EFFECT OF SOIL AMENDMENTS ON THE PERFORMANCE OF SELECTED AFRICAN INDIGENOUS VEGETABLES IN UASIN GISHU AND TRANS NZOIA COUNTIES

BY

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DECLARATION

DECLARATION BY THE CANDIDATE

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DEDICATION

This work is dedicated to my parents Mr. & Mrs. Kibiru, my dear sisters and my nephew, Amos Wachira for their great support and encouragement throughout my study period.

ABSTRACT

African Indigenous Vegetables (AIVs) have high nutritive value, require less inputs and can be a reliable source of income to resource challenged families. However, their production in western Kenya is hampered by limited information on their soil nutrition requirements. To meet these needs two studies (Agronomic trial and soil pH study) were conducted during the rainy season and dry season, which was between July 2013 and March 2014 under drip irrigation. The studies aimed at determining the best fertilizer-variety combination and ideal soil pH level in the two regions for growing AIVs. The experiments were laid out in a Randomized Complete Block Design in a split-split plot arrangement for the agronomic trial and a split-plot for pH study. Both experiments were replicated three times. In the agronomic study, three vegetable types formed the main plot treatments which included Spider plant (*Cleome gynandra*), African Nightshade (*Solanum scabrum*) and *Amaranthus spp*. Varieties formed the sub plot treatments which were Local variety, UG-SF-15 and ML-SF-29 for spider plant; Local variety, UG-AM-40 and Ex-Zim for *Amaranthus spp and* Local variety, BG-16 and SS-49 for African nightshade. Fertilizer treatments formed the sub-sub plots and include Mavuno fertilizer, poultry manure and the control. In the soil pH study, species (African nightshade, Amaranths & Spiderplant) formed the main plot treatment while the lime rates formed the sub plot treatment. Data were collected on cumulative fresh yield, soil pH trend and characterization, biomass and nutrient concentration, root biomass and root length density and chlorophyll content at flowering. Data were subjected to ANOVA using SAS version 9.3. In the agronomic study, the results exhibited that fertilizer application significantly (p=0.05) increased cumulative fresh yield of all selected varieties of the three AIVs. In African nightshade, developed variety BG-16 with mavuno fertilizer had the highest mean cumulative yields in Eldoret (9,980 kg/ha) and Kitale (13,880 kg/ha). In Amaranths, developed variety UG-AM-40 with poultry manure recorded the highest yields in Eldoret (4,490 kg/ha) and Kitale (6,060 kg/ha). In spiderplant, local variety (LV-SP) and developed variety (UG-SF-15) recorded highest yields with mavuno fertilizer while developed variety ML-SF-29 had highest yields in Eldoret (2600 kg/ha) and Kitale (3830 kg/ha) with poultry manure. In the soil pH study, acid soils responded to liming, whereby all the liming rates were significantly different at P=0.05. A mean pH of 6.33 for liming rate 4.1625 t/ha , 5.78 for liming rate 2 t/ha and 5.18 for the control were achieved. Generally, in all the species, fresh biomass at floweing was highest at lime rate 2 t/ha with a target pH of 5.5. For dry biomass mixed response was exhibited with Amaranth recording highest biomass at lime rate 2 t/ha (2370 kg/ha), spiderplant at zero liming(1350 kg/ha) and African nightshade at lime rate 4.16 t/ha with a target pH 6.5 (1340 kg/ha). In all the vegetable species, %N and % P in the plant tissue increased tremendously in the rainy season though no significant differences (p=0.05) were exhibited. Root biomass increased with increase in lime applied. In all the species zero lime treatment had the lowest dry root biomass. There were significant differences in spider plant and amaranthus (P=0.05) whereby, treatments with zero lime (NL0 and AL0) were significantly different from the other lime rates. However, in spiderplant there were no significant differences (p=0.05) between the lime rates. Overall, the studies concluded that yields of AIVs will greatly increase with utilization of improved germplasm, use of appropriate fertilizer and maintaining ideal soil pH through liming of acid soils.

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ABBREVIATIONS AND ACRONYMS

AIVs	African Indigenous Vegetables
N	Nitrogen
P	Phosphorus
C	Soil organic carbon
AVRDC	Asian Vegetable Research and Development Center
FAO	Food and Agriculture Organization
AFFP	Department of Agriculture, Forestry and Fisheries, Pretoria
FSNP	National Food Security and Nutrition Policy, Kenya
DRB	Dry root biomass
RLD	Root length density
DS	Dry season
AMPATH	Academic Model Preventive and Treatment of HIV
FADINAP	Fertilizer Advisory Development and Information Network for Asia. . and Pacific
IPNI	International Plant Nutrition Institute
TE	Trace elements

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CHAPTER ONE

INTRODUCTION

1.1 Background information

African Indigenous Vegetables (AIVs) provide a reliable source of proteins, calories, elements and Vitamins-A, B and C (Mhontlo *et al*., 2007; United Nation University, 2005). In Kenya, 210 of the edible 10,000 known species in Africa are used as leafy vegetables (IPGRI, 2006). These vegetables are well adapted to harsh climatic conditions, disease infestation and require little inputs for optimal production compared to their exotic counterparts (Habwe and Walingo, 2008). Despite their nutritional value and agronomic advantages, their yields continue to decline and they remain underutilized while 43% of the population in Sub-Saharan Africa is suffers from chronic malnutrition (FAO/WHO, 2004).

According to Hutchinson *et al.,* (2006), across the AIVs species high yielding lines have been developed but these lines have not been tested in several environments. Most of these lines therefore remain underutilized and since critical information regarding their production techniques is still lacking.

Nitrogen has been identified as the most limiting nutrient under most environments; applying N increased plant height, number of leaves and the fresh yield of AIVs significantly (Pospisil *et al*., 2006, Mauyo *et al*., 2008). According to Okalebo *et al*., (2002), low and declining soil fertility due to continuous cultivation, soil erosion and nutrients losses through runoff and leaching is a serious problem in many parts of Kenya. Previous studies have identified African Nightshade (*Solanum scabrum*), Spiderplant

(*Cleome gynandra*) and *Amaranthus spp*. are the most popular and preferred in central and western Kenya and therefore are potential commercial AIVs (Masinde *et al.,* 2005; Abukutsa, 2007).

As a result, AIVs remain to be very essential crops to the majority of resource poor population living in the rural areas and hence the need to fast track development of optimal production packages for adoption in order to boost production and improve livelihoods of these small scale farmers in Kenya.

AIVs production information

Across Eastern and Central African AIVs available include: vegetable amaranth, spider plant and African nightshade among others (Habwe and Walingo, 2008). These vegetables are a common delicacy for many communities in Kenya. Many of the AIVs are identified with the communities that use them and by their local names. African Indigenous Vegetables are mainly found as weeds and where cultivated are produced within the homestead on small scale whereas those which are hardy like cowpeas are intercrops in main cropping lands. However, in some parts of Kenya farmers have started growing them for commercial purposes but the demand exceeds the supply. Studies have shown that there are more diverse indigenous vegetables in the Lake Victoria region (Mwai *et al*., 2010).

African Indigenous Vegetables have been identified to have potential of making positive contribution to world food production. It has been observed over a period of time that they adapt easily to harsh environment, require low inputs for growth, and are resistant to pathogens. Benefits associated with AIVs production include: high nutritive qualities, easy to grow, adaptable to the local growing conditions, provide vital food security for the rural resource poor families and have can be a major income earner for poor families. This makes them suitable for cultivation by the rural poor farmers who are majority in Africa (Habwe and Walingo, 2008).

A study by Abukutsa *et al.,* (2010), revealed that the main AIVs that need to be promoted as commercial crops are: amaranths, African nightshade and spiderplant among others. Another study in Central Kenya revealed that farmers have identified ignorance of utilization and preservation methods as production constraints. Other major challenges in the production of AIVs include lack of technical production techniques and information on fertilization (Mhontlo *et al.,* 2007). These are just but a few of the many challenges facing AIVs production.

As a way of solving some of the production constraints, this study aimed at bridging the knowledge gap in liming and fertilizer use in AIVs production through determining AIVs responses to organic and inorganic fertilizers as well as soil pH amendments in two sites in Western Kenya.

1.2 Statement of the problem

Production of African indigenous vegetables (AIVs) is a viable option of enhancing food security in the rural areas. This is as result of their adaptability to harsh climatic conditions and disease infestation, high nutritive value and medicinal value among other agronomic advantages.

However, lack of information on fertilizer-use, declining soil fertility and increasing acidity has led to reduced production of AIVs. In Kenya production share of AIVs is 5 %

of all vegetables grown where the estimated yields are 1 to 3 t/ha which is far below the optimal yielding of 30 to 40 t/ha (IPGR, 2006, Mhontlo *et al.,* 2007; eFIL, 2010, Zhang *et al.,* 2012, Abukutsa-Onyango, 2003). Due to the aforementioned limitations, any effort that will contribute to development of a comprehensive technical package is therefore crucial (Marschner, 1995). This study was designed to generate some of the lacking and essential information in ensuring sustainability and increase in production of AIVs that will be a key ingredient in developing a comprehensive technical production package.

1.3 Objectives

1.3.1 Broad Objective

To evaluate the effects of different N-fertilizers and liming on the agronomic performance of the selected African Indigenous Vegetables

1.3.2 Specific Objectives

i. To determine the effects of poultry manure and mavuno fertilizers on the cumulative fresh yield of *Amaranthus spp.*, *Cleome gynandra* and *Solanum scabrum*.

ii. To determine the effects of liming on the root growth of *Amaranthus spp.*, *Cleome gynandra* and *Solanum scabrum*.

iii. To determine the effect of liming on the above ground biomass and nutrient concentration in the plant tissue of *Amaranthus spp.*, *Cleome gynandra* and *Solanum scabrum*.

1:4 Research questions

i. Does use of organic and inorganic N sources affect cumulative fresh yield of *Amaranthus spp.*, *Cleome gynandra* and *Solanum scabrum*?

ii. Does adjusting soil pH through liming affect root growth of *Amaranthus spp.*, *Cleome gynandra* and *Solanum scabrum*?

iii. Does liming have effect on accumulation of the above ground biomass and nutrient concentration in the plant tissue of *Amaranthus spp.*, *Cleome gynandra* and *Solanum scabrum*?

CHAPTER TWO

LITERATURE REVIEW

2.1 Selected African Indigenous Vegetables

Some of African Indigenous vegetables (AIVs) consumed in Africa include: amaranths (*Amaranthus species*), spiderplant (*Cleome gynandra*), African nightshades (*Solanum species*), cow peas (*Vigna unguiculata*), African eggplant (*Solanum eathiopicum*), African kale *(Brassica carinata*) and Jute mallow (*Corchorus olitorius*) (Schippers, 2000). In Kenya, the most widely produced and consumed AIV species include: Amaranthus, Spiderplant and African nightshade (FARM Africa, 2012; Mbugua *et al*., 2011).

2.1.1 Amaranths

Amaranth is a plant that grows well in hot humid and hot dry climates (AVRDC, 2003). It belongs to the Amaranthaceae family and is an extremely variable, erect to spreading herb. The height of mature plants varies between 0.3 m and 2 m, depending on the species, growth habit and environment. Some species have distinct markings on their leaves. Terminal and auxiliary inflorescences occur. The small seeds of the leafy amaranths are usually very shiny and dark brown to black. Amaranth is a C4 plant that grows optimally under warm conditions (day temperatures above 25°C and night temperatures not lower than 15°C, bright light and adequate availability of plant nutrients. The various amaranth species are tolerant to adverse climatic conditions and they are quite drought-tolerant, but prolonged dry spells induce flowering and decrease leaf yield. Amaranth is photoperiod sensitive and starts to flower as soon as the day length shortens. Under cultivated conditions amaranth produces cumulative fresh leaf yields of up to 40 t ha^{-1} (Jansen *et al.,* 2007).

2.1.2 Spider plant

Spider plant (*Cleome gynandra*) belongs to the Capparaceae family and is an herbaceous, erect, mainly branched plant. In a growing season C. gynandra can reach a height between 0.5 m and 1.5 m, depending on the environment. Stems and leaves are covered with glandular hair. Pigmentation on the stems varies from green to pink and purple. There are different species of spider plant, but *Cleome gynandra* is the most widely used as a leafy vegetable. Other species like *Cleome monophylla* and *Cleome hirta*, which are close relatives, are also used occasionally. Cleome grows best during summer and is sensitive to cold. At temperatures below 15°C it does not grow well. Preferred soil conditions for Cleome are well drained medium-textured soils and its performance is affected by poorly drained or heavy clay soils. It requires full exposure to sunlight and performs poorly when shaded. Cleome grows best when adequately supplied with water. Water stress hastens flowering and senescence consequently reducing yield. Fertilizer use has effects on the plant. For example, when fertilizers containing appreciable amounts of nitrogen are applied flowering is delayed and increases the number and size of leaves. Spider plant can either be harvested by uprooting or ratoon harvesting (Jansen *et al.,* 2007).

The species is a C4 plant, and hence combines efficient water utilization with high photosynthetic capacity at high temperatures (Imbamba 1976). This allows it to grow in areas with short periods of useful rainfall. Spiderplant grow in areas with short periods of useful rainfall and the plants can tolerate some degree of drought.

2.1.3 African nightshade

The African nightshade (*Solanum spp.*) plants are erect, branched and herbaceous plants that can reach a height of 75 cm. They have leaves that alternate and bright green in color but purple pigmentation may be present. Other features of the plant include: shiny, black to purple-black fruit which are used to make jam. The African nightshade plants are mainly found in fairly humid environments with at least 500 mm of rain per annum. They prefer fertile soils with high nitrogen and phosphorus contents (organic soils). The optimal temperature range for growth is between 20°C and 30°C, but most species will tolerate a temperature range of 15°C to 35°C.

The yield potential of African nightshade species depends on several factors which include: type of species, length of the growing season, number of harvests and agro-ecological conditions. Under favorable conditions the cumulative leaf yields of 20 t/ha can be achieved. Yield potential also depends on the plant spacing, nutrient, water supply and pest and diseases control practices (Jansen *et al.,* 2007).

2.2 Use, utilization and importance of AIVs

African Indigenous vegetables possess numerous advantages and potentials which remain underutilized. The vegetables have been identified to be a vital component of human diet as a significant source of essential minerals, proteins and vitamins in western Kenya (Abukutsa-Onyango, 2007a and Musotsi *et al.,* 2008). Other studies have reported medicinal values and health benefits associated with consumption of AIVs. (Olembo *et al.,* 1995).

African leafy vegetables have significant potential as an income earner in the rural communities (Onyango, 2003). According to HCDA (2008), indigenous vegetables contribution to the value of domestic market demand rose from 4% in 2001 to 10% in 2007 without exporting.

2.3 Soil conditions, Water requirement and Nutrient requirement of AIVs

African indigenous vegetables grow best at soil pH range 5.8 to 7.5, of loamy to silty loam texture, with good water holding capacity. It has also been noted that they grow in wide range of soil types and soil moisture levels. These vegetables especially Amaranthus sp. are known to have large leaf surface area and for this reason the plant lose a lot of water through transpiration. The crop can grow during both wet and dry seasons but irrigation is required for dry season. Amaranth sp. can tolerate periods of drought once the plant has become established.

The harvestable part of the plant is the leaf (leafy vegetables). This makes nitrogen a very essential element required in large amounts. There exists synergy between phosphorus and nitrogen uptake hence these plants also require phosphorus in relatively large quantities together with other mineral elements (IPNS/FADINAP). This may serve as an explanation why these plants grow best in organic soils.

2.4. Fertilizer-use in AIVs production

AIVs are low management crop which can grow in poor soils. But for the purpose of increasing yield, replenishing soil fertility and maximizing profits fertilizer-use is fundamental. Integrated soil fertility management whereby both inorganic and organic fertilizers are used together is recommended as a way of improving yield and maintaining soil fertility (AVRDC, 2003; Islam *et al.,* 2011). It has been realized that neither the chemical fertilizer nor organic manure alone can help achieve sustainable crop production

(Islam *et al.,* 2011). The amount of fertilizer that needs to be applied must be accurately determined to avoid resource wastage and soil pollution. Several factors are considered in fertilizer rate determination: soil fertility, soil type, fertilizer recovery rate, and soil organic matter. An initial soil characterization is highly recommended to determine the available N, P, and K. This facilitates calculation of the amount of fertilizer to be applied based on the target yield and adjusted for residual nutrients. Recommended rates of N, P and K application by AVRDC are 94 kg N/ ha applied in split 48 kg pre-plant, 30, 8 and 8, P: 64, 8, and 8, K: 48, 15, and 8 during the growing season (AVRDC, 2003).

A study investigating AIVs' grain production revealed nitrogen as the most limiting nutrient under most environments while phosphorous and potassium are only applied in soils that are especially deficient in these nutrients with the rate of 50 kg P/ha which has been considered optimum after field trials (Nyankanga *et al.,* 2012).

2.5 Soil pH and Liming

Soil pH is a very important chemical property of soil that affects its productivity. It is for this reason that before investing in crop production, soil testing is key, in order to determine soil pH among other properties. Different crops thrive in different soil pH ranges and this calls for amendments such as liming where the soil pH is not within the required range. Soil acidity affects plant nutrient availability especially phosphorus, build-up of toxic elements (Al, Fe, H, Mn) and affects microbial growth (Kisinyo *et al.,* 2012). Effect of soil pH on plant growth varies from soil to soil and from crop to crop. Many elements in the soil change form as a result of reactions taking place in the soil. Under acidic conditions iron (Fe) and aluminium (Al) ions reacts with elements in soil solution such as $H_2PO_4^-$ and HPO_4^{2-} (orthophosphates) while in alkali condition calcium reacts with the soluble ions to form complex insoluble compounds making them unavailable to plants (Kanyanjua *et al*., 2002).

Aluminium toxicity causes reduction in yields of non-acidic tolerant crops. It also affects root development which lowers water and nutrient uptake. In soil pH less than 4.0, the carrier system responsible for potassium translocation is impaired. These adverse effects affect most vegetables (horticultural crops) because they do not tolerate acidity and can only grow well in soils with pH above 6.0. Acid soils can be improved by applying inputs such as fertilizers, lime, manure and composts. These practices require additional costs and labour thus causing an increase in the production cost (Kanyanjua *et al*., 2002).

Liming materials used include: burned lime, calcitic lime, dolomitic lime and hydrated lime. In Kenya Koru lime (20.8% CaO) is the most common liming material. It is available in large quantities but transportation and ignorance are the limitations to its use. Lime neutralizes soil acidity in two ways, calcium replacing hydrogen and aluminium ions in the exchange sites by mass action and CO^{-}_{3} neutralizing the H^{+} in solution. This leads to rise in the percentage base saturation (Kisinyo *et al*., 2012). Several factors inform the farmer how much lime to apply: the present soil pH, the desired pH, the soil CEC and the neutralizing power of the liming material.

Recommended rate of lime application in western Kenya is 2 tonnes per hectare (Osundwa *et al.,* 2013). The agricultural lime used is Koru lime which has 20.8% CaO. Lime requirement can therefore be adjusted according to the desired pH. This can be achieved by using various equations or spreadsheets developed to make refinements in limestone recommendations (IIT, 2012). The spreadsheet requires inputting of the values of desired pH and the soil depth the lime will be incorporated. The Mehlich buffer method determines the lime required to neutralize the extractable acidity (Ac). Extractable acidity is the acidity that limits crop growth (IIT, 2012).

$CaCO_3$ tons/ha=Ac (Desired pH- soil pH)/ (6.6-soil pH) –Mehlich equation.

