EFFECT OF PHOSPHATE FERTILIZER RATES ON GROWTH AND LEAF YIELD OF AFRICAN NIGHTSHADE (*Solanum* L. section *solanum*) GENOTYPES IN UASIN GISHU COUNTY, KENYA

BY

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DECLARATIONS

DECLARATION BY THE CANDIDATE

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ABSTRACT

The African nightshade vegetable is in high demand in many parts of western Kenya, this demand has not been met due low yields caused by low use of fertilizer inputs in the region. Most of the soils found in Uasin Gishu County are acidic and deficient of phosphorus but there is inadequate information available on the appropriate rate of phosphorus to be used to produce optimum yields of the African nightshade. The specific objectives of this study were to evaluate the effect of phosphate fertilizer application rate on the growth, leaf yields and financial benefits of growing the three African nightshades in Uasin Gishu County. The experiment treatments consisted of three genotypes; *Solanum scabrum* (C1), *Solanum villosum* var. *villosum* (C2) and *Solanum villosum* var. *miniatum* (C3) and four rates of phosphorus; 0 (P0), 20 (P1), 40 (P2) and 60 (P3) kg P ha^{-1} arranged in a factorial combination. A randomized complete block design with three replications was used. The study was conducted for two consecutive seasons in Moiben Location, Eldoret East District. Phosphate fertilizer, as triple superphosphate was applied at planting time while top dressing with calcium ammonium nitrate (CAN) at 60 kg N ha^{-1} was done six weeks later. Soils were sampled prior to planting and later analyzed for available phosphorus using standard procedures. The plant height, leaf area, number of leaves, fresh and dry weight leaf yields were taken from 45 days after sowing and harvesting done at 78 and 77 days after sowing for season one and two respectively by picking all leaves and tender shoots. Leaf yields were determined by weighing the fresh weight and also the dry weight after drying them in an oven at 70^0C to a constant weight. A benefit-cost analysis for each treatment was done to determine their economic attractiveness. Plant height, leaf area, number of leaves and number of branches in the main stem increased significantly ($p < 0.001$) with the increase of phosphorus rate applied. The increase in fresh and dry leaf with increase in phosphorus rate was highly significant ($p < 0.001$) in the two seasons. The fresh leaf yields increased over the control by 285-346% and 84-407% in season one and two respectively. The dry leaf yields increased over the control by 162-328% and 163-362% in season one and two respectively. There was significant ($p \leq 0.05$) interaction between genotype and phosphorus on leaf yields in the two seasons. *Solanum villosum* var. *villosum* had higher percentage increase over the control in the number of leaves in a plant and leaf yields in season one. It also had higher percentage increase over the control in the height, number of leaves, number of branches, leaf area and leaf yields. *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum* had high net benefits in season one and two respectively. It is recommended that 60 kg P ha^{-1} rate should be used for all the sampled genotypes in the long rains season. In the short rains season 40 kg P ha^{-1} should be used for *Solanum villosum* var. *villosum* and 60 kg P ha^{-1} for *Solanum villosum* var. *miniatum.* The best genotype for short and long rain season was *Solanum villosum* var. *miniatum* and *Solanum villosum* var. *villosum* respectively. Further work need to be done on the effect of *Solanum villosum* var. *villosum* at higher than 40 kg P ha^{-1} in the short rain season.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The African nightshade (*Solanum* L. section *solanum*) is an indigenous vegetable that belongs to the family *Solanaceae* and genus *solanum*. It is an important vegetable and cash crop grown in smallholder households in Kenya (Abukutsa-Onyango, 2007). The consumers' demand for vegetable and the income generated from its sales has been reported to be high as compared to the other available African indigenous leafy vegetables (Irungu *et al*., 2007).

The common genotypes of the African nightshade found in Kenya include *Solanum villosum* Miller, *Solanum americanum* Miller, *Solanum scabrum* Miller and *Solanum physalifolium* (Ondieki *et al*., 2011a). Abukutsa-Onyango (2007), Onim and Mwaniki (2008) and Irungu *et al*. (2007) reported that *Solanum scabrum* and *Solanum villosum* are the prioritized nightshade vegetables both for consumption and sale in Kenya. They are grown in home gardens for consumption and marketed as leafy vegetable. They are a source of food security and generate income to many resource poor farmers (Mwai *et al.*, 2005; Chadha *et al.*, 2007 and Onyango *et al.*, 2009). The production of the vegetable has been constrained by inadequate use of nitrogen, phosphorus and potassium fertilizers that are required in large amount for proper plant growth (Ashilenje *et al.*, 2012). The available nutrients in cultivated soils of North Rift, Kenya have been reported to be inadequate for plant growth and therefore it necessitated their addition in the form of inorganic fertilizers whose rate would vary depending on soil nutrient availability, the crop species and the environmental factors (Tisdale *et al.,* 1985; Kipkosgei *et al.*, 2003 KARI., 2005a). Researchers have been trying to find out the optimum levels of nutrients application rate which can maximize the production of African nightshade. Nitrogen application rates have been studied by a number of researchers (e.g. Abukutsa-Onyango and Karimi, 2005; Opiyo, 2006; Kipkosgei *et al.*, 2003; Juma, 2006). The effect of potassium fertilizer on African nightshade was studied by Shibonje (2009) in western Kenya.

1.2 Justification

African nightshades are important in food security, nutrition and income generation. The demand for the vegetable is ever increasing by the consumers due to promotional strategies that have been adopted by Non-governmental organization with the aim of improving income generation and nutritional status which will ultimately lead to reduction of dietary diseases (Irungu *et al.,* 2007). The demand has not been met due to low production. This study seeks to increase the leaf yield and financial through use of appropriate rate of phosphate fertilizer on three genotypes of African nightshade

1.3 Problem statement.

The effect of phosphorus on African night shade fresh leaf yields has not been given much attention by previous workers. Khan *et al*. (2000) studied the effect of phosphorus on *Solanum nigrum* L. fresh yields in Pakistan and van Averbeke *et al*. (2007) did the study with *Solanum retroflexum* Dun in South Africa. The two researchers had their studies done in pots. These researchers came out with varying optimum rate of phosphorus for production of African nightshade. The variations of the recommendation have possibly been due to the varying agro-ecological conditions, soil factors on where the study was done and the crop genotype. Many of the studies have been done in greenhouses with few conducted under field conditions. Where the studies were done in the field, their findings have been found to vary depending on climatic factors. There is little information available from the published findings on the rate of phosphorus that can be used by Uasin Gishu county farmers in field plots to increase the leaf yields of different genotypes of African nightshades.

However African nightshade leaf yields are low, ranging between 1- 3 tons ha^{-1}, compared to the potential leaf yields of 20-40 tons ha^{-1} in western Kenya (Ashilenje *et al*., 2012). The low yield is largely attributed to low soil fertility, especially phosphorus, which limits plant growth despite the good climatic conditions in the region (Okalebo, 2009; Opala *et al*., 2010). This necessitates the additions of phosphorus in form of inorganic fertilizers (KARI, 2005a). The response of the vegetables to application of fertilizers is usually site specific and is likely to vary among the various genotypes of solanum (Okalebo, 2009). The agronomic data on the effect of phosphate fertilizer to use on different genotypes of the African nightshade is lacking in this Uasin Gishu County.

1.4 Objectives of the Study

1.4.1 General Objective

To determine the growth and performance of three African nightshade genotypes (*Solanum scabrum, Solanum villosum* var. *villosum and Solanum villosum* var. *miniatum*) due phosphate fertilizer.

1.4.2 Specific Objectives.

1) To evaluate the effect of phosphate fertilizer application rate on the growth and leaf yields of three African nightshade genotypes in Uasin Gishu county.
2) To determine the influence of phosphate fertilizer application on financial benefits of growing the three African nightshade genotypes in Uasin Gishu county.

1.5 Hypotheses

HI: - There is significant difference of phosphate fertilizer application rate on growth and leaf yields in three African nightshade genotypes in Uasin Gishu county.

HI: - There is significant influence of phosphate fertilizer rate on financial benefits obtained from growing the three genotypes of the African nightshade Uasin Gishu county.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Economic importance of the African Nightshade

African nightshade (*Solanum* L. section *solanum*) is reported to be one of the preferred African leafy vegetables in western Kenya (Abukutsa - Onyango, 2007). The importance of the vegetable was further observed by Irungu *et al.* (2007) as the main African leafy vegetable genotype traded in Nairobi markets (Plate 1) followed by amaranthus, cowpeas and spider plants with high sales being made in the months of March, April, May September and October. The vegetable prices during this period have been found to be low but they rise towards the peak at the beginning of rainy season in March (Bujulu and Matee, 2005). The difference of vegetable prices in the two periods was ascribed to the favourable rainfall which comes between March and October that was responsible for the increased production that led to high supply and low vegetable prices (Irungu, *et al.*, 2007 and Jaetzold *et al.*, 2011).

Source: Odhiambo and Oluoch, 2008

Plate 1: *Solanum villosum* sold in the markets.

The vegetable has been reported to be important for dietary diversification and has become the vegetable of choice especially in the segments where consumption had been minimal (Habwe *et al.*, 2010). It is further reported that 100 g of the fresh vegetables consumed can provide 100% of the recommended daily allowance of calcium, Iron, B-Carotene and ascorbic acid and 40% of proteins for adult (Abukutsa – Onyango and Karimi, 2005). The composition of 100 g edible portion of African nightshade freshly harvested leaves have water 87.8 g, energy 13 KJ (39 cal), proteins (especially amino acids, methionine, rarely found in plants) 3.2 g, fat 1.0 g, carbohydrates 6.4 mg, fibre 2.2 g calcium 200 mg, phosphorus 54 mg, Fe 0.3 mg , B-Carotene 3.7 mg and ascorbic acid 24 mg (Fontem and Schippers, 2004). The vegetable`s importance to the consumers' nutritional requirements has represented cheap but quality nutrition for large parts of the population in both rural and urban areas (Mibei *et al.*, 2011). In Maragua, Thika and Machakos districts, deficiencies such as marasmus and kwashakor in children and anaemia especially in expectant mothers have been reported to occur in the dry season due to shortage of green vegetables (Mbugua *et al.*, 2008). The availability of these vegetables at all seasons could alleviate poverty for the poor rural households who have been found to be relying on indigenous vegetables as a source of micronutrients for their bodies (Chadha *et al.*, 2007).

According to the farmer participatory prioritization exercise conducted in Maragua district by Mbugua *et al*. (2008), African nightshade was found to be the leading vegetable among the indigenous vegetables prioritized. The vegetable`s importance was also reported in Kakamega district where 57% of the total African nightshade vegetables were grown for sale and 43% solely for food (Ndinya, 2005). The tender shoots, leaves and flowers are harvested (Abukutsa-Onyango, 2007) and berries removed before cooking (Schippers, 1998).

The vegetable has been widely used as a medicinal plant. Its medicinal value is attributed to the alkaloidal contents of the plants (Mohy-ud-din *et al.*, 2010). Leaf extracts have been used to treat diarrhea in children, certain eye infections and jaundice, soothe toothache, stomachache and tonsillitis (Manoko and van Weerden, 2004a). Jain *et al.* (2011) reported that the leaves are used in the treatment of ringworms, dressing of warts, stomachache, stomach ulcers and rabies. Roots have been used to increase fertility in women, treat asthma and whooping cough while the sap has been used to treat erysipelas (acute streptococcus bacterial infection). The whole plant is used to treat coughs, burns, dermal affection, snake bites and other stings by venous animal. According to Yousof *et al.* (2006), *Solanum nigrum* has been used in lowering blood pressure and breakdown of cholesterol build up. In India, *Solanum nigrum* has gained importance in pharmaceutical industry due to its amazing drug potential. The whole plant has been recommended for use in reducing excitement or irritability, excessive sweating, cleansing bowels and relieving stress (Sivakumar and Ponnusami, 2011). Akubugwo *et al*. (2007) further reported that the leaves extract have antitumor and neuropharmacological properties which can be used as antioxidant and cancer chemo preventive matter. The vegetable has provided employment to the rural people, mainly women, who have been mainly involved in the cultivation and marketing of the African nightshade. According to the survey conducted in 2001 in two rural markets and one municipal market in western Kenya by Abukutsa – Onyango (2007), it was found out that women constituted 95% and 70% of the farmers who were producing and trading on African leafy vegetables in the rural and municipal markets of western Kenya respectively. The vegetable has been a source of income to the producers and the traders. Irungu, *et al*. (2007), found out African nightshades to be leading among the African leafy vegetables analyzed in the Nairobi City markets and its peri-urban areas in terms of weekly traded quantities and gross values.

The growth in production has been greatly influenced by increase in consumer demand caused by promotional strategies by local non-governmental organizations, increased health awareness and consciousness on the effect of HIV /AIDS and the improved African leafy vegetables presentations in supermarkets stores (Irungu, *et al.*, 2007). However there seems to be some confusion on the *Solanum nigrum* complex toxicity. According to Onim and Mwaniki (2008), African nightshades (e.g *Solanum scabrum*, *Solanum americanum* and *Solanum villosum*), the non poisonous, widely and commonly cultivated in many regions of Africa have been confused with the deadly nightshade (*Atropa belladonna* and *Solanum nigrum*) which have been reported to be native to North Africa, Europe and West Asia mainly referred to as weeds (Jain *et al*, 2011). Ondieki *et al.* (2011a) observed that the confusion about the toxicity of African nightshade has led to the decline in use and consumption of the vegetable. However, Dhellot *et al*. (2006) reported that the African nightshade tender shoots and leaves contain only low levels of the alkaloids which are however associated with bitterness The bitterness and toxicity have been reported to be reduced by cooking and the toxic effects of glycoalkaloids are destroyed (Schippers, 1998).

Despite the positive attributes of the African nightshade, the vegetable has been neglected by African researchers, policy makers and farmers (Mibei *et al.*, 2011). Although the vegetable`s potential of reducing food insecurity and poverty have been recognized, its cultivation is still low (MOA, 2000; Mwai *et al.,* 2005). It has always been produced mainly at subsistence level, where it is grown in home gardens, around homestead or collected from the wild and increasingly near major cities for market supply (Fontem and Schippers, 2004; Abukutsa – Onyango and Karimi, 2005; Musotsi *et al.,* 2008). The reported leaf yield of the vegetable is low, ranging between 1-3 tons ha^{-1} which is below the optimal level of 20-40 tons ha^{-1} (Ashilenje *et al.*, 2012). The low yields have been obtained from poor seeds used, insufficient amount and type of fertilizers used, poor pest and disease control (Ashilenje *et al.*, 2011). The farmers` seeds are reportedly bought from seed traders at open air market where the seeds may have not been processed and stored properly, damaged by pests and diseases (Abukutsa-Onyango, 2003; Kipkosgei *et al.*, 2003; Onim and Mwaniki, 2008). According to K`Opondo *et al.* (2005), the seeds have been found to have low germination capacity or the total failure to germinate.

