EFFECT OF WATER STRESS AND NITROGEN NUTRITION ON GROWTH AND YIELD OF SELECTED AFRICAN TOMATO (*Solanum lycopersicum*) ACCESSIONS AND COMMERCIAL TOMATO VARIETIES

WAITI MARTIN MAINA

B.Sc. Horticulture (Hons.), University of Nairobi

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR

THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

FACULTY OF AGRICULTURE

UNIVERSITY OF NAIROBI

2019

DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other university**.**

WAITI MARTIN MAINA

Signed …… Date…….....

This thesis has been submitted with our approval as University supervisors.

Prof. George N. Chemining'wa

Department of Plant Science and Crop Protection

University of Nairobi

Signed…….…….. Date……

Prof. Jane L. Ambuko

Department of Plant Science and Crop Protection

University of Nairobi

Signed…….. Date……..

DECLARATION OF ORIGINALITY

Name of Student: **Waiti Martin Maina**

Registration Number: **A56/88818/2016**

College: **College of Agriculture and Veterinary Sciences**

Faculty/School/Institute: **Faculty of Agriculture**

Department: **Department of Plant Science and Crop Protection**

Course Name: **Master of Science in Agronomy**

Title of the work: **Effect of water stress and nitrogen nutrition on growth and yield of selected African tomato (*Solanum lycopersicum*) accessions and commercial tomato varieties**

DECLARATION

1. I understand what Plagiarism is and I am aware of the University's policy in this regard
2. I declare that this **thesis** is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other peoples' work or my own work has been used, this has properly been cited and referenced in accordance with the University of Nairobi's requirements.
3. I have not sought or used the services of any professional agencies to produce this work.
4. I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her own work.
5. I understand that any false claim in respect of this work shall result in disciplinary action, in accordance with University Plagiarism Policy.

Signed _____Date: _____

DEDICATION

This work is dedicated to the memory of my late mother Susan Waitherero and my late grandfather Stanley Waiti for their earnest efforts for my schooling through the 8.4.4 system.

ACKNOWLEDGEMENTS

Glory to God, who in His own gracious ways has enabled and sustained me through-out this research work. I also really appreciate the University of Nairobi for awarding me a scholarship to pursue my postgraduate studies at its College of Agriculture and Veterinary Sciences.

I am forever indebted to my thesis supervisors Prof. George N. Chemining'wa and Prof. Jane L. Ambuko for not only guiding me in coming up with the project, implementing it and writing but also going an extra mile of personally providing facilitation whenever I got strained of resources.

I am sincerely grateful to my family members, friends, pastors and my fiancée for their unconditional love, financial and moral support, encouragement, prayers and motivation for me to achieve this degree.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

AFA	Agriculture and Food Authority
ASALs	Arid and Semi-Arid Lands
AVRDC	Asian Vegetable Research Development Centre
CAN	Calcium Ammonium Nitrate
FAO	Food and Agriculture Organization of the United Nations
GoK	Government of Kenya
Ha	Hectare
HCD	Horticulture Crops Directorate
IITA	International Institute for Tropical Agriculture
KALRO	Kenya Agricultural and Livestock Research Organization
KEPHIS	Kenya Plant Health Inspectorate Services
MoALF	Ministry of Agriculture, Livestock and Fisheries
NAAIAP	National Accelerated Agricultural Inputs Access Programme
NFNSP	National Food and Nutritional Policy of Kenya
PC	Pot Capacity
RCBD	Randomized Complete Block Design
WHO	World Health Organization

ABSTRACT

Tomato ranks among the most consumed fruit vegetables in Kenya and in the world. The Kenyan agro-ecosystem, however, faces persistent challenges of inadequate water resources and nitrogen deficient soils that limit productivity of the crop. There exists a wide range of abiotically adapted African tomato accessions that could be harnessed to develop better varieties adaptable to limited moisture conditions and improved nitrogen use efficiency. A study was conducted with objectives of: (i) evaluate the effect of water stress on growth and yield of 10 African tomato accessions [VI005895, VI007540, VI005987, VI006840, VI006825, VI006828, RVI01885, GBK050580, VI005871, VI005990] and five commercial varieties [Rio grande, Cal J, Stallion F1, Master F1, ATM F1] (ii); evaluate the effect of varying levels of nitrogen on growth and yield of selected African tomato accessions and commercial varieties. Trials were set up in 2018 and 2019 both in the greenhouse (for water stress evaluation) and in the field (for nitrogen nutrition evaluation) in randomized complete block design with three replications. The greenhouse experiment was conducted at the University of Nairobi's Kabete field station while the field experiment was conducted at Kabete field station and at Kenya Agricultural and Livestock Research Organization (KARLO) –Mwea field station, Kenya. Greenhouse-grown tomato plants were subjected to three water levels throughout the season: 100%, 70% and 40% pot capacity (PC) i.e the moisture held by pot soil after draining for 24 hours determined using gravimetric moisture determination method. Open field-grown tomato plants were subjected to six levels of nitrogen (control of 0 kg N/Ha, 50 kg N/Ha, 100 kg N/Ha, 150 kg N/Ha, 200 kg N/Ha and 250 kg N/Ha) at vegetative growth stage. Data was collected on growth parameters (plant height, number of primary branches, stem girth, internode length, single leaf area, days to 50% flowering) and yield parameters (total yield, number of fruits per plant/plot, single fruit

weight, fruit length and fruit width, total fruit weight per plant). Data collected were subjected to analysis of variance using Genstat V.15 and means were separated using the least significant difference test at ($P \leq 0.05$). Moisture stress of 70% PC and 40% PC caused significant reductions in plant height, internode length, stem girth and single leaf area of the tomato plants compared to unstressed moisture conditions (100% PC). Total number of fruits per plant, total fruit weight per plant, average single fruit weight, fruit length and fruit width were significantly reduced by reduction in moisture level from 100% PC to 70% PC and below. There was significant variability among genotypes in all the growth and yield traits evaluated. Indigenous tomato genotypes had higher variability than commercial genotypes in growth traits i.e plant height, internode length, and stem girth. Level of nitrogen applied significantly affected ($P \leq 0.05$) the growth parameters observed. Vegetative growth parameters: number of primary branches, plant stem height, stems girth and single leaf area increased with each level of nitrogen applied from control to the other five levels (50, 100, 150, 200 and 250 kg N/Ha) with 250 kg N/Ha recording the highest means for the traits evaluated. Number of fruits per plot and fruit yield per plant increased with increase in N level from 0 to 250 kg N/Ha. The growth and yield traits evaluated in the field varied significantly with genotype. Indigenous tomato genotypes (VI005871, VI005895 and VI005987) were higher performers than commercial genotypes Cal J and Rio Grande in terms of single fruit weight per plant, number of fruits per plant and fruit yield per plant. Variability was mostly evident on agro-morphological parameters such as plant stem height and fruit yield per plant. This genetic variability and better adaptability to drought can be exploited to develop new or improve tomato cultivars through integrating desirable yield traits such as high single fruit weight. These genotypes can also be selected as competitive, cheaper tomato opv seed source option for tomato farmers in Kenya and sub-Saharan Africa.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Tomato (*Solanum lycopersicum*) is one of the most frequently used vegetable in the world and ranks among the top nutritional culinary vegetables consumed in most meals. It is also one of the most affordable crop produce options in improving nutritional security and ameliorating micronutrient deficiencies, especially in Kenya, where malnutrition is prevalent (NFNSP, 2011). Being a tropical crop that can grow even in semi arid areas tomato is a suitable alternative to curb malnutrition in such areas. Tomato fruit is an excellent source of Vitamin C (13.7 mg/100g serving) that is essential for the enhancement of the body immune system and Vitamin K (7.9 μg/100g serving) important for bone protein formation and in aiding blood clotting. It is also a leading source of potassium (237mg/100 g serving) which is important in lowering blood pressure (USDA National Nutrient Database for Standard Reference, 2018).

In the fast growing horticulture industry in Kenya, tomato is ranked second to potato in production among the leading vegetables with approximately 20,111 ha production area, producing 341,026 Metric tonnes valued at Kenyan shillings 13.68 billion in the year 2016 (AFA-HCD, 2015-2016). Despite the importance of tomato in Kenya, various constraints have hindered consistency in production of this crop leading to unfavorable fluctuations in supply hence prices (Sigei *et al*, 2014). These include highly expensive hybrid seeds, high pest and diseases management costs, drought exacerbated by climate change, poor agronomic practices, low soil fertility and high post harvest losses. Unreliable rainfall and frequent droughts in Kenya interrupt open field tomato production often leading to tomato crop failure in many parts of the country (Sigei *et al*, 2014). Tomato crop is sensitive to drought stress, requiring 400-600 mm of water supply daily after transplanting depending on climate (FAO, 2018).

Most Kenyan arable land soils have shown deficiency in nitrogen nutrient due to high mining rate through continuous cropping without adequate external nutrient replenishment among other factors (NAAIAP, 2014). To ensure high productivity of tomato, especially on continuously cultivated arable land, farmers have had to adopt different ways to replenish the soil in order to supply sufficient plant nutrients such as using compost manure, farm yard manure and synthetic fertilizers. Incorrect fertilizer use continues to be a major challenge to many farmers even as the government implements fertilizer subsidy programmes to facilitate access by the Kenyan resource challenged farmer to promote agricultural productivity (NAAIAP, 2014). However, there exists a knowledge gap among farmers in the area of the level of fertilizers to apply for optimum yield without making economic losses (Mangale *et al*., 2015). Therefore most farmers just apply the fertilizers incorrectly with generalized consideration of crop's optimum requirements which may lead to reduced quantity and quality of the yield, soil acidity and poor returns on agro-investment

1.2 Problem statement

Production of tomato in Kenya is largely dependent on irrigation (AFFA-HCD, 2014) which, in most cases, is insufficient particularly with the current shortage of annual rainfall associated with climate change. Research indicates that water requirement for greenhouse grown tomato crops especially in the tropics range from 0.9 litres to 2.3 litres per plant per day (Hermanto, 2005). Tomato being herbaceous is very sensitive to shortage in soil moisture during growth. Severe water stress causes a reduction in vegetative growth rate which results in reduced stem diameter, stem height and chlorophyll content (Sibomana, 2013). If intense water stress occurs at flowering or fruit formation stage, flower abscission occurs and small sized fruits result thus lower yield (Nurrudin, 2001). Kenya has overtime experienced intra- and inter-seasonal fluctuations in

rainfall necessitating adaptation strategies to manage the available water resources for horticultural production which cannot do without sufficient water availability. Effects of such rainfall fluctuations have adversely affected the horticultural subsector in Kenya which includes tomato production. HCDA (2010) indicated a decline in vegetable exports from 82,000 to 72,000 tonnes in year 2008-2009 and attributed this majorly to drought in the same period. FAOSTAT (2016) reported a decline in tomato production in Kenya between year 2008 to 2009 of 30.6 t/ha to 20.9 t/ha and this could be attributed to drought conditions experienced in the country during that period (Republic of Kenya, 2012). A survey carried out in one of the leading tomato producing counties in Kenya, Kiambu, indicated that the major constraint in optimum tomato production is insufficient moisture (Karuku *et al*., 2017). This suggests the need to evaluate climate resilient crop strategies such as using drought tolerant indigenous tomato or developing new cultivars that are better adapted to low soil moisture availability in order to mitigate against climatic variability effects.

Additionally, Kenyan soils have shown significant nitrogen deficiency due to high mining rate through continuous cropping without adequate external nutrient replenishment (NAAIAP, 2014). This necessitates use of synthetic fertilizers to supply the various nutrients. Karuku et al., (2017) reported that low soil fertility in tomato fields is the second major constraint to high tomato yield attainment by farmers in Kenya. Even though in tomato the level of nitrogen fertilizer to be applied will depend on target yield, variety and absence of other abiotic stresses such as water, various field trials by fertilizer and seed companies have indicated that for optimal yields from tomato of 75- 100 t/ha, one should supply the crop with 200-250 kg N/ha. This is because 2.2 to 2.4 kg of nitrogen is removed from the soil per each tonne of tomato fruits produced (Yara, 2010). The presence of high level of diversity in tomato accessions (Tembe, 2016) presents an

opportunity to evaluate their nitrogen use efficiency as compared with the commercial varieties which, in most cases, have higher demand for nitrogen and other macro nutrients to enable high performance than local accessions.

1.3 Justification

While drought stress and low soil fertility are some of the major constraints to optimization of tomato production, there exist a wide range of water stress tolerant tomato accessions in Africa that could be harnessed to improve the current available commercial varieties for adaptability to limited moisture conditions. Accessions and wild tomato genotypes are potentially the best source of drought tolerance genes for tomato improvement. African tomato accessions have been evaluated for diversity in agro-morphological traits and shown to exhibit widely varied genetic diversity (Tembe *et al,* 2017). Evaluation of various African accessions with respect to tolerance to water stress demonstrated significant variations in response to different levels of water stress (Tembe *et al,* 2017).

Agong et al. (2001) reported that there exists a wide range of variation among the genotypes and within genotype groups that contribute to diversity in morphological expression of tomato traits such as varying fresh fruit weight in the study plants. Etissa et al., (2013) reported that NPK application 200 kg N/Ha application in tomato Money Maker increased the biomass yield of such as increased leaf area for photosynthesis. Therefore certain indigenous tomato accessions with superior traits can be used to breed for drought tolerant and nitrogen use efficient tomato hybrids for the Kenyan farmers. The accessions can also be used as competitive alternatives to the expensive, one season hybrid tomato varieties, saving costs for the resource poor farmers who wish to have higher tomato yield production but are constrained by insufficient inputs like fertilizers and irrigation water that are often necessary for hybrid tomato production.

Tomato productivity is imperative to the horticulture subsector, considering that it ranks 2nd after potato in this economic subsector, contributing greatly to the Kenyan economy. In addition, tomatoes contain vitamins such as vitamin C which is useful for strong immune systems, vitamin K needed by the body for stronger bones and vitamin A which is a pre-cursor of beta-carotene and important for vision (Serio *et al*, .2005). Tomato is also a major source of important carotenoids such as lycopene and beta-carotene which are natural dietary antioxidants that destroy free radicals thus reducing risks of cancers in individuals (Bhowmik *et al*, 2012). Cancer is a leading cause of death ranking 3rd in Kenya accounting for 7% of deaths in the country (KNCCS, 2011-2016). This strategy (KNCCS) outlined low vegetable and fruit intake as one of the risk factors leading to cancer cases and sought to increase intake of fruits and vegetables such as tomato by 5% by 2016. This underscores the nutritional importance of tomato in Kenya.

1.4 Objectives

The general objective of the study was to contribute to enhancement of productivity of tomato in Kenya through drought tolerant and nitrogen-use efficient varieties.

The specific objectives of the study were:

(i) To evaluate the effects of water stress on growth and yield components of selected African tomato accessions and commercial varieties

(ii) To evaluate the effects of varying levels of nitrogen nutrient supply on growth and yield components of selected African tomato accessions and commercial varieties

1.5 Hypotheses

(i) The selected African tomato genotypes are more tolerant to soil moisture stress conditions than commercial tomato varieties.

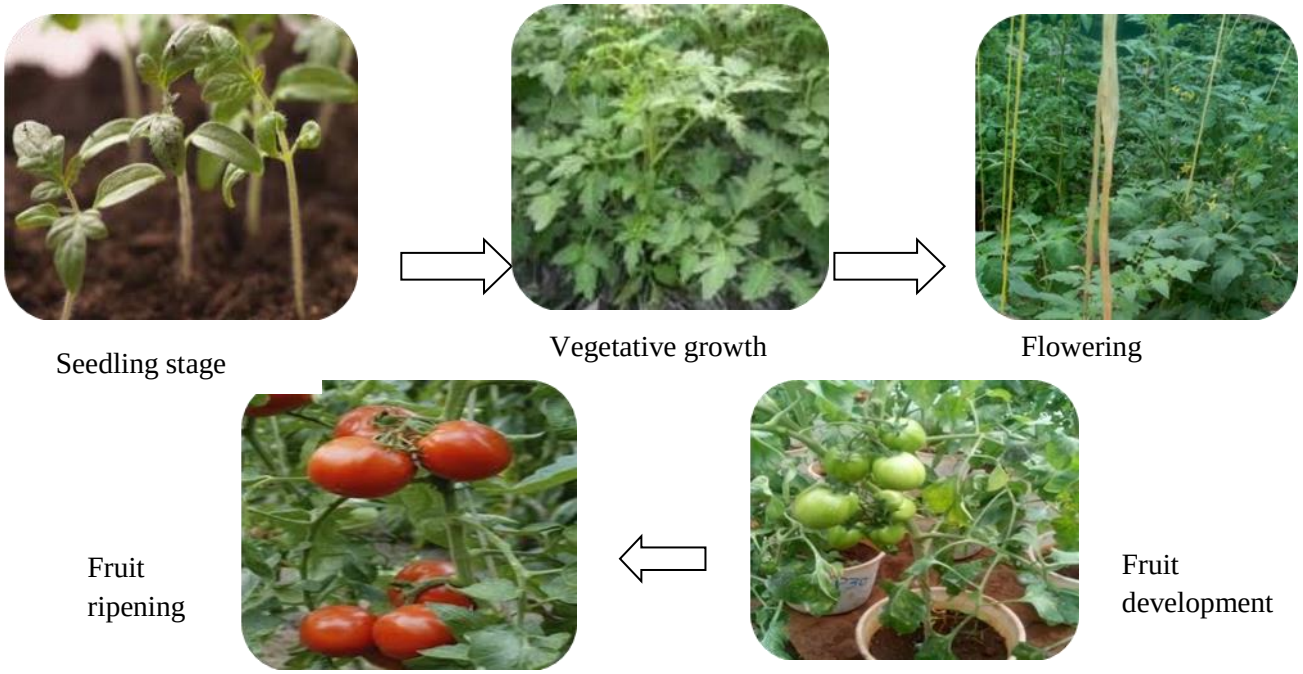
(ii) The selected African tomato genotypes are more responsive to nitrogen fertilizer application than the commercial tomato varieties.

CHAPTER TWO: LITERATURE REVIEW

2.1 Tomato taxonomy, origin and botany

Cultivated tomato (*Solanum lycopersicum* L.) is a very popular and widely grown crop in agricultural systems around the world. Taxonomically, tomato belongs to domain Eukaryota; kingdom Plantae; phylum Spermatophyta; sub-phylum Angiospermae; class Dicotyledonae; order Solanales; family Solanaceae; genus Solanum; species *Solanum lycopersicum* (CAB International, 2018). Tomato is botanically a berry fruit but mostly used as a vegetable. Tomato typically is an annual vine crop growing in three basic stages; the seedling stage where seeds give rise to seedlings, then grows vegetatively till first flower buds appear and then reproductively when the flowers keep budding and fruits set, grow and ripen (Fig 2.1).

Fig 2.1 Pictorial tomato morphological growth cycle
Photo Source: by the author



Tomato plants normally grow to a height of one to three metres and some genotypes can grow up to six metres necessitating staking support. Tomato can be categorized into three categories based on growth patterns; the indeterminate, determinate and semi-determinate. In indeterminate tomato, the apex shoot doesn't bear a flower hence the main and side shoots keep vegetatively growing through several seasons while at the same time producing flowers, fruits and ripening (Gould, 1983). For determinate tomato, the main and side shoots stop growth after cultivar specific number of inflorescences is attained (Haifa, 2017). In semi-determinate tomato, optimum growth is signaled by attainment of specific number of inflorescences but at an advanced stage of growth. Most of the accessions are characterized by the indeterminate growth pattern but few are also determinate (Tembe, 2016).

Tomato is a native of tropical Central and South America especially Peru and Mexico (Sandra and Iris, 2017). With many years since domestication of tomato, it's estimated that there are over 75,000 accessions collected and preserved in different gene banks in the world (Larry *et al.*, 2007). Through selection and breeding for modern cultivar development, much of the diversity has since been sidelined by dropping many accessions and it's estimated that modern tomato varieties contain only 5% of the variation of their wild relatives (Yuling and Pim, 2007). This means that there are many desirable traits, including abiotic stress tolerance traits, which can be exploited if accessions are continuously evaluated and selected.

2.2 Tomato uses and nutritional benefits

Tomato plant uses range from the use of the whole plant for manure composting, animal feed or mulching when the crop has been harvested. However the most commonly used part of the plant is the fruit which is harvested when ripe or near ripe after maturity. The tomato fruit is consumed in different forms including use as a culinary vegetable either raw in diets, used as salads and

preparing fruit desserts, juices and cocktails (Dias, 2012). The fruit can also be cooked as part of the main dish or used as tomato sauce when processed and preserved. Tomato can be grouped into fresh market tomatoes which are consumed fresh and canning / processing tomatoes which are packaged in cans in order to transport/ keep for long time while maintaining value and quality (Villareal, 1980). Tomato fruits nutritional benefits are numerous when incorporated in diets fresh, cooked or processed. They include: major source of important carotenoids such as lycopene, beta-carotene which are dietary natural antioxidants that destroy free radicals thus reducing risk of various types of cancers (Bhowmik *et al*, 2012). Tomatoes contain vitamins such as vitamin C useful for strong immune systems, vitamin K needed by the body for stronger bones and vitamin A which is a pre-cursor of beta-carotene and important for vision (Serio *et al*, .2005). Tomato also contains high iron content needed by the body for hemoglobin synthesis and high potassium content which is important in lowering blood pressure (Table 2.1).