CHAPTER THREE

MATERIAL AND METHODS

3.1 General description

Two studies (agronomic and soil pH trials) were conducted to meet the objectives mentioned in chapter one. The agronomic study was carried out in two counties of Kenya, Trans Nzoia (KARI Kitale) and Uasin Gishu (University of Eldoret farm) while the soil pH study was conducted in Uasin Gishu County only. This chapter describes the sites, experimental design, layout and the general experimental methods which include: soil and manure analysis, determination of lime requirement, land preparation, seeding and spacing, fertilizer placement and lime application methods and the crop management practices.

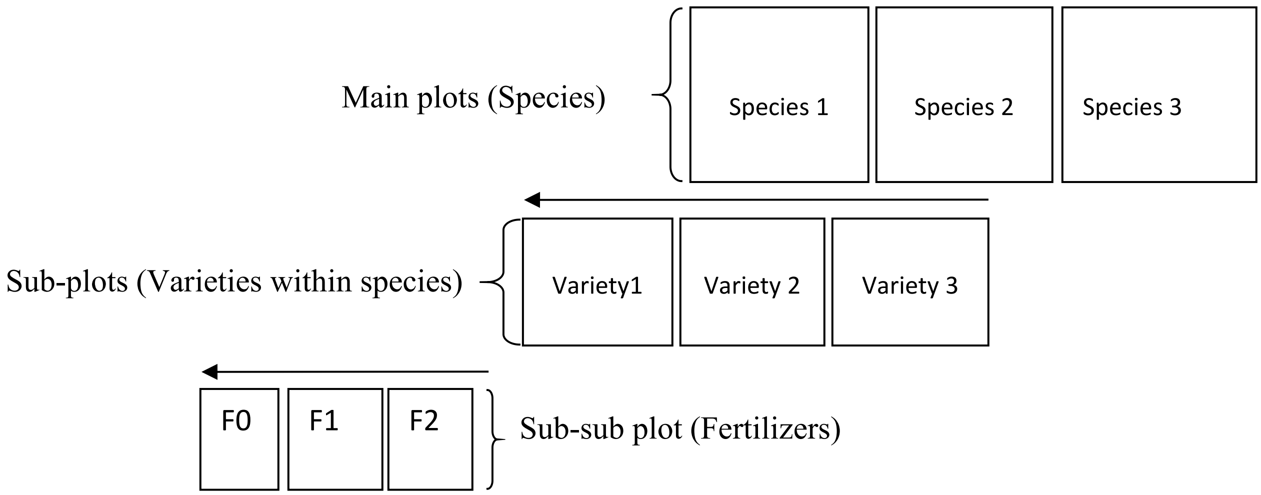
3.2 Site description

The field experiment sites were University of Eldoret farm, Uasin Gishu County (0.57° N 35.30 ° E and 2150 m elevation) and KARI Kitale, Trans Nzoia County (0.99°N 34.99° E and 1848m elevation). The soil types in the two sites are Orthic Ferralsols and hence the problem of soil acidity due to Fe, Al and Mn oxides being the resident elements. The areas have a unimodal rainfall pattern with a peak in March and May a dry period occurs in the months of October and December (Jaetzold *et al., 2005*).

3.3 Experiment design and layout

In the agronomic study, two developed varieties from Asian Vegetables development Research Centre (AVRDC) and a local variety sourced from the local market of *Cleome gynandra*, *Solanum scabrum* and *Amaranthus spp.* were used. The varieties were {amaranths: Ex-Zim (A_1), UG-AM-40 (A_2), and LV-AM (A_3)}, {spiderplant: ML-SF-29 (S_1), UG-SF-15 (S_2), LV-SP (S_3)} and {nightshade: BG-16 (N_1), SS-49 (N_2), and LV-NS (N_3)}. They were all treated with poultry manure, mavuno (10:26:10) planting fertilizer and zero fertilizer to give an experiment with 27 (3×3×3) treatments combinations in three replications. Treatments were arranged in a split-split plot layout whereby the AIVs type formed the main plot treatment while the variety formed the sub-plot treatments and fertilizer formed the sub-sub plot treatment (figure 3.1). Soil pH at Eldoret site was adjusted to 5.5 through liming because initial soil analysis indicated it was below 5.4 (refer table 4.1). In the soil pH study, a selected developed variety of each AIV type (spiderplant; PS 2012, nightshade; Ex-hai 2012 and amaranthus; Ex-Mwanga 2012) was tested against three lime rates (L0, L1 and L2 (3×3). One level of N-94 kg/ha from an organic source (poultry manure) was used in all the treatments. The 9 treatments "species lime rate combinations" were designated as: AL_0, AL_1, AL_2, NL_0, NL_1, NL_2, SL_0, SL_1 and SL_2 and were replicated three times, each replicate had 3 main plots whereby the liming rate treatment (L_0, L_1, L_2) was allocated and within the main plot were three sub-plots (figure 3.2) and their effect on the biomass accumulation, nutrient uptake, soil nutrient content and root growth (root biomass and root length density) at harvesting stage established.

3.3.1 Agronomic study

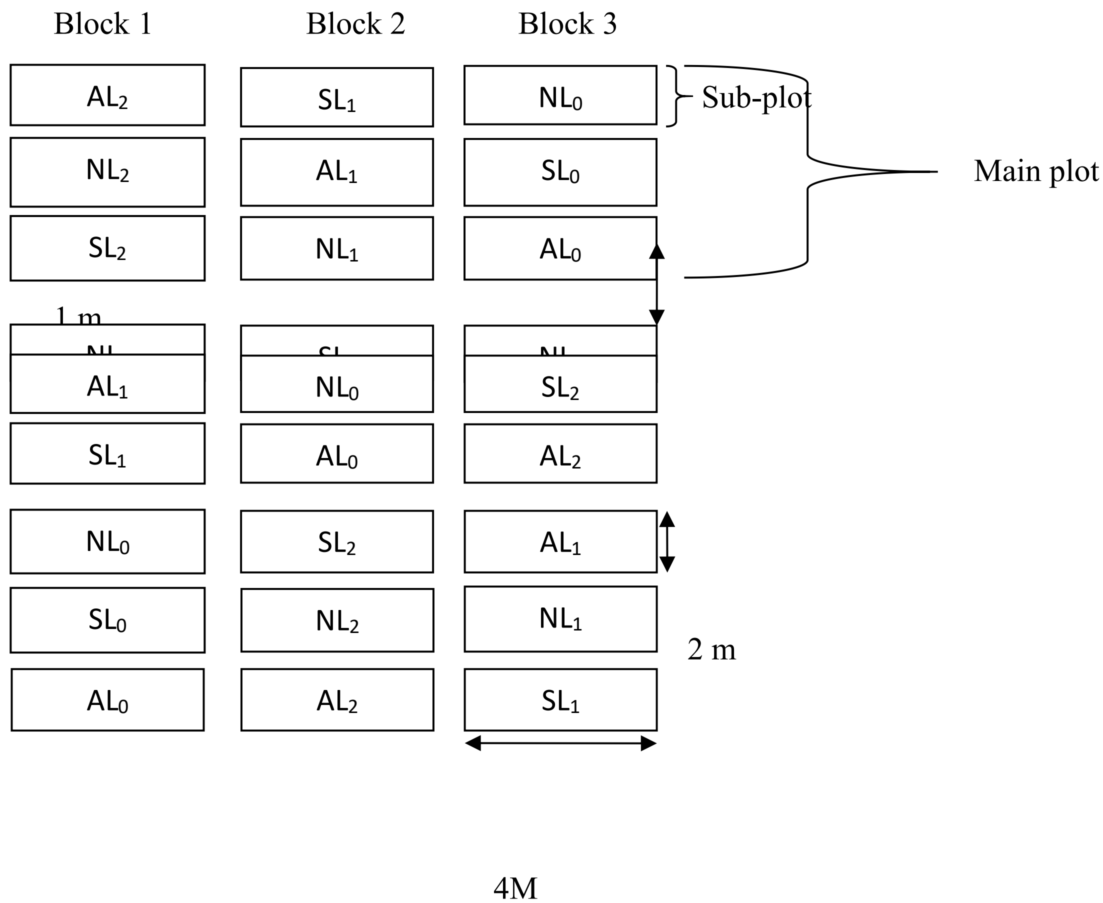


Key: FO-Zero fertilizer (control), F1-Mavuno fertilizer (10:26:10 plus TE) and F2-Poultry manure.

Figure 3.1: Experiment layout of the agronomic trial.

NB: There were three (3) blocks. Randomization was in three levels; species were assigned randomly in the main plots within the blocks. Varieties were assigned randomly in the sub plots within the main plots while fertilizers were assigned randomly within each sub-sub plot.

3.3.2 Soil pH study



Key: A-Amaranthus, N-African nightshade, S-Spiderplant, L_0-zero liming, L_1-liming rate 2t/ha, and L_2-lime rate 4.1625t/ha.

Figure 3.2: Experimental layout of the soil pH study

3.4 Soil and manure analysis

Soil samples at 20 cm depth were taken from the experimental plot before treatment application. Soil analysis was carried out according to Okalebo *et al.,* (2002) laboratory manual whereby total N%, available P, pH (H_20), Ca, Mg, Fe, Cu, Mn, K, organic carbon and soil texture were determined. Like soil, a representative manure sample was obtained from which pH and macro elements Nitrogen (N) and Phosphorus (P) were analyzed according to Okalebo *et al.,* (2002) laboratory manual.

3.5 Determination of lime requirement

From the measured soil pH and the textural class the lime requirement was determined so as to adjust the initial soil pH to the target pH of 5.5 (L_1) and 6.5 (L_2) in the soil pH study and 5.5 for the agronomic trial. Lime rate zero (L_0) was the control experiment unit where the initial pH was maintained. In calculating the lime requirement the necessary information such as tonnes of Calcium Carbonate Equivalent (CCE) recommended per Acre for vegetable types with a Target pH of 5.2 and Target pH of 6.5 were provided in tables 3.1 and 3.2 (Ghidiu *et al*., 2013).

Table 3.1: Tonnes of Calcium Carbonate Equivalent (CCE) recommended per hectare for Crops with a Target pH of 6.5.

	Soil Texture and Fertility				
Initial Soil pH	**Loamy Sand**	**Sandy Loam**	**Loam**	**Silt Loam**	**Clay Loam**
4.1-4.4	4.86	5.83	10.58	12.52	25.16
4.5-4.8	3.89	4.86	8.75	10.58	20.30
4.9-5.2	2.92	3.89	6.80	8.75	16.42
5.3-5.6	1.94	2.92	4.86	6.80	13.5
5.7-6.0	0.97	1.94	3.89	4.86	8.75
6.1-6.4	0.54	0.97	1.94	3.89	5.83
Above 6.5	0	0	0	0	2.92

Table 3.2: Tonnes of Calcium Carbonate Equivalent (CCE) recommended per

ha for Crops with a Target pH of 5.2

	Soil Texture and Fertility			
Initial Soil pH	**Loamy Sand**	**Sandy Loam**	**Loam**	**Silt Loam**
4.5	0.68	1.07	1.46	1.93
4.6	0.58	0.87	1.25	1.35
4.7	0.49	0.68	1.02	1.35
4.8	0.39	0.58	0.82	1.07
4.9	2.92	0.49	0.58	0.82
5	0.19	0.29	0.43	0.53
5.1	0.10	0.11	0.19	0.29
5.2	0	0	0	0

Equation 3.1: Actual amount of liming material = (Soil test CCE recommendation) / (% CCE of liming material) X 100. (Ghidiu *et al.,* 2013).

3.6 Cultural operations

3.6.1 Land preparation, seed sowing and spacing

In both studies, direct seeding was done in raised beds 20 cm high, plot sizing (8 square meters) and spacing is per AVRDC recommendation for AIVs studies. Plots were raised after ploughing and harrowing until a fine tilth was obtained. Seeding rate was 0.5 g per plot which is equivalent to 600 g per hectare. Spacing: Nightshade; 40 cm between plants and 60 cm between rows within the bed while for Spiderplant and Amaranth; 25 cm between plants and spacing between row 60 cm. Seeds were placed on the rows were covered with a thin layer of fine soil and watering done thereafter.

3.6.2 Fertilizer application and liming

3.6.2.1 Lime application

Where soil pH was less or equal to 5.4 liming preceded fertilizer application and planting. Determined lime requirement was broadcast on the entire plot and incorporated into the soil 20cm depth using a rake and thorough watering done thereafter to facilitate quick reaction. Fifteen (15) days after liming, routine soil pH measurements were taken to monitor the extent of reaction within the 20 cm ploughed layer.

Using nitrogen (N) as the base element, fertilizer rates were calculated as follows:

3.6.2.2 Fertilizer rates and application

3.6.2.2.1 Mavuno fertilizers

For the mineral fertilizer (Mavuno): AVRDC recommended an NPK with 20% N at a rate of 250 kg/ha. Unfortunately this was not available in the market and the closest match fertilizer with similar composition was Mavuno planting (10:26:10 plus TE). Using N as the base element in determining the amount to apply the consequent rate was 500 kg/ha of mavuno planting. This supplied: 0.4 kg or 400 g /8 square meter plot. Supplying nutrients at the rate of 50 kg N/ha, and 130 kg P_2O_5/ha.

3.6.2.2. 2 Poultry manure

For manure the recommended application rate was an amount equivalent to supplying 94 kg N/ha. Using the measured attributes and N as base element: % N-1.86, % P-2.68. Application rate was 4 kg/ 8 square metre plot. But the N rates differ in organic and inorganic fertilizer treatments. This brings in the concept of N mineralization in manure which it has been reported to be between 30 to 70% of the measured N i.e. an average of

50%. Having this in mind supplied nutrients through poultry manure application: 47 kg N/ha, and 135 Kg of P_20_5.

The calculated fertilizer amounts were applied evenly on the treated plots while control plots received no fertilizer. The fertilizer was spread evenly on the shallow rows marked using a sharp stick. The calculations to determine fertilizer amounts are showed in appendix 1 and 2.

3.6.3 Crop management and harvesting

The plots were kept weed free at all times and irrigation was used to maintain stress free moisture conditions. This was achieved using a soil moisture probe to monitor soil moisture and maintain moisture levels at ≥50% of the field capacity of the soil.

Harvesting was done after the crop had developed 6 to 10 leaves whereby any biomass above four leaves/clusters from bottom was plucked and weighed promptly. Data on yield was obtained from a 1.5 m^2 quadrants of the 8 m^2 plot. Harvesting was done in two weeks interval.

3.7 Data collection

In the agronomic study data was collected on cumulative fresh yield while on the pH study was collected on above ground biomass fresh and dry biomass, root biomass, chlorophyll content and nutrient concentration in the plant tissue at flowering.

3.8 Data analysis

Data were analyzed using SAS Statistical software version 9.3 (SAS Institute Inc, 2012). Data collected were statistically evaluated by analysis of variance (ANOVA) using the general linear model; PROC GLM procedure (SAS, 2012). Least Significant Difference (LSD) test was used to separate treatment means significant at 95 % confidence level (Steel & Torrie, 1981). Tables 3.3 and 3.4 give the skeleton ANOVAS of the two experiments.

3.8.1 Statistical models

3.8.1.1 Agronomic trial

$$Y_{ijkl} = \quad + B_i + S_j + \varepsilon_{ij} + V_k + SV_{ik} + \varepsilon_{ijk} + F_l + SF_{jl} + VF_{kl} + SVF_{jkl} + \varepsilon_{ijkl}$$

Where:

= the general mean

B_i = effect due to Block i

S_j = effect due to vegetable Species j

ε_{ij} = main plot error

V_k = effect due to Variety k

SV_{ik} = interaction between vegetable Species j and Variety k

ε_{ijk} = subplot error

F_l = effect due to l^{th} fertilizer type

SF_{jl} = effect due to vegetable Species j and l^{th} fertilizer type

VF_{kl} = effect due to Variety k and l^{th} fertilizer type

SVF_{jkl} = effect due to vegetable Species j, Variety k and l^{th} fertilizer type

ε_{ijkl} = the random error effect

Table 3.3: ANOVA skeleton: Agronomic trial (RCBD in a split-split plot arrangement)

Sources of Variation	***Degrees of freedom***
Blocks (B)	2
Species (S)	2
Whole plot error (s)= B*S	4
Varieties (V)	2
Interaction (S*V)	4
Split plot error (v)=B*V+B*S*V	12
Fertilizer (F)	2
S*F	4
V*F	4
S*V*F	8
Sub-sub plot error (f)=Residual Error	36
Total	**80**

3.8.1.2 Liming trial

$$Y_{ijkl} = \quad + R_i + S_j + \varepsilon_{ij} + L_k + SL_{ik} + \varepsilon_{ijk}$$

Where:

= the general mean

B_i = effect due to Block i

S_j = effect due to vegetable Species j

ε_{ij} = main plot error

L_k = effect due to Variety k

SL_{ik} = interaction between vegetable Species j and Variety k

ε_{ijk} = subplot error

Table 3.4: ANOVA skeleton-Liming trial (RCBD in a split plot arrangement)

Sources of Variation	***Degrees of freedom***
Block (B)	2
Liming regime (L)	2
Whole plot error (l)=(R*L)	4
Species (S)	2
Liming*Species (L*S)	4
Sub plot error (s)=R (L*S)	12
Total	**26**

CHAPTER FOUR

Effects of poultry manure and Mavuno fertilizers on the agronomic potential of African Indigenous Vegetables (AIVs) in Uasin Gishu and Trans Nzoia Counties, Rift Valley

Abstract

Continuous cropping over a long period of time with little or no fertilizer use among other factors for example, soil acidity has led to decline in soil fertility. Two field trials were conducted during the rainy season and dry season, which was between July 2013 and March 2014 under drip irrigation at Kenya Agricultural Research Institute, Kitale and School of Agriculture and Biotechnology Farm, University of Eldoret in Trans Nzoia and Uasin Gishu Counties respectively. The aim of the study was to determine the effects of poultry manure and Mavuno fertilizers on the cumulative yield of the selected varieties of spiderplant (*Cleome gynandra*), black nightshade (*Solanum nigrum*) and *Amaranthus spp*. The treatments consisted of rates recommended by AVRDC, 94 kg N/ha for poultry manure fertilizer and 500Kg/ ha of mavuno planting (10:26:10+Trace elements) and zero fertilizer, and three varieties of each AIV type. The soil pH was adjusted to 5.5 through liming where it was found to be less than 5.4 (the Eldoret site was limed to increase pH to 5.5). The experiment was laid out in RCBD in a split-split-plot arrangement with three replications. The species (Amaranthus, Spiderplant and African nightshade) formed the main plot treatments while the variety formed sub-plots while fertilizer formed the sub-sub-plot treatments. Data was collected on the cumulative fresh leaf yields, initial and final nutrient contents in the soil. Results showed that fertilizer use increased yields

significantly in all the varieties of the three AIVs. In African nightshade, developed variety BG-16 with mavuno fertilizer had the highest mean cumulative yields in Eldoret (998 g/m^2) and Kitale (1,388 g/m^2). In Amaranths, developed variety UG-AM-40 with poultry manure recorded the highest yields in Eldoret (449 g/m^2) and Kitale (606 g/m^2). In spiderplant, local variety (LV-SP) and developed variety (UG-SF-15) recorded highest yields with mavuno fertilizer while developed variety ML-SF-29 had highest yields in Eldoret (260 g/m^2) and Kitale (383 g/m^2) with poultry manure. The study concluded that yields of AIVs will greatly increase with utilization of improved germplasm and use of appropriate fertilizer. To achieve high yields in both counties consider variety-fertilizer combinations BG-16 F1, UG-AM-40F2 and LV-SPF1 in African nightshade, Amaranthus and Spiderplant respectively.