The potential yields ha^{-1} has been reported differently by different authors. For example, Manoko and van der Weerden (2004a) reported that the optimum yields of *Solanum villosum* as 20-25 ton ha^{-1} per year for small scale farmers in Kenya and Tanzania while the cumulative leaf yield per growing season in Kenya is 12-20 tons ha^{-1}. Ashilenje *et al.* (2011) reported that the optimum yield level is between 20 – 40 tons ha^{-1}. The cumulative yields of *Solanum scabrum* per growing season is reported to be 40 tons ha^{-1} and the leaf yield per harvest is 7-27 tons ha^{-1} declining from the sixth harvest (Fontem and Schippers, 2004). Onim and Mwaniki (2008) reported the yield to be 27.53 tons ha^{-1} from three harvests. Edmonds and Chweya (1997) reported the leaf yield as 12-20 tons ha^{-1} while Schippers (1998) reported the average yields of first harvest as 7-13 tons ha^{-1}. In Arumeru district in Tanzania, the average leaf yield has been reported as 3.83 tons ha^{-1} (Weinberger and Msuya, 2004). Mwangi and Mumbi (2006) reported the leaf yield as 28.41 tons ha^{-1}. The difference of yields reported could be due to the genotype, soil chemical and physical content, the agro-ecological zones, seed germination capacity or the fertilizer type and amount used (Kipkosgei *et al.*, 2003; Opala *et al.*, 2010 and Ashilenje *et al*, 2011). The marketing and consumption of African nightshade vegetable has steadily changed from the time it was presumed to be eaten by lower socio-economic group (Onyango *et al.*, 2009). After harvesting the vegetables are tied in bundles before they are sold (Schippers, 1998). The weight of each bundle ranges between 350 – 600 g depending on the genotype and seasons (Onyango *et al.,* 2009). The price per bundle remains constant but the quality and quantity may vary considerably depending on the supply (Schippers, 1998; Irungu, *et al.,* 2007).

2.2 Ecological factors

African nightshade grows from sea level to 3500 m above sea level distributed from temperate to tropical regions (Schippers, 2000; Mwai *et al.*, 2007). It has been reported that the vegetable requires high moisture conditions with rainfall of about 1500 mm per annum (Mwai *et al.*, 2007). According to Rensburg *et al.* (2007*)* *Solanum nigrum* has been found in humid environments with at least 500 mm of rain per annum. Schippers (2000) reported that one of the *Solanum villosum* species is found in relatively drier areas such as Ethiopia, northern Uganda and the eastern part of Kenya. The African nightshade has been found to prefer organic soils with high nitrogen, phosphorus and potassium (Kipkosgei *at all.*, 2003; AVRDC, 2003; Masinde *et al.*, 2010) with a pH of between 6.0 – 6.5 and does not tolerate drought (Edmonds and Chweya, 1997). It is noted to require a temperature of 20ºC – 30ºC (Schippers, 2000; Mwai *et al.*, 2007).

2.3 Genotypes of the African nightshade

Two genotypes; *Solanum scabrum* and *Solanum villosum*, have been reported to be popular in western Kenya (Abukutsa – Onyango and Karimi, 2005). The potential yields realized depended on the management practices including plant spacing, nutrient and water availability (Edmonds and Chweya, 1997; Rensburg *et al.*, 2007).

2.3.1 *Solanum scabrum*

The plant is reported to be medium to tall (up to 1.8 m) and has an erect to slightly spreading branches, mostly with primary and secondary branches (Mwai *et al*, 2005). It is one of the most important vegetable widely cultivated in East Africa, Africa and Southern Asia (Manoko, *et al.*, 2008; Muthomi and Musyimi, 2009). The whole range of diversity of *Solanum scabrum* (Plate 2) especially in Nigeria and Cameroon suggests that its origin is likely to be in warm humid forest belt of West and Central Africa (Muthomi and Musyimi, 2009). It is reported to be a commercial crop in Southwest Uganda (Olet *et al*, 2011). It has been found to be most important vegetable in section *solanum* which is preferred by many farmers because of potential of intercropping, multiple harvesting per cropping season and is not bitter (Irungu *et al.*, 2007; Manoko, *et al.*, 2008). The crop is reported to be constrained by drought as abiotic stress that limit the productivity and it will require watering every week if there is no rain (Muthomi and Musyimi, 2009). The vegetable has not been commonly found in dry areas as it prefers areas with high rainfall (Schippers, 2002; Keding *et al.*, 2007). The genotype has been reported to be affected by season. Ondieki *et al.* (2011a) in the experiment done in Kisii, Kenya (without applying fertilizers) found *Solanum scabrum* leaf yields to be higher in long rain season (4120 kg ha^{-1}) and lower in short rain season. *Solanum scabrum* leaf yields in the first harvest are reported to be between 7 – 13 tons ha^{-1} while the cumulative yield is between 12- 20 tons ha^{-1} (Schippers, 1998). Ashilenje *et al*. (2012) found the genotype`s average fresh leaf yield to be 11460 kg ha^{-1} using 48 kg P ha^{-1} with 66 kg K ha^{-1} during the long rains season (April to June, 2007) in Ikolomani, Kenya. AVRDC (2003) reported the optimum leaf yield to be 40 tons ha^{-1}. The seeds of *Solanum scabrum* are sold by Simlaws seed (Kenya Seed Company) as giant black nightshade (AVRDC, 2003). *Solanum scabrum*, a broad leaved vegetable is reported to be less bitter and preferred by the consumers living in Central highlands and urban areas (Onim and Mwaniki, 2008).

Source: Odhiambo and Oluoch, 2008

Plate 2: ***Solanum scabrum***

2.3.2 *Solanum villosum*

The genotype has been reported (Schippers, 2000) to have two subspecies which are differentiated by hairs on the plant surface. The first one has been found to have short hairs while the second subspecies appears to be smooth. *Solanum villosum* (Plate 3) is a red or orange fruited vegetable which is reported to have originated in Eurasia and sometimes considered to have southern European origin (Manoko and van der Weerden, 2004a). *Solanum villosum* grows either in wild or is semi-cultivated as small scale productions (Kipkosgei *et al.*, 2003). Masinde *et al.* (2010) noted that the genotype is widely consumed in Kenya and many parts of sub-Sahara Africa. The vegetable requires relatively lower moisture than *Solanum scabrum.* Schippers (2000) and Weinberger and Msuya (2004) reported that one of the *Solanum villosum* species has been found growing in drier areas of Kenya and Tanzania respectively. The plant has been observed to have small leaves with bitter taste that is preferred by people in Coastal and Western Kenya (Onim and Mwaniki, 2008). In Arumeru district, Tanzania, it has been reported that farmers prefer this vegetable due to its good taste and high marketability (Weinberger and Msuya, 2004). It is reported to be the most expensive and a common product at many local markets in rural and urban markets in Kenya and Tanzania (Manoko and van der Weerden, 2004a).

It requires fairly large amount of nutrients. The vegetable will do well in soils rich in organic matter with high amount of nitrogen, phosphorus and potassium (Kipkosgei *et al.*, 2003; Manoko and van der Weerden, 2004b; Mwai *et al.*, 2007). In Tanzania, a maximum yield was obtained at 50 – 100 kg N, 11 kg P and 20 kg K ha^{-1} (Manoko and van der Weerden, 2004a). Edmondss and Chweya (1997) reported the annual yield to be between 12-20 tons ha^{-1}. Ondieki *et al.* (2011b) in Kisii while using fortified manure (N= 2.13%, K= 5%, P= 3.38% and Mg= 0.57%) found a leaf yield of 4.93 tons ha^{-1}. Mwai *et al.* (2005) and Edmonds and Chweya (1997) have taxonomically described *Solanum villosum* to two varieties of *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum*

Source: Onim and Mwaniki, 2008

Plate 3: ***Solanum villosum***

2.3.2.1 ***Solanum villosum*** **miller var.** ***villosum***

The plant of this genotype is medium in height and grows up to 1.1 m with widely spreading erect branches. Its stems are greenish purple with green purple nodes (Mwai *et al.*, 2005). The stems are cylindrical or nearly so, slender with smooth ridges (Edmonds and Chweya, 1997). The mature berries are rounded, orange and remaining on plant when fully ripe. The fruit flesh is orange when physiologically ripe (Mwai *et al.*, 2005). The leaf yields in Western Kenya in long rains season was found to be 4890 kg ha^{-1} (Ashilenje, 2012).

2.3.2.2 ***Solanum villosum*** **miller var.** ***miniatum***

They are medium to tall plants growing up to 1.5 m in height with slightly spreading erect branches as opposed *Solanum villosum* miller var. *villosum* which is widely spreading. It has short hairs as on its surfaces. The stems are green with the nodes colour ranging from green to purplish (Mwai *et al.*, 2007). Stems are usually angular with dentate ridges as opposed to *Solanum villosum* miller var. *villosum* which has smooth ridges (Edmonds and Chweya, 1997). Mature berries range from slightly flattened to rounded, are orange dull and remain on plant when fully ripe. The fruit flesh is orange when physiologically ripe (Mwai *et al.*, 2005). The fresh genotype`s leaf yield in the long rains in Ikolomani, western Kenya, was found to be 4580 kg ha^{-1} (Ashilenje *et al*., 2011)

2.3.3 *Solanum americanum*

It is also referred to as *Solanum nodiflorum* (Plate 4) mainly in West Africa or glossy nightshade (Schippers, 2000 and Manoko and Van der Weerden, 2004b). Its origin is believed to be South America, but is widespread and found throughout the tropics and subtropics often in disturbed localities (Manoko and Van der Weerden, 2004b). It is considered as a cosmopolitan weed which is native to Australia (Spencer, 2006). The crop is not important in Africa as *Solanum villosum* and *Solanum scabrum* (Weinberger and Msuya, 2004). It is mainly grown in coastal areas and areas surrounding the great lakes such Lake Victoria (Manoko and Van der Weerden, 2004b). In Kongwa district in Tanzania, where *Solanum americanum* was newly introduced, the vegetable had not been popular but the popularity has increased due to the belief that it has more vitamin C, helps boost appetite and medicinal properties of curing malaria (Keding *et al.*, 2007). The vegetable requires organic soils with high amount of nitrogen, phosphorus and potassium and does not tolerate drought (Mwai *et al.*, 2007). It matures earlier than the *Solanum villosum* and *Solanum scabrum* with a total leaf yield of 5 tons ha^{-1} when spaced 10 cm x 60 cm from six sequential harvests (Juma, 2006 and Keding *et al.*, 2007). According to Manoko and van der Weerden (2004b) the leaf yield is 12 – 20 tons ha^{-1} which is same as for *Solanum scabrum* and *Solanum villosum*. Ondieki *et al*. (2011b) in Kisii, Kenya found the fresh leaf yields to be 5.19 tons ha-1. The plant`s height is reported to be medium to tall with erect branches, up to tertiary branches. The stems are purplish green in colour, glabrous and without wings. (Mwai *et al.,* 2005). The berries are 6-8 mm in diameter. They are usually spherical in shape and black in colour. It is usually shiny when mature. The seeds are 1- 1.5 cm long (Edmondss and Chweya, 1997).

Source: Manoko *et al*., 2007

Plate 4: *Solanum americanum*

2.4 Phosphorus

Phosphorus is an important plant macronutrient, making about 0.2% of a plant’s dry weight. It is often the second most limiting macro-nutrient for plant growth and crop production after nitrogen (Schachtman *et al.,* 1998 and Kisinyo *et al.,* 2011). The phosphorus deficiency has been observed to limit crop production in many tropical soils (Opala *et al*., 2012). Phosphorus in plants is plays an important role in energy transfer and storage. It is also a key component in the molecule Adenosine Triaphosphate (ATP) and Adenosine diaphosphate (ADP) which are integral to most energy transport process. It is a constituent of chromosomes, essential for the formation of proteins and enzymes, fundamental components of the cell membrane as well as Deoxyribonucleic Acid (DNA) (Schachtman *et al.*, 1998). Phosphorus is reported to stimulate the development of roots and strengthens the skeletal structure of the plant thereby preventing lodging (Okalebo, 2009; Onasanya *et al.*, 2009). The element is required in large amounts in young cells such as in the shoot and root tip where metabolism is high and cell division is rapid (Bationo *et al*., 2006). However the plant available fraction of soil phosphorus is typically low in agricultural soils (Krasilnikoff *et al*., 2003) and may not meet plant requirement for phosphorus. The loss of phosphorus at the soil surface has been attributed to soil erosion and removal by crops (Okalebo, 2009). Phosphorus applied in form of inorganic fertilizers to soils could meet plant phosphorus needs that come as a result of low soil fertility (Diaz *et al*., 2011).

Phosphorus is present in soils in combination with other elements forming complex inorganic minerals and organic compounds (Diaz *et al*., 2011). The phosphorus ions readily react with iron, aluminum, and manganese compounds in acid soils and with calcium compounds in neutral and alkaline soils. They become strongly attached to the surfaces of these compounds to form insoluble phosphate precipitate (Schulte and Kelling, 1996). According to Tisdale *et al.* (1985), highest phosphorus uptake by plants is at pH between 6.0 and 6.5. The soil moisture is important for phosphorus uptake by plants since phosphate anions, like other nutrients, is taken up by the plant primarily from soil solution (Schachtman *et al,* 1998). The uptake of phosphorus in dry soils, according to Horner (2008), is reduced considerably.

Phosphorus moves little in the soil (immobile nutrient) and roots must be close to phosphorus in the soil for uptake to occur (De Villiers, 2007). According to Diaz *et al*. (2011), the phosphorus fertilizer must be applied closer to the roots through broadcast or banding. Broadcast application is reported to be an excellent way to fertilize, specifically in phosphorus deficient soils, such as ferralsols which are rich in aluminum and iron and need the level of phosphorus to be increased (Gachene and Kimani, 2003). Broadcasting fertilization has been found to increase the volume of soil coming into contact with phosphorus in the bulk of soil. However in cool, wet soils experienced in cold seasons, banding is twice as efficient as broadcast since root development is limited (Schulte and Kelling, 1996). The soil conditions if wet or cold have been noted to reduce root metabolic activity which will cause low phosphorus absorption by the plants (De Villiers, 2007). The availability of phosphorus to plants has been reported to be dependent on temperature. The temperature has been found to increase the soil microbial activity which increases the enzyme phosphatase (an enzyme responsible for mineralization for transformation of organic phosphorus to inorganic phosphates) actions and thereafter increase plant available phosphorus (Horner, 2008). Islam *et al.* (2009) reported that the amount of phosphorus applied to the soil determines uptake of the other minerals by plant. It might increase or decrease the uptake of copper, zinc, manganese and iron by the plant.

Some studies have been done on the effect of some nutrients with respect to increasing production of African nightshades. Shibonje (2009) in field experiment at

Ikolomani, western Kenya studied the effect of potassium on African nightshades. Masinde *et al.* (2010) in field experiment at Juja, Kenya; Abukutsa-Onyango and Karimi (2005) in pot and field experiment at Maseno, Kenya; Juma (2006) in pot experiment in Pretoria, South Africa; Opiyo (2006) in field experiment at Njoro, Kenya and Kipkosgei *et al.* (2003) in field experiment, Keiyo, Kenya studied the effect of nitrogen fertilizers on the production of African nightshade. Limited research on phosphorus performance on African nightshade has been done in pot and field conditions. Khan *et al*. (2000) in pot experiment studied the response of black nightshade (*Solanum nigrum* L.) to phosphorus application in Pakistan. The study found 0.45 g of phosphorus pot^{-1} in 3.5 kg of soil as the optimum rate for high production of the African nightshade. Van Averbeke *et al.* (2007) and Juma (2006) in Pretoria, South Africa, working on yield response of *Solanum retroflexum* Dun. to phosphorus using pots in a greenhouse conditions found 100 and 61 kg P ha^{-1} respectively as the optimum rate. The optimum rates realized from the greenhouse experiment is in contrast to what was reported by Juma (2006) citing AVRDC (2004) for *Solanum villosum*, *Solanum americanum* whose optimum phosphorus rate was 40 kg P ha^{-1}, garden peas phosphorus rate was 83 kg P ha^{-1} and tomatoes ranged between 100 to 200 kg P ha^{-1}. The study on the response of okra (*Abelmoschus esculentus)* to phosphorus done in greenhouse at Ibadan, Nigeria found 40 kg P ha^{-1} as the optimum rate (Oluwatoyinbo *et al.*, 2005). The study of phosphorus on chick pea (*Cicer arietinum*) yield and yield components by Khorgamy and Farnia (2009) in Lorestan, Iran, found 130 kg P ha^{-1} as the optimum phosphorus rate.

