. The emergence of *Striga* in the lime and fertilizer based plots took longer days, a mean of 41 days compared to 14 days in control plots after planting. In control plots, Striga infestation resulted in maize grain yield loss was between 20 to 100% but in plots where lime and fertilizer were applied maize grain yield loss was low 10 to 30%. This finding was comparable to those of Rao et al. (1989a) who quoted yield losses of 30% in rain fed crops in western Kenya. Based on these findings, *Striga* could be significantly controlled by incorporating lime in combination with multi nutrient fertilizers.

5.5 An economic evaluation to assess suitability, potential adoption and profitability of integrated soil fertility management (ISFM)

Generally findings of economic evaluation in this study showed that: the application of lime with fertilizers was highly profitable except where there was less response to liming of the soil and the farmers were remote from markets. With the average maize price of Kenya Shillings thirty thousand (Khs. 30,000) per ton at harvesting in 2011, the use of lime was worthwhile even on the less acidic soils. The benefits from using lime with multi nutrient fertilizers varied depending on location, maize prices, and the acidity of the soil, SHF's living closer to the source of their farm inputs, realized high returns if maize prices remained constant. On the other hand, farmers living far from the source of their farm inputs realized low returns as part of the expected income is used on transporting inputs. However, these low returns could improve if SHFs' purchase their inputs in bulk to reduce transport costs.

To alleviate food insecurity in the country, SHF should understand the production constraints and strategize. Most SHFs in the study sites do not carry out farming as a business because they do not understand the root causes of their low economic empowerment. The lack of economic empowerment of SHFs' led to food insecurity. Therefore, these interventions to improve economic empowerment are unlikely to succeed in moving the SHFs' out of food insecurity due to inadequate information shared with SHFs'. To influence changes in the economic empowerment for SHFs' one needs to take into account a framework that considers the relationship between internal and external influences on the households to their livelihood outcomes.

The survey (GOK, 2010), showed that a household of 5.5 persons feed on approximately 1 ton of maize per year (Denning et al., 2009). This study lime with fertilizer improved maize between 3,5 and 3.7 t ha^{-1}. Therefore a household adopting the use of fertilizer with 2 t of lime ha^{-1} could therefore produce on average sufficient maize (3.6 tons ha^{-1}) of which 1 tons/year would be for family consumption and remain with a surplus of 2.6 tons tons/year valued at approximately US$ 795 for sale. Financial returns to fertilizer + lime over the farmers practice with maize crop stood at US$ 815 /ha/year and the fertilizer + lime application was financially attractive (benefit-cost ratio of 2.2). By definition an intervention is financially attractive when its benefit-cost ratio is more than 2, implying returns of Ksh. 160 per every Ksh. 80 that is invested (Kaizzi *et al*,, 2011).

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

From the baseline survey, soil analysis, field experimentations as well as grain yield, the following are concluded

- There was a wide gap in many SHF fields, between the technologies SHFs know (heard/and or had seen) and what was actually put into use on their fields in the study sites. It was however, important to note that whether or not a household was aware of soil fertility management practice did not always determine the adoption decision. Situational constraints such as lack of financial resources to buy inputs and lack of technical information reduced the ability to use the practices. Conversely, a household could be unwilling to use the practices despite the perceived usefulness of the practices because of education levels, cultural, religious and other considerations.

- The differential endowment and education levels of SHF's greatly influence the adoption and management of resources. Effective communication and dissemination of ISFM information needed to be strengthened so that target recommendations are not constraint by illiteracy levels.

- Strategic stakeholders (agro dealers, farmer associations, Non-Governmental Organizations (NGO's) and other extension agents are instrumental in influencing the farming activities of the SHF, it is suggested that they be incorporated to give services as stocking and selling of agricultural inputs (e.g. fertilizer, seed and pesticides), training of smallholder farmers on agronomic effective practices (e.g. crop rotation, diversification, and crop management and soil conservation), post-harvest technologies (e.g. grain storage) and facilitation and formation of farmer groups/co-operatives.

- There being some convergences between SHFs' and scientists' indicators of soil fertility with regard to visual indicators and fundamental divergence between scientists' and farmers' indicators of soil fertility based on how the indicators are derived and a range of parameters used.

- Application of lime alone increases soil pH but do not significantly improve maize yield without additional fertilizers. In this study application of lime alone was always closer to farmers practice (control). This study finding agrees with early studies elsewhere in Africa (Lagoke *et al.*, 1991) whose data obtained from liming experiments in other parts of Africa have shown that addition of lime alone is insufficient to rehabilitate poor or depleted soils

- Increased use of inorganic fertilizers alone can exacerbate soil acidity problem so a combination of lime and inorganic fertilizers is the most efficient technique of addressing the problem of soil acidity and enhancing soil fertility.

- Although the study demonstrated effects of lime use on maize crop, lessons learnt from the trials motivated farmers to try lime on other crops like sugarcane, banana, sweet potatoes and bean fields and the results were positive. In Kakamega County SHFs reported a 3 folds increase (from 4 to 12 tons/ha) in sugarcane yields where lime was incorporated into production of sugarcane.

- Use of lime rose from zero on sugar cane fields in 2009, to approximately 2,800 ha by end of 2011 upon noticing the positive impact of fertilizer-lime combination. The West Kenya sugar company in Kakamega started promoting widespread use of lime in sugarcane production with a target of reaching over 30,000 contracted sugarcane farmers.

- There was a significant difference ($p < 0.05$) in *Striga* population count between control and other fertilizer based treatments The nitrogen levels in the respective fertilizer for planting and top dressing attributed to this significance. The nitrogen influenced the *Striga* population as compared to the plots that received lime only and control plots that received no fertilizer and lime.

- CaO from lime had no significant ($p< 0.05$) influence on *Striga* population compared to the control plots that received no fertilizer and lime. The findings disapproved the hypothesis that stated that there was no significant additive effect of combining lime with fertilizers on maize crop yield and Striga growth in Kakamega and Ugenya Counties. In fact there was a significant ($p< 0.05$) effect of combining lime with fertilizers on maize crop yield and Striga growth reduction.

- The field and laboratory methods in *Striga* research trials were an important aspect. They allowed the observation of the individual processes of *Striga* development. Accurately quantifying *Striga* at various stages in its life cycle in the field was difficult like e.g. below-ground stages than the quantification of the above-ground stages. In this study, laboratory method gave the simplest way to get a relative (but not accurate) measure of the numbers of *Striga* plants at emergence, flowering, and mature stages.