4.1 Introduction

Most farmers in Africa practice low-input agriculture that depends on inherent fertility to sustain production (Woomer *et al*., 1994). Unfortunately, effects of the human-induced declining soil fertility are particularly felt in Africa where the majority of the population entirely depends on agriculture (Oldeman, 1992). This has culminated to the continued decline in soil fertility since to a greater extent agriculture in the continent is soil-based. Soil-based agriculture can only be made sustainable when all the stakeholders understand the nutrient requirements of the subject crop. Soil constraints among other agronomic related challenges have made it difficult to increase productivity of AIVs to meet the increasing demand accrued to population explosion. Increase in productivity can only be achieved when plants are supplied with adequate and balanced proportions of the nutrients.

However, there is limited scientific knowledge on many aspects of production and fertilizer requirement of traditional vegetables (IPGRI, 1997, Mhontlo, *et al*., 2007).

Timely intervention for example, fertilizer use and liming to amend the nutrient composition in the soil available for uptake by plants is mandatory. A study conducted in Nyanza revealed that lack of fertilizer use was one of the major constraints of production of the African leafy vegetables (Onyango *et al.,* 2000).

Use of Fertilizer increases total yields of vegetables (Demchack & Smith, 1990). Availability of essential nutrients such as N, P, and K in adequate amounts causes substantial increases in yield and growth of Amaranthus (Ainka *et al.,* 2012). However, crops differ in their response to fertilizer application. Soil pH, fertilizer amount and placement are among the key factors that affects efficiency of nutrient uptake in the soil. Low soil pH (<5.4) affects availability of essential nutrients such as P, N, K, Bo, Mn, and Zn. Previous studies revealed that fresh leaf yields of Amaranthus increases with N-fertilization up to until 90 kg N/ha, 40 kg/ha P_2O_5 and 40 kg/ha K_2O (Bahrat *et al.,* 1996: Rana and Rameswar., 2003). Kipkosgei *et al.,* 2003, reported that yields of *Solanum villosum* (black night shade) where farmyard manure (5, 10, 15, 20 t/ha) was used were generally higher than those with mineral fertilizer. These authors further stated that farmer's conventional methods (use of fertilizer in low amounts) though better than treatments with zero fertilizer were comparable. The latter was also observed in a study whereby all fertilizer treatments increased total yields of broccoli (Demchak & Smith, 1990). This study sought to establish the best fertilizer variety combinations in each AIV type.

4.3 Material and methods

4.3.1 Experiment site

The field experiment sites were University of Eldoret farm, Uasin Gishu County (0.57° N 35.30 ° E and 2140 m elevation) and KARI Kitale, Trans Nzoia County (0.99°N 34.99 1848 m elevation). The soil types in the two sites are Orthic Ferralsols and Acrisols in Uasin Gishu and Trans Nzoia respectively. The areas have a unimodal rainfall pattern (Jaetzold *et al*., 2005).

4.3.2 Initial soil sampling and characterization

Soil samples at 20 cm depth were taken from the experimental plot before treatment application whereby the samples were bulked and a composite sample obtained for lab analysis. Soil samples were analyzed for soil pH (Soil H_2O; 1:2.5-potentiometric method), soil texture using the hydrometer method, total carbon (%)-wet oxidation method and total nitrogen (%) using the colorimetric method and available phosphorus using the Olsen method (Okalebo *et al.,* 2002).

4.4 Experimental design and layout

The study involved three AIVs types' spider plant, African nightshade, and Amaranthus. Three varieties were selected from each type (2 improved varieties from AVRDC and a local variety sourced from the market): amaranths; Ex-Zim (A_1), UG-AM-40 (A_2), LV-AM (A_3), spiderplant; ML-SF-29 (S_1), UG-SF-15 (S_2), LV-SP (S_3), nightshade; BG-16 (N_1), SS-49 (N_2), LV-NS (N_3). These varieties were treated with an organic (F_2-poultry manure; locally available), inorganic fertilizer (F_1-mavuno planting; available in the market) and no fertilizer (F_0). Treatments were arranged in a split-split plot layout whereby the AIVs species formed the main plot treatment while varieties formed the sub-plot treatments while fertilizers formed the sub-sub plot treatments. Soil pH was adjusted to 5.5 where it was below 5.4 using a calcitic lime from Athi river mining company. Calculations on the amount of lime applied refer to appendix 3.

4.5 Data collection and analysis

The data collected was analyzed using SAS Statistical software version 9.3 (SAS Institute Inc, 2012). Least Significant Difference (LSD) test was used to separate treatment means significant at 95 % confidence level.

4.6 **Results**

4.6.1: Initial soil characterization

Uasin Gishu (Eldoret) soils are strongly acid while Trans Nzoia (Kitale) soils are moderately acid. Both soils contained low nitrogen content (%N) and were deficient in both zinc (Zn) and copper (Cu). Both soils were found to be sandy loam.

Table 4.1: **soil chemical properties before planting**

Soil characteristics				Macro nutrients					Micro nutrients			
Site	**Soil texture**	**pH**	**C** (%)	**N** (%)	**P** Mg kg^{-1}	**K** Mg-$cmol_c$ kg^{-1}	**Ca** Mg-$cmol_c$ kg^{-1}	**Mg** Mg-$cmol_c$ kg^{-1}	**Mn** ppm	**Zn** ppm	**Cu** ppm	**Fe** ppm
Uasin Gishu	Sandy Loam	4.96 (S. A)	2.29 (M)	0.14 (L)	12 (M)	1070 (H)	1470 (Md)	336 (V.h)	120 (M)	5 (D)	2 (D)	19 (S)
Trans Nzoia	Sandy Loam	5.29 (M.A)	2.67 (M)	0.19 (L)	5 (M)	1720 (H)	263 (V.l)	359 (V.h)	46 (L)	2 (D)	6 (D)	31 (S)

NB: Rating on nutrient content adopted from Thomas et.al, (1997), (**S.A-strongly acid, M.A-moderately acid, M-moderate, H-high, Md-medium, V.l-very low, V.h-very high, D-deficient, S-sufficient).**

4.6.2 Cumulative fresh yield of African Nightshade

4.6.2.1 Effects of variety on cumulative fresh yield of African nightshade

4.6.2.1.1 Uasin Gishu County-Eldoret site

Means for cumulative fresh yield of African nightshade in Eldoret are presented in table 4.2.During the dry season, there were significant differences (p=0.05) observed in the mean cumulative fresh yield in all varieties of African nightshade in Eldoret. In the wet season, significant differences were observed between the developed varieties (BG-16 & SS-49) and the local variety (LV-NS).

Table 4.2: Mean cumulative fresh yield of three varieties of African nightshade in Eldoret.

Variety	Dry season Yield (g/m^2)	Wet season Yield (g/m^2)
LV-NS	437.56a	219.78a
BG-16	854.78b	459.67b
SS-49	628.89c	426.11b
Lsd	91.54	42.44
CV%	13.92	11.21

Means with different letters in the column are significantly different at *P≤ 0.05.*

During the dry season, the mean cumulative fresh yields of BG-16 variety were significantly higher than those of SS-49 variety. The fresh yields of both varieties were significantly higher than those of the local variety. In the wet season, there was no significant difference in the mean cumulative fresh yields of BG-16 and SS-49 varieties. However, the yields of the two varieties were significantly higher than those of the local variety.

4.6.2.1.2 Trans Nzoia County-Kitale site

Means for cumulative fresh yield for African nightshade in Kitale are presented in table 4.3. There were significant differences (p=0.05) observed in the mean cumulative fresh yield of the three varietes of African nightshade in the dry season. In the wet season, the developed varieties had significantly higher yields than the local variety while their yields were not significantly different.

Table 4.3: Mean cumulative fresh yield of three varieties of African nightshade in Kitale.

Variety	Dry season Yield (g/m^2).	Wet season Yield (g/m^2).
LV-NS	529.00a	276.11a
BG-16	1073.56b	611.22b
SS-49	816.67c	545.11b
Lsd	120.87	66.47
CV%	14.59	13.55

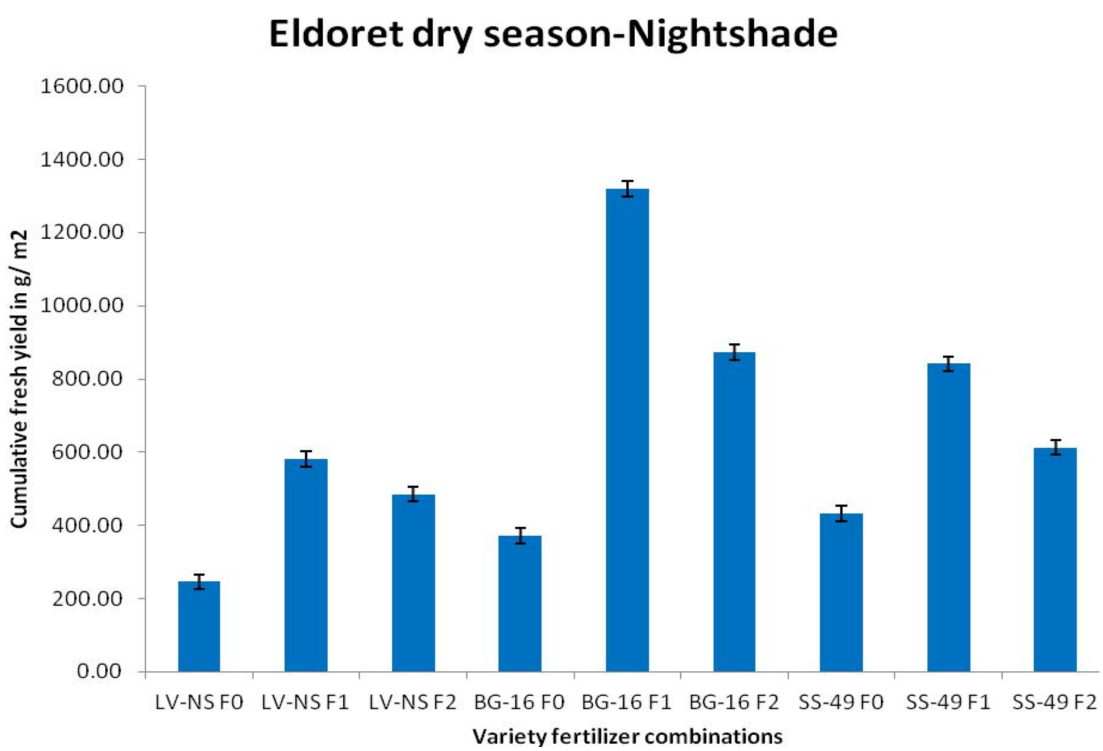
Means with different letters in the column are significantly different at $P \leq 0.05$.

In the dry season, the mean cumulative fresh yields of BG-16 variety were significantly higher than that of SS-49 variety which were also significantly higher than those of the local variety. In the wet season, the cumulative fresh yields of BG-16 and SS-49 varieties had significantly higher yields than those of the local variety while their yields were not significantly different.

4.6.2.2 Effect of fertilizers in cumulative fresh yield of African nightshade

4.6.2.2.1 Uasin Gishu County-Eldoret site

Effects of fertilizer on cumulative fresh yield of African nightshade in Eldoret during the dry season (figure 4.1) and wet season are showed in figures 4.1 and 4.2 respectively.There were significant differences observed in the mean cumulative fresh yield of African nightshade in the dry season in Eldoret. In all the three African nightshade varieties, mavuno fertilizer had significantly higher yields compared to poultry manure and the control treatment. Poultry manure had significantly (p=0.05) higher yields than the control.



Key: LV-NS (Local variety African nightshade), F0-Zero fertilizer, F1-Mavuno and F2-Poultry manure.

Figure 4.1: Mean cumulative fresh yield (g/m^2) of African nightshade in Eldoret during the dry season. Error bars represent the standard error of the mean.

In the local variety, the mean cumulative fresh yield of mavuno fertilizer (581 g/m^2) was significantly ($p=0.05$) higher than that of poultry manure (485 g/m^2). Both mavuno fertilizer and poultry manure were significantly higher than that of the control of 246 g/m^2. In BG-16 variety, the mean cumulative fresh yield of mavuno fertilizer (1320 g/m^2) was significantly higher than that of poultry manure (872 g/m^2) which was also significantly higher than that of the control (371 g/m^2). In the SS-49 variety, the mean cumulative fresh yield of mavuno fertilizer (841 g/m^2) was significantly higher than that of poultry manure (613 g/m^2). The cumulative fresh yield of poultry manure was higher than that of the control (432 g/m^2).

In the wet season (figure 4.2), significant differences ($p=0.05$) were also observed in the mean cumulative fresh yield of the three varieties of African nightshade in Eldoret. The yields from mavuno fertilizer were significantly higher than those of poultry manure and control. Poultry manure yields were also significantly higher than those of the control.

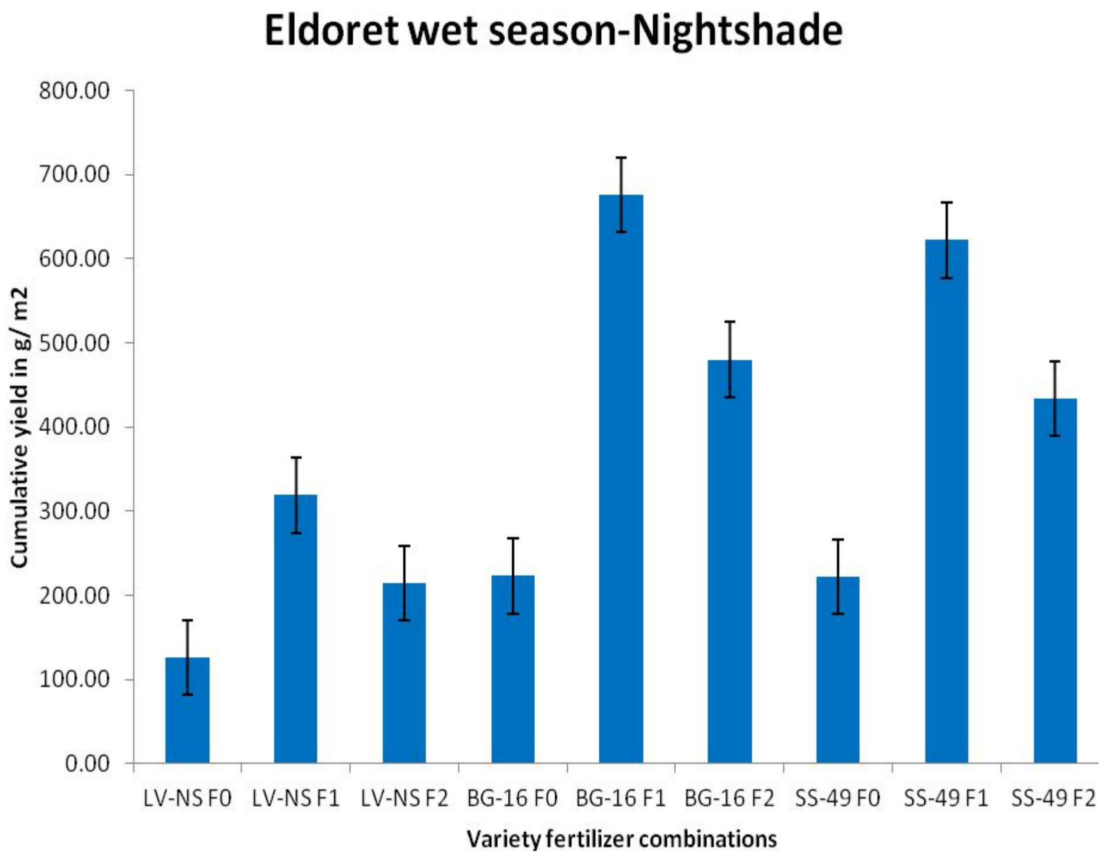
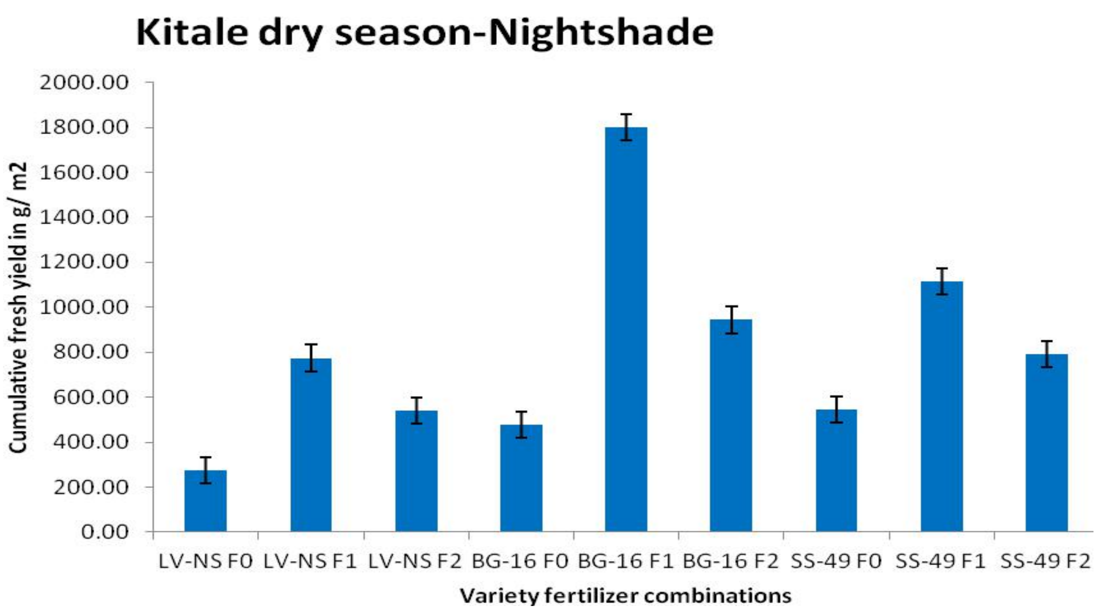


Figure 4.2: Mean cumulative fresh yield (g/m^2) of African nightshade in Eldoret during the wet season. Error bars represent the standard error of the mean.

In the local variety, the mean cumulative fresh yields of both mavuno fertilizer and poultry manure were significantly (p=0.05) higher than that of the control of 126 g/m^2. The mean cumulative fresh yield of mavuno fertilizer (319 g/m^2) was significantly higher than that of poultry manure (214 g/m^2). In the BG-16 variety, the mean cumulative fresh yield of mavuno fertilizer (676 g/m^2) was significantly higher than that of poultry manure of 480 g/m^2. The cumulative fresh yield of poultry manure was higher than that of the control (223 g/m^2). In SS-49 variety, the mean cumulative fresh yield of mavuno fertilizer (622 g/m^2) was significantly higher than that of poultry manure (434 g/m^2) which was also significantly higher than that of the control (222 g/m^2).

4.6.2.2.2 Trans Nzoia County-Kitale site

Effects of fertilizer on cumulative fresh yield of African nightshade in Kitale as presented in figure 4.3 and 4.4 during the dry season and wet season respectively. There were significant differences (p=0.05) observed in the mean cumulative fresh yield of African nightshade in the dry season in Kitale as shown in figure 4.3 below. In all the three African nightshade varieties, mavuno fertilizer had significantly higher yields than poultry manure and the control. Poultry manure also had significantly higher yields than the control.



Key: LV-NS (Local variety African nightshade), F0-Zero fertilizer, F1-Mavuno and F2-Poultry manure.

Figure 4.3: Mean cumulative fresh yield (g/m^2) of African nightshade in Kitale during the dry season. Error bars represent the standard error of the mean.