The literature reviewed showed variation of optimum phosphorus rate and its importance for different crops which was expected due the variation in soil fertility and specific crop response towards phosphorus nutrition. From the limited research findings from field experiments, it was shown that phosphorus fertilizer influenced the growth of plant height, leaf area, number of branches in main stem and the number of leaves in a plant. The current study seeks to find out the optimum phosphorus rate for high production of three genotypes of African nightshade (*Solanum scabrum*, *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum*) and its financial benefit.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The Study Area

The study was conducted in Lelaibei farm, Toloita sub location, Moiben location, Eldoret East District, Uasin Gishu County. The site lies at an altitude of 2163 m above sea level and is within latitude 0º 49`0 N and longitude 35º 49`60 E. The site is reported to receive an average rainfall of 900 - 1200 mm per annum distributed over two cropping seasons. The rain occurs between the months of March and September with two distinct peaks in May and August. Dry spells begin in November and end in February. The temperatures range between 8.4ºC and 26.1ºC (Jaetzold *et al*., 2011).

The soils at the site are rhodic ferralsols which have been depleted of nutrients through continuous cropping with little or no fertilizer inputs added (Okalebo, 2009). They are well drained, moderately deep, yellowish red friable clay in some places (Jaetzold *et al*, 2011 and MOA and NARL, 1987). The study area has acidic soils with a pH less than 5 (Kamwaga *et al.*, 2005).

3.1.1. Rainfall, temperature and wind run for the year 2010.

The rainfall, temperature and wind run data for the year 2010 were obtained from Eldoret meteorological station, the district headquarters, Kapsoya. Kapsoya is the district headquarters where meteorological data for the district is obtained. Moiben is served by a rain gauge situated at Moiben District officer`s office, about three kilometers from the experiment site.

3.2 Soil Sampling and Analysis

Before the experiment was laid down, soil samples were taken from the farm in which the experiment was carried out for initial chemical and physical characterization. Later at six weeks after sowing, soil samples were taken from each experimental plot for available phosphorus analysis. The zigzag sampling approach was used in which nine soil samples were taken from the farm at a depth of 0 – 20 cm as described by Colwell (1971). The samples were labelled as they were being taken from the plots. Soils from nine sampling points in the farm and each experimental plot were bulked and mixed thoroughly and a composite sample of about 1 kg taken for soil analysis.

The samples were air dried by placing them in a shallow tray at a thickness of 1.8 cm in a well ventilated area. The soil lumps were crushed so that the gravel, roots and large organic residues become separated. The soils were then sieved through a 2 mm sieve for pH and available phosphorus analysis. The soils were further sieved through a 60 mesh screen for organic carbon analysis (Okalebo *et al.*, 2002). The soil pH was determined using a glass electrode pH meter in the general procedure for soil pH (2.5:1 H_2O: soil ratio) according to Rhoades (1982) method. The available phosphorus was determined by the Olsen *et al.* (1954) method. The organic carbon was determined according to procedures described by Okalebo (1985). Sulphuric acid and aqueous potassium dichromate digestion followed by back titration with ferrous ammonium sulphate (Nelson and Sommers, 1975). The total phosphorus was determined by digesting 0.3 g of soil sample in a mixture of selenium, salicylic acid and hydrogen peroxide and concentrated sulphuric acid (Anderson and Ingram, 1989). The phosphorus contents were determined calorimetrically by procedures described by Okalebo *et al*. (2002). The particle size distribution was determined by the Bouyoucos (1962) method.

3.3 Experimental materials

Triple superphosphate (46% P_2O_5) was obtained from Mea Ltd, Eldoret depot.

The seeds of African nightshade, sold by Kenya Seed Company as giant black nightshade (*Solanum scabrum*) and black nightshade (*Solanum villosum* var. *villosum*) were obtained from Kenya Seed Company depot in Eldoret on 26/4/2010. The seeds of the locally grown landrace African nightshade were obtained from Mrs Jenipher Okonda, a seed merchant at Ziwa open air market, Eldoret West district, Soy division on 27/4/2010. Only one seed merchant had been selling African nightshade seeds at the market. The seeds had been bought by the seed merchant from surrounding farmers of Moiben and Soy divisions and the neighbouring areas of Matunda, Lugari district.

3.4 Field Experimental Design and Layout

The field experiment was conducted on smallholder farm (Appendix 1) over two cropping seasons; the long rains of May to August 2010 and in the short rains season of September to December 2010 (Appendix 2). The smallholder farm was under wheat production in the preceding year of 2009. The two experiments were independent of each other and done at different rain seasons and position within the same farm. The two sites, for long rain and short rain seasons were adjacent to each other. While the long rain season experiment was going on, the plot for the short rain experiment was under bean productions. Beans were harvested at the beginning of august 2010 and immediately land was prepared for the second season experiment.

Each of the experiment, one in each season, was laid out in randomized complete block design (RCBD) with three replicates (Figure 3.1). The treatments consisted of four levels of phosphorus (0, 20, 40 and 60 Kg P ha^{-1}) and three levels of African nightshade genotypes: giant black nightshade (*Solanum scabrum*), Black nightshade (*Solanum villosum* var. *villosum*) and farmer`s seeds (Table 3.1) which were later described using Mwai *et al*. (2005) and Edmonds and Chweya (1997) descriptor to be *Solanum villosum* var. *miniatum.*

Table 3.1: Treatment combinations

Treatment	Genotype x Phosphorus rate
T1	CI X P0
T2	C1 X P1
T3	C1 X P2
T4	C1 X P3
T5	C2 X P0
T6	C2 X P1
T7	C2 X P2
T8	C2 X P3
T9	C3 X P0
T10	C3 X P1
T11	C3 X P2
T12	C3 X P3

Key: C1= *Solanum scabrum,* C2= *Solanum villosum* var. *villosum* C3= *Solanum villosum* var. *miniatum*, P0= 0 Kg P ha^{-1}, P1= 20 Kg P ha^{-1}, P2 = 40 Kg P ha^{-1} and P3= 60 Kg P ha^{-1}

The treatments were assigned to the experimental plots in each block using the table of random numbers as described by Gomez and Gomez (1976). Each plot measured 2 m x 3 m with 1 m paths between blocks and 0.5 m path between plots (Shibonje, 2009). The plots layout for season one and two were as shown in Figure 3.1.

	SEASON I				**SEASON II**			
BLOCK 1	C_1P_3	C_3P_2	C_1P_3	C_3P_0	C_1P_3	C_2P_3	C_3P_2	C_3P_0
	C_3P_3	C_2P_2	C_2P_3	C_1P_1	C_1P_2	C_3P_1	C_2P_0	C_3P_3
	C_1P_2	C_2P_3	C_3P_1	C_1P_1	C_2P_1	C_1P_0	C_2P_2	C_1P_1
BLOCK 2	C_2P_0	C_2P_1	C_1P_1	C_3P_2	C_2P_3	C_3P_0	C_3P_3	C_2P_2
	C_2P_3	C_3P_1	C_3P_0	C_1P_3	C_2P_1	C_1P_2	C_3P_1	C_3P_2
	C_1P_2	C_2P_2	C_1P_0	C_3P_3	C_1P_1	C_2P_0	C_1P_3	C_1P_0
BLOCK 3	C_3P_1	C_3P_2	C_2P_3	C_2P_1	C_2P_1	C_2P_0	C_1P_2	C_3P_3
	C_2P_2	C_3P_2	C_1P_2	C_1P_0	C_3P_2	C_1P_3	C_1P_1	C_3P_1
	C_2P_0	C_2P_3	C_1P_3	C_1P_1	C_3P_0	C_2P_3	C_2P_2	C_1P_0

Figure 3.1: Treatment Combination and field layout for the two seasons

Key:

C1= *Solanum scabrum,* C2= *Solanum villosum* var. *villosum,* C3= *Solanum villosum* var. *miniatum,* P0= 0 kg P ha^{-1}, P1=20 kg P ha^{-1}, P2=40 kg P ha^{-1}, P3= 60 kg P ha^{-1}.

The layout for season one and two were different but they were in one farm.

3.4.1 Field experimental management and data collection.

The soils were worked out to fine tilth as recommended for small seeds (MOA, 2000). Various rates of phosphorus fertilizer were broadcasted evenly on the respective plots (Nyongesa *et al.*, 2009; Shibonje, 2009; Diaz *et al.*, 2011). Calcium ammonium nitrate (CAN 26% N) at 10 kg N ha^{-1} and Muriate of potash, MOP (60% K_2O) at 30 kg K ha^{-1} (Manoko and van der Weerden, 2004a) were broadcasted and incorporated into the soil in each plot and in each of the two seasons before planting (Shibonje, 2009). The nitrogen and potassium fertilizers were added to the soil so that the plant growth could not be inhibited if the two elements were limiting in the soil.

Seeds of respective genotypes were directly sown at 4 – 6 seeds per hole (Schippers, 2000) with a spacing of 30 cm x 30 cm (Abukutsa-Onyango and Karimi, 2005 and Shibonje, 2009). These seeds were sown on 19/5/2010 and 13/8/2010 in season one and season two respectively at different sites within the same farm. The fields were kept weed free by manual weeding. Insects and diseases were controlled using appropriate pesticides. Thinning was done four weeks after sowing to leave one plant per hole, while top dressing with CAN 26% at 60 kg N ha^{-1} was done six weeks after sowing.

To determine the effect of treatments on plant growth, eight plants in each plot were systematically random sampled (Gomez and Gomez, 1976), tagged and their heights, number of branches and leaf area determined. Further three plants were random sampled for total number of leaves per plant.

3.4.1.1 Plant height

Plant height was measured, in cm, from the ground level up to the apex of the youngest leaf using a tape measure (Maritim *et al.*, 2009) on the eight sampled plants. Measurements were taken weekly from 45 to 73 days after sowing in the two seasons.

3.4.1.2 Leaf area

The leaf size was determined by measuring the last and largest leaf in main stem from the ground level. Leaf length and leaf width were measured using a ruler. Leaf area was calculated using the formula, leaf area= L x W x 0.75, where L is leaf length, W is leaf widest width and 0.75 is a multiplying factor as was used by Muthomi and Musyimi (2009). The leaf area for the two seasons was taken at 52 and 59 days after sowing.

3.4.1.3 Number of leaves per plant

The total number of fully expanded mature leaves per plant was counted weekly from the three sampled plants. The data collected were recorded starting from 59 - 73 days after sowing in the two seasons.

3.4.1.4 Number of branches in main stem

Number of branches in the main stem was counted at 59 and 66 days after sowing for the two seasons.

3.4.1.5 Fresh and dry leaf yields

Harvesting was done once at 78 and 77 days after sowing (DAS) for season one and two respectively when the plant had attained 50% flowering (Maritim *et al.*, 2009). All the leaves and tender shoots of the entire plant from the ground level were harvested from the net plot (Shibonje, 2009). The harvested vegetables were put in paper bags and the fresh weight taken using kitchen balance and recorded immediately, to avoid lose of moisture (Masinde *et al.*, 2010). The weighed leaves were subsequently oven-dried at 70°C for 48 hours to a constant weight at University of Eldoret and the dry weight recorded. The plant leaf yield was determined as fresh and dry weight in grams per net plot and was used to estimate the fresh leaf yields in kg ha^{-1}. The dry leaf yields were ground into powder form and used in analysis for plant total phosphorus according to procedures described by Okalebo *et al*. (2002).

3.5 Data Analysis

Analysis of Variance (ANOVA) on plant growth (height, leaf area, number of leaves in a plant), leaf yields, soil nutrients (available phosphorus) and plant nutrients (total phosphorus) was performed to determine whether there was any significant difference between the treatments by using Genstat computer package analysis (Genstat Release 12.2, 2010). The means were separated using SED at $p \leq 0.05$. The available phosphorus was correlated with fresh and leaf yields.

3.5.1 The field experimental model

Yij = µ + Mi +Nj +ßk + (MiNj)ij + Σijk

Where: Yij = Yield; µ = Mean; Mi= Effect of fertilizer, P; Nj= Effect of genotype; ßk = Block effects; (MiNj)ij = Interaction effects of genotype and phosphorus fertilizer; Σijk = Error term effect.

Table 3.2: Skeleton of ANOVA table

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F calculated (5%)	F tabulated (5%)
Total					
Genotypes					
Phosphorus rate					
Block					
Interaction Genotype X phosphorus rate					
Experimental error					

3.6 Benefit-cost analysis

The Benefit-cost analysis was carried out to determine the BCR (benefit-cost ratio) and net benefit resulting from the application of different rates of phosphorus fertilizer to each genotype of vegetable African nightshade (Ashilenje *et al*., 2012).

The net benefit of each treatment was computed using partial budgeting, which included only costs and benefits that varied from the control (Opala *et al*, 2010). The change in leaf yield of each genotype over the control was assumed to be solely due to the application of phosphorus fertilizer. The prices of African nightshade leaf yield, transport of input and produce were obtained from the farmers and vegetables traders (Appendix 5). The labour on harvesting was calculated basing on number of bags harvested where the weight of one bag of fresh leaf yield was taken to be 65 kg

(MOA, 2010). The payment of harvesting labour was made on unit bag harvested. The price of 50 kg bag of triple superphosphate (46 % P_2O_5) was got from MEA Ltd, Eldoret depot. The total cost of added fertilizer, labour for applying extra fertilizer, harvesting labour and transport cost of the extra yields obtained from the addition of phosphorus fertilizer to Eldoret town were calculated. The total added cost was subtracted from the total added revenue obtained from the sale of the extra output due to the application of phosphorus fertilizer (over the control). The BCR (benefit-cost ratio) was got by dividing the net benefit due to increased leaf yield over the control by the increased cost due to the use of phosphorus fertilizer (Ashilenje *et al*., 2011).

CHAPTER FOUR

4.0 RESULTS

4.1 Soil properties

4.1.1 Initial soil properties and Available phosphorus

The soil texture at the experimental site was sandy loam (Table 4.1). The available phosphorus and soil pH in season one was higher than in season two. Available phosphorus in season two was lower than what was available in season one, the highest difference between the two seasons than any of the initial soil chemicals analyzed. The soil pH in season two was slightly lower than in season one.

Table 4.1: Initial soil properties

Season	Soil layer	pH	Soil nitrogen %	Olsen P mg kg^{-1}	Organic Carbon % (OC)	Textural class
Season 1	Top soil	5.47	0.11	6.00	1.82	Sand 66% Clay 12%
Season 2	Top soil	5.21	0.11	4.72	1.92	Silt 22% (Sandy loam)

The available phosphorus in the soil increased with increasing rate of applied phosphorus fertilizer in the two seasons (Table 4.2). The response of applied phosphorus depended on season.

