EFFECT OF FERTILIZER APPLICATION, HARVESTING METHOD AND MOISTURE STRESS ON GROWTH, YIELD AND NUTRITIONAL QUALITY OF *Solanum spp.* AND *Vigna unguiculata* L. Walp (Cowpea)

Caroline Chemutai

University of Nairobi
B.Sc. Agriculture (Hons.)

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DECLARATION

I hereby declare that the work contained in this thesis is my original work and has not been presented for a degree in any other University.

Caroline Chemutai Signature …………………………. Date ……………………..

This thesis has been submitted for examination with our approval as University supervisors:

Prof. George N. Chemining'wa
Department of Plant Science and Crop Protection
University of Nairobi

Signature……………………………….………. Date …………………………

Dr. Jane L. Ambuko
Department of Plant Science and Crop Protection
University of Nairobi

Signature……………………………….………. Date …………………………

DEDICATION

To my Mom, Mrs. Alice Langat, without whose support I would not have an education; and to my hubby, Dr. Dickson K. Langat and my daughter, Chepchumba, for their patience, support and prayers.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic absorption spectrophotometer
ALVs	African leafy vegetables
A.O.A.C	Association of Analytical Chemists
AVRDC	Asian Vegetables Research and Development Centre
CAN	Calcium ammonium nitrate
CP	Crude protein
DAP	Di ammonium phosphate
FAO	Food and Agriculture Organization of the United Nations
FYM	Farmyard manure
HCDA	Horticultural crops development authority
HPLC	High Performance Liquid Chromatography
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute of Tropical Agriculture
IPGRI	International Plant Genetic Resources Institute
LSD	Least significant difference
PM	Poultry manure
PROTA	Plant Resources of Tropical Africa
RCBD	Randomized complete block design
SSA	Sub-Saharan Africa
WHO	World Health Organization

GENERAL ABSTRACT

The low productivity of the African nightshade (*Solanum spp.*) and cowpea (*Vigna unguiculata* L. Walp.) leafy vegetables in smallholder farms in Kenya is partly attributed to moisture stress, declining soil fertility and poor leaf harvesting practices. To increase the productivity and utilization of these crops requires development of suitable agronomic practices such as appropriate watering regimes, effective nutrient management, and best harvesting practices. Pot and field experiments were conducted at the University of Nairobi's Kabete field station, to determine the effects of water stress, nutrient management and leaf harvesting method on growth, yield and nutritional quality of African nightshade and cowpea. In the first objective, individual plants were grown in10 liter polythene pots containing 10 kg of soil (a mixture of sand, topsoil and manure in the ratio of 2:4:1) each and watered daily for two weeks with tap water, to maintain soil at pot capacity, until the start of the treatments. The treatments, comprising four watering regimes namely 100% pot capacity (PC), 80% PC, 60% PC and 40% PC, were laid out in a randomized complete block design (RCBD) and replicated three times. In the second objective, the fertilizer treatments comprising 200 kg/ha Di-ammonium phosphate (DAP) fertilizer, 10 t/ha farmyard manure (FYM), 10 t/ha chicken manure (CM), 100 kg/ha DAP + 5 t/ha FYM, 100 kg/ha DAP + 5 t/ha CM and no- fertilizer (control) were tested against two harvesting methods (piecemeal and wholesome harvesting) in a randomized complete block design, replicated three times. Growth and yield data collected included leaf number, leaf area, plant height, number of branches, leaf fresh weight, leaf dry weight, leaf yield, number of pods/fruits, total grain weight, seed weight and grain yield. Chlorophyll concentration was determined at weekly intervals for four weeks. Data on leaf vitamin A and C, total anti-oxidant activity and phenolic content were also collected. All data collected were subjected to analysis of variance (ANOVA) and means separated, where the F-test was significant, using the least significant difference test at $p \leq 0.05$.

Plant height, leaf area, number of branches per plant, number of leaves per plant, total grain weight, leaf yield, number of pods or fruits per plant and chlorophyll concentration, vitamin A and vitamin C significantly decreased with reduction in soil moisture levels in both cowpea and African nightshade. Reduction of moisture level from 100% pot capacity to 40% pot capacity led to decreases in chlorophyll, leaf yield, vitamin A and vitamin C by 21.1, 65.9, 78.1 and 81.6 %, respectively, in cowpea and 52.5, 85.3, 52% and 55.8%, respectively, in African nightshade. In cowpea, reduction in soil moisture levels significantly decreased 100-seed weight, and grain yield. Phenolic content and total anti-oxidant activity significantly ($p \leq 0.05$) increased with reduction in soil moisture levels in both crops. Reduction of moisture from 100% PC to 40% PC led to increases in phenolics and total antioxidant by 29.4 and 18.7%, respectively, in cowpea and 34.5 and 45%, respectively, in African nightshade. Fertilizer application significantly increased plant height, number of leaves per plant and leaf yield of cowpea and African nightshade. Compared to the no-fertilizer control, application of DAP, DAP + CM, DAP + FYM, CM and FYM increased leaf yield by 68.6, 58.3, 56.6, 52.2 and 42.6%, respectively, in cowpea and 74.9, 63.7, 60.8, 56.4 and 41.1%, respectively, in African nightshade. Fertilizer application had no significant effect on vitamin A and C, phenolics and antioxidant activity in both crops. Compared to wholesome harvesting, piecemeal harvesting significantly increased the number of leaves and leaf yield by 54.1 and 43.9%, respectively, in cowpea and 51.2 and 49.3%, respectively, in African nightshade.

Water stress reduced growth, yield and nutritional quality of cowpea and African nightshade, but increased phenolic content and total antioxidant activity in both crops. Fertilizer application increased the growth and leaf yield but had no influence on leaf vitamin A, leaf vitamin C, phenolics and antioxidant activity in both cowpea and African nightshade. Relative to wholesome harvesting, piecemeal harvesting enhanced growth and leaf yield of cowpea and African nightshade but reduced the leaf nutritional quality in both crops

CHAPTER ONE: INTRODUCTION

1.1 Background Information

African leafy vegetables (ALVs) constitute a significant source of food in both rural and urban areas. Their production and consumption are, however, constrained by declining yields. Callas (1994) noted that there were more than 45,000 species of plants in Sub-Saharan Africa (SSA) and about 1000 of these species were consumed as green leafy vegetables. African leafy vegetables are vegetables which have been consumed over a long period in Africa until they form part of the cultures and traditions of communities (Maundu, 1999); they could have originated in that area or were introduced (Abukutsa-Onyango, 2007). These vegetables include: African nightshades (*Solanum* spp), Amaranth (*Amaranthus* spp), cowpea leaves (*Vigna unguiculata* L.), spider plant (*Cleome gynandra* L.), African kales (*Brassica oleracea*), sweet potato leaves (*Ipomeas* spp*),* cassava leaves (*Manihot esculenta* L.*),* jute mallow (*Corchorus* spp) and pumpkin leaves (*Curcurbita* spp) (Lebotse and Lyatuu, 2010). The leafy parts comprising flowers, young fruits and young succulent stems are used as vegetables (Chelang'a *et al*., 2013).

There exist approximated 6,376 important indigenous African plants exist, 397 of which are vegetables (PROTA, 2004). Africa's annual per capita production of vegetables estimated at 50 kg is lower than the rest of the world, and is declining (Kamga *et al*., 2013). Onim and Mwaniki (2008) found large differences in the amount of vegetables eaten in different Sub-Saharan African countries. Vegetable consumption is very low in some countries such as Ethiopia (20 kg/person/year), Malawi, Tanzania and urban Guinea (40 kg/person/year each) and Ghana (50 kg/person/year) compared to Kenya with an average vegetable consumption of 147 kg/person/year in urban areas and 73 kg/person/year in rural areas. In Kenya, there are about 210 species of indigenous plants used as leafy vegetables (IPGRI, 2006). A study done in western Kenya, (Abukutsa, 2007) reported that leafy vegetable cultivation continued to face challenges of optimal production. Their cultivation is limited to subsistence levels, hence their potential for commercial production has not been tapped into adequately yet the region continues to face high poverty levels.

Most people in SSA include ALVs in their diets, though the consumption patterns differ from region to region among households. For instance, in South Africa, the consumption is different and varies with poverty status, degree of urbanization, season of the year and distance to fresh market (Van Rensburg *et al*., 2007). In Kenya, the consumption of ALVs increases during the rainy season, when ALVs are normally plenty and cheap. Besides, ethnicity also influences preference and consumption of ALVs (Kimiywe *et al*., 2007). Intake of ALVs, especially spider plant and African nightshade, which are the most affordable and available sources of micronutrients, help avert health problems, high mortality and low economic productivity (WHO-FAO, 2013). African leafy vegetables have been reported to provide important sources of both micronutrients and non-nutrient bio-active phyto-chemicals that have been related to protection against cardiovascular and other degenerative diseases (Akhtar *et al*., 2012). These vegetables are very important component of human diet as they give indispensable micronutrients that encourage proper development of the human body and good health (Abukutsa-Onyango, 2007a).

The contribution of these African leaf vegetables in the Kenyan domestic market is reported to have risen from 4.3% in 2011 to 5% in 2013 (Abukutsa, 2013). Acreage of production also increased from 31,864 ha to 40,000 ha in the same time frame, leading to production increase per unit area from 1 t/ha to 4.5 t/ha (HCDA, 2014), way beneath the optimal range of 20-40 t/ha (Abukutsa-Onyango, 2003). The ALVs have a significant potential as income earners (Onyango, 2002a). According to Chelang'a *et al*., (2013), ALVs would fetch a higher price at supermarkets than in open air markets (informal markets) given that formal markets are patronized by many nutritionally vigilant clientele with higher incomes and the supermarkets hire contemporary retail technology in relation to storage, display and packaging.

The ALVs are better adapted to widespread environmental conditions and constitute food that is readily accessible and affordable to the resource challenged consumers (Keantinge *et al*., 2011; Ojiewo *et al*., 2012). Even though vegetables are commonly cultivated in the country, there are many production challenges that lead to reduced productivity. The major limiting factors include: low soil fertility (inadequate N, P, K, Ca. Mg, S and organic matter), plant nutrient imbalances, low soil moisture content, particularly in drought periods, poor harvesting methods and the use of unsuitable agronomic practices (poor land preparation, late and unsuitable weeding and inappropriate plant population densities and fertilizer application rates). Other constraints include the perception of these traditional vegetables as crops for the poor, lack of partnership and networking, low capacity within institutions, poor policies, undeveloped value chains and markets, and low research attention (Eyzaguire *et al*., 2006).

1.2 Statement of the Problem and Justification

Although the African nightshade and cowpea are increasingly becoming important vegetables in Kenya, their yields in smallholder production systems are far below the crops' potential partly due to inadequate soil fertility, low soil moisture and poor harvest practices. For example, growers of African nightshades obtain yields of about 1.5-3.0 t/ha (MOALD and M, 1995) compared to the potential yields of 20-30 t/ha (Chweya and Mnzava, 1997). Continuous cultivation with limited external fertilizer inputs leads to nutrient mining and reduced crop productivity of ALVS. Compared to inorganic fertilizers, the use of organic fertilizers which comprise farmyard, compost and green manures are cheap and has been regarded to have long term benefits that include release of nutrients to plants slowly and for a prolonged period of time in addition to improving the soil physical properties.

Organic fertilizers also sustain cropping systems through better nutrient recycling (Gulshan *et al*., 2013). However, the amount of farmyard manure and plant biomass (other than crop residues) readily obtainable to African farmers as organic input is usually inadequate (Tittonel and Giller, 2012). Besides, they have low nutrient content and release nutrients slowly hence they cannot be used during periods of peak crop nutrient demand. However, inorganic fertilizers which release nutrients fast and in large quantities are expensive and therefore out of reach of poor farmers.

Most smallholder farmers involved in ALVs production depend on rain-fed agriculture which limits production to the rainy seasons. However, irrigation during the off-season presents an opportunity for the farmers to benefit from the low-supply versus high demand scenario with better returns and good nutritional quality of these crops. There is need to establish the impact of water stress on leaf yield and nutritional quality of ALVs. There are various harvesting options used in ALVs production. Some of the harvesting practices such as wholesome and piecemeal harvesting may affect the productivity and nutritional quality of ALVs. Thus, call for studies to establish optimal water, nutrient management and best harvest practices to realize the yield potential without compromising the quality attributes of ALVs.

African leafy vegetables have been regarded as ‘insignificant crops’ and excluded from research attention in favor of major food and cash crops such as maize and tea even though they have short production cycles, high yields with strong nutritional quality. Limited studies have been carried out to determine the impact of fertilizers (organic and inorganic), moisture stress and harvesting method on yield and nutritional quality of cowpea and African nightshade.

1.3 Objectives

The main objective of this study was to determine the leaf yield and nutritional quality of cowpea and African nightshade grown under different fertilizer application, harvesting methods and water stress levels to alleviate food insecurity, malnutrition and poverty in Kenya.

The specific objectives of the study were:

i. To evaluate the effect of inorganic and organic fertilizers on growth, yield and nutritional quality of African nightshade and cowpea.
ii. To evaluate the effect of harvesting method on the yield and nutritional quality of African nightshade and cowpea.
iii. To determine the effect of water stress on growth, yield and nutritional quality of African nightshade and cowpea.

1.4 Null Hypothesis

i. Organic and inorganic fertilizers enhance the growth, yield and nutritional quality of African nightshade and cowpea.

ii. Piecemeal harvesting enhances the yield and nutritional quality of African nightshade and cowpea.
iii. Water stress reduces the growth, yield and nutritional quality of African nightshade and cowpea.

CHAPTER TWO: LITERATURE REVIEW

2.1 Botany of African Nightshade and Cowpea

2.1.1 African Nightshade

African nightshade (*Solanum spp.*) belongs to the genus *Solanum* in the family solanaceae. The family comprises about 90 genera and between 2000 to 3000 species (Edmonds and Chweya, 1997). African nightshade is a dicot with many branches, 0.5 to 1.0 m high. The plant has thin, oval leaves which are about 15 cm in length and grayish green in color. Leaf margins may be entire or with blunt teeth. The plant has numerous flowers that are white or purple and round berries of about 0.75 cm in diameter, having small, flat, yellow seeds. The berries can be black or orange, depending on the species (Mwai *et al*., 2007). The plant has a slender tap root with a fibrous root system. African nightshade is diverse in relation to growth patterns, leaf sizes, tastes (bitterness), flowering time, color, nutritional and nutraceutical value, and quantities and composition of anti-nutrient factors (Abukusta-Onyango *et al*., 2003).

2.1.2 Cowpea

Cowpea (*Vigna unguiculata* L. Walp.) belongs to genus *Vigna* in the family *Fabaceae*. It is a warm season, annual legume that can be erect, semi-erect (trailing) and climbing plant. It follows an epigeal emergence pattern which makes it prone to seedling injury (Shiringani, 2007). There is high variability within species, in terms of growth habits; range from indeterminate to moderately determinate. It forms a long taproot of about 2.4 m within eight weeks after planting, especially if drought conditions prevail. The leaves are trifoliate with a smooth surface, dull to shiny and develop alternately (Davis *et al*., 1991). Cowpea has vigorous growth and can reach a height of about 48-61 cm when growing conditions are suitable. Early or late planting may lead to the crop having elongated internodes, more vegetative growth and lower yield than those planted at optimum time (Davis *et al*., 1991). Cowpea seeds differ in size, and a single pod can contain about 10 - 20 seeds. Initially, the seed develops into a kidney shape; when the pod is not restrictive, the seed maintains that shape until maturity (Gomez, 2004). However, the pod has the disposition of restraining seed shape to a more globular shape.

The seed coat can be smooth or wrinkled. Seed colour varies from white, cream, brown, red and black and it is not restricted to uniform colours: they can be speckled, mottled, and blotchy or eyed (black eye, pink eye, purple eye) (Aeling, 1999).

Like most other legumes, cowpea is self-pollinated and is a typical day neutral plant; it may flower within 30 days after sowing when temperatures are around 30°C. Flowers are borne in alternate pairs at the tip of the branches, and two or more flowers can be found per inflorescence (Gomez, 2004). Flowers are borne on short pedicels with corollas that are either white, dirty yellow, pink, pale blue or purple and are displayed above the foliage such that they can attract insects for pollination. The plant produces smooth, cylindrical and curved pods. As the seeds approach the green-mature stage for use as a vegetable, pod colour may change to green, yellow or purple. As the seeds dry up, pod colour of the green and yellow types changes into tan or brown (Aeling, 1999).