In the local variety, the mean cumulative fresh yield of mavuno fertilizer (773 g/m^2) was significantly (p=0.05) higher than that of poultry manure (540 g/m^2). Both mavuno fertilizer and poultry manure had significantly higher mean cumulative yields than that of the control of 273 g/m^2) . In BG-16 variety, the mean cumulative fresh yield of mavuno fertilizer (1799 g/m^2) was significantly higher than that of poultry manure (943 g/m^2) which was also significantly higher than that of the control (478 g/m^2). In the SS-49 variety, the mean cumulative fresh yield of mavuno fertilizer (1114 g/m^2) was significantly higher than that of poultry manure of 791 g/m^2) . The mean cumulative fresh yield of poultry manure was higher than that of the control (544 g/m^2).

In the wet season (figure 4.4), significant differences at p=0.05 were also observed in the mean cumulative fresh yields of the three varieties of African nightshade in Eldoret. The yields from mavuno fertilizer were significantly higher than those of poultry manure and control. Poultry manure mean cumulative yield was also significantly higher than that of the control.

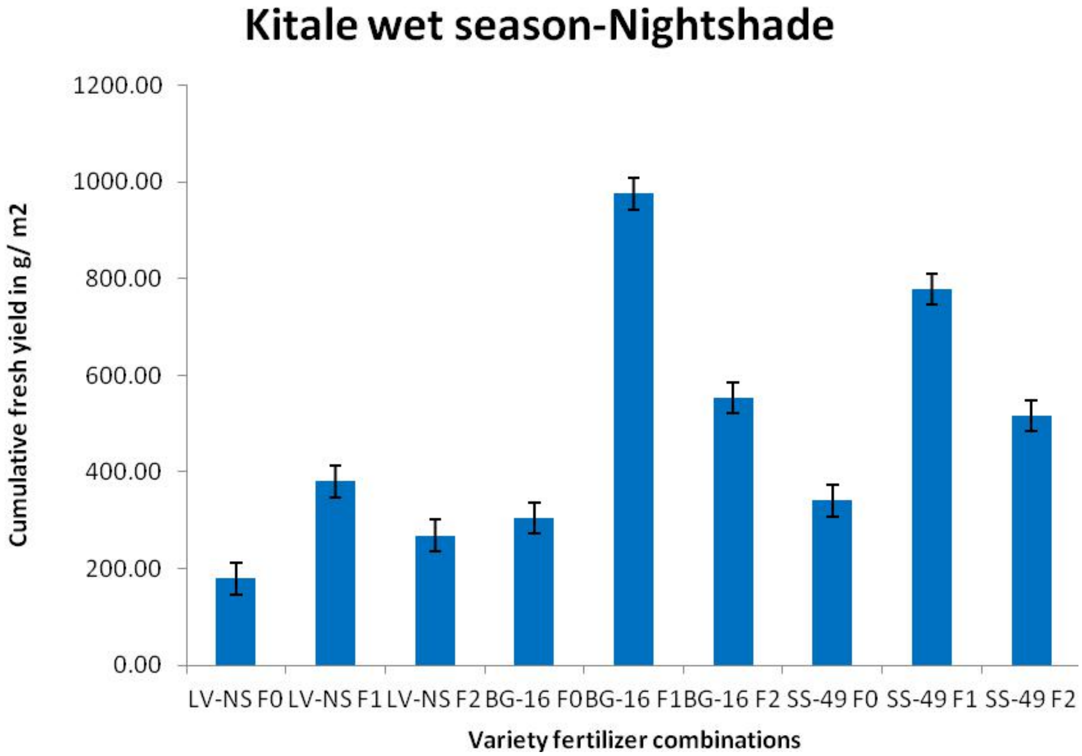


Figure 4.4: Mean cumulative fresh yield (g/m^2) of African nightshade in Kitale during the wet season. Error bars represent the standard error of the mean.

In the local variety, the mean cumulative fresh yield of mavuno fertilizer (380 g/m^2) was significantly higher (P=0.05)than that of poultry manure (268 g/m^2) . The mean cumulative fresh yield of poultry manure was higher than that of the control (179 g/m^2). In the BG-16 variety, the mean cumulative fresh yields of both mavuno fertilizer and poultry manure were significantly higher at p=0.05 than those of the control of 305 g/m^2) . The mean cumulative fresh yield of mavuno fertilizer (975 g/m^2) was significantly higher than that of poultry manure (553 g/m^2). In SS-49 variety, the mean cumulative fresh yield of mavuno fertilizer (779 g/m^2) was significantly higher than that of poultry manure (515 g/m^2) which was also significantly higher than that of the control treatment (340 g/m^2).

4.6.3 Cumulative fresh yield of amaranthus

4.6.3.1 Effects of variety on cumulative fresh yield of amaranthus

4.6.3.1.1Uasin Gishu County-Eldoret site

Means for cumulative fresh yield of African nightshade in Eldoret are presented in table 4.4. There were significant differences (p=0.05) observed in the mean cumulative fresh yields of the three varieties of *Amaranthus spp* both in the dry season and the wet season.

Table 4.4: Mean cumulative fresh yield of three varieties of amaranth in Eldoret.

	Dry season	**Wet season**
Variety	**Yield**	**Yield**
LV-AM	359.74a	284.33a
EX-ZIM	443.44b	333.89b
UG-AM-40	552.89c	429.11c
Lsd	57.85	47.16
CV%	12.46	13.15

Means with different letters in the column are significantly different at $P\leq 0.05$.

In both seasons, UG-AM-40 variety had significantly higher yields than that of EX-ZIM variety. Both developed varieties had significantly higher yields than the local variety in both seasons.

4.6.3.1.2 Trans Nzoia County-Kitale site

Means for cumulative fresh yield of African nightshade in Kitale are presented in table 4.5. There were significant differences (p=0.05) observed in the mean cumulative fresh yield of the three varietes of *Amaranthus spp* in the dry season. In the wet season the developed varieties had significantly higher yields than the local variety while their yields were not significantly different.

Table 4.5: Mean cumulative fresh yield of three varieties of amaranthus in Kitale.

Variety	Dry season Yield (g/m^2)	Wet season Yield (g/m^2)
LV-AM	359.78a	211.22a
EX-ZIM	443.44b	291.00b
UG-AM-40	552.89c	287.22b
Lsd	57.85	66.47
CV%	12.46	13.55

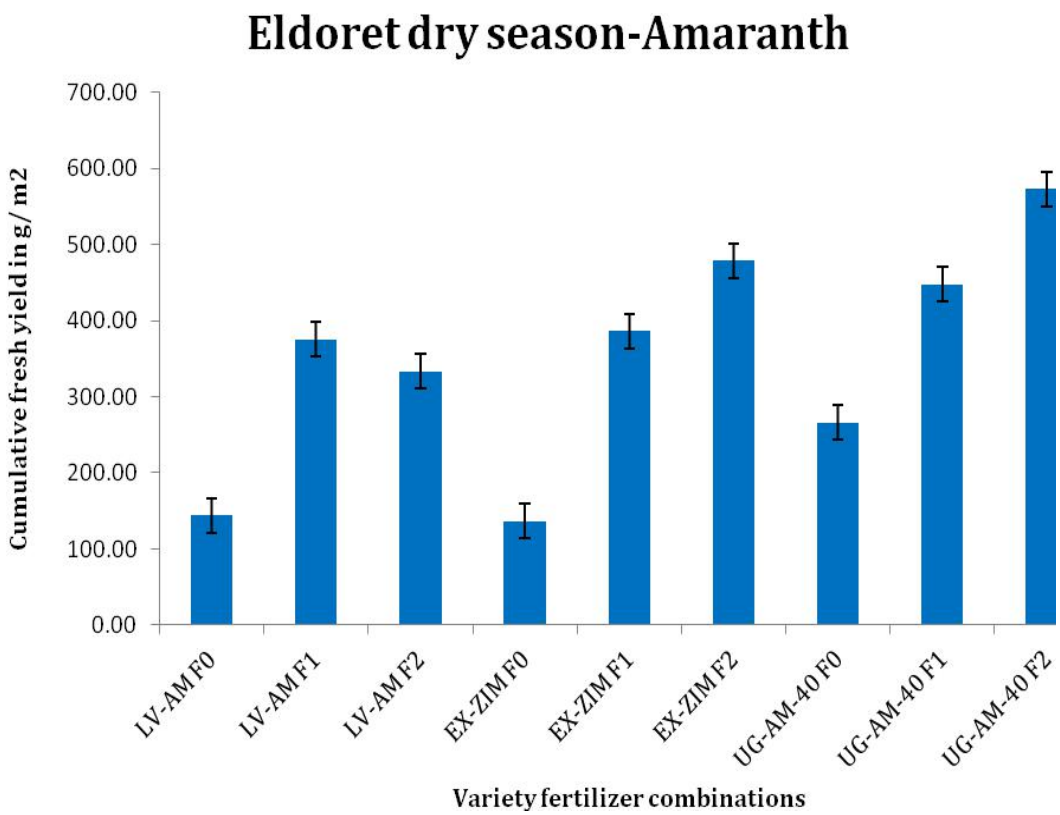
Means with different letters in the column are significantly different at $P \leq 0.05$.

In the dry season, the mean cumulative fresh yields of UG-AM-40 variety were significantly higher than those of EX-ZIM variety. The fresh yields of both varieties were significantly higher than those of the local variety. In the wet season, there was no significant difference in the mean cumulative fresh yields of UG-AM-40 and EX-ZIM varieties. However, the yields of the two varieties were significantly higher than those of the local variety.

4.6.3.2 Effect of fertilizers on cumulative fresh yield of amaranthus

4.6.3.2.1 Uasin Gishu County-Eldoret site

Effect of fertilizer on cumulative fresh yield of Amaranthus in Eldoret during the dry season and wet season are showed in figures 4.5 and 4.6 respectively. There were significant differences observed in the mean cumulative fresh yield of amaranthus in the dry season in Eldoret. In the developed (EX-ZIM and UG-AM-40) amaranthus varieties, poultry manure had significantly higher yields compared to mavuno fertilizer and the control treatment. Mavuno fertilizer and poultry manure had significantly (p=0.05) higher yields than the control in all the varieties.



Key: LV-Local variety, AM- Amaranthus, F0-Zero fertilizer, F1-Mavuno fertilizer and F2-Poultry manure.

Figure 4.5: Mean cumulative fresh yield of amaranth in Eldoret during the dry season. Error bars represent the standard error of the mean.

In the local variety, there was no significant difference (p=0.05) in the mean cumulative fresh yields of poultry manure (333 g/m^2) and mavuno fertilizer (375 g/m^2). Both yields of poultry manure and mavuno fertilizer were significantly higher than that of control of 144 g/m^2. In EX-ZIM variety, the mean cumulative fresh yield of poultry manure (478 g/m^2)

was significantly higher than that of mavuno fertilizer (386 g/m^2) which was also significantly higher than that of the control (136 g/m^2). In the UG-AM-40 variety, the mean cumulative fresh yield of poultry manure (573 g/m^2) was significantly higher than that of mavuno fertilizer (448 g/m^2). The cumulative fresh yield of mavuno fertilizer was higher than that of the control (266 g/m^2).

In the wet season (figure 4.6), significant differences were also observed in the mean cumulative fresh yields of the developed (EX-ZIM and UG-AM-40) varieties of amaranth in Eldoret. The yields from poultry manure were significantly higher than those of mavuno fertilizer and control. Mavuno fertilizer yields were also significantly higher than those of the control.

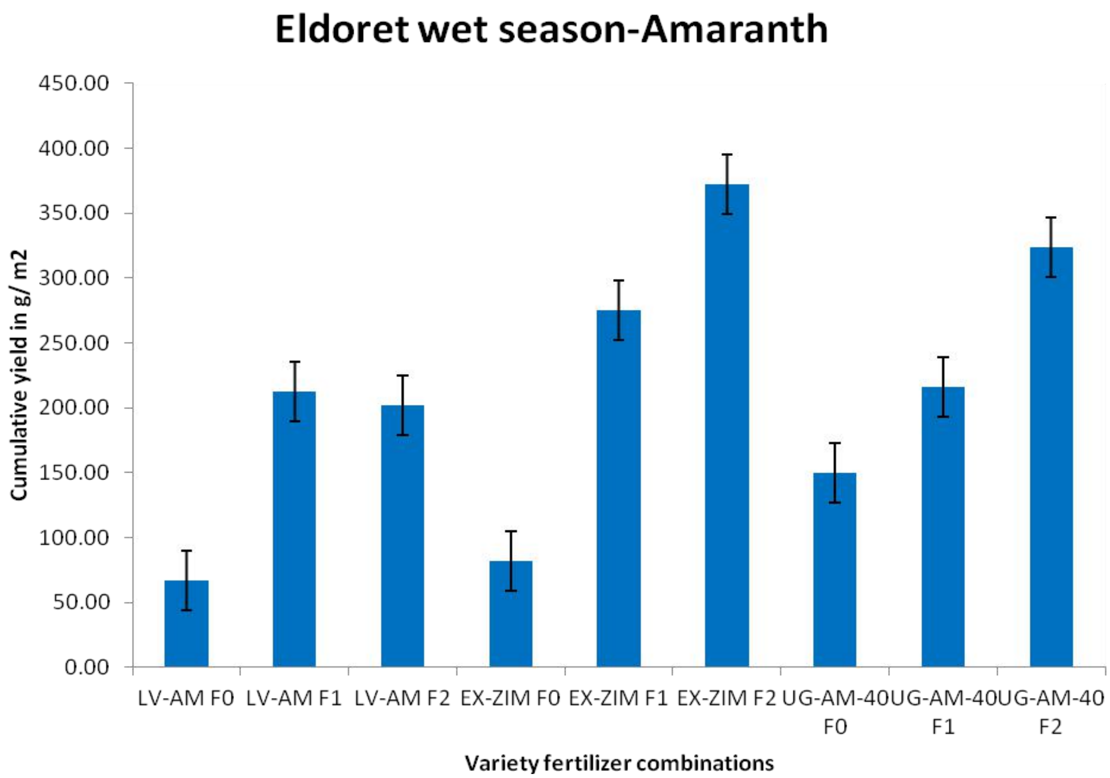


Figure 4.6: Mean cumulative fresh yield of amaranth in Eldoret during the wet season. Error bars represent the standard error of the mean.

In the local variety, the mean cumulative fresh yields of both poultry manure and mavuno fertilizer were significantly higher than that of the control of 67 g/m^2 at p=0.05 level of significance. The mean cumulative fresh yield of poultry manure (202 g/m^2) and mavuno fertilizer (212 g/m^2) were not significantly different (P=0.05). In the EX-ZIM variety, the mean cumulative fresh yield of poultry manure (372 g/m^2) was significantly higher than that of mavuno fertilizer of 275 g/m^2. The cumulative fresh yield of mavuno fertilizer was higher than that of the control (81 g/m^2). In UG-AM-40variety, the mean cumulative fresh yield of poultry manure (324 g/m^2) was significantly higher than that of mavuno fertilizer (215 g/m^2) which was also significantly higher than that of the control (150 g/m^2).

4.6.3.2.2 Trans Nzoia County-Kitale site

Effect of fertilizer on cumulative fresh yield of Amaranthus in Kitale during the dry season and wet season are showed in figures 4.7 and 4.8 respectively. There were significant differences (p=0.05) observed in the mean cumulative fresh yield of amaranthus in the dry season in Kitale. In the developed (EX-ZIM and UG-AM-40) amaranthus varieties, poultry manure had significantly higher yields compared to mavuno fertilizer and the control treatment. Mavuno fertilizer and poultry manure had significantly (p=0.05) higher yields than the control in all the varieties.

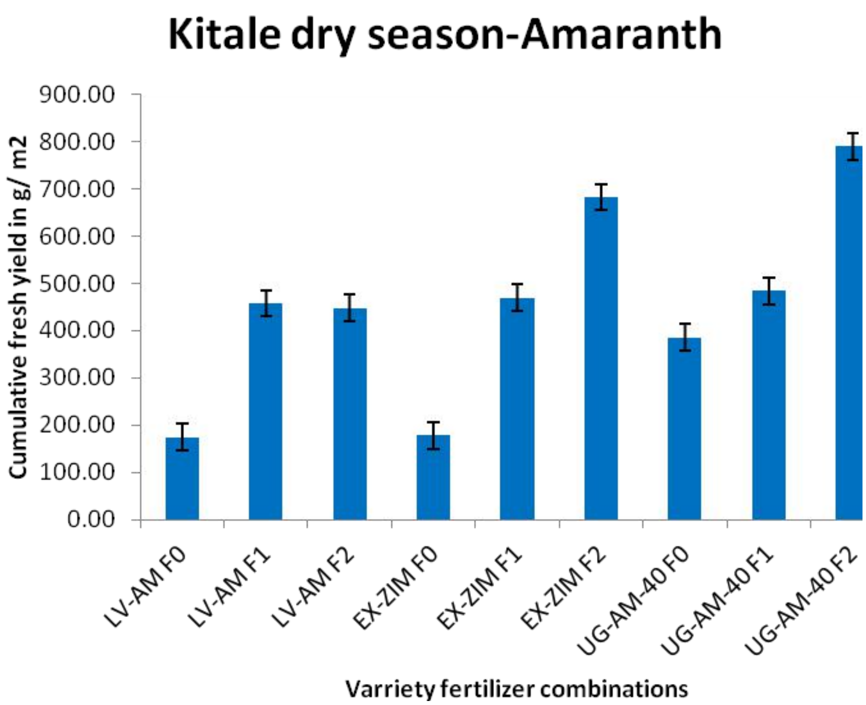


Figure 4.7: Mean cumulative fresh yield (g/m^2) of amaranth in Kitale during the dry season. Error bars represent the standard error of the mean.

In the local variety, there was no significant difference at $p=0.05$ in the mean cumulative fresh yields of poultry manure (448 g/m^2) and mavuno fertilizer (458 g/m^2). Both yields of poultry manure and mavuno fertilizer were significantly higher than that of control of 174 g/m^2. In EX-ZIM variety, the mean cumulative fresh yield of poultry manure (683 g/m^2) was significantly higher than that of mavuno fertilizer (470 g/m^2) which was also significantly higher than that of the control (178 g/m^2). In the UG-AM-40variety, the mean cumulative fresh yield of poultry manure (790 g/m^2) was significantly higher than that of mavuno fertilizer of 484 g/m^2). The mean cumulative fresh yield of mavuno fertilizer and poultry manure were significantly higher than that of the control (385 g/m^2).

In the wet season (figure 4.8), significant differences at $p=0.05$ were also observed in the mean cumulative fresh yields of the developed (EX-ZIM and UG-AM-40) varieties of amaranth in Kitale. The yields from poultry manure were significantly higher than those of mavuno fertilizer and control. Mavuno fertilizer and poultry manure yields were also significantly higher than those of the control.