In season one, the plot of *Solanum scabrum* had high available phosphorus in the soil at 40 kg P ha^{-1}. *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum* had high available phosphorus in their plots at 60 kg P ha^{-1}.

In season two, *Solanum scabrum* and *Solanum villosum* var. *villosum* had high available phosphorus at their plots at 40 kg P ha^{-1}. *Solanum villosum* var. *miniatum* had high available phosphorus in its plot at 60 kg P ha^{-1}. The plot of *Solanum villosum* var. *villosum* at 40 kg P ha^{-1} had relatively the highest available phosphorus for season two. The response of genotype and the interaction of genotype and phosphorus rates were not significant in the two seasons.

Table 4.2: Effect of Phosphorus rate and solanum genotypes on available phosphorus in mg P kg^{-1} at six weeks after sowing

Prate kg P ha^{-1}	Season one				Season two			
	Genotype							
	C1	C2	C3	Means	C1	C2	C3	Means
	Available phosphorus in mg P kg^{-1}							
0	5.26	5.08	8.77	6.37	7.74	11.01	10.10	9.62
20	7.08	5.32	6.90	6.43	11.31	8.95	9.50	9.92
40	14.22	6.90	9.32	10.14	17.42	14.6	19.00	17.00
60	10.47	13.86	15.18	13.17	18.03	21.96	18.09	19.36
Means	9.3	7.79	10.04	9.03	13.63	14.1	14.17	13.97
SED P rate	2.02				2.22			
SED Genotype	NS				NS			
P rate X Genotype	NS				NS			
Probabilities for F test ($p \leq 0.05$)								
P rate	0.007				< 0.001			
Genotype	0.438				0.952			
P rate X Genotype	0.401				0.699			

Key:

C1= *Solanum scabrum,* C2= *Solanum villosum* var. *villosum,* C3= *Solanum villosum* var. *miniatum,* S.E.D = Standard error of difference of means, NS = Not significant, $p \leq 0.05$= the probability at or less than 5 %.

There was no significant difference in the response to phosphorus fertilizer and genotype on total phosphorus in the plant (Table 4.3).

Table 4.3: Effect of Phosphorus rate and solanum genotypes on total phosphorus (%) in plants.

P level kg P ha^{-1}	Season one				Season two			
	Genotype							
	C1	C2	C3	Means	C1	C2	C3	Means
	Total plant phosphorus (%)							
0	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
20	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
40	0.4	0.3	0.4	0.4	0.3	0.3	0.3	0.3
60	0.4	0.3	0.4	0.3	0.3	0.3	0.3	0.3
Means	0.4	0.3	0.4	0.4	0.3	0.3	0.3	0.3
SED P rate	NS				NS			
SED Genotype	NS				NS			
SED P rate X Genotype	NS				NS			
Probabilities for F test ($P \leq 0.05$)								
P rate	0.272				0.192			
Genotype	0.059				0.199			
P rate X Genotype	0.838				0.282			

Key:

C1= *Solanum scabrum*, C2= *Solanum villosum* var. *villosum*, C3= *Solanum villosum* var. *miniatum*, S.E.D = Standard error of difference of means, NS = Not significant, $p \leq 0.05$= the probability at or less than 5 %.

4.2 Effect of Phosphorus fertilizer rates and solanum genotypes on growth parameters

4.2.1 Plant height

No significant ($p \leq 0.05$) interaction was found for plant height between the genotype and the phosphorus rate in the two seasons (Tables 4.4 and 4.5). The response of phosphorus rate on plant height was highly significant ($p \leq 0.001$) for the genotypes in the two seasons at all the days sampled. The plant heights increased with increasing phosphorus rate. *Solanum villosum* var. *miniatum* and *Solanum villosum* var. *villosum* tended to have taller plants at 60 kg P ha^{-1} as opposed to *Solanum scabrum* whose height was taller 40 kg P ha^{-1} in season one. In season two, *Solanum scabrum* had higher plant heights at 60 kg P ha^{-1} as opposed to *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum* which had higher plant heights at 40 kg P ha^{-1}. There was significant ($p \leq 0.05$) effect of genotype on height in season one for the whole plant growth period. The trend differed in season two where the genotypic effect was only observed at 66 DAS.

The plant heights` growth trends differed with the seasons. In the second season all the genotypes sampled did not differ significant in their heights at 40 and 60 kg P ha^{-1}. The mean height at 73 DAS for season two was 43.1% lower than the height in season one. The growth in height of the genotype was influenced by the season. *Solanum scabrum* had an increase of height by between 50-85% and 54-105% in season one and two respectively more than its control. *Solanum villosum* var. *villosum* increased its height from the addition of phosphorus by 51-75% and 101-170% in season one and two respectively more than the control. *Solanum villosum* var. *miniatum* had high increase of 79-137% and 208-391% in season one and two respectively increase in height from its control. The performance of *Solanum villosum* var. *miniatum* in the first and second season was favourable.

The genotypes consistently maintained the same trend in their plant height with respect to each other for the two seasons (Figure 4.4). *Solanum villosum* var. *villosum* maintained higher plant height than the two genotypes, followed by *Solanum scabrum* and *Solanum villosum* var. *miniatum* had relatively lower height over their growing period.

Table 4.4 Effect of Phosphorus rate and solanum genotypes on plant height (cm), season one

P rate kg P ha^{-1}	Season one																			
	Genotype																			
	45 DAS				52 DAS				59 DAS				66 DAS				73 DAS			
	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means
	Plant height in cm																			
0	3.9	4.3	2.8	3.7	6.7	8.0	5.0	6.6	12.6	14.8	8.6	12.0	20.8	23.3	12.6	18.9	32.1	36.8	25.3	31.4
20	5.5	4.4	3.4	4.4	13.7	8.3	10.3	10.3	20.3	16.9	14.9	17.4	30.2	25.2	22.9	26.1	40.8	38.5	37.0	38.8
40	6.3	6.2	5.0	5.8	12.7	9.9	11.8	11.8	22.6	24.5	16.8	21.3	35.3	39.5	23.5	32.8	48.0	57.5	40.0	48.5
60	7.2	6.5	5.0	6.2	11.8	13.7	11.3	12.3	17.8	25.9	20.4	21.4	30.1	37.9	29.6	32.5	43.4	48.9	47.8	46.7
Means	5.7	5.4	4.0	5.0	11.2	10.8	8.6	10.2	18.3	20.5	15.2	18.0	29.1	31.5	22.2	27.6	41.1	45.4	37.5	41.3
SED P rate	0.41				1.18				1.58				2.11				3.11			
SED Genotype	0.35				1.02				1.37				1.83				2.70			
SED P rate X Genotype	NS				NS				NS				NS				NS			
Probabilities for F test (p≤ 0.05)																				
P rate	< 0.001				< 0.001				< 0.001				< 0.001				< 0.001			
Genotype	< 0.001				0.043				0.003				< 0.001				0.026			
P rate X Genotype	0.745				0.331				0.120				0.095				0.269			

Table 4.5: Effect of phosphorus rate and solanum genotypes on plant height (cm), season two

P rate kg P ha^{-1}	Season two																			
	Genotype																			
	45 DAS				52 DAS				59 DAS				66 DAS				73 DAS			
	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means
	Plant height in cm																			
0	2.3	2.1	1.2	1.8	3.7	3.1	2.0	2.9	7.6	5.6	3.6	5.6	9.8	9.0	5.3	8.1	17.5	16.2	8.1	14.0
20	2.4	2.7	2.4	2.5	4.1	4.4	4.1	4.2	8.0	6.8	10.4	8.4	11.8	12.7	10.2	11.5	19.4	20.4	17.8	19.2
40	3.5	4.5	3.6	3.9	6.0	7.5	6.6	6.7	9.7	15.1	12.3	12.4	16.6	22.9	17.0	18.9	26.3	32.5	39.8	32.8
60	3.9	4.2	3.7	3.9	7.6	7.2	6.1	7.0	11.7	13.5	11.6	12.3	18.1	21.8	17.8	19.2	28.6	29.8	25.2	27.8
Means	3.0	3.4	2.7	3.0	5.3	5.5	4.7	5.2	9.2	10.2	9.5	9.7	14.1	16.6	12.6	14.4	23.0	24.7	22.7	23.5
SED P rate	0.379				0.636				1.571				1.655				4.66			
SED Genotype	NS				NS				NS				1.433				NS			
SED P rate X Genotype	NS				NS				NS				NS				NS			
Probabilities for F test (p≤ 0.05)																				
P rate	< 0.001				< 0.001				< 0.001				< 0.001				0.002			
Genotype	0.143				0.298				0.756				0.031				0.863			
P rate X Genotype	0.821				0.711				0.287				0.675				0.612			

Key:

C1= *Solanum scabrum*, C2= *Solanum villosum* var. *villosum*, C3= *Solanum villosum* var. *miniatum*, NS= Not significant, P= phosphorus, DAS= Days after sowing.

4.2.2 Leaf area

The effect of phosphorus fertilizer rate and genotype on leaf area were highly significant ($p \leq 0.001$) on leaf area in the two seasons (Table 4.6). There was an increasing in leaf area with increase in phosphorus applied. The response of phosphorus was observed to be affected by genotype and season. In season one *Solanum scabrum* had higher leaf area at 40 kg P ha^{-1} and at 60 kg P ha^{-1} in season two. The leaf area increase over the control was between 107 -111% and 102-251% in season one and two, respectively. *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum* at 59 days after sowing had higher leaf area at 60 kg P ha^{-1} in season one and 40 kg P ha^{-1} in season two. The leaf area of *Solanum villosum* var. *villosum* increase over the control was between 51-68% and 118-161 in season one and two, respectively. *Solanum villosum* var. *miniatum* had higher percentage increase both in season one and two. The leaf area increase over the control was 43-109% and 161- 400% in season one and two respectively. *Solanum scabrum* had higher leaf area than the two genotypes in both seasons. An interaction of the genotype and phosphorus on leaf area was observed in season two at 52 DAS. The leaf area of *Solanum scabrum* at 60 kg P ha^{-1} was 298 % more than *Solanum villosum* var. *villosum* at 40 kg P ha^{-1} and 286 % more than *Solanum villosum* var. *miniatum* at 60 kg P ha^{-1}.

Table 4.6: Effect of Phosphorus rate and genotype on leaf area in (cm^2)

P rate kg P ha^{-1}	Season one								Season two							
	Genotype															
	52 DAS				59 DAS				52 DAS				59 DAS			
	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means
	Leaf area in cm^2															
0	15.7	8.4	6.4	10.2	31.5	11.6	8.8	17.3	7.5	3.4	0.7	3.9	22.9	6.6	5.1	11.5
20	27.7	8.7	11.0	15.8	46.9	11.3	12.8	23.7	12.7	4.2	3.9	6.9	26.0	10.6	9.5	15.4
40	33.2	13.0	11.8	19.3	65.3	16.2	13.5	31.6	9.2	7.4	6.1	7.5	28.7	17.2	17.8	21.3
60	31.9	14.1	13.4	19.8	52.9	17.5	15.6	28.7	26.3	6.6	6.8	13.2	46.3	15.4	15.7	25.8
Means	27.1	11.1	10.7	16.3	49.2	14.1	12.7	25.3	13.9	5.4	4.4	7.9	40.0	12.5	12.0	18.5
SED P rate	1.65				4.01				1.46				2.76			
SED Genotype	1.43				3.47				1.27				2.39			
SED P rate X Genotype	NS				NS				2.53				NS			
Probabilities for F test (p≤ 0.05)																
P rate	< 0.001				0.009				< 0.001				< 0.001			
Genotype	< 0.001				< 0.001				< 0.001				< 0.001			
P rate X Genotype	0.282				0.110				< 0.001				0.096			

Key:

C1= *Solanum scabrum,* C2= *Solanum villosum* var. *villosum,* C3= *Solanum villosum* var. *miniatum,* S.E.D = Standard error of difference of means, NS = Not significant, p ≤ 0.05= the probability at or less than 5 %, DAS = Days after sowing.

4.2.3 Number of leaves per plant

There was significant ($p \leq 0.05$) interaction between genotype and phosphate fertilizer rate in the short rain season on the number of leaves per plant. The genotypic effect on the number of leaves per plant was highly significant ($p \leq 0.001$) in the two seasons. However, the effect of phosphorus rate depended on season. The effect of phosphorus in season two was highly significant ($p \leq 0.001$) as compared to the first season where the significant was at $p \leq 0.05$ (Tables 4.7 and 4.8). The number of leaves increased with increase in phosphorus rate applied. In season one all the genotypes sampled relatively produced high number of leaves at 60 kg P ha^{-1}. In season two, *Solanum scabrum* produced high number of leaves at 60 kg P ha^{-1} while *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum* in the same season produced high number of leaves at 40 kg P ha^{-1}.

Solanum scabrum number of leaves increased by 30-108% and 31-37% over its control in season one and two respectively. The number of leaves of *Solanum villosum* var. *villosum* increased by 80-116% and 126-291% more than its control in season one and two respectively. *Solanum villosum* var. *miniatum* had high leaf number increase by between 21-107% and 272-480% in season one and two respectively. *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum* had relatively the highest number of leaves in season one and two, respectively.

Table 4.7: Effect of phosphorus rate and solanum genotypes on total number of leaves per plant in season one.

P rate kg P ha^{-1}	Season one											
	Genotype											
	59 DAS				66 DAS				73 DAS			
	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means
	Total number of leaves in a plant											
0	13	32	44	29	28	69	75	57	72	110	127	103
20	25	44	65	45	35	78	86	66	74	130	119	119
40	23	53	61	46	39	91	81	70	94	147	129	129
60	27	69	74	57	43	139	123	102	84	198	154	154
Means	22	49	61	44	36	94	91	74	81	146	126	126
SED P rate	6				11				14			
SED Genotype	6				9				12			
SED P rate X Genotype	NS				NS				NS			
Probabilities for F test ($p \leq 0.05$)												
P rate	0.003				0.003				0.010			
Genotype	< 0.001				< 0.001				< 0.001			
P rate X Genotype	0.749				0.464				0.412			

Table 4.8: Effect of phosphorus rate and solanum genotypes on total number of leaves per plant in season two

P rate kg P ha^{-1}	Season two											
	Genotype											
	59 DAS				66 DAS				73 DAS			
	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means
	Number of leaves											
0	18	23	15	19	32	34	32	33	54	59	67	60
20	20	40	41	34	27	75	87	63	55	121	163	113
40	20	52	87	53	40	119	154	104	74	231	249	185
60	24	49	77	50	42	118	122	94	69	177	245	164
Means	21	41	55	39	35	87	99	74	63	147	181	130
SED P rate	7				14				19			
SED Genotype	6				12				16			
SED P rate X Genotype	12				NS				32			
Probabilities for F test ($p \leq 0.05$)												
P rate	< 0.001				< 0.001				< 0.001			
Genotype	< 0.001				< 0.001				< 0.001			
P rate X Genotype	0.008				0.074				0.014			

Key: C1= *Solanum scabrum,* C2= *Solanum villosum* var. *villosum,* C3= *Solanum villosum* var. *miniatum,* . S.E.D = Standard error of difference of means, NS = Not significant, $p \leq 0.05$ = the probability at or less than 5 %, DAS = Days after sowing.