2.2 Origin, Distribution and Production of African Nightshade and Cowpea

2.2.1 African Nightshade

African nightshade originated within South America and is widely distributed throughout the tropical and temperate regions of the world (Edmonds and Chweya, 1997). African nightshades are largely domesticated in Sub-Saharan Africa. While African nightshade was formerly known as “food for the poor” by the middle class in countries like Kenya (Abukusta-Onyango *et al*., 2013), there has been transformation over the last decade that has assisted African nightshade make its way from growing wild or being semi-cultivated to being available in supermarkets (Omami *et al*., 2013). Traditionally, African nightshade was gathered from the wild and provided as a souvenir by family and friends to urban people (Abukusta-Onyango *et al*., 2013). Promotion of this crop based on its nutritional and medicinal benefits by Non-Governmental Organizations, researchers and other interest groups converted it into a delicacy in urban areas.

2.2.2 Cowpea

Cowpea originated in Africa and is commonly grown in Africa, Latin America, South East Asia and Southern United States (Fatokum *et al*., 2000; Shaw, 2007; FAO, 2010).

About 84% of the world's cowpea grain production is done in Sub-Saharan Africa. Nigeria stands out as the largest producer and consumer of cowpea in the World with more than 45% production followed by Niger at nearly 15 % (Abate *et al*., 2012). According to FAO (2001-2011), Nigeria produces an average of 2.58 +/-0.31 million metric tonnes. The production of cowpea as a leafy vegetable has intensified markedly in many areas in the recent years as farmers shift to more drought tolerant vegetable crops in the light of repeated droughts facing many parts of Africa (Saidi *et al*., 2007). In Kenya, it is the second most preferred grain legume after common bean. The area under cowpea cultivation is approximated at 1800 ha excluding the area under home gardens. About 85% of the total area is in ASALs of Eastern Province and 15% in Coast, Western and Central Provinces (Kimiti *et al*., 2009).

2.3 Ecological Requirements of African Nightshade and Cowpea

2.3.1 African Nightshade

African nightshade does well in varying degrees of climatic conditions, but performs best within cool, high-moisture environments in both medium and high altitudes (Abukusta-Onyango *et al*., 2013). For adequate growth of African nightshade, annual rainfall of about 500-1200 mm is required. African nightshade requires optimum temperatures of 20 to 30^0C. The plant prefers full sunlight, but can grow in partially shaded areas. African nightshade grows in a variety of soils but requires abundant amounts of nutrients and is best adapted to soils with high nitrogen, phosphorous and is rich in organic matter (Abukusta-Onyango *et al*., 2013). Sandy loam to friable clay soils with a pH of 6.0-6.5 is appropriate for the African nightshade (Abukutsa-Onyango *et al*., 2013).

2.3.2 Cowpea

Cowpea is adapted to different soil types; it has been observed to grow well in sandy soils where root growth is not restricted (DAFF, 2011). It can survive under infertile acid soils but it is reported to be less tolerant to cold soils (DAFF, 2011). The crop requires well drained soils with a pH of 5.6 - 6.0, but can still produce reasonable yield in waterlogged and heavy soils (Smith, 2006). Cowpea grows best in warm conditions. The optimum temperature for growth and development is around 20 to 35^0C. The optimum rainfall conditions for cowpea range from 400 to 700 mm per annum (Smith, 2006). It is important that the rainfall is well–distributed for normal growth and development. Since South Africa is faced with a problem of uneven rainfall, this may have negative consequences on cowpea growth and yield.

2.4 Importance of African Nightshade and Cowpea

2.4.1 African Nightshade

African nightshade has medicinal properties; for instance in Kenya, where unripe fruits of *S.villosum* are applied to aching teeth, an extract from pounded leaves and fruits used to treat tonsillitis, and even roots are boiled in milk and given to children as tonic (Maundu *et al*., 1999a). Furthermore, in Tanzania the juice obtained from *S. americanum* leaves is used to treat chronic conjunctivitis (Manoko; Van Der Weerden, 2004a). The leaves of African nightshade comprise 87.2 g water, 1.0 mg iron, 4.3 g protein, 38 k calories, 5.7 g carbohydrates, 1.4 g fibre, 442 mg calcium, 20 mg ascorbic acid, 3660 ug beta carotene, 75 mg phosphorous and 0.59 mg riboflavin per 100 g fresh weight (Orech *et al*., 2005). The leaves also consist of high levels of vitamin A, B and C, phenolics and alkaloids, including quinine and nicotine. African nightshade acts as a source of income to rural smallholders in Kenya. For instance, it is the second most important vegetable among the main communities inhabiting Western Kenya, with yields ranging from 2.38 t/ha to 13.35 t/ha (Abukutsa, 2007). The anthocyanin pigments within the black and purple fruits can be used as both dyes and as a type of ink (Musyimi and Muthomi, 2009).

2.4.2 Cowpea

Cowpea leaves, green pods and grains are consumed as good sources of nutrients. The grain contains approximately 24% crude protein, 53% carbohydrate, 2% fat (FAO, 2012) and micronutrients such as zinc and iron which are necessary for healthy living (Boukar *et al*., 2010). The grains can be processed into flour or paste to make exotic baked products or a variety of dishes (Akubor, 2008). Green leaves contain 4.7% protein while immature pods have 4-5% protein (Shaw, 2007). The leaves, like many green leafy vegetables, are an essential source of minerals in the human diet. They give inexpensive and numerous supply of minerals such as calcium (Ca) (0.256%), magnesium (Mg), sodium (Na), potassium (K), phosphorus (P) (0.063%), iron (Fe) (0.005%), zinc (Zn),manganese (Mn), copper (Cu) and selenium (Se). These minerals play a crucial role in the various body functions (FAO/WHO, 2004). Due to high nutritive value of cowpea leaves, they are used as special delicacies in African countries like Nigeria, Zaire, Zimbabwe, and Zambia where they are cooked fresh together with immature pods or may be dried and conserved for later use (Ghaly and Alkoaik, 2010). Cowpea is a major income earner to the producers. For instance, in Northern Ghana an income of between 340-362 USD is created yearly and 40% of this goes to women farmers (ICRISAT, CIAT and IITA, 2012). It is a cost effective crop since it is capable of fixing up to 80% nitrogen for its growth demand, thereby reducing nitrogen fertilizer demand for the crop (Asiwe *et al*., 2009).

Cowpea forms a significant component of the tropical farming system due to its ability to increase marginal lands through nitrogen fixation and as a cover crop (Sanginga *et al*., 2003; Aboyami, 2008). The crop can fix approximately 240 kg/ha of atmospheric nitrogen and make available about 60-70 kg/ha nitrogen for sequential crops grown in rotation (CRI, 2006, cited by Aikins and Afuakwa, 2008). It is also an excellent crop in controlling erosion and a good weed suppressor due to its bushy characteristic (Clark, 2007). It has also shown capability of suppressing nematode production system (Roberts *et al*., 2005). The crop is used as forage, hay and silage. Forage cowpea has the potential to significantly increase the nutritive value of monoculture sorghum forage (Conteras-Govea *et al*., 2009). As silage, it should be combined with sorghum, maize or molasses to give sugar for fermentation (FAO, 2012). Cowpea being drought tolerant, early maturing and multi-purpose in use makes it a desirable alternative for farmers in marginal, drought prone areas with low rainfall and less developed irrigation systems (Hallensleben *et al*., 2009).

2.5 Constraints to African Nightshade and Cowpea

2.5.1 African Nightshade

Nutrient-poor, degraded and often acidic soils limit crop production in many tropical regions. When coupled with high cost of inorganic fertilizers, especially in Africa, much of the small-scale agriculture occurs under conditions of nutrient deprivation and metal ion toxicity. Drought is perhaps the biggest constraint to agricultural productivity worldwide. Socio-economic factors affecting the production of African nightshade are gender, occupation, education level, location, land ownership type, size of the land owned by the farmer, household size and income (Mairura *et al*., 2007). Major pests that attack African nightshade are black aphids, caterpillars and beetles while the major diseases are late blight and powdery mildew (Manoko and Van Der Weerden, 2004b). Nchore *et al*., (2010) and Muturi *et al*., (2010) reported a root knot nematode (RKN) disease incidence of up to 60% on African nightshades in parts of Kenya. Several virus infections are also often reported including potato mop top and pepper mosaic virus (Odu, 2003). Bacterial diseases caused by 'Candidatus Phytoplasma' occur in many *Solanum* spp. and are also reported for African nightshade (Tolu *et al*., 2006). Utilization of African nightshade is limited by its bitter taste (Chigumira and Mnzava, 2004); however, boiling and draining of water several times reduces its bitterness, but there is a tradeoff of loss of nutrients (Chweya and Mnzava, 1997).

2.5.2 Cowpea

The effects of environment on plant growth may be divided into enforced damage effects (stress), caused by environment and adaptive responses, controlled by the plant (resistance). Damage, which may be manifested as death of all or part of the plant or merely as reduced growth rate due to physiological malfunction is a common phenomenon and the agents are various: temperature, water availability, soil chemistry, physical properties and others such as air pollution and wind. However, the most important environmental agent affecting plant growth in semi-arid tropical zone is drought (Hall, 2004). Drought is currently the most important abiotic stress limiting cowpea production in Kenya (Hall, 2012). Socio-economic factors are age, education, household size, income level and marital status. Economic issues like income level affect access to inputs such as fertilizers, labour and seeds while communal rules to land ownership dictated access to land (Kilonzi, 2011).Attack by parasitic weeds such as *Alectra vogeli* causes a major threat in cowpea production. Karanja *et al*., (2010) reported that more than 80% of farmers' field in eastern Kenya had been infested with the weed and farmers reported about 100% yield loss under severe infestation. Pests such as white fly feeds on phloem sap of cowpea, compromising the photosynthetic capacity, vegetative and reproductive development of the plant (Legg, 2010; Cameron *et al*., 2013). Furthermore, it transmits cowpea golden mosaic virus which causes significant losses in production (Fazolin *et al*., 2009). Pod borer damages cowpea pods in the fields and in severe infestation yield losses of between 70-80% have been reported (simbi, 1983; Haile *et al*., 1998). Major economic diseases in the humid agro-ecological regions include anthracnose, *cercospora* leaf spot, web blight, *sclerotium* stem blight (Adegbite and Amusa, 2008). Emechebe and Lagoke (2002) noted that bacteria blight occurs in all cowpea growing seasons causing yield losses of more than 64% in some areas of West Africa. The viral diseases that cause great losses include: cowpea aphid-borne mosaic virus, black eye cowpea mosaic virus, cowpea mosaic virus and cowpea aphid-borne mosaic virus (Ittah *et al*., 2010). Other diseases include root knot nematodes and powdery mildew (Okechukwu and Ekpo, 2008).

2.6 Effect of Organic and Inorganic Fertilizers on Production of African Nightshade and Cowpea

In contemporary agriculture, certain emphasis is set on soil amendment, improved agricultural equipment, techniques and improved varieties of tolerant plants for improving quality and quantity of yield per hectare. However, the full potential of the improved varieties can only be met if important inputs especially chemical and organic fertilizers are applied in required quantities and in timely manner (Teboh, 2009; Savci, 2012; Ogbodo, 2013). Osman *et al*., (2010) reported that chemical fertilizers had negative effects on root length and plant height. Increase in nitrogen rates in other vegetable crops like onions (*Allium cepa*) (Onyango, 2003) and in African nightshades (*Solanum villosum)* (Kipkosgei, 2004) increased their growth in terms of plant height, number of leaves per plant and leaf area per plant. Ghaly and Alkoaik (2010) observed that nutrient deficiencies, for instance, sulphur, phosphorus, potassium and magnesium reduce plant growth, protein content and plant yields. Magani and Kuchinda (2009) reported that clear response to phosphorus utilization observed in terms of growth and protein content of two cowpea varieties confirms that phosphorus is a vital nutrient element affecting yield.

According to Atakora *et al*., (2014), phosphorus application increased stover yields of cowpea. Use of 24 kg/ha P recorded improved cowpea grain yields. Application of N has been reported to improve beta carotene content in other crops such as *Solanum spp.* (Murage, 1990). Nitrogen promotes synthesis of chloroplasts, which are rich in Beta carotene (Salisbury and Ross, 1991). Use of N has been observed to decreases vitamin C content in other crops such as *Solanum spp.* complex (Murage, 1990). Increasing N rates has been found to increase accumulation of nitrates in *Solanum spp*. (Chweya, 1986), kales and collards (Karampiu, 1987).

Organic manures are in most cases more locally available and cheaper than inorganic fertilizers and so most small-scale farmers are able to purchase them. These fertilizers improve soil physical conditions in addition to supplying the plant nutrients (Smaling, 1993). Cattle manures and other livestock manures could supply an estimated 30% of nitrogen needs for crop production; hence it could be an important source of nitrogen to crops in livestock intensive regions (Jokela, 1992). Bima *et al*., (2015) reported that organic fertilizers enhance plant height, root length, leaf fresh weight and leaf dry weight. These findings had earlier been observed by Gulshan *et al*., 2013 where plots treated with FYM showed positive effects on growth of roots and shoots. Lawal and Girei (2013), had reported earlier that FYM increases dry matter content by 54% due to increases in nutrient content of soil and soil moisture holding capacity, reduction in soil pH and improvement of other physic-chemical properties of the soil. In a similar study conducted biofertilizers JUR2 (*Bradyrhizobium* sp) and JUF2 (*Trichoderma* sp) increased dry matter (by 30%) and content of carbohydrates and proteins in cowpea.

Tagoe *et al*., (2008) reported that plant total phosphorus content of cowpea was affected by both carbonized organic amendments and chemical fertilizer application. Adeyemi *et al*., 2012 in Nigeria reported that cowpea plants grown on manure treated soils indicated higher content of protein than those without manure treatment. A previous study by Abebe *et al*., (2005) showed that use of dried goat manure improved crude protein concentration.

A combination of 7.5 t/ha farmyard manure and 150 kg /ha of calcium ammonium nitrate obtained 16.9 t/ha black nightshade compared to the no-fertilizer. Similarly, Love, (2012) while working on grain amaranth reported that a combination of cow dung manure (6.8 t/ha) with Calcium Ammonium Nitrate (83.25 kg/ha) significantly improved the growth, development and yield of grain amaranth, through increased number of flowers per plant, individual plant canopy size, plant height, stem width, plant dry matter weight and 1000 seed weight. Ainika *et al*., (2011), reported similar findings. In their study, all the soil amendment programmes, both organic and inorganic improved leaf chlorophyll content with coconut coir and farmyard manure significantly promoting total chlorophyll content of cowpea plant by 101-103%. A positive response of cowpea to the application of organic and inorganic fertilizer has been reported by several authors from various cowpea growing areas (Singh *et al*., 2011a; Nkaa *et al*., 2014; Daramy et *al*., 2016).

2.7 Effect of Harvesting Method on African Nightshade and Cowpea

Two main harvesting systems are widely used in production of leafy vegetables; uprooting the entire plant at 3-4 true leaf before the leaves become too mature and fibrous or cutting the plant near the ground level and having succeeding leaf harvests during the vegetative phase growth of the plant which involves plucking leaves or picking branches containing leaves (Onyango and Imungi, 2007). An assessment of harvesting techniques done in Tanzania indicated that continuous harvesting of black nightshade with topping provided the highest economic leaf yield of 32.0 t/ha, while continuous harvesting without topping gave the lowest leaf yield (17.8 t/ha) (Bubenheim *et al*., (1990).

Uprooting the whole plant after two plantings and two harvests was the second highest yielding method with 29.8 t/ha, and plants harvested with this method had the smallest leaf size but gave better marketable leaf quality of African nightshade (Baloyi *et al*., 2013). Harvesting of leaves of leafy vegetables for human consumption is an essential management practice among African communities (Baloyi *et al*., 2013). This is because leaf harvesting practices and procedure have the potential to reduce or increase the yield of essential components of the crop (Rahman *et al*., 2008). In a trial carried out by Saidi, (2007) in Katumani, Kenya, frequent harvesting of cowpea leaves at 7-day interval resulted in significantly higher leaf vegetable yields of 2500 and 1500 kg/ha in short and long rainy seasons, respectively, than 1100 and 800 kg/ha, respectively, at 14-day interval. Bubenheim *et al*., (1990) found earlier that defoliation stimulated leaf production.