Table 2.1 Nutritional composition of tomatoes (red, ripe, raw, year round average)

Nutrient	Unit	Value per 100g	Value /NLEA 148g	Nutrient	Unit	Value /100g serving	Value /NLEA 148g
Proximates				**Vitamins**			
Water	G	94.52	139.89	Vitamin C	mg	13.7	20.3
Energy	kcal	18	27	Thiamin	mg	0.037	0.055
Protein	G	0.88	1.3	Riboflavin	mg	0.019	0.028
Total lipid (fat)	G	0.2	0.3	Niacin	mg	0.594	0.879
Carbohydrates	G	3.89	5.76	Vitamin B-6	mg	0.08	0.118
Fiber (dietary)	G	1.2	1.8	Folate, DFE	µg	15	22
Sugars, total	G	2.63	3.89	Vitamin B-12	µg	0	0
Minerals				Vitamin A, RAE	µg	42	62
Calcium, Ca	mg	10	15	Vitamin A, IU	IU	833	1233
Iron, Fe	mg	0.27	0.4	Vitamin E	mg	0.54	0.8
Magnesium, Mg	mg	11	16	Vitamin D (D2 + D3)	µg	0	0
Phosphorus, P	mg	24	36	Vitamin D	IU	0	0
Potassium, K	mg	237	351	Vitamin K	µg	7.9	11.7
Sodium, Na	mg	5	7				
Zinc, Zn	mg	0.17	0.25				

Source: USDA National Nutrient Database for Standard Reference, 2018. NLEA- Nutrition Labeling and Education Act of 1990 of the U.S Federal law.

2.3 Ecological requirements and production of tomato

Tomato is a self pollinated warm season crop which grows best at a temperature range of 18-24 °C and takes about 3-4 months from seeding to first ripe fruit production (Seisuke and Neelima, 2008). It does well in soils with high organic matter, well drained with average moisture level since the crop cannot withstand waterlogged conditions due to bacterial wilt and *Pythium* infections (Wilbur, 1983) Best soil type for growing tomatoes is sandy loam with slightly acidic pH of 5.5-7. Tomato is highly susceptible to frost damage and extended periods of high relative humidity leads to high incidence of late blight occurrence (Getachew, 2017). It is moderately sensitive to soil salinity, tolerating salinity of up to ECe 2.5 mmhos/cm and requires about 400-600 mm of water supply after transplanting depending on climate (FAO, 2018). The crop can be categorized as greenhouse or open field tomato depending on best production environment for each with the indeterminate tomato types being preferred for the greenhouse conditions for extended production while the determinate bushy varieties are preferred for short term open field production (Karuku *et al*., 2017).

Tomato is a widely cultivated vegetable in the world ranking second in production after potato with the largest producers being China recording 56,308,914 tonnes and India hitting 18,399,000 tonnes in 2016 (FAOSTAT, 2016). Africa's contribution to the global tomato production is low at 11.3 % when averaged for the period 2010- 2016 (Figure 2.2).

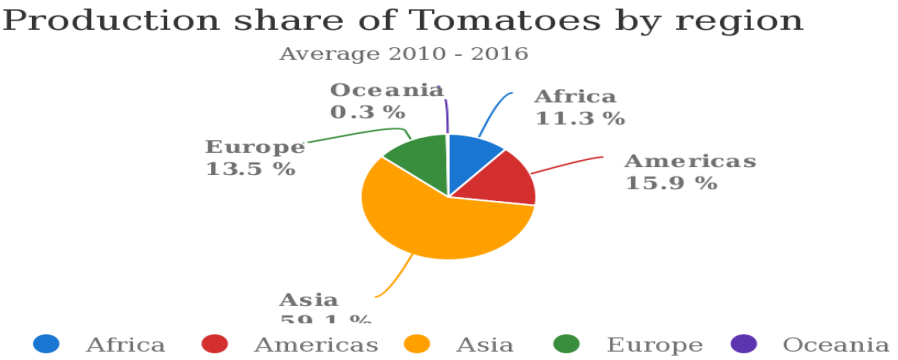


Fig 2.2: Production share of tomatoes in different regions of the world, average 2010-2016. *Source: FAOSTAT, 2018.*

In Kenya, tomato ranks 2nd vegetable in production with 20,111 ha area under it in 2016 which accounted for 20% of the domestic value derived from vegetable production in that year and the largest producers of this commodity were Kirinyaga, Kajiado and Taita Taveta counties (AFA-HCD, 2015-2016) (Table 2.2)

Table 2.2: Tomato performance in selected counties in Kenya 2015-2016

	Year 2015			**Year 2016**		
County	**Area (Ha)**	**Volume (MT)**	**Value (million KES)**	**Area (Ha)**	**Volume (MT)**	**Value (million KES)**
Kirinyaga	2,015	42,780	2,100	3,128	54,185	2,323
Kajiado	1,360	27,440	1,388	1,452	32,789	1,613
Taita Taveta	579	13,745	557	830	18,026	1,158
Laikipia	536	12,674	650	583	14,070	986
Bungoma	1,055	25,429	1,211	811	21,305	951
Trans Nzoia	659	14,690	617	723	16,660	638
Narok	784	14,920	529	1,561	20,744	596
Nakuru	851	14,158	294	946	15,179	492
Kisumu	591	16,512	726	646	8,545	397
Homa Bay	752	6,771	324	669	8,249	394
Machakos	795	9,500	246	689	12,765	381
Kiambu	986	16,545	692	965	9,132	327
Meru	928	7,903	230	1,050	9,951	323
Bomet	862	10,785	284	527	9,047	261
Lamu	360	7,719	285	374	7,190	248
Others	5,265	89,108	2,790	5,147	83,189	2,599
Total	**18,3878**	**330,679**	**12,922**	**20,111**	**341,026**	**13,687**

Source: AFA-HCD -Horticulture validated report 2015-2016; *MT-metric tonnes; KES-Kenya* shilling

Most Kenyan tomato farmers(95%) produce the crop in open field systems under irrigation and the rest under greenhouse production to ensure all year round production especially for commercial purposes, while a few do hydroponic tomato production (Seminis, 2007). The most popular varieties that are cultivated in Kenya include determinate open pollinated varieties such as Cal J, Eden, Rio Grande, Marglobe, Money maker and indeterminate hybrids such as Anna F1, Stallion F1 and Rambo F1(Odema, 2007; NAFIS Kenya,2015)

2.4 Factors limiting tomato production in Kenya

Kenya lies strategically and favorably on the tropics hence very suitable for tomato production. Several studies have been conducted to establish the major constraints to optimum tomato production in Kenya. Karuku *et al.* (2017) cited drought/ irrigation water limitations, high cost of managing diseases and pests, low soil fertility and poor access to credit facilities to finance production costs as key constraints facing smallholder tomato farmers in Kenya. AFA-HCD (2014) has attributed the fluctuations in tomato production to unfavorable weather conditions, low access to quality seeds and high post harvest losses.

Many smallholder farmers lack the resources to produce the crop using good agronomic practices thus leading to poor production. Sigei *et al* (2014) pointed out the production constraints among tomato farmers as poor nutrient management in tomato fields, insufficient irrigation and weeds. Insect pests such as tomato leaf miner (*Tuta absoluta*) and diseases such as fusarium wilt, bacteria wilt and fusarium wilt-root knot nematode complex have also been a major challenge to the tomato farmers with the latter causing massive damage (75- 100%) to tomato farms amounting to millions of shillings in losses (MoALF, 2012).

Green house technology, ranging from use of simple, semi-permanent wooden structure covered with polythene to complex metallic permanent greenhouses, has gained popularity among Kenyan farmers with more sensitization of the accrued benefits over open field production (Odema, 2009). Many of the greenhouses though have overtime been virtually neglected due to the tomato menace of bacterial wilt (Karuku *et al*., 2017). Further studies done on tomato value chain in Kenya reported that seasonality of Kenyan climate is also a factor influencing productivity of tomato since a third of tomato farmers (about 30%) depend on rainfall for cultivation of the crop (Koenig et al.,2008).

The seasonality of tomato production in Kenyan market that occurs often between May and August, leads to fluctuations in market prices and costly importation from Uganda and Tanzania (Koenig et al., 2008; AFA – HCD, 2014). In an annual report prepared by the Department of Agriculture in Taita Taveta county (2013) it was noted that tomato yield potential in that county had been significantly reduced from 50 to 35 t/ha due to drought conditions. Moranga (2016) reported further constraints in the tomato value chain such as inadequate and unreliable weather information dispensation to farmers, low access to credit to buy fertilizer inputs and the high cost of the high yielding hybrid tomato variety seeds forcing farmers to resort to the use of poor quality varieties, and unreliability of available water resources for irrigation hence leading to farmers becoming victims of drought.

2.5 Effect of Water stress on tomato growth and yield

Water is one of the basic requirements for the growth and development of plants. Water stress can be described as the state where a plant's access to water for uptake through the roots is limited hence affecting its physiological processes. Lisar (2012) described water stress as limitation of water supply to plant roots or intense transpiration higher than water uptake by roots. It can be caused by atmosphere moisture deficit created by factors such as high atmospheric temperature, low atmospheric relative humidity coupled with low inconsistent precipitation, high wind velocity, high soil salinity, very low ambient temperature and flooding. When the processes requiring water such as photosynthesis are hindered in the plant, crop productivity is greatly constrained. Farmers resort to supplemental irrigation to ensure that production is not hampered particularly when there is insufficient rainfall.

Effects of water stress in cultivated crops are varied. They include: seedling wilting and drying, slow vegetative growth rate, poor development of reproductive structures, flower abscission, poor pollination due to pollen desiccation or insufficient stigma moisture, poor seed set or undeveloped seeds, fewer, shrunk and small sized fruit and fruit abscission (Bryan and Yaakov, 1994). When a plant is under severe water deficit it tends to produce increased levels of abscissic acid (ABA) which facilitates a series of physiological responses such as stomatal closure to cushion itself from drying up (Osakabe *et al*., 2014)

Crop species and cultivars respond differently to water stress of various levels and this is referred to as drought tolerance. Drought tolerance can be attributed to a crop's anatomical features (eg root or leaf characteristics) and physiological features including accumulation of compatible solutes such as proline (Matsuda and Rayan, 1990). When water deficit become severe and prolonged, a plant may succumb and die but the level and period a plant can tolerate the water shortage vary with species.

Different growth stages of tomato respond differently to water stress depending on the water requirements. Nuruddin (2001) reported that water stress at flowering growth stage in tomato reduces flower production leading to poor fruit and low final harvestable yield. A study conducted on the effects of water limitation on different cultivars of tomato showed a decrease in dry matter yield in response to various moisture levels (Nahar *et al*., 2002). Aguyo et al., (2013) reported that very low water deficits (about 40% pot capacity) to the plants caused a reduction in stem diameter, plant height, chlorophyll concentration and caused the highest yield reduction of 69%. According to FAO (www.fao.org/crop information, 2018), tomato crops exhibit different requirements of water during the various stages of growth. For example, water requirements basing on reference evapo-transpiration in mm/period are given by Kc (crop factor) and it clearly

shows that as the crop grows, the water requirement increases. Initial stages record 0.4-0.5 Kc, development/vegetative stage 0.7-0.8 Kc, mid season stages 1.05-1.25 Kc, late season stage 0.8-0.9Kc and harvest stage 0.6-0.65 (FAO,2018). This means when water stress occurs at stages when water requirement by the crop is high such as the mid and late season stages is likely to cause significant reduction in harvestable yield from the crop. Evaluation of various African accessions with respect to tolerance to water stress demonstrated significant variations in response to different levels of water stress (Oduor et al., 2016). Agong et al (2001) reported that there exists a wide range of variation among the genotypes and within genotype groups that contributed to diversity in morphological expression of tomato traits such as varying fresh fruit weight in the study plants. Studies on comparative performance of indigenous tomato genotypes and commercial varieties with regard to crop adaptability to moisture limitations are limited.

2.6 Effect of nitrogen nutrition on tomato growth and yield

All crops, including tomato, need sufficient nutrition of both macro and micro-nutrients for proper growth, development and yield. Nitrogen is a very essential element for plant growth and development. Nitrogen is a component of DNA, proteins, enzymes and the intermediaries that are used in physiological processes in plants such as the energy transfer process of respiration (Razaq *et al.*, 2017). In most cases, nitrogen availability is the most limiting factor for plant growth and especially in agricultural crop production systems.

Nitrogen promotes growth of plants parts including roots, stems and foliage and also enhances crop maturity, fruit and seed development (Razaq *et al.*, 2017). Some of the effects of deficient nitrogen supply to the crop include stunted growth, chlorosis and later necrosis of older leaves thus lowered photosynthetic capacity, late maturity and reduced yield especially of the vegetables, forage and other crops whose leaves are harvested (Jahan *et al*., 2016; McCauley *et*

al., 2011). On the other hand, excess supply of nitrogen from whichever source leads to more vegetative growth and less reproductive growth hence lowering yield where the fruit or seed is the target produce of the crop. Excess nitrogen also causes susceptibility of a plant to diseases, lodging due to the plant developing more protoplasm than supportive materials in cells and delayed crop maturity (Tucker, 1999).

Nitrogen, among the primary nutrients, is also the most susceptible nutrient to losses through leaching, denitrification and volatilization. Therefore rate, place and time of application of nitrogen inputs for crops including tomato is important for management of these losses (Jahan *et al*., 2016). Recent trials conducted in all the counties in Kenya to evaluate soil nitrogen and phosphorous levels indicated that about 57 % of the sites considered were deficient in nitrogen (Gicheru, 2012). Continued decline of soil fertility especially nitrogen has been cited by the author as the major limitation to high crop production in Kenya. Nitrogen is taken up by plants in form of nitrate or ammonium and can be supplied in varying forms and rates leading to varied tomato response in respect to growth and yield realized from the crop. Various recommended rates of nitrogen fertilizer for optimum tomato production have been suggested. Food and agricultural organization (FAO, 2018) recommended for high producing varieties a nitrogen rate of 100-150 kg N/Ha. Feijuan and Cheng (2012) reported that increasing nitrogen supply from 100 kg N/ha to 350 kg N/ha increased the yield of tomato but an increase to 600 kg N/ha did not translate to increased yield. In another study, excess use of nitrogen fertilizer delayed maximum leaf growth by one week (Moreno et al., 2014). The correct level of external nitrogen supply is vital in management of growth and yield of tomato crop.

CHAPTER THREE: EFFECT OF WATER STRESS ON GROWTH AND YIELD OF SELECTED AFRICAN WILD TOMATO ACCESSIONS AND COMMERCIAL TOMATO VARIETIES

3.1 Abstract

Drought stress is one of the major constraints to enhancement of tomato productivity in Kenya. However, there exist a wide range of water stress tolerant tomato accessions in Africa that could be harnessed to improve the adaptability of the currently grown commercial tomato varieties to limited moisture conditions. A study was conducted to evaluate the effect of water stress on growth and yield components of 10 African tomato accessions and five widely grown Kenyan commercial tomato varieties. Greenhouse-grown tomato plants were subjected to three water levels; 100% pot capacity (PC) (moisture held by pot soil after draining for 24 hours), 70% PC and 40% PC (representing stress conditions) in a randomized complete block design with three replications. Plant growth (plant height, stem girth, internode length, single leaf area) and yield (total yield, number of fruits per plant, single fruit weight, fruit length and fruit width) attributes were evaluated at flowering and during harvesting respectively. Data collected were subjected to analysis of variance using Genstat version 15 and means separated using the least significant difference test at ($P \leq 0.05$). Moisture stress and genotypes had significant effects ($P \leq 0.05$) on growth parameters (plant height, internode length, stem girth and single leaf area). Total number of fruits per plant, total fruit weight per plant, average single fruit weight, fruit length and fruit width significantly decreased with reduction in moisture level from 100 % PC to 70 % and 40 % PC. Fruit weight per plant was significantly affected ($P \leq 0.05$) by moisture stress, genotype and moisture stress x genotype interaction. Accession VI005895 was least affected by reduction of moisture level from 100 % PC to 40 % PC, recording a reduction of fruit weight per plant of 20.2 % while the commercial genotype Master F1 recorded higher reduction of 81.2 % under same conditions. African accessions had higher variability in plant stem height, internode length and

stem girth. Accession VI005871, VI005895 and VI006840 were not significantly different from commercial varieties Stallion F1 and Master F1 in total fruit weight per plant and average single fruit weight. Breeding programmes aimed at exploiting genetic variability in yield and adaptability to drought during crop growth can exploit accessions VI005871, VI005895 and VI006840 to improve existing commercial cultivars of tomato for enhancement of tomato productivity.

Key words: Accessions, adaptability, pot capacity, *Solanum lycopersicum*

3.2 Introduction

Tomato (*Solanum lycopersicum* L.) is the second-most important exotic vegetable crop in Kenya. Its production increased from 330,679 metric tonnes in 2015 to 341,026 metric tonnes in 2016 translating to 20 % of total the value derived from exotic vegetable sub-sector, partly attributed to expansion in greenhouse production and enhanced irrigation (AFA-HCD, 2016). However, various constraints have hindered consistency in production of tomato leading to unfavorable fluctuations in supply and hence prices (Sigei *et al*, 2014). Among these constraints are high costs of high yielding hybrid seeds, high pest and diseases management cost, drought and heat stress associated with climate change, lack of drought tolerant varieties and poor agronomic practices (Karuku *et al*., 2017). Drought stress, especially in critical growth stages, is one of the main hindrances of potential yield achievement in tomato production by the Kenyan farmers (Sibomana et al., 2013). HCDA (2010) indicated a decline in vegetable exports from 82,000 to 72,000 tonnes in year 2008-2009 and attributed this majorly to drought in the same period. FAOSTAT (2016) reported a decline in tomato production in Kenya between year 2008 to 2009 of 30.6 t/ha to 20.9 t/ha and this could be attributed to drought conditions experienced in the country during that period (Republic of Kenya, 2012). Water plays critical roles in plant's physiological functions such as being a solvent for soluble materials such as fertilizers and

minerals and also is a raw material in some physiological processes such as photosynthesis to produce food for the plant (Lisar, 2012). Water also acts as a transport medium in plants to translocate nutrients and organic compounds, medium for chemical reactions and maintains cell turgidity for structural support to ensure the plants remain upright. The detrimental effects of continued water stress conditions in the tomato plants include stunted growth leading to reduced growth (Lisar 2012). Water stress reduce tomato dry matter yield but the reduction is higher in hybrid genotypes than in open pollinated cultivars (Nahar *et al*,. 2002). Improvement of current tomato varieties with respect to adaptability to drought stress is critical to improvement of tomato production. Indigenous tomato genotypes are potentially the best source of drought tolerance genes for tomato improvement. Various studies have focused on tomato single genotype response under water stressed conditions. The objective of this study was to comparatively evaluate the effect of water stress on growth and yield of selected African tomato accessions and commercial varieties.

3.3 Materials and methods

3.3.1 Site description

The study was conducted in a greenhouse at the University of Nairobi's Kabete Field Station from October 2017 to February 2018 and a repeat during the period of April to July 2018. The site is situated in agro-ecological zone (AEZ) three (Jaetzold and Schmidt, 1983) and on an attitude of 1940 meters above sea level, latitude of 1° 15'S and longitude of 36°41'E (Sombroek et al., 1982). It is normally a humid and high potential zone with a mean minimum temperature of 11.8° C, mean maximum temperature of 25.1°C and mean annual rainfall of 1000 mm (Kenya Met Dept., 2013). The soils are deep, well drained and reddish-brown humic nitisols (Michieka, 1978; FAO, 1990) which are good conditions for growing tomatoes.

3.3.2 Planting materials

Ten tomato accessions and five commercial tomato varieties (Table 3.1) were evaluated at three watering levels (100 %PC, 70 % PC and 40 % PC).

Table 3.1: African tomato accessions and commercial tomato varieties used in the trial

S.no	Accession (AVRDC/NGRI code)	Major attributes				
		Origin	DTF	DTM	fruit wgt/ plant (gm)	Growth habit
1	VI005895	Egypt	43	92	1711	Indeterminate, erect growth, dense foliage.
2	VI007540	South Africa	59	105	1784	Determinate, bushy growth, medium foliage
3	VI005987	Morocco	53	109	2343	Indeterminate, erect growth, dense foliage.
4	VI006840	Ethiopia	57	114	3126	Indeterminate, erect growth, dense foliage.
5	VI006825	Ethiopia	58	109	2526	Indeterminate, bushy growth, medium foliage
6	VI006828	Ethiopia	53	98	2346	Indeterminate, erect growth, dense foliage.
7	RVI01885	Madagascar	55	100	2173	Determinate, bushy, dense foliage.
8	GBK050580	Kenya	54	126	463	Indeterminate, erect growth, dense foliage.
9	VI005871	Morocco	51	107	2171	Indeterminate, erect growth, medium foliage
10	VI005990	Morocco	55	109	2165	Determinate, erect growth, medium foliage
	Commercial varieties					
11	Rio grande(OPV)	Italy	45	85	1600	Determinate, bush type, medium foliage.
12	Cal J (OPV)	North America	42	80	1100	Determinate, bush type, dense foliage.
13	Stallion F1	Kenya	47	95	2637	Semi-determinate, erect growth, medium foliage
14	Master F1	Kenya	50	95	2000	Determinate, erect growth, dense foliage.
15	ATM F1	Kenya	45	90	1350	Semi determinate, bushy , dense foliage.