- The field method through three counts at immediately prior to first weeding, at silking and at harvest were not strictly accurate because different *Striga* plants emerge, flower, and mature at different times. The early, mid and late-developing individuals were missed either at second weeding or after harvesting. Despite all these challenges, the results of this study found reduction in *Striga* infestation with the application of 2t ha^{-1} lime with fertilizers.

6.2 Recommendation

- Future studies should initiate and enhance collaboration with strategic stakeholders such as farm input manufacturers, financial institutions, distributors, agro dealers, farmer associations, Non-Governmental Organizations (NGO's) and extension agents. Enhanced collaborations are instrumental on availing services that include stocking of agricultural inputs (e.g. fertilizer, seed and pesticides).

- Capacity building is recommended to improve the high levels of illiteracy among the SHFs that constrain the change from normal farming to farming as a business and rate of adoption of ISFM technologies in the two study sites.
- The study further recommends that before implementation of any soil fertility study, site morphological and characterization be carried out to better understand the study sites. It is also recommend that since there are convergences between SHFs' perceptions of soil fertility by visual crop performance parameters and scientists' indicators of soil fertility, the two Schools of thought be synchronized and adopted as a guide to SHFs' who have no access to laboratories for formal soil analyses. This will be consistent with current soil science paradigms which use yield as one of the best proxies for soil fertility.

- The study also recommends that for economic growth and profitability to benefit SHFs living in acid soils of western Kenya and other areas of the country that have similar soil acidity problems, adopt combined use of lime with fertilizers and improved maize seed.

- Based on the profitability (benefit-cost ratio of 2.2), the study recommends adoption of the use of lime with fertilizers in acid soils as financial returns to lime+ fertilizer over the control (farmers practice) with maize crop stood at US$ 815 /ha/year

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APPENDICES

Appendix I: Questionnaire: Baseline Survey on the use of Lime to enhance Soil Health for Increased Crop Production in Acid Soils of western Kenya

I: GENERAL INFORMATION

1.1 District------------------------Division-----------------Location----------------

1.2 Sub-Location------------------------Village--------------------------------------

1.3 Agro ecological zone ---

1.4 Name of the respondent --

1.5 Sex of the respondent 0= female---------- 1=male

1.6 Name of interviewer --

1.7 Date of interview---

1.8 GPS reading Latitude----------------Longitude-------------Altitude------------

II. DEMOGRAPHIC CHARACTERISTICS AND LIVELIHOOD STRATEGIES

2.1. Household and farm characteristics

S/No.	**Household member name (start with hh head)**	**Relationship to hh head** *1 =Head,* *2 =spouse* *3= Son/ daughter* *4=Parent* *5= Brother/sister* *6 = Grandchild* *7= In law* *8 =Employee* *9 =Other*	**Year of birth**	**Gender:** male= 1 female =0	**Highest level of education** *1-None* *2-Primary* *3- Secondary.* *4-College.* *5- University* ***(Include actual years completed e.g 1-8 for***	**Informal education** *1. None* *2-Adult Education* *3-Farm training, 4- Artisan training*	**Most important occupation **(see code)**	**Second important occupation **(see code)**

		relatives 10=Others--------			***class 8 in primary)***			
1								
2								
3								

Occupation codes: 1= Farming 2= Civil servant 3= Teaching 4=Private sector employee 5= Casual laborer in agricultural sector 6=.Casual laborer-non-agriculture 7 =none (applicable to 2nd most important occupations and preschool-age children only) 8 Student (children actually going to school) 9 Child (of school going age not in school) 10= others (specify) _______________

2.2. What type of household is this? 1=monogamous 2=polygamou

2.3 In which year did this household start farming on this farm? ---------------

2.4. Has your household suffered food shortages in the past 5

years? 1. Yes 2. No ***If "no", go to section III!***

2.5 If yes, what is the frequency of food shortages?
1. Every year, 2. Once in 2 years, 3.Once in 3 years, 4. Once in 4 years,
5. Once in 5 years

2.6. In case the household has suffered food shortages, what were the minimum and maximum hunger periods in a year?

Minimum: 1.__________ weeks 2. __________ months 3. Cannot remember

Maximum 1.__________ weeks 2. __________ months 3. Cannot remember

III. OWNERSHIP, ACCESS TO AND USE OF ASSETS

3.1. Which materials were used to construct the main household house?

(Enumerator to be shown main house and then records)*!*

3.1a**. Roof**: 1. Corrugated iron sheets, 2=Tiles 3= Concrete, 4. Asbestos sheets, 5=Grass 6=Tin, 7=Others (specify)____________________

3. 1b**. Wall:** 1. Brick/Blocks 2. Stone 3=Mud 4=wood 5=corrugated iron sheets 6=Grass 7=Tin, 8=others (specify) _________________

3.1c. **Floor:** 1=Cement 2=Tiles 3=Wood 4=Earth 5=Others (Specify)______________________________

3.2. How many parcels of land does your household presently have access to? (*State acres, tenure and the year of acquisition of each land parcel*).

Parcel No.	Acres	*Method of acquisition	**Tenure	Area cultivated	Year of acquisition	Area rented out (Acres)
1.						
2.						
3						
Total					▨	

***Method of acquisition**1 = Inherited 2 = Bought 3 = Govt settlement 4 = Rented-in 5 = other (specify)

****Tenure:** 1= Freehold with the title 2=Freehold without title 3=Leasehold 4=Communal 5=others (specify)____________

3.3. Do you possess any of the following assets? If you own any, please indicate the number owned.

Asset	**Number**
Radio	
Television	
Bicycle	
Motor vehicle	
Landline phone	
Mobile phone	
Ox-plough.	
Hoe	
Wheel barrow	
Others(Specify)	

3.4. Does your household presently have any of the following animals, and if so, how many?

Please read the options tick all that is relevant and write the number owned

Livestock	Number	Major breed 1=local 2=cross
Cattle		
Oxen		
Sheep		
Goat		
Chicken		

3.5. Which **5 crops** do you consider the most important for your household? (State area under each crop in 2009 rain season, why the crop is preferred, and yield in 2009LR for annual crops and average yield in the past three years.