2.8 Effect of Water Stress on African Nightshade and Cowpea

2.8.1 Adaptation of Plants to Drought

In the context of crop production, drought refers to a lack of sufficient water in the soil to support normal plant growth (Jaleel *et al*., 2009). It occurs when available water in the soil is reduced and the atmospheric conditions cause continuous loss of water through transpiration and evaporation. This may be as a result of meteorological drought, uneven rainfall distribution or even inefficient irrigation systems. Plants are able to adapt and survive under drought stress through morphological, biochemical and physiological responses. Mitra (2001) suggested three categories of drought tolerance mechanisms in plants based on earlier descriptions by Levitt (1972), namely: drought escape, drought avoidance and drought tolerance.

Drought escape is when the plant grows rapidly to shorten its life cycle and reproduce before drought stress becomes terminal. This mechanism is closely linked with time to flowering as it allows the plant to escape drought through a short life cycle (Araus *et al*., 2002). Drought escape makes time to flowering, a major trait for crop adaptation to drought stress. It has been proven that early maturing cowpea varieties are very useful in some dry environments due to their ability to escape drought (Singh, 1994). Mortimore (1997) reported that there has been a shift towards growing early maturing cowpea varieties especially in drought prone areas. In a study by Suliman and Ahmed (2010), cowpea varieties grown under water stressed conditions flowered 1-15 days earlier than those grown under well watered conditions. Water stress had a similar effect even on days to maturity, whereby water stressed cowpea matured faster than the control treatment. However, not all cowpea genotypes responded the same way to water stress with respect to maturity. Dadson *et al*. (2005) found that water stress delayed the maturity of certain cowpea genotypes.

Drought avoidance is made up of mechanisms that lower water loss from plants. These mechanisms consist of stomatal control and enhanced water uptake through a broad and prolific root system (Turner *et al*., 2001; Kavar *et al*., 2007). The major drought avoidance traits include the root characteristics like biomass, length, density and depth. In addition to enhanced soil water capture, plants also avoid stress by reducing the size of their canopy. For instance, decreases in plant size, leaf area per plant and leaf area index are major mechanisms controlling water use and decreasing injury under drought stress (Mitchell *et al*., 1998). These traits allow plants to reduce water use in order to avoid drought stress.

Drought tolerance is the capacity of the plant to maintain or conserve plant function under water stress conditions. This mechanism is rarely found in crop plants; it usually exists in seed embryo but is eventually lost after germination (Turner *et al*., 2001; Kavar *et al*., 2007). Cowpea has not been revealed to possess this drought resistant mechanism.

2.8.2 Impact of Water Deficit on Photosynthesis, Plant Growth and Yield

Water deficit is a problem to plant growth and crop productivity in the vast areas of Kenya. Plants avoid water deficit by developing deep roots or by minimizing water loss (e.g., stomatal closure, small leaves). Reduction in soil moisture levels has been found to cause reductions in lateral branching, leaf formation, plant height and leaf and shoot expansion in both herbaceous and woody plants (Osorio *et al*., 1998; Ngugi *et al*., 2003; Luvaha *et al.,* 2008). Generally, plants show increased root: shoot ratio under water deficit conditions. This is an adaptation for survival in drought areas since increased root surface area allows more water to be absorbed from the soil (Luvaha *et al.,* 2008). Photosynthesis is highly affected by drought due to reduction in leaf expansion, impaired photosynthetic machinery, premature leaf senescence and reduction in dry matter production (Wahid and Rasul, 2005). Water stress reduces gaseous exchange due to stomatal closure hence limiting the amount of CO_2 entering the leaves, which reduces photosynthesis. Anjum *et al* (2011) observed a significant reduction in net photosynthesis (33%), transpiration rate (38%), stomatal conductance (25%), water use efficiency (51%) and intracellular CO_2 (6%) in highly stressed maize compared with well-watered plants. A combination of stomatal and non-stomatal restrictions was shown to reduce photosynthetic activity under drought stress (Ahmadi, 1998; Samarah *et al*., 2009). Farooq *et al* (2008) though, revealed small limitations to photosynthesis due to stomatal mechanisms as compared with non-stomatal mechanisms. Stomatal limitations refer to closure of stomata in reaction to water deficit and is one of the first responses to water stress often resulting in a reduced rate of photosynthesis. Non-stomatal limitations however include changes in chlorophyll formation, functional and structural changes in chloroplast, and interruption in processes of accumulation, transport, and distribution of assimilates (Farooq *et al*., 2008).Important photosynthetic pigments such as chlorophyll a and b and carotenoids are affected by drought stress (Anjum *et al*., 2003). Fu and Huangi (2001) observed that water stress damaged photosynthetic apparatus, decreased activities of Calvin cycle enzymes, and reduced yield (Monakhova and Chernyadev, 2002). The ratio of the photosynthetic pigments was also changed by water stress (Anjum *et al*., 2003; Farooq *et al*., 2009). Similar results were observed by Manivannan *et al.* (2007) where chlorophylls a and b, and total chlorophyll content of sunflower declined significantly in response to water stress. In Kenya, Ndiso *et al*., (2017) and Tembe et *al*., (2017) reported that water stress significantly reduced chlorophyll content in cowpea and African tomato, respectively. Anjum *et al* (2011) reported that loss of chlorophyll content under water deficit is considered as the main cause of inactivation of photosynthesis.

The main purpose of growing crops is to obtain high harvestable yield. Under water stress, crops show great differences in harvestable yield (Jaleel *et al*., 2009). Drought can be regarded as a permanent constraint to agricultural production especially in developing countries and occasionally causes losses to agricultural production in developed countries (Ceccarelli and Grando, 1996). The severe effect of drought stress on grain yield occurs when water stress coincides with the reproductive stage (Thomas, 1997). Drought stress reduces leaf production and expansion, consequently leading to leaf senescence and abscission (Karamonos, 1980). As a result of limited leaf production, leaf area is reduced and thus, reduced biomass accumulation. Since seed production is positively correlated with leaf area, reduction in leaf area would result in reduced seed production (Rawson and Turner, 1982).

Yield is obtained through an interaction of many processes that occur during plant growth and development (Anjum *et al.,* 2011). Exposure of plants to water stress compromises the ability of the plant to express yield traits. This occurs primarily due to the disruption of leaf gas exchange which results in loss of harvestable yield. Impaired leaf gas exchange limits the size of the source and sinks tissue, phloem loading, assimilate translocation and dry matter partitioning (Farooq *et al.,* 2009). Water stress also inhibits dry matter production through its inhibitory effect on leaf expansion and consequently reduced light interception (Nam *et al.,* 1998). If drought stress is imposed during reproductive phase, it becomes very critical because it affects the partitioning of dry matter to the sinks.

Studies done by Jaleel *et al*. (2009) showed the loss of harvestable yields in cowpea was 60% and 46% in chickpea when water stress was imposed at reproductive stage. Similar results were observed by Ogbonnaya *et al*. (2003) and Nayyar *et al*. (2006). Qasem and Biftu, (2010) studied the yield response of cowpea under low water potential and they reported that yield was reduced through decreased pod size and number of seeds per plant. Studies by Suliman and Ahmed (2010) and Ndiso *et al.* (2017) indicated that cowpea seed yield was significantly reduced by water stress. These authors also confirmed the findings of Qasem and Biftu (2010) above that loss in seed yield was due to significant reduction in yield components such as number of pods per plant, number of seed per pod and seed mass.

Severe water stress decreased plant leaf area due to reduction of cell elongation and cell size which decreases interception of solar radiation and consequently decreases biomass production and reduction of total dry matter by 27-43% in spider plant and *Solanum spp.*(Masinde *et al*., 2005). Moisture stress at vegetative and flowering reduced growth parameters and chlorophyll content, but enhanced grain yield and yield components of some cowpea varieties (Ndiso *et al*., 2017).

2.9 Effect of Water Stress on Nutritional Quality of African Leafy Vegetables

When plants are subjected to water stress, they change physically and chemically in numerous ways. In addition, they produce a huge number of metabolites to adapt to the stress conditions. Similar results were observed for *Prunella vulgaris* L. plants, where phenolic contents (rosmarinic, ursolic acid and oleanolic acid) increased under drought stress (Chen *et al*., 2011). Some nutrients, especially carbohydrate supplies, influence the phenolic composition. Stress factors like drought can increase the phenolic compounds (ferolic acid) in the leaves of triticale seedlings (Hura *et al*., 2009). Drought stress reduces growth, so the carbon fixed during photosynthesis could be used to form secondary metabolites (phenolics) (Hale *et al*., 2005). Phenolics and antioxidant activity increase the scavenging capacity against reactive oxygen species (ROSs) that damage cellular membranes under drought stress. There was reduction in plant growth and yield but plants have the ability to cope with stress by generating secondary metabolites including phenols. According to Nahar and Gretzmacher (2002), glucose, fructose, sucrose, malic acid, ascorbic acid and citric acid content increased significantly with water stress and sweetness of tomatoes and quality enhanced.

CHAPTER THREE: INFLUENCE OF WATER STRESS ON GROWTH, YIELD AND NUTRITIONAL QUALITY OF AFRICAN NIGHTSHADE AND COWPEA

3.1 Abstract

Drought is a major abiotic stress limiting productivity of African leafy vegetables in arid and semi-arid regions of Kenya. A study was conducted at the University of Nairobi's Kabete field station to determine the effects of water deficit on growth, yield and nutritional quality of African nightshade (*Solanum spp*.) and cowpea (*Vigna unguiculata* L). Individual plants were grown in 10 liter polythene pots containing 10 kg of soil (a mixture of sand, topsoil and manure at the ratio of 2:4:1) each, and watered daily for two weeks with tap water to keep soil moisture at pot capacity, until the start of the treatments. The treatments were four watering levels (40% pot capacity, 60% pot capacity, 80% pot capacity and 100% pot capacity) imposed at seedling stage. The treatments were laid out in a greenhouse in a randomized complete block design with three replicates. Data on leaf number, leaf area, plant height, branches, leaf fresh and dry weights, leaf yield and chlorophyll concentration were determined, before the start of the first harvest, at weekly intervals for four weeks while pod/fruits number, total grain weight, 100 seed weight, and grain yield were determined after harvest.

Data collected were subjected to analysis of variance and means separated using the least significant difference test at $p \leq 0.05$. Plant height, leaf area, number of branches per plant, number of leaves per plant, total grain weight, leaf yield, number of pods/fruits per plant and chlorophyll concentration, vitamin A and C significantly decreased with reduction in soil moisture levels in both cowpea and African nightshade. Reduction of moisture level from 100% pot capacity to 40% pot capacity led to decreases in chlorophyll, plant height, leaf area/plant, number of branches/plant, number of leaves/plant, number of pods or fruits/plant, leaf yield, vitamin A and vitamin C by 21.1, 63.7, 39.5, 77.3, 70.8, 88.8, 65.9, 78.1 and 81.6 %, respectively, in cowpea and 52.5, 71, 75, 60, 52.4, 85.4, 85.3, 52 and 55.8%, respectively, in African nightshade. Similarly, reduction in soil moisture levels significantly decreased 100-seed weight and grain yield in cowpea. Phenolic content and total anti-oxidant activity significantly ($p \leq 0.05$) increased with reduction in soil water levels in both crops. Reduction of moisture from

100% PC to 40% PC led to increases in phenolics and total antioxidant by 29.4 and 18.7%, respectively, in cowpea and 34.5 and 45%, respectively, in African nightshade. Water stress reduced growth, yield and nutritional quality of cowpea and African nightshade, but increased phenolic content and total antioxidant activity in both crops.

Key words: African nightshade, cowpea, growth, water stress and yield

3.2 Introduction

Leafy African vegetables such as African nightshade (*Solanum spp*) and cowpea (*Vigna unguiculata* L.) are commonly consumed in Kenya. However, their importance has been recognized only recently due to their nutritional and medicinal value (Prasad *et al.,* 2008). Green leafy vegetables occupy an important place among food crops as they provide adequate amounts of crude fiber, carotene (a precursor of vitamin A), vitamin C, riboflavin, folic acid and mineral elements like calcium, iron and phosphorous. They form a cheap and best source of food (Prasad *et al.,* 2008) but their yields in smallholder production systems are far below the crops' potential, partly due to drought, low soil fertility, pests, diseases and poor harvest practices. Water has been described as the single physiological and ecological factor upon which plant growth and development depends more heavily than other factors (Kramer and Boyer, 1995). Water deficit is a problem to plant growth and crop productivity in the vast areas of Kenya. It affects growth, development, yield and quality of plants in the greenhouse and field conditions (Luvaha *et al.,* 2008). Water stress causes reductions in leaf area, dry matter production, plant water status and transpiration. Total dry matter reduction by 27-43% under severe water stress has been reported in spider plant and *Solanum spp.*(Masinde *et al.,* 2005).

Reduced leaf area is a drought avoidance mechanism, aimed at reducing plant water consumption and hence conserving water during periods of drought. It is achieved through inhibition of leaf expansion and initiation, reduced branching and plant height. Reduced leaf area decreases interception of solar radiation and consequently decreases biomass production for most crops (Masinde *et al.,* 2005). Under more prolonged water deficit, dehydration of plant tissue can result in an increase in oxidative stress which causes deterioration in chloroplast structure and an associated loss of chlorophyll. This leads to a decrease in the plant's photosynthetic activity (Jafar *et al.,* 2004). Total chlorophyll content reduction up to 55% compared to well water plants has been reported in some crops (Cengiz *et al.,* 2006).

Yield is obtained through an interaction of many processes that occur during plant growth and development (Anjum *et al*., 2011) thus exposure of plants to water stress compromises the ability of the plant to express yield traits. Qasem and Biftu (2010) studied the yield response of cowpea under low water potential and reported that grain yield was reduced through decreased pod size and number of seeds per plant. There have been relatively few studies on the growth responses of indigenous vegetables (Masinde *et al.,* 2005) including African nightshades and cowpea to water deficit. Water stress increases secondary metabolites such as phenolics and total antioxidant activity which scavenge against reactive oxygen species (ROSs) that damages cellular membranes in most plants under drought stress (Hale *et al*., 2005). They also reported decreases in leaf vitamin A and C. The main objective of the study was to determine the effect of water stress on the growth, yield and nutritional quality of cowpea and African nightshade.

3.3 Materials and Methods

3.3.1 Study Site

The study was conducted in a greenhouse at the University of Nairobi's Kabete Field Station, situated about 15 km to the west of Nairobi city. The site lies at 1940 meters above sea level (Michieka, 1977). The area receives bimodal rainfall of about 1000 mm per annum, distributed in two seasons; long rains from March to June and short rains from October to December. The mean monthly temperature has a minimum of 12^0C and maximum of 23^0C (Anon, 1985). The first cropping was done in October-December, 2015 while the second cropping was done in February- April, 2016.

3.3.2 Experimental Design, Treatments and Crop Husbandry

Treatments were laid out in a randomized complete block design, replicated three times. African nightshade and cowpea trials were conducted independently. Treatments consisted of four watering regimes, namely: 100% of pot capacity (control supplied with

3,000 ml per pot), 80, 60 and 40% of pot capacity (Sibomana *et al.*, 2013). The seeds of African nightshade line-Olevolosi and cowpea line-Tumaini were sourced from the Asian Vegetables Research and Development Centre (AVRDC), Arusha, Tanzania. Five viable seeds of each plant species were planted per 10 liter pot and thinning was done 10 days after emergence to achieve one plant per pot. Each treatment had 12 pots where a pot had 10 kg of soil (a mixture of sand, topsoil and manure at the ratio of 2:4:1). Plants were subjected to the four watering regimes throughout their growth cycle. The amount of water added was determined based on the percentage of pot capacity (Sibomana *et al.*, 2013). Before the onset of water treatments at two weeks after seedling emergence, soil moisture was kept at field capacity by watering daily with tap water all the pots to promote root development. Weeds were controlled by hand pulling and pests such as white flies were controlled by spraying with Atom 2.5 EC, active ingredient deltametrin (0.5 l/ha). All these crop maintenance activities were uniformly applied to all pots.

3.3.3 Data Collection

To measure the growth, chlorophyll, yield and nutritional quality parameters for both African nightshade and cowpea, four pots with one plant each were randomly selected and tagged for data collection.

Plant height: Plant height from each of four tagged plants was measured from ground level to the tip of the longest stem on weekly intervals for four weeks using a meter rule.

Number of leaves: Number of leaves per plant was determined by counting fully expanded leaves from each of four tagged plants on weekly intervals for four weeks.

Number of branches per plant: Branches were recorded by counting the number of branches from four tagged plants on weekly intervals for four weeks.

Leaf area: The leaf area of each of the four tagged plants was calculated using the following formula by Jose *et al*., (2000.) $AL= 0.73(L_L *W_L)$, where L_L is the leaf length and W_L is the maximum width on weekly intervals for four weeks.