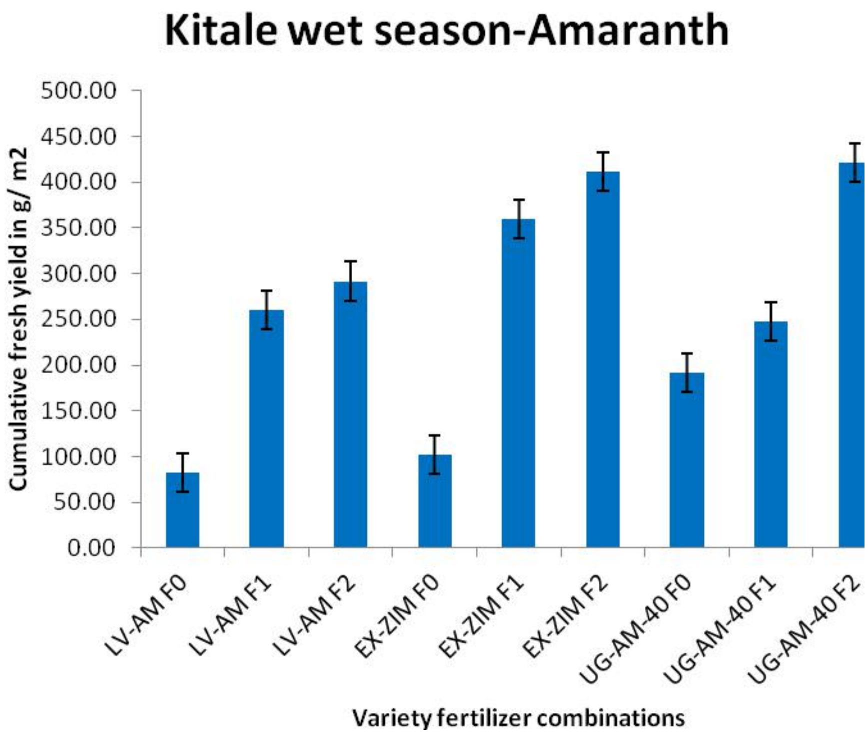


Figure 4.8: Mean cumulative fresh yield (g/m^2) of amaranth in Kitale during the wet season. Error bars represent the standard error of the mean.

In the local variety, the mean cumulative fresh yields of both poultry manure and mavuno fertilizer were significantly higher than that of the control of 82 g/m^{2}at P=0.05 level of significance . The mean cumulative fresh yield of poultry manure (260 g/m^2) and mavuno fertilizer (292 g/m^2) were not significantly different (P=0.05). In the EX-ZIM variety, the mean cumulative fresh yields of both poultry manure and mavuno fertilizer were significantly higher than those of the control of 102 g/m^2) . The mean cumulative fresh yield of poultry manure (411 g/m^2) was significantly higher than that of mavuno fertilizer (360 g/m^2). In UG-AM-40variety, the mean cumulative fresh yield of poultry manure

(422 g/m^2) was significantly higher than that of mavuno fertilizer (248 g/m^2) which was also significantly higher than that of the control treatment (192 g/m^2).

4.6.4 Cumulative fresh yield of Spider plant

4.6.4.1 Effects of variety on cumulative fresh yield of spider plant

4.6.4.1.1 Uasin Gishu County-Eldoret site

Means for cumulative fresh yield of Spiderplant in Kitale are presented in table 4.6. Significant differences (P=0.05) were observed between the mean cumulative fresh yields of the local variety (LV-SP) and the developed varieties (UG-SF-15 and ML-SF-29) in the dry season. The yields of the developed varieties were not significantly different. In the wet season, significant differences were observed in the mean cumulative fresh yield of the three varieties of spider plant.

Table 4.6: Mean cumulative fresh yield of three varieties Spiderplant in Eldoret.

Variety	Dry season Yield (g/m^2)	Wet season Yield (g/m^2)
LV-SP	316.11a	230.67a
UG-SF-15	274.89ab	194.56b
ML-SF-29	259.78b	167.89c
Lsd	45.72	23.85
CV%	15.69	11.75

Means with different letters in the column are significantly different at *P= 0.05*.

In the dry season (table 4.6), the mean cumulative fresh yields of the local variety were significantly higher than those of UG-SF-15 and ML-SF-29 varieties. The fresh yields of both varieties (UG-SF-15 and ML-SF-29) were not significantly different. In the wet season, the mean cumulative fresh yields of the local variety were significantly higher than those of UG-

SF-15 and ML-SF-29 varieties. The fresh yields of UG-SF-15 variety were also significantly higher than those of ML-SF-29 variety.

4.6.4.1.2 Trans Nzoia County-Kitale site

Means for cumulative fresh yield of African nightshade in Kitale are presented in table 4.7. There were no significant differences (p=0.05) observed in the mean cumulative fresh yields of the three varieties of spider plant in the dry season. In the wet season, significant differences were observed in the fresh yields of all the three varieties.

Table 4.7 Mean cumulative fresh yield of three varieties Spiderplant in Kitale.

Variety	Dry season Yield (g/m^2)	Wet season Yield (g/m^2)
LV-SP	397.67a	230.67a
UG-SF-15	382.33a	194.56b
ML-SF-29	358.89a	167.89c
Lsd	.	66.47
CV%	12.46	13.55

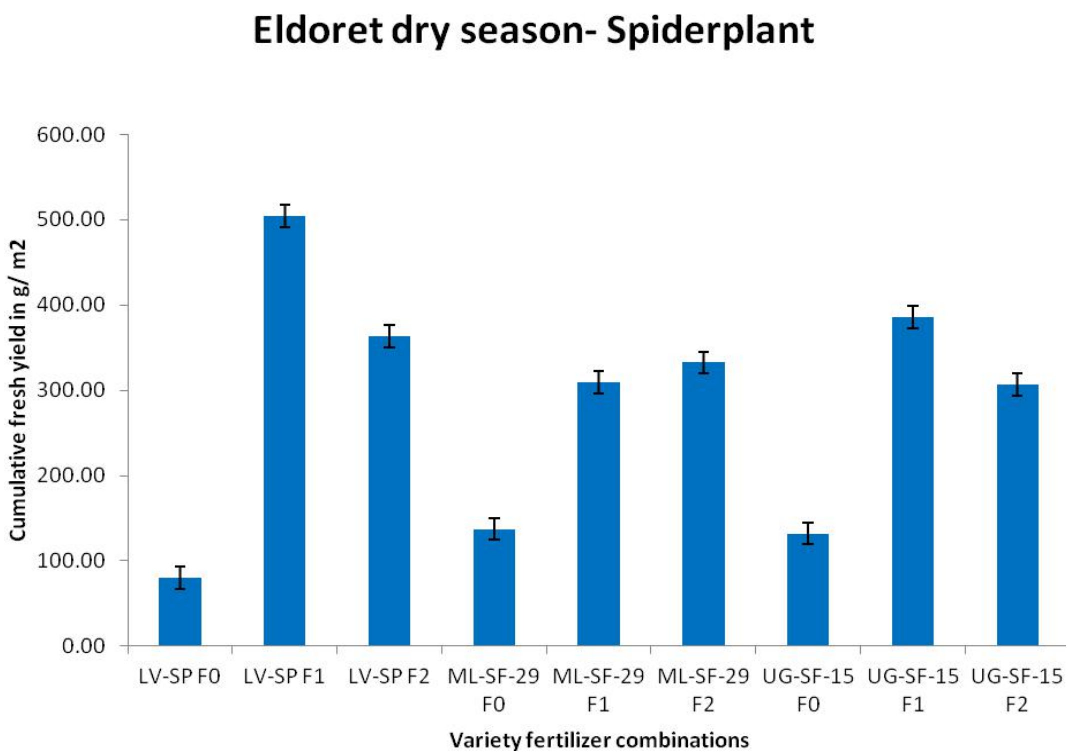
Means with different letters in the column are significantly different at $P \leq 0.05$.

In the dry season, there were no significant differences observed in the mean cumulative fresh yields of the local variety, UG-SF-15 variety and ML-SF-29 variety. In the wet season, the mean cumulative fresh yields of the local variety was significantly higher than that of UG-SF-15 variety which was in turn significantly higher than that of the ML-SF-29 variety.

4.6.4.2 Effect of fertilizers in cumulative fresh yield of spider plant

4.6.4.2.1 Uasin Gishu County-Eldoret site

Effects of fertilizer on cumulative fresh yield of Spiderplant in Eldoret during the dry season and wet season are showed in figures 4.8 and 4.9 respectively. There were significant differences (p=0.05) observed in the mean cumulative fresh yield of spider plant in the dry season in Eldoret. In all two varieties (LV-SP and UG-SF-15), mavuno fertilizer had significantly higher yields compared to poultry manure and the control treatment. In ML-SF-29 variety, there was no significant difference in the yields of poultry manure and mavuno fertilizers. In all varieties, mavuno fertilizer and poultry manure had significantly (p=0.05) higher yields than the control.



Key: LV-local variety, SP-Spiderplant, F0-Zero fertilizer, F1-mavuno, F2-Poultry manure.

Figure 4.9: Mean cumulative fresh yield (g/m^2) of spider plant in Eldoret during the dry season. Error bars represent the standard error of the mean.

In the local variety, the mean cumulative fresh yield of mavuno fertilizer (505 g/m^2) was significantly higher than that of poultry manure (363 g/m^2) at P=0.05 level of significance. Both mavuno fertilizer and poultry manure were significantly higher than that of the control of 80 g/m^2. In ML-SF-29 variety, there was no significant difference in mean cumulative fresh yield of mavuno fertilizer (309 g/m^2) and poultry manure (333g/m^2). Poultry manure and mavuno fertilizer yields were significantly higher than that of the control (137 g/m^2). In the UG-SF-15 variety, the mean cumulative fresh yield of mavuno fertilizer (386 g/m^2) was significantly higher than that of poultry manure (307 g/m^2). The cumulative fresh yield of poultry manure was higher than that of the control (132 g/m^2).

In the wet season (figure 4.10), significant differences were also observed in the mean cumulative fresh yield of the three varieties of spider plant in Eldoret. The yields of mavuno fertilizer were significantly higher than those of poultry manure in local variety and UG-SF-15 variety. In ML-SF-29,poultry manure yields were significantly higher than those of mavuno fertilizer. In all the varieties, poultry manure and mavuno fertilizer yields were significantly higher than those of the control.

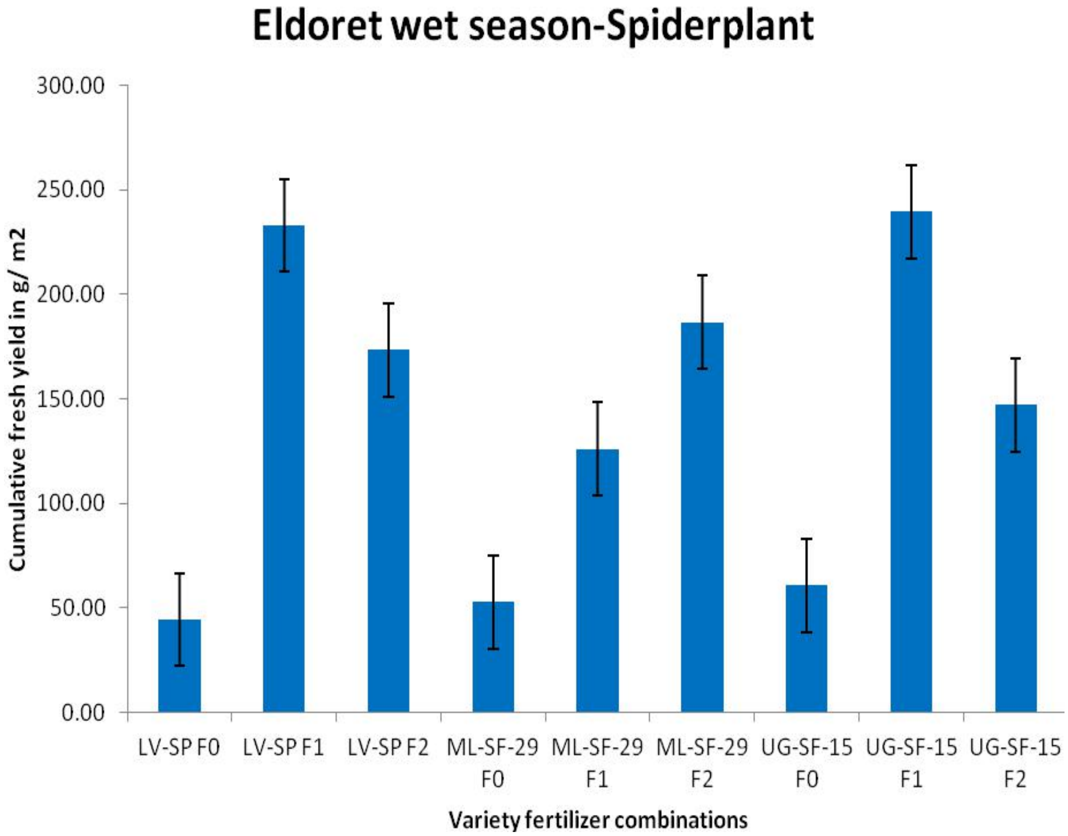


Figure 4.10: Mean cumulative fresh yield (g/m^2) of spider plant in Eldoret during the wet season. Error bars represent the standard error of the mean.

In the local variety, the mean cumulative fresh yields of both mavuno fertilizer and poultry manure were significantly higher than that of the control of 44 g/m^2. The mean cumulative fresh yield of mavuno fertilizer (233 g/m^2) was significantly higher than that of poultry manure (173 g/m^2). In the ML-SF-29 variety, the mean cumulative fresh yield of poultry manure (187 g/m^2) was significantly higher than that of mavuno fertilizer of 126 g/m^2. The cumulative fresh yield of poultry manure and mavuno fertilizer were significantly higher than that of the control (53 g/m^2). In UG-SF-15 variety, the mean cumulative fresh yield of mavuno fertilizer (240 g/m^2) was significantly higher than that of poultry manure (147 g/m^2) which was also significantly higher than that of the control (61 g/m^2).

4.6.4.2.2 Trans Nzoia County-Kitale site

Effects of fertilizer on cumulative fresh yield of Spiderplant in Kitale during the dry season and wet season are showed in figures 4.8 and 4.9 respectively. There were significant differences observed in the mean cumulative fresh yield of spider plant in the dry season in Kitale. In the two varieties (LV-SP and UG-SF-15), mavuno fertilizer had significantly higher yields compared to poultry manure and the control treatment. In ML-SF-29 variety, poultry had significantly higher cumulative yield than mavuno fertilizer. In all varieties, mavuno fertilizer and poultry manure had significantly (p=0.05) higher yields than the control.

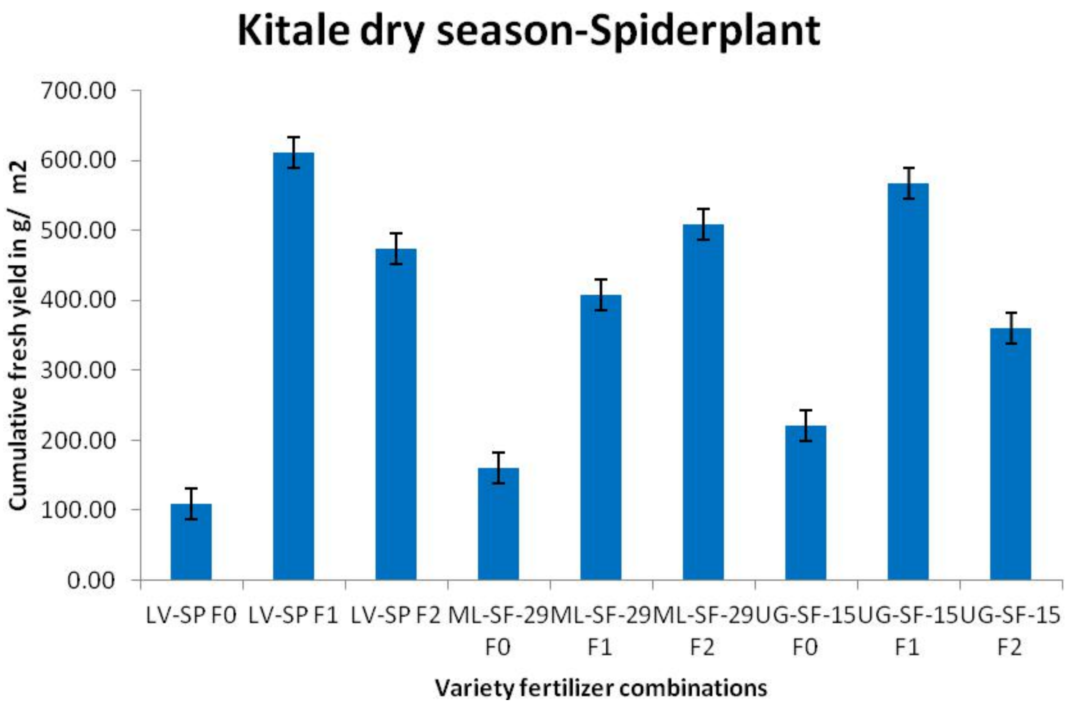


Figure 4.11: Mean cumulative fresh yield (g/m^2) of spider plant in Kitale during the dry season. Error bars represent the standard error of the mean.

In the local variety, the mean cumulative fresh yield of mavuno fertilizer (458 g/m^2) was significantly higher than that of poultry manure (448 g/m^2) at p=0.05 level of significance. Both mavuno fertilizer and poultry manure had significantly higher mean cumulative yields than that of the control of 174 g/m^2) . In ML-SF-29 variety, the mean cumulative fresh yield of poultry manure (683 g/m^2) was significantly higher than that of mavuno fertilizer (470 g/m^2) which was also significantly higher than that of the control (178 g/m^2). In the UG-SF-15 variety, the mean cumulative fresh yield of mavuno fertilizer (484 g/m^2) was significantly higher than that of poultry manure of 790 g/m^2. The mean cumulative fresh yield of poultry manure was higher than that of the control (385 g/m^2).

In the wet season (figure 4.12), significant differences (p=0.05) were also observed in the mean cumulative fresh yield of the three varieties of spider plant in Kitale. The yields of mavuno fertilizer were significantly higher than those of poultry manure in local variety and UG-SF-15 variety. In ML-SF-29,poultry manure yields were significantly higher than those of mavuno fertilizer. In all the varieties, poultry manure and mavuno fertilizer yields were significantly higher than those of the control.

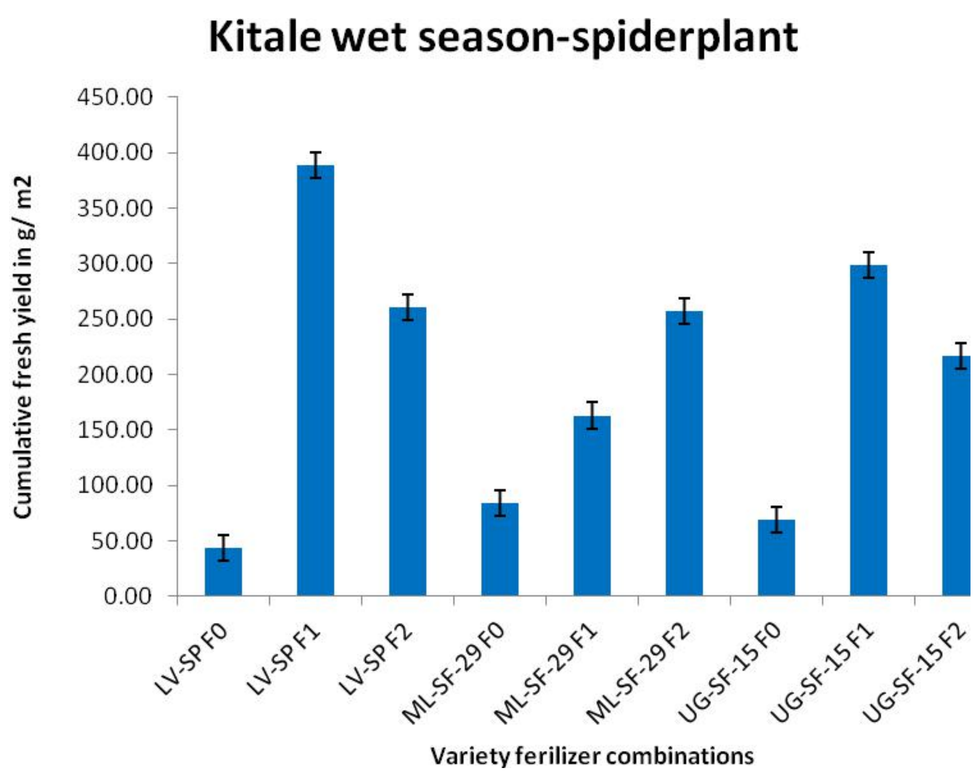


Figure 4.12: Mean cumulative fresh yield (g/m^2) of spider plant in Kitale during the wet season. Error bars represent the standard error of the mean.