Crop name	*Rank	Why the crop is preferred			Acre 2009LR	Yield 2009LR	average yield /acre
		1st	2nd	3rd			

* Rank: 1=most important…5=least important

** Why the crop is preferred 1= Food security 2= income generation 3=Multiple uses for household (e.g., ugali, blended with other foods) 4=high yield 5=Good yield in bad weather 6=others (specify)…………………

3.6. Are there any crops you have abandoned growing? 1. Yes 2. No

3.7. If yes, what are the reasons?

Crop name	Reasons for abandonment

3.8. During the last two seasons has your household ever hired labourers?

1. Yes 2. No

3.9. If yes, for what activities did you hire the labourers?

____

3.10. What are the three major sources of income for your household?

Choose maximum 3 relevant options and rank them (1=most important)

Source	**Rank**	**% of total income**
Permanent employment		
Self-employment off-farm (business)		
Casual labour		
Remittances		
Pension		
Sale of crop products		
Sale of livestock products		
Others (specify):_________		

3.11. What are the three major expenses of the household income?

Choose maximum 3 relevant options and rank them (1=most important)

Source	**Rank**	**% of total expenditure**
Food		
School fees		
Medical care		
Purchase of farm inputs		
Hiring labour		
Others (specify)		

IV. FARMERS' PERCEPTIONS OF SOIL FERTILITY DEPLETION, AWARENESS AND ADOPTION OF SOIL FERTILITY MANAGEMENT TECHNOLOGIES

4.1. How have crop yields generally changed on your farm in the past 5 years?
1=Decreased; 2=increased; 3=No change

4.2. If the crop yield has decreased, in your opinion, what are the main reasons responsible for this?

Reasons	**Rank**
Planting local varieties	
Pests and diseases	
Unreliable rainfall	
Poor soil fertility	
Soil erosion	
Striga	
High cost of inputs	
Others (specify)	

4.3. In case soil fertility is mentioned above, in your opinion what Causes poor soil fertility?

Cause	**Rank**
Soil erosion	
Inadequate manure supply	
Low technical-know how	
No cash to buy chemical fertilizers	
Lack of crop rotation	
Frequent application of inorganic fertilizers	
Do not know	
Others(specify)	

4.4 How do you know that soil fertility is declining? **(Tick all mentioned responses)**

1. Low crop yields	2. Poor crop growth vigour
3. Colour of plant leaves	4. Presence of indicator weeds
5. Soil becoming lighter in colour	6. Others

(specify)______________________________

4.5. If indicator weeds are mentioned, list them

Names of weeds associated with fertile soil	**Names of weeds associated with infertile soil**

4.6. Are there differences in soil fertility across fields on your farm? 1=Yes 2=No
If yes, can you point to me the **most fertile** and **least fertile** fields and crops grown in the fields and crops that cannot perform well in the soil?

Soil fertility status	Distance from homestead	Crop(s) grown in the field **(At most 3 crops)**	Crop(s) not grown in the field **(At most 3 crops)**
Lowest			
Moderate			
Highest			

4.8. Are there any fields where plants do not respond to application of the following inputs?
a. Inorganic fertilizers? ____ Yes____ No;
b. Organic fertilizers______ Yes_____ No

4.9. Which soil fertility management technologies have you ever seen or heard of (aware) and/or used on your farm? (*Also state the year you first applied)*

Practice type	**Awareness** *1=Yes* *2=No*	**Use status** **0**=*Never used* **2**=*Used before and in 2009LR* **3**=*Used before but not in 2009 LR and to use it next season* **4**=*stopped using it;* **5**=*Others (Specify)*_____________________	**Year first used**
Farmyard manure			
Inorganic fertilizer			
Green manure			
Compost			

Lime			
Others (specify)			

4.10. What are your three most important reasons for preferring to use the practices in question 4.9 above (if **use status** is 2 or 3)?

Reasons: 1.Low cost 2.Less risky to use 3. Easy to apply 4. Availability of requisite inputs locally 5.Long residual effect; 6.Less labour required 7.Convenient to apply

Who is/are **most** responsible for carrying out the following tasks? *(In case of* **Technology**	**Who is responsible * (see codes below the Table)**				
	Decides the use	**Purchase of inputs**	**Collect and prepare**	**Application in fields**	**Sourcing technical knowledge**
Farmyard manure					
Inorganic fertilizer			▨		
Green Manure					
Compost					
Lime			▨		
Others (specify)……					
***Code:**1=male adult members; 2= female adult members 4=male children 5=Female children 6= male hired casuals 7= female hired casuals 8. Fast impact 9. Expected benefits are high 10. Does not "spoil the soil"					

Technology type	**Reason 1 (*Code)**	**Reason 2**	**Reason 3**
Farmyard manure			
Inorganic fertilizer			
Green Manure			
Compost			
Lime			
Others (specify)			

4.11. In case you have **never used or stopped using** any technology listed in **4.10**, please state the reasons

	***Reason never used**			****Reason stopping to use**		
Technology	Reason 1	Reason 2	Reason 3	Reason 1	Reason 2	Reason 3
Farmyard manure						
Inorganic fertilizer						
Green Manure						
Compost						
Lime						

*** Reason for never or stopping to use codes:** 1=land is fertile, 2=high cost 3=very risky 4=Difficult to apply 5= Non-availability of requisite inputs locally 6=Low residual effect; 7=more labour required 8=Slow impact 9=low expected benefits 10= “spoil the soil“ 11. Lack of know-how 12=Others(specify)______________________

4.12. For each of the soil management options you practice (mentioned above), *equal responsibility, write all responsible).*

4.13. What inputs did you apply on your major crop fields in 2009 long rains (LR) and what were the harvests in the fields? {Include one field where **no** soil fertility inputs were applied for farmers who applied some inputs. For farmers who did not apply any soil fertility inputs, select with help of the farmer **the two** most important fields and fill the table below}. (Note: A field is a single piece of land which is connected. Pieces of land not connected are different fields. Fill one row per field and in case of intercrops/crop mixtures in the field, consider only two dominant crops.