Sources: Tembe *(2016), Kenya seed company Ltd website, Continental seeds Ltd website, Hygene Biotech Seeds Ltd websites (Accessed September 2017).* DTF – Days to 50% flowering, DTM – Days to maturity, AVRDC - Asian Vegetable Research and Development Centre (Taiwan). NGK- National Gene Bank (Kenya)

3.3.3 Planting media preparation

The top soil, 15 cm deep, from uncultivated forested land in the Field Station site was collected for use in pots in the greenhouse. The potting media was made by mixing soil with sand and well decomposed manure in the ratio of 2:1:1 to improve drainage and fertility. The media volume contained in each pot was approximately 10 kg and only one experimental tomato seedlings were planted each pot.

3.3.4 Treatments and experimental design

Soil moisture stress treatments were 100 % pot capacity (PC), 70 % PC and 40 % PC. The experiment was laid out in a randomized complete block design (RCBD) with a 15x3 factorial arrangement, replicated three times. Moisture stress was determined using gravimetric moisture determination method (Reynolds, 1970). Gravimetric moisture content (GMC) of pot soil was derived from the formula: (wet soil core weight-dry soil core weight)/ dry soil core weight- core can weight) x 100. Gravimetric moisture content was then used to calculate volumetric moisture content (VMC) of soil in the pots using the formula: (%GMC x bulk density of pot soil x density of water) x volume of pot soil (cm^3). This gave the 100 % PC volume of moisture about 1.9 lt of water per pot. Moisture stress treatments were achieved by multiplying 1.9 L by 70% and 40% to give 1.3 L (70 % PC) and 0.8 L (40 % PC) respectively. The period of time that elapsed before successive watering was determined by water potential readings in tensiometers inserted in pots at a depth of 15 cm (CTAHR, 1999) which indicated when to water the plants depending on prevailing weather conditions throughout the season. For example, when readings in the tensiometers inserted in pots with 100 % PC were higher than the predetermined reading of 3 centibars for 100 % PC, then moisture level was deemed to have fallen below control and hence watering was done. One three- weeks-old seedling was planted in each pot was and moisture stress imposed at two weeks after transplanting when the root systems were already established.

3.3.5 Crop husbandry

For proper nutrition, 10 g of Diammonium Phosphate (DAP) was pre-mixed with soil media in each pot before transplanting seedlings for rapid root establishment. Seedlings were watered every two days for two weeks to enable strong establishment, thereafter the moisture stress treatments were initiated. Topdressing was done using Calcium Ammonium Nitrate (CAN) fertilizer at a rate of 10 g per plant at the fourth week after transplanting then NPK fertilizer was applied at the same rate at flowering. The tomato plants were pruned and maintained at a single stem. The growing pots were kept weed free by rouging weeds. Crop insect pests such as whiteflies, *Tuta absoluta* and thrips were controlled using Coragen 20 SC, 4 ml/20 L (active ingredient; chlorantraniliprole). Late blight disease was controlled by using Ridomil gold MZ 68 WG, 100 g/20 L (active ingredient; metalaxyl and mancozeb).

3.3.6 Data collection

Data on growth parameters (plant height, stem girth, internode length and single leaf area) were collected at flowering while data on yield parameters (average single fruit weight, average fruit length and average fruit width, number of fruits per plant and total yield) were collected at harvest time. For growth parameters, plant stem height was measured using a metre rule from the base of tomato plant stem at pot soil level to the apex of the plant. Stem girth was measured using a tape measure around the stem at 10 cm from the base of pot soil level. Internode length was measured using a ruler between two tagged trusses. Single leaf area (SLA) was calculated by measuring tagged leaf length (L) from leaf pulvinus to its tip and width (W) at widest width across the leaf using a ruler. Single leaf area (SLA) was determined using formula suggested by Rivera *et al.,* 2007 for estimation of eggplant leaf area which is in the same family (Solanaceae) as tomato: $SLA= 0.763L+ 0.340L^2$

For average fruit width determination, six fruits sampled in each plant were cut along cross-sectional plane and width measured using a ruler average of the six fruits recorded. Average fruit length was determined by sampling six fruits per plant, cut longitudinally along the middle, and length measured using a ruler from stem end to blossom end of opened fruits and the average of the six fruits recorded. Total number of fruits per plant was determined by counting all fruits harvested in each plant. Total weight of fruits per each plant was determined by weighing all fruits harvested from a plant using an electronic weighing balance. Average single fruit weight was determined by weighing a sample of six fruits per plant and taking the average.

3.3.7 Data analysis

Data collected were subjected to analysis of variance (ANOVA) using Genstat version 15 and treatment means separated using the least significant difference (L.S.D) test at ($P \leq 0.05$). Correlation analyses were also conducted between growth parameters (plant height, single leaf area, internode length and stem girth) and yield parameters (total fruits per plant, total fruit weight per plant, fruit length and fruit width) using Genstat software.

3.4 Results

3.4.1 Effect of water stress on growth attributes of selected African tomato accessions and commercial varieties.

(i)Effect of water stress on plant height of selected African tomato accessions and commercial varieties

Moisture level and tomato genotype had significant effects (P≤0.05) on plant height (Table 3.2). There was no interaction between tomato genotype and moisture level with respect to plant height. Reduction in moisture level from 100% PC to 40 % PC reduced the overall mean plant height among genotypes by 12.3 %. The various genotypes recorded mean stem heights ranging from 53.2 cm (Rio Grande) to 107.3 cm (VI005987). The commercial tomato genotypes plant heights ranged from 53.2 cm to 75.7 cm compared to African tomato accessions whose plant heights ranged from 68.2 cm to 107.3 cm.

Table 3.2: Mean values for plant height of tomato genotypes under different moisture levels

	Plant height (cm)			
Genotype	**100 % PC**	**70 % PC**	**40 % PC**	**MEAN**
ATM F1	68.7	51.6	52.5	**57.6**
Cal J	69.1	63.7	65.4	**66.1**
GBK050580	70.9	72.1	62.7	**68.6**
Master F1	65.4	67.0	55.4	**62.6**
Rio Grande	58.4	51.2	49.9	**53.2**
RVI01885	67.9	69.9	56.3	**64.7**
Stallion F1	83.5	75.1	68.5	**75.7**
VI005871	79.2	78.7	65.3	**74.4**
VI005895	79.4	78.2	71.8	**76.5**
VI005987	115.3	105.1	101.5	**107.3**
VI005990	75.5	77.6	66.7	**73.3**
VI006825	77.3	70.3	68.2	**71.9**
VI006828	70.5	70.8	63.3	**68.2**
VI006840	83.5	81.3	78.0	**80.9**
VI007540	90.2	94.8	86.7	**90.6**
MEAN	**77.0**	**73.8**	**67.5**	
Fpr. Genotype (Gen)	**<.001**			
Fpr. Moisture Level (ML)	**<.001**			
Fpr. Gen*ML	**0.6^{NS}**			
L.S.D Gen (P≤0.05).	**7.2**			
L.S.D (P≤0.05). **ML**	**3.2**			
CV%	**10.6**			

PC- pot capacity, NS-not significant, CV- covariance

(ii)Effect of water stress on stem girth of selected African tomato accessions and commercial varieties

Stem girth measurements of the tomato genotypes showed there were significant effects ($P \leq 0.05$) caused by the moisture level and genotype (Table 3.3). However, the interaction between tomato genotype and moisture level had no significant effect on stem girth. Reduction of moisture level from 100 % to 40 % PC caused 11.4 % overall reduction in stem girth among genotypes. Mean stem girth of genotypes ranged from 2.9 cm (VI005987 and VI007540) to 3.6 cm (VI005990 and GBK050580). Commercial genotypes stem diameter ranged from 3.1 to 3.4 cm while accessions recorded stem girth ranging from 2.9 to 3.6 cm.

Table 3.3: Mean values for stem girth of tomato genotypes under different moisture levels

	Stem girth (cm)			
Genotype	**100 % PC**	**70 % PC**	**40 % PC**	**MEAN**
ATM F1	3.8	2.7	2.9	**3.1**
Cal J	3.4	3.4	3.3	**3.4**
GBK050580	4.0	3.7	3.1	**3.6**
Master F1	3.4	3.2	2.7	**3.1**
Rio Grande	3.3	3.0	3.1	**3.1**
RVI01885	3.6	3.5	3.5	**3.5**
Stallion F1	3.2	3.2	3.1	**3.2**
VI005871	3.6	3.5	3.1	**3.4**
VI005895	3.6	3.4	3.5	**3.5**
VI005987	3.0	2.7	2.9	**2.9**
VI005990	3.9	3.4	3.6	**3.6**
VI006825	3.8	3.4	3.1	**3.4**
VI006828	3.6	3.5	3.4	**3.5**
VI006840	3.1	2.9	2.9	**3.0**
VI007540	3.0	2.7	2.9	**2.9**
MEAN	**3.5**	**3.2**	**3.1**	
Fpr. Genotype (Gen)	**<.001**			
Fpr. Moisture level (ML)	**0.001**			
Fpr. Gen*ML	**0.124^{NS}**			
L.S.D ($P \leq 0.05$**)Var**	**0.3**			
L.S.D ($P \leq 0.05$**) ML**	**0.1**			
L.S.D ($P \leq 0.05$**) Gen*ML**	**NS**			
CV%	**10.6**			

Gen- genotype, ML - moisture level, NS- not significant, PC - pot capacity.

(iii)Effect of water stress on internode length of selected African tomato accessions and commercial varieties

Internode length was significantly affected by genotype and moisture level at P≤0.05 (Table 3.4). The interaction between tomato genotype and moisture level had no significant effect on the internode length. An overall reduction of 8.8% in internode length was observed among genotypes when moisture level was reduced from 100 % to 40 % PC. Genotype internode lengths varied from the shortest 3.2 cm (VI006828) to the longest 6.0 cm (VI005987). Accessions showed an internode range of 3.2- 6.0 cm compared to 3.5 - 4.2 cm in commercial genotypes.

Table 3.4 : Mean values for internode length of tomato genotypes under different moisture levels

	Internode length (cm)			
Genotype	**100 % PC**	**70 % PC**	**40 % PC**	**MEAN**
ATM F1	4.0	3.2	3.4	**3.5**
Cal J	4.4	4.0	4.3	**4.2**
GBK050580	3.9	4.3	3.8	**4.0**
Master F1	4.4	5.3	3.6	**4.4**
Rio Grande	4.2	3.2	3.8	**3.7**
RVI01885	4.8	3.9	3.8	**4.2**
Stallion F1	4.5	3.8	4.1	**4.1**
VI005871	3.3	4.2	3.0	**3.5**
VI005895	5.2	5.1	4.9	**5.1**
VI005987	6.4	5.5	6.2	**6.0**
VI005990	5.1	3.1	4.2	**4.1**
VI006825	4.4	4.5	4.3	**4.4**
VI006828	3.3	3.2	3.0	**3.2**
VI006840	5.0	4.1	4.6	**4.6**
VI007540	4.0	4.4	3.9	**4.1**
MEAN	**4.5**	**4.1**	**4.1**	
Fpr. Genotype (Gen)	**<.001**			
Fpr. Moisture level (ML)	**0.002**			
Fpr. Gen*ML	**0.609^{NS}**			
L.S.D (P≤0.05)**Var**	**0.8**			
L.S.D (P≤0.05**) ML**	**0.4**			
L.S.D (P≤0.05**) Gen*ML**	**NS**			
CV%	**21**			

Gen- Genotype, ML - moisture level, NS- not significant, PC - Pot capacity.

(iv)Effect of water stress on single leaf area of selected African tomato accessions and commercial varieties

Moisture levels and tomato genotype had significant effects ($P \leq 0.05$) single leaf area (Table 3.5) Interaction between tomato genotype and moisture level had no significant effect on single leaf area. Single leaf area recorded ranged from 45.7 cm^2 (ATM F1) to 32.5 cm^2 (VI006825) with an overall genotype leaf area mean of 40 cm^2. Moisture level reduction from 100 % to 40 % PC resulted in overall mean decrease in single leaf area by 13%. Commercial genotypes recorded SLA of 37.2 to 45.7 cm^2 compared to accessions which varied from 32.5 to 44.2 cm^2.

Table 3.5 : Mean values for single leaf area of tomato genotypes under different moisture levels

	Single leaf area (cm^2)			
Genotype	**100 % PC**	**70 % PC**	**40 % PC**	**MEAN**
ATM F1	48.4	45.4	43.2	**45.7**
Cal J	38.7	40.2	32.9	**37.2**
GBK050580	34.9	33.1	32.2	**33.4**
Master F1	46.5	45.0	37.5	**43.0**
Rio Grande	37.8	42.4	37.5	**39.2**
RVI01885	44.7	46.1	41.8	**44.2**
Stallion F1	49.7	43.0	41.0	**44.6**
VI005871	41.8	40.2	36.2	**39.4**
VI005895	40.5	38.8	34.2	**37.8**
VI005987	38.8	40.7	35.9	**38.4**
VI005990	43.4	43.7	36.6	**41.3**
VI006825	35.2	32.2	30.2	**32.5**
VI006828	45.9	38.7	37.3	**40.6**
VI006840	45.6	42.1	37.2	**41.6**
VI007540	43.1	43.0	38.3	**41.5**
MEAN	**42.3**	**41.0**	**36.8**	
Fpr. Genotype (Gen)	**<.001****			
Fpr. Moisture level (ML)	**<.001****			
Fpr. Gen*ML	**0.753^{NS}**			
L.S.D ($P \leq 0.05$**)Var**	**3.4**			
L.S.D ($P \leq 0.05$**) ML**	**1.5**			
L.S.D ($P \leq 0.05$**) Gen*ML**	**NS**			

Gen- genotype, ML - moisture level, NS- not significant, PC - pot capacity.

(v)Effect of water stress on days to floral initiation of selected African tomato accessions and commercial varieties

Days to floral initiation was significantly influenced ($P \leq 0.05$) by moisture level, genotype and genotype by moisture level interaction (Table 3.6). Genotypes VI006840, VI006828, Cal J and ATM F1 were significantly affected moisture limitation to 70% PC while GBK050580 and VI005871 were only affected by further moisture limitation of 40 % PC. The aforementioned genotypes took at least six days more to floral initiation compared to the number of days they took when moisture level was at 100 % PC. The rest (Master F1, Rio Grande, RV101885, Stallion F1, VI005895, VI005990, VI007540, VI006825 and VI005987) recorded no significant response as a result of moisture reduction from 100 % PC to 70 % PC and to further 40 % PC (Table 3.6). Comparison of genotypes response within same moisture level showed that at 100 % PC, VI006840 took shortest time (38 days) while Master F1 took 63 days. At 70 % PC, VI005990 took shortest time (41.3 days) while Master F1 took 59.7 days and at 40 % PC still VI005990 took shortest time (47 days) while Master F1 took longest at 63.8 days (Table 3.6).

Table 3.6: Mean values for days to floral initiation of tomato genotypes under varying soil moisture levels

	Days to floral initiation				
Genotype	**100 % PC**	**70 % PC**	**40 % PC**	**MEAN**	**Additional days at lowest ML**
ATM F1	43.3	49.3	51.7	**48.1**	**8.4**
Cal J	39.3	48.7	52.7	**46.9**	**13.4**
GBK050580	41.7	42.7	51.3	**45.2**	**9.6**
Master F1	63.0	59.7	63.8	**62.2**	**0.8**
Rio Grande	59.0	58.3	60.3	**59.2**	**1.3**
RVI01885	56.0	56.7	56.9	**56.5**	**0.9**
Stallion F1	51.0	51.0	52.0	**51.3**	**1.0**
VI005871	50.7	45.0	56.0	**50.6**	**5.3**
VI005895	42.7	47.7	49.0	**46.4**	**6.3**
VI005987	39.7	44.7	50.0	**44.8**	**10.3**
VI005990	44.3	41.3	47.0	**44.2**	**2.7**
VI006825	40.3	44.7	47.3	**44.1**	**7.0**
VI006828	53.0	59.0	59.3	**57.1**	**6.3**
VI006840	38.0	45.0	48.3	**43.8**	**10.3**
VI007540	52.3	52.3	55.7	**53.4**	**3.4**
MEAN	**47.6**	**49.7**	**53.4**		
Fpr. Genotype (Gen)	**<.001**				
Fpr. Moisture level (ML)	**<.001**				
Fpr. Gen*ML	**0.002**				
L.S.D (P≤0.05**)Var**	**3.5**				
L.S.D (P≤0.05**) ML**	**1.6**				
L.S.D (P≤0.05**) Gen*ML**	**6.0**				
CV%	**7.4**				

3.4.2 Effect of water stress on yield attributes of selected African tomato accessions and commercial varieties

(i)Total number of fruits per plant

Total number of fruits harvested per plant was significantly influenced (P≤0.05) by the genotype and the level of moisture but not by the interaction between tomato genotype and moisture level (Table 3.7). Mean number of fruits per plant ranged from 6 fruits in RV101885 to 35 fruits in VI007540. Reduction of moisture level to 40 % PC resulted in an overall reduction of number of fruits per plant by 40.3%. Commercial genotypes recorded overall fruit number ranging from 7 (master f1) to 11 (stallion f1) while the accessions ranged between 6 (RV101885) and 35 (V1007540) fruits per plant.

Table 3.7: Mean values for total number of fruits per plant of genotypes under different moisture levels

	Total number of fruits per plant			
Genotype	**100 % PC**	**70 % PC**	**40 % PC**	**MEAN**
ATM F1	9.0	8.0	6.3	**7.8**
Cal J	11.7	3.0	7.7	**7.5**
GBK050580	7.0	5.0	5.0	**5.7**
Master F1	8.0	11.0	2.3	**7.1**
Rio Grande	11.0	8.0	7.0	**8.7**
RVI01885	9.3	6.7	2.7	**6.2**
Stallion F1	14.3	10.7	8.0	**11.0**
VI005871	13.0	7.3	8.0	**9.4**
VI005895	13.7	6.3	6.7	**8.9**
VI005987	11.7	10.3	5.7	**9.2**
VI005990	12.3	5.3	5.7	**7.8**
VI006825	11.0	6.7	2.7	**6.8**
VI006828	11.7	7.7	10.0	**9.8**
VI006840	10.3	9.3	4.7	**8.1**
VI007540	39.7	34.3	32.3	**35.4**
MEAN	**12.9**	**9.3**	**7.7**	
Fpr. Genotype (Gen)	**<.001**			
Fpr. Moisture level (ML)	**<.001**			
Fpr. Gen*ML	**0.63^{NS}**			
L.S.D (P≤0.05**)Var**	**5.2**			
L.S.D (P≤0.05**) ML**	**2.3**			
L.S.D (P≤0.05**) Gen*ML**	**NS**			

(ii)Total fruit weight per plant

Genotype, moisture level and genotype by moisture level interaction significantly affected (P≤0.05) the total fruit weight per plant (Table 3.8). Cal J and accession VI005871 recorded significant decline in fruit weight per plant when moisture level reduced from 100% PC to 70% PC while Master F1, Stallion F1, VI006825 and VI005895 were significantly affected when moisture level was reduced further 40 % PC. The rest of the genotypes were not significantly affected by reduction in moisture level from 100 % PC to 70 % PC and to the lowest 40 % PC. Within various moisture levels, genotype VI005895 had highest fruit weight per plant (282.7 g) while VI007540 weighed 25.8 g at 100 % PC. At 70 % PC, VI005895 weighed highest (216.6 g)

while RV101885 weighed least (24.6 g) and at 40 % PC VI005871 had the highest weight (143.6 g) while VI006828 weighed 14 g (Table 3.8).

Table 3.8 : Mean values for total fruit weight per plant of tomato genotypes under different moisture levels

	Total fruit weight per plant (g)				
Genotype	**100 % PC**	**70 % PC**	**40 % PC**	**MEAN**	**Weight decline (100 % PC-40 % PC)**
ATM F1	108.6	63.3	76.0	82.6	32.6
Cal J	258.5	68.9	85.1	137.5	173.4
GBK050580	28.0	27.5	16.0	23.8	12.0
Master F1	214.0	193.9	40.3	149.4	173.7
Rio Grande	67.1	51.9	45.1	54.7	22.0
RVI01885	38.1	24.6	19.9	27.5	18.2
Stallion F1	222.7	162.9	101.8	162.5	120.9
VI005871	180.0	42.5	143.6	122.0	36.4
VI005895	282.7	216.6	129.7	209.7	153
VI005987	93.1	108.3	50.1	83.8	43.0
VI005990	49.7	34.3	20.5	34.8	29.3
VI006825	162.5	79.7	14.7	85.6	147.8
VI006828	30.3	28.5	14.0	22.6	21.3
VI006840	147.7	120.1	86.9	118.2	60.8
VI007540	25.8	32.6	20.1	26.2	5.7
MEAN	**127.3**	**83.7**	**57.3**		
Fpr. Genotype (Gen)	**<.001**				
Fpr. Moisture level (ML)	**<.001**				
Fpr. Gen*ML	**0.006**				
L.S.D (P≤0.05)**Var**	**53.48**				
L.S.D (P≤0.05**) ML**	**23.9**				
L.S.D (P≤0.05**) Gen*ML**	**92.6**				
CV%	**66.5**				

Gen- Genotype, ML - moisture level, NS- not significant, PC - Pot capacity, ns- not significant

(iii) Average single fruit weight

The average single fruit weight was significantly affected (P≤0.05) by the genotype and moisture level (Table 3.9). The interaction between genotype and moisture level had no significant effect on average single fruit weight. Average single fruit weight among genotypes ranged from 0.8 g in VI007540 to 22.2 g in Master F1. The lowest moisture level resulted to lowest overall single

fruit weight mean of 10.1 g compared to 70 % PC which recorded 11.1 g and 100 % PC which recorded a mean single fruit weight of 14.1g.