4.2.4 Number of branches on main stem

The response of phosphorus on number of branches was not significantly ($p \leq 0.05$) observed in season one **(**Table 4.11). However, the significant ($p \leq 0.05$) difference was found in season two where the number of branches increased with increasing phosphorus rate. In both seasons the significant difference ($p \leq 0.05$) on number of branches between 40 and 60 kg P ha^{-1} was not observed. There was significant response on number of branches from the genotype (Table 4.9). *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum* had significantly higher number of branches than *Solanum scabrum. Solanum scabrum* had significantly ($p \leq 0.05$) lower number of branches than the two genotypes in the two seasons. There was no interaction observed in the two seasons. *Solanum scabrum* had number of branches increase of 67-75% and 20-100% in season one and two respectively. *Solanum villosum* var. *villosum* had lower number of branches increase of 0-14% in season one while *Solanum villosum* var. *miniatum* had high number of branches of between 80-200% over its control. The second season favoured the production of number of branches for *Solanum villosum* var. *miniatum.*

Table 4.9: Effect of Phosphorus rate and solanum genotypes on number of branches on main stem

P rate kg P ha^{-1}	Season one								Season two							
	Genotype															
	59 DAS				66 DAS				59 DAS				66 DAS			
	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means	C1	C2	C3	Means
	Number of branches															
0	3	7	6	5	4	9	7	7	2	4	2	3	5	6	5	5
20	5	7	7	6	6	8	8	8	3	5	6	5	5	8	9	7
40	5	8	8	7	7	9	8	8	4	7	8	6	7	9	9	8
60	5	8	9	7	7	8	10	8	4	7	8	6	7	8	9	8
Means	4	8	7	6	6	9	8	8	3	6	6	5	6	8	8	7
SED P rate	NS				NS				1				1			
SED Genotype	1				1				1				1			
SED P rate X Genotype	NS				NS				NS				NS			
Probabilities for F test (p≤ 0.05)																
P rate	0.059				0.053				< 0.001				< 0.001			
Genotype	< 0.001				< 0.001				< 0.001				< 0.001			
P rate X Genotype	0.710				0.326				0.228				0.111			

Key: C1= *Solanum scabrum,* C2= *Solanum villosum* var. *villosum,* C3= *Solanum villosum* var. *miniatum,* S.E.D = Standard error of difference of means, NS = Not significant, p≤0.05 = the probability at or less than 5 %, DAS = Days after sowing.

4.3 Effect of phosphorus rate and genotype on fresh and dry leaf yields (kg ha^{-1})

4.3.1 Fresh and dry leaf yields

There were significant ($p\leq0.05$) interactions of fresh leaf yields between the phosphorus level and the genotypes in season one. The phosphorus rate and genotype effect on fresh leaf yields were highly significant ($p\leq0.001$). In the second season the effect of phosphorus rate applied, genotype and the interaction of genotype and phosphorus rate were highly significant ($p\leq0.001$). The fresh leaf yield (kg ha^{-1}) significantly ($p\leq0.05$) increased with increase in phosphorus level in the two seasons (Table 4.10 and Plate 5). Each genotype had high yields at 60 kg P ha^{-1}. The highest fresh leaf yield in season one was realized from *Solanum scabrum* at 60 kg P ha^{-1} which was 335 % more than the yields realized from its control (0 kg P ha^{-1}). However *Solanum villosum* var. *villosum* yield at 60 kg P ha^{-1} was higher by 345 % more than its control. In season two, high fresh leaf yield was realized from *Solanum villosum* var. *miniatum* at 60 kg P ha^{-1}, which was 407 % higher than its control. *Solanum villosum* var. *miniatum* and *Solanum scabrum* both at 60 kg P ha^{-1} in season two produced their high leaf yield compared to their control which was in contrast to *Solanum villosum* var. *villosum* which had its high fresh leaf yield at 40 kg P ha^{-1}. The 60 kg P ha^{-1} negatively affected the leaf yield of *Solanum villosum* var. *villosum*. Generally the performance of the genotypes was influenced by season (Plate 6). The genotypes had higher leaf yields in the long rain season as compared to the short rain season. *Solanum scabrum* and *Solanum villosum* var. *miniatum* had high performance in season one and two respectively.

Table 4.10: Effect of Phosphorus rate and solanum genotypes on fresh leaf yield (kg ha^{-1})

P level Kg P ha^{-1}	Cultivar.							
	Season one				Season two			
	C1	C2	C3	Means	C1	C2	C3	Means
	Fresh leaf yields (kg ha^{-1})							
0	3066	2475	2379	2640	3685	2007	2104	2599
20	7934	6421	5500	6618	5170	4524	5857	5184
40	11220	7384	7494	8699	4909	7700	8154	6921
60	13351	11027	9157	11178	6792	4909	10670	7457
Means	8893	6827	6132	7284	5139	4785	6696	5540
SED P rate	447				539			
SED Genotype	386				466			
SED P rate X Genotype	774				932			
Probabilities for F test ($p \leq 0.05$)								
P rate	<0.001				<0.001			
Genotype	<0.001				0.001			
P rate X Genotype	0.032				<0.001			

Key:
C1= *Solanum scabrum,* C2= *Solanum villosum* var. *villosum,* C3= *Solanum villosum* var. *miniatum,* S.E.D = Standard error of difference of means, NS = Not significant, P = Phosphorus, $p \leq 0.05$= the probability at or less than 5 %, DAS = Days after sowing.

A. **B.**

Plate 5: Difference in growth of *scabrum* between 0 kg P ha^{-1} (A) and 60 kg P ha^{-1} (B) in season two

A. **B.**

Plate 6: Difference in growth of *Solanum villosum* var. *villosum* at 40 kg P ha^{-1} between season one (A) and Season two (B)

The effect of phosphorus rate applied, genotype and the interaction between phosphorus rate applied and genotype were highly significant ($p \leq 0.001$) on dry leaf yields in the short rain season. However, the phosphorus rate applied was highly significant ($p \leq 0.001$) on dry leaf yields in season one. The dry leaf yields significantly ($p \leq 0.001$) increased with increase in phosphorus rate applied in season one (Table 4.11). All the genotypes had significantly ($p \leq 0.001$) high dry leaf yields at 60 kg P ha^{-1} which were higher than their respective controls by between 162- 328% and 163-362% in season one and two respectively. In season one *Solanum villosum* var. *miniatum* had relatively the lowest percentage dry leaf yield increase over the control but had higher percentage increase of 362% more than what was observed in the two genotypes in season two. All the sampled genotypes had high percentage increase in dry leaf over the control at 60 kg P ha^{-1} in the two seasons except *Solanum villosum* var. *villosum* in season two. It had high percentage dry leaf increase at 40 kg P ha^{-1}. There was a significant ($p \leq 0.05$) interaction between the genotype and phosphorus rate on dry leaf yields in season two. The interaction response of genotype and phosphorus on dry leaf yield was not observed in season one, however the response was seen in season two.

Table 4.11: Effect of Phosphorus rate and solanum genotypes on dry leaf yield

P level Kg P ha^{-1}	Cultivar.							
	Season one				Season two			
	C1	C2	C3	Means	C1	C2	C3	Means
	Dry leaf yields (kg ha^{-1})							
0	371	289	381	346	257	252	234	247
20	756	945	756	819	587	642	623	616
40	1031	962	802	932	536	664	1027	742
60	1220	1237	1000	1152	752	573	1082	802
Means	844	858	734	813	532	533	741	602
SED P rate	77				40			
SED Genotype	NS				35			
SED P rate X Genotype	NS				69			
Probabilities for F test ($p \leq 0.05$)								
P rate	<0.001				<0.001			
Genotype	0.148				<0.001			
P rate X Genotype	0.431				<0.001			

Key:

C1= *Solanum scabrum,* C2= *Solanum villosum* var. *villosum,* C3= *Solanum villosum* var. *miniatum,* S.E.D = Standard error of difference of means, NS = Not significant, P = Phosphorus, $p \leq 0.05$= the probability at or less than 5 %, DAS = Days after sowing.

4.3.2: Correlation between available phosphorus (Olsen P) and fresh and dry leaf yields

The available phosphorus (Olsen P) in the soil was strongly positive correlated with fresh and dry leaf yields of all the sampled genotypes in season one. The correlation trend in season two differed from season one where *Solanum scabrum* in season one and *Solanum villosum* var. *villosum* in both seasons had weak correlation with leaf yields (Figure 4:1).

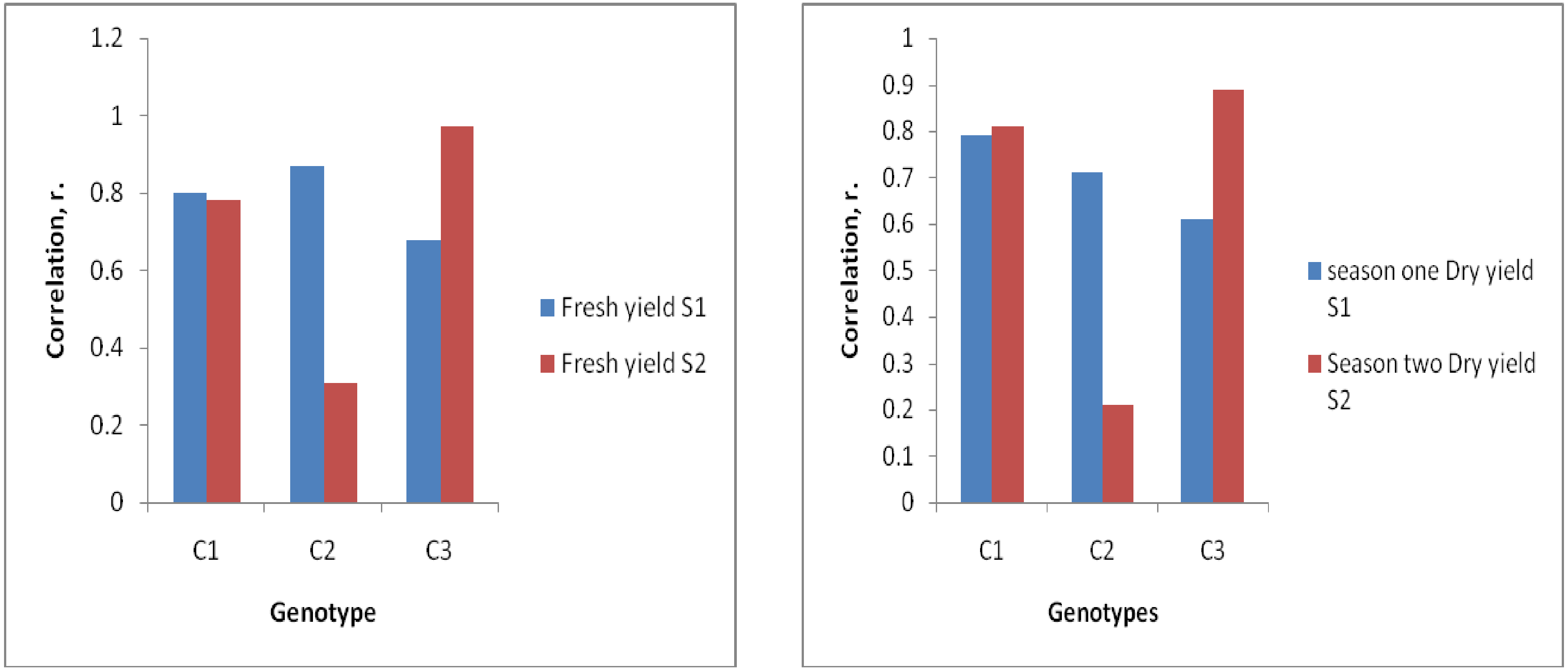


Figure 4.1: Correlation (r) between available phosphorus (Olsen P) and fresh and dry leaf yields.

C1= *Solanum scabrum,* C2= *Solanum villosum* var. *villosum,* C3= *Solanum villosum* var. *miniatum.*

4.4 Effect of Phosphorus application rate on financial benefit of growing African nightshade.

4.4.1 Benefit-cost analysis ha^{-1}

The net benefits and benefit cost ratio from the added cost to the control were high in season one than in season two (Table 4.12). The net benefit increased with increasing rate of phosphorus applied in season one. The benefit-cost ratios (BCR) for all the sampled genotypes for season one was between 3.0 and 4.1. The BCR in season two was relatively lower than in season one which ranged between 1.0 and 3.7. *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum* had high net benefit in season one and two respectively (Table 4.12). The genotypes sampled had higher net financial benefit and benefit cost ratio at between 20 and 40 kg P ha^{-1} in the two seasons. *Solanum scabrum* had good performance in season one as opposed to season two where the performance was relatively low. *Solanum villosum* var. *miniatum* had good performance in season two but in season one it was relatively lower than the two genotypes. *Solanum scabrum* had low performance with BCR ranging between 1.0 and 2.0.

Table 4.12: Effect of genotype and phosphorus rate on BCR and net benefit ha^{-1}

Genotype	P rate kg P ha^{-1}	Season one Net benefit in Kshs ha^{-1}	Season one Benefit-Cost Ratio (BCR)	Season two Net benefit in Kshs ha^{-1}	Season two Benefit-Cost Ratio (BCR)
C1	-	-	-	-	-
	20	58456	3.4	12318	2.0
	40	93273	3.2	865	1.0
	60	116325	3.0	18603	1.5
C2	-	-	-	-	-
	20	63735	3.8	37793	3.1
	40	73318	3.1	87550	3.3
	60	130398	3.3	28982	1.8
C3	-	-	-	-	-
	20	48758	3.4	60231	3.7
	40	84757	4.1	94031	3.4
	60	99347	3.0	131806	3.3

Key

C1= *Solanum scabrum,* C2= *Solanum villosum* var. *villosum,*

C3= *Solanum villosum* var. *miniatum.*

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of phosphorus rate and solanum genotypes on growth parameters

The difference in plant height, leaf area and number of leaves per plant realized from the two seasons could have been due to the different environmental factors prevailing at that season`s growing period. There was higher amount of rainfall, lower temperatures and lower wind flow in season one (Appendices 2, 3 and 4), a period when higher yields were realized. The amount of rainfall available in the long rain season might have contributed to increased phosphorus uptake as evidenced from lower soil available phosphorus levels in season one (Table 4.2) This difference was also observed by Ondieki *et al*. (2011a) in Kisii, Kenya where the increase in plant height, edible leaf yield of African nightshades depended on the season and the genotype.

The low plant height, leaf area, number of leaves per plant and leaf yields at phosphorus rate of 0 and 20 kg P ha^{-1} could be attributed to low shoot and leaf initiation which might have been as a result of low level of phosphorus in the soil. The level of phosphorus in the soil affects the leaf initiation in meristem and activity of shoot meristem due to lower rate of cell division, cell development and lower rate of enzymatic activity (Balemi, 2009).

The increase in leaf area with increasing phosphorus applied could be due to increased leaf growth that comes as a result of increased leaf elongation which subsequently increased the leaf length. Kavanova *et al*. (2006) reported that phosphorus deficiency reduced leaf elongation rate due to decrease in cell production rate and final length. The leaf area is reported to dictate the amount of biomass a plant is capable to produce (Balemi, 2009). The reduced leaf area may have ultimately reduced the leaf yield and the plant growth parameters since less food for the plant were produced from reduced leaf area. At low phosphorus (0 and 20 kg P ha^{-1}) rate, the rate of cell division and elongation may have been reduced which led to reduction of the rate of leaf appearance from the meristematic shoot (Chiera *et al.*, 2002).