Field No. **GPS readings**	Acres **(GPS)**	Soil fertility status	Distance from home (km)	1.Crop name (use codes)				Types and quantity of soil improvement inputs applied(e.g.manure,chemical fertilizer)							Output
				Crop 1	Crop 2	Variety 1=improved 2=local		Type 1	Quantity 1 (kg)	Price1	Type 2	Quantity 2 (kg)	Price 2	Yield crop1 (kg)	Yield crop2 (kg)
						Crop 1	Crop 2								
1															
2															
3															
4															
5															

Crop code:
01 = Maize pure stand
02 = Maize beans intercrop
03 = Beans
04 = Bananas
05 = Sorghum
06 = Sweet potatoes
07 = Cassava
08 = Groundnuts
09= Sugarcane
10 = Kale
11 = Tomatoes
12 = Cabbage
13 = Local vegetables 14 = Onions
15 = French beans
16 = Finger millet
17=Other (specify)____

Soil fertility status code
1.Low
2. Moderate
3. High

Fertilizers code:
0=None
2=DAP
3=CAN
4=MAP
5=SSP
5= farm yard manure
7=Green manure
8=lime

V. ACCESS TO AGRICULTURAL SERVICES

5.1. Did you obtain any agricultural advice or assistance in the last 2 years?
1 =. Yes 2 =. No

5.2. If yes, indicate the source of the advice, and frequency of access.

Sources of information	Frequency of receipt per year	Main messages*
Visit by government extension agent		
Radio		
Baraza		
TV		
Newspaper		
KARI		
NGOs (Specify)		
Other farmers		
Field days/demonstrations		
Exchange visits		
Shows		
Others(specify)----------------		

***Main messages** 1= soil management technologies, 2=crop varieties, 3= crop management 4=disease and pest control 5=others_____________ (*record multiple responses).*

5.3 Have any of your household members ever applied for credit either in cash or kind? 1. Yes 2. No

5.4. If no credit was applied for, why?

____

5.5. Have you ever-obtained credit? 1. Yes- 2.No

5.6. If yes, what are the three main sources of credit?
1.Money lender, 2=Credit association/group, 3=Bank 4= Cooperative,
5= Family members, 6=Agro-dealer, 7= Self Help Group, 8= Relatives,
9=Friends 10= Neighbours, 11=Others (specify)___________

Indicate in the boxes below the codes of the 3 main sources

1	2	3
☐	☐	☐

5.7. What conditions are required to borrow?

____

5.8. For what purpose was the credit granted?

____

5.9. If credit was not granted, what is the source of finance for your agricultural activities?

____

5.10. Have you sold any farm produce in the past two seasons? 1. Yes 2. No

5.11. Where do you generally sell the produce?

Name of product	**Who sells** 1=male 2=Female	**Where sold** 1. Farm gate 2.Local market 3. Far market. 4.Others (specify)___	**Frequency of sale****	**Mode of sale** 1=Individual 2=Group 3=cooperative	**% of total harvest sold**

5.12. How far are you from your major divisional/district head quarters?_______km

5.13. How far is your main input and output markets from your farm?

Market type	Minimum walk time to reach the market (minutes)	Fare (Ksh.)	Total Distance (km)
Output market			
Input market			

VI. GROUP /ORGANIZATIONS MEMBERSHIP AND BENEFITS

6.1. Do any of your household members belong/participate in any community/ outside community groups/organization activities? 1. Yes 2. No

6.2. If yes, which organizations do you belong to? (***Tick all as appropriate)***

1 Community Based Organization (CBO)
2.Farmer group
3. Agricultural group
4. Trade and business
5. NGO
6. Religious
7. Political/movement
8. Social welfare (Burial, sickness),
9. Savings group / 'merry go round'
10. Others(specify) _______

6.3. Of the groups/organizations above that you belong to, which are the **three** are the most important to you and/or your household? **(1=most important)**

Org/group 1 ☐ Org/group 2 ☐ Org/group 3 ☐

6.4. How many times in a year/month, on average do, anyone in your household participate in each of the **three** most important groups by attending group's activities (e.g., by meetings or group work?)

Group name	Frequency of meetings (e.g., per month or year)

6.5. What are the **three** main benefits of joining the groups? *(Indicate in boxes below)*

1. Credit/loan services 2. Supply of agricultural inputs (gift)
   3= Technical advice on agriculture 4= Group marketing of produce
   5=. Information (e.g. prices) 6= Important at time of emergency
   (e.g., sickness, funerals), 7= Labour supply
   8= Beneficial to community 9= others (specify) ________________

group 1 ☐ group 2 ☐ group 3 ☐

6.6. Which leadership position, if any, do you or any member of your household hold in this community? 0=None 2= Councilor 3= School board member 4=Village elder 5=Assistant chief 6=Chief 7=. Others (specify)__________

CLOSURE OF THE INTERVIEW

We would like to thank you now for your collaboration and your time and for all the information you have provided us with.

Appendix II: Soil samples for characterization on Indombela's farm in Kabras, Kakamega County (Source: Author, 2010)

Appendix III: Lime application and planting of maize in study sites

a) Broadcasting Lime after land preparation on Njega's farm Got Nanga, Ugenya, Siaya County(Source: Author, 2009)

b) Incorporating lime immediately after broadcasting on Njega's

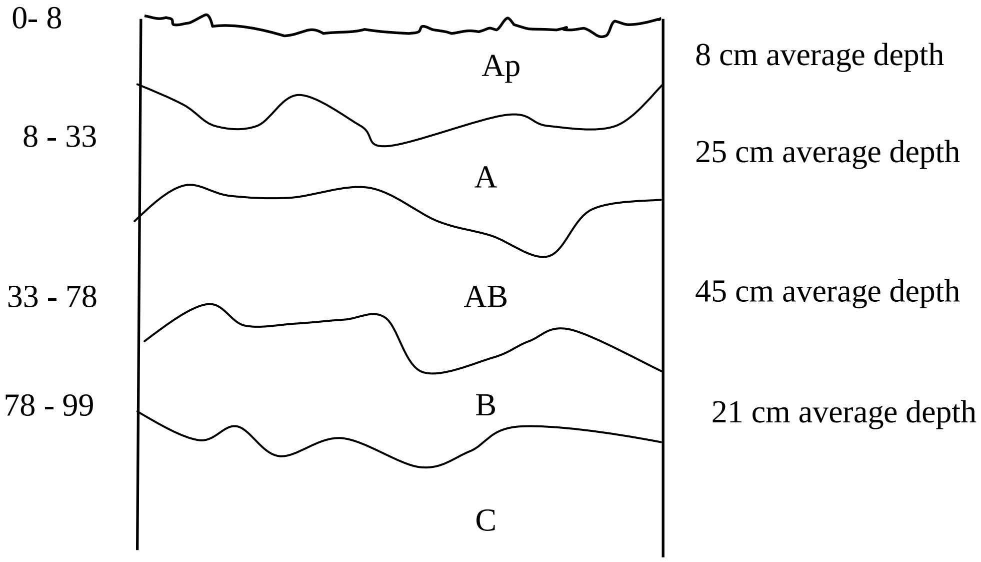
farm Got Nanga, Ugenya, Siaya County (Source: Author, 2009)

c) Planting of Maize four weeks after the in cooperation of Lime on Njega's farm Got Nanga, Ugenya, Siaya County (Source: Author, 2009)

