IMPROVING MAIZE PRODUCTION PRACTICES IN A SEMI–CORAL AREA IN PEMBA

ALI MOHAMMED OMAR

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP
SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE.
MOROGORO, TANZANIA.

2014

ABSTRACT

Maize (*Zea mays* L.) is an important food crop grown in the semi-coral area in Pemba. Despite its high yield potential, it is giving low yields because of lack of appropriate information on varieties, plant population and fertilizer recommendations. Keeping this in view, the present study was done to establish the best combination of variety, plant density and nitrogen fertilizer for maximizing maize yield in the semi-coral area. Three improved varieties (Staha, Situka and TMV-1) were compared with the local variety (JKU) at three plant densities (44 444, 53 333 and 66 666 plants/ha) and four nitrogen levels (23, 46, 70 and 90 kg N/ha) during the 2013 cropping season. A field experiment was laid out using a randomized complete block design in split-split-plot arrangement with three replications. Varieties were kept to the main plots, plant densities to the sub-plots and nitrogen levels to the sub-subplots. Results indicated that Staha produced significantly ($P \leq 0.05$) higher grain yield (4.953 tons/ha) followed by the local variety (4.411 tons/ha). The local variety flowered and matured earliest. Plant density had no significant effect on flowering, maturity and seed rows/cob but recorded significantly tallest plants (1.848 m) at 66 666 plants/ha and greatest yield (4.291 tons/ha) at 53 333 plants/ha. Application of 90 kg N/ha led to significantly ($P \leq 0.05$) tallest plants but delayed flowering and maturity while 70 kg N/ha was better for the yield and yield components. Interaction of variety with plant density, variety with nitrogen fertilizer and plant density with nitrogen fertilizer were all significant for the grain yield. Interaction of variety with plant density and nitrogen led to significantly highest grain yield (6.415 t/ha) from Staha with 66 666 plants/ha and 70 kg N/ha and therefore recommended for the semi-coral area.

DECLARATION

I, **Ali Mohammed Omar,** do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work and [illegible] has neither been submitted or concurrently being submitted for degree award in any other Institution.

A. Omar

20/10/2014

Ali Mohammed Omar

Date

(MSc Crop Science candidate)

The above declaration is confirmed;

20. 10. 2014

Prof. D. G. Msuya

Date

(Supervisor)

COPYRIGHT

ACKNOWLEDGEMENTS

I wish to be grateful to the Almighty God for rewarding the high-quality diplomacy He has with my life. I wish to express without limits, my special thanks to my supervisor Prof. D. G. Msuya for his expert leading, patience, comments and commendable guidance through the whole period of research conduct to the preparation of this dissertation.

Sincere thanks are due to Prof. C. L. Rweyemamu, Head, Department of Crop Science and Production and the entire staff for their constructive contributions and roles played by different sections during the course work up to the completion of this research work.

I remain honestly grateful to the Zanzibar Ministry of Agriculture and Natural Resources by nominating me for EPINAV sponsorship and the EPINAV Programme at Sokoine University of Agriculture for the full financial support on my studies and the research work. I have been waiting for many years such an opportunity ever since I completed my Bachelors degree studies.

My earnest gratitude is due to my beloved wives, Salama and Kulthum, my sons and daughters for their patience and tolerance on difficulties during my absence at home.

Preparation and submission of this dissertation could not be easy without review of a number of literatures from different authors and other researchers' reports. Since it is not easy to mention them all, whoever referred and cited in this document is highly acknowledged.

DEDICATION

This document is dedicated to my late father Mohammed Omar Ussi, my late mother Zena Ali Juma and my late brother Juma Mohammed Omar who made me strive for the best especially in my academic career.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

%	Percent
≤	Equal or less than
AATF	African Agricultural Technology Foundation
CFF	Canadian Fertilizer Foundation
C.V	Coefficient of variation
cm	Centimeter
cmol	Centimole
et al.	And others
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agricultural Organization Statistics
FARA	Forum for Agricultural Research in Africa
g	Gram
ha	Hectare
IGC	International Grain Council
IITA	International Institute of Tropical Agriculture
IRRI	International Rice Research Institute
K	Potassium
kcal	Kilocalorie
kg	Kilogram
LSD	Least significant difference
m	Meter
N	Nitrogen