The reduced number of leaves in the second season was probably a physiological mechanism meant to reduce the moisture loss from the plant (Muthomi and Musyimi, 2009). These conditions may have been harsh to *Solanum scabrum* which is reported to prefer the forest humid climate (Schippers, 1998; Muthomi and Musyimi, 2009).

The increase in number of branches among the genotypes could have been due to genetic makeup of individual plants where *Solanum villosum* var. *miniatum* may have had more branches than the two genotypes and therefore needed more phosphorus for shoot formation which eventually produced branches. The shoots formed were the harvestable tender shoots and leaves by the consumers. The higher number of branches at higher phosphorus rate could have been due to high shoot and leaf initiation derived from increased cell division, expansion and activation (Chiera *et al*, 2002; Khorgamy and Farnia, 2009). The 0 and 20 kg P ha^{-1} could have been to low rate for proper shoot and leaf initiation for branches to be formed due to less energy transported or stored for enzymatic activities, cell division and development. *Solanum villosum* var. *miniatum* had significantly ($p \le 0.05$) higher number of branches at 60 kg P ha^{-1} in season one as was expressed in height. The difference in the number of branches among the genotypes may have been due to their genetic makeup of individual plants where *Solanum villosum* var. *miniatum* had more branches than the two genotypes. The genotype with higher number of branches may have required more amount of phosphorus for shoot formation to produce more branches. The shoots formed were the harvestable tender shoots and leaves by the consumers.

The significant interaction of genotype and phosphorus on the number of leaves per plant in the second season may have been brought about by the genotypes` response difference towards environmental factors that prevailed in the season. The high number of leaves for *Solanum villosum* var. *miniatum* and the lower number in *Solanum scabrum* could be due genetic make-up and environmental effects towards individual genotype. The lower performance of the genotype in short rain was in agreement to Weinberger and Msuya (2004) who reported that *Solanum scabrum* is not usually found in drier areas of Tanzania.

Solanum villosum var. *miniatum* had higher growth increase in season two over the control in height, number of leaves per plant, number of branches in main stem and leaf area which might have led to the high increase of fresh leaf over the control. The environmental conditions in the season might have favoured its growth. *Solanum villosum* var. *villosum`s* high increase over the control was observed in number of leaves which may have increased the leaf yield in season one though *Solanum scabrum* had the high fresh leaf yields. The higher leaf increase of *Solanum villosum* var. *villosum* over its control than *Solanum scabrum* in season one could be an indication that *Solanum villosum* var. *villosum* use phosphate fertilizer efficiently when there enough rainfall.

5.2 Effect of phosphorus rate on genotype fresh and dry leaf yields.

5.2.1 Fresh and dry leaf yields

The fresh and dry leaf yields of African nightshades for all the genotypes were affected by the season. High mean leaf yields were obtained from *Solanum scabrum* and *Solanum villosum* var. *villosum* during the long rain period as compared to the short rain period. This finding is agreement to what was found by Ashilenje *et al*. (2011). The difference in yields could be due to higher amount of available soil moisture than what was available in the short rain season (Appendices 2, 3 and 4). However the leaf yield ha^{-1} found was relatively higher than what was found by Ondieki *et al*. (2011b) during the long rain season in Kisii. The yields of *Solanum scabrum* and *Solanum villosum* using 8 tons ha^{-1} of fortified manure (N= 2.13%, K= 5%, P=3.38% and Mg= 0.8%) were 3780 and 4930 kg ha^{-1} respectively (Ondieki *et al*., 2011b). Ashilenje *et al*. (2012) while using 46 kg P ha^{-1} and 66 kg K ha^{-1} in the long rain season obtained overall mean yield of 4890, 4580 and 11460 kg ha^{-1} for *Solanum villosum* var. *villosum*, *Solanum villosum* var. *miniatum* and *Solanum scabrum* respectively. In the current study, while using 60 kg P ha^{-1} in the long rains season, the leaf yields were found to be 11027, 9157 and 13351 kg ha^{-1} for *Solanum villosum* var. *villosum*, *Solanum villosum* var. *miniatum* and *Solanum scabrum* respectively. The difference in yields realized in current study and Ashilenje *et al.* (2012) could be due to the type of fertilizer used and agro ecological zones where the studies were done.

The positive correlations (Choudhury, 2009) between the available phosphorus and leaf yields, both fresh and dry, could be an indicator that application of phosphorus fertilizer increases yields. The high leaf yields might have been obtained due to favourable climatic conditions that prevailed in the long rain season (Appendices 2, 3 and 4). The available moisture might have made plants to increase phosphorus uptake which was observed with the difference of available phosphorus in the two seasons. The finding was in agreement with what was found by Kipkosgei *et al*. (2003) in Keiyo. However, the short rain season favoured *Solanum villosum* var. *miniatum* where relatively higher number of leaves and leaf yields were obtained. The effect of environmental changes within the year (Appendices 2, 3 and 4) might have contributed to the changes in leaf yield and plant growth parameters (Wasonga *et al.*, 2008).

The fresh leaf yields realized in season one depended on genotype and phosphorus rate where *Solanum scabrum* produced significantly ($p \leq 0.05$) high leaf yields at 60 kg P ha^{-1}. The positive correlation between the available phosphorus and leaf yields indicated that yields increased with increase in phosphorus rate (Figure 4.1). The high leaf yield noted in *Solanum scabrum* was in agreement to what Ondieki *et al*. (2011a) found in Kisii with *Solanum americanum* and *Solanum villosum* in two seasons at high altitude conditions. Though *Solanum scabrum* had high fresh leaf yield in season one at 60 kg P ha^{-1}, it had lower increase (335%) of fresh leaf over its control than *Solanum villosum* var. *villosum* at 60 kg P ha^{-1} which had relatively the highest yield increase (346%) over its control. The genotypes failed to maintain the same trend in second season. The genotypes might have been affected by the changes in environmental factors. The high wind speed, temperatures and lower amount of rain prevailed in season two which was in contrast to the warm humid forest environment required by *Solanum scabrum* (Schippers, 1998). The variation in the response of genotype and phosphorus on fresh and dry leaf yields could be related to the specific genotype and environmental factors. The genotype *Solanum scabrum* may have lost more moisture through evaporation from the leaves in season two than the other two genotypes. The plant biomass production might have been reduced due to lower moisture in the plant (van Averbeke *et al.*, 2007).

The leaf yield increase with increasing phosphorus applied indicated the importance of phosphate fertilizer addition. 60 kg P ha^{-1} produced optimum leaf yield for all genotypes in season one. However, in season two *Solanum villosum* var. *villosum* had its high yields at 40 kg P ha^{-1}. The low yields of *Solanum villosum* var. *villosum* at 60 kg P ha^{-1} and the weak correlation with available phosphorus in season two could be attributed to the environmental factors and the genotype`s failure to use the available phosphorus. The high yields obtained at 60 kg P $ha^{-1}$ is in agreement with Juma`s (2006) work in a pot experiment on *Solanum retroflexum* done in Vhembe district, Limpopo Province, South Africa where she found 61 kg P ha^{-1} as the optimum rate and 100 kg P ha^{-1} caused reduced leaf yields. . The yield response pattern of *Solanum villosum* var. *villosum* towards phosphorus fertilizer has a major practical significance on the production of the crop. The significant ($p \leq 0.05$) response pattern on genotypes in season two may be important to be followed as it might assist future workers to establish a genotype that produces high yields in the short rain season. The lower rates of phosphorus (0 and 20 kg P ha^{-1}) had significantly ($p \leq 0.05$) lower leaf yields possibly due to decreased rate of shoot growth and especially leaf number and leaf size (Chiera *et al.*, 2002 and Kamaru *et al.*, 2008) and thereby reducing the plant biomass (van Averbeke *et al.*, 2007). Sarker *et al.* (2010) reported that phosphorus deficiency causes reduced number of stomata, reduced number of cells, small leaf size and decreased stem diameter which eventually reduces the leaf yield. The 20 kg P ha^{-1} may still be a lower rate to satisfy the plant phosphorus requirement as was seen with the leaf yields obtained and it will necessitate addition of phosphorus.

The difference in biomas production from the three genotypes sampled could be due to the photosynthetic efficiency. The lower phosphorus rates (0 and 20 kg P ha^{-1}) had fewer plant growth parameters that included small leaf area. This caused low photosynthetic area which might have reduced plant biomass produced from photosythesis. The plant growth parameters production were at the optimum level at 40 kg P ha^{-1} while the optimum leaf yields was at 60 kg P ha^{-1}. The difference may have been caused by the tender shoots harvested for consumption from the sublateral branches. The sublateral branches may have unproportionally increased the leaf weight as compared to plant growth parameters.

5.3 Effect of phosphate fertilizer application rate on financial benefit of growing African nightshade

5.3.1 Financial benefit and Benefit- cost analysis

The benefit-cost analysis obtained indicated that net financial benefit increased with increase in phosphorus rate. Low application of phosphate fertilizer could produce lower net financial benefit but had higher added benefit over the added unit cost over the control. The higher benefit-cost ratio at lower phosphorus could be important for small scale farmers who have low income (Irungu *et al*., 2007). Though farmers have their preferred benefit-cost ratio (BCR), the BCR of between 3.0 and 4.1 had high added benefit from a unit of added input. The BCR at higher phosphorus rate was lower due to increased cost of labour, transport and higher amount of fertilizer cost.

The benefits depended with season, genotype and the fresh leaf increase over the control. The performance of the genotypes` on net benefit followed similar trend taken by the genotypes` percentage leaf increase over the control. High benefit was obtained in season one where optimum environmental conditions of rainfall, temperature and wind run (speed) prevails. The adoption of planting *Solanum scabrum* in season two might not be taken by farmers due to the low BCR of 2.0 and below. The genotype if planted in the short rain season might be uneconomical. Farmers prefer a BCR of more than 2.0 (Opala *et al*., 2010). Basing on the economical point, *Solanum villosum* var. *villosum* at 40 kg P ha^{-1} and *Solanum villosum* var. *miniatum* at 20 kg P ha^{-1} may be adopted due to the high added benefit over the control per unit of extra added input over the control.

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Phosphate fertilizer increased plant height, leaf area, number of leaves in a plant and leaf of African nightshades (*Solanum* L. section *solanum*). Low levels of phosphorus caused reduced growth parameters which ultimately caused a reduction in leaf biomass. Higher phosphorus application rate increased the plant growth morphological characters which ultimately increased fresh and dry leaf yields. There was high uptake of phosphorus in the long rain season as compared to short rain season due differences in environmental conditions.

The response of genotype to phosphorus application was genotypic specific and depended on season. All the sampled genotypes utilized applied phosphorus effectively during the long rain period where high yields were obtained at higher levels of phosphorus. *Solanum scabrum* performed well in long rain season while *Solanum villosum* var. *villosum* did well in the short rain season.

Phosphorus and genotype influenced the financial benefit obtained from the increased leaf yields. The high benefit cost ratios in season one make the genotypes to be easily adopted since they had between 300 % - 410 % financial benefit over the added cost from the control. The choice of the specific genotype will depend on the farmer`s preferred choice of BCR and net financial benefit. *Solanum villosum* var. *miniatum* will be easily adopted by small scale farmers and the entrepreneur farmers producing and trading on the African nightshade vegetable due the high benefit cost ratio in the two seasons with a more favourable benefit cost ratio in season two.

6.2 Recommendations

1) *Solanum scabrum, Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum* all with 60 kg P ha^{-1} should be grown in the long rains season. It is important that phosphorus fertilizer be used as it will increase the leaf yield and the financial benefit.
2) *Solanum villosum* var. *villosum* with 40 kg P ha^{-1} is recommended for the short rain period. *Solanum villosum* var. *miniatum* should be planted with 60 kg P ha^{-1} for higher leaf yields and financial benefit.
3) The production of African nightshade is mostly done by women and other small scale farmers with low income. The production of African nightshade is able to raise their financial level. It is recommended that these farmers produce *Solanum villosum* var. *villosum* with 20 and 40 kg P ha^{-1} and *Solanum villosum* var. *miniatum* with 40 and 20 kg P ha^{-1} in long and short rain seasons respectively.
4) *Solanum scabrum* is adversely affected by environmental conditions in the short rain season. For higher economic benefit from the genotype, it be should be planted in the long rain season.
5) Economically, *Solanum villosum* var. *villosum* and *Solanum villosum* var. *miniatum* does well in long and short rain season respectively.

6.3 Further research

The performance of *Solanum villosum* var. *villosum* should be investigated further during the short rain periods to determine the cause of the reduced leaf yield at higher than 40 kg P ha^{-1} phosphorus rate.

7.0 REFERENCES

Abukutsa-Onyango, M.O.A., (2003). Unexploited Potential of indigenous African Vegetables in Western Kenya. *Maseno Journal of Education Arts and Science* 4 (1), 103 – 122.

Abukutsa-Onyango M. (2007). The Diversity of Cultivated African Leafy Vegetables in the Three Communities in Western Kenya. *African Journal of Food, Agriculture, Nutrition and Development* Online, 7 (3). http://www.ajfand.net/Volume7/No3/Abukutsa-IPGRI1-3 pdf. Accessed on 22nd August 2010

Abukutsa-Onyango, M.O. and Karimi, K. (2005). Response of Broad Leaved African Nightshade to Nitrogen Application. *African Crop Science Conference Proceedings.* Entebbe , Uganda. 7: 1237 – 1240.

Akubugwo, I. E., Obasi, A. N and Ginika, S. C (2007). Nutritional Potential of the leaves and Seeds of black nightshade-*Solanum nigrum* L. var.. *virginicum* Nigeria. *Pakistan Journal of Nutrition* (Abstract). Asian Network for Scientific Information. 6 (4) : 323 – 326.

Anderson, J.M and Ingram,J .S.I (1989). TSBF: A handbook of methods of analysis. CAB International : 39.

Ashilenje, D.S., Omunyin, M.E and Okalebo, J.R (2011). Influence of potassium on aphid and Yield of vegetable African nightshades (*Solanum* L. section *Solanum). Annals of Biological Research,* 2 (3): 317-326.

Ashilenje, D.S., Omunyin, M.E and Okalebo, J.R (2012). Potassium Nutrition: Towards sustainable and profitable production vegetable African nightshades (*Solanum* L.section *Solanum*) in Western Kenya. *Journal of Chemical and Pharmaceutical Research,* 2012, 4(4): 2306 – 2311.

AVRDC (Asian Vegetable Research Development Centre) (2003). International Cooperators Guide. Narrow leaved nightshade. http://libnts.avrdc.org.tw/fulltext_pdf/FLYER/f0073.pdf. Accessed on 4th May 2010.

AVRDC (Asian Vegetable Research Development Centre) (2004). Evaluation of variation in plant population for yield adaptation and horticultural characteristics of promising nightshade lines. AVRDC report 2003. Shanshua, Taiwan: The World Vegetable Center. http://203.64.245.61/fulltext_pdf/AR/2004.pdf. Accessed on 4th September 2010.

Balemi, T (2009). Effect of phosphorus nutrition on growth of potato genotype with contrasting phosphorus efficiency. *African Crop Science Journal* 17 (4): 199 – 212.