Table 3.9: Mean values of single fruit weight of tomato genotypes under different moisture levels

	Single fruit weight (g)			
Genotype	**100 % PC**	**70 % PC**	**40 % PC**	**MEAN**
ATM F1	11.9	7.4	11.0	**10.1**
Cal J	25.1	21.0	10.3	**18.8**
GBK050580	11.1	8.2	6.7	**8.7**
Master F1	26.3	20.9	19.3	**22.2**
Rio Grande	15.4	12.1	10.5	**12.7**
RVI01885	9.6	4.1	9.5	**7.7**
Stallion F1	15.5	15.9	12.7	**14.7**
VI005871	17.2	7.5	14.8	**13.2**
VI005895	20.7	22.9	19.4	**21.0**
VI005987	12.0	10.9	8.8	**10.6**
VI005990	3.9	5.1	3.3	**4.1**
VI006825	17.4	11.7	6.2	**11.8**
VI006828	2.6	4.5	1.3	**2.8**
VI006840	22.0	13.0	16.3	**17.1**
VI007540	0.7	1.0	0.6	**0.8**
MEAN	**14.1**	**11.1**	**10.1**	
Fpr. Genotype (Gen)	**<.001**			
Fpr. Moisture level (ML)	**0.033**			
Fpr. Gen*ML	**0.785^{NS}**			
L.S.D (P≤0.05**)Var**	**5.6**			
L.S.D (P≤0.05**) ML**	**2.5**			
L.S.D (P≤0.05**) Gen*ML**	**NS**			
CV%	**52**			

Gen- genotype, ML - moisture level, NS- not significant, PC - pot capacity

(iv)Average fruit length

Genotype and moisture level had significant effects (P≤0.05) on average fruit length but the interaction between genotype and moisture level had no significant effect on fruit length (Table 3.10). Average fruit length among genotypes ranged from 0.9 cm (VI007540) to 2.7 cm in Stallion F1 with overall fruit length mean of 1.9 cm. The varying moisture levels resulted in

different overall fruit length reduction by 14.3% and 19% when moisture level reduced from 100 % PC to 70 % PC and 40 % PC respectively.

Table 3.10: Mean values of average fruit length of tomato genotypes under different moisture levels

	Average fruit length (cm)			
Genotype	**100 % PC**	**70 % PC**	**40 % PC**	**MEAN**
ATM F1	2.7	2.5	2.0	**2.4**
Cal J	3.3	1.6	2.1	**2.3**
GBK050580	0.9	1.4	0.8	**1.0**
Master F1	3.3	2.5	1.5	**2.4**
Rio Grande	2.3	1.8	2.2	**2.1**
RVI01885	1.1	1.0	0.8	**1.0**
Stallion F1	3.0	2.4	2.8	**2.7**
VI005871	2.2	1.5	1.9	**1.9**
VI005895	2.3	2.5	2.1	**2.3**
VI005987	3.3	1.8	2.1	**2.4**
VI005990	1.6	1.6	1.5	**1.6**
VI006825	2.0	2.1	1.9	**2.0**
VI006828	1.3	1.3	1.3	**1.3**
VI006840	2.0	2.1	2.0	**2.0**
VI007540	0.9	1.0	0.7	**0.9**
MEAN	**2.1**	**1.8**	**1.7**	
Fpr. Genotype (Gen)	**<.001**			
Fpr. Moisture level (ML)	**0.016**			
Fpr. Gen*ML	**0.262^{NS}**			
L.S.D (P≤0.05)**Var**	**0.62**			
L.S.D (P≤0.05**) ML**	**0.28**			
L.S.D (P≤0.05**) Gen*ML**	**NS**			
CV%	**35.1**			

Gen- genotype, ML - moisture level, NS- not significant, PC -pot capacity

(v) Average fruit width

Average fruit width was significantly affected (P≤0.05) by genotype and moisture level but the interaction between the moisture level and genotype had no significant effect on fruit width (Table 3.11). Average fruit width among genotypes ranged from 0.7 cm in VI007540 to 3.2 cm in VI005895 while overall fruit width mean was 2.0 cm. Different moisture levels resulted in

different overall fruit width reduction of 13.6% when moisture level was reduced from 100 % PC to 70 % PC and 40 % PC.

Table 3.11: Mean values of average fruit width of tomato genotypes under different moisture levels

	Average fruit width (cm)			
Genotype	**100 % PC**	**70 % PC**	**40 % PC**	**MEAN**
ATM F1	2.3	2.1	1.7	**2.0**
Cal J	2.6	1.5	2.1	**2.1**
GBK050580	0.8	1.3	0.7	**0.9**
Master F1	3.2	2.1	1.6	**2.3**
Rio Grande	2.3	1.7	2.3	**2.1**
RVI01885	1.4	1.0	0.7	**1.0**
Stallion F1	2.5	2.3	2.4	**2.4**
VI005871	2.4	2.1	2.1	**2.2**
VI005895	3.3	3.3	3.0	**3.2**
VI005987	3.8	2.1	2.9	**2.9**
VI005990	2.0	1.9	1.8	**1.9**
VI006825	2.3	2.1	2.1	**2.2**
VI006828	1.4	1.4	1.3	**1.4**
VI006840	2.9	2.7	2.6	**2.7**
VI007540	0.5	1.1	0.5	**0.7**
MEAN	**2.2**	**1.9**	**1.9**	
Fpr. Genotype (Gen)	**<.001****			
Fpr. Moisture level (ML)	**0.006**			
Fpr. Gen*ML	**0.331^{NS}**			
L.S.D (P≤0.05)**Var**	**0.54**			
L.S.D (P≤0.05**) ML**	**0.24**			
L.S.D (P≤0.05**) Gen*ML**	**NS**			
CV%	**29.1**			

Gen- genotype, ML - moisture level, NS- not significant, PC – pot capacity.

3.4.3 Correlation analysis for growth and yield traits

Significant correlations between growth and yield traits were observed in the study. Internode length showed a significant negative correlation with stem girth(r=-0.016) (Table 3.12). Plant height had significant positive correlation with total fruit weight per plant (r=0.139) while total

number of fruits per plant had significant positive correlation with total fruit weight per plant(r=0.036).

Table 3.12 Correlation table for growth and yield traits for greenhouse grown tomato

	fruit weight (g)	**Days to 1st flower**	**Plant height (cm)**	**SLA_ Cm²**	**TFPP**	**TWPP (g)**	**Internode length (cm)**	**Stem girth (cm)**
Single fruit weight (g)	-							
Days 1st Flower	0.1593	-						
Plant height (cm)	-0.1593	-0.3668	-					
SLA (cm²)	0.3012	0.0664	-0.0942	-				
TFPP	0.3139	-0.0565	0.0139*	-0.2986	-			
TWPP (g)	0.5667	-0.1584	0.0695	0.1563	0.036*	-		
Internode (cm)	0.1708	-0.0782	0.3373	0.0285*	0.0588	0.1917	-	
Stem girth (cm)	0.0646	0.2621	-0.1203	0.3838	-0.1814	0.0144	-0.0165*	-

SLA-single leaf area, TFPP-total fruits per plant, TWPP-Total fruit weight per plant.

**Significant*

3.5 Discussion

The results of this study indicated that as the level of soil moisture decreased, plant stem length and stem internode length decreased. Plant height as a measure of growth of a plant is usually dependent on the nutrients and water available for plant uptake. The rates of cell division and elongation are high when there adequate moisture for the plant (Nagashima and Hikosaka, 2011). Plants experience stunted growth or reduced growth rate as a result of drought stress (Lisar, 2012). Stem internode length, like plant height, is also a key indicator of tomato growth rate. Plants such as tomato growing in the open field increase stem length by increasing the internode to enhance light interception. These results agree with those of Sibomana et al (2013) who reported that stem internode length in tomato is sensitive to drought stress and reduction in

moisture availability relatively reduced the length of the internodes in greenhouse grown tomato plants

Stem girth or stem diameter was shown to decrease with decrease in level of soil moisture availability. Moisture stress reduces cell growth rate and sizes of the various layers of the stem such as the epidermal and parenchyma cells hence resulting to prolonged reduced cell turgor resulting to thinner stems than when there is sufficient soil moisture available (Amina *et al*. 2014). These results are similar to the results of Aguyo et al. (2013) who reported that severe water stress led to decrease in stem diameter and plant height.

Single leaf area in tomato plants was significantly affected by soil moisture level and the tomato genotype. Leaf area index cumulatively increases as plant maximizes light interception area and for more efficient photosynthesis. The results agree with Nahar *et al*., (2002) who showed that water limitation on different cultivars of tomato led to decrease in dry matter yield. Plant architecture of different genotypes also determines the single leaf area (María et al., 2002) and varying genotypes hence exhibit varied single leaf area.

Genotypes VI006840, VI006828, Cal J and ATM F1 were significantly affected moisture limitation to 70% PC while GBK050580 and VI005871 were only affected by further moisture limitation of 40 % PC recording an increase of at least six days taken to floral initiation as compared to the number of days taken at 100 % PC. Moisture limitation hinders plant initiation of reproductive growth and development of reproductive parts of plants such as flower buds. Nuruddin (2001) reported that severe water stress hampered floral development in flowering stage in green-house grown tomato. Similarly, Nicacias (2009) concluded that water stress conditions increased days to 50% flowering in tomato cultivars grown in greenhouse and also in

the field. Total number of fruits per plant in the study was significantly affected by moisture level and genotypes. Severe moisture limitation especially at flowering stage severely causes flower abortion and abscission hence poor fruit set. It also causes low pollination rate because of reduced pollen viability since it's desiccated in the process of pollination. Other studies done on water stress in tomato have similarly demonstrated that water stress reduces the number of fruits formed by a plant (Nuruddin, 2001; Sibomana et al., 2013). Genotypes or varieties have different yield potential and thus the total number of fruits differ. The indeterminate types tend to continue to bear more flowers and set fruits over longer period of time than the determinate types hence have higher total number of fruits that can be harvested. Indeterminate accessions such as VI007540, VI005895, VI006828, and VI005871 yielded higher number of fruits than the others showing that they have higher yield potential that can be harnessed in tomato variety improvement programmes.

Single fruit weight and total weight of all the harvested tomato fruits in each plant were significantly influenced by level of moisture stress but also different genotypes showed varied responses in these aspects. Cal J and accession VI005871 recorded significant decline in fruit weight per plant when moisture level reduced from 100% PC to 70% PC while Master F1, Stallion F1, VI006825 and VI005895 were significantly affected when moisture level was reduced further 40 % PC. Some accession like VI005895, VI005871 and VI006840 exhibited the potential to have heavy fruits despite the water stress conditions unlike other accessions and commercial varieties. Tembe *et al.* (2016) also reported similar results of tomato genotype variability in fruit weight when exposed to moisture stress. Moisture stress affects the water that's available for fruit formation to accumulate fruit dry matter accumulation. This is because

the tomato fruit is over 65 % water in composition. Some young fruits even shrink in size or fail to fully develop when the plant is under severe water stress hence affecting the fruit weight.

Fruit equatorial diameter (width) and fruit longitudinal length as the main contributors of fruit size were affected by the level of moisture availability and genotype. Water limitation during fruit development limits water used for dry matter accumulation in a plant leading to reduced fruit sizes. The results are in agreement with the study results of Aguyo *et al*. (2013) and Nicacias (2000) who also demonstrated that water stress reduced tomato fruit sizes. Genotype variation in terms of fruit size was very significant which can be attributed to the different shapes of the fruits in each genotype. There was positive correlation between plant height and number of fruits in a variety and as height increased, number of fruits also increased. This is because the taller the plant, the more flowers it will bear in its floral apices especially for indeterminate tomato varieties. This agrees with the results of Nurruddin *et al*. (2012) who reported higher fruit number in the taller indeterminate tomato varieties in the trial. Negative correlation between internode length and stem girth showed that longer internodes tend to have thinner stem girth especially true for herbaceous plants such as tomato.

3.6 Conclusion

The results demonstrated water stress reduces growth and negatively affects fruit production in tomato. There exists varied drought tolerance potential among tomato genotypes demonstrated by different genotypes. Total fruit weight per plant of accession VI007540, VI006840, VI006828, VI005990, VI005987, RV101885, GBK050580 was not significantly affected by reduction in moisture level indicating they may be potentially adaptable to water stressed conditions. Accession VI005895 exhibited superiority in average fruit size and mean fruit weight per plant aspects over commercial tomato genotypes studied hence can be exploited in breeding

for improved production hybrids. Accession VI007540 had the highest mean number of fruits per plant compared to the rest of the genotypes in the study including commercial varieties and can equally be bred with other varieties which do not have this production trait. Screening and selection of large pool of African tomato accessions with respect to drought tolerance is an important pre-requisite for improvement of better tomato cultivars. Screening indigenous tomato genotypes will also contribute to preservation of genetic material that could otherwise have been under risk of loss of biodiversity/genetic erosion. More work need to be done on evaluating the various accessions to understand their genetic composition through molecular characterization to identify the genes responsible for some variations and their heritability. This will enhance the breeding work for tomato variety development.

CHAPTER FOUR: EFFECT OF NITROGEN NUTRITION STRESS ON GROWTH AND YIELD OF SELECTED AFRICAN TOMATO ACCESSIONS AND COMMERCIAL TOMATO VARIETIES

4.1 Abstract

Tomato (*Solanum lycopersicum*) ranks second vegetable crop in production, consumption and revenue in Kenya. Low soil fertility, especially soil nitrogen deficiency is a major constraint to optimum tomato yields in Kenya. African accessions' variability can be exploited with respect to nitrogen use efficiency to improve and/or develop new varieties. This study evaluated growth and yield responses of African tomato accessions and commercial genotypes to different levels of nitrogen fertilizer application. Four accessions (VI005895, VI005871, VI006840 and VI005990) and four commercial genotypes (Stallion F1, Master F1, Cal J and Rio Grande) were subjected to 0, 50, 100, 150, 200 and 250 kg N/ha rates of nitrogen application. The experiment was laid out as randomized complete block design with 8 x 6 factorial arrangement replicated three times. Growth and yield parameters were taken at 50% flowering and at harvest time respectively and subjected to analysis of variance at **(**$P \leq 0.05$**)**. Growth (number of primary branches, plant stem height, stem girth and single leaf area) and yield (number of fruits per plot and fruit yield per plant) increased with the level of nitrogen fertilizer supplied. Nitrogen rate of 250 kg N/ha yielded highest results than the rest of the levels. Higher nitrogen use efficiency was observed in Stallion F1 and accession VI005871. Growth and yield traits evaluated significantly also varied with genotype. Accessions VI005871, VI005895 and VI005987 performed better than commercial genotypes Cal J and Rio Grande in terms of single fruit weight per plant, number of fruits per plant and fruit yield per plant. These genotypes present an opportunity to harness them in tomato cultivar development programmes by introgression of desirable traits genes such as heavy single fruit weight.

Key words: Accessions, nitrogen use efficiency, primary branches, commercial genotypes

4.2 Introduction

Tomato is ranked second to potato in production among the leading vegetables in Kenya with approximately 20, 111 ha production area, producing 341,026 Metric tonnes valued at Kenyan shillings 13.68 billion in the year 2016 (AFA-HCD, 2015-2016). However optimal tomato production has been constrained by drought occurrence, high pest and diseases infestation, low soil fertility and lack of affordable but good quality seed (Sigei *et al.,* 2014). Karuku et al., (2017) also reported that low soil fertility in tomato fields is a major constraint to high tomato yield attainment by farmers in Kenya. Kenyan soils in arable land have significantly low level of nitrogen due to high mining rate through continuous cropping, soil erosion among other factors (NAAIAP, 2014). To address the constraint of low soil fertility, farmers adopt different ways to replenish their soils such as use of organic manure and synthetic fertilizers. Tomato nitrogen deficiency in the farmer's fields manifests as chlorosis on the foliage which later leads to early senescence, reduced apical growth rate, reduced formation of lateral branches resulting to retarded growth and thin stems. These challenges during growth lead to significant reduction of yield from such tomato crop. Nitrogen deficiency in soils is brought about by the rapid losses of applied nitrogen fertilizers that occur through denitrification, volatilization and leaching (FAO, 2016). Most of the arable land in Kenya experiences irregular rainfall hence leading to leaching of nitrogen. However, most farmers in those areas are resource challenged in terms of access to inputs such as inorganic fertilizers (Sigei *et al*, 2014). Optimal tomato yields of 75 to 100 tonnes/ha require application of 200-250 kg N/ha (Yara group Kenya, 2011). Farmers normally struggle with decision on what level of fertilizers to apply for optimum yield without making economic losses (Mangale *et al*., 2015). Incorrect rates of organic fertilizer application, poor timing of stage to apply and poorly responsive tomato varieties to nitrogen application is challenge to farmers, hence affecting overall productivity.

Poor fertilizer use in irrigated crops including tomato may lead to soil acidity, poor returns on agro-investments, leaching and contamination of water bodies. Tomato accessions have been shown to exhibit varied genetic diversity with potential local adaptability (Tembe *et al.*, 2016). Evaluation of African tomato genotypes and commercial varieties' response to nitrogen application variation may identify genotypes that have higher nitrogen use efficiency which can be utilized in tomato improvement programmes to enhance tomato production in Kenya.

4.3 Materials and methods

4.3.1 Sites Description

Field studies were conducted at Kabete field station and at Mwea field station between the months of October 2018 and February 2019. Kabete field station is situated in agro-ecological zone (AEZ) three (Jaetzold and Schmidt, 1983) and lies on an attitude of 1940 meters above sea level, latitude of 1°15'S and longitude of 36°41'E (Sombroek *et al*., 1982). It is normally a humid and high potential zone with mean annual rainfall of 1000 mm. Kabete site experienced a mean minimum temperature of 12° C and mean maximum temperature of 25° C (Table 4.1). The soils are deep, well drained, reddish-brown humic nitisols (Michieka, 1978; FAO, 1990) which are good conditions for growing tomatoes. Mwea field station is situated in agro-ecological zone four and lies on an attitude of 1640 metres above sea level. It experiences bimodal rainfall ranging from 850- 1000 mm annually with a long rains season between March and May and the short rains season in October –December. Temperatures in this site ranged from minimum 16 ^{o}C to mean maximum 28 ^{o}C (Table 4.2). The soils in the site are vertisols which are slightly acidic with a pH of 5.1- 5.3 (Wahome *et al.* 2011).

Table 4.1: Weather conditions at Kabete station between September 2018 and February 2019 cropping season

Month	Temperature (º C)		Rainfall (mm) Total	Relative humidity (%) mean
	Mean max	Mean min		
September	23	15	27.4	45.2
October	19	13	85.7	65.3
November	24	16	190	73.7
December	22	14	176	69.9
January	25	12	20.1	35.1
February	24	15	24.6	36.7

Source: Kabete field Met. weather station

Table 4.2: Weather conditions at Mwea station between September 2018 and February 2019 cropping season

Month	Temperature (º C)		Rainfall (mm) Total	Relative humidity (%) mean
	Mean max	Mean min		
September	24	17	30.0	45.2
October	22	13	85.7	50.4
November	23	19	165.7	66.4
December	25	17	198.8	75.0
January	28	14	19.6	27.9
February	27	16	39.5	40.1

Source: KARLO -Mwea Met. weather station

4.3.2 Planting materials

Four African tomato genotypes (VI005895, VI005871, VI005987 and VI005990) and four Kenyan commercial tomato genotypes (Rio Grande, Cal J, Stallion F1 and Master F1) were used in the study (Table 4.3). The African tomato genotypes were selected based on having high fruit weight per plant and commercial genotypes were selected among those which farmers normally grow, both open pollinated varieties and hybrid varieties in Kenya.