NBS	National Bureau of Statistics
P	Phosphorus
RSR	Root shoot ratio
SED	Standard error of the differences
SMI	Silking to maturity interval
TDM	Total dry matter
TFSNAS	Tanzania Food Security and Nutrition Analysis System
WEMA	Water Efficient Maize for Africa
ZARC	Zanzibar Agricultural Research Council

CHAPTER ONE

1.0 INTRODUCTION, JUSTIFICATION AND OBJECTIVES

1.1 Introduction

Maize (*Zea mays* L.) is a long time crop in Pemba. It was first introduced and grown in the Island by Portuguese planters in the sixteenth century to feed their coastal barracks (McCann, 2001). Since then, it remained as one of the traditional crops though it was mainly produced for eating green and not for flour (Suleiman, A. H. personal communication, 2012). Its importance as a food security crop has been increasing rapidly in the last twenty years especially on the Eastern side of Pemba. This follows the failure of other traditional crops due to changes in weather trends and frequent occurrences of plant diseases and pests outbreaks to which other crops are more prone (Rashid, H. I. personal communication, 2012). Since the outbreaks of cassava mealy bugs in 1980s and the cassava mosaic virus and brown streak virus currently prevailing, maize is now a major crop grown by semi-coral area farmers for dry grain and flour production.

Semi-coral area by itself is one of the five livelihood zones of Pemba Island. It is the farming and fishing zone running all along the eastern side of the Island from far North to far South and some parts on the North-West making one-third of the total agricultural land in Pemba. Other livelihood zones are the deep soil farming zone in the central part, the farming-fishing-plantation zone on the western side, the peri-urban and the urban zones as shown in Fig. 1. In the semi-coral area, agriculture is the most important livelihood activity followed by animal keeping mostly local