Chlorophyll concentration: A non-destructive approach method was used to evaluate total chlorophyll concentration in two fully opened leaves from each of four tagged plants, using a spectrophotometer (SPAD), at vegetative stage. Chlorophyll concentration measurements were done on a weekly interval for four weeks.

Leaf fresh and dry weights: Fully expanded leaves from all four tagged plants were harvested on a continuous basis at weekly intervals for four weeks after thinning. During each harvest, fresh leaves were placed in brown envelopes and weighed immediately using a sensitive weighing balance. The fresh leaves were oven-dried at a temperature of 60^{o}C for 72hrs until constant was attained and weighed.

Number of pods per pot: The number of pods was determined by counting the pods from each of the four tagged plants at physiological maturity.

A 100-seed weight for cowpea: one hundred seeds per treatment were counted after harvest and then weighed using a sensitive weighing balance to determine 100-seed weight.

Leaf yield: Total leaf yield for each treatment was obtained by summing up the leaf fresh weight from each of the four tagged plants at weekly intervals for four weeks and average leaf yield per plant determined.

Grain yield for cowpea: Grain yield at maturity for each treatment was obtained by summing up the yields from each of the four tagged plants and average grain yield per plant determined.

Nutrition Quality

Leaf samples for analysis of quality attributes such as vitamin A and C, phenolics and total antioxidant activity were obtained from four tagged plants 14 weeks after emergence. Vitamin A and C content were determined using high performance liquid chromatography (HLPC) according to Vikram et *al*., 2005,phenolics was determined by Folin-ciocalteau reagent in alkaline medium and was expressed as Gallic acid equivalent (Sadasivam, 1992). Total antioxidant activity was determined using Diphenyl Picryl Hydrazyl radical (DPPH) according to Ayoola *et al*., (2006).

3.3.4 Data Analysis

Data collected were subjected to analysis of variance using Genstat Version and where F test showed significant differences, comparison of means was done using the least significant difference test at $p \leq 0.05$.

3.4 Results

3.4.1 Effects of Water Stress on Plant Growth, Chlorophyll Concentration, Yield and Nutritional Quality of Cowpea

3.4.1.1Plant Growth and Chlorophyll Concentration

The results showed that plant height, leaf area per plant, number of branches per plant, number of leaves per plant and chlorophyll concentration significantly ($p \leq 0.05$.) reduced with decline in soil water levels in cowpea in both seasons (Table 3.1 and 3.2).However, no significant difference in chlorophyll concentration in season one was observed between 40 and 60% pot capacity. Reduction of moisture level from 100% pot capacity to 40% pot capacity led to decreases of 63.7, 39.5, 77.3, 70.8 and 21.1% and 63.8, 61.2, 75, 55.9 and 32.4% in plant height, leaf area per plant, number of branches per plant, number of leaves per plant and chlorophyll concentration in season one and two, respectively.

Table 3.1: Effect of water stress on plant height, leaf area, number of branches, number of leaves and chlorophyll concentration of cowpea grown in the greenhouse under different water levels in season one during 2015

Watering levels	Plant height (cm)	Leaf area (cm^2)	Branches no./plant	Leaf number/plant	Chlorophyll concentration
40% PC	25.7a	53.7a	2.9a	18.2a	37.0a
60% PC	41.2b	64.9b	5.1b	33.4b	39.4a
80% PC	58.2c	77.1c	8.7c	43.6c	43.7b
100% PC	70.8d	88.7d	12.8d	62.4d	46.9c
Mean	49	71.1	7.4	39.4	41.7
P-value	<.001	<.001	<.001	<.001	<.001
$LSD_{0.05}$	7.9	5.3	1.3	6.1	2.7
CV%	19.7	9	22	18.6	8

PC-pot capacity

Table 3. 2: Effect of water stress on plant height, leaf area, number of branches, number of leaves and chlorophyll concentration of cowpea grown in the greenhouse under different water levels in season two during 2016

Watering levels	Plant height (cm)	Leaf area (cm^2)	Branches no./plant	Leaf number/plant	Chlorophyll concentration
40% PC	25.6a	25.6a	3.0a	34.1a	35.5a
60% PC	41.1b	34.3b	4.9b	48.4b	39.0b
80% PC	58.1c	55.7c	9.6c	58.6c	45.4c
100% PC	70.7d	66.0d	12.0d	77.4d	52.5d
Mean	48.9	45.4	7.4	54.6	43.1
P-value	<.001	<.001	<.001	<.001	<.001
$LSD_{0.05}$	7.9	5.6	1	6.3	1.5
CV%	19.7	14.9	15.1	14	4.4

PC-pot capacity

3.4.1.2 Yield and its Components

The results showed that yield and its components significantly ($p \leq 0.05$) reduced with decline in soil water levels in cowpea in both seasons (Table 3.3 and 3.4).Reduction of moisture level from 100% pot capacity to 40% pot capacity led to decreases of 88.4, 88.8, 33, 65.9 and 88.5% and 91.6, 89.5, 60.6, 62 and 91.3% in total grain weight, number of pods per plant, 100-seed weight, leaf yield and grain yield, in season one and two, respectively.

Table 3. 3: Effect of water stress on yield and its components of cowpea grown in the greenhouse under different water levels in season one during 2015

Watering levels	Grain weight (g)	Pod no./plant	A 100-seed weight (g)	Leaf yield (g/plant)	Grain yield (g/plant)
40% PC	26.9a	4.0a	6.3a	8.4a	1.1a
60% PC	62.9b	12.3b	7.1b	18.2b	2.6b
80% PC	170.5c	31.3c	8.1c	23.0c	7.1c
100% PC	231.3d	35.7d	9.4d	24.6d	9.6d
Mean	122.9	20.8	7.7	18.5	5.1
P-value	<.001	<.001	<.001	<.001	<.001
$LSD_{0.05}$	3.9	0.6	0.2	0.6	0.2
CV%	3.2	2.7	2.7	3.3	3.2

PC-pot capacity

Table 3. 4: Effect of water stress on yield and its components of cowpea grown in the greenhouse under different water levels in season two during 2016

Watering levels	Grain weight (g)	Pod no./plant	A 100-seed weight (g)	Leaf yield (g/plant)	Grain yield (g/plant)
40% PC	25.5a	3.7a	6.1a	9.2a	1.1a
60% PC	65.3b	11.0b	9.3b	15.3b	2.7b
80% PC	173.0c	28.7c	14.2c	21.3c	7.2c
100% PC	302.8d	35.3d	15.5d	24.2d	12.6d
Mean	141.7	19.7	11.3	17.5	5.9
P-value	<.001	<.001	<.001	<.001	<.001
$LSD_{0.05}$	24.7	0.7	0.3	0.6	1.0
CV%	17.5	3.5	2.5	3.5	17.5

PC-pot capacity

3.4.1.3 Nutritional Quality

Results showed that Vitamin C and A levels significantly ($p \leq 0.05$.) reduced with decline in soil water levels in cowpea (table 3.5). However, no significant differences were observed between 60 and 80% pot capacity and between 80 and 100% pot capacity in phenolics and total antioxidant activity, respectively. Reduction of moisture level from 100% pot capacity to 40% pot capacity led to decreases of 81.6 and 78.1% in vitamin C and A, respectively. The total phenolic content and antioxidant activity significantly ($p \leq 0.05$) increased with decline in soil water levels. Reduction of moisture level from 100% pot capacity to 40% pot capacity led to increases of 29.4% and 18.7% in phenolics and total anti-oxidant activity, respectively.

Table 3. 5: Influence of water stress on vitamin C, vitamin A, phenolics and total antioxidant activity of cowpea grown in the greenhouse under different water levels

	Cowpea			
Watering levels	Vit C (mg/100g)	Vit A (mg/100g)	Phenolic (mg/100g)	Total antioxidant activity (mg/ml)
40% PC	23.3a	23.4a	192.8a	16.7a
60% PC	52.6b	48.6b	168.5b	14.6b
80% PC	74.2c	76.6c	162.8b	13.6c
100% PC	126.4d	108.0d	136.1c	13.5c
Mean	69.1	64.2	165.1	14.6
P value	<.001	<.001	<.001	<.001
$LSD_{0.05}$	3.7	3.4	6.4	0.8
CV%	2.7	2.6	1.9	2.6

PC- pot capacity

3.4.2 Effects of water stress on plant growth, chlorophyll concentration, yield and nutritional quality of African nightshade

3.4.2.1 Plant Growth and Chlorophyll Concentration

The results showed that plant height, leaf area per plant, number of branches per plant, number of leaves per plant and chlorophyll concentration significantly ($p \leq 0.05$.) reduced with decline in soil water levels in African nightshade in both seasons (Table 3.6 and 3.7). However, no significant differences were observed in leaf number in season one among 60, 80 and 100% pot capacity and in plant height and leaf number in season two between 60 and 80% pot capacity. Reduction of moisture level from 100% pot capacity to 40% pot capacity led to decreases of 71, 75, 60, 52.4 and 52.5% and 72.1, 75, 75.8, 56.6 and 54.6% in plant height, leaf area per plant, number of branches per plant, number of leaves per plant and chlorophyll concentration in season one and two, respectively.

Table 3. 6: Effect of water stress on plant height, leaf area, number of branches, number of leaves and chlorophyll concentration of African nightshade grown in the greenhouse under different water levels in season one during 2015

Watering levels	Plant height (cm)	Leaf area (cm^2)	Branches no./plant	Leaf number/plant	Chlorophyll concentration
40% PC	23.0a	63.0a	5.2a	20.1a	26.7a
60% PC	43.1b	100.2b	7.6b	30.5b	36.5b
80% PC	63.5c	148.5c	10.6c	37.2b	46.3c
100% PC	79.4d	251.5d	13d	42.2b	56.2d
Mean	52.2	140.8	9.1	32.5	41.4
P-value	<.001	<.001	<.001	<.001	<.001
$LSD_{0.05}$	12.7	24.9	1.1	8.0	2.0
CV%	29.5	21.5	14.8	29.9	5.8

PC-pot capacity

Table 3. 7: Effect of water stress on plant height, leaf area, number of branches, number of leaves and chlorophyll concentration of African nightshade grown in the greenhouse under different water levels in season two during 2016

Watering levels	Plant height (cm)	Leaf area (cm^2)	Branches no./plant	Leaf number/plant	Chlorophyll concentration
40% PC	21.4a	65.5a	3.6a	20.6a	26.4a
60% PC	49.9b	104.9b	6.4b	30.3b	36.2b
80% PC	61.3b	156.2c	9.6c	36.2b	43.9c
100% PC	76.7c	262.4d	14.9d	48.6c	58.1d
Mean	52.3	147.3	8.6	46.8	41.2
P-value	<.001	<.001	<.001	<.001	<.001
$LSD_{0.05}$	12.8	27.8	1.0	8.3	1.3
CV%	29.7	22.9	14.5	29.8	3.7

PC-pot capacity

3.4.2.2 Yield and its Components

The results showed that yield and its components significantly ($p \leq 0.05$) reduced with decline in soil water levels in African nightshade in both seasons (Table 3.8 and 3.9). Reduction of moisture level from 100% pot capacity to 40% pot capacity led to decreases of 85.2, 85.9, 85.4 and 85.3% and 76.6, 86, 86.6 and 76.6% in leaf fresh weight, leaf dry weight, number of fruits/plant and leaf yield, in season one and two, respectively.

Table 3. 8: Effect of water stress on yield and its components of African nightshade grown in the greenhouse under different water levels in season one during 2015

Watering levels	Leaf fresh weight (g/plant)	Leaf dry weight (g/plant)	Number of fruits/plant	Leaf yield (g/plant)
40% PC	7.4a	1.4a	44.4a	4.9a
60% PC	15.9b	2.9b	85.4b	10.6b
80% PC	27.2c	6.2c	180.0c	18.1c
100% PC	49.9d	9.9d	304.3d	33.4d
Mean	25.1	5.1	153.5	16.8
P-value	<.001	<.001	<.001	<.001
$LSD_{0.05}$	6.1	1.2	19.8	1.3
CV%	29.3	29.4	12.9	7.6

PC-pot capacity

Table 3. 9: Effect of water stress on yield and its components of African nightshade grown in the greenhouse under different water levels in season two during 2016

Watering levels	Leaf fresh weight (g/plant)	Leaf dry weight (g/plant)	Number of fruits/plant	Leaf yield (g/plant)
40% PC	10.5a	1.4a	44.0a	7.0a
60% PC	16.7b	2.9b	90.0b	11.1b
80% PC	24.6c	6.0c	191.3c	16.4c
100% PC	44.9d	10.0d	327.6d	29.9d
Mean	24.2	5.0	163.2	16.1
P-value	<.001	<.001	<.001	<.001
$LSD_{0.05}$	4.8	1.2	15.86	0.2
CV%	24.3	28.3	9.7	1.0

PC-pot capacity

3.4.2.3 Nutritional Quality

Results showed that Vitamin C and A levels significantly ($p \leq 0.05$.) reduced with decline in soil water levels in African nightshade (table 3.10).However, no significant difference in vitamin A, vitamin C, phenolics and total antioxidant activity was observed between 80 and 100% pot capacity. Reduction of moisture level from 100% pot capacity to 40% pot capacity led to decreases of 55.8% and 52% in vitamin C and vitamin A, respectively. The total phenolic content and antioxidant activity significantly ($p \leq 0.05$) increased with decline in soil water levels. Reduction of moisture level from 100% pot capacity to 40% pot capacity led to increases of 34.5% and 45% in phenolics and total anti-oxidant activity, respectively.

Table 3.10: Influence of water stress on vitamin C, vitamin A, phenolics and total antioxidant activity of African nightshade grown in the greenhouse under different water levels

Watering levels	Vit A (mg/100g)	Vit C (mg/100g)	Phenolics (mg/100g)	Total antioxidant activity (mg/ml)
40% PC	29.2a	31.5a	198.2a	23.5a
60% PC	29.5a	36.0b	177.6b	17.3b
80% PC	64.1b	62.4c	133.3c	13.5c
100% PC	66.1b	65.6c	129.8c	12.9c
Mean	47.2	48.9	159.7	16.8
P-value	<.001	<.001	<.001	<.001
$LSD_{0.05}$	4.0	4.0	12.4	1.3
CV%	4.3	4.2	3.9	3.9

PC-pot capacity

3.5 Discussion

In both cowpea and African nightshade, chlorophyll concentration and all plant growth characters including plant height, number of branches per plant, number of leaves per plant, leaf area per plant significantly decreased with decline in soil water levels. A decline in plant growth in response to water stress might be caused by decreases in cell turgor, volume and eventually in plant photosynthetic efficiency, mainly due to the closing of stomata and inhibition of Rubisco enzyme (Lawlor, 2002). The decrease in chlorophyll concentration under drought stress is a commonly observed phenomenon (Kumar *et al.,* 2011; Ndiso *et al*., 2017) and might be attributed to reduced synthesis of the main chlorophyll pigment complexes encoded by the cabgene family (Nikolaeva *et al.,* 2010), destruction of the pigment protein complexes which protect the photosynthesis apparatus, or oxidative damage of chloroplast, lipids and proteins, resulting in reduced synthesis of chlorophyll a, b and carotenoids (Anjum *et al*., 2003). Leaves as the media of most physiological processes in the plant are among plant organs that are most affected by drought in different ways with abscission being the most common (Wien *et al.,* (1979); Gwathmey *et al.,* 1992). Akyeampong (1985) found that leaf expansion and abscission were sensitive to drought stress at vegetative, flowering or pod-filling stages.

Decreasing soil water content induced gradual reduction in leaf and grain yields and its components as compared with non-stressed plant (100% PC). The most negative effect of water stress on yield and its components was recorded at 40% PC, at which the number of pods per plant, total grain weight, grain yield per plant and 100-seed weight were reduced by 89.2%, 90.2%, 90.2%, and 50.5%, respectively, and leaf yield per plant was reduced by 79.6% compared to 100% PC in cowpea. In African nightshade, reduction of moisture level from 100% pot capacity to 40% pot capacity led to decreases of 81.2%, 86.1% and 81.2% in leaf fresh weight, leaf dry weight and leaf yield, respectively and number of fruits per plant was reduced by 86%. The reduced yield may be due to the negative effect of water stress on number of branches per plant, number of leaves per plant and leaf area per plant, resulting in a reduction in the supply of carbon assimilates and photosynthetic rate by plants and consequently less biomass produced as well as decreased translocation of assimilates towards the developing fruits (Vurayai *et al.*, 2011). In addition, grain yield of cowpea may be reduced under drought conditions due to increased rate of flower abscission and pod abortion (Liu *et al.*, 2003).