In the local variety, the mean cumulative fresh yield of mavuno fertilizer (260 g/m^2) was significantly higher than that of poultry manure of 292 g/m^2 at p=0.05. The mean cumulative fresh yield of poultry manure was higher than that of the control (82 g/m^2). In the ML-SF-29 variety, the mean cumulative fresh yields of both mavuno fertilizer and poultry manure were significantly higher than those of the control of 102 g/m^2) . The mean cumulative fresh yield of poultry manure (411 g/m^2) was significantly higher than that of mavuno (360 g/m^2). In UG-SF-15 variety, the mean cumulative fresh yield of mavuno fertilizer (248 g/m^2) was significantly higher than that of poultry manure (422 g/m^2) which was also significantly higher than that of the control treatment (192 g/m^2).

4.7 Discussion

4.7.1 African nightshade (*Solanum scabrum*)

4.7.1.1 Effects of variety on cumulative fresh yield of African nightshade

In the dry season at both Eldoret and Kitale, BG-16 variety had the highest yields. This may be attributed to the fact that the variety had broader and longer leaves hence was able to accumulate more biomass compared to the other two varieties (LV-NS and SS-49). An evaluation conducted by Ojiewo *et al.,* (2013) on nine elite lines of solanum scabrum revealed that BG-16 line had the highest leaf yields. BG-16 was also found to have the longest number of days to reach 50 % flowering, an attribute leading to a higher leaf yield potential. During the wet season, there was no significant differences (p=0.05) observed in both BG-16 and SS-49 mean cumulative leaf yields. Both varieties yielded higher than the local variety. This may be attributed to fluctuating water supply associated with rain-fed conditions leading to a decrease in yields of BG-16 variety. Inconsistent supply of water may have prevented the variety from achieving its full potential during the wet season.

4.7.1.2 Effect of fertilizers in cumulative fresh yield of African nightshade

In both seasons, mavuno fertilizer performed better than poultry manure and the control in all the three varieties of African nightshade. This may be attributed to mavuno fertilizer containing readily available nitrogen and phosphorus which are needed in large quantities by the African nightshade. Application of phosphorus nutrient has been found to increase the fresh yields of African nightshade. A study conducted by Opala *et al.,* (2013) showed that application of phosphorus (P) at the rates of 40 to 60 kg/ha increased plant height, leaf numbers, leaf area and leaf yields of African nightshade. Addition of Nitrogen (N) has also been found to increase the leaf yields of African nightshade. According to Bvenura and Afolayan, 2014 application of 100 kg N/ha significantly increased the total number of leaves, stem diameter and root:shoot ratio. All these growth indicators led to increase in the cumulative fresh yield of African nightshade.

4.7.2 Amaranthus (*Amaranthus species*)

4.7.2.1 Effects of variety on cumulative fresh yield of amaranthus

In the dry season at both Eldoret and Kitale, UG-AM-40 variety had the highest yields. This is may be attributed to the variety having a greater plant height compared to the EX-ZIM and the local variety. Greater plant height has been found to increase other yield parameters such as number of leaves per plant and number of branches per plant (Shankar *et al.,* 2012; Shukla *et al.,* 2010). The variety also had broader and longer leaves compared to the other varieties hence was able to accumulate more biomass as compared to the other varieties. Vegetables with broader and longer leaves have been found to accumulate more biomass as compared to short and narrow leaved varieties (Ojiewo *et al.,* 2013).

4.7.2.2 Effect of fertilizers in cumulative fresh yield of amaranthus

In both seasons, the developed varieties of amaranth performed better in poultry manure compared to mavuno fertilizer. This can be attributed to higher nutrient levels of poultry manure and its ability to hold more water and nutrients as well as serve as a slower release of nutrients compared to mavuno fertilizer. Plants grown with chicken manure were observed to have larger leaves and higher vigour than those grown under Mavuno fertilizer and in plots that had no fertilizer (Ayua *et al.,* 2016). A separate study by Bvenura and Afolayan, 2014 also revealed that application of manure at 8.13 t/ha significantly boosted the moisture content, plant height and leaf area.

4.7.3 Spiderplant (*Cleome gynandra*)

4.7.3.1 Effects of variety on cumulative fresh yield of spiderplant

The local variety of spiderplant had significantly higher mean cumulative fresh yields compared to the two developed varieties (ML-SF-29 and UG-SF-15) both in Eldoret and Kitale. This might be due to the local variety being well adapted to the prevailing climatic conditions. Although the developed varieties may have had a high leaf yield potential, they may not be well adapted to local temperature and soil moisture conditions leading to low yields.

4.7.3.2 Effect of fertilizers in cumulative fresh yield of spiderplant

In spider plant, the local variety and UG-SF-15 performed best when treated with mavuno fertilizer while ML-SF-29 performed best with poultry manure. Organic fertilizers aid in improving soil structure, increase in soil organic carbon and microbial biomass. They also provide significant quantities of major and trace elements and have a persistent effect on the soil (Suresh *et al.,* 2004). ML-SF-29 variety had traits which may have enabled it to perform best at poultry manure application. The above mentioned mixed responses may be due to many factors among them the ease in absorption and utilization of the mineral fertilizers compared to the organic sources (Vernon, 1999). Most inorganic sources for example mavuno have nutrients available in absorb-able forms (NO_3^- and NH_4^+) while, the organic sources like poultry manure have to undergo mineralization to release nutrients.

4.8 Conclusions

Generally, in all the AIVs type and varieties within them, fertilizer (N) application increased the mean cumulative fresh yield. In African nightshade BG-16 variety had the highest mean cumulative fresh yields compared to SS-49 and the local variety. In amaranthus, UG-AM-40 variety had the highest mean cumulative fresh yields compared to EX-ZIM and the local variety. In Spiderplant, the local variety had the highest mean cumulative fresh yields compared to UG-SF-15 and ML-SF-29 varieties. In African nightshade, all the three varieties had the highest mean cumulative fresh yields under mavuno fertilizer application compared to the poultry manure and control. In Amaranthus, all the developed had the highest mean cumulative fresh yields under poultry manure application compared to mavuno fertilizer and control. In Spiderplant, the local variety and UG-SF-15 had the highest mean cumulative fresh yields with mavuno fertilizer application while ML-SF-29 variety had the highest yields in in poulty manure application.

4.9 Recommendations

1. For African nightshade, BG-16 variety and mavuno fertilizer application formed the best variety – fertilizer combinations for both Uasin Gishu and Trans Nzoia Counties.
2. For amaranthus, UG-AM-40 and poultry manure application formed the best variety – fertilizer combinations for both Uasin Gishu and Trans-Nzoia Counties.
3. For Spiderplant, local variety and mavuno fertilizer application formed the best variety – fertilizer combinations for both Uasin Gishu and Trans-Nzoia Counties.

CHAPTER FIVE

Effect of lime rates on above ground dry, fresh biomass, root growth and nutrient concentration in the plant tissue at flowering in *Amaranths spp., Cleome gynandra and Solanum scabrum*

5.1 Abstract

Soil acidity determines nutrient sufficiency, deficiency and toxicity of some essential nutrients in the soil. An ideal soil pH assures high bioavailability of most nutrients essential for vegetable growth and development. A study on soil acidity modification (liming) was conducted at the University of Eldoret farm, Uasin Gishu County in the wet season (LR-March to July 2013) to assess effects on yields of selected African indigenous vegetables (AIVs). Locally sourced liming material was applied at the rate of 0 t/ha (L_0), 2t/ha (L_1) and 4.1625t/ha (L_2) to achieve the different levels of the desired pH (initial pH, 5.5 and 6.5 respectively). Data was collected on fresh and dry biomass, nutrient concentration in the plant tissue, root length density (RLD) and dry root biomass (RB) at flowering. Results indicated that soils response to liming, was significant (p=0.05). Soil pH means of 6.33 for liming rate L_2, 5.78 for liming rate L_1 and 5.18 for L_0 were achieved. Mixed responses were exhibited on effects of liming on fresh and dry biomass. In spiderplant, liming had no significant effect (p=0.05) on fresh biomass but in dry biomass. In Amaranth, fresh biomass of AL_0 (1457g/m^2) differed significantly from lime rates AL_1 (2729g/m^2) treatments during the rainy season. Dry biomass of AL_1 (199g/m^2) was the best overall during the dry season. In African nightshade (Ex-Hai), the effect liming on dry biomass in both seasons were significant (p=0.05). In amaranths, P uptake in all lime rates combinations (AL_0-0.53%, AL_1-0.62 %and AL_2-0.59%) differed significantly at

α=0.05 during the wet season. In African nightshade, %P content in the tissue of NL_1 (0. 26%) differed significantly (P=0.05) from NL_0 (0.33%) and NL_2 (0.32%) during the dry season. Chlorophyll content was highest in the lime rate L1 (adjusted pH of 5.5) in spiderplant (54.3) and amaranthus (44.6). Significant differences (P≤0.05) within the species were observed in amaranthus. Across the species significant differences at p=0.05 were evident between all the species. In all the species, effects of lime rates on RLD varied across AIV species and no significant differences (p=0.05) were recorded. Liming increased root dry biomass in all the species. Effects of liming were significantly different (P=0.05) in root biomass of black nightshade and Spiderplant between zero lime and other rates. Liming was also beneficial to all the AIVs species in root growth and increased fresh and dry biomass.

5.2 Introduction

Soil pH is among the most important attributes of soil and a chemical indicator of soil quality. Soil quality of acid soils can be improved by several management techniques among them liming and use of organic manure to adjust pH to the levels needed by the crop to be grown. Liming is the most widely used remedy for soil acidity. Most agricultural and horticultural crops including vegetables are highly sensitive to soil acidity and their ideal soil pH is above 6.0. However, most soils in the humid tropics that constitute a bigger percentage of the arable land have Nitisols, Acrisols and Ferralsols soils which are characteristically acidic soils (Brett *et al.,* 2005, Kamprath, 1984 and de Dorlodot *et al.,* 2007).

In Kenya, acid soils cover about 13% of land area, which is approximately 7.5 million hectares of the arable land (Gudu *et al*., 2007). Among the soil attributes in acid soil continuum of Ferralsols include: permanent charge acidity as a result of Al and Fe present, 1:1 Clay type (kaolinite), very low base saturation (Ca and Mg) , very high potential of fixing soluble orthophosphates, low release of K, high structural stability and presence of Fe and Al as the aggregate binders (Mclean, 1971). These attributes of acid soils affect crop performance through influencing nutrient availability and root growth.

Acid soils impede agricultural production of acid sensitive crops through their inhibition on plant root growth and availability of essential plant nutrients, for example, N, P, K, Mn, Cu, Zn, and Mo (Iqbal, 2012). A well-developed root system enables a plant to thrive soil environments where nutrients and water are deficient (Malamy, 2005). Soethe et al., 2006 reported that root length density has been used as a good descriptor of how well resources reserved in the soil such as, water and nutrients can be absorbed efficiently. Fine root biomass has been identified as an indicator of carbon allocation and carbon turnover at the ecosystem level (Jackson et al. 1997). According to de Dorlodot *et al*., (2007), a healthy root system promotes water and nutrient uptake which translates to high yields. Root development is significantly affected by the supply of mineral nutrients in the soil (Brain & Helena, 2001). Phosphorus unavailability for uptake by plants triggers more root growth. In addition, lack of both nitrogen and phosphorus affects root/shoot ratio in favor of root growth (Zhang *et al*., 2012).

As a matter of fact, liming surface layer of the soil therefore may benefit many crops because other than raising the pH, liming increases availability of P and Ca, reduces availability of potential phytotoxic heavy metals like Al and Mn, improves soil structure and increases rate of infiltration (USDA staff, 1999). In addition, liming often increases availability of S and Mo. However, liming acid soils can reduce vegetable yields through inhibiting uptake of Mg and K.

A previous study in an acid Ferralsol soil revealed that root soil contact of selected cereal lines was reduced by soil acidity. Both root hair length and density were adversely affected by soil acidity. Soil acidity was also found to restrict root growth of cotton (Adcock et al., 1999). Other similar studies have shown contradictory effects of liming on root growth. Some findings indicate that liming can either increase or decrease the fine root biomass and growth of trees (Hahn and Marschner, 1998; Helmisaari and Hallbacken, 1999). The response on lime application was found to entirely depend on availability of nutrients (Staaf *et al*., 1996).

Information regarding production of AIVs is very scanty and very little is known about their production (Smith and Ezyzaguirre, 2007, Mhontlo *et al*., 2007). This study investigated the effects of different lime rates on performance and identify the most ideal soil pH for growing selected varieties of AIVs in the acidic soils (Orthic Ferralsols) of Uasin Gishu County (Jaetzold *et al*, 2005).

5.2: Materials and methods

5.2.1: Site description

The experimental site was at the University of Eldoret farm, which lies on 0.57° N 35.30 ° E and 2140m elevation. The major soils in the county are Orthic Ferralsols and hence the problem of soil acidity due to Fe, Al and Mn oxides being the resident elements. The area has a unimodal rainfall pattern whereby rainy season is between March and May while the dry season between the months of October and December (Jaetzold *et al.,* 2005). The average daily temperatures in the area range from low of 10°C and high of 25°C (Meoweather, 2012).

5.2.2: Experimental design and treatments description

The experiment was laid in a split plot layout in RCBD whereby an improved variety from AVRDC for Spiderplant (S), Amaranth (N) and Amaranths (A) was subjected to three liming rates (L0, L1, L2) treated with an organic fertilizer (poultry manure) adjusted to supply 94 Kg N/ha (AVRDC). The 9 treatments "species liming rate combinations" designated as: AL_0, AL_1, AL_2, NL_0, NL_1, NL_2, SL_0, SL_1 and SL_2 were replicated three times, each replicate had 3 main plots whereby the liming rate (L_0-0, L_1-2 and L_2-4.1625t/ha) was the main plot treatment and within the main plot were three sub-plots (2 by 4 square meters) whereby the a selected variety of each vegetable type (Species: Spider plant- PS 2012, Nightshade- Ex-Hai, Amaranthus-Ex-Mwanga) was the subplot treatment.

5.2.3: Initial soil analysis and lime requirement

Soil samples at 20cm depth were taken in the plot before treatment application and due to uniformity, the samples were bulk and a composite sample obtained for laboratory analysis. Soil analysis was carried out according to Okalebo et al., (2002) laboratory manual whereby total N%, available P, pH (H_2O), organic carbon (C%) and texture were determined. From the measured soil pH and the textural class the lime requirement was determined to adjust the initial soil pH to the target pH of 5.5 (L_1) and 6.5 (L_2); L_0 was the control experiment unit no pH adjustment was done. In calculating the lime requirement the necessary information was obtained from tables 3.1 and 3.2, that is, tonnes of Calcium

Carbonate Equivalent (CCE) recommended per hectare for vegetable types with a Target pH of 5.2 and 6.5 respectively (Ghidiu *et al.,* 2013).

Formula used in obtaining actual amount of lime to be applied.

Actual amount of liming material = (Soil test CCE recommendation)/ (% CCE of liming material) x 100

(Ghidiu *et al.,* 2013; Publication E001)

5.2.4: Land preparation and agronomic practices

Ploughing was done a month before planting whereby a fine tilth was achieved, fine ground agricultural lime from Athi river mining company with a calcium carbonate equivalence (CCE) of 30% was applied in different rates(0, 2 and 4.1625t/ha) to the respective completely randomized experimental units. The lime was incorporated into the soil “20 to 25 cm depth” using a rake and thorough watering done during the dry season. The lime was allowed to react and the extent of reaction confirmed through soil pH test of the 20 cm ploughed layer after 15 days. The plot size was 4 by 2 square meters, 0.5m path between the plots and 1m path separating the replicates (blocks). The spacing within the plots was, nightshade; 40cm between plants and 60cm between rows within the bed while for spider plant and amaranth; 25cm between plants and spacing between row 60cm.

5.2.5: Data collection

5.2.5.1 Above ground biomass, nutrient concentration and chlorophyll content

Data collected included above ground biomass; fresh and dry weight at flowering per plot of the inner two rows. Fresh biomass was weighed. The harvested foliage was then air dried, weighed and recorded. A sample of the dry plant material was obtained, ground and total N and P in the plant tissue analyzed according to Okalebo *et al.,* (2002). Chlorophyll content in the mature leaves was measured using a Chlorophyll Meter SPAD-502 Plus.

5.2.5.2 Root sampling and determination of root length density

Two plants in each plot were identified randomly for root sampling. Soil coring root-sampling technique was adopted and a soil auger of known dimensions; diameter (7cm) and volume (577 cm^3) used to extract soil volume containing the roots within 15cm of the plowed layer (Anderson and Ingram, 1993). Soil bounding the roots was washed off using running water through sieves to extract the roots. Roots were then sorted by hands from insoluble debris then preserved using ethanol at temperatures below 5°C.

Root length was measured according to Newman and Tennant (1975); roots were spread out with random orientation on a grid of known area (A cm^2). All the vertical and horizontal intersections of roots and gridlines counted and summed (N). The results obtained were substituted in the Newman (1968) equation for estimation of root length.

$$L = \frac{\pi N A}{2H}$$

Where: **L**-total length, **N**-total horizontal and vertical intercepts between spread out roots and gridlines, **H**-total length of the gridlines (cm), **A**-area of grid (cm^2).

Root length density was obtained using the formula: $\textit{Root length density}$ **(cm cm^{-3})** $= \frac{L\ mm}{soil\ volume}$

5.2.6: Data analysis

The data collected was managed using general linear model (Proc GLM: SAS Institute Inc. 9.0). Where means were significantly different they were further be separated using the Duncan's multiple range test (DMRT) at p=0.05. ANOVA skeleton showed in table 3.4.

5.3: Results

5.3.1: Soil and manure analysis

Some of soil parameters measured included; %N-0.14%, available P, %C- 2.24 and particle size-sandy loam. Attributes of poultry manure used were: % N-1.86, %P-2.68, and pH -8.82.

Lime application increased the soil pH effectively (figure 5.4). Micro nutrients content in the soil like iron (Fe) was not affected by liming (figures 5.1, 5.2 and 5.3). Applying lime reduced copper concentration in the soil from 19ppm to as low as <1ppm by enhancing uptake by the crop (Table 5.3). Iron content remained unchanged in the soil after the two growing season. This may be attributed to the soil type (red clay soil-Ferralsols) which has Fe as one of the resident element responsible for its red color. Zinc content in the soil did not change much; before planting-5ppm and after planting the content ranged from 5 to 3ppm. Figures 5.1, 5.2 and 5.3 shows soil nutrient concentration before and after liming.