Bationo, A., Hartemink , A., Lungu, O., Naimi, M., Okoth, P., Smaling, E., and Thiombiano, L. (2006). African Soils: Their Productivity and Profitability of Fertilizer use, Background paper Prepared for the African Summit June 9-13, 2006 Abuja, Nigeria. 1-6

Benvenuti, S., Simonelli, G and Macchia, M. (2001). Temperature and darkness improve *Passiflora incarnata* L. *Seed Science and Technology* 29: 533-541.

Bouyocos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. *Agronomy Journals*. 53: 464- 465.

Bujulu, E and Matee, J. J (2005). A survey on production and consumption of Traditional leafy vegetables in Arusha region, Tanzania. In: Abukutsa-Onyango, M.O., Muriithi, A.N., Ngamau, A., Anjichi, V., Agong, S.G., Frickie, A., Hau, B and Stützel, H (2005). Proceedings of the third Horticulture workshop on sustainable Horticulture Production in the tropics 26th – 29th Nov. 2003. Maseno University, MSU, Maseno Kenya. 100-105.

Chadha, M. L., Oluoch, M.O and Silue, D (2007). Promoting indigenous vegetables for health, food security and income generation in Africa (Abstract) *Acta Hort* (ISHS) 762: 253 -262

Chiera, J., Thomas, J and Rufty, T (2002). Leaf initiation and development in Soyabean under Phosphorus stress, *Journal of Experimental Botany*. 53 (368): 473- 481

Choudhury, A (2009). Statistical correlation. Retrieved on 22 March 2012 from Experiment Resources.
http:// www.experiment-resources.com/statistical correlation html.

Colwell, J.D (1971). Estimates of sampling intensities for the characteristics of soil within experiment sites. *Australian Journal of experimental Agriculture and Animal Husbandry* 11: 541-545.

De Villiers, J.C (2007). The effect of phosphorus on the growth, plant mineral content and essential oil composition of Buchu (*Agathosma betulina*). M.Sc Thesis, Stellenbosch University, South Africa.

Dhellot, J.R., Matouba, E., Maloumbi, M.G., Nzikou,J.M., Dzondo, M.G., Linder, M., Parmentier, M and Desobry, S (2006). Extraction and nutritional properties of *Solanum nigrum* L. Seed oil. *African Journal of Biotechnology*. Academic journal. 5 (10): 987-991.

Diaz, R.A.D., Mengel, B.D., and Martin, L.K., (2011). Phosphorus Facts: Soil, Plant and Fertilizer. K. State Research and Extension Publication C – 665, Kansas State University, January, 2011. http://www.ksre.ksu.edu/library/crpsl2/c665.pdf. Accessed on 26 June 2012

Edmondss, J.M. and Chweya, J.A (1997). Black Nightshade Solanum nigrum L. and related genotype. Promoting the Conservation and Use of underutilized and neglected crop. 15. Institute of Plant Genetics and Crop Plant Research. Gatersleben/ International Plant Genetic Resources Institute. Rome, Italy. 9-20

Fontem, D.A. & Schippers, R.R. (2004). **Solanum scabrum** Mill. [Internet] Record from Protabase. Grubben, G.J.H. & Denton, O.A. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. < http://database.prota.org/search.htm>. Accessed on 16 July 2012.

GenStat (2010). GenStat Procedure Library Release PL20.2. GenStat Release 12.2 (PC/Windows XP). Copyright 2010, VSN International Ltd.

Gachene, C.K.K and Kimani (2003). Soil fertility and land productivity- A guide for extension workers in the Eastern Africa Regional Technical Handbook No. 30. Regional Land Management Unit (RELMA). Swedish International Development Cooperation Agency (SIDA). 9-22

Gomez, K.A and Gomez, A.A (1976). Statistical procedures for agricultural research, with emphasis on rice. International Rice Research Institute, Los Banos, Philippines. 239-241, 264.

Habwe, F., Walingo. K.W and Abukutsa-Onyango (2010). Copper and ascorbic acid Content of cooked African indigenous vegetables. Conference on International Research Management and Rural development. Tropentag, ETH. Zurich. Sept. 14 – 16, 2010.

Horner, E, R. (2008). The effect of Nitrogen application liming on plant available phosphorus M. Sc Thesis, The Ohio State University.

Irungu, C., Mburu, J and Maundu, P (2007). Analysis of Markets for African leafy vegetables within Nairobi and its environs and implication for on-farm conservation of biodiversity, Global facilitation unit for underutilized species (GFU), Rome, Italy. 10-23

Islam, M., Ali, S and Hayat, R (2009). Effect of integrated application of phosphorus and Sulphur on yield and micronutrient uptake of Chick pea (*Cicer ariettinum* L.) (Abstract). *Int. J. Agric. Biol.*, 11: 33-38.

Jaetzold, R., and Schmidt, H., Hornetz, B and Shisanya, C. (2011). Farm Management Handbook of Kenya. Volume II. Natural Conditions and Farm Management Information 2nd Edition Part B. Central Kenya. Subpart B1. Northern Rift Valley Province, Ministry of Agriculture and German Agricultural Team (GAT) of the German Agency for Technical and Co-operation GTZ, Nairobi. 107-174

Jain, R., Sharma, A., Gupta, S., Sarethy, P and Gabrani, R (2011). Solanum nigrum: Current Perspective on Therapeutic Properties. *Alternative Medicine Review* 16 (1): 78-85

Juma, A.J (2006). Response of *Solanum retroflexum* Dun. To Nitrogen, phosphorus and potassium in pots. Magister Technologiae, Tshwane University of Technology.

Kamaru, A. Y., Kwari,J.,Ekeleme, F., Omoigui,L and Abaidoo, R (2008). Effect of Phosphorus application and Soyabean species on grain and dry matter yield of Subsequent Maize in the Savannahs of North Eastern Nigeria. *African J. Biotech*. 7 (15): 2593-2599.

Kamwaga, J., Nafuma, L., Maina, M., Langat, P., Ooro, P., Macharia, P., Mwangi, H., Njuguna, M., Amadi, D., Osoo, J., Moraa, L., Banda, P., Bor, P., Waweru, J and Kirui, P (2005). Crop Management. In: KARI (2005) Crop Production Handbook for Wheat, Oil and Horticulture, KARI, Njoro. 4-10

Kanyanjua, S.M., Ireri, L., Wambua, S and Nandwa, S.M (2002. Acidic soils in Kenya: Constraints and remedial options. Technical notes series. Kenya Agricultural Research Institute, KARI (11): 1-10.

Kavanova, M.,Lattanzi,F.A.,Grimoldi, A.A. and Schnyder (2006). Plant Physiology, *American Society of Plant Biologists.* 141: 766-775

Keding, G., Weinberger. K., Swai, L and Mndinga, H (2007). Diversity traits and use of traditional vegetables in Tanzania .Technical Bulletin no. 40. Shanhua, Taiwan:. AVRDC- The World Vegetable Center. 53

Kenya Agricultural Research Institute (2005a). Use of Organic and Inorganic Fertilizer. For Maize, Vegetables and Finger Millet Production Bulletin, KARI.

Kenya Agricultural Research Institute (2005b). Produce Quality Seed of Black Nightshade and Make more money (Sucha). Bulletin, KARI.

Khan, M.M.A., Samiullah., Afag, S.H and Afridi, R.M (2000). Response of black nightshade (*Solanum nigrum* L.) to phosphorus application (abstract). *Journal of Agronomy and Crop Science* 184 (3):157-163.

Khorgamy, A and Farnia, A (2009). Effect of phosphorus fertilizer and zinc fertilization on Yield and yield components of Chick pea species. African Crop Science Conference proceedings. Uganda. *African Crop Science Society*. 9: 205-208.

Kipkosgei, L.K, Akundabweni and Hutchinson, M.J. (2003). The Effect of Farmyard Manure and Nitrogen Fertilizer on Vegetative Growth, leaf yield and quality Attributes of *Solanum villosum* (Black Nightshade) in Keiyo District, Rift Valley. In Proceedings of *African Crop Science Conference*, Uganda, 6: 514 – 518.

Kisinyo, P.O., Ngetich, W.K., Othieno, C.O., Okalebo, J.R and Opile, W.R (2011). Phosphorus depletion- Should the ACP countries be concerned? What are the Current issue for the future research and policy? http:/knowledge.cta.int/en/Dossiers/S-T-Issues-in perspective/phosphorus-depletion/Articles/phosphorus-depletion. Accessed 6th August 2012

K'Opondo, F.B.O., Muasya, R.M and Kiplagat, O.K (2005). A review on the seed Production and handling of indigenous vegetables (Spider plant, Jute mallow and African nightshade complex). In: Abukutsa- Onyango, M.O., Muriithi, A.N., Ngamau, A., Anjichi, V., Agong, S.G., Frickie, A., Hau, B and Stützel, H (2005). Proceedings of the third Horticulture workshop on sustainable Horticulture Production in the tropics 26th – 29th Nov. 2003. Maseno University, MSU, Maseno Kenya. 42-48

Krasilnikoff, G., Gahoonia, T. and Nielsen, E.N (2003). Variation in phosphorus uptake Efficiency by genotype of cowpea (*Vigna unguiculata*) due to differences in root and root hair length and induced rhizosphere processes. *Plant and Soil* 251:83-91.

Makhdum, M.I., Malik, M.N.A., Shabab-ud-Din and Chaudhry, F.I (2001) Effect of phosphorus fertilizer on growth, yield and fibre quality of two cotton species. *Journal of Research (Sciences)*. Bhauddin Zakariya University, Multan, Pakistan 12(2): 140-146.

Manoko, M.L. and Van der Weerden, G.M., (2004a). *Solanum villosum* Mill [Internet] Record from Protabase. : Grubben, G.J.H. and Denton, O.A. (Editors). PROTA) (Plant Resources for Tropical Africa/Resources végétales de L'Afriques. http://www.prota4u.org/protav8.asp?g=pe&p=Solanum+villosum+Mill. Accessed on 7th October 2010

Manoko, M.L. and Van der Weerden, G.M., (2004b). *Solanum americanum*, Mill in Grubben. G.J.H and Denton O. A (Editors). PROTA 2. Vegetables/ Legumes [CD-ROM] PROTA, Wageningen, Netherlands.

Manoko, M.L.K., Berg, G.R., Feron, R.M.C., van Weerden. G.M and Mariani, C (2007). AFLP Markers support separation of *Solanum nodiflorum* from *Solanum americanum sensu strcto* (Solanacea) *P.I Syst. Evol.* 267: 1- 11.

Manoko, M.L.K., Berg, G.R., Feron, R.M.C., van Weerden. G.M and Mariani, C (2008). Genetic diversity of African hexaploid species *Solanum scabrum* Mill and *Solanum nigrum* L. (Solanaceae). Genetic resource crop evolution. *Springer Science and Business Media* B.V 2007. 55: 409-418.

Maritim, K.J., Onyango, J.C., Onyango, M. and Ng`etich, W. (2009). A study of intra-specific competition in *Solanum scabrum* grown at different inter row spacing within tea plants. *Journal of Agriculture, Pure and Applied Sciences and Technology* (JAPAST). Moi University Press. 1: 25-32.

Masinde, P.W., Onyango, C.A., Abukutsa-Onyango, M., Wasonga, J.M., Ojiewo, C.O and Agong, S.G (2010). Response of leaf yield and nutritive value of African Nightshade (*Solanum villosum*) genotype to nitrogen application. *Afr. J. Hort. Sci.* 3: 34- 47.

Mbugua, G.W., Muriuki, A., Anyango, J.J., Ndung`u, B., Gathambiri, C and Manyeki, L. (2008). Enhancing Production of African nightshade (*Solanum scabrum*), Spider plant (*Cleome gynandra*) and Amaranthus (*Amaranthus cruentus*) amongst small scale farmers in Maragua district, Central Kenya. Paper submitted for poster Presentation at KARI *11th Biennial Scientific Conference*. 1-10

Mibei E. K., Ojijo, N.K.O., Karanja, S.M., Kinyua, J.K (2011). Compositional attributes of the leaves of some indigeneous African leafy vegetables commonly consumed in Kenya. *Annals. Food Science and Technology*. 12(2): 146 – 154.

Ministry of Agriculture (2000). Local and Export Vegetables Growing Manual. Agriculture Information Resource Centre (AIRC), Nairobi. 133-139

Ministry of Agriculture (2010). Horticultural Crops. Quarter II report, December 2010. Eldoret East District

Ministry of Agriculture and National Agricultural Research Laboratories, (1987). Fertilizer Use Recommendation Project Phase I. Vol. II.

Ministry of Environment and Natural Resources, MENR (2011). Data for Rainfall, Temperature and Wind run for the year 2010, Kenya Meteorological Department, Eldoret Meteorological Station.

Mohy-ud-din, A., Khan, Z., Ahmad, M. J and Kashmir, M.A (2010). Chemotaxonomic value of alkaloids in *Solanum nigrum* complex *Pakistan Journal of Botany* 42 (1) 653 - 660

Musotsi, A. A., Sigot, A. J and Onyango, M.O.A (2008). The role of home gardening in household food security in Butere Division of Western Kenya. *African Journal of Agriculture Nutrition and Development.* 8 (4): 375 - 390

Muthomi, J and Musyimi, D. M (2009). Growth Responses of African nightshades (*Solanum scabrum* mill) seedling to water deficit *ARPN Journal of Agricultural and Biological Science* 4 (5): 24-31.

Mwai G.N., Onyango, J.C and Abukutsa-Onyango, M. O (2007). Taxonomic identification and characterization of african nightshade *Solanum* L. Section *solanum*). *African Journal of Food, Agriculture, Nutrition and Development. Rural Outreach programme.* 7 (4)

Mwai, G.N., Tiomo, B., Manoko, L., Mariani, G.M., Werden, Van Der., and Schippers, R.R. (2005). Taxonomic Characterization and Identification of African Nightshades (Solanum L. Section Solanum). In: Abukutsa-Onyango, M.O., Muriithi, A.N., Ngamau, A., Anjichi, V., Agong, S.G., Frickie, A., Hau, B and Stützel, H (2005). Proceedings of the third Horticulture workshop on sustainable Horticulture Production in the tropics 26th – 29th Nov. 2003. Maseno University, MSU, Maseno Kenya. 79 – 86.

Mwangi, S and Mumbi, K (2006). African leafy vegetables evolves from underutilized species to commercial cash crops. In Research Workshop on Collective Action and Market Access for Smallholders. 2-5 October, Cali, Colombia. 1-19

Ndinya, C (2005). Seed production and supply system of three African leaf vegetable in Kakamega district. In: Abukutsa- Onyango, M.O., Muriithi, A.N., Ngamau, A., Anjichi, V., Agong, S.G., Frickie, A., Hau, B and Stützel, H (2005). Proceedings of the third Horticulture workshop on sustainable Horticulture Production in the tropics 26th – 29th Nov. 2003. Maseno University, MSU, Maseno Kenya. 60-67

Nelson, D.W and Sommers, L. E (1975). A rapid and accurate method for estimating organic Carbon in soil. *Proceeding of Indiana academy of Science* 84: 456- 462.

Nyongesa, H.W., Obura, R.K., Kitur, B.K., Ouma, J.P and Nakhone, L.N (2009). Effect of organic and inorganic nutrient sources on maize yield and yield components in Nandi district, Rift Valley province, Kenya. African Crop Science Proceedings. *African Crop Society*. 9: 55-61.

Odhiambo, Z and Oluoch, M (2008) African leafy vegetables come out of shade. Global Facilitation Unit for underutilized species, World Vegetable Centre, Arusha.