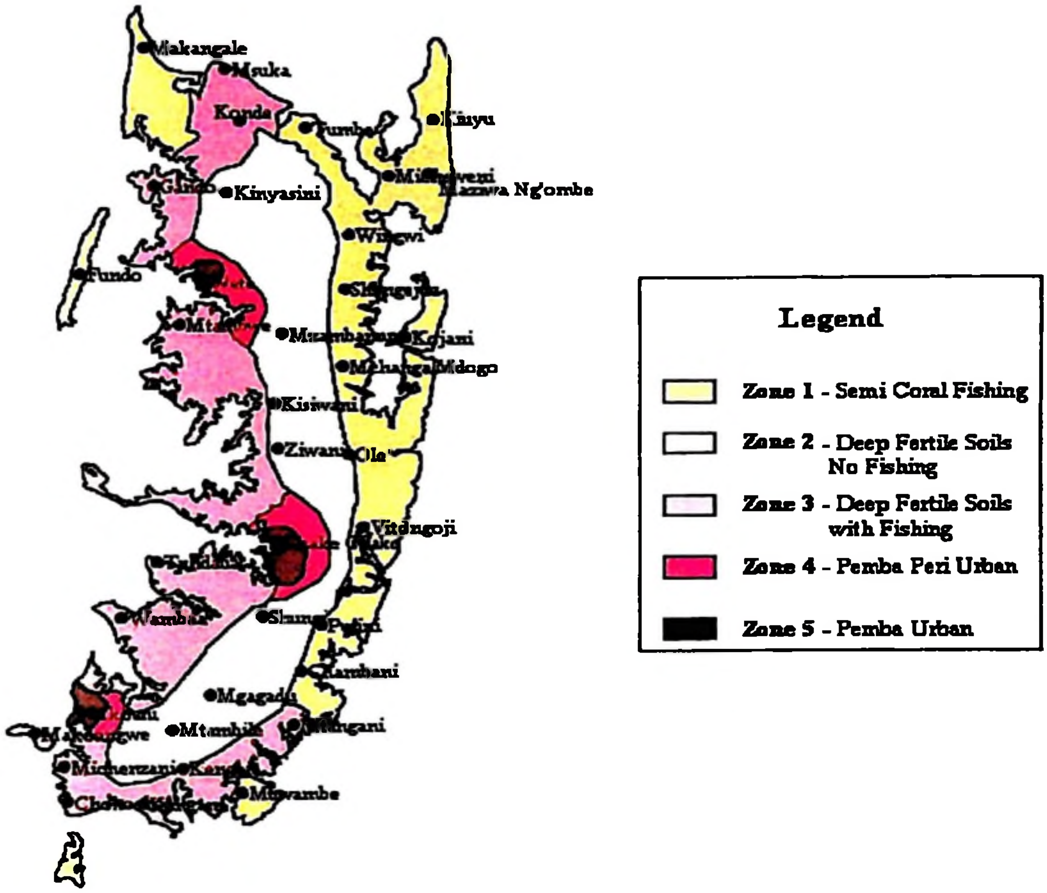

Figure 1: Pemba livelihood zones

Source: Save the children, 2003 - Zanzibar Household Economy Analysis Report.

breeds of cattle, goats and chicken. Fishing is another livelihood activity but it is very seasonal and minor, only done by men from very few households. It persists only for three to four months in a year during North-East winds when the sea is calm, thus contributing very little to the people's food and income security in this area. Petty business and cutting of stone bricks for building purposes are other livelihood options among households in the semi-coral area. In most parts of the semi-coral area, the soil is very shallow with continuous bed of stones and rocks. In some parts, big stones are at less than the ploughing depth. This characteristic makes semi-coral area not suitable for deep rooted crops such as the major plantation crops common in Pemba i.e. cloves and coconuts. Also, because of that characteristic the agricultural system is dominated by small-holder subsistence production of annual crops such as maize, cowpeas, sorghum, pea nuts, sweet potatoes and cucurbits with maize being grown by almost every household as the major food security crop and for generation of cash (Ali *et al.*, 1995).

Outside the semi-coral area maize flour is currently one of the five food items including cassava, bananas, wheat flour and sweet potatoes supplementing rice in Zanzibar. According to the Zanzibar Ministry of Agriculture (2012), the total supply of maize flour in Zanzibar has increased from 6000 metric tons in 2007 to 8000 metric tons in 2011, at an average growth rate of 11.67%. Meanwhile, in the last five years the average supply from domestic production was just 2400 metric tons per year, with growth rate of only 4.17%. The gap between the demand and the domestic supply is covered by importation of more than 3500 metric tons per year from Tanzania mainland.

1.2 Problem Statement

Maize is the most important food crop produced in the semi-coral area in Pemba. However, production has never met the demand due to very poor yields. This is probably because farmers are continuously using their local varieties with no consideration of improved production technologies such as proper spacing, proper plant densities, types and rates of fertilizers and other agronomic practices. This constantly results in production that is very far below the yields already obtained with improved practices and far below the food demand for the increasing population in the semi-coral area. The current maize yield in this area (1.0 ton ha^{-1}) is lower than the potential yield (2.0 – 3.9 tons ha^{-1}) reported by Shin-Gu *et al.* (2011) from Kizimbani research station in Zanzibar and far lower than the average yield of 2.5 – 4.5 tons ha^{-1} reported by Kaliba *et al.* (1998) from varieties recommended for the Eastern zone in Tanzania.

1.3 Justification

The big challenge in the semi-coral area in Pemba is to produce enough maize for food to meet households' demand. Increasing productivity per unit area through agronomic management is one of the important strategies to increase the production of maize grain. However, no particular package of maize production technologies specifically for the semi-coral area has ever been established. According to Shin-Gu *et al.* (2011) only four improved maize varieties; Tuxpcno-1, Staha, Situka and TMV-1 had been tested in Zanzibar in 2006. Though, no information is available on the performance of the four tested varieties under on-farm conditions. Information on fertilizers and plant densities on maize for the semi-coral area is also not available. Due to differences in agro-climatic conditions and soil type, broad or general recommendations that assume homogeneity of farming conditions can be erratic thus partly contributing to poor crop production among small-scale farmers (Hassan *et al.*, 1998). For recommendations to have proper impact, there is need for careful targeting of specific areas (Shiluli *et al.*, 2003). Findings by Shin-Gu *et al.* (2011) were not applicable in the semi coral area and other areas of Zanzibar where the nature of land and soil is far different from that of Kizimbani research centre.