Table 4.3: African tomato genotypes and Kenyan commercial genotypes used in the trial

S.no	Accessions (AVRDC/ code)	Origin	DTM	Fruit weight/plant (g)	Growth habit
1	VI005895	Egypt	92	1711	Indeterminate, erect growth, dense foliage
2	VI005987	Morocco	109	2343	Indeterminate, erect growth, dense foliage
3	VI005871	Morocco	107	2171	Indeterminate, erect growth, medium foliage
4	VI005990	Morocco	109	2165	Determinate, erect growth, medium foliage
	Commercial varieties				
5	Rio grande (OPV)	Italy	85	1600	Determinate, bush type, medium foliage
6	Cal J (OPV)	North America	80	1100	Determinate, bush type, dense foliage
7	Stallion F1	Kenya	95	2637	Semi-determinate, erect growth, medium foliage
8	Master F1	Kenya	95	2000	Determinate, erect growth, dense foliage

Sources: Tembe *(2016), Kenya Seed Company Ltd website, Continental Seeds Ltd website.*
DTF – days to 50% flowering, DTM – days to maturity, AVRDC - Asian Vegetable Research and Development Centre (Taiwan), NGK- National Gene Bank (Kenya)

4.3.3 Soil analyses

Soil tests for both sites were conducted at KALRO –Nairobi soil analysis laboratory (Table 4.4 and Table 4.5). Soils were tested for pH, K, P, Na, Ca, Mg, Mn, Fe, Zn & Cu (Mehlich *et al*., 1962). Soils were also tested for total organic carbon using calorimetric method (Anderson and Ingra, 1993) and for total nitrogen using Kjeldahl method (Page *et al*., 1982).

Table 4.4: Chemical characteristics of sampled soil at Kabete Field Station

Fertility parameter and unit of measurement	Value	Class
Soil pH	5.60	medium acid
Total Nitrogen (%)	0.20	Low
Total Org. Carbon (%)	1.40	Moderate
Phosphorus (ppm)	63.0	Adequate
Potassium me (%)	1.00	Adequate
Calcium me (%)	7.10	Adequate
Magnesium me (%)	5.30	High
Manganese me (%)	0.50	Adequate
Copper (ppm)	4.00	Adequate
Iron (ppm)	60.0	Adequate
Zinc (ppm)	24.3	Adequate
Sodium me (%)	0.30	Adequate

Table 4.5: Chemical characteristics of sampled soil at Mwea Field Station

Fertility parameter and unit of measurement	Value	Class
Soil Ph	5.90	medium acid
Total Nitrogen (%)	0.14	Low
Total organic Carbon (%)	1.36	Moderate
Phosphorus (ppm)	250	High
Potassium me (%)	1.03	Adequate
Calcium me (%)	12.4	Adequate
Magnesium me (%)	4.40	High
Manganese me (%)	0.48	Adequate
Copper (ppm)	1.42	Adequate
Iron (ppm)	58.1	Adequate
Zinc (ppm)	4.75	Low
Sodium me (%)	0.28	Adequate

Source: Soil test results from Kenya Agricultural & Livestock Research Organization-National Agricultural Research Laboratory

4.3.4 Treatments and experimental design.

Eight tomato genotypes (four accessions VI005895, VI005987, VI005871, VI005990 and four commercial genotypes Cal J, Master F1, Stallion F1, and Rio Grande) were subjected to six levels of nitrogen. These included: a control (0 kg N/ha), 50 kg N/ha, 100 kg N/ha, 150 kg N/ha, 200 kg N/ha and 250 kg N/ha supplied in form of calcium ammonium nitrate (CAN). Nitrogen was applied in two equal splits, first topdress at two weeks after transplanting and second topdress at floral initiation. The experiments were laid out in a randomized complete block design (RCBD) with 8 x 6 factorial arrangement replicated three times. Plot sizes were 2.4 m by 1.4 m. Plots were separated by a distance of 1m while the blocks were separated by 2 m. Each plot accommodated two rows with four plants each, with 75 cm spacing between the rows and 60 cm spacing within the rows.

4.3.5 Crop husbandry

The fields in both locations were cleared of previous crops and ploughed using a tractor. Harrowing to break hardpans, levelling and establishing planting holes in the demarcated plots was then carried out manually. Seedlings which were grown in germination trays for four weeks were transplanted to prepared holes. Prior to transplanting, the soil in the planting holes was

uniformly mixed with basal fertilizer triple super phosphate (TSP) at a rate of 44.44 kg P/ha to enable rapid plant establishment after transplanting. Potassium was supplied to the tomato crops through spraying straight fertilizer foliar feed, Dimiphite® 600 (containing 33% K_20) at dosage of 20ml/20 L during pre-flowering for two times, with a span of fifteen days.

Fig. 4.1 Tomato crop growing at the field during vegetative and fruit development stages
Photo source: by author

The field was kept weed free through constant hand weeding in the vegetative and reproductive growth phases of the crop (Fig 4.1). Whiteflies, *Tuta absoluta* and thrips infested tomato plants and were controlled using Coragen 20 SC, 4 ml/20 L (active ingredient; chlorantraniliprole) and Escort® 19EC; 20ml/20 L (active ingredient; Emamectin Benzoate). Late blight also infected the crop and was controlled by using Ridomil Gold MZ 68 WG, 100g/20 L (active ingredient; metalaxyl and mancozeb).

4.3.6 Data collection

Data were collected on the following growth parameters at flower initiation: numbers of primary branches, plant height, stem girth, internode length, leaf length, leaf width and days to 50%

flowering. Data were also collected on yield parameters at harvest time: total number of fruits per plot, total fruit weight per plot, average single fruit weight, average fruit length, average fruit width and total yield per plant. Both growth and yield parameters data were collected from a sample of four (4) plants in each plot, which was 50 % of the total plants in each experimental plot. Number of primary branches was counted manually and plant height was measured using a metre rule from the base of tomato plant stem at the soil level to the apex of the plant. Number of days to 50 % flowering was counted from the day tomato seeds were sown. Stem girth was measured using a tape measure around the stem at a distance of 10 cm from soil level. Internode length was measured using a ruler between two tagged trusses. Single leaf area (SLA) was calculated by measuring tagged leaf length (L) from leaf pulvinus to its tip and width (W) at widest width across the leaf using a ruler. The SLA was determined by the formula: $SLA= 0.763L+ 0.34L^2$ (Rivera et al., 2007).

Fruit width measurements were taken from sample of six fruits per plant measured using a ruler along equatorial diameter of opened fruits. Fruit length measurements were taken from sample of six fruits per plant measured using a ruler starting from the stem end to the blossom end of opened fruits. Total number of fruits per plant was determined by counting all fruits harvested per plant. Total fruits weight per plant was determined by weighing all fruits harvested cumulatively from a plant using an electronic weighing balance. Single fruit weight was determined by weighing a sample of six fruits per plant and taking the average. Nitrogen use efficiency of genotypes was evaluated using agronomic efficiency (AE_N) term; AE_N= (Genotype's yield (kg/ha) in fertilized plots-genotype's yield (kg/ha) in control plots) / amount of N applied.

4.3.7 Data analysis

Data collected were subjected to analysis of variance (ANOVA), separation of means for significant treatment effects done using the least significant difference (L.S.D) test at ($P \leq 0.05$). Correlation among growth traits (primary branches, plant height, internode length and stem girth, single leaf area, days to 50% flowering) and yield traits (number of fruits per plant, fruit weight per plant and yield) and linear regression analyses of N fertilizer levels and number of fruits per plant, fruit weight per plant and yield was done using Genstat software version 15.

4.4 Results

4.4.1 Effect of nitrogen fertilizer rate on growth attributes of selected African tomato accessions and commercial varieties

(i) Number of primary branches per plant

In both trial sites, the numbers of primary branches were significantly affected ($P \leq 0.05$) by genotype and N level applied but not by the interaction of the two factors (Table 4.6). At Kabete field station accession VI005871 had the more branches per plant than all genotypes while Rio Grande had the fewest compared to the rest of the genotypes. In Mwea field station, similar observations were made except that accessions had higher number of primary branches than commercial varieties. Application of N increased number of primary branches per plant compared to the control. 200 kg N/ha and 250 kg N/ha had higher increase on primary branches than at 50, 100 and 150 kg N/ha. Tomato plants of all genotypes recorded higher average number of primary branches at Mwea field station site than at Kabete field station.

(ii) Plant height

Main stem height was significantly influenced ($P \leq 0.05$) by the genotype and the N level but not by genotype x N level interaction in both Kabete and Mwea sites (Table 4.7). Three the four accessions (VI005871, VI005895 and VI005987) recorded taller stem heights (69.9 cm to 84 cm

in Kabete and 72.5 to 86.8 cm in Mwea) than three of the commercial genotypes (Cal J, Master F1 and Rio Grande) which ranged from 55.2 to 59.1 cm in Kabete and 56.1 to 60.5 cm in Mwea. Application of 50 kg N/ha and above led to increase in plant stem height in Kabete field station while application of 100 kg N/ha and above led to increase in plant height in Mwea field station. Mwea field station site recorded higher mean plant stem height (67.3 cm) compared to Kabete field station (64.9 cm)

(iii) Internode length

There were significant differences ($P \leq 0.05$) in tomato internode length due to genotype and level of fertilizer applied to the plants but not due to genotype x N level interaction in both Kabete and Mwea trial sites (Table 4.8). Mean internode ranged from 2.9 cm in Cal J to 3.4 cm in VI005895 in Kabete station and 4.6 cm in Cal J to 5.6 cm in VI005895 in Mwea station. Mean internode length in Mwea station was higher in Kabete station. Overall internode length increased from 2.5 to 3.9 cm in Kabete and 4.1 to 5.7 cm in Mwea when N level increased from 0 kg N/Ha to 250 kg N/Ha, representing 35.9% and 28.1 % increase at the two sites respectively. Application of 200 and 250 kg N/ha had significantly higher internode length than the control (0 kg N/ha), 50 and 100 kg N/ha

(iv) Stem girth

Tomato stem girth was significantly affected ($P \leq 0.05$) by genotype and N level applied but not by the interaction between genotype and N level in both sites (Table 4.9). Cal J, Rio Grande and VI005990 genotypes had narrower stem girth than most of the other genotypes in both sites. Generally, stem girth increased with increase in N level in both sites. Addition of N from 0 kg N/Ha to 250 kg N/Ha resulted to an increase in stem girth from 2.9 to 4.4 cm in Kabete and 3.2 to 4.6 cm in Mwea station.

Table 4.6: Mean values of number of primary branches per plant of tomato genotypes grown under different N levels at Kabete and Mwea Field stations

Number of primary branches per plant							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	5.2	6.3	6.0	6.2	6.7	7.3	6.3
Master F1	4.7	4.9	5.8	5.8	6.1	6.8	5.7
Rio Grande	4.5	4.9	5.7	5.8	6.3	6.5	5.6
Stallion F1	4.8	5.9	6.1	6.7	7.5	8.6	6.6
VI005871	6.5	6.9	7.4	8.0	8.4	8.5	7.6
VI005895	5.9	6.1	6.8	7.1	7.3	7.8	6.8
VI005987	5.8	6.5	6.9	7.2	8.5	9.0	7.3
VI005990	4.9	5.3	5.7	7.2	7.8	8.2	6.5
Mean	5.3	5.9	6.3	6.7	7.3	7.8	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	0.6						
l.s.d (P≤0.05) Gen	0.4						
l.s.d (P≤0.05) NL	0.4						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	10.2						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	5.3	6.5	5.8	5.9	6.7	7.9	6.4
Master F1	5.0	5.7	6.1	6.3	6.8	7.5	6.2
Rio Grande	5.2	5.4	6.0	6.2	6.2	6.9	6.0
Stallion F1	4.8	6.1	6.5	6.6	7.5	8.7	6.7
VI005871	7.2	7.9	8.0	8.9	9.3	9.5	8.5
VI005895	6.3	8.2	8.4	8.8	9.1	9.6	8.4
VI005987	6.8	7.3	7.9	8.2	8.7	9.2	8.0
VI005990	6.1	6.7	6.6	8.1	8.5	8.9	7.5
Mean	5.8	6.7	6.9	7.4	7.8	8.5	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	1.0						
l.s.d (P≤0.05) Gen	0.6						
l.s.d (P≤0.05) NL	0.5						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	11.9						

Fpr - F probability, Gen- genotype, NL - nitrogen level, NS- not significant.

Table 4.7: Mean values of plant height (cm) at 50 % flowering of tomato genotypes grown under different N levels at Kabete and Mwea field stations

Plant height (cm)							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	48.4	47.5	56.6	59.1	61.5	64.5	56.3
Master F1	46.9	51.9	59.2	62.6	65.4	68.8	59.1
Rio Grande	45.0	49.7	54.9	57.8	59.9	63.7	55.2
Stallion F1	58.5	62.9	68.1	69.6	71.9	74.6	67.6
VI005871	53.0	60.7	69.8	73.9	79.9	82.2	69.9
VI005895	60.2	66.2	69.8	70.7	73.8	90.3	71.8
VI005987	73.3	82.6	84.8	89.0	90.5	83.7	84.0
VI005990	41.2	45.0	58.5	60.5	62.3	65.2	55.5
Mean	53.3	58.3	65.2	67.9	70.7	74.1	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level	<.001						
Fpr. Gen*NL	0.6						
l.s.d (P≤0.05) Gen	4.0						
l.s.d (P≤0.05) NL	3.5						
l.s.d (P≤0.05) Gen*N	NS						
CV%	9.3						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	45.8	49.9	53.6	57.7	61.4	68.1	56.1
Master F1	50.0	54.4	57.3	60.6	64.0	68.0	59.0
Rio Grande	53.3	54.3	60.5	61.8	64.3	68.7	60.5
Stallion F1	64.0	67.7	70.5	71.9	74.6	75.8	70.8
VI005871	59.5	63.6	71.3	75.6	78.8	86.3	72.5
VI005895	61.7	62.9	64.8	73.8	81.6	91.8	72.8
VI005987	77.3	81.4	84.9	87.1	92.5	97.7	86.8
VI005990	45.7	48.3	63.0	66.1	67.9	69.4	60.1
Mean	57.1	60.3	65.7	69.3	73.1	78.2	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level	<.001						
Fpr. Gen*NL	0.7						
l.s.d (P≤0.05) Gen	3.8						
l.s.d (P≤0.05) NL	3.3						
l.s.d (P≤0.05)Gen*NL	NS						
CV%	8.6						

Fpr - F probability, Gen- genotype, NL - nitrogen level, NS- not significant.

Table 4.8: Mean values of internode length (cm) of tomato genotypes grown under different N levels at Kabete and Mwea field stations

Internode length (cm)							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	2.2	2.5	2.9	3.1	3.2	3.7	2.9
Master F1	2.5	2.6	3.1	3.4	3.6	4.2	3.2
Rio Grande	2.6	2.1	3.0	3.1	3.3	3.8	3.0
Stallion F1	2.8	2.6	3.3	3.3	3.6	3.7	3.2
VI005871	2.2	2.5	2.8	3.2	3.4	4.0	3.0
VI005895	3.0	3.2	3.4	3.3	3.5	3.8	3.4
VI005987	2.5	2.3	2.9	3.3	3.4	3.7	3.0
VI005990	2.4	3.1	3.2	3.5	3.7	4.0	3.3
Mean	2.5	2.6	3.1	3.3	3.5	3.9	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	1.0						
l.s.d (P≤0.05) Gen	0.2						
l.s.d (P≤0.05) NL	0.2						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	11.2						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	3.4	4.1	4.5	5.0	5.2	5.4	4.6
Master F1	3.8	4.3	4.5	4.8	5.2	5.5	4.7
Rio Grande	3.9	4.5	4.7	4.9	5.0	5.2	4.7
Stallion F1	4.1	4.5	4.6	4.9	5.3	5.7	4.9
VI005871	4.2	4.6	4.9	5.3	5.4	5.7	5.0
VI005895	4.7	5.1	5.2	5.8	6.1	6.4	5.6
VI005987	4.1	4.7	5.3	5.4	5.6	5.8	5.2
VI005990	4.3	4.7	5.4	5.6	5.9	6.1	5.3
Mean	**4.1**	**4.6**	**4.9**	**5.2**	**5.5**	**5.7**	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level	<.001						
Fpr. Gen*NL	1.0						
l.s.d (P≤0.05) Gen	0.3						
l.s.d (P≤0.05) NL	0.2						
l.s.d (P≤0.05)Gen*NL	NS						
CV%	8.2						

Fpr - F probability, Gen- genotype, NL - nitrogen level, NS- not significant.

Table 4.9: Mean values of stem girth (cm) of tomato genotypes grown under different N levels at Kabete and Mwea field stations.

Stem girth (cm)							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	2.8	3.0	3.3	3.6	3.7	4.2	3.4
Master F1	2.7	3.2	3.5	3.6	3.7	4.1	3.5
Rio Grande	2.6	2.9	3.5	3.6	3.8	4.0	3.4
Stallion F1	3.2	3.7	3.8	4.1	4.3	4.8	4.0
VI005871	3.2	3.6	3.7	3.8	4.3	4.8	3.9
VI005895	3.3	3.7	3.8	3.9	4.1	4.5	3.9
VI005987	3.2	3.4	3.7	4.1	4.2	4.6	3.9
VI005990	2.1	2.8	3.5	3.9	4.0	4.3	3.4
Mean	2.9	3.3	3.6	3.8	4.0	4.4	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	0.9						
l.s.d (P≤0.05) Gen	0.2						
l.s.d (P≤0.05) NL	0.2						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	10.0						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	2.8	3.1	3.3	3.6	3.9	4.3	3.5
Master F1	3.3	3.5	3.7	3.8	4.2	4.5	3.8
Rio Grande	3.0	2.9	3.5	3.6	3.9	4.0	3.5
Stallion F1	3.6	3.9	4.2	4.3	4.4	4.6	4.2
VI005871	3.5	4.1	4.0	4.4	4.7	5.0	4.3
VI005895	3.7	4.0	4.1	4.1	4.4	4.7	4.2
VI005987	3.1	3.3	3.8	4.0	4.3	4.7	3.9
VI005990	2.4	3.0	3.9	4.2	4.5	4.7	3.8
Mean	3.2	3.5	3.8	4.0	4.3	4.6	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	0.3						
l.s.d (P≤0.05) Gen	0.2						
l.s.d (P≤0.05) NL	0.2						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	8.7						

Fpr - F probability, Gen- genotype, NL - nitrogen level.

(v) Single Leaf Area

Genotype and N level significantly affected (P≤0.05) the single leaf area but the interaction between genotype and N level had no significant effect on the leaf area in both sites (Table 4.10). Accessions VI005987 and VI005871 had small leaf area (28.8 cm^2 and 27.6 cm^2 respectively) while Stallion F1 recorded the highest single leaf area in both sites. Overall mean of single leaf area was higher, 34.7 cm^2 in Kabete and 34 cm^2 in Mwea station. At Kabete, single leaf area increased with increase in N level. At Mwea site, application of 200 and 250 kg N/ha had large leaf area than 0, 50 and 100 kg N/ha. Overall means of single leaf area among fertilizer levels increased from 28.5 to 40.7 cm^2 in Kabete and 27.7 to 39.4 cm^2 in Mwea station when N level was increased from 0 kg N/Ha to 250 kg N/Ha.

(vi) Number of days to 50 % flowering

In both trial sites, mean number of days taken to attain 50 % flowering was significantly affected (P≤0.05) by genotype but not by N level and interaction of genotype x N level (Table 4.11). Accessions except VI005990 took shorter time (54 to 56 days) to achieve 50 % flowering than commercial genotypes (58-59 days) in Kabete. Similarly in Mwea site, accessions except VI005990 took shorter time (42 to 44 days) to achieve 50 % flowering than commercial genotypes (46-50 days). On average, accessions and commercial genotypes took relatively shorter time to achieve 50 % flowering (42-50 days) in Mwea field station compared to Kabete field station (54-59 days).

Table 4.10: Mean values for single leaf area (cm^2) for tomato genotypes grown under different N levels at Kabete and Mwea field stations.