The total phenolics content and antioxidant activity of cowpea and African nightshade significantly increased with decline in soil water levels. Similar results were observed for *Prunella vulgaris* L. plants, where phenolics contents (rosmarinic, ursolic acid and oleanolic acid) increased under drought stress (Chen *et al*., 2011). Some nutrients, especially carbohydrate supplies, influence the phenolics composition. Stress factors like drought can increase the phenolics compounds (ferolic acid) in the leaves of triticale seedlings (Hura *et al*., 2009). Drought stress reduces growth, so the carbon fixed during photosynthesis could be used to form secondary metabolites (phenolics) (Hale *et al*., 2005). Phenolics and antioxidant activity increase the scavenging capacity against reactive oxygen species (ROSs) that damage cellular membranes under drought stress. Results confirmed that *Vigna unguiculata* L. and *Solanum spp*. plants under dry conditions decreased plant growth but enhanced their phenolics contents and total anti-oxidant activity. There was reduction in plant growth and yield but plants have the ability to cope with stress by generating secondary metabolites including phenols. Decline in soil moisture reduced vitamins A and C in both crop species. Similar findings were observed by Wen and Begg (2014), water deficit reduced ascorbic acid and vitamin A on amaranth, African nightshade and Ethiopian kale. Leaf area and chlorophyll content declined more in African nightshade than in cowpea. This suggests that cowpea is more tolerant to drought stress than African nightshade (Dadson *et al*., 2005).

Reduction of moisture level from 100% pot capacity to 40% pot capacity led to decreases of 81.6 and 78.1% in vitamin C and A, respectively, in cowpea compared to decreases of 55.8% and 52%, respectively, in African nightshade. This suggests that the African nightshade has a higher capacity to retain its nutritional quality, with respect to Vitamins A and C, than cowpea. In contrast, water stress increased phenolics and antioxidant activity in African nightshade more than in cowpea, indicating that the former crop species has a greater scavenging capacity against oxygen species that normally increase under water stress (Chen *et al*., 2011).

3.6 Conclusion

Water stress reduced the growth parameters, yields, nutritional quality (Leaf vitamins A and C) and chlorophyll concentration of both African nightshade and cowpea but increased phenolics contents and total antioxidant activity in both species. In both cowpea and African nightshade reduction of plant height, number of branches, number of leaves, leaf yield and number of pods/fruits per plant were nearly the same. Leaf area and chlorophyll concentration decreased by 48.7 and 27%, respectively, in cowpea and by 75 and 53.5%, respectively, in African nightshade. These crop species can cope with water stress due to generation of secondary metabolites such as phenolics and total antioxidant activity which increase scavenging capacity against reactive oxygen species that damages cellular membranes.

CHAPTER FOUR: EFFECT OF FERTILIZERS AND HARVESTING METHOD ON GROWTH, YIELD AND NUTRITIONAL QUALITY OF COWPEA AND AFRICAN NIGHTSHADE

4.1 Abstract

The low productivity of the African nightshade (*Solanum spp*.) and cowpea (*Vigna unguiculata* L. Walp.) leafy vegetables in smallholder farms in Kenya is partly attributed to moisture stress, declining soil fertility and poor harvesting practices. To increase the productivity and utilization of these crops requires development of suitable agronomic practices such as effective nutrient management and best harvesting practices. A field experiment was conducted at the University of Nairobi's Kabete field station, to determine the effect of fertilizer application and harvesting method on growth, yield and nutritional quality of African nightshade and cowpea. The fertilizer treatments, comprising 200 kg/ha Di-ammonium phosphate (DAP) fertilizer, 10 t/ha farmyard manure (FYM), 10 t/ha chicken manure (CM), 100 kg/ha DAP + 5 t/ha FYM, 100 kg/ha DAP + 5 t/ha CM and no- fertilizer (control), were tested against two harvesting methods (piecemeal and wholesome harvesting) in a randomized complete block design, replicated three times. Growth and yield data collected included leaf number, leaf area, plant height, number of branches, leaf fresh weight, leaf dry weight, leaf yield, number of pods/fruits, total grain weight, seed weight and grain yield. Data on chlorophyll, leaf vitamins A and C, total antioxidant activity and phenolics content were also collected.

All data collected were subjected to analysis of variance (ANOVA) and means separated, where the F-test was significant, using the least significant difference test at $p \leq 0.05$. Fertilizer application significantly increased plant height, number of leaves per plant and leaf yield of cowpea and African nightshade. Compared to the no-fertilizer control, application of DAP, DAP + CM, DAP + FYM, CM and FYM increased leaf yield by 68.6, 58.3, 56.6, 52.2 and 42.6%, respectively, in cowpea and 74.9, 63.7, 60.8, 56.4 and 41.1%, respectively, in African nightshade. Fertilizer application had no significant effect on vitamin A and C, phenolics and antioxidant activity in both crops. Compared to wholesome harvesting, piecemeal harvesting significantly increased the number of leaves and leaf yield by 54.1 and 43.9%, respectively, in cowpea and 51.2 and

49.3%, respectively, in African nightshade. Fertilizer application increased the growth and leaf yield but had no influence on leaf vitamin A, leaf vitamin C, phenolics and antioxidant activity in both cowpea and African nightshade. Relative to wholesome harvesting, piecemeal harvesting enhanced growth and leaf yield of cowpea and African nightshade.

Keywords: Harvesting method, inorganic, manures, quality and yield

4.2 Introduction

African nightshade (*Solanum spp*.) and cowpea (*Vigna unguiculata* L.) are largely domesticated in Sub-Saharan Africa (Abukusta-Onyango *et al*., 2004). They are known for their nutritional, medicinal value and source of livelihood; rich in iron, calcium, vitamins A and C (Yang *et al*., 2009). It has been reported that the nutrient content of these vegetables can provide 100% of the recommended daily allowance for an adult for calcium, iron, B-carotene, and ascorbic acid and 40% of protein if 100 g of the fresh vegetable is consumed (Abukutsa Onyango, 2003). Consumption, demand, and market value of these vegetables have rapidly and steadily risen as consumers become increasingly aware of their nutritional, economical and medicinal values. In recent years, the resurgence in popularity has prompted rapid domestication and commercialization of African nightshade and cowpea production, from subsistence to commercial farming (Schippers, 2004). Even though vegetables are commonly cultivated in Kenya, there are many production challenges that lead to reduced productivity.

The major limiting factors include: low soil fertility (inadequate N, P, K, Ca. Mg, S and organic matter), plant nutrient imbalances, low soil moisture content, particularly in drought periods, poor harvesting methods and the use of unsuitable agronomic practices (poor land preparation, late and unsuitable weeding and inappropriate plant population densities and fertilizer application rates). Other constraints include the perception of these traditional vegetables as crops for the poor, lack of partnership and networking, low capacity within institutions, poor policies, undeveloped value chains and markets, and low research attention (Eyzaguire *et al*., 2006). Ghaly and Alkoaik (2010) observed that nutrient deficiencies, for instance, sulphur, phosphorus, potassium and magnesium reduce plant growth, protein content and plant yields. A positive response of cowpea to the application of organic and inorganic fertilizer has been reported by several authors from various cowpea grown areas (Singh *et al*., 2007; Singh *et al*., 2011a; Nkaa *et al*., 2014; Daramy et *al*., 2016).

Organic manures are in most cases more locally available and cheaper than inorganic fertilizers and so most small-scale farmers are able to purchase them. These fertilizers improve soil physical conditions in addition to supplying the plant nutrients (Smaling, 1993). Cattle manures and other livestock manures could supply an estimated 30% of nitrogen needs for crop production; hence it could be an important source of nitrogen to crops in livestock intensive regions (Jokela, 1992). Application of N has been reported to improve beta carotene content in other crops such as *Solanum spp*. (Murage, 1990). Nitrogen promotes synthesis of chloroplasts, which are rich in Beta carotene (Salisbury and Ross, 1991). Use of N has been observed to decrease vitamin C content in other crops such as *Solanum spp.* complex (Murage, 1990). An assessment of harvesting techniques done in Tanzania indicated that continuous harvesting of black nightshade with topping provided the highest economic leaf yield of 32.0 t/ha, while continuous harvesting without topping gave the lowest leaf yield(17.8 t/ha) (Bubenheim *et al.*,1990). In contemporary agriculture, certain emphasis is set on soil amendment, improved agricultural equipment, techniques and improved varieties of tolerant plants for improving quality and quantity of yield per hectare. However, the full potential of the improved varieties can only be met if important inputs especially chemical and organic fertilizers are applied in required quantities and in a timely manner (Teboh, 2009; Savci, 2012; Ogbodo, 2013). The main objective of the study was to evaluate the effects of fertilizer application and harvesting method on growth, yield and nutritional quality of African nightshade and cowpea.

4.3 Materials and Methods

4.3.1 Study Site

The study was conducted at the University of Nairobi’s Kabete Field Station. It situated about 15 km to the west of Nairobi city and lies at latitude Kenya 1° 15’S, 36°44’ E, and is 1940 meters above sea level (Michieka, 1977). The area receives bimodal rainfall of about 1000 mm per annum, distributed in two seasons; long rains from March to June and short rains from October to December. The mean monthly temperature has a minimum of 12 ^{0} C and maximum 23 ^{0} C (Anon, 1985). The soil types are well drained, very deep, reddish brown to dark red crumble clay with acidic humid top soils developed from Limuru Trachyte (Michieka, 1977). The trial was carried out in two seasons. The first trial was done during the short rains of October to December 2015 and the second trial during the long rains of March-June 2016.

4.3.2 Soil and Manure Analyses

Prior to planting the top 0- 20 cm of soil in all the field plots were sampled, bulked and analyzed at the University of Nairobi's Soil Science Laboratories for Ph, organic carbon, total N, Ca, P, Mg and CEC. Soil pH using a pH meter (Schofield and Taylor, 1955); organic carbon using Walkley-Black method (Walkley and Black, 1934); total soil N using micro Kjedahl method (Kjedahl, 1883); soil available P using Mehlich's method; basic cations (Na, K, Mg and Ca) were evaluated by leaching with 1 N NH4OAc at pH 7.0 (Warnkce and Brown, 1998) while cation exchange capacity (CEC) evaluated by leaching further with KCL then distilling the leachate with 10 N NaOH and further titration with 0.01 N HCL. Chicken and farmyard manures used in the study were also sampled and analyzed for the same parameters as for the soil. The soil and manure test results for the two seasons are given in table 4.1.

Table 4.1: Chemical Properties of the soil at experimental Sites and Manures used in the Study during 2015 and 2016, respectively

	First Season			Second season		
Source	Soil	FYM	CM	Soil	FYM	CM
pH	5.93	7.78	8.5	5.78	7.79	8.1
N %	0.24	1.05	0.65	0.26	1.08	0.61
OC %	3.4	27.62	22.05	2.59	26.63	22.01
K (cmol/kg)	1.1	14	38.6	1.72	13	37.6
Na (cmol/kg)	0.54	28.5	33.7	0.55	27.5	32.7
Ca(cmol/kg)	8.1	25.1	35.2	9.2	24.1	34.2
Mg (cmol/kg)	3.65	7.4	11.45	3.64	7	11.35
P(cmol/kg)	13.5	756	1300	19.75	745	1290

4.3.3 Experimental Design and Treatments

Experimental design was a randomized complete block design with a 2*6 factorial arrangement replicated three times. African nightshade and cowpea experiments were conducted independently. Two factors namely fertilizer regimes and harvesting methods were investigated. Fertilizer regimes comprised: 200 kg/ha Di-ammonium phosphate (DAP) fertilizer, 100 kg/ha DAP + 5 tons/ha CM, 100 kg/ha Di-ammonium phosphate (DAP) + 5 t/ha FYM, 10 t/ha chicken manure (CM), 10 t/ha farmyard manure (FYM) and no- fertilizer (control). Harvesting treatments comprised wholesome harvesting (uprooting the entire plant at 3-4 true leaf before the leaves become too mature and fibrous) and piecemeal harvesting (plucking leaves or picking branches containing leaves).

4.3.4 Land Preparation and Crop Husbandry

Land preparation was done two months prior to sowing by performing deep ploughing using a tractor followed by hand breaking of clods to attain good tilth. Beds were divided into plots measuring 1.5 m by 1 m and raised to 20 cm high to ensure inter-plot measuring 0.5 m and 0.75 m path separating blocks was maintained. The seeds of African nightshade line-Olevolosi and cowpea line-Tumaini were sourced from AVRDC, Arusha, Tanzania. Farmyard and chicken manures were obtained from Kabete Field Station while the Di-ammonium phosphate was obtained from Agrovets in Ndumbuini Shopping Centre, Nairobi. The African nightshade were sown directly in drills made 30 cm apart and two cowpea seeds were sown in holes and both covered with soil at about 1cm deep and thinning was done 4 weeks later to give a spacing of 30 cm within rows and between plants for African nightshade and 1 plant per hole for cowpea. Supplementary irrigation was done in case of water shortage and weeding was done manually on emergence of weeds. Pests such as white flies and spider mite were controlled by spraying with Atom 2.5 EC, active ingredient deltametrin (0.5l/ha) and 2-DC-Tron plus, active ingredient Ampol (839 g/l) respectively and leaf rust disease was controlled by spraying fungicide Ridomil copper, active ingredients metalaxyl and copper hydroxide (2 kg/ha). All these maintenance activities were uniformly applied to all plots.

4.3.5 Data Collection

Growth and Yield Parameters

To measure the growth, yield and nutritional quality parameters for African nightshade and cowpea, four plants per plot were randomly selected from the two inner rows excluding guard rows. The parameters measured included: plant height, leaf number, branch number, leaf area, chlorophyll concentration, leaf dry weight, leaf fresh weight, leaf yield, grain yield, 100-seed weight, leaf vitamin A, leaf vitamin C, phenolics and total antioxidant activity.

Plant height: Plant height from each of four randomly selected plants was measured from ground level to the tip of the longest stem on weekly intervals for six weeks using a meter rule.

Number of leaves: Number of leaves per plant was determined by counting fully expanded leaves from each of four randomly selected plants on weekly intervals for six weeks.

Number of branches per plant: Number of branches was determined by counting the number of branches from four randomly selected plants on weekly intervals for six weeks.

Leaf area: Leaf area from each of four randomly sampled plants per plot was calculated using the following formula by Jose *et al*., (2000.): $AL = 0.73(L_L * W_L)$, where L_L is the leaf length and W_L is the maximum width on weekly intervals for six weeks.

Chlorophyll concentration: A non-destructive approach method was used to evaluate total chlorophyll concentration in two fully opened leaves from each of four randomly selected plants, using a spectrophotometer (SPAD), at vegetative stage. Chlorophyll concentration measurements were done on a weekly interval for six weeks.

Leaf fresh and dry weights: Fully expanded leaves from all four tagged plants were harvested on a continuous basis at weekly intervals for six weeks after thinning. During each harvest, fresh leaves were placed in brown envelopes and weighed immediately using a sensitive weighing balance. The fresh leaves were oven-dried at a temperature of 60°C for 72hrs until constant was attained and weighed.

Leaf yield: Total leaf yield for each treatment was obtained by summing up the leaf fresh weight from plants in 1.5 m^2 at weekly intervals for six weeks.

Grain yield for cowpea: Grain yield for each treatment was obtained by summing up the yields from plants in 1.5 m^2 and adjusted to 14% moisture level.

Numbers of pods per plot: Numbers of pods per plot were determined by counting pods from each of four randomly selected plants from various plots at harvesting and the mean was taken to give the average of number of pods/plant.

A 100-seed weight for cowpea: one hundred seeds per plot were counted after harvest and then weighed using a sensitive weighing balance.

A 1000-seed weight for African nightshade: one thousand seeds per plot were counted after harvest and then weighed using a sensitive weighing balance.

Nutritional quality

Leaf samples for analysis of quality attributes such as vitamin A and C, phenolics and total antioxidant activity were obtained from four tagged plants 14 weeks after emergence. Vitamin A and C content were determined using high performance liquid chromatography (HLPC) according to Vikram, et al., 2005,phenolics was determined by Folin-ciocalteau reagent in alkaline medium and was expressed as Gallic acid equivalent (Sadasivam, 1992). Total antioxidant activity was determined using Diphenyl Picryl Hydrazyl radical (DPPH) according to Ayoola et al., (2006).

4.3.6 Data Analysis

Data collected were subjected to analysis of variance using Genstat Version and, where F test showed significant differences, comparison of means was done using the least significant difference test at $p \leq 0.05$.