Research to identify and establish improved production practices for the semi-coral area in order to increase maize production was therefore of great importance.

1.4 Objectives

1.4.1 Overall objective

To increase maize production in semi-coral area of Pemba through better cultural practices and improved varieties.

1.4.2 Specific objectives

1.4.2.1. To identify a maize variety that performs better in semi-coral area among those recommended for the Eastern Zone of Tanzania.

1.4.2.2. To establish the best variety-plant density combination that maximizes maize yield.

1.4.2.3. To establish an optimum rate of nitrogen fertilizer for improved maize production in semi-coral area.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Classification of Maize (*Zea mays* L.)

Maize (*Zea mays* L.) is an annual crop of the genus *Zea* and the family *Poaceae*. *Zea mays* is one of the five species of the genus *Zea*. Other species are *Zea diploperennis* (H.H.Iltis), *Zea perennis* ((Hitchc.) Reeves and Mangelsdorf), *Zea luxurians* ((Durieu and Asch.) R.M.Bird) and *Zea nicaraguensis* (H.H.Iltis and B.F.Benz). The species *Zea mays* is further divided into four subspecies: *Zea mays huehuetenangensis, Zea mays mexicana, Zea mays parviglumis and Zea mays mays*. The first three subspecies are teosintes (wild types); the last is maize or corn, the only domesticated taxon in the genus *Zea* (Doebley *et al*., 1990).

2.2 Centre of Origin of Maize

The geography of origins and diversification of agricultural species has important implications for straightening out the ecological context of Neolithic societies and for understanding current patterns of diversity in domesticated plants and animals (van Heerwaarden *et al.*, 2011). Because of its economic importance, maize has long been a focus of genetic and evolutionary analyses. Yet, many aspects of the evolutionary genetics of maize to its stage of domestication remain an obscurity (Gaut and Doebley, 1997). Therefore, the origin of maize has been the subject of intense debate (Doebley *et al.*, 1990). Nevertheless, both botanists and archaeologists agree that this crop of the world was the basic food plant of the ancient American civilizations (Mangelsdorf and Reeves, 1938). According to Doebley *et al.* (1995), maize starch recovered by "starch grain analysis" from stone tools obtained from the Pacific lowlands of central Panama confirms previous archaeobotanical evidence for the use of maize there by 7800-7000 cal BP ("calibrated years before the present"). Also Starch evidence from pre-ceramic sites in the less seasonal, humid premontane forests of Chiriqui province western Panama shows that maize and root crops such as manioc (*Manihot esculenta*), and arrowroot (*Maranta arundinacea*) were present by 7400-5600 cal BP, several millennia earlier than previously documented (Dickau *et al.*, 2007).

Although some paradox still remains, botany and archaeology (the study of plant science and plant domestication) and genetic studies have provided firm evidence that maize was domesticated from Balsas teosinte (*Zea mays* subspecies *parviglumis*), a wild relative that is endemic to the mid-to-lowland regions of south-western Mexico (van Heerwaarden *et al.*, 2011; Prasanna, 2012).

2.3 Introduction of Maize into Africa

Linguistic evidence strongly suggests that maize penetrated the interior of tropical Africa from the coastal regions, but the timing and mode of its introduction cannot be established (Miracle, 1965). However, it is now strongly believed that maize was introduced into Africa in the sixteenth century as part of the massive global ecological and demographic transformation called the "Columbian Exchange" and has since become one of Africa's dominant food crops (Miracle, 1966; McCann, 2001). Maize was probably introduced to tropical Africa from the Americas at more than one point along the western and eastern coasts, gradually moving inward as a ration with the slave trade and at different times during the sixteenth century (Miracle, 1965, 1966). Following its introduction, maize was first widely grown along the coast from River Gambia to Sao Tome, around the mouth of River Congo, and possibly in Ethiopia, in the sixteenth century. McCann (2001) reported that in the sixteenth century Portuguese planters began to raise foodstuffs in Pemba Island, including maize, to supply their coastal garrisons (barracks). In addition, Miracle (1965) reported that there are references to maize introduction in all these places, in Zanzibar, and around the mouth of River Ruvuma in the seventeenth century. These references mentioned and described maize as an important foodstuff and a major provision for slave ships between Liberia and the Niger Delta during the seventeenth century. Less information is available for the interior of Africa, but it clearly seems to have never been in South Africa until after 1652 and in Uganda until 1861. However, by the last decade of the 20th century, a tidal wave of maize had engulfed Africa, save its driest and wettest crannies, supplanting historical African food grains like sorghum, millet and rice (McCann, 2001).