Appendix IV: Description of soil classification of profile pit No.1

Soil Classification	Ferralo Humic Acrisol
Agro-climatic zone	UM1 to transition LM1
Parent material	Kavirondian shales
Physiography	Sloping on western slopes of Nandi hills
Surrounding landform	Gentle sloping with potential drainage density of 0 -25
Meso- relief	Gentle slope part of Nandi hills complex
Slope gradient	2% - 3%
Land use/ land cover	Native and exotic trees, grasses, cultivated crops maize, bananas, cassava, sugar cane
Drainage class	moderately well drained
Depth of groundwater table	below 10 metres
Presence of surface stones/rock outcrops	Nil
Evidence of erosion	Rill and gully erosion evident
Human activities	Farming

Sketch of the profile No. 1



Ap	0-8 cm	Dull reddish brown (2.5YR to dark red (10R) in the lower Horizons, clay sandy loam, angular to sub angular, fine and very fine roots of vegetation and cultivated crops prominent, no mottles or concretions, soils reaction to Hydrogen peroxide (H_2O_2 violent, pH of 4.5
A	8-33 cm	Dark reddish brown (2.5YR), clay sandy loam, angular to Sub angular blocky, few fine and very fine roots of vegetation and cultivated crops prominent, no cutans or mottles, poorly developed in consistence, soils reaction to H_2O_2 slightly violent as compared to that of Ap, boundary of horizon was diffused and pH of 4.0
AB	33-78 cm	Reddish brown (10R), fine to gritty, sub angular, few plant roots, slight presence of cutants and concretions, pores, soils reaction to H_2O_2 was violent, diffused horizon boundary, gradual and smooth transition, pH of 4.0.
B	78-99 cm	Dark red (10R), fine texture, presence of cutans, well Developed consistence (moist), sub angular blocky, few fine pores, no cutans or mottles, poorly developed in

consistence, violent reaction to H_2O_2, pH of 4.0

Identifying horizons in the open pit No. 1 on Atsango's farm in Kabras Kakamega North, Kakamega County (Source: Author, 2010).

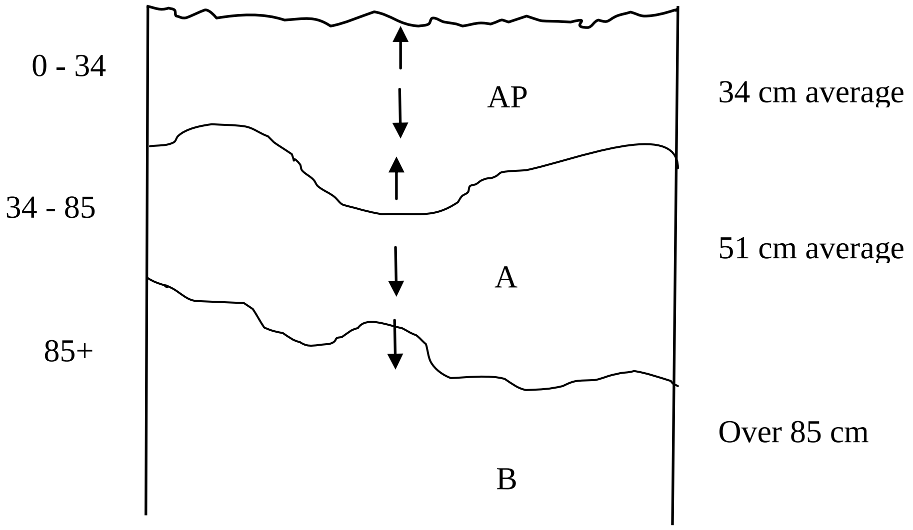
Based on the above characteristics on the overall soils around the profile pit were classified as Ferralo Humic Acrisol. Overall, the soil around the profile pit was classified as Ferralo Humic Acrisol.

Appendix V: Description of soil classification of profile pit No.2

Soil Classification	Ferral Humic Acrisol
Agro-climatic zone	LM1
Parent material	Kavirondian shales
Physiography	Sloping
Surrounding landform	Flat/ level land to gentle sloping southwards with potential drainage density of 0 -25
Meso- relief	flat part of a complex end of Nandi escarpment slope
Slope gradient	1%

Land use/ land cover	Native and exotic trees, grasses, cultivated crops maize, bananas, cassava, sweet potatoes, sugar cane
Drainage class	moderately well drained
Depth of groundwater table	below 15 metres
Presence of surface stones/rock outcrops	Nil
Evidence of erosion	Sheet erosion evident
Human activities	Farming

Sketch of the profile No. 2



Ap	0-34 cm	Dark reddish brown (5YR 3/3), gritty, sub angular blocky, Poor consistency, fine and very fine roots, visible abundant mottles, cutans, concretions, very violent reaction with hydrogen peroxide (H_2O_2) pH value (water) 4.5
A	34-85 cm	Dull reddish brown when moist (5.5YR 4/4), very few fine and very fine roots of vegetation and cultivated crops, no mottles, fine gritty texture, poor consistence, slight concretions, very violently reaction to H_2O_2 , lower

		horizon boundary diffused and pH value (water) 4.0
B	85 + cm	Dark reddish brown (2.5YR 3/4), no mottles, gritty, sub Angular blocky, slight presence of cutants and concretions, moderately developed consistence, lower boundary of horizon boundary diffused, soils reaction to hydrogen peroxide (H_2O_2) violently, pH value water) 4.0.

Measuring the depth a soil profile pit No. 2 on Indombela's farm Kabras, Kakamega County (Source: Author, 2010)

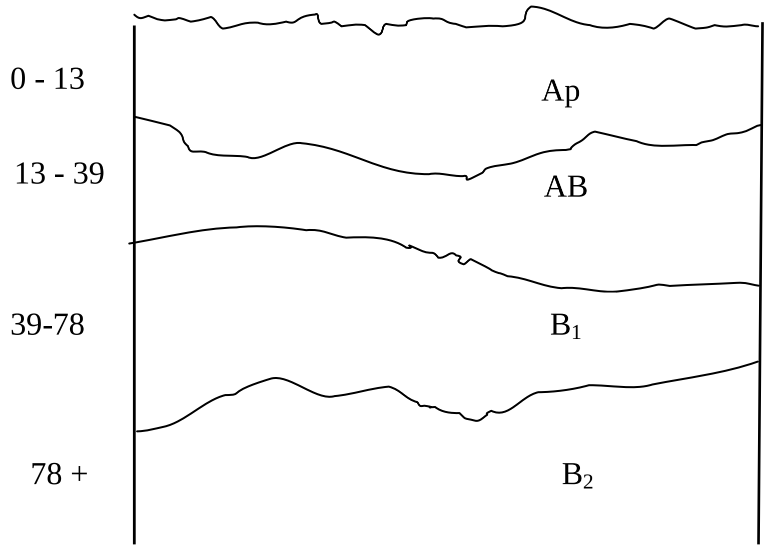
Overall, the soil around the profile was classified as Ferralo Humic Acrisol.