4.4 Results

4.4.1: Impact of fertilizer application and harvesting method on plant growth, chlorophyll concentration, yield and nutritional quality of cowpea and African nightshade

4.4.1.1 Plant Height

Fertilizer application, harvesting method and their interaction had significant effects ($p \leq 0.05$) on plant height of cowpea and African nightshade in both seasons (Table 4.2 and 4.3). In cowpea, in both seasons, fertilizer application significantly increased plant height in both piecemeal and wholesome harvested plots (Table 4.2). Application of DAP had significantly the highest cowpea plant height compared to all other fertilizer treatments in piecemeal harvested plots in both seasons and wholesome harvested plots in the first season. However, there were no significant differences in cowpea plant height between DAP + CM and DAP + FYM treated plants in piecemeal harvested plots in both seasons and among all fertilizer treated plants in wholesome harvested plots in both seasons. Generally, DAP + CM and DAP + FYM out-performed CM and FYM treatments in both piecemeal and wholesome harvested cowpea plots. Irrespective of the fertilizer treatment, wholesome harvested plots had significantly shorter cowpea plant height in both seasons than piecemeal harvested plots (Table 4.2).

In African nightshade, in both seasons, fertilizer application significantly increased plant height in piecemeal harvested plots (Table 4.3).Application of DAP had significantly the highest African nightshade plant height compared to all other fertilizer treatments in piecemeal harvested plots in both seasons. However, there were no significant differences in plant height between CM and FYM treated plots in piecemeal harvested plants in both seasons and among all the treatments in fertilizer supplied plots in wholesome harvested plots in both seasons. Generally, DAP + CM and DAP + FYM significantly out-performed CM and FYM treatments in both piecemeal and wholesome harvested plots in both seasons. Irrespective of the fertilizer treatment, wholesome harvested plots had significantly shorter plants than piecemeal harvested plots in both seasons (Table 4.3).

Table 4.2: Effect of fertilizer application and harvesting method on plant height (cm) of cowpea in the first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method(HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert.)	19.7a	9.0f	14.4	16.8a	7.0f	11.9
CM	31.3b	11.0f	21.2	27.3b	9.2f	18.3
DAP	52.6c	15.0f	33.8	49.6c	14.0f	31.8
DAP + CM	45.0d	14.0f	29.5	42.0d	12.0f	27.0
DAP + FYM	39.5d	13.0f	26.2	37.5d	10.2f	23.9
FYM	29.1e	10.0f	19.6	26.0e	8.0f	17.0
Mean	36.2	12.0		33.2	10.1	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	3.9			3.8		
$LSD_{0.05}$ HM	2.2			2.2		
$LSD_{0.05}$ Fert.HM	5.5			5.4		
CV%	34.4			37.5		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

Table 4.3: Effect of fertilizer application and harvesting method on plant height (cm) of African nightshade in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method(HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	17.8a	10.2f	14.0	15.0a	10.2f	12.6
CM	35.7b	13.2f	24.4	32.6b	13.2f	22.9
DAP	54.5c	16.2f	35.4	50.7c	16.2f	33.4
DAP + CM	47.4d	15.1f	31.3	44.5d	15.1f	29.8
DAP + FYM	40.3e	14.1f	27.2	37.1e	14.1f	25.6
FYM	32.6b	12.3f	22.4	29.6b	12.3f	20.9
Mean	38.1	13.5		34.9	13.5	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
LSD$_{0.05}$ Fert.	4.4			4.3		
LSD$_{0.05}$ HM	2.5			2.5		
LSD$_{0.05}$ Fert.HM	6.2			6.1		
CV%	36.6			38.1		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

4.4.1.2 Number of Branches/Plant

Fertilizer application, harvesting method and their interaction had significant effects ($p \leq 0.05$) on the number of branches/plant of cowpea and African nightshade in both seasons (Table 4.4 and 4.5). In cowpea, in both seasons, fertilizer application significantly increased the number of branches/plant in both wholesome and piecemeal harvested plots (Table 4.4). Application of DAP had significantly the highest number of cowpea branches/plant compared to all the other fertilizer treatments in piecemeal harvested plots in both seasons and wholesome harvested plots in the first season. In most cases, DAP+CM and DAP+FYM treatments significantly out-performed CM and FYM treatments in both piecemeal and wholesome harvested cowpea plots. In all fertilizer supplied plots, wholesome harvested plants had significantly lower number of cowpea branches/plant than piecemeal harvested plants only in both seasons (Table 4.4). Similar observations were made for African nightshade. CM, FYM, DAP+FYM and DAP+CM did not significantly increase the number of branches/plant relative to the no-fertilizer control in wholesome harvested plots in both seasons (Table 4.5). In addition, wholesome harvested plants had significantly lower number of branches/plant than piecemeal harvested plants in both seasons (Table 4.5).

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Table 4.4: Effect of fertilizer application and harvesting method on number of branches/plant of cowpea in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control(No fertilizer)	5.2a	1.7g	3.4	2.6a	1.4g	2.0
CM	8.9b	3.1h	6.0	6.0b	1.6g	3.8
DAP	12.9c	3.7h	8.3	10.0c	3.8h	6.9
DAP.CM	11.0d	3.3h	7.2	8.0d	2.7i	5.3
DAP.FYM	10.1e	3.2h	6.7	7.1e	1.7g	4.4
FYM	8.0f	3.6h	5.8	4.9f	1.5g	3.2
Mean	9.3	3.1		6.4	2.1	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	0.7			0.6		
$LSD_{0.05}$ HM	0.4			0.4		
$LSD_{0.05}$ Fert.HM	0.9			0.8		
CV%	22.5			29.6		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

Table 4.5: Effect of fertilizer application and harvesting method on number of branches/plant of African nightshade in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	4.6a	1.7g	3.1	2.3a	1.3g	1.8
CM	8.0b	2.0g	5.0	5.1b	1.7g	3.4
DAP	12.6c	4.7h	8.6	9.5c	3.6h	6.5
DAP + CM	10.3d	2.7g	6.5	7.3d	2.0g	4.6
DAP + FYM	9.3e	2.3g	5.8	6.4e	1.7g	4.1
FYM	7.1f	1.9g	4.5	4.3f	1.4g	2.9
Mean	8.7	2.5		5.8	2.0	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	0.7			0.6		
$LSD_{0.05}$ HM	0.4			0.4		
$LSD_{0.05}$ Fert.HM	1.0			0.9		
CV%	26.3			35.1		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

4.4.1.3 Number of Leaves/Plant

Fertilizer application, harvesting method and their interaction had significant effects ($p \leq 0.05$) on the number of leaves/plant of cowpea and African nightshade in both seasons (Table 4.6 and Table 4.7). In cowpea, under piecemeal harvested plots, fertilizer application significantly increased the number of leaves/plant in both seasons (Table 4.6). There were no significant differences between DAP + CM and DAP + FYM and between FYM and CM in piecemeal harvested plots in both seasons. Under wholesome harvested plots, fertilizer application significantly increased number of cowpea leaves/plant except CM and FYM applications in both seasons and DAP + FYM applications in second season. Generally, DAP + CM and DAP + FYM treatments had significantly higher number of leaves/plant than CM and FYM treatments in both piecemeal and wholesome harvested cowpea plots in both seasons. Irrespective of the fertilizer regime, wholesome harvested plants had significantly lower cowpea leaves/plant in both seasons (Table 4.6).

In African nightshade, under piecemeal harvested plants, fertilizer application had significantly increased the number of leaves/plant in both seasons (Table 4.7). A similar observation was made under wholesome harvested plots expect that FYM application had no significant effect on the number of leaves/plant in both seasons. Application of DAP had significantly the highest number of leaves/plant compared to all the other fertilizer treatments in both piecemeal and wholesome harvested plots in both seasons. There were no significant differences noted between CM and FYM treatments and between DAP + CM and DAP + FYM treated plants in piecemeal harvested plots in both seasons and among the treatments in fertilizer supplied plots in wholesome harvested plants except DAP and FYM treated plots in both seasons. Regardless of the fertilizer treatment, wholesome harvested plots had significantly lower number of African nightshade leaves/plant than piecemeal harvested plots in both seasons (Table4.7).

Table 4.6: Effect of fertilizer application and harvesting method on number of leaves/plant of cowpea in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	19.7a	12.0e	15.9	16.9a	16.0e	16.5
CM	31.9b	16.1f	24.0	27.9b	19.1f	23.5
DAP	53.6c	21.0g	37.3	49.6c	24.0g	36.8
DAP + CM	44.7d	20.0h	32.3	40.7d	22.0h	31.3
DAP + FYM	41.6d	18.1i	29.9	37.3d	19.9f	28.6
FYM	30.6b	15.0f	22.8	26.6b	18.0f	22.3
Mean	37.0	17.0		33.2	19.8	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	3.9			3.8		
$LSD_{0.05}$ HM	2.2			2.2		
$LSD_{0.05}$ Fert.HM	5.5			5.4		
CV%	30.7			30.8		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

Table 4.7: Effect of fertilizer application and harvesting method on number of leaves/plant of African nightshade in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	16.9a	10.0 e	13.5	14.0a	7.0e	10.5
CM	27.9b	16.0f	22.0	24.8b	13.0f	18.9
DAP	49.6c	20.0f	34.8	46.4c	17.1f	31.8
DAP + CM	40.7d	19.0f	29.8	37.7d	16.0f	26.8
DAP + FYM	37.3d	18.0f	27.6	34.1d	15.0f	24.6
FYM	26.6b	14.0ef	20.3	23.6b	11.1ef	17.3
Mean	33.2	16.2		30.1	13.2	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	3.8			3.7		
$LSD_{0.05}$ HM	2.2			2.2		
$LSD_{0.05}$ Fert.HM	5.3			5.3		
CV%	32.7			37.0		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

4.4.1.4 Leaf Area/Plant

Fertilizer application, harvesting method and their interaction had significant effects ($p \leq 0.05$) on leaf area/plant of cowpea and African nightshade in both seasons (Table 4.8 and Table 4.9). In cowpea, fertilizer application significantly increased leaf area/plant in both piecemeal and wholesome harvested plots in both seasons except FYM treated plots in wholesome harvested plots in the first season. Application of DAP had significantly the largest leaf area/plant compared to all the other fertilizer treatments in both piecemeal and wholesome harvested plots in both seasons. However, there were no significant differences in leaf area/plant noted between DAP + CM and DAP + FYM treatments in the first season and between DAP + FYM and CM treatments in the second season in wholesome harvested plots. Generally, DAP + CM and DAP + FYM treated plots had significantly higher leaf area/plant than CM and FYM treatments in piecemeal harvested plots in both seasons and wholesome harvested plants in the first season. Irrespective of the fertilizer treatment, wholesome harvested plants had significantly smaller leaf area than piecemeal harvested plants in both seasons (Table 4.8). Similar observations were made for the African nightshade except that no significant differences in leaf area/plant were noted between CM and FYM treated plots in wholesome harvested plants in both seasons (Table 4.9).

Table 4.8: Effect of fertilizer application and harvesting method on leaf area (cm^2)/plant of cowpea in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	19.8a	7.6g	13.7	15.1a	8.8g	11.9
CM	30.0b	10.9h	20.4	24.9b	20.7h	22.8
DAP	44.1c	29.3i	36.7	38.9c	35.0i	37.0
DAP + CM	39.6d	21.9j	30.7	34.4d	29.2j	31.8
DAP + FYM	33.7e	20.5j	27.1	28.6e	21.7h	25.1
FYM	26.0f	8.8k	17.4	21.7f	10.8k	16.3
Mean	32.2	16.5		27.3	21.0	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	1.10			1.13		
$LSD_{0.05}$ HM	0.6			0.7		
$LSD_{0.05}$ Fert.HM	1.6			1.6		
CV%	9.7			10.1		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

Table 4.9: Effect of fertilizer application and harvesting method on leaf area (cm^2)/plant of African nightshade in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	22.5a	13.6g	18.1	17.7a	13.6g	10.5
CM	48.9b	20.7h	34.8	44.2b	20.7h	18.9
DAP	75.7c	45.5i	60.6	70.6c	44.4i	31.8
DAP + CM	69.2d	35.6j	52.4	64.1d	35.6j	26.8
DAP + FYM	60.0e	26.5k	43.2	54.8e	26.5k	24.6
FYM	43.3f	18.5h	30.9	38.5f	18.5h	17.3
Mean	53.3	26.7		48.3	26.5	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	2.8			2.8		
$LSD_{0.05}$ HM	1.6			1.6		
$LSD_{0.05}$ Fert.HM	4.0			4.0		
CV%	15.0			16.2		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

4.4.1.5 Chlorophyll Concentration

Fertilizer application, harvesting method and interaction between fertilizer and harvesting method had significant effects ($p \leq 0.05$) on chlorophyll concentration of cowpea in both seasons (Table 4.10). In both seasons, farmyard manure and DAP + FYM treated plants had significantly higher chlorophyll concentration than plants that did not receive any fertilizer under both piecemeal and wholesome harvested plots. In most cases, combinations of manures and inorganic fertilizers had significantly higher chlorophyll concentration than sole applications of inorganic fertilizers and manures. Wholesome harvested plants had significantly higher chlorophyll concentration than piecemeal harvested plants in plots that had no fertilizer (control) and plots supplied with DAP in both seasons. No significant differences in chlorophyll concentration were noted in plants treated with CM, DAP + FYM and FYM in the first season and plots supplied with CM, DAP + CM, DAP + FYM and FYM in the second season (Table 4.10).

In African nightshade, DAP +FYM treated plants generally had significantly higher chlorophyll concentration than the control plants and plants subjected to the other fertilizer treatments. Wholesome harvested plants had significantly higher chlorophyll concentration than piecemeal harvested plants under the no-fertilizer control and CM plots in both seasons. In contrast, piecemeal harvested plants had significantly higher chlorophyll concentration than wholesome harvested plants under DAP + FYM and DAP +CM plots in both seasons (Table 4.11).

Table 4.10: Effect of fertilizer application and harvesting method on chlorophyll concentration of cowpea in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	36.0a	38.2e	37.1	39.0a	41.3e	40.1
CM	37.6bh	37.7eh	37.7	40.5bh	40.9eh	40.7
DAP	36.3b	40.0fg	38.1	39.4b	42.9f	41.2
DAP + CM	37.8c	39.5f	38.6	41.3ci	42.2fi	41.8
DAP + FYM	41.6di	41.4gi	41.5	44.4dj	44.2gj	44.3
FYM	40.4d	40.1gi	40.2	43.4dk	43.2gk	43.3
Mean	38.3	39.5		41.3	42.4	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	1.0			1.0		
$LSD_{0.05}$ HM	0.6			0.6		
$LSD_{0.05}$ Fert.HM	1.4			1.4		
CV%	5.4			5.0		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

Table 4.11: Effect of fertilizer application and harvesting method on chlorophyll concentration of African nightshade in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	43.3a	46.9e	45.1	41.3a	44.9e	43.1
CM	43.7a	45.1f	44.4	41.6a	43.0f	42.3
DAP	46.0bj	45.4fj	45.7	43.6bj	43.2fj	43.4
DAP + CM	48.7c	43.5g	46.1	46.3c	40.8g	43.5
DAP + FYM	47.7c	46.2h	47.0	45.3c	43.9h	44.6
FYM	44.0dk	44.4ik	44.2	41.6dk	42.1ik	41.8
Mean	45.6	45.3		43.3	43.0	
P-value Fert.	<.001			<.001		
P-value HM	NS			NS		
P-value Fert. HM	<.001			<.001		
$LSD_{0.05}$ Fert.	0.8			0.8		
$LSD_{0.05}$ HM	NS			NS		
$LSD_{0.05}$ Fert.HM	1.1			1.2		
CV%	3.7			4.0		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

4.4.1.6 Number of Pods/Fruits per Plant

Fertilizer application and the interaction between fertilizer and harvesting method had significant effects ($p \leq 0.05$.) on the number of pods/fruits per plant of cowpea and African nightshade in both seasons (Table 4.12 and Table 4.13). In cowpea, fertilizer application significantly increased the number of pods/plant in both piecemeal and wholesome harvested plots in both seasons except FYM treated plants in wholesome harvested plots in both seasons. Application of DAP had significantly the highest number of pods/plant compared to all other fertilizer treatments in piecemeal harvested plots in both seasons and application of DAP + CM significantly increased number of pods per plant compared to all the other fertilizer treatments in wholesome harvested plants in both seasons. However, there were no significant differences in number of pods per plant noted in fertilizer supplied plots between FYM and CM treated plants in piecemeal harvested plots in both seasons and CM and FYM treated plants and between DAP and DAP + CM treated plants in wholesome harvested plots in both seasons. Generally, DAP + CM and DAP + FYM treatments had significantly higher number of pods/plant than CM and FYM treatments in both piecemeal and wholesome harvested cowpea plots in both seasons (Table 4.12).