Single leaf area (cm^2)							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	28.5	30.3	32.0	34.5	37.8	39.2	33.7
Master F1	29.0	32.8	33.7	35.2	37.6	40.8	34.8
Rio Grande	28.2	30.4	35.8	37.5	43.3	47.2	37.1
Stallion F1	32.5	34.7	36.7	39.9	41.6	44.1	38.2
VI005871	26.9	28.3	30.5	34.8	37.4	39.4	32.9
VI005895	31.1	32.4	33.4	35.5	37.3	38.6	34.7
VI005987	22.7	25.5	28.7	30.5	31.7	33.5	28.8
VI005990	29.6	31.6	37.0	39.1	42.0	42.8	37.0
Mean	28.5	30.7	33.5	35.9	38.6	40.7	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	1.0						
l.s.d (P≤0.05) Gen	2.3						
l.s.d (P≤0.05) NL	2.0						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	9.9						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	27.5	28.7	31.1	33.1	36.9	38.9	32.7
Master F1	27.5	32.2	34.2	36.2	38.5	40.1	34.8
Rio Grande	30.4	30.5	35.1	38.4	37.1	38.3	35.0
Stallion F1	30.3	34.5	37.3	40.8	42.3	45.3	38.4
VI005871	25.0	23.3	27.8	27.8	30.2	31.5	27.6
VI005895	29.4	34.9	36.4	38.3	39.3	40.7	36.5
VI005987	22.7	26.0	29.8	34.8	37.3	39.3	31.6
VI005990	29.0	29.9	35.5	37.3	38.5	41.0	35.2
Mean	27.7	30.0	33.4	35.8	37.5	39.4	
Fpr. Genotype(Gen)	<.001						
Fpr. Nitrogen level	<.001						
Fpr. Gen*NL	1.0						
l.s.d (P≤0.05) Gen	3.2						
l.s.d (P≤0.05) NL	2.8						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	14.4						

Fpr - F probability, Gen- genotype, NL - nitrogen level, NS-not significant

Table 4.11: Mean values of number of days taken to 50% flowering among tomato genotypes grown under different N levels at Kabete and Mwea field stations

Number of days to 50% flowering							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	58	59	58	61	59	59	59
Master F1	57	59	59	59	58	58	58
Rio Grande	60	60	59	57	60	60	59
Stallion F1	59	60	56	59	57	56	58
VI005871	55	57	57	55	56	57	56
VI005895	54	54	57	55	58	55	56
VI005987	53	55	53	54	54	55	54
VI005990	57	58	58	59	56	56	57
Mean	57	58	57	57	57	57	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level(NL)	0.76						
Fpr. Gen*NL	0.69						
l.s.d (P≤0.05) Gen	1.5						
l.s.d (P≤0.05) NL	NS						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	4.0						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	47	48	47	51	53	52	50
Master F1	46	47	49	49	47	48	48
Rio Grande	49	48	49	47	50	49	49
Stallion F1	45	49	45	47	46	44	46
VI005871	41	46	45	43	43	46	44
VI005895	42	42	47	42	46	43	44
VI005987	40	42	41	43	42	44	42
VI005990	47	45	46	47	46	44	46
Mean	45	46	46	46	47	46	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level(FL)	0.42						
Fpr. Gen*NL	0.6						
l.s.d (P≤0.05) Gen	2.0						
l.s.d (P≤0.05) NL	NS						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	6.7						

Fpr - F probability, Gen- Genotype, NL - Nitrogen level, NS- not significant

4.4.2 Effect of nitrogen nutrition on yield components of selected African tomato accessions and commercial varieties

(i) Fruit length

Cross sectional length of tomato fruits was significantly affected ($P \leq 0.05$) by the genotype in both trial sites (Table 4.12). However, N level and interaction of genotype x N level had no significant effect on the average fruit length in both sites. Mean fruit length among genotypes ranged from 3.6 cm (VI005987) to 5.2 cm (Master F1) in Kabete and 3.7 cm (VI005987) to 4.9 cm in Mwea field station site. Generally, accessions (VI005871, VI005895, VI005987, VI005990) recorded shorter fruit length than commercial genotypes in both sites. Genotype VI005990 however had longer fruits than the rest of accessions and it was significantly different from Cal J in fruit length. Mean fruit length values were 4.4 cm and 4.3 cm in Kabete field station and Mwea field station respectively.

(ii) Fruit width

Equatorial fruit width was significantly affected ($P \leq 0.05$) by tomato genotypes in both Kabete and Mwea trial sites (Table 4.13). Nitrogen level and interaction of genotype x N level had no significant effect on fruit width. Genotype average fruit width (cm) ranged from 4.3 cm (Rio Grande) to 6.1 cm (VI005871) in Kabete site and 4.0 cm (Cal J) to 6.0 cm (VI005871) in Mwea site. Generally, accessions recorded larger fruit width ranging from 5.1 to 6.1 cm in Kabete and 4.9 to 6.0 cm in Mwea compared to commercial genotypes which recorded average fruit width of 4.3 to 4.9 cm at Kabete field station site and 4.0 to 4.7 cm in Mwea site. Mean of tomato fruit width was 5.1 cm and 5.0 cm in Kabete field station and Mwea field stations respectively.

Table 4.12: Mean values of fruit length (cm) of tomato genotypes grown under different N levels at Kabete and Mwea field stations.

Fruit length (cm)							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	4.6	4.3	4.3	4.6	4.4	4.5	4.4
Master F1	4.9	5.3	5.4	5.3	4.8	5.4	5.2
Rio Grande	4.8	4.8	4.8	5.0	4.9	5.0	4.9
Stallion F1	4.9	5.2	5.1	5.0	4.9	5.3	5.0
VI005871	3.7	3.6	3.5	4.0	3.7	3.8	3.7
VI005895	3.6	4.0	3.9	4.0	3.5	3.4	3.7
VI005987	3.6	3.6	3.7	3.9	3.5	3.8	3.6
VI005990	4.2	4.0	4.8	4.1	4.4	4.5	4.3
Mean	4.3	4.3	4.4	4.5	4.3	4.4	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	0.5						
Fpr. Gen*NL	0.9						
l.s.d (P≤0.05) Gen	0.3						
l.s.d (P≤0.05) NL	NS						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	9.1						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	4.3	4.3	4.3	4.5	4.5	4.6	4.4
Master F1	4.4	4.5	4.8	5.2	5.3	5.3	4.9
Rio Grande	4.5	4.4	4.6	4.6	4.7	5.0	4.6
Stallion F1	4.9	4.4	4.4	4.8	4.9	4.7	4.7
VI005871	3.7	3.8	3.5	3.9	3.7	3.8	3.7
VI005895	3.4	3.7	3.7	4.0	3.5	4.2	3.8
VI005987	3.5	3.7	3.7	3.9	3.5	4.0	3.7
VI005990	4.3	4.3	4.3	4.2	4.4	4.8	4.4
Mean	4.1	4.1	4.2	4.4	4.3	4.5	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	0.1						
Fpr. Gen*NL	1.0						
l.s.d (P≤0.05) Gen	0.3						
l.s.d (P≤0.05) NL	NS						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	11.9						

Fpr - F probability, Gen- genotype, NL - nitrogen level, NS- not significant.

Table 4.13: Mean values of fruit width (cm) of tomato genotypes grown under different N levels at Kabete and Mwea field stations

Fruit width (cm)							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	5.0	5.6	5.2	4.6	4.6	4.4	4.4
Master F1	4.8	5.0	4.9	4.9	4.6	4.9	4.9
Rio Grande	4.2	4.5	4.7	4.4	4.6	4.3	4.3
Stallion F1	4.5	4.8	4.7	4.6	4.3	4.7	4.7
VI005871	6.7	6.7	5.8	5.1	6.3	6.1	6.1
VI005895	7.6	6.0	5.8	5.1	6.9	5.7	5.7
VI005987	5.7	5.9	5.3	5.2	5.8	5.7	5.7
VI005990	4.7	4.7	4.7	5.1	4.5	5.1	5.1
Mean	5.4	5.4	5.1	4.9	5.2	5.1	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	1.0						
Fpr. Gen*NL	0.3						
l.s.d (P≤0.05) Gen	0.5						
l.s.d (P≤0.05) NL	NS						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	13.1						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	4.0	4.3	3.8	4.0	4.0	4.0	4.0
Master F1	4.4	4.4	4.6	4.5	4.6	5.1	4.6
Rio Grande	4.3	4.6	4.5	4.5	4.6	4.7	4.5
Stallion F1	4.6	4.4	4.4	4.8	4.6	5.1	4.7
VI005871	6.0	6.0	5.9	6.0	6.0	6.2	6.0
VI005895	5.6	5.5	6.4	5.0	6.3	5.8	5.8
VI005987	5.8	5.4	5.4	5.1	5.1	5.7	5.4
VI005990	4.7	4.9	4.6	5.2	4.7	5.2	4.9
Mean	4.9	4.9	4.9	4.9	5.0	5.2	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	0.7						
Fpr. Gen*NL	1.0						
l.s.d (P≤0.05) Gen	0.5						
l.s.d (P≤0.05) NL	NS						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	15.8						

Fpr - F probability, Gen- genotype, NL - nitrogen level, NS- not significant

(iii) Single fruit weight

Average single fruit weight (g) was significantly affected ($P \leq 0.05$) by genotypes (Table 4.14). No significant effects on single fruit weight were observed as a result of N fertilizer level and interaction of genotype x N fertilizer level in both trial locations. Tomato single fruit weights varied 49.8 g (Rio Grande) to 98.8 g (VI005895) at Kabete and 50.6 g (Rio Grande) to 96.1 g (VI005895) in Mwea site. Single fruit weights of accessions VI005871, VI005895 and VI005987 were higher than those of commercial genotypes in both sites. Mean single fruit weight in Kabete field station was 70.5 g compared to Mwea field station where mean single fruit weight recorded was 68.8 g.

(iv) Number of fruits per plant

Number of fruits per plant was significantly affected ($P \leq 0.05$) by genotype and level of nitrogen in both sites (Table 4.15). However, the interaction between genotype and nitrogen level had no significant effect on number of fruits per plant. Number of fruits per plant among genotypes ranged from 16 to 25 in Kabete site and 11 to 21 in Mwea site. Application of 100 kg N/ha and above significantly increased the number of fruits per plant relative to the control. Application of 250 kg N/ha had the highest number of fruits per plant compared to the other lower levels of nitrogen. Accessions fruits ranged from 16 fruits (VI005990) to 20 fruits (VI005987) both in Kabete and Mwea field stations compared to 14 fruits (Cal J) to 25 fruits (Stallion F1) in Kabete site and 11fruits (Cal J) to 21 fruits (Stallion F1) in Mwea site for commercial genotypes. Application of nitrogen fertilizer caused overall mean number of fruits per plant to rise from 11fruits (in 0 kg N/Ha) to 25 fruits (in 250 kg N/Ha) representing an increase of 56%.

Table 4.14: Mean values of single fruit weight (g) among tomato genotypes grown under different N levels at Kabete and Mwea field stations

Single fruit weight (g)							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	60.4	66.7	61.4	54.0	44.8	48.0	55.9
Master F1	57.5	74.8	68.8	69.2	60.8	70.3	66.9
Rio Grande	44.7	49.7	51.4	50.1	51.1	52.0	49.8
Stallion F1	53.4	70.8	68.6	61.0	48.7	71.7	62.4
VI005871	107.4	106.2	77.4	69.0	116.3	93.9	95.0
VI005895	154.2	95.5	94.5	69.5	107.8	71.0	98.8
VI005987	76.6	71.6	69.7	66.4	80.3	74.3	73.2
VI005990	51.5	56.3	63.9	68.4	62.5	71.8	62.4
Mean	75.7	74.0	69.5	63.5	71.5	69.1	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	0.5						
Fpr. Gen*NL	0.1						
l.s.d (P≤0.05) Gen	14.3						
l.s.d (P≤0.05) NL	NS						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	30.7						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	65.2	66.0	62.6	59.7	49.3	52.3	59.2
Master F1	68.4	73.5	69.3	69.3	66.8	70.3	69.6
Rio Grande	44.8	50.1	51.4	50.2	52.5	54.4	50.6
Stallion F1	54.0	70.7	58.3	60.8	49.1	60.7	58.9
VI005871	107.4	104.0	71.6	70.0	101.1	95.2	91.6
VI005895	150.7	87.4	89.9	68.8	106.1	73.6	96.1
VI005987	76.6	78.6	62.7	66.7	80.6	74.6	73.3
VI005990	51.8	48.4	47.7	42.8	53.3	61.8	51.0
Mean	77.4	72.3	64.2	61.0	69.9	67.9	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	0.1						
Fpr. Gen*NL	0.3						
l.s.d (P≤0.05) Gen	13.7						
l.s.d (P≤0.05) NL	NS						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	30.0						

Fpr - F probability, Gen- genotype, NL - nitrogen level, NS- not significant

Table 4.15: Mean values of number of fruits per plant among tomato genotypes grown under different N levels at Kabete and Mwea field stations

Number of fruits per plant							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	8	9	14	16	17	19	14
Master F1	10	12	14	17	21	22	16
Rio Grande	9	10	12	14	19	22	14
Stallion F1	14	15	23	27	29	40	25
VI005871	10	13	17	18	20	28	18
VI005895	12	15	18	19	21	26	19
VI005987	15	16	18	22	25	27	20
VI005990	10	12	17	18	19	20	16
Mean	11	13	17	19	21	25	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	0.4						
l.s.d (P≤0.05) Gen	2.5						
l.s.d (P≤0.05) NL	2.1						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	21.1						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	8	8	9	11	11	18	11
Master F1	9	13	12	11	16	22	14
Rio Grande	10	10	12	14	12	22	13
Stallion F1	14	14	19	21	27	34	21
VI005871	8	11	14	16	17	28	16
VI005895	12	14	15	17	18	21	16
VI005987	17	18	18	20	21	26	20
VI005990	10	13	17	17	19	21	16
Mean	11	13	14	16	18	24	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	0.5						
l.s.d (P≤0.05) Gen	2.4						
l.s.d (P≤0.05) NL	2.1						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	22.9						

Fpr - F probability, Gen- genotype, NL - nitrogen level, NS- not significant

(v) Total fruit weight per plant

In both trial sites, the total fruit weight per plant was significantly affected ($P \leq 0.05$) by both genotype and N level but not by the interaction between genotype and N level in both Kabete and Mwea field stations (Table 4.16). Total fruit weight per plant varied from 0.60 kg (Cal J) to 1.32 kg (Stallion F1) in Kabete site and 0.55 kg (Cal J) to 1.19 kg (Stallion F1) in Mwea site. Three of the four accessions in the study (VI005871, VI005895, and VI005987) recorded higher fruit weight per plant (above 1 kg fruit yield per plant) than the commercial genotypes Cal J, Rio Grande and Master F1 in both sites. In Kabete, application of 100 kg N/ha had significantly higher fruit weight per plant than the control. Application of 250 kg N/ha had the highest fruit weight per plant compared to the lower treatments.

(vi) Fruit yield per Ha

Fruit yield per hectare was significantly affected ($P \leq 0.05$) by genotype and level of nitrogen applied in both trial sites (Table 4.17). The interaction between genotype and N level applied had no significant effect on fruit yield per hectare. Fruit yield varied from 16.7 t/ha (Cal J) to 31.7 t/ha (VI005871) in Kabete and 15.3 t/ha (Cal J) to 33.4 t/ha (Stallion F1) in Mwea. At Kabete site, accession (VI005871) outperformed all other genotypes while in Mwea site, Stallion F1 outperformed all the other genotypes in fruit yield per hectare. Accessions VI005895, VI005987 and VI005990 had significantly higher fruit yield per hectare than Cal J and Rio Grande commercial varieties. Application of 100 kg N/ha and above in Kabete and 150 kg N/ha and above in Mwea significantly increased fruit yield relative to no-fertilizer control. Increasing N fertilizer level from 0 kg N/Ha to 250 kg N/Ha led to an increase in fruit yield per hectare from 16.3 to 37.1 t/ha in Kabete and 18.6 to 34.4 t/ha, representing an percentage increment of 55.8% and 45.9 % respectively.

Table 4.16: Mean values of Total fruit weight per plant (kg) among tomato genotypes grown under different N levels at Kabete and Mwea field stations

Total fruit weight Per Plant (kg)							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	0.40	0.46	0.55	0.63	0.74	0.83	0.60
Master F1	0.67	0.78	0.81	1.01	1.09	1.31	0.94
Rio Grande	0.41	0.53	0.61	0.78	0.79	0.86	0.66
Stallion F1	0.72	0.88	0.97	1.02	1.11	3.24	1.32
VI005871	0.63	0.71	0.85	1.17	1.32	2.17	1.14
VI005895	0.76	0.89	1.01	1.07	1.22	1.45	1.07
VI005987	0.62	0.66	0.83	1.01	1.35	1.68	1.03
VI005990	0.53	0.56	0.88	0.96	1.00	1.08	0.84
Mean	0.59	0.68	0.81	0.96	1.08	1.58	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	0.23						
l.s.d (P≤0.05) Gen	0.16						
l.s.d (P≤0.05) NL	0.13						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	26.00						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	0.56	0.43	0.44	0.44	0.69	0.75	0.55
Master F1	0.71	0.73	0.87	1.02	1.02	1.34	0.95
Rio Grande	0.42	0.57	0.58	0.70	0.74	0.89	0.65
Stallion F1	0.68	1.09	1.06	1.19	1.33	1.77	1.19
VI005871	0.70	0.77	0.81	1.25	1.16	1.61	1.05
VI005895	1.07	1.00	1.02	0.87	1.15	1.48	1.10
VI005987	1.05	0.70	0.66	1.03	1.35	1.65	1.07
VI005990	0.52	0.55	0.65	0.71	0.75	0.92	0.68
Mean	0.71	0.73	0.76	0.90	1.02	1.30	0.90
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	0.94						
l.s.d (P≤0.05) Gen	0.19						
l.s.d (P≤0.05) NL	0.17						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	32.70						

Fpr - F probability, Gen- genotype, NL - nitrogen level, NS- not significant

Table 4.17: Mean values of fruit yield per hectare among tomato genotypes grown under different N levels at Kabete and Mwea field stations

Fruit yield (t/ha)							
Kabete Field Station							
Genotype	0 Kg N/Ha	50 Kg N/ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	11.0	12.7	15.4	17.4	20.5	23.2	16.7
Master F1	18.5	21.6	22.5	28.1	29.2	36.2	26.0
Rio Grande	11.0	14.7	17.0	19.1	21.8	24.0	17.9
Stallion F1	19.1	24.5	27.0	28.3	30.9	47.5	29.6
VI005871	17.4	19.7	23.5	32.6	36.7	60.3	31.7
VI005895	21.2	24.7	28.0	29.6	33.8	40.2	29.6
VI005987	17.3	18.4	23.2	27.9	32.1	35.4	25.7
VI005990	14.8	15.6	24.4	26.8	27.7	30.1	23.2
Mean	16.3	19.0	22.6	26.2	29.1	37.1	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	0.2						
l.s.d (P≤0.05) Gen	4.3						
l.s.d (P≤0.05) NL	3.7						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	26.0						
Mwea Field Station							
Genotype	0 Kg N/Ha	50 Kg N/Ha	100 Kg N/Ha	150 Kg N/Ha	200 Kg N/Ha	250 Kg N/ha	**Mean**
Cal J	15.2	12.0	12.3	12.3	19.1	20.8	15.3
Master F1	20.0	20.4	24.1	28.2	28.4	37.1	26.4
Rio Grande	12.7	15.8	16.0	19.3	20.5	24.6	18.2
Stallion F1	21.7	30.4	29.4	33.1	36.9	49.1	33.4
VI005871	19.3	22.3	25.0	29.8	36.9	47.8	30.2
VI005895	26.0	27.8	27.7	24.0	32.0	41.2	29.8
VI005987	19.1	19.6	18.4	28.6	25.8	28.7	23.4
VI005990	14.5	16.8	18.2	19.7	20.9	25.5	19.2
Mean	18.6	20.6	21.4	24.4	27.6	34.4	
Fpr. Genotype (Gen)	<.001						
Fpr. Nitrogen level (NL)	<.001						
Fpr. Gen*NL	0.9						
l.s.d (P≤0.05) Gen	5.3						
l.s.d (P≤0.05) NL	4.6						
l.s.d (P≤0.05) Gen*NL	NS						
CV%	32.7						

Fpr - F probability, Gen- genotype, NL - nitrogen level, NS- not significant

4.4.3 Correlation analysis for tomato growth traits and yield traits

In both Kabete and Mwea stations, primary branches correlated positively with plant height (r=0.68, r=0.61), stem girth (r=0.71, r=0.62) and internode length (r=0.53, r=0.63) but correlated negatively with days to 50% flowering (r=-0.39, -0.32) (Table 4.18). Number of primary branches also had a positive correlation with number of fruits per plant (r=0.49, r=0.46) and fruit weight per plant (r=0.59, r=0.35). Plant height had a positive correlation with number of fruits recorded per plant in both locations (r=0.51, r= 0.52) and fruit weight per plant (r=0.58, r=0.43). Days to 50% flowering showed negative correlation with number of fruits per plant (r=-0.11, r=-0.12) and total fruit weight per plant (r=-0.21, r=-0.18) in both sites. Number of fruits per plant had a significant positive correlation with total fruit weight per plant in both Kabete and Mwea field stations (r= 0.69, r= 0.58).

4.4.4 Nitrogen agronomic efficiency

An analysis of agronomic efficiency of the genotypes (as an aspect of evaluating nitrogen use efficiency) indicated that accession VI005871 had the highest fruit yield increment (125.3 kg/ha) in Kabete field station when nitrogen was applied at 250 kg N/Ha rate relative to the genotype in control plots while in Mwea field station, Stallion F1 recorded the highest fruit yield increment (114.1 kg/ha) per added kg of nitrogen compared to control (Fig 4.2, fig 4.3). However, the lowest efficiency was observed in commercial genotype Cal J which recorded 48.7 kg/ha fruit yield increment in Kabete field station and 22.5 kg/ha in Mwea field station.