Appendix VI: Description of soil classification of profile pit No.3

Soil Classification	Orthic Acrisol
Agro-climatic zone	LM1
Parent material	Basalt (volcanic activity)
Physiography	Sloping
Surrounding landform	level land with potential drainage density of 0 -25
Meso- relief	gently slope towards a stream

Slope gradient	4%
Land use/ land cover	Native trees and grasses, crops maize, beans, sorghum, bananas, tomatoes, cassava
Drainage class	moderately well drained
Depth of groundwater table	Below 5 metres (a shallow well is on the farm)
Presence of surface stones/rock outcrops	Nil
Evidence of erosion	Sheet and rill erosion evident
Human activities	Farming

Sketch of the profile No. 3



Ap	0-13 cm	Dull brown (7.5YR 5/4), blocky, less developed consistency, prominent fine and very fine roots of vegetation and cultivated crops, no visible mottles, cutans, concretions, slight reaction to hydrogen peroxide (H_2O_2) pH value (water) 5.0
AB	13-39 cm	Dark brown (7.5YR 3/4), very few fine roots of vegetations, few mottles, massive structure, developed consistence, slight presence of cutans, few concretions, minimal

		reaction to H_2O_2, pH value (water) 5.0
B_1	39 - 78 cm	Bright brown (7.5YR 5/6), angular, presence of mottles, cutants, concretions prominent, moderately developed consistence, minimal reaction with hydrogen peroxide (H_2O_2), pH value (water) 5.5.
B2	78 + cm	Bright reddish brown (7.5YR 5/6), slightly gritty, presence of mottles, no structure dominated by concretions, developed consistence, minimal reaction with H_2O_2, pH value (water) 5.5.

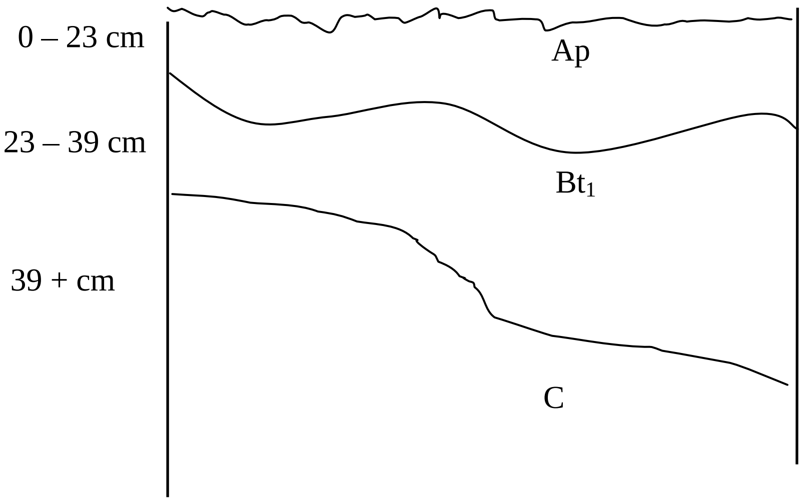
Overall, the soil around the profile was classified as Orthic Acrisols.

Appendix VII: Description of soil classification of profile pit No.4:

Soil Classification	Orthic Acrisol
Agro-climatic zone	LM1
Parent material	Kavirondian shales
Physiography	Sloping
Surrounding landform	Undulating with potential drainage density of 0 -25
Meso- relief	Fairly flat
Slope gradient	2%
Land use/ land cover	Native trees and grasses, crops maize, bananas, finger millet, sorghum, cassava, Oil palm
Drainage class	Moderately well drained
Depth of groundwater table	Below 8 metres

Presence of surface stones/rock outcrops	Nil
Evidence of erosion	Sheet and rill erosion evident
Human activities	Farming

Sketch of the profile No. 4

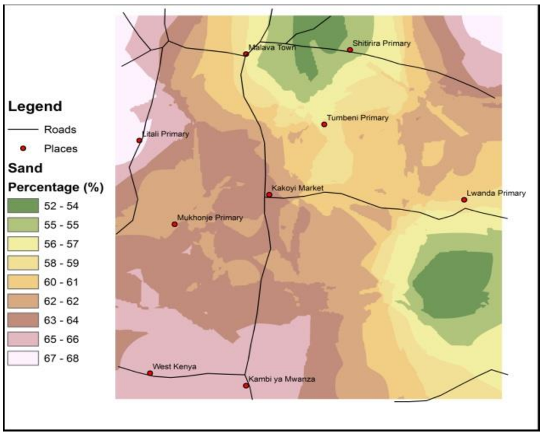


Ap	0-23cm	Brown (5YR 5/6), fine texture, blocky, no mottles poor consistency, prominent fine roots of vegetation and cultivated crops, very violent reaction with hydrogen peroxide (H_2O_2) very, pH value (water) 4.5
A	23-39 cm	Dull reddish brown when moist (5.5YR 4/4), fine structure, very few fine roots of vegetation and cultivated crops, no mottles, poor consistence, no concretions, very violent reaction to H_2O_2, pH value (water) 4.0
C	39 + cm	Orange soil (5YR 6/8), massive, no mottles, poor consistence, presence of concretions, no roots, few cutans indicating illuviation and eluviation process taking place, developed consistence, violently reacted with H_2O_2 violently and pH value (water) 4.0.

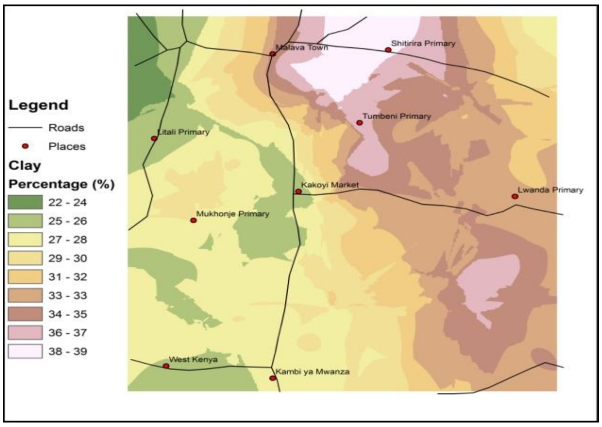
Overall, the soil around the profile was classified as Orthic Acrisols.