2.4 Morphology of the Maize Plant

2.4.1 The root system

Maize has fibrous root system; a typical root system of grasses, in three different types of which one system successes another along the age of the maize plant. The first type called the seminal (primary) root system comprises of the radical and the very fine lateral roots originating from the base of the radical. This set of root system serves to anchor the young plant and absorbs nutrients and water for up to the first three weeks (Nielsen, 2000). As the seedling grows and emerges out of the soil, the seminal roots perish slowly succeeded by the permanent nodal roots developing from the first node at the mesocotyl just below the soil surface. At six leaves (V1) stage of development the nodal roots are fully developed, clearly visible and are the main root system of the maize plant (Nielsen, 2000; Belfield and Brown, 2008). Near tasseling stage, more roots called "brace roots" comparatively thick, pigmented and covered with a waxy substance but identical to nodal roots in function, grow from the two to three nodes just above the soil to support the plant from lodging and to scavenge the surface layer of soil for water and nutrients. Favourable soils may allow maize root growth up to 60 cm laterally and in depth (Tripathi *et al.*, 2011).

2.4.2 The stem

The maize plant is a single cylindrical solid stem, clearly divided into nodes and internodes. Depending on variety and the environment on which maize is grown, stem height may vary from less than 0.6 m to more than 5 m in extreme cases with 18 to 21 nodes and internodes (Nielsen, 2000; du Plessis, 2003). The first three to four nodes and internodes are still below the ground and fused together. The fifth internode is usually the first noticeable one but it is not elongated, whereas the sixth, seventh and eighth internodes lengthen to approximately 25, 50 and 90 mm, respectively (du Plessis, 2003). Some abnormal tillers may develop from nodes below the soil surface. The lateral shoot bearing the main ear develops more or less from the bud on the eighth node above the soil surface. The five or six buds directly below the main ear bud give rise to rudimentary lateral shoots of which one or two may develop to produce small ears.

2.4.3 The maize leaves

Leaves grow in spiral arrangement on the stem, one from each node, and they occur alternately in two opposite rows on the stem. The maize leaf is a typical grass leaf with sheath, ligules, auricles and a blade as the main features. The leaf blade is about ten times longer than it is wide, tapers towards the tip and is glabrous to hairy (Tripathi *et al.*, 2011). The upper leaves are more responsible for the interception of solar radiation (active photo radiation) and are major contributors of photosynthates to the grains. A prominent mid-rib along its entire length supports the leaf. Stomata occur in rows along the entire of the leaf surface. More stomata occur on the underside of the leaf than on the upper surface. One interesting feature is the presence of large, wedge-shaped cells called "motor cells" on the upper surface of the leaf. During moist conditions, these cells rapidly absorb water, become turgid and unfold the leaf. During warm, dry weather, the motor cells quickly lose their turgor with the result that leaves curl inwards exposing a smaller leaf surface to evaporation (du Plessis, 2003). This is a mechanism of maize plant to tolerate moisture stress.

2.4.4 The maize flowers

Another distinguishing feature of maize is the presence of male and female sexes in separate inflorescences. Each individual plant has both male and female flowers, i.e. monoecious plant (Belfield and Brown, 2008). The Male inflorescence (tassels) emerges as the crown at the plant apex. The female inflorescences (cobs or ears) are born at the apexes of lateral branches protruding from leaf axils almost halfway of the plant height. The male inflorescence is a loose panicle that produces pairs of free spikelets each enclosing a fertile and a sterile floret. The female (pistillate) inflorescence, a spike, produces pairs of spikelets on the surface of highly condensed rachis (central axis or cob). For better chances of fertilization, each of the female spikelets encloses two fertile florets, one of whose ovary will mature into a maize kernel once sexually fertilized by pollen.