In African nightshade, fertilizer application significantly increased the number of fruits/plant in both piecemeal and wholesome harvested plots in both seasons (Table 4.13). Application of DAP had significantly the highest number of fruits/plant compared to all the other fertilizer treatments in both piecemeal and wholesome harvested plots in both seasons. Generally, DAP + CM and DAP + FYM treatments had significantly higher number of fruits/plant than CM and FYM treatments in both piecemeal and wholesome harvested plots in both seasons. Irrespective of the fertilizer treatment, wholesome harvested plots had significantly lower number of African nightshade fruits/plant than piecemeal harvested plots in both seasons (Table 4.13).

Table 4.12: Effect of fertilizer application and harvesting method on number of pods/plant of cowpea in the first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	3.7a	4.7f	4.2	2.0a	2.7f	2.3
CM	7.0b	7.0g	7.0	5.0b	5.0g	5.0
DAP	19.3c	13.3h	16.3	17.3c	11.3h	14.3
DAP + CM	12.7d	14.3h	13.5	11.3d	12.3h	11.8
DAP + FYM	9.3e	10.0i	9.7	7.3e	8.3i	7.8
FYM	6.3b	5.7g	6.0	4.3b	4.0g	4.2
Mean	9.7	9.2		7.9	7.3	
P-value Fert.	<.001			<.001		
P-value HM	NS			NS		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	1.2			1.3		
$LSD_{0.05}$ HM	NS			NS		
$LSD_{0.05}$ Fert.HM	1.7			1.8		
CV%	26.7			34.4		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

Table 4.13: Effect of fertilizer application and harvesting method on number of fruits/plant of African nightshade in first and second season during 2015 and 2016, respectively

	First season			Season second		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	42.4a	35.4g	38.9	22.4a	15.4g	18.9
CM	151.3b	122.0h	136.7	131.3b	102.0h	116.7
DAP	282.6c	201.3i	242.0	262.6c	181.3i	222.0
DAP + CM	205.3d	183.7j	194.5	185.3d	163.7j	174.5
DAP + FYM	180.7e	152.7k	166.7	160.7e	132.7k	146.7
FYM	123.7f	83.0l	103.4	103.7f	63.0l	83.4
Mean	164.3	129.7		144.3	109.7	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	1.3			1.3		
$LSD_{0.05}$ HM	0.7			0.7		
$LSD_{0.05}$ Fert.HM	1.8			1.8		
CV%	1.7			2.0		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 tons/ha), DAP (100 kg/ha) + CM (5 tons/ha), DAP (100 kg/ha) + FYM (5 tons/ha), farmyard manure (FYM) (10 tons/ha) and LSD-least significant difference

4.4.1.7 Seed WEIGHT

Fertilizer application and the interaction between fertilizer and harvesting method had significant effects ($p \leq 0.05$.) on 100-seed weight of cowpea in both seasons (Table 4.14). However, harvesting method had no significant effect ($p \leq 0.05$.) on 100-seed weight of cowpea in both seasons (Table 4.14).Fertilizer application significantly increased 100-seed weight in both piecemeal and wholesome harvested plots in both seasons. Application of DAP had significantly the highest 100-seed weight compared to the other fertilizer treatments in both piecemeal and wholesome harvested plots in both seasons. However, there were no significant differences in seed weight noted between CM and DAP + FYM treated plots in piecemeal and wholesome harvested plots in both seasons. There were no significant differences between piecemeal and wholesome harvested plants in plots supplied with CM, DAP + CM and DAP + FYM in both seasons. Generally, DAP + CM treatment out-performed CM and FYM treatments in both piecemeal and wholesome harvested plants in both seasons (Table 4.14).

Fertilizer application, harvesting method and their interaction had significant effects ($p \leq 0.05$.) on 1000-seed weight of African nightshade in both seasons (Table 4.15). Fertilizer application significantly increased 1000-seed weight in both piecemeal and wholesome harvested plots in both seasons. Application of DAP had significantly the highest 1000-seed weight compared to the other fertilizer treatments in both piecemeal and wholesome harvested African nightshade plots in both seasons. Generally, DAP + CM and DAP + FYM treatments had significantly higher 1000-seed weight than CM and FYM treatments in both piecemeal and wholesome harvested plots in both seasons. However, no significant differences in 1000-seed weight were noted between piecemeal and wholesome harvested plants in plots supplied with DAP + CM, DAP + FYM and FYM treatments in both seasons (Table 4.15).

Table 4.14: Effect of fertilizer application and harvesting method on 100-seed weight (g) of cowpea in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	6.6a	6.7f	6.6	5.6a	5.7f	5.6
CM	8.7bk	8.7gk	8.7	7.7bk	7.7gk	7.7
DAP	9.7c	10.5h	10.1	8.7c	9.5h	9.1
DAP + CM	9.4dl	9.3il	9.3	8.4dl	8.3il	8.3
DAP + FYM	8.9bm	8.9gm	8.9	7.9bm	7.9gm	7.9
FYM	7.8e	7.6j	7.7	6.8e	6.6j	6.7
Mean	8.5	8.6		7.5	7.6	
P-value Fert.	<.001			<.001		
P-value HM	NS			NS		
P-value Fert.HM	<.001			<.001		
LSD$_{0.05}$ Fert.	0.2			0.2		
LSD$_{0.05}$ HM	NS			NS		
LSD$_{0.05}$ Fert.HM	0.2			0.2		
CV%	4.0			4.6		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

Table 4.15: Effect of fertilizer application and harvesting method on 1000-seed weight (g) of African nightshade in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	1.5a	1.2g	1.4	1.4a	1.2g	1.3
CM	3.2b	2.9h	3.0	2.2b	2.4h	2.3
DAP	6.6c	6.1i	6.4	5.6c	5.1i	5.3
DAP + CM	5.2dm	5.1jm	5.2	4.2dm	4.2jm	4.2
DAP + FYM	4.2en	4.1kn	4.2	3.3en	3.2kn	3.2
FYM	2.1fo	2.0lo	2.1	2.0fo	2.0lo	2.0
Mean	3.8	3.6		3.1	3.0	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
LSD$_{0.05}$ Fert.	0.04			0.1		
LSD$_{0.05}$ HM	0.02			0.1		
LSD$_{0.05}$ Fert.HM	0.05			0.1		
CV%	1.9			6.3		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

4.4.1.8 Leaf Yield

Fertilizer application, harvesting method and their interactions had significant effects ($p \leq 0.05$) on leaf yields of cowpea and African nightshade in both seasons (Table 4.16 and Table 4.17). In cowpea, fertilizer application significantly increased leaf yield in both piecemeal and wholesome harvested plots in both seasons. Application of DAP had significantly the highest leaf yield compared to all the other fertilizer treatments in both piecemeal and wholesome harvested plots in both seasons. However, there were no significant differences in leaf yield noted between DAP + CM and DAP + FYM treated plots in wholesome harvested plots in the first season. Generally, DAP + CM and DAP + FYM treatments significantly out-yielded CM and FYM treatments in both piecemeal and wholesome harvested plots in both seasons. Irrespective of the fertilizer treatment, wholesome harvested plots had significantly lower leaf yield than piecemeal harvested plots in both seasons (Table 4.16).In African nightshade, fertilizer application significantly increased leaf yield in both piecemeal and wholesome harvested plots in both seasons. Application of DAP had significantly the highest leaf yield compared to all the other fertilizer treatments in both piecemeal and wholesome harvested plots in both seasons. Generally, DAP + CM and DAP + FYM treatments significantly out-yielded CM and FYM treatments in both piecemeal and wholesome harvested plots in both seasons. Irrespective of the fertilizer treatment, wholesome harvested plots had significantly lower leaf yield than piecemeal harvested plots in both seasons (Table 4.17).

Table 4.16: Effect of fertilizer application and harvesting method on leaf yield (kg/ha) of cowpea in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (fert.)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control(No fertilizer)	1731.3a	975.1g	1353.2	1203.8a	716.4g	960.1
CM	3647.1b	2017.4h	2832.2	3219.3b	1991.5h	2605.4
DAP	5588.1c	3032.1i	4310.1	5160.0c	2971.4i	4065.7
DAP + CM	4173.9d	2318.6j	3246.3	3745.0d	2157.7j	2951.3
DAP + FYM	3946.3e	2292.6j	3119.4	3526.8e	2060.4k	2793.6
FYM	2976.1f	1735.5k	2355.8	2547.5f	1570.8l	2059.1
Mean	3677.1	2061.9		3233.7	1911.4	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ fert.	26.8			13.4		
$LSD_{0.05}$ HM	15.5			7.8		
$LSD_{0.05}$ Fert.HM	38.0			19.0		
CV%	1.9			1.1		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference.

Table 4.17: Effects of fertilizer application and harvesting method on leaf yield (kg/ha) of African nightshade in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	1103.6a	616.2g	859.9	706.4a	411.1g	558.7
CM	2619.4b	1324.9h	1972.1	2216.3b	1136.9h	1676.6
DAP	4560.1c	2304.8i	3432.4	4134.3c	2096.1i	3115.2
DAP + CM	3145.0d	1591.1j	2368.0	2742.3d	1384.5j	2063.4
DAP + FYM	2926.8e	1460.4k	2193.6	2498.6e	1238.8k	1868.7
FYM	1947.5f	970.8l	1459.2	1543.6f	771.8l	1157.7
Mean	2717.1	1378.0		2306.9	1173.2	
P-value Fert.	<.001			<.001		
P-value HM	<.001			<.001		
P-value Fert.HM	<.001			<.001		
$LSD_{0.05}$ Fert.	5.6			8.1		
$LSD_{0.05}$ HM	3.3			4.7		
$LSD_{0.05}$ Fert.HM	8.0			11.5		
CV%	0.6			1.0		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

4.4.1.9 Grain Yield

Fertilizer application and harvesting method had significant effects ($p \leq 0.05$.) on grain yield of cowpea in both seasons (Table 4.18). However, the interaction between fertilizer and harvesting method had a significant effect on grain yield only in the second season (Table 4.18). In the first season, all fertilizer treated plots had significantly higher grain yield than plots that did not receive fertilizer. However, no significant differences in grain yield were noted among CM and FYM, DAP + CM and DAP + FYM treatments in wholesome harvested plots in the second season and among DAP and DAP + CM treatments and between DAP + CM and DAP + FYM treatments in piecemeal harvested plots in the second season. Piecemeal harvested plants had significantly higher grain yield than wholesome harvested plants (Table 4.19). In the second season, fertilizer application significantly increased grain yield in both piecemeal and wholesome harvested plots, except CM in both piecemeal and wholesome harvested plots and FYM in wholesome harvested plots. Piecemeal harvested plants had significantly higher grain yield than wholesome harvested plants in plots supplied with DAP + FYM and FYM treatments (Table 4.18).

Table 4.18: Effect of fertilizer application and harvesting method on grain yield (kg/ha) of cowpea in first and second season during 2015 and 2016, respectively

	First season			Second season		
	Harvesting method (HM)					
Fertilizers (Fert)	Piecemeal	Wholesome	Means	Piecemeal	Wholesome	Means
Control (No fert)	801.0a	854.0b	827.0	1011.0a	1059.0e	1035.0
CM	1395.0a	1219.0b	1307.0	1105.0b	1140.0f	1123.0
DAP	2074.0a	2208.0b	2141.0	1937.0b	2072.0g	2005.0
DAP + CM	1938.0a	1743.0b	1840.0	1803.0c	1609.0h	1706.0
DAP + FYM	1520.0a	1355.0b	1438.0	1774.0c	1460.0h	1617.0
FYM	1442.0a	934.0b	1188.0	1435.0d	945.0f	1190.0
Mean	1528.0	1385.0		1511.0	1381.0	
P-value Fert.	<.001			<.001		
P-value HM	0.02			0.03		
P-value Fert.HM	NS			0.02		
LSD$_{0.05}$ Fert.	212.1			195.4		
LSD$_{0.05}$ HM	122.4			112.8		
LSD$_{0.05}$ Fert.HM	NS			276.3		
CV%	29.8			27.6		

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha) and LSD-least significant difference

4.4.1.10 Vitamin A, Vitamin C, Phenolics and total Antioxidant Activity

Fertilizer application, harvesting method and their interaction had no significant($p \leq 0.05$) effect on Vitamin A, Vitamin C, phenolics and total antioxidant activity of both species in both seasons (Table 4.19- 4.26). Among the fertilizer treatments, average vitamin A, vitamin C, phenolics and total antioxidant activity contents of cowpea ranged from 63.3 to 35.9 mg/100g, 59.1 to 33.1 mg/100g, 201.4 to 161.1mg/100g and 17.7 to 11.9 mg/ml, respectively, in the first season (Table 4.19) and 63.0 to 40.4 mg/100g, 64.5 to 49.4 mg/100g, 191.4 to 151.1mg/100g and 14.7 to 8.9 mg/ml, respectively, in the second season (Table 4.20). Between the harvesting methods, average vitamin A, vitamin C, phenolics and total antioxidant activity contents ranged from 55.8 to 46.3 mg/100g, 51.9 to 42.7 mg/100g, 186.3 to 178.1mg/100g and 14.8 to 14.4 mg/ml, respectively, in the first season (Table 4.21) and from 56.2 to 45.9 mg/100g, 58.5 to 55.1mg/100g, 176.3 to 168.1mg/100g and 11.8 to 11.5 mg/ml, respectively, in the second season (Table 4.22). Among the fertilizer treatments, average of vitamin A, vitamin C, phenolics and total antioxidant activity of African nightshade ranged from 61.3 to 39.1mg/100g, 62.5 to 40.9 mg/100g, 190.3 to 154.2 mg/100g and 17.7 to 11.91 mg/ml, respectively, in the first season (Table 4.23) and from 57.6 to 35.1 mg/100g, 59.5 to 44.6 mg/100g, 180.3 to 144.2 mg/100g and 15.7 to 9.9 mg/ml, respectively, in the second season (Table 4.24). Between harvesting methods, average vitamin A, vitamin C, phenolics and total antioxidant activity contents ranged from 54.2 to 45.4 mg/100g, 55.2 to 46.3 mg/100g, 177.7 to 168.3 mg/100g and 14.8 to 14.4 mg/ml, respectively, in the first season (Table 4.25) and 50.9 to 41.8 mg/100g, 53.6 to 50.0 mg/100g, 167.7 to 162.4 mg/100g and 12.8 to 12.4 mg/ml, respectively, in the second season (Table 4.26).