Figure 5.1: A scatter plot of Soil nutrient concentration in lime treatments in *Amaranths spp.*

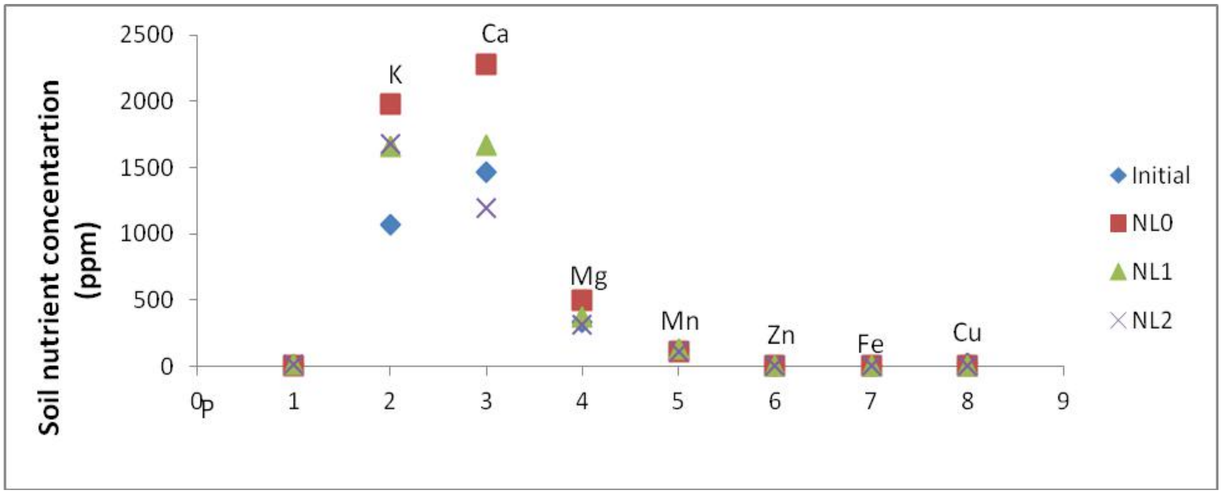


Figure 5.2: A scatter plot of Soil nutrient concentration in lime treatments in Spiderplant

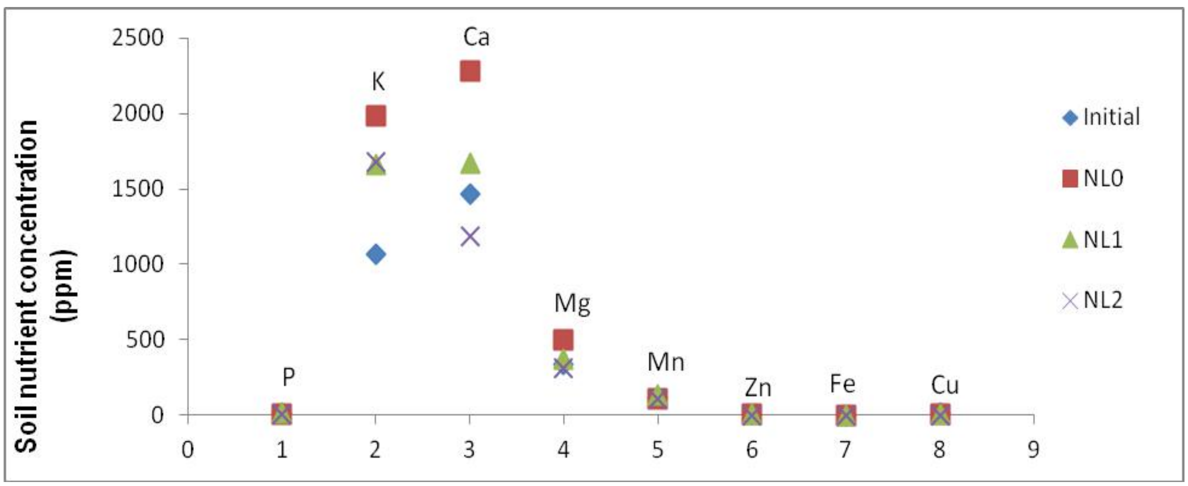


Figure 5.3: A scatter plot of Soil nutrient concentration in lime treatments in African nightshade

5.3.2: Effectiveness of liming on the soil pH trend

Soils response to liming was positive (figure 5.4) where the soil pH in all the liming rates were significantly different at α=0.05. A mean of 6.33 for liming rate 4.1625 t/ha , 5.78 for liming rate 2t/ha and 5.18 for the control were achieved. At the end of the season, there was an increase in pH of zero lime plots. This may be due to the use of manure , which is found to be alkaline (pH=8.82) and hence had a neutralizing effect on the acidic soils. Figure 5.4 shows soil pH trends in different liming rates.

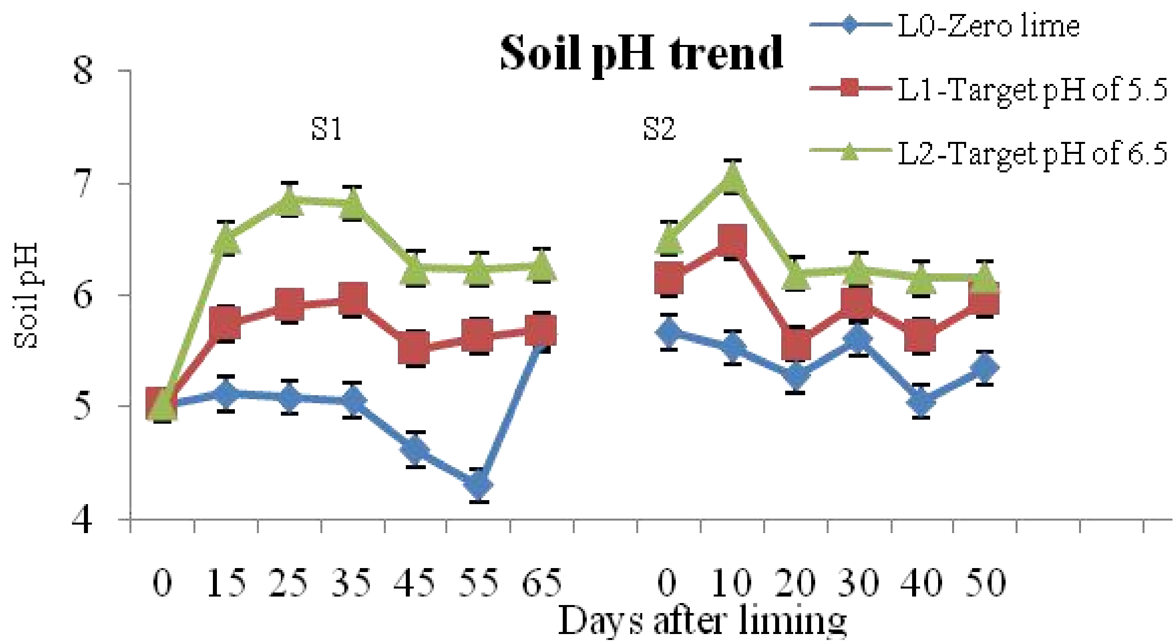


Figure 5.4: Soil pH trend against time in Feralsols, S1-season 1 and S2- season 2

5.3.3: Effects of lime rates on the above ground dry and fresh biomass at flowering

Means of above ground dry and fresh biomass are showed in table 5.1.There were no significant differences at p=0.05 of lime on fresh biomass of spider plant in both seasons. However, fresh biomass of amaranths differed significantly between some treatments during the rainy season. Amaranth with zero lime (AL_0) differed significantly from amaranthus with AL_1. But amaranth with lime rate two (AL_2) was not significantly different from AL_0 and AL_1.

Dry biomass of amaranth during the dry season AL1 and AL_2 (table 5.1) differed significantly from AL_0. AL_1 was the best overall at p=0.05. However, during the rainy season there were no significant differences between the lime rates. AL_2 had the highest dry biomass while the control (AL_0) had the lowest.

In African nightshade (Ex-Hai), the effect of lime rates on dry biomass in both seasons was not significantly different. Lime addition had some significant effect on the dry biomass at flowering of the selected variety of spiderplant (PS 2012) during the dry season. Spiderplant where zero lime (SL_0) had the highest dry biomass in both seasons and differed significantly from SL_1 at α=0.05. There were no significant differences on dry biomass between all treatments during the rainy season (Table 5.2).

Table 5.1: Effects of lime rates on above ground dry and fresh biomass at flowering

Species 1-Amaranthus (*Amaranthus species)*

	Dry Season				Rainy Season			
	Dry Biomass(g/m^2)		Fresh Biomass (g/m^2)		Dry biomass (g/m^2)		Fresh Biomass (g/m^2)	
Treatment	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
AL0	110.52a	16.53	1066.13a	168.17	151.96a	22.73	1456.58a	546.09
AL1	199.39ab	1.52	1998.33a	304.06	274.16ab	2.09	2728.92b	870.73
AL2	171.49b	62.61	1733.93a	802.56	235.79b	8.08	1970.83ab	23.14
LSD	78.95		1210.6		108.56		946.55	
Alpha	0.05		0.05		0.05		0.05	
Critical Value	2.78		2.78		2.78		2.78	

Species 2-Spiderplant (*Cleome gynandra*)

	Dry Season		Rainy Season	
	Dry	Fresh	Dry	Fresh Biomass

	Biomass (g/m²)		Biomass (g/m²)		biomass (g/m²)		(g/m²)	
Treatment	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
SL0	88.58a	14.88	969.37a	125.35	180.85a	78.65	1655.50a	436.66
SL1	81.76a	23.48	980.60a	179.62	52.35b	45.15	2121.17a	1161.57
SL2	93.38a	74.93	1458.90a	479.72	83.96ab	66.09	1699.50a	1052.82
LSD	97.24		787.86				2591.5	
Alpha	0.05		0.05		0.05		0.05	
Critical Value	2.78		2.78		3.18		2.78	

Species 3-African Nightshade (*Solanum scabrum*)

	Dry Season				**Rainy Season**			
	Dry Biomass(g/m²)		Fresh Biomass(g/m²)		Dry biomass (g/m²)		Fresh Biomass (g/m²)	
Treatment	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Std Dev**
NL0	131.53a	57.20	1427.93a	754.34	133.85a	24.85	5574.25a	994.42
NL1	38.07b	32.84	332.10a	316.36	151.80a	50.31	6411.17a	904.84
NL2	61.06ab	48.07	385.97a	291.5	206.32a	56.89	6175.58a	1040.10
LSD					88.09		2448.3	
Alpha	0.05		0.05		0.05		0.05	
Critical Value	3.18		31.18		2.78		2.78	

NB: Comparison is within the species means with the same letter are not significantly different at p≤0.05.

5.3.4: Effects of liming rates on nutrients content in the plant tissue at flowering

In all the AIVs N and P nutrients in the plant tissue were higher during the rainy season compared to the dry season-2013. Spiderplant had the highest %N and %P content in the tissue in the rainy season. There were no significant differences (p=0.05) in N and P uptake in both seasons. In Amaranthus, AL_1 had the highest %P in the plant tissue during the rainy season while that with zero lime had the lowest. All amaranthus lime rates combinations (AL_0, AL_1 and AL_2) differed significantly at α=0.05. In African nightshade, %P content in the tissue during the dry season NL_1 differed significantly from NL_0 and NL_2. Percentage phosphorus in the tissue was highest where lime was not added (NL_0) and lowest where soil pH was adjusted to 5.5 (NL_1). In all other treatments no significant differences were recorded though the means were different (Refer to Table 5.2).

Table 5.2: Effects of lime rates on N and P content in the plant tissue at flowering

Dry season			Rainy season	
Treatment	**Total N (%)**	**Total P (%)**	**Total N (%)**	**Total P (%)**
Amaranths				
AL0	2.18a	0.34a	4.48a	0.53c
AL1	2.15a	0.32a	4.23a	0.62a
AL2	2.11a	0.25a	4.097a	0.59b
Black Nightshade				
NL0	2.6a	0.33a	4.09a	0.56a
NL1	2.53a	0.26b	4.23a	0.55a
NL2	2.42a	0.32a	4.21a	0.59a
Spiderplant				
SL0	2.41a	0.30a	4.61a	0.73a
SL1	1.68a	0.29a	4.65a	0.81a
SL2	2.71a	0.34a	4.86a	0.78a

NB: Comparison is within and means with the same letter are not significantly different at $p \leq 0.05$.

In all the AIVs, like N and P, the concentration of the secondary macro nutrients (Ca and Mg) and Fe in the plant tissue increased in the second season (S2-rainy season 2014). The Mg concentration was very high in the amaranthus compared to Spiderplant and African nightshade. There were no major changes exhibited in the concentrations of K, Mn, and Cu during the two growing seasons.

In AL_2, NL_0, NL_1, spiderplant, the Zn content in the tissue increased in the rainy season-2014 (S2). In all the AIVs, effects of lime rates were not detected in the concentration of Cu in the plant tissue.

Table 5.3: Effects of lime rates on concentration of other macro and micro nutrients in the plant tissue

	%K		**%Ca**		**%Mg**		**%Mn**		**Zn ppm**		**Fe ppm**		**Cu ppm**	
Treatment	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
AL0	2.21	2.13	1.62	1.7	2	2.2	0.05	0.04	55	31	157	213	13	12
AL1	2.13	1.98	1.38	2.1	1.79	1.9	0.05	0.03	47	33	122	220	13	12
AL2	2.21	2.26	1.43	2.3	1.78	2.2	0.05	0.03	45	50	107	231	13	12
SL0	1.42	1.59	1.68	2	0.53	0.9	0.02	0.02	33	55	155	175	12	12
SL1	1.53	1.71	1.82	2.4	0.6	0.9	0.02	0.02	37	54	159	220	12	12
SL2	1.46	1.5	1.71	2.6	0.57	0.8	0.02	0.02	38	44	159	299	12	12
NL0	2.07	2.09	1.28	1.9	0.94	0.7	0.03	0.03	30	41	183	274	12	12
NL1	2.08	1.95	1.37	1.8	0.98	0.8	0.03	0.03	36	40	221	225	12	12
NL2	2.2	2.24	1.65	1.9	1.22	0.7	0.03	0.02	47	26	187	259	12	12

5.3.5: Effects of lime rates on the chlorophyll content at flowering

Chlorophyll content was highest in the lime rate L1 (adjusted pH of 5.5) in spiderplant and amaranthus. Significant differences (P≤0.05) within the species were only observed in amaranthus. This was between lime rate AL1 and AL2. Across the species significant differences at p=0.05 were evident between all the species. Spiderplant contained high amount while, amaranthus contained low amount of chlorophyll.

Table 5.4: Effects of lime rates on chlorophyll content in the mature leaves at flowering stage

Chlorophyll content					
Spiderplant		**Black Nightshade**		**Amaranthus**	
SL0	52.8a	NL0	44.0bc	AL0	39.8cd
SL1	54.3a	NL1	46.0b	AL1	44.6b
SL2	51.9a	NL2	46.5b	AL2	39.4d

Lsd-4.95 R^2-0.87 CV%-5.69 P=0.05

NB: Comparison is within and across the species: means with the same letter are not significantly different at p=0.05.

5.3.6 Root length density

Effects of lime rate on root length density were evident in all species as showed in table 5.5 below. Effects were more in nightshade than in amaranthus and Spiderplant. In nightshade, there were significant differences (p≤0.05) in root length density at 4.1625t/ha lime (NL2) and 2t/ha (NL1). In spider plant, significant differences (P≤0.05) were between zero lime (SL0) and the other two levels of lime (SL1 and SL2).

In amaranthus, significant differences (P≤0.05) were between zero lime (AL0) and 2t/ha lime (AL1). In all the AIV species, there was no common trend observed in increase or decrease of root length density with different rates of lime. The responses differed significantly (p=0.05) in all the species. In nightshade root length density of NL2 was the highest and NL1 the lowest. Spiderplant with zero lime (SL0) had the highest root length density while SL1 (2t/ha) had the lowest. In amaranthus, AL1 (amaranthus with 2t/ha lime) had the highest root length density while that with zero lime (AL0) had the lowest.

Table 5.5: Effects of lime rates on root length density (cm/ cm^3) at flowering

Lime rate	Nightshade(N)	Spiderplant(S)	Amaranthus(A)
Zero lime (L0)	15.40ab	3.78a	2.30b
2t/ha (L1)	12.59b	2.22b	3.97a
4.1625t/ha (L2)	22.60a	2.88b	3.10ab
R^2	**0.77**	**0.93**	**0.85**
CV%	**21**	**17.7**	**14.6**
Lime (Pr =0.05)	**0.05**	**0.007**	**0.03**

NB: Comparison is within the species and means within a column with the same letter are not significantly different at p=0.05.

5.3.7 Dry root biomass at flowering

Lime application had effects on dry root biomass of all the selected varieties of the AIVs as exhibited in figure 5.5. Root biomass increased with increase in lime applied. In all the species zero lime treatment had the lowest dry root biomass. There were significant differences in spider plant and amaranthus ($P \leq 0.05$) whereby, treatments with zero lime (NL0 and AL0) were significantly different from the other lime rates. However, in spiderplant there were no significant differences between the lime rates. Black nightshade had the highest dry root biomass (NL2) and the spider plant the lowest (SL0).

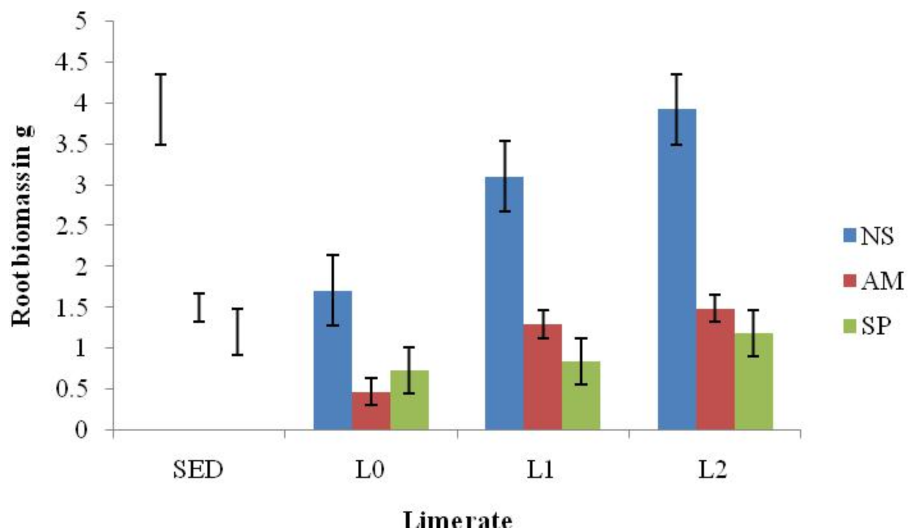


Figure 5.5: Effects of the lime rates on the dry root biomass of black nightshade (*Solanum scabrum*), amaranthus (*Amaranthus spp.*) and Spiderplant (*Cleome gynandra*).

Note: The bar graphs are the means of three replications. The error bars represent the standard error of deviation

5.4: Discussion

5.4.1 Soil properties and effects of lime rates on soil pH

Effects of lime rates on the fertility status of the soil in terms of the soil nutrient content were exhibited (Figures 5.1, 5.2 and 5.3). Soils in the experiment site were Orthic Ferralsols which are acidic (Jaetzold *et al*., 2005). Ferralsols are known to have low CEC of ≤ 16 cmol Kg^{-1} (FA0, 1988). From the analysis the percentage organic carbon and nitrogen were moderate while available P was slightly higher than the critical level of 10 mg P/Kg of soil (Tekalign, 1991 and Okalebo *et al.,* 1989). Upon lime addition the soil pH change was rapid. This may be attributed to the low CEC and low buffer capacity of the soils. According to Bierman and Rosen, (2005), soils that are poorly buffered and with low CEC have low lime requirement and shows rapid changes in pH after liming. They further reported that for soils which are well buffered and have high CEC that is, soils with high clay and organic matter content changes in soil pH are slow for example, Nitisols and Andosols. pH rise in the zero lime treatment may be attributed to the neutralising effect of the organic fertilizer applied as N source in both seasons. The routine soil pH test showed that the target soil pH was achieved (Figure 5.4).