2.4.5 The maize seed or kernel

The individual maize grain is botanically a caryopsis, a dry fruit containing a single seed fused to the inner tissues of the fruit case. The seed contains two sister structures, a germ from which a new plant will develop, and an endosperm which provides nutrients for the germinating seedling until the seedling establishes sufficient leaf area to become autotrophic (until it exercises photosynthesis). The germ consists of a miniature plant axis, including approximately five embryonic leaves, a radicle, from which the root system will develop and an attached seed leaf (scutellum).

2.5 Growth and Development

Maize is a determinate annual C4 crop. Nature greatly influences maize growth and yield. Depending on the variety, temperature, photoperiod and soil environment, maize plant takes 80 days for the early maturing to 120 days for the mid-term varieties to complete the life cycle. Late varieties take up to 180 days to mature. However, the maize producer can manoeuvre the environment with managerial/cultural practices including genotype selection, tillage operations, soil fertilization, crop rotation, irrigation and pest control (O'Keeffe, 2009). It is therefore critically important for the growers and farm managers to understand the growth and development of maize to enable the timely application of production practices that increase yields and profit and better diagnosis of the crop problems in the field (Nielsen, 2000; O'Keeffe, 2009).

What so longer the variety takes to mature, physiologists divide maize plant growth and development period into vegetative (V) and reproductive (R) phases. Sub-divisions of vegetative phase are designated as VE (the seedling emergence), V1, V2, through Vn, where the numerical indicates the number of fully emerged leaves at particular growth stage and Vn is the last leaf stage just before tasseling stage (Vt). In the same manner of occurrence of events from flowering to physiological maturity, sub-divisions of reproductive phase are R1 to R6, where R6 is the last stage of development just before physiological maturity.

2.6 Food Security and Nutritional Value of Maize

Maize is an important food and feed crop of the world. It is the third most important cereal crop after wheat and rice (Bello *et al.*, 2010; Abuzar *et al.*, 2011). Maize provides at least 30% of the food calories of more than 4.5 billion people in 94 developing countries. This figure includes 900 million poor consumers for whom maize is the preferred staple, 120 to 140 million poor farm families and about one-third of all malnourished children (CIMMYT and IITA, 2011).

Maize is also of supreme importance in the diets of many native African populations. Sixteen out of twenty-two countries in the world where maize forms the highest percentage of energy in their national diet are in Africa (Dowswell *et al.*, 1996). The chemical composition and nutritional value of maize is variable depending on the maize variety, stage of maturity as well as pre- and post-harvest handling. Generally, maize is low in saturated fat and cholesterol as well as sodium but a good source of dietary fiber, thiamin and folate (Ver Ecke, 2011).

The maize seed or kernel contains two structures, a germ and an endosperm. The germ is the source of maize vegetable oil (total oil content of maize grain is 4% by weight). The endosperm accounts for approximately 86% of the kernel dry weight. The primary component of endosperm is starch, with about 10% bound protein in the form of gluten (IITA, 2012). This stored starch is the basis of maize kernel's nutritional uses where 82 percent of the calories in maize food are from carbohydrates (Ver Ecke, 2011). Whole ground maize meal has an average energetic value of about 3.6 cal. g^{-1} (3.6 kilocal. kg^{-1}). However, this value differs slightly from one maize type to another.

Kean *et al.* (2008) documented that maize-based food products are good dietary sources of bioaccessible carotenoids ranging from a low of 1.77 - 6.50 mg kg^{-1} in yellow maize bran (YCB) to 12.04 - 17.94 mg kg^{-1} in yellow corn meal (YCM) but lacks adequate amounts of the essential amino acids e.g. lysine and tryptophan. For those depending for more than 50 percent of their daily energy on maize, endemic protein malnutrition may exist (Nuss and Tanumihardjo, 2011) unless improved through cooking methods such as fermentation and mixtures with other crops like sweet potatoes (Ejigui *et al.*, 2007; Oyarekua, 2013).