Table 4.19: Effect of fertilizer application on vitamin A (mg/100g), vitamin C (mg/100g), phenolics (mg/100g) and total antioxidant activity (mg/ml) of cowpea in the first season during 2015

First season				
Fertilizers	Vit A	Vit C	Phenolic	Total antioxidant activity
Control (No fert	35.9	33.1	161.1	11.9
CM	55.5	51.2	192.5	16.3
DAP	63.3	59.1	201.4	17.7
DAP + CM	56.8	53	191.9	15.1
DAP + FYM	48.6	45.3	178.7	14.2
FYM	46.2	42.1	167.6	12.4
Mean	51.1	47.3	182.2	14.6
P-value	NS	NS	NS	NS
$LSD_{0.05}$	NS	NS	NS	NS
CV%	31	32.2	19.1	30.6

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha), LSD-least significant difference, vitamin A (Vit A) and vitamin C (Vit C)

Table 4.20: Effect of fertilizer application on vitamin A (mg/100g), vitamin C (mg/100g), phenolics (mg/100g) and total antioxidant activity (mg/ml) of cowpea in the second season during 2016

		Second season		
Fertilizers	Vit A	Vit C	Phenolic	Total antioxidant activity
Control (No fert	40.4	49.4	151.1	8.9
CM	58.1	60.3	182.5	13.3
DAP	63	64.5	191.4	14.7
DAP + CM	54	58.5	181.9	12.3
DAP + FYM	44.4	56.6	168.7	11.2
FYM	46.4	51.3	157.6	9.4
Mean	51.1	56.8	172.2	11.6
P-value	NS	NS	NS	NS
$LSD_{0.05}$	NS	NS	NS	NS
CV%	32.8	30.3	20.3	38.4

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha), LSD-least significant difference, vitamin A (Vit A) and vitamin C (Vit C)

Table 4.21: Effect of harvesting method on vitamin A (mg/100g), vitamin C (mg/100g), phenolics (mg/100g) and total antioxidant activity (mg/ml) of cowpea in the first season during 2015

		First season		
Harvesting method	Vit A	Vit C	Phenolic	Total antioxidant activity
Piecemeal	46.3	42.7	178.1	14.4
Wholesome	55.8	51.9	186.3	14.8
Mean	51.1	47.3	182.2	14.6
P-value	NS	NS	NS	NS
$LSD_{0.05}$	NS	NS	NS	NS
CV%	31	32.2	19.1	30.6

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha), LSD-least significant difference, vitamin A (Vit A) and vitamin C (Vit C)

Table 4.22: Effect of harvesting method on vitamin A (mg/100g), vitamin C (mg/100g), phenolics (mg/100g) and total antioxidant activity (mg/ml) of cowpea in the second season during 2016

Second season				
Harvesting method	Vit A	Vit C	Phenolic	Total antioxidant activity
Piecemeal	45.9	55.1	168.1	11.5
Wholesome	56.2	58.5	176.3	11.8
Mean	51.1	56.8	172.2	11.6
P-value	NS	NS	NS	NS
$LSD_{0.05}$	NS	NS	NS	NS
CV%	32.8	30.3	20.3	38.4

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha), LSD-least significant difference, vitamin A (Vit A) and vitamin C (Vit C)

Table 4.23: Effect of fertilizer application on vitamin A (mg/100g), vitamin C (mg/100g), phenolics (mg/100g) and total antioxidant activity (mg/ml) of African nightshade in the first season during 2015

		First season		
Fertilizers	Vit A	Vit C	Phenolic	Total antioxidant activity
Control (No fert	39.1	40.9	154.2	11.9
CM	57.1	53.7	179.2	16.3
DAP	61.3	62.5	190.3	17.7
DAP + CM	52.8	52.5	181.3	15.1
DAP + FYM	43.6	52	170.4	14.2
FYM	44.9	42.8	162.1	12.4
Mean	49.8	50.7	172.9	14.6
P-value	NS	NS	NS	NS
$LSD_{0.05}$	NS	NS	NS	NS
CV%	34.4	35.2	20.3	30.6

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha), LSD-least significant difference, vitamin A (Vit A) and vitamin C (Vit C)

Table 4.24: Effect of fertilizer application on vitamin A (mg/100g), vitamin C (mg/100g), phenolics (mg/100g) and total antioxidant activity (mg/ml) of African nightshade in the second season during 2016

		Second season		
Fertilizers	Vit A	Vit C	Phenolic	Total antioxidant activity
Control (No fert)	35.1	44.6	144.2	9.9
CM	53.1	55.3	183.8	14.3
DAP	57.6	59.5	180.3	15.7
DAP + CM	48.8	53.5	171.3	13.1
DAP + FYM	39.3	51.7	158.7	12.2
FYM	41.2	46.1	152.1	10.4
Mean	45.9	51.8	165.1	12.6
P-value	NS	NS	NS	NS
$LSD_{0.05}$	NS	NS	NS	NS
CV%	36.8	33.2	20.3	35.4

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha), LSD-least significant difference, vitamin A (Vit A) and vitamin C (Vit C)

Table 4.25: Effect of harvesting method on vitamin A (mg/100g), vitamin C (mg/100g), phenolics (mg/100g) and total antioxidant activity (mg/ml) of African nightshade in the first season during 2015

		First season		
Harvesting method	Vit A	Vit C	Phenolic	Total antioxidant activity
Piecemeal	45.4	46.3	168.1	14.4
Wholesome	54.2	55.2	177.7	14.8
Mean	49.8	50.8	172.9	14.6
P-value	NS	NS	NS	NS
$LSD_{0.05}$	NS	NS	NS	NS
CV%	34.4	35.2	20.3	30.6

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha), LSD-least significant difference, vitamin A (Vit A) and vitamin C (Vit C)

Table 4.26: Effect of harvesting method on vitamin A (mg/100g), vitamin C (mg/100g), phenolics (mg/100g) and total antioxidant activity (mg/ml) of African nightshade in the second season during 2016

	Second season			
Harvesting method	Vit A	Vit C	Phenolic	Total antioxidant activity
Piecemeal	41.8	50	162.4	12.4
Wholesome	50.9	53.6	167.7	12.8
Mean	46.4	51.8	165.1	12.6
P-value	NS	NS	NS	NS
$LSD_{0.05}$	NS	NS	NS	NS
CV%	36.8	33.2	20.3	35.4

DAP-Di-ammonium phosphate (200 kg/ha), chicken manure (CM) (10 t/ha), DAP (100 kg/ha) + CM (5 t/ha), DAP (100 kg/ha) + FYM (5 t/ha), farmyard manure (FYM) (10 t/ha), LSD-least significant difference, vitamin A (Vit A) and vitamin C (Vit C)

4.5 Discussion

Fertilizer application significantly increased plant growth attributes (plant height, leaf area, number of branches/plant and number of leaves/plant), leaf yield, grain yield and yield components of cowpea and African nightshade in both piecemeal and wholesome harvested plots. This finding is in agreement with Onyango (2003, Kipkosgei, 2004, Akanbi *et al*., (2006), and Ojetayo *et al*., (2011) who observed increase in growth parameters with fertilizer application. Fertilizer application significantly increased the number of pods/plant, hundred seed weight and grain yield. Similar findings were observed by Atakora *et al*., (2014), who reported that phosphorus application increased stover and grain yields of cowpea. Similar findings were observed by Rajput (1994) Owolade *et al*. (2006) and Singh *et al*. (2011b) who reported significant effects of chemical fertilizers on 100 seed weight, number of pods per plant and number of seeds per pods leading to higher grain yield.

In most cases, application of 200 kg/ha DAP significantly out-performed FM (10 t/ha), CM (10 t/ha), DAP (100 kg/ha) + CM (10 t/ha) and DAP (100 kg/ha) + FYM (5 t/ha)) in growth attributes, leaf yield and grain yield. This can be attributed to the fact that 200 kg/ha DAP released higher N and P nutrient levels than manures alone and manures combined with low DAP doses (100 kg/ha). Nitrogen is an essential element and important determinant in growth and development of vegetables. It helps in cell division and cell elongation hence facilitates more shoot formation (Miller, 2010). Adequate supply of phosphorous early in plant life is important in laying down the primordial for plant growth. It is also an essential constituent of majority of enzymes which are responsible in the transformation of energy in carbohydrate metabolism, fat metabolism and also in respiration that stimulates shoot formation in vegetables. This might also be due to the fact that nitrogen and phosphorous from the inorganic fertilizers have been shown to be readily available for plant uptake compared to that supplied by manures (Powlsen *et al*. 2014). Nitrogen application of between 100-250 Kg N/ha has been shown to increase fresh and dry weight above ground biomass in leafy vegetables such as *Solanum retroflexum* and *Brassica raph* (Van Averbeke *et al*., 2007) in comparison to vegetables which did not receive any nitrogen.

Combinations of inorganic and organic fertilizers significantly increased plant growth attributes, leaf yield, grain yield and yield components of cowpea and African nightshade relative to sole applications of chicken manure and farmyard manure. This is possibly due to the synergistic effects of inorganic and organic fertilizers which result in increased soil available macro and micro nutrients status that are readily available for plants uptake hence promoting vegetative growth and yields (Singh *et al*., 2006; Zeid *et al*., 2015). Studies by Kipkoskei *et al.* (2003) demonstrated that a combination of 7.5 t/ha FYM and 150 kg N/ha, increased yields of edible parts of African nightshade from about 2 t/ha in controls to approximately 16.9 t/ha. Love, (2012) while working on grain amaranth reported that a combination of cow dung manure (6.8 t/ha) with Calcium Ammonium Nitrate (83.25 kg/ha) significantly improved the growth, development and yield of grain amaranth, through increased number of flowers per plant, individual plant canopy size, plant height, stem width, plant dry matter weight and 1000 seed weight. Combinations of inorganic and organic fertilizers significantly increased chlorophyll content of cowpea and African nightshade in both seasons. Similar findings were observed by Ainika *et al.*, (2011), who reported that combination of organic and inorganic improved leaf chlorophyll concentration. Piecemeal harvesting had significantly more superior plant growth attributes, leaf yield, grain yield and yield components of cowpea and African nightshade in fertilizer supplied plots. Similar findings were observed by Bubenheim *et al.*, (1990) that continuous harvesting of black nightshade with topping provided the highest economic leaf yield of 32.0 t/ha, while continuous harvesting without topping gave the lowest leaf yield (17.8 t/ha). In a trial carried out by Saidi (2007) in Katumani, Kenya, frequent harvesting of cowpea leaves at 7-day intervals resulted in significantly higher leaf vegetable yields of 2500 and 1500 kg/ha in short and long rainy seasons, respectively compared to 14-day intervals of 1100 and 800 kg/ha in the short and long rains, respectively, because frequent leaf harvesting stimulated leaf production. In the present study, wholesome harvested plants had significantly higher chlorophyll content than piecemeal harvested plants under the no-fertilizer control and manure alone plots. In contrast, piecemeal harvested plants had significantly higher chlorophyll content than wholesome harvested plants in plots supplied with combinations of inorganic and organic fertilizers. This is due to piecemeal harvested plants required nutrients for the regrowth while wholesome harvested plants utilize nutrients in the soil thus high chlorophyll concentration than piecemeal harvested plants.

Fertilizer, harvesting method and their interactions had no significant effects on leaf vitamins A and C, phenolics and total antioxidant activity of cowpea and African nightshade in both seasons. According to Murage, 1990, use of N has been observed to decrease vitamin C content in other crops such as *Solanum spp*. complex. According to Ong'era *et al*., 2013, use of CAN fertilizer led to significant reductions in the amount of total phenolics, total flavonoids and tannins. Phenolics and antioxidant activity increase the scavenging capacity against reactive oxygen species (ROSs) that damage cellular membranes under drought stress.

4.6 Conclusion

Fertilizer application increased the growth parameters, grain yield and leaf yield but had no influence on leaf vitamin A, leaf vitamin C, phenolics and antioxidant activity in both cowpea and African nightshade in both seasons. Piecemeal harvesting had significantly more superior plant growth attributes, leaf yield, grain yield and yield components of cowpea and African nightshade than wholesome harvesting in fertilizer supplied plots. Harvesting method had no significant effect on leaf vitamins A and C, phenolics and antioxidant activity in both crops. Irrespective of the fertilizer treatment, wholesome harvested plants had significantly lower growth parameters, leaf yield, and grain yield of cowpea and African nightshade than piecemeal harvested plants. Di-ammonium phosphate (200 kg/ha) and the combinations of inorganic (DAP 100 kg/ha) and organic (chicken manure 5 t/ha) were the best treatments in this study.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

In both cowpea and African nightshade, chlorophyll concentration, all plant growth parameters including plant height, leaf number, number of branches/plant and leaf area/plant and leaf/grain yield and its components significantly reduced with decline in soil water levels in both seasons. A decrease in photosynthetic rate under drought stress occurs through stomatal closure and reduction of photosynthetic activity (Lawlor, 2002). Similar findings were observed by Kumar *et al.,* (2011) and Ndiso *et al*., (2017), who reported that the decrease in chlorophyll concentration under drought stress is a commonly observed phenomenon. Leaf yield reduction with decline in soil water levels was associated with dramatic decrease in its components such as leaf number, branches number, leaf fresh weight and leaf area. Grain yield reduction was associated with dramatic decrease in all grain components such as number of pods/plant and seed weight. Similar findings were observed by Liu *et al.,*(2003) and Vurayai *et al.*, (2011), who reported that the negative effect of water stress on plant growth, resulting in a reduction in the supply of carbon assimilates to new formation of branches and leaves and a decreased translocation of assimilates towards developing fruits and also increased flower abscission and pod abortion.

Total phenolics and antioxidant activity contents significantly increased with reduction in soil water levels in order to increase scavenging capacity against reactive oxygen species (ROSs) that damage cellular membranes under drought stress. Similar findings were observed by Chen *et al*., 2011 who reported that water stress increased phenolics and total antioxidant activity in *Prunella vulgaris* L. plants. Leaf vitamin A and C decreased with decline in water levels (Wen and Begg (2014). Fertilizer application significantly increased chlorophyll concentration; plant growth parameters, leaf and grain yield of cowpea and African nightshade but had no significant effect on leaf nutritional quality of both species in both seasons. Similar findings were observed by Akanbi *et al*., (2006) and Ojetayo *et al*., (2011) who observed increased in growth parameters with fertilizer application.DAP (200 kg/ha) fertilizer had significantly higher growth parameters, leaf and grain yield and their components than sole application of either chicken manure (10 t/ha) or farmyard manure (10 t/ha) in both seasons because DAP fertilizer release nutrients fast and in large quantities than manures alone (Powlsen *et al*., 2014). Combinations of DAP + CM and DAP + FYM had significantly higher growth parameters, chlorophyll concentration, leaf yield, grain yield and their components of cowpea and African nightshade than sole application of either chicken manure and farmyard manure in both seasons but they out-performed CM and FYM treatments in both crops. Similar finding was observed by Love, (2012) while working on grain amaranth reported that a combination of cow dung manure (6.8 t/ha) with Calcium Ammonium Nitrate (83.25 kg/ha) significantly improved the growth, development and yield of grain amaranth.

Irrespective of the fertilizer treatment, piecemeal harvested plants had significantly higher number of branches/plant, leaf number/plant, leaf area/plant, number of pods/fruits per plant, seed weight and leaf yield of cowpea and African nightshade than wholesome harvested plants in both seasons. It also had significantly higher grain yield of cowpea in both seasons. Similar findings was observed by (Bubenheim *et al*., (1990) that continuous harvesting of black nightshade with topping provided the highest economic leaf yield of 32.0 t/ha, while continuous harvesting without topping gave the lowest leaf yield(17.8 t/ha). Wholesome harvested plants had significantly higher chlorophyll content of cowpea than piecemeal harvested plants in both seasons. Fertilizer application, harvesting method and their interactions had no significant effects on leaf vitamins A and C, phenolics and total antioxidant activity of cowpea and African nightshade in both seasons. Similar findings were observed by Murage, 1990 and Ong'era *et al*., 2013, who reported that use of N decreases vitamin C content, total phenolics and total flavonoids in other crops such as nightshades.

5.2 Conclusion

Moisture stress significantly reduced plant height, leaf area, number of branches per plant, number of leaves per plant, chlorophyll concentration, leaf yield, number of pods/fruits per plant leaf vitamin A, and leaf vitamin C in both cowpea and African nightshade. In cowpea, reduction in soil moisture levels also significantly decreased 100-

seed weight and grain yield. Moisture stress significantly increased the phenolics content and total anti-oxidant activity with reduction in soil water levels in both crops. Reduction of moisture from 100% PC to 40% PC led to increases in phenolics and total antioxidant by 29.4 and 18.7%, respectively, in cowpea and 34.5 and 45%, respectively, in African nightshade. Fertilizer application significantly increased plant height, branches number, leaf area, chlorophyll concentration, pods/fruits number, seed weight, number of leaves per plant and leaf yield of cowpea and African nightshade and grain yield of cowpea in both seasons. Inorganic (DAP) fertilizer had significantly higher plant growth parameters, leaf/grain yield and their components than either chicken manure or farmyard manure. Combinations of inorganic and organic fertilizers had higher plant growth parameters, chlorophyll concentration, leaf yield and its components and grain yield and its components of both species than sole application of either farmyard or chicken manure in both seasons. Relative to wholesome harvesting, piecemeal harvesting significantly increased the number of leaves, pods/fruits number per plant, grain yield and leaf yield in both crops.

Fertilizer application and harvesting method had no significant effect on leaf vitamin A and C, phenolics and antioxidant activity in both crops in both seasons. Irrespective of either combinations of organic and inorganic fertilizers or DAP fertilizer, piecemeal harvested plants had significantly higher plant growth parameters, leaf and its components and grain yield components of both species in both seasons and grain yield of cowpea in season two than wholesome harvested plants.

5.3 Recommendations

1. The use of DAP (200 kg/ha) and combination of organic (chicken manure 5 t/ha) and inorganic fertilizers (DAP 100 kg/ha) are thus recommended for smallholder farmers to sustain soil fertility and productivity because most soils are continuously cropped.
2. Small-scale farmers can grow these crops in areas with little rainfall.
3. Long term studies of fertilizers treatments used in this study should be conducted to further discover their impacts on the physico-chemical properties of the soil.

4. Further research is required to evaluate adaptation of a broad range of cowpea and African nightshade varieties to moisture stress in order to identify more drought tolerant varieties.
5. Further research is required to evaluate adaptation of cowpea and African nightshade to moisture stress in field conditions.

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