Okalebo, J. R (1985). A simple wet ashing technique of P, K, Ca analysis of plant tissue in a single digest. *Kenya Journal of Scienve and Technology*. B6: 129-133

Okalebo, J.R. (2009). Recognizing the constraint of soil fertility Depletion and Technologies to Reverse it in Kenyan Agriculture. Inaugural Lecture, Moi University Press, Eldoret, Kenya 9-40

Okalebo, J.R., Gathua, K.W., and Woomer P.L., (2002). Laboratory Methods of soil and Plant Analysis: A Working Manual. The Second Edition. TSBF – CIAT and SACRED Africa, Nairobi Kenya, 2002. 33-61, 78-79

Olet, E.O., Lye, A. K and Heun (2011). Amplified fragment length polymorphism (AFLPs) analysis of species of Uganda. *Africa Journal of Biotechnology*. Academic Journal. 10 (34): 6387-6395.

Olsen, S.R., Cole, C.V., Watanabe, F.S and Dean, L.A (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular, 939.

Oluwatoyinbo, F.I., Akande, M.O., and Adediran, J.A (2005). Response of Okra (*Abelmoschus esculrntus*) to lime and phosphorus fertilization in an acid soil. *World Journal of Agricultural Sciences*. IDOSI Publications. 1(2): 178-185

Onasanya, R.O., Aiyelari,O.P., Onasanya, A.,Oike,S.,Nwile,F.E and oyelakin,O.O., (2009). Growth and Yield response of Maize (Zea mays L.) to different Rates of Nitrogen and Phosphorus Fertilizers in Southern Nigeria. *World Journal of Agricultural Sciences.* IDOSI Publication. 5(4):400-407.

Ondieki, M.J., Aguyo, J.N., Opiyo, A. (2011a). Variations in growth and yield characteristic of three black nightshade species grown under high altitude conditions. *Agriculture and Biology Journal of North America*. ScienceHuβ. : 2 (3):401-406

Ondieki, M.J., Aguyo, J.N., Opiyo, A. M. (2011b). Fortified compost manure improves yield and growth of African nightshades. *International Journal of Science and Nature* 2 (2): 231-237.

Onim, M and Mwaniki, P (2008). Cataloguing and Evaluation of available community/Farmers- based seed enterprises of African indigenous vegetables (AIVS) four ECA Countries. Lagrotech consultants. 18-19, 31-46

Onyango, C. M., Imungi, J.K., Mose, L.O., Habinson, J. and Kooten O. (2009). Feasibility of Commercial production of amaranth leaf vegetable by small scale farmers in Kenya. Africa Crop Science Conference Proceedings. *African Crop Science Society*. 9: 767 – 772

Opala, P.A., Okalebo, J.R. and Othieno, C.O. (2012). Effects of organic and inorganic materials on soil acidity and phosphorus availability in a soil incubation study. *International Schorlarly Reasearch Network*. 2012 (59219): 1- 10.

Opala, P.A, Othieno, C.O., Okalebo, J.R., and Kisinyo, P.O. (2010). Effects of Combining Organic Materials with Inorganic Phosphorus Sources on Maize yield and financial benefits in western Kenya. *Expl. Agric.* 46(1): 23 -34.

Opiyo, A.M (2006). Effect of Nitrogen Application on leaf yield and nutrition quality of black nightshade (*Solanum nigrum* L.). In: Isutsa, D. K.; Wesonga, J. M.; Onyango, M. O. A.; Njoroge, J. B. M.; Waiganjo, M. M.; Agong,S. G.; Fricke, A.; Hau, B.; Stuetzel, H. (Eds.) (2006). Proceedings of the Fifth Workshop on Sustainable Horticultural Production in the Tropics. 23rd to 26th November 2005. Agricultural Resources Centre, Egerton University, Njoro, Kenya. 130-140.

Rensburg W.J.V., van Averbeke, W., Slabbert, R., Faber, M., van Jaarsveld, P., van Heerden, I., Wenhold, F and Oelofse, A (2007). African leafy vegetables in South Africa. *Water SA* 33(3) (Special edition):317-326

Rhoades, J.D (1982). In methods of soil analysis , Part 2. Second edition (A.L. page, R.H Miller and D.R Keeney, Eds). *American Society of Agronomy*. Madison, USA.

Sarker, B.C., Karmoker, J. L and Rashid, P (2010). Effect of phosphorus deficiency on anatomical structure in maize (*Zea mays* L.). Bangladesh J. Bot. 39(1): 57-60

Schachtman, D.P., Reid, R.J., and Ayling, S.M. (1998). Phosphorus uptake by Plants: From Soil to cell. *Plant Physiology*, 116: 447 – 453.

Schippers, R (1998). Notes on Huckleberry, *Solanum scabrum*, and related Black Nightshade species. Natural Resource Institute, University of Greenwich.http://www.dfid.gov.uk/r4d/pdf/outputs/R6964a.pdf. Accessed on 20th February 2010.

Schippers, R.R. (2000). African Indigenous Vegetables. An Overview of the Cultivated species. Chatham UK: Natural Resources Institute/ACP – EU Technical Centre for Agricultural and Rural Cooperation.176-189.

Schippers, R.R. (2002). African Indigenous Vegetables. An Overview of the Cultivated species, 2002- Revised version on CD-ROM. Natural Resources International Limited, Aylesford, UK. www.dfid.gov.uk/r4d/Output/179575/Default.aspx. Accessed on 20th February 2010

Schulte, E. E and Kelling, K. A (1996). Soil and Applied Phosphorus. A2520. Understanding plant nutrients. University of Wisconsin, cooperative extension. http://www.soils.wisc.edu/extension/pubs/A2520.pdf. Accessed on 16th December 2010

Shibonje, D.A. (2009). Effect of Potassium Nutrition on Growth, Leaf Yield and Aphid Incidence in Vegetable African Nightshade (*Solanum* L. Section *Solanum*) M. Phil Thesis, Moi University.

Sivakumar, V and Ponnusami, V (2011). Influence of spacing and organics on plant nutrient uptake of black nightshade (*Solanum nigrum*). *Journal of Horticulture and Forestry. Academic Journals.* 3(11): 333-335.

Spencer, R. (2006) Garden plants as environmental and agricultural weeds. Resource and information pack with emphasis in Victoria. Royal Botanic garden, Melbourne, Weed working group. www.rbg.vic.gov.au/__data/assets/.../WEEDS-DRAFT-LATEST.doc. Accessed on 15th September 2011

Tisdale, S. L., Nelson, W.L and Beaton, J. D (1985). Soil fertility and fertilizers, Macmillan publishing Co. New York, 1985, 4th edition: 207 – 214.

Van Averbeke, W., Juma K.A., and Tshikalange, T.E. (2007). Yield Response of African Leafy Vegetable to Nitrogen, Phosphorus and Potassium. The Case of *Brassica rapa* L. Var. *chinenesis* and *Solanum retroflexum*. Dun *Water S.A*. 33 (3): 352 – 362

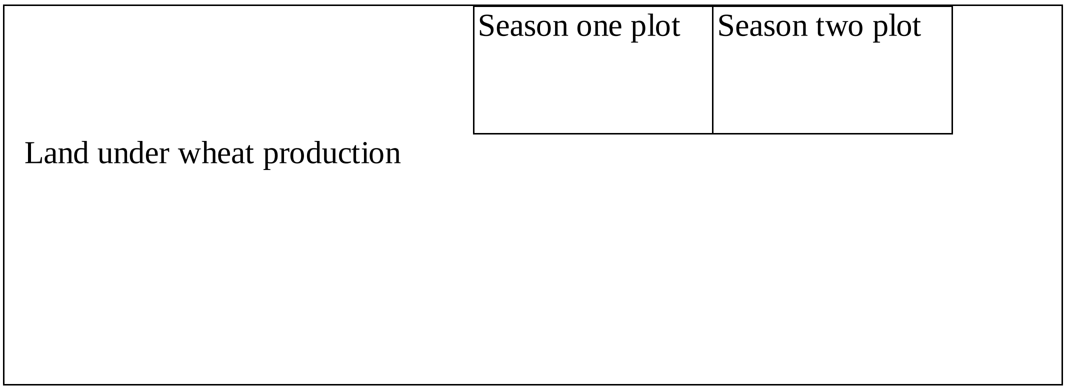
Wasonga, C.J., Sigunga, D.O., and Musandu, A.O. (2008). Phosphorus Requirements by Maize Varieties in different Soil Types of Western Kenya. *African Crop Journal*, 16(2): 161 – 173.

Weinberger, K and Msuya, J (2004). Indigeneous vegetables in Tanzania – Significance and Prospects. Shanhua Taiwan. AVRDC- The World Vegetable Center, Technical Bulletin No. 31, AVRDC Publication 04-600. 14-23, 35-49

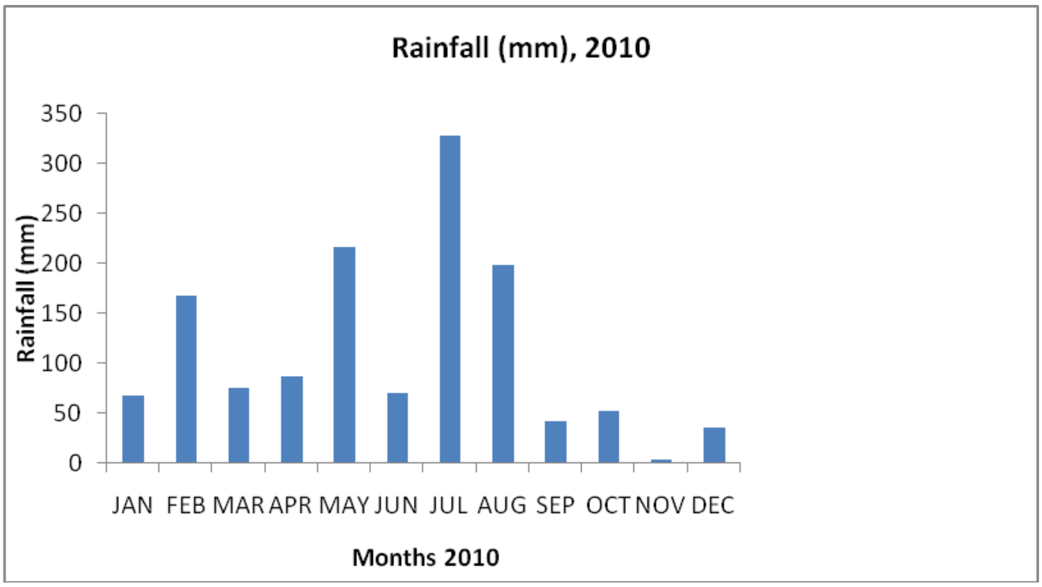
Yousof, Z., Masood, S., Shinwari, Z.K., Khan, M.A and Rabani, A (2006). Evaluation of taxonomic status of medicinal species of the genus Solanum and Capsicum based on polyacrylamide Gel electrophoresis. *Pak. J. Bot*, 38 (1): 99-106.

8.0 APPENDICES

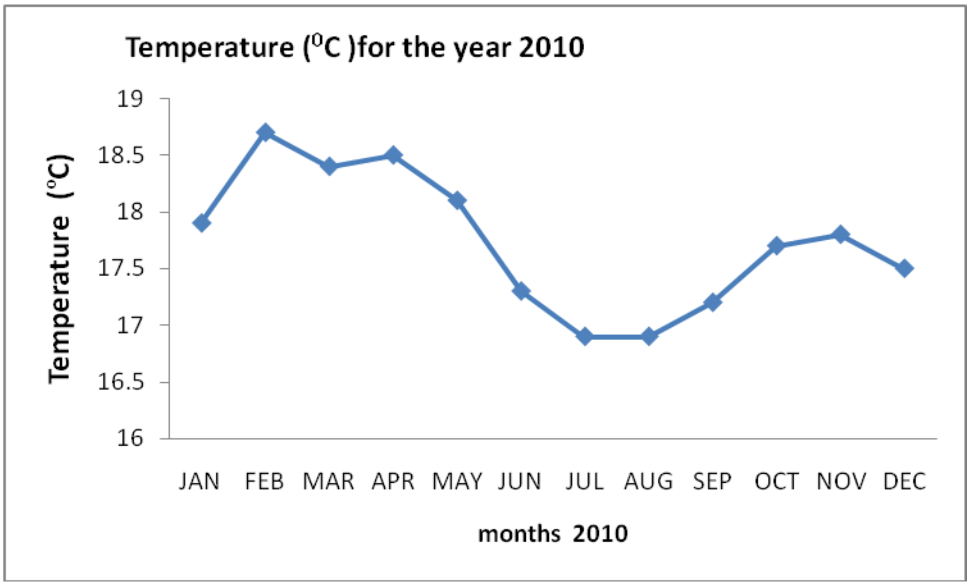
Appendix 1: Farm sketch where the experiment was done



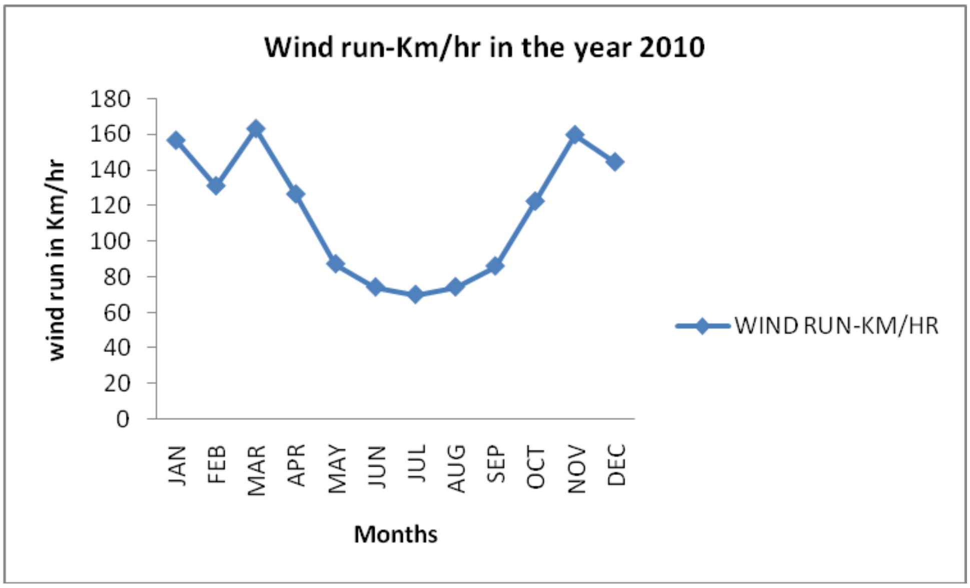
Appendix 2: Rainfall (mm) for the year 2010 (MENR, 2011).



Appendix 3: Mean monthly temperature for the year 2010 (MENR, 2011).



Appendix 4: The wind run for the year 2010 (MENR, 2011)



Appendix 5: Values used for benefit-cost analysis in Kshs

Parameter	Kshs
Price of TSP per 50 kg bag	3750
Transport of fertilizer per 50 kg bag	100
Harvesting labour per bag of 65 kg	100
Transport of harvested fresh leaf yield per bag of 65 kg to Eldoret municipal market	120
Price per kg of *Solanum scabrum* fresh weight	17
Price per Kg of *Solanum villosum* fresh weight	22
Fertilizer application , labour, per 50 kg bag	100