Identifying horizons in profile pit No. 4, on Owoko's farm in Got Nanga, Siaya County (Source: Author, 2010)

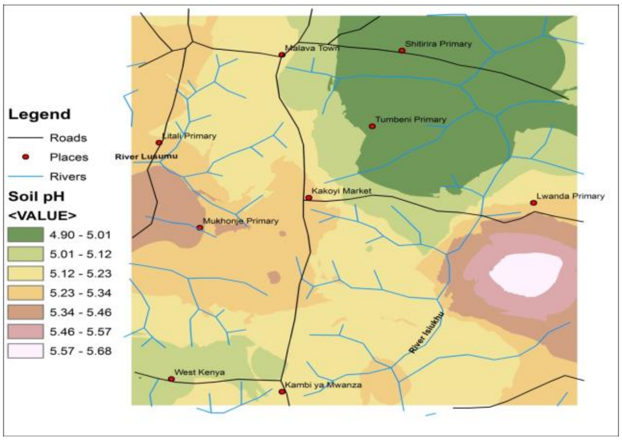
Appendix VIII: Maps of soil characteristics generated from data collected and analyzed in Kakamega County



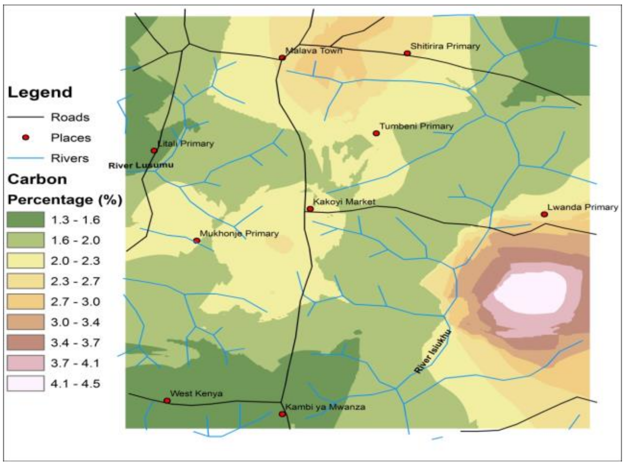
a) **Pattern of sand distribution in Kakamega County (Map generated from data collected in study area in 2009) (Source: Author, 2010)**



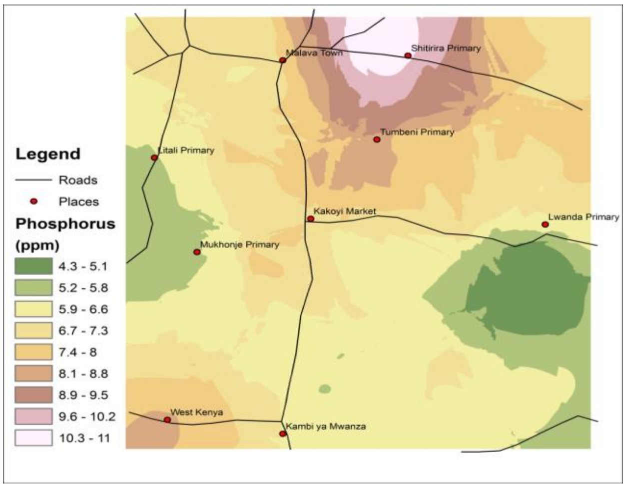
b) **Pattern of clay distribution in Kakamega County (Map generated from data collected in study area in 2009) (Source: Author, 2010)**



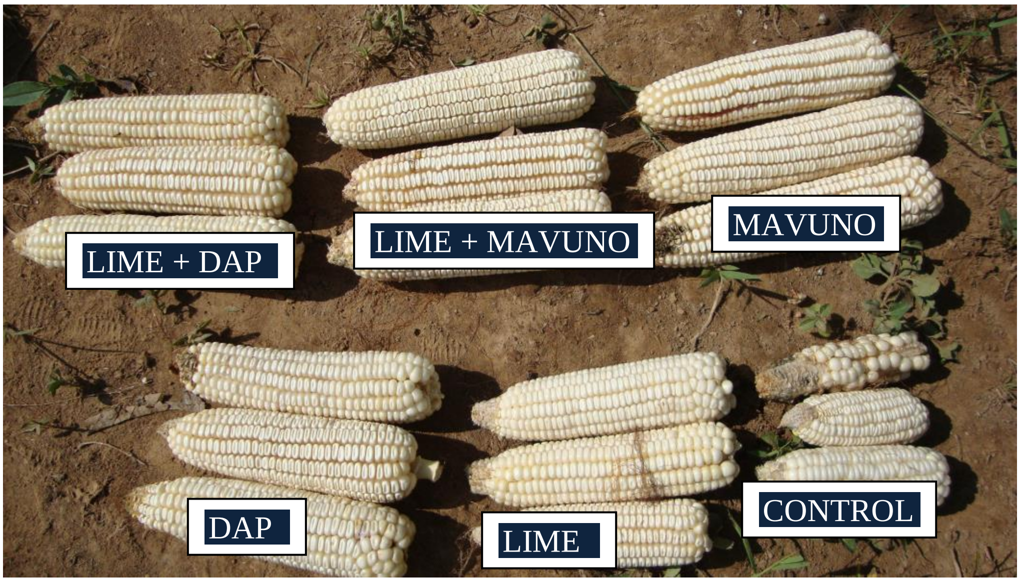
c) **Soil pH pattern in Kakamega County (Map generated from data collected in study area in 2009)**