2.7 World Production of Maize

Based on FAOSTAT (2012) data, world maize harvested area has increased from 144.7 million hectares in 2002/03 to 177 million hectares in 2011/12 with production increase from 645 million tons to 875 million tons respectively. This means that within the period of 10 years the land productivity also increased from 4.5 tons per hectare to 5.0 tons per hectare in average. IGC report (2012) showed that world maize production has increased from 828 million tons in the year 2010/2011 to 865 million tons in 2011/2012 and was projected to reach 900 million tons during 2012/2013 production season.

Over the five years 2006/07 to 2010/11, the 15 largest maize producers accounted for an average of 90% of the world production. United States produced 42% (330 million metric tons) of the global production and supplied nearly 56 % of the world traded maize followed by China 21%, Brazil 6.5%, Mexico 2.6%, India 2.2% and Argentina 1.7% (FAOSTAT, 2011; O'Brien, 2011).

2.8 Maize Production in Africa

Comparing with other regions of the world, Africa is a minor producer of maize, accounting for only 7% of global production (FARA, 2009). Average annual production has increased from 32 million tons during the period 1985-1987 to only 49 million tons during the period 2005-2007 with yields still very low (1.7 tons ha^{-1}) by world standards (FARA, 2009). Most of the increase in African maize production has come from expansion in the area harvested, 131 million hectares in 1986 to 152 million hectares in 2006, rather than from increases in yield. The largest African producers are Nigeria and South Africa with nearly 8 million tons each (du Plessis, 2003).

2.9 World Utilization of Maize

Maize is a staple food and the main source of calories especially in Latin America and Africa. However, because of its low prices and worldwide distribution, it has become the most important raw material for animal feed and for several industrial processes. Global maize utilization stays close to around 870 million tons per year for food, feed, seed and industry, including ethanol production (IGC, 2012). About 65% of the global consumption is for animal feeds; the remaining 15% is for food and 20% for seed and industrial purposes FAO (2010). In the year 2007/08, maize utilization for animal feed went to the peak, 496.813 million metric tons from 172.986 million metric tons during 1970/71 market year (O'Brien, 2011). Over the more recent years, 1998/99 - 2010/11 period, world maize consumption for feed, seed and industrial use has increased annually at a higher average rate of 13.002 million metric tons in 2010/11 (O'Brien, 2011). In United States alone, maize used for feeds, seed and industry (FSI) is projected to be 164 million metric tons, followed by China 50.4 million metric tons, Mexico 16 million metric tons, the European Union 15 million metric tons, India 9.6 million metric tons and Brazil 7 million metric tons (O'Brien, 2011).

Worldwide consumption of maize directly for food is around 120 million tons, with Africa consuming 30% and Sub-Sahara Africa 21%. Lesotho has the largest per capita consumption with 174 kg per year. Eastern and Southern Africa uses 85% of its production as food, while Africa as a whole uses 95% of its production for food (McCann, 2001; IITA, 2012).

2.10 Maize Production in Tanzania

Maize is the most widely grown crop in Tanzania. It is produced by 4.5 million farm households across the country, representing about 82% of all Tanzanian farmers (NBS, 2010). Unlike paddy and sorghum, the production of which is concentrated in only few regions, maize production is geographically distributed all over the country (Minot, 2010). During 2007/2008, maize occupied 4 086 555 hectares (70%) of the entire land (5 830 972 hectares) planted with cereals (NBS, 2010). By virtue of its importance and dominance over other crops, maize has made Tanzania to be currently one of the twenty major producers of maize in the world and the third in Africa (FAOSTAT, 2011). However, maize production estimates vary significantly from year to year and among different sources of information (Minot, 2010).

Despite variation in production statistics, most of available information (NBS, 2010; FAOSTAT, 2011; FAOSTAT, 2012) have shown that maize production in Tanzania had doubled that of 2002/03 production season (2 617 115 tons) and is generally around 4.5 - 5.5 million metric tons per year in the current years (NBS, 2010). However, this increase is mainly due to an increase in land under maize production than an increase in yields (NBS, 2010; FAOSTAT, 2012).

According to National Bureau of Statistics (NBS, 2010) the total production of maize during 2007/2008 production season was 5 444 178 tons (5 438 776 tons in the

Mainland and 5402 tons in Zanzibar). Report by TFSNAS (2012) showed that maize production was 4 410 555 ton in 2010/11 production season very close to FAOSTAT (2012) statistics which showed that in 2010/2011 season Tanzania produced 4.48 million tons of maize that was worth 526 million US dollars.