Table 4.18: Correlation table for tomato growth and yield traits among tomato genotypes grown under different N levels at Kabete and Mwea field stations

	PB	PH (cm)	SG (cm)	Int. (cm)	SLA (cm^2)	DTF	NFPP	TFWPP (Kg)	FY (t/ha)
Kabete field station									
PB	-								
PH (cm)	0.68*	-							
SG (cm)	0.71*	0.67*	-						
Int. (cm)	0.53*	0.42	0.57*	-					
SLA (cm^2)	0.41	0.16	0.53*	0.64*	-				
DTF	-0.39	-0.50*	-0.21	-0.03	0.14	-			
NFPP	0.49	0.51*	0.62*	0.50*	0.45	-0.11	-		
TFWPP (kg)	0.59*	0.58*	0.61*	0.49	0.46	-0.21	0.69*	-	
FY (t/ha)	0.59*	0.58*	0.61*	0.49	0.46	-0.21	0.69*	1.00	-
Mwea field station									
PB	-								
PH (cm)	0.61*	-							
SG (cm)	0.62*	0.58*	-						
Int. (cm)	0.63*	0.56*	0.60*	-					
SLA (cm2)	0.25	0.20	0.47	0.49	-				
DTF	-0.32	-0.41	-0.13	-0.15	0.13	-			
NFPP	0.46	0.52*	0.59*	0.51*	0.39	-0.12	-		
TFWPP (Kg)	0.35	0.43	0.46	0.38	0.29	-0.18	0.58*	-	
FY (t/ha)	0.35	0.43	0.46	0.38	0.29	-0.18	0.58*	1.00	-

Key: **PB**-primary branches, **PH**-plant height, **SG**-stem girth, **Int**.- internode length, **SLA**-single leaf area, **DTF**- days to 50 % flowering, **NFPP**-number of fruits per plant, **TFWPP**-total fruit weight per plant, **FY**-fruit yield, *-Significant

Fig. 4.2: Nitrogen agronomic efficiency of tomato genotypes grown at Kabete field station for rate of 250 kg N/ha

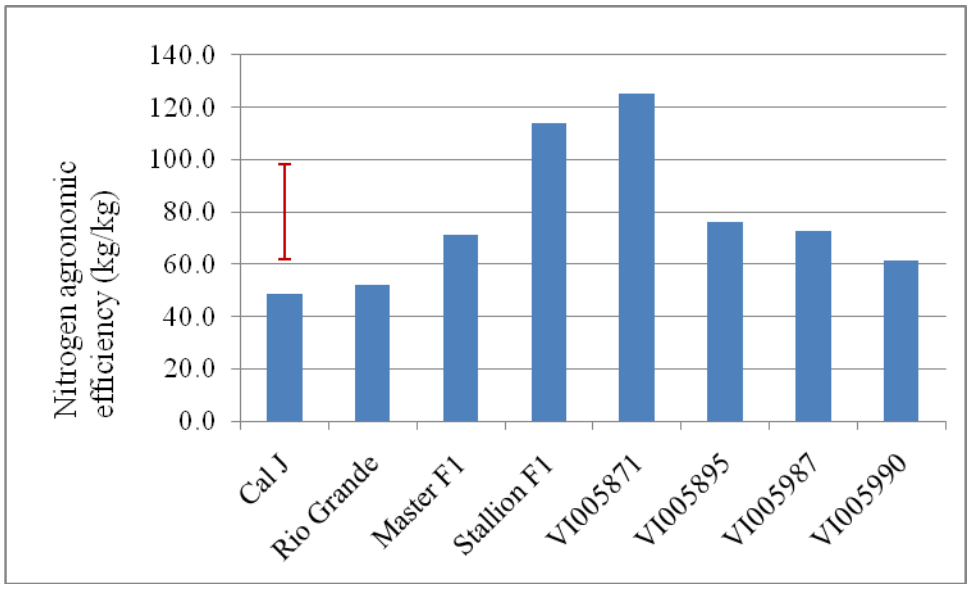
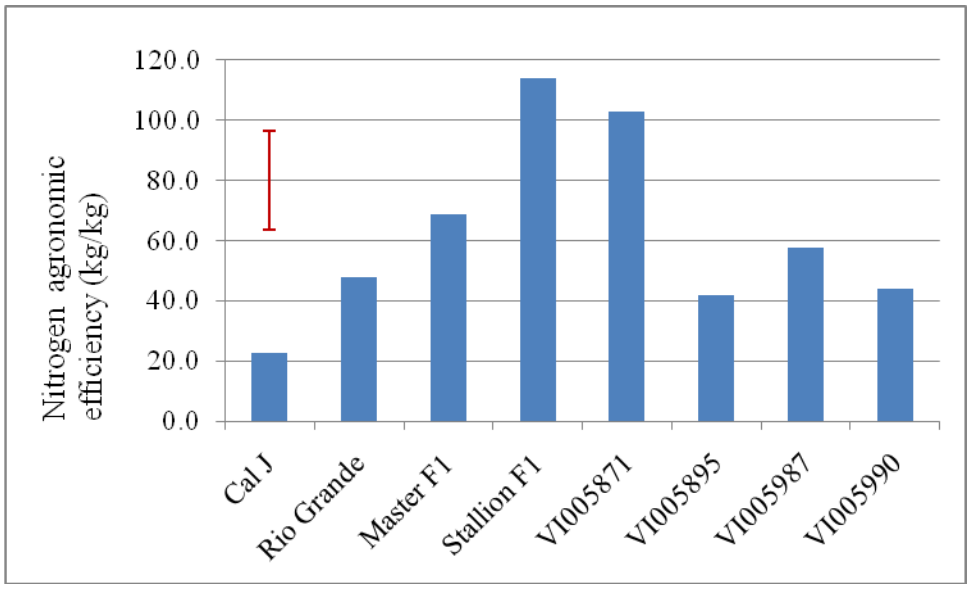
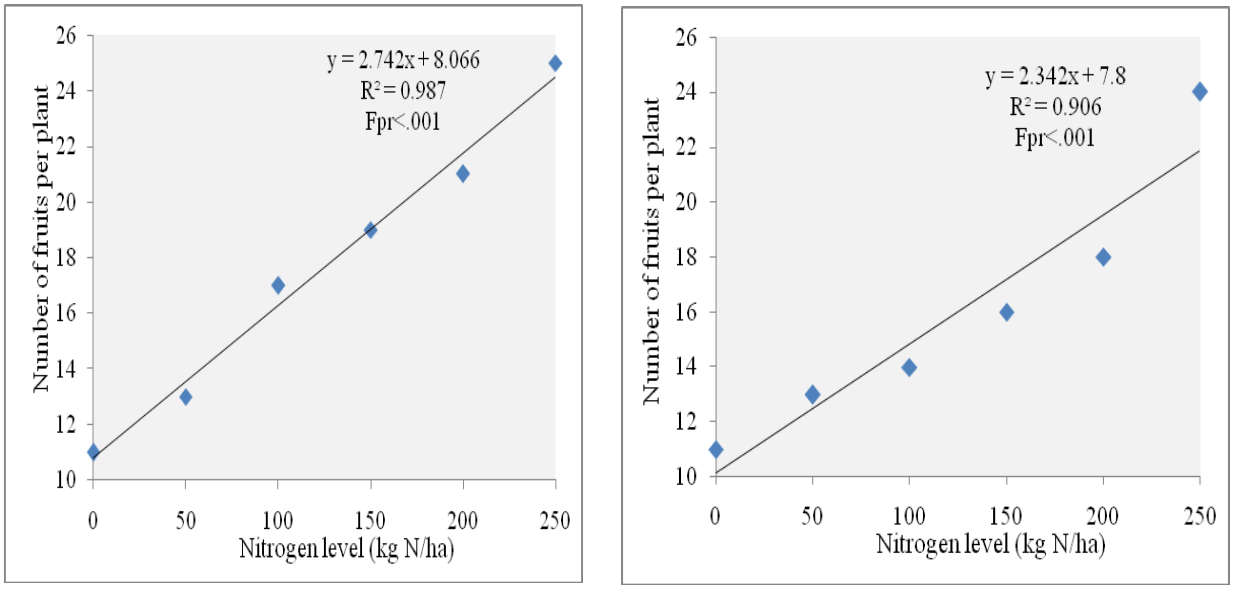


Fig. 4.3: Nitrogen agronomic efficiency graphs of genotypes grown at Mwea field station for rate of 250 kg N/ha



4.4.5 Response of tomato yield components to N fertilizer application rates

Analysis of yield responses in both Kabete field station and Mwea field station indicated a linear relationship between N fertilizer levels and number of fruits per plant, fruit weight per plant and yield (Figure 4.4, 4.5 and 4.6 respectively). The yield components (number of fruits per plant, total fruit weight per plant and yield per hectare) increased with the level of nitrogen.

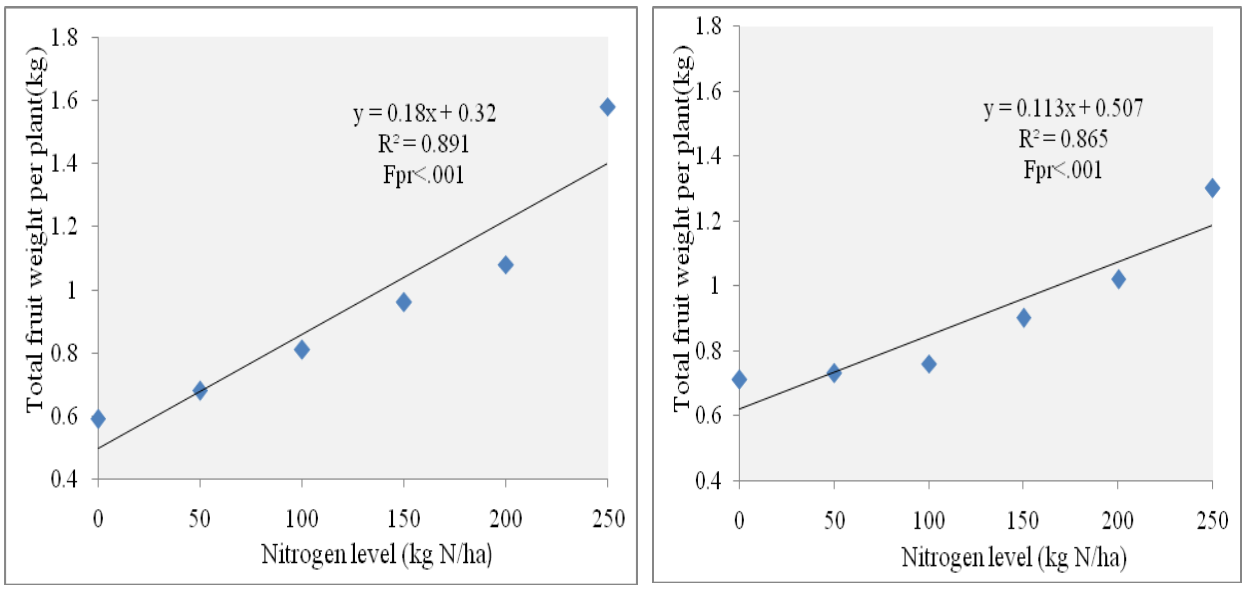


Kabete site

Mwea site

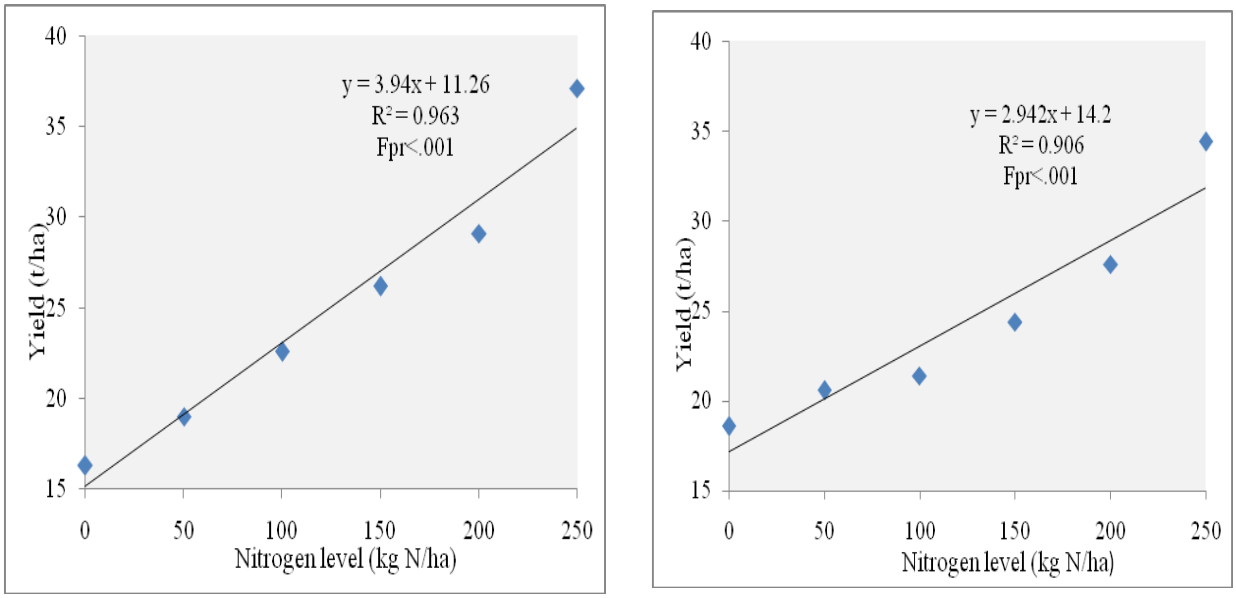
Fig 4.4 Linear regression relationship between number of fruits per plant and nitrogen fertilizer levels in Kabete field station and Mwea field station

Fig 4.5 Linear regression relationship between total fruit weight per plant and nitrogen fertilizer levels in Kabete field station and Mwea field station



Kabete site Mwea site

Fig 4.6 Linear regression relationship between yield per hectare and nitrogen fertilizer levels in Kabete field station and Mwea field station



Kabete site Mwea site

4.5 Discussion

Vegetative growth traits of the tomato, that is, primary branches, plant stem height, internode length and stem girth, single leaf area were significantly affected by level of nitrogen applied to the crop. Nitrogen is involved in the manufacture of building blocks of plants such as nucleic acids (DNA and RNA), proteins and enzymes that promote cell division and elongation hence resulting to vegetative growth. Nitrogen deficiency causes stunted growth which could be shown by shorter average plant height, shorter internode lengths and thinner stem girths observed in the control plots where no N was applied. Nitrogen deficiency also leads to leaf chlorosis and necrosis of older leaves and defoliation which cause overall reduction of crop photosynthetic capacity. Studies on effect of nitrogen on tomato growth have been conducted and they show that tomato growth and yield increases with increase in availability of this macro nutrient. Etissa *et al*., (2013) reported significant increases in the biomass of tomato plants including canopy diameter, stem diameter and plant height with application of NPK fertilizer. Oyinlola and Jinadu (2012) also reported increase of plant height, mean single fruit weights and fruit yield as a result of applying nitrogen fertilizer.

Vegetative growth traits (primary branches, plant stem height, internode length, single leaf area and stem girth) also varied with genotype. Indigenous tomato genotypes had more vigorous vegetative growth than commercial genotypes. For example, VI005871, VI005895 and VI005987 recorded taller stem heights and internode lengths while VI005871 and VI005987 had more primary branches than the commercial genotypes. This could be attributed to the fact that most of the indigenous tomato genotypes were of indeterminate growth habit (Oduor, 2016). The indeterminate tomato plants tend to have longer internodes because they grow relatively taller than the determinate tomato types. This genetic trait gives the plant an adaptive advantage to grow more trusses for production of fruits (Haifa, 2017).

Single leaf areas were smaller in accessions (VI005987 and VI005871) than the rest of genotypes including commercial varieties such as Stallion F1 which recorded the highest single leaf area. Among the commercial genotypes, Stallion F1 was more vigorous in vegetative growth than the other one hybrid (Master F1) and open pollinated varieties (Cal J and Rio Grande) probably because of it being a superior hybrid, genetically enhanced through breeding. Days to 50 % flowering varied with tomato genotype. Most accessions took shorter time to reach 50 % flowering than commercial varieties, with the earliest flowering genotype being VI005987, suggesting that they have faster growth rate and earlier maturity than commercial genotypes. Genotypic variability in days to flowering can be related to genetic makeup of the various tomato accessions and varieties used in the study. Studies have shown there is greater diversity in indigenous tomato genotypes or accessions than there are among the current commercial tomato genotypes which have been subjected to narrowed breeding to suit the market (Bhattarai et al., 2018) .Other studies on different tomato genotypes have shown that days to 50 % flowering is significantly affected by genotypic differences. For instance, Meseret et al. (2012) and Debela et al. (2016) reported six to eleven days variation in days taken to attain 50 % flowering by the various tomato genotypes in their studies.

Experimental site differences showed notable effect on tomato crops vegetative growth in that Mwea field station site recorded higher means of vegetative traits measurements such as primary branches, plant height, stem internode lengths and thicker stem girth. This can be attributed to higher mean daily temperatures in Mwea field station (See appendix) which generally quickens the rate of biochemical reactions such as photosynthesis and respiration thus increasing the cell growth and multiplication. Additionally, both accessions and commercial genotypes took relatively shorter time to achieve 50 % flowering in Mwea field station (46 days) than in Kabete

(57 days). This could be explained by the fact that, mean temperatures in Mwea field station were higher (25.5 ^{0}C) than at Kabete field station (22.5 ^{0}C) (See section 4.3.1). Higher temperatures up to the optimum for tomato (24-25^{0}C), speeds up biochemical reactions in the plants such as photosynthesis and respiration causing faster growth due to faster cell multiplication and division (Jahan *et al*., 2016).

Fruit length and fruit width varied with genotype but not with nitrogen level suggesting fruit length and width as factors that contribute to the shape of a fruit. Fruit length and fruit width are mostly genetic traits, and are less affected by biotic and abiotic stresses. Fruit length and fruit width are among key physical traits that differentiate tomato genotypes (Salim *et al*., 2018). The accessions had shorter average fruit length but larger fruit width than the commercial genotypes. This variation in fruit indices could be explained by the different fruit shapes traits. The indigenous tomato genotypes used in the study have been characterized and shown to bear irregularly shaped, rounded and flattened fruits with short fruit length but wide fruit diameter (Oduor, 2016). Accession (VI005990) had statistically similar fruit length and fruit width as the commercial genotype (Cal J). The commercial varieties, as a result of fruit shape trait selection and breeding to get consumer preferred shape, possess longer fruit length and narrower fruit diameter resulting to a regular, cylindrical shaped tomato preferred by consumers (Joan *et al.* 2018).

Average single tomato fruit weight varied with genotypic differences. Indigenous tomato genotypes, VI005871, VI005895 and VI005987 had heavier single fruit weights compared to the commercial varieties. This differs with Agong *et al*., (2001) in whose study the commercial varieties were reported to have higher fresh fruit weight than the accessions used in the study. Number of fruits per plant and total fruit weight per plant also varied with genotypes where most

accessions (VI005871, VI005895, and VI005987) recorded higher number of fruits and total fruit weight per plant than the commercial genotypes except Stallion F1. Variation in single fruit and number of fruits per plant weight could be attributed to the genetic yield potential of individual genotypes. This suggests that these genotypes have greater potential for heavy fruits and more fruits per plant which is a trait of interest to farmers especially for commercial production. Warner *et al*., (2004) studies also showed that cultivar differences affected fruit weight per plant among the four cultivars used in their study. Superior hybrid, Stallion F1, show high productivity potential harnessed from the parents it was bred from, which exploits hybrid vigour of the first filial (F1) generation (Krishna *et al*., 2016). However higher single fruit weight, number of fruits per plant and total fruit weight per plant of accessions VI005871, VI005895, and VI005987 than the open pollinated varieties, Cal J and Rio Grande, indicates better productivity and existence of superior genes than can be exploited in tomato breeding programmes as superior parents in crosses to improve other tomato lines.

Nitrogen level increase also increased number of fruits per plant, total fruit weight and fruit yield (t/ha). Increasing nitrogen application from 0 kg N/Ha to 250 kg N/Ha caused an increase in mean number of fruits by 56% in the two sites and increased total fruit weight per plant by 62.7 % and 45.4 % in Kabete and Mwea sites respectively. Formation and accumulation of dry matter in fruits requires the amino acids which are supplied by available nitrogen uptaken by tomato plants. Warner *et al*., (2004) and Kirimi *et al*., (2011) also reported that fruit yield and total weight of tomato increased as level of nitrogen fertilization increased and 200 kg N/Ha maximized marketable fruits yield. Productivity of tomato increases with nitrogen level in that as more nitrogen was supplied from 0 kg N/Ha up to 250 kg N/Ha the number of fruits and total fruit weight per plant also increased. In this study the highest level of nitrogen (250 kg N/Ha)

had the highest number of fruits, highest total fruit weight and highest yield in all genotypes indicating that the optimum amount of nitrogen needed by the plants was not yet reached at that level. Some studies on nitrogen effect on tomato growth and yield have in contrary reported lower levels of optimum nitrogen required for optimal tomato production. These include Kirimi *et al*. (2011) and Yara Group Kenya (2011) whose research has recommended nitrogen rates of 200 and 250 kg N/ha respectively. These differences in optimal nitrogen levels required by tomato emphasize the importance of carrying out site specific analysis of soils in order to determine exact levels of nitrogen required in the area the tomato are going to be grown.

Significant correlations were observed among growth traits and between vegetative growth traits and yield traits. Plant height had positive correlation with number of primary branches, internode length, number of fruits per plant and total fruit yield per plant which means genotypes with taller plant stem mostly will have higher number of primary branches, longer internodes, more fruits per plant and higher fruit weight per plant. Primary branches also correlated positively with number of fruits per plant. Increasing one trait primary branches or plant heights increases the other traits and vice versa. This means that manipulation of one of the traits, for example through crossing genotypes with higher vegetative growth with the ones that are poor genotypes, during tomato improvement breeding may lead to the improvement of some yield aspects such as fruit number and consequently fruit yield. Days to 50 % flowering among genotypes showed negative correlation with the yield and yield components studied i.e. fruit number per plant, fruit weight per plant as well as yield (t/ha). Genotypes which take more days to reach 50 % flowering affect the number of fruit and fruit weight per plant negatively (Kanneh *et al*., 2017). Early genotype maturity, hence early flowering, enables tomatoes to produce more flower buds during

reproductive phase which translates to more fruit yield and more total fruit weight of the harvested tomato per plant.