5.4.2 Effects of lime rates on the dry and fresh biomass

Overall, selected variety of African nightshade had the high fresh biomass in all the lime rates variety combinations and the highest was at lime rate 2 t/ha (6411g) in both seasons. Biomass in the rainy season increased by 449 %, 451.52 % and 401.52 % in L_0, L_1 and L_2 respectively compared to dry season. This is a result of high rainfall received in the growing season. Soil moisture was reported as an important factor in crop response to treatments (Okalebo *et al.,* 1989). African nightshade grows well under moist conditions, in acid, neutral to basic soils rich in nitrogen, phosphorus and organic matter (AFF, 2013). Spiderplant with lime rate L1 had the lowest fresh biomass (332.1 g) and lowest dry biomass at flowering in both seasons. An increase in fresh biomass was observed in all the treatments during the rainy season. However, there was enormous increase in both dry and fresh biomass of spider plant in the rainy season. This may be due to introduction of chemical pest management and high rainfall received in the season. Fresh biomass increased by 15.94 %, 538.72 % and 340.32 % while dry biomass increased by 37.5 %, 359 % and 129.28 % in treatments SL_0, SL_1 and SL_2 respectively. Spiderplant is sensitive to cold such that temperature below 15°C affects its growth. Spiderplant requires adequate soil moisture throughout the growing period (Woomer & Imbumi, 2003).

Fresh biomass in amaranth was low compared to African nightshade and Spiderplant. Biomass increased by 36.63 %, 36.56 % and 13.65 % in treatments AL_0, AL_1 and AL_2 respectively. This may be attributed to the difference in moisture requirement of the two crops. Previous studies have described amaranth as warm season or summer crop, well adapted to warm conditions and have a C4 pathway enabling it to grow rapidly at high temperatures (Webster, 2006; Shrestha & Swanton, 2007).

In all the species fresh and dry biomass increased during the rainy season. Rainfall distribution and air temperatures during the growing season among other factors affect retention, availability and uptake of nutrients. According to Splittstoesser, (1990), nitrogen is a very important nutrient and its uptake is influenced by soil water availability and soil pH. Addition of N-fertilizer increases growth and yield of leafy vegetables (Bierman & Rosen, 2005; Onyango, 2002). There exist a very close relationship between the soil moisture content and crop yield (Luvaha *et al.,* 2008). From the results obtained liming impact seems to have been realized in the second season. It has also been reported that ground lime reacts slowly and should be applied several months in advance of planting.

The differences in dry and fresh biomass observed in the two seasons can be explained by reduction of total dry matter as result of water stress. Water stress reduces total dry matter by 27-43 %. Plants respond to water stress by reducing their leaf area as a mechanism of reducing water loss through evapotranspiration. This affects the process of photosynthesis by reducing interception of photosynthetic active radiations and consequently causes a decrease in biomass production (Masinde *et al.,* 2005).

5.4.3 Effects of lime rates on N and P content in the tissue

Nutrient concentration in the plant tissue represents uptake, transport, metabolism and utilization of nutrients by the crop. In all the vegetable species %N and %P in the plant tissue increased tremendously in the rainy season. This may be attributed by heavy rainfall received in the season. Mendoza *et al.,* (1995) reported that soil water content is an important factor that significantly influences the impact of applied amendments and fertilizer. The results also agree with previous study findings that soil water enhances the release of plant nutrients from applied fertilizers through mineralization reactions for example hydrolysis (Koerselman *et al.,* 1993). It has also been reported that soil water enhances P uptake in some plants like wheat in, soils with low P (Strong *et al.,* 1980). A positive linear relationship has been confirmed to exist between soil water and P uptake (Olsen *et al.,* 1961).

In amaranths increase in %N in the plant tissue was between 94.4% and 105.5%. Percentage P increment was between 55.88% and 136%. P in the tissue increased with increase in lime applied. Liming acid soils increases availability of applied and soil P. Soil reaction near neutral enhances microbial biodiversity which in the process of breaking down the organic matter some of available N become immobilized.

In the second season (rainy season), the increase in %N of African nightshade was between 30.56 % and 57.31 % this was the lowest in all the AIVs species. This is may be attributed to the ratio of yield and available N in the soil. African nightshade recorded the highest fresh and dry biomass (Table 5.1).

Spiderplant had the highest N and P, 4.86 % and 0.81 % respectively in the plant tissue in the second season (rainy season). Interaction between P levels with soil water content and soil reaction affects concentration of P in the plant tissue (Luvaha *et al.,* 2008).

5.4.4 Effects of lime rates on the chlorophyll content in the mature leaves at flowering

Chlorophyll content in plant leaves is an indicator of the health status of the plant. Healthy crops have high amount of chlorophyll and vice versa. Nitrogen and magnesium are integral parts of the chlorophyll. Liming acid soils facilitates uptake of N and raises base saturation (Ca, K and Mg) in the soil solution making them available for uptake by plants (Mclean, 1971). High amount of chlorophyll in the leaves at adjusted soil pH-5.5 (L1) indicates that the plants were generally healthier.

Therefore crops that produce large harvest-able materials for example, leafy vegetables remove large amounts of nutrients from the soil. The plant P and N varied greatly in the two seasons. In the dry season the nutrient concentration was low. This may be attributed to the effects of water deficit and dehydration of the tissue. When plants are subjected to water stress total chlorophyll content reduces by 55 % compared to well-watered crops (Kirknak *et al.,* 2001; Cengiz *et al.,* 2006). Nitrogen is a constituent ingredient of chlorophyll and therefore reduced chlorophyll means low N concentrations. This may also be as result of lime not being applied early enough to allow it to neutralize the soil acidity and therefore it did not have a huge impact in the first season.

5.4.5 Effects of lime rates on root length density

Lime application in acid soils increases availability of P and Ca. The two elements are very essential in root growth. Increasing P availability in the soil reduces affinity of root to grow. Increasing the lime rate increases Ca content in the soil (USDA, 1999). Calcium (Ca) is very key ingredient in structural development of roots and therefore lack of calcium causes poor root development (White & Broadley, 2003).

In amaranthus, zero lime (control) had the lowest root length density. Soil acidity restricts root growth (Adcock *et al.,* 1999). Root length density increased by 72.6 % and 34.8 % in Al_1 and AL_2 respectively compared to control. The results indicated liming at 2 tons/ha, to adjust soil pH to 5.5, as the ideal pH for growing spider plant. This was further affirmed by the results of % P in the tissue in the same study where AL_1 had the highest content, AL_2 second highest and un-limed unit had the lowest.

In spider plant, zero lime treatment (SL0) had the highest root length density. This may be attributed to the fact that spider plant has high P requirement. Low soil P content have been reported to enhanced root growth in order to increase soil-root contact for more P uptake (Zhang *et al.,* 2012); hence the low P content in SL0 might have triggered root growth.

Root length density in black nightshade increased by 46 % in NL_2 and reduced by 22 % in NL_1 compared to the control (NL_0). Black nightshade requires more nitrogen than amaranthus and spider plant. This may be attributed to the high harvestable material (leaves) produced by nightshade reflected in the dry and fresh biomass production data (table 5.1). When the most required nutrient by any plant is available, there is a positive influence on shoot and root growth (Zhang *et al.,* 2012). Liming acid soils increases microbial activity in the soil which in turn increases N mineralization. At soil pH 5.5 (2t/ha) the root length density was the lowest. Cao and Tibbtts, (1998), reported that under high nitrogen rates most plant species show stunted root growth system.

Different responses of the three species to lime rates may be attributed to different levels of ideal soil pH and the different nutrient requirement of the AIVs species. This concurs with Marschner, (1995) who reported that different cultivars vary widely in their susceptibility to deficiencies or element toxicities.

5.4.6 Effects of lime rates on dry root biomass

In all the species a similar trend was observed. Dry root biomass increased with increase in the lime rate. This may be attributed to increased availability of calcium for uptake by plants. The increased concentration of Ca in the root tissue particularly at the root tip influence growth by altering the action or concentration of the growth inhibitor (Schiefelbein et al., 1992). Picchioni *et al.,* (2001), showed that calcium addition increased accumulation of total dry matter of roots in vegetables. It has also been reported that calcium plays an essential role in root growth and it is thought to promote growth of lateral roots and primary meristems (Marschner, 1995; Jackson 1967). A similar study showed that root dry matter of alfalfa increased with increasing lime rates (Moreira & Fageria, 2010).

5.5 Conclusion

Liming was beneficial to all the AIVs species and increased fresh and dry biomass. Highest fresh biomass was realized at lime rate 2 t/ha in all AIVs types while, highest dry biomass was realized at lime rate 4.1625 t/ha but not always in all the species. Response on liming seemed to be season specific with rainy season appearing to favour African nightshade and Spiderplant more than Amaranth. For enhancing and ensuring efficient nutrient uptake adequate, soil moisture is an important factor. Plant nutrient concentration was affected by water availability (seasons-rain distribution) and lime rates in all the species. Moreover, liming Ferralsols improved root growth in all the selected AIVs types. Based on the data that was obtained, application of lime increased dry root biomass in all the selected varieties of AIVs. Lime rate 4.1625 t/ha (adjusted soil pH-6.5) had the highest root biomass and zero lime (Inherent soil pH-5.02) the lowest in all the species. Contrary, root length density in the three AIVs type responded differently on application of lime. This emphasized the need to identify the ideal soil pH levels for the newly developed and domesticated lines of AIVs.

5.6 Recommendations

Adjusting soil pH through liming is recommended where soils are acidic i.e. pH<5.4 to realise optimum yields in production of Spiderplant, African nightshade and Amaranthus. A target pH of 5.5 is recommended. Soil testing is a perquisite before liming.

CHAPTER SIX

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. Generally, in all the AIVs type and varieties within them, fertilizer (N) application increased the mean cumulative fresh yield. In African nightshade, all the three varieties had the highest mean cumulative fresh yields under mavuno fertilizer application compared to the poultry manure and control. Developed variety BG-16 with mavuno was the best variety-fertilizer combination. In Amaranthus, all the developed had the highest mean cumulative fresh yields under poultry manure application compared to mavuno fertilizer and control. The best variety-fertilizer combination being UG-AM-40 with poultry manure. In Spiderplant, the local variety and UG-SF-15 had the highest mean cumulative fresh yields with mavuno fertilizer application while ML-SF-29 variety had the highest yields in poultry manure application. Local variety with Mavuno was the best variety-fertilizer combination.
2. Lime rate at 2 tonnes/ha with an adjusted pH of 5.5 was the most ideal for production of the most selected African Indigenous Vegetables in enhancing biomass production and essential plant nutrients uptake.
3. Application of Calcitic lime in acid soils increased root growth significantly in all the selected African Indigenous Vegetables.

6.2 Recommendations

1. Sustainability in AIVs production can be achieved by use of the two fertilizer sources which will improve soil health and quality. This is because there were no major significant differences exhibited between the Mavuno and poultry manure treatments.
2. Routine soil analysis is an essential land-use practice. This will ensure that there is timely reaction if any soil amendment like liming is required. It is therefore recommended that farmers, as far as possible, test their soils before amendments.
3. Liming tropical soils which in most cases are acidic is a necessity. This will ensure there is adequate supply of basic cations (Ca^{2+} and Mg^{2+}) to raise soil pH and consequently enhance efficient nutrient uptake and root growth. Lime rate at 2 t/ha is ideal for improvement of pH.

6.3 Way forward

1. There is need to evaluate the perfect match of N-sources to all the new developed varieties of AIVs. From the obtained data varieties responded positively and differently to N-sources.
2. To achieve high yields that are of high quality there is need to examine which N-source (organic and inorganic) meet the threshold in terms of nutrient concentration (NO^{-}_{3}) in the edible parts of the AIVs that is fit for human consumption.

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APPENDICES

Appendix 1: Determining amount of mineral fertilizer to be applied

Mavuno planting fertilizer N: P: K was 10:26:10, therefore to supply the required amount the rate was 500Kg/ha based on nitrogen in the fertilizer.

Let the amount of fertilizer to apply in a $8M^2$ plot be Y Kg and since $1ha=10,000M^2$

$$Y = \frac{8 \times 50}{10000} = 0.4Kg\ or\ 400g\ of\ mavuno\ fertilizer(10{:}26{:}10)\ per\ 8M^2$$

Appendix 2: Determining amount of poultry manure (1.86 %N) to be applied in season one and 2 respectively.

Recommended rate of N application was 94Kg N/ha.

Percentage nitrogen in the poultry manure is 1.86 this implies that 1.86Kg of nitrogen (N) is in a 100Kg of poultry manure.

Amount of poultry manure (Z) to supply 94Kg of nitrogen,

$$Z=\frac{94 \times 100}{1.86} = 5053.76\ Kg\ of\ Poultry\ Manure\ per\ hactare$$

How much of the poultry manure will be applied in (4×2) $8M^2$ plot of land.

$1Ha=10000M^2$

$$Q = \frac{5054 \times 8}{10000} = 4.0432Kg\ or\ 4Kg$$

Appendix 3: Lime requirement determination; amount of lime to apply in 8M^2 plot (8-10 inches soil layer)

Lime requirement was determined using a liming program table prepared based on the soil textural class and the initial soil pH. A liming material; Athi river mining lime whose calcium carbonate equivalent (CCE) is known to be 30% was used. From the table the recommended amount is read and substituted in an equation below to obtain the actual amount of lime to apply for the purpose of increasing the soil pH of an 8 inches soil layer.

1hectare=2.4710581 acres 1acre=4,050M^2

$$\textit{Actual amount of liming material to apply} = \frac{(\textit{Soil test CCE recommendation})}{\%\ \textit{CCE of liming material}} \times 100$$

i. Target pH of 4.5 (Control; zero lime [Lo])

ii. Target pH of 5.5 (L_1)

Initial soil pH: Lowest 4.9, soil texture; sandy loam

Pounds of $CaCO_3$ equivalent recommended per acre to raise soil pH to 5.2

1 pound= 0.45359237Kg

1 acre= 4050M^2

$$\textit{Amount of liming material per acre} = \frac{450 \times 100}{30} = 1500\textit{pounds (lb) or } 3307\textit{Kg}$$

$$L1 = \frac{8 \times 3307}{4050} = 6.532345679\textit{Kg of lime}$$

Using 10,000M^2 instead of 4050M^2 basing the lime recommendation per hectare the amount to apply is 4Kg of fine ground lime.

iii. Target pH of 6.5 (L_2)

Initial pH 4.9-5.2

Soil texture; sandy loam

Pounds of $CaCO_3$ equivalent recommended (from the table) to be applied per acre to raise soil pH to 6.2-6.5.

$$Amount\ of\ CaCO3 = \frac{3600 \times 100}{30} = 12000 Pounds\ or\ 5443.10844 Kg\ per\ acre$$

$$L2 = \frac{8 \times 5443.10844}{4050} = 10.751819 Kg\ of\ lime$$

Using 10,000M^2 areas squared for one hectare the lime to be applied per 8M^2 plot is 4.3544Kg.

Appendix 4: Eldoret-Dry season; African Nightshade

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
BLOCKS	2	28.741	14.370	0.00	0.9982
VARIETY	2	785125.852	392562.926	49.42	<.0001
VARIETY*BLOCKS	4	9449.259	2362.315	0.30	0.8740
FERT	2	1436791.630	718395.815	90.45	<.0001
VARIETY*FERT	4	344995.704	86248.926	10.86	0.0006

Appendix 5: Eldoret-Wet season; African Nightshade

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCKS	2	13038.2963	6519.1481	3.82	0.0521
VARIETY	2	303738.2963	151869.1481	88.97	<.0001
VARIETY*BLOCKS	4	2441.4815	610.3704	0.36	0.8340
FERT	2	547116.5185	273558.2593	160.26	<.0001
VARIETY*FERT	4	58268.5926	14567.1481	8.53	0.0017

Appendix 6: Kitale-Dry season; African Nightshade

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCKS	2	14245.630	7122.815	0.51	0.6105
VARIETY	2	1335854.296	667927.148	48.23	<.0001
VARIETY*BLOCKS	4	30285.926	7571.481	0.55	0.7050
FERT	2	2891090.741	1445545.370	104.38	<.0001
VARIETY*FERT	4	669168.148	167292.037	12.08	0.0004

Appendix 7: Kitale-Wet season; African Nightshade

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCKS	2	3813.6296	1906.8148	0.46	0.6448
VARIETY	2	567093.4074	283546.7037	67.70	<.0001
VARIETY*BLOCKS	4	12246.3704	3061.5926	0.73	0.5880
FERT	2	871619.1852	435809.5926	104.06	<.0001
VARIETY*FERT	4	171282.1481	42820.5370	10.22	0.0008

Appendix 8: Eldoret dry season; Amaranthus

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCKS	2	6824.0000	3412.0000	1.62	0.2386
VARIETY	2	97450.8889	48725.4444	23.12	<.0001
VARIETY*BLOCKS	4	7803.1111	1950.7778	0.93	0.4810
FERT	2	390929.5556	195464.7778	92.74	<.0001
VARIETY*FERT	4	30790.2222	7697.5556	3.65	0.0361

Appendix 9: Eldoret wet season; Amaranthus

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCKS	2	6824.0000	3412.0000	1.62	0.2386
VARIETY	2	97450.8889	48725.4444	23.12	<.0001
VARIETY*BLOCKS	4	7803.1111	1950.7778	0.93	0.4810
FERT	2	390929.5556	195464.7778	92.74	<.0001
VARIETY*FERT	4	30790.2222	7697.5556	3.65	0.0361

Appendix 10: Kitale dry season; Amaranthus

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCKS	2	4784.2963	2392.1481	0.75	0.4915
VARIETY	2	168810.2963	84405.1481	26.61	<.0001
VARIETY*BLOCKS	4	17599.7037	4399.9259	1.39	0.2962
FERT	2	703869.4074	351934.7037	110.94	<.0001
VARIETY*FERT	4	103508.5926	25877.1481	8.16	0.0020

Appendix 11: Kitale wet season; Amaranthus

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCKS	2	363.1852	181.5926	0.10	0.9033
VARIETY	2	36464.2963	18232.1481	10.30	0.0025
VARIETY*BLOCKS	4	1371.2593	342.8148	0.19	0.9371
FERT	2	289428.9630	144714.4815	81.74	<.0001
VARIETY*FERT	4	38170.1481	9542.5370	5.39	0.0101

Appendix 12: Eldoret dry season; Spiderplant

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCKS	2	541.6296	270.8148	0.14	0.8736
VARIETY	2	15303.1852	7651.5926	3.86	0.0507
VARIETY*BLOCKS	4	2103.7037	525.9259	0.27	0.8946
FERT	2	396138.7407	198069.3704	99.95	<.0001
VARIETY*FERT	4	53585.9259	13396.4815	6.76	0.0043

Appendix 13: Eldoret wet season; Spiderplant

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCKS	2	151.4074	75.7037	0.11	0.8932
VARIETY	2	4672.2963	2336.1481	3.52	0.0628
VARIETY*BLOCKS	4	4857.2593	1214.3148	1.83	0.1882
FERT	2	108305.8519	54152.9259	81.54	<.0001
VARIETY*FERT	4	22586.1481	5646.5370	8.50	0.0017

Appendix 14: Kitale dry season; Spiderplant

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
BLOCKS	2	7317.6296	3658.8148	1.88	0.1951
VARIETY	2	6865.4074	3432.7037	1.76	0.2133
VARIETY*BLOCKS	4	9879.2593	2469.8148	1.27	0.3356
FERT	2	664520.5185	332260.2593	170.58	<.0001
VARIETY*FERT	4	117443.0370	29360.7593	15.07	0.0001

Appendix 15: Kitale wet season; Spiderplant

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
BLOCKS	2	8582.2963	4291.1481	7.96	0.0063
VARIETY	2	17868.5185	8934.2593	16.57	0.0004
VARIETY*BLOCKS	4	750.8148	187.7037	0.35	0.8404
FERT	2	243273.8519	121636.9259	225.55	<.0001
VARIETY*FERT	4	65372.5926	16343.1481	30.30	<.0001