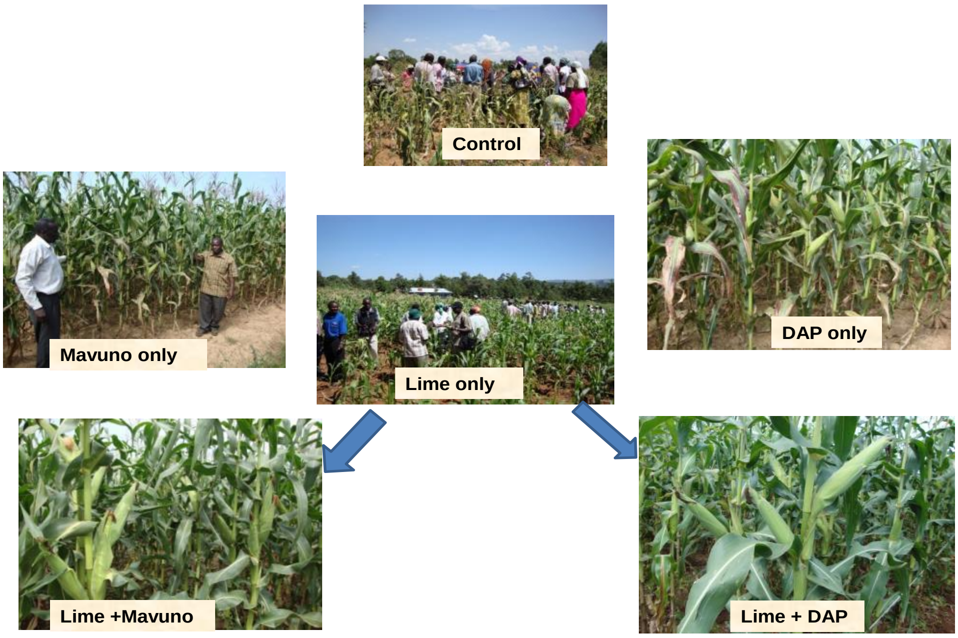
d) **Soil Total Organic Carbon (TOC) distribution pattern in Kakamega County (Source: Author, 2010)**



e) **Soil phosphorous (p) distribution pattern in Kakamega County (Source: Author, 2010)**

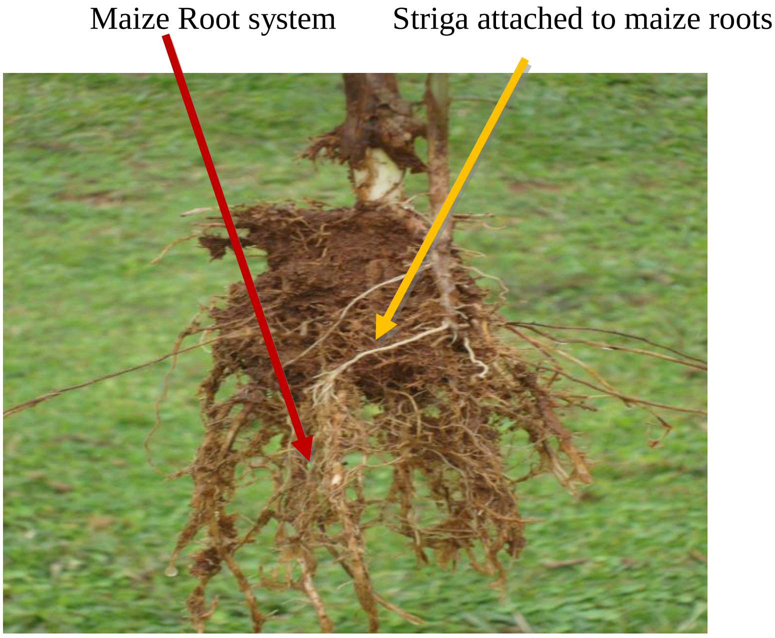


Appendix IXP: Maize cobs from different treatment during the 2011 long rains seasons in Siaya County (Source: Author, 2011)



Appendix X: Performance of maize grown under various fertilizer and Lime amendments during the 2011 long rains season in Siaya County (Source: Author, 2011)

Appendix XI: Maize crop under two different treatments during the 2010 short rains cropping seasons in Siaya County (Source: Author, 2010)



Appendix XII: Striga hermonthica roots attached to Maize root system ((Source: Author, 2010)

Appendix XIII: Testimonies of farmers from Kakamega and Siaya Counties

Francis Sakula Kakamega North district, Kakamega County - Kenya:

"In our village, we thought the land was bewitched. Many people were selling land to those who did not know that land was bewitched. Before KARI Kakamega came to our area, I had decided to sell my land and go to Lugari Settlement Scheme where most people thought land was good. When KARI came in and told us that our land was not bewitched but soil was acidic (Chumvi) that makes our maize not to grow well. KARI came in and took soil samples to go and analyze. When they came the second time they brought something like ash which they told us that it was Lime that will reduce acidity. Most of us did not believe, but I reluctantly gave part of my land for testing. The first season maize was not good and this proved to many that the ash was not going to improve maize yield. Because of good results from limed plots in the third season, farmers have named the Lime a "saviour". We, the members of the Mwangaza Farmers Group Isanjiro village, Central location, East Kabras division, have been planting maize in our acid infested fields for the past many years. Little did we know that our soils were not bewitched by our ancestors as claimed by those who sell their land and go to buy land in the settlement Schemes. With the use of Lime, we have improved maize our productivity from an average of less than 0.2 t h^{-1} *to over 5.8 t* h^{-1}. per season.

Francis Sakula +254 729526430

Isanjiro village, Kabras East Location, Kakamega North Sub County, Kakamega County, Kenya

Isaac Ochieng Okwanyi, Ugenya District, Siaya County, Kenya:

*Just like any other young man, I thought that working in the city of Nairobi was the best way of earning a living. But after I lost everything during the post-election violence, I decided to leave Nairobi city for my rural home and try my luck in farming" said Okwanyi, who hails from Nyangera village in Siaya County***?** *I asked my grandmother to spare me an acre of land so that I try farming. She quickly warned me not to plant maize because her land had been cursed by our ancestors and as a result a maize crop would not thrive on it. I did not heed her words and I planted maize, but to tell you the truth, my efforts were largely futile. It didn't matter how much fertilizer I used and times I weeded the farm, Striga always won. When I heard that KARI Scientists under the leadership of Mr. David Mbakaya were in the area encouraging farmers to neutralize their soils using Lime, I reluctantly asked for it just to try. "I tried liming my land my grandmother gave me for three seasons, and what I saw in the third season was nothing short of a miracle! My maize has gradually became very healthy every subsequent season, Striga weed population in the plot I applied Lime was disappearing and my wife was happy to work on the farm as she was encouraged by the good crop. My grandmother was keenly observing to see if the lime was breaking the curse on our land" said Isaac Ochieng Okwanyi, a 29 year old father of two, who settled for farming after he was evicted from Nairobi's Mathare Slum in 2008 following the post-election violence in Kenya". "I will never go back to Nairobi a city of problems" says Okwanyi. KARI through Mr. Mbakaya has taught and made me an innovator model farmer in the village. "Agriculture is a chair to sit on and not going to city", says Okwanyi*

Isaac Okwanyi,+254716652461

Nyangera village, North East Ugenya Location, Ugenya, Sub County, Siaya County. Kenya