Nitrogen use efficiency measured by agronomic efficiency of tomato genotypes' fruit yield (kg/ha) at 250 kg N/Ha fertilizer level, was found to be higher in accession VI005871 and hybrid Stallion F1 than in the other genotypes used in the study. This means the two genotypes respond better to nitrogen fertilizer application in terms of fruit yield gain per each kg of nitrogen applied. This can be attributed to the individual genotype's dense root density for intercepting nutrients in the soil solution, higher capacity to uptake and utilize available nitrogen in the root zone. Agele et al (2008) has also reported variation in the way different cultivars respond to nitrogen application for example early maturing cultivars recorded higher N use efficiency than the late maturing cultivars. These genotypes, especially the accession can therefore be a good source of superior genes for tomato breeding programs aiming to improve nitrogen use efficiency. It can also be selected in to pure line and its seed multiplied for farmer's use because it could yield more returns from each unit of nitrogenous fertilizer applied which translates to higher economic return on investment in tomato production enterprises. The response (number of fruits per plant, fruit yield per plant and yield) of the tomato in the study increased linearly as level of nitrogen was increased up to the maximum level applied. This could mean that higher levels of nitrogen would probably have higher output and thus higher levels than the maximum should be used for tomato production depending on result of soil analyses.

4.6 Conclusion

Majority of growth parameters showed significant variations as a result of genotype differences among indigenous and commercial genotypes. Accessions were more vegetative and had wider range of variations than commercial genotypes in plant stem height and primary branches. The observed variability presents key morphological traits which could be used during genotype selection to identify better parents for crosses in tomato breeding programmes. In regard to yield variation as a result of genotypic variation, accessions (VI005871, VI005895, and VI005987) recorded higher single fruit weight, number of fruits per plant and total fruit weight per plant than the open pollinated varieties commercial cultivars (Cal J and Rio Grande) and therefore could be better genotypes to cultivate. Nitrogen nutrition was also observed to be critical in enhancing productivity of tomato crop. Number of primary branches, plant height, stems girth, single leaf area, number of fruits per plant, fruit yield per plant and genotype yield per hectare increased with increase in level of nitrogen. Nitrogen rate of 250 kg N/ha yielded highest results than the rest of the levels and therefore highlights it as the best in this context but since the response curve didn't reach the optimum, higher levels of nitrogen could yield better results. The higher nitrogen use efficiency in accession VI005871 present an opportunity to develop it through introgression of desirable trait genes such as heavy single fruit weight to come up with better varieties.

CHAPTER 5: GENERAL DISCUSSION, CONCLUSION AND RECOMMEDATIONS

5.1 Discussion

This study demonstrated that abiotic stresses (soil moisture and nitrogen nutrition) affect the performance of tomato crop and that there is significant level of variability among African tomato accessions and commercial genotypes. Moisture stress levels of 70% and 40 % PC had critical effect on growth aspects of tomato crop. For example, they caused reduction in plant height, internode length, single leaf area and stem girth of the tomato plants compared to unstressed tomato plants. Reducing moisture level from 100% to 70% and 40% also caused reduction in total number of fruits per plant, total fruit weight per plant, average single fruit weight, fruit length and fruit width. Sufficient moisture is critical for plant growth since water is important in biochemical reactions, translocation of nutrients, enhancement of plant cell turgor pressure and stomatal adjustment. Therefore limited soil moisture leads to reduction in plant stem height, internode length, stem girth and leaf lamina hence reduced growth rate. It also causes reduced dry matter formation and development, for example fruits, ultimately affecting productivity of the crop. Evaluation of indigenous and commercial genotypes showed that accessions possess wider ranges in morphological traits such as plant height, internode length and stem girth than the commercial genotypes pointing to wide genotypic variability among them that is useful in the process of cultivar development. Accessions VI005871, VI005895 and VI006840 had similar total fruit weight per plant and average single fruit weight with commercial genotypes Stallion F1 and Master F1. This means they can be selected for harnessing desirable traits in breeding programmes to develop better varieties and can also be selected for use by farmers as a cheaper option of seed than the commercial hybrids that are normally expensive.

Nitrogen supply increase from 0 kg N/Ha to higher levels of 50,100,150,200 and 250 kg N/ha caused a significant increase in growth aspects such as plant stem height, number of primary branches, internode length, stem girth and single leaf area. Nitrogen promotes plant growth plants since it forms part of nucleic acids, plant proteins and amino acids and is also a component of chlorophyll used during photosynthesis. Nitrogen level variation affected the vegetative growth traits more than reproductive growth aspects except for number of fruits per plant, fruit weight per plant and fruit yield (t/ha) which increased with increase in level of nitrogen applied. Significant variations were also observed among the genotypes in the efficiency of using supplied nitrogen. Genotype variability was mostly evident on morphological parameters such as plant stem height, leaf area, number of primary branches, number of fruits per plant, single fruit weights, fruit size and total fruit weight per plant of harvested fruits. Accessions were shown to have wider variations in both growth and yield aspects than commercial genotypes used in the study. This points to the large pool of variability that exist among the accessions which could be exploited either as source of desired traits or improve these accessions to varieties than can be cultivated by tomato farmers.

5.2 Conclusion

Different moisture stress levels lead to varied effects on tomato growth and yield potential depending on severity of the soil moisture stress. Forty percent of pot capacity stress level had the severest impact on growth parameters and yield parameters of tomato genotypes studied. Level of nitrogen nutrient availed to tomato crop also affects the growth vigour of tomato plants and hence the ultimate fruit yield obtained from the crop. Nitrogen level of 250 kg N/Ha recorded highest plant height, stem girth and number of primary branches. It also showed highest number of fruits per plant and total fruit yield per plant.

Wide morphological traits variation (in growth and yield parameters) among genotypes may also be used to select superior genotypes with desirable characteristics. Accessions such as VI005895, VI005871, VI006840 and VI005987 with heavier single fruit weight, higher number of fruits per plant and higher total fruit weight per plant than commercial varieties such as Rio Grande and Cal J demonstrate potential superior genetic material in them. They can be used as superior parents during conventional cross-breeding for new tomato varieties programmes that seek to upgrade existing commercial genotypes which are not hybrids.

5.3 Recommendations

Genotypes (VI005895, VI005871, VI006840, VI005987) identified as competitive performers against commercial genotypes, in the aspects of single fruit weight, number of fruits per plant and fruit yield per plant, can be further screened for biotic stresses tolerance for example bacterial wilt or early and late blight resistance and tolerance.

These genotypes could be further developed to pure lines, have their seeds multiplied and farmer's on-farm trials be conducted with several farmers to evaluate performance and preferences by the farming communities.

Additionally, these genotypes can be further evaluated through molecular characterization for genetic composition in order to inform market-driven and trait-specific tomato breeding.

More accessions could be incorporated in the studies on water stress and nitrogen nutrition so as to identify interaction between the genotypes and the abiotic stresses. Additionally, the maximum level of nitrogen fertilizer could be increased to more than 250 kg N/ha to identify specific optimum level of nitrogen requirement by tomato genotypes.

REFERENCES

Agele S.O., Adeniji I. A., Alabi E. O., and Olabomi A. (2008) Responses of growth, yield and N use efficiency of selected tomato cultivars to variations in hydrothermal regimes of the cropping seasons in a tropical rainforest zone of Nigeria. *Journal of plant interactions, 3*(4), 273-285

Agong S.G., Schittenhelm S., and Friedt W., (2001) Genotypic variation of Kenyan tomato (*Lycopersicon esculentum* L.) germplasm. *The Journal of Food Technology in Africa 6*(7), 13-17

AFA-HCD (2014) Horticulture validated report, ministry of agriculture, livestock and fisheries, Kenya

AFA-HCD (2016) Horticulture validated report, ministry of agriculture, livestock and fisheries, Kenya

Amina L., Ahmed A., Youcef H., and Samira S., (2014) Effects of water regime on the structure of roots and stems of Durum wheat (*Triticum durum* Desf.). *Journal of Botany 3*(2), 356-364

Anderson J.M. and Ingram J.S. (eds.) (1993) *Tropical Soil Biology and Fertility: Handbook of Methods* (2nd ed.). Wallingford, UK. CBA International

Bhattarai K., Sharma S. and Dilip R.P (2018) Diversity among Modern Tomato Genotypes at Different levels in Fresh-Market Breeding. *International journal of Agronomy 18*(1) 417-432

Bhowmik D.K., Sampath K., Shravan P., and Shweta S., (2012) Tomato- A natural medicine and its health benefits, *Journal of Pharmacognosy and Phytochemistry 1*(1) 321-324

Bryan D.M. and Ya'acov Y.L. (1994). *Stress and Stress Coping in Cultivated Plants*. Dordrecht, Boston- London,. Kluwer Academic Publishers

CAB international -CABI (2018). https://www.cabi.org/ISC/datasheetreport/31837 Accessed 22 July 2019

College of Tropical Agriculture & Human Resources (1999). *Using tensiometers for measuring soil water and scheduling irrigation*. University of Hawaii, Manoa. www.ctahr.hawaii.edu/oc/freepubs/pdf/L-10.pdf . Accessed 7th November 2018.

Debela Ketema, Derbew Belew and Jima Nego (2016) Evaluation of tomato (*Lycopersicon Esculentum* Mill.) Varieties for growth and seed quality under Jimma condition, South Western Ethiopia. *International Journal of Crop Science and Technology (2)* 69-77

Dias J.S. (2012) Nutritional quality and health benefits of vegetables: A review. *J. food and nutritional sciences* (*3*) 1354-1374

Etissa E., Nigussie D., Tena A., Yibekal A., and Lemma D., (2013) Growth and yield components of tomato as influenced by nitrogen and phosphorous fertilizer applications in different growing seasons. *Ethiopian journal of agricultural sciences* (*23*) 57-77

FAO (2018) retrieved from www.fao.org/Home>Land &Water> Databases & Software>Crop Information>Tomato.

FAOSTAT (2016) retrieved from http://www.fao.org/faostat/en/#data/QC/visualize.

Feijuan W. and Cheng Z. (2012) Effects of nitrogen and light intensity in tomato (*Lycopersicon esculentum* Mill) production under soil water control. *African journal of Agricultural Research 7*(31) 4408-4415

Frias-Moreno N. (2014) Effect of nitrogen deficiency and toxicity in two varieties of tomatoes (*Lycopersicum esculentum* L.) *Journal of agricultural Sciences (*5*)*1361-1368.

Getachew G.M. (2017) *Integrated Management of Tomato Late Blight[Phytophthora infestans(Mont.) de Bary] Through Host Plant Resistance and Reduced Frequency of fungicide application in Gamo Gofa Zone, Southern Ethiopia*. Unpublished thesis, Haramaya University, Haramaya, Ethiopia

Gould W.A. (ed)(1983) *Tomato production, processing and Quality Evaluation* (2nd ed.*)* Westport, Connecticut, AVI Publishing Company inc

Gicheru P. (2012) An overview of soil fertility management, maintenance and productivity in Kenya. *Archives of Agronomy and Soil Science (58)* 22-32

HAIFA GROUP- Kenya (2017) retrieved from https://www.haifa-group.com/files/Guides/tomato/Tomato.pdf

Hermanto A., Salokhe V.M., Babel M.S., and Tantau H.J., (2005) Water requirement of drip irrigated tomatoes grown in greenhouse in tropical environment. *Journal of agricultural and water management (71)*, 225-242

Nagashima H. and Hikosaka K. (2011) Plants in a crowded stand regulate their height growth so as to maintain similar heights to neighbours even when they have potential advantages in height growth. *Annals of botany 108*(1) 207-214

HCDA (2010). *Export statistics, 2008 and 2009 and provision for 2010*. Horticultural crops development authority, Nairobi, Kenya

Jaetzold R. & Schmidt H. (1983) *Farm Management Handbook of Kenya, Vol II: Natural Conditions and Farm Management Information.Part A: West Kenya; PartB: Central Kenya; PartC: EastKenya.* Ministry of Agriculture, Nairobi, Kenya.

Jahan S.L, Niaz A.W, Ghulam M.L, Abdul H. and Khalid H.T (2016) Role of Nitrogen for Plant Growth and Development: A Review. *Advances in Environmental Biology 10*(9)209-218

Joan C., Ana R., Joseph S., Roser R., and Joan S., (2018) Cherry and Fresh market tomato: Differences in chemical, morphological and sensory traits and their implications to consumer acceptance. *Journal of Agronomy (6)*9-10

Kanneh S., Dan D.Q., Patrick M.N., and Peter D.M., (2017) Evaluation of tomato (*Solanum lycopersicum* L.) genotypes for horticultural characteristics on the upland in Southern Sierra Leone. *Journal of Agricultural Science 9* (6) 210-215

Karuku G.N., Kimenju J.W., and Verplancke H., (2017) Farmers' Perspective on factors limiting tomato production and yields in Kabete , Kiambu County, Kenya. *East African Agricultural and Forestry Journal (1)* 70-89

Kenya Meteorological Department (2018) retrieved from *www.meteo.go.ke*

Kirimi J.K., Itulya F.M., and Mwaja V.N., (2011) Effects of Nitrogen and spacing on fruit yield of tomato. *African Journal of Horticultural Science (5)* 50-60

Koenig T., Blatt J., Brakel K., Kloss K., Nilges T., and Woellert F., (2008) Market-driven development and poverty reduction: A value chain analysis of fresh vegetables in Kenya and Tanzania (SLE Series) Humboldt University, Berlin, Germany. Center for advanced training in rural development

Krishna B., Frank J.L., John D.W., and Dilip R.P., (2016) Diversity analysis of tomato genotypes based on morphological traits with commercial breeding significance for fresh market production in eastern USA. *Australian Journal of Crop Science 10*(8) 1098-1103

Larry R, Joanne L. Genetic resources of tomato. In: Razdan MK, Mattoo AK, editors. Genetic improvement of solanaceous crops. Vol. 2. Enfield, NH: Science Publishers

Lisar S.Y., Rouhollah M., Mosharraf M.H., and Ismael M.R., (2012) Water stress in plants: causes, effects and responses. *InTechOpen (14)* 67-72

Mangale N. (2015) *Handbook for Intergrated Soil Fertility Management; Extension Approaches and Guidelines in Kenya*. Ministry of Agriculture, Livestock and Fisheries, Kenya

María G.C., Constantino R., and José R. L., (2002) Effect of water stress on leaf area development, photosynthesis and productivity in Chardonnay and Airén Grapevines**.** *American Journal of enology and viticulture(53)*138-143

Matsuda K. and Rayan A. (1990) Anatomy: a key factor regulating plant tissue response to water stress. Pp 63-72. The Hague, the Netherlands, Academic press.

McCauley A., Jones C., Jacobsen J., (2011) *Plant nutrient; functions, deficiency and toxicity symptoms. 9th Nutrient Management Module*, Unpublished article, Montana State University Extension, 4449-9, CCA 1.5 NM CEU

Mehlich A., Pinkerton A., Robertson W., and Kepton R., (1962) *Mass Analysis Methods for Soil Fertility Evaluation.* Cyclostyled Paper, National Agric. Laboratories, Nairobi, Kenya

Meseret D., Ali M., and Kassahun B., (2012) Evaluation of tomato (*Lycopersicon esculentum* Mill.) genotypes for yield and yield components. *African journal of plant science and biotechnology (6)* 45-49

Michieka D.O., Van der Pouw B.J. and Leeshouwer J.J., (1978) *Soils of the Kwale Mombasa-LungaLunga Area, vol I &II and Soil maps 1:100,000* Kenya Soil Survey, Ministry of Agriculture, Nairobi, Kenya

Moranga L.O (2016*) Analysis of factors influencing tomato farmers' willingness to adopt innovative timing approaches for management of climate change effects in Taita Taveta county, Kenya.* Unpublished thesis, University of Nairobi, Kenya

NAAIAP (2017) www.naaiap.go.ke Accessed on 21st Sep 2017

NAAIAP (2014) *Report on Soil Suitability Evaluation for Maize production in Kenya*, Ministry of Agriculture, Nairobi, Kenya

Nahar K. and Gletzmacher R. (2002) Effect of water stress on nutrient uptake, yield and quality of tomato (*Lycopersicon esculentum* Mill.) under sub-tropical conditions. Die Bodenkultur, Germany *53* (1) 534-537

National farmers information system (NAFIS) Kenya www.nafis.go.ke Accessed on Nov 6th 2018

National Food and Nutritional Security Policy of Kenya, (2011) Nairobi, Kenya

Nuruddin M. (2001) Effects of water stress on tomato at different growth stages. Unpublished thesis, McGill University, Canada

Odema P.S. (2009*) Manual on Greenhouse Technology-agriculture information resource centre*. Essensho Company Ltd, Nairobi, Kenya

Osakabe Y., Osakabe K. and Tran L.P., (2014) Response of plants to water stress. *Journal of frontiers in plant science (5)* 86-87

Oyinlola E.Y. and Jinadu S.A.(2012) Growth, yield and nutrient concentrations of tomato as affected by soil textures and nitrogen. *Asian journal of agricultural research (6)* 39-45

Page A.L., Miller R.H., and Keeney D.R., (eds.) (1982) *Methods of soil analysis (2nd ed)*. 595-622.Winconsin, USA, American Society of Agronomy

Republic of Kenya (2013c) *Annual report- Department of Agriculture, Taveta Sub-County. County Government of Taita Taveta.* Retrieved from www.moalf.go.ke

Republic of Kenya (2012) *Kenya Post Disaster Needs Assesment (PDNA);2008-2011 Drought. With technical support from the European Union, United Nations and World Bank*. Retrieved from *www.alnap.org*

Reynolds S.G. (1970) Gravimetric method of soil moisture determination Part 1; A study of equipment, and methodological problems . *Journal of Hydrology (11)* 258-273.

Rivera C.M., Rouphael Y., Cardarelli M., and Colla G., (2007) A simple and accurate equation for estimating individual leaf area of eggplant from linear measurements. *European Journal of Horticulture Science 72* (5) 228-230

Razaq M., Zhang P., Shen H., and Salahuddin (2017) Influence of nitrogen and phosphorous on the growth and root morphology of *Acer mono*. *PLoS ONE* journal *12*(2) 256-259

Salim M.R., Rashid M.H., Hossain M.M., and Zakaria M. (2018) Morphological characterization of tomato (*Solanum lycopersicum* L.) genotypes. *Journal of the Saudi Society of Agricultural Sciences(5)* 212-216

Sandra K. and Iris E.P. (2017) *The tomato (Solanum lycopersicum L.,Solanaceae) and its Botanical relatives. M Causse et al. (eds.) The Tomato Genome, Compendium of plant Genomes* (2).

Seisuke K. and Neelima S. (2008) *How to grow tomatoes*. Cold Spring Harbour Laboratory press 3(11) 78-81

Seminis- Kenya (2007) Accessed at http//www.freshplaza.com/

Serio F., Ayala S., Bonasia A., and Santamaria P. (2005). Antioxidant Properties and Health Benefits of Tomato , *Journal for Recent Progress in Medicinal Plants (13)*3-19

Sibomana I.C., Aguyoh J.N. and Opiyo A.M (2013) Water Stress Affects Growth and Yield of Container Grown Tomato (*Lycopersicon esculentum* Mill) Plants. *Global Journal of Bio-Science and Biotechnology 2* (4) 461-466

Sigei K.G., Ng'eno K.H., Kibe M.A., Mwangi M., and Mutai C.M., (2014) Challenges and Strategies to Improve Tomato Competitiveness along the Tomato Value Chain In Kenya. *International journal of Business and Management (9)* 38-50

Sombroek W.G., Braun H.M.H., and Van der pouw B.J.A., (1982) *Exploratory Soil Survey. Report No. E1*. Ministry of Agriculture, Nairobi, Kenya.

Tembe K.O. (2016) *Agro-morphological and Nutritional Characterization of Tomato Accessions in Africa*. Unpublished thesis, University of Nairobi, Kenya.

Tembe K.O., Chemining'wa G.N., Ambuko J.L. and Owino W., (2017) Effects of water stress on yield and physiological traits among selected African tomato (*Solanum lycopersicon*) accessions. *International journal of agronomy and agricultural research 10* (2) 78-85

Tucker M.R., (1999) Essential plant nutrients; their presence in North Carolina Soils and Role in Plant Nutrition

Villareal L.R (1980) *Tomatoes in the tropics*. 55-72. Colorado, U.S.A Westview Press.

Warner J., Zhang T.Q., and Hao X., (2004) Effects of nitrogen fertilization on fruit yield and quality of processing tomatoes. *Canadian journal of plant science (84)* 865–871

Yara research centre website www.yara.com.gh/crop-nutrition/crops/tomato/yield . Accessed on September 14 , 2017.

Yulind B. and Pim L. (2007) A Review; Domestication and breeding of tomato: What have we gained and what can we gain in the future? *Annals of botany 100*(5) 1085-1094