Iringa, Ruvuma, and Rukwa regions in the southern highlands, Tabora, Kigoma, and Kagera in the west and Manyara in the north are the leading maize producers in Tanzania (NBS, 2010). In those regions yields are also higher (up to 1.8 tons ha^{-1}) compared with less than 1 ton ha^{-1} in less producing areas like Zanzibar, Lindi and Mtwara in the coast (NBS, 2010).

2.11 Importance of Maize in Tanzania

Importance of maize in Tanzania is both economic and social. It is the major cereal consumed and marketed in Tanzania (Shiferaw *et al.*, 2008). About 85 percent of Tanzania's population depends on maize as an income-generating commodity (Isinika *et al.*, 2003; Amani, 2004). It is estimated that the annual per capita consumption of maize in Tanzania is 73 kilograms (Amare *et al.*, 2012), contributing 33% of the total household food consumption (Minot, 2010). However, AATF (2010) reported that estimated per capita consumption of maize in Tanzania is 115 kg, accounting for 31 percent of the total food consumption and constitutes more than 75 percent of the cereal consumption in the country. Estimated values calculated from FAO food balance sheets of 2007 showed that, maize consumption in Tanzania is up to 162.2 g $capita^{-1}$ day^{-1} (60 kg $capita^{-1}$ $year^{-1}$), providing 25.7% of per capita energy intake and 25.3% of the daily protein intake (Nuss and Tanumihardjo, 2011).

Mwakalinga and Massawe (2007) and AATF (2010) reported that, Tanzania national maize consumption is estimated to be three to four million tons year^{-1}, contributing 60% of dietary calories and more than 50% of utilizable protein to Tanzanians.

2.12 Maize Cropping System in Tanzania

Maize being the most important food crop in Tanzania is in most cases intercropped with a minor/companion crop. Most of the intercrops are legumes, although a variety of crops can be found including other cereals, root crops and horticultural crops (Tuaeli *et al.*, 2003). In Northern Tanzania, the most common practice is maize/beans intercropping. Beans (*Phaseolus vulgaris*) are intercropped with maize because it is used as a complement in most local dishes. Other reasons for intercropping include maximizing land use, spreading economic risk and improving soil productivity through nitrogen fixation. In Southeast Tanzania maize is often intercropped with sesame where maize is an essential food crop and sesame is added to generate cash (Mkamilo, 2004).

2.13 Weather Conditions for Maize Production

2.13.1 Temperature

Maize grows over a wide range of temperature, though it is primarily a warm weather crop (Tripathi *et al.*, 2011). It is not grown in areas where the mean daily temperature is less than 19 °C or where the mean of the summer months is less than 23 °C. Minimum temperature for germination is 10 °C but germination is faster and uniform at soil temperatures of 16 to 18 °C. At 20 °C, maize should emerge within five to six days. The critical temperature detrimentally affecting yield is approximately 32 °C. Frost can damage maize at all growth stages and a frost-free period of 120 to 140 days is required to prevent damage (du Plessis, 2003).

Average optimum temperatures vary according to the place, varieties and altitude. In temperate areas the range is between 20 to 30°C, in highland tropical areas it is from 17–20°C and for the lowland tropical maize, the range lies between 30 and 34°C (Badu-Apraku *et al.*, 1983). According to Lobell *et al.* (2011), each degree day spent above 30°C reduced the final yield by 1% under optimal rain-fed conditions, and by 1.7% under drought conditions.

2.13.2 Rainfall and water requirement

Maize is cultivated over a wide range of climatic conditions, differing in distribution and quantity of seasonal rainfall (Asare *et al.*, 2011; Thimme *et al.*, 2013). It is grown under both, irrigated and rain-fed conditions. Rain-fed maize production forms about 75% of maize production in areas where the crop is the main source of food and income for the people (Rockstrom *et al.*, 2011). It is considered that maize is more susceptible to water stress than other crops because of its unusual floral structure with separate male and female floral organs and the near-synchronous development of florets on a (usually) single ear borne on each stem (Huang *et al.*, 2006). In areas such as the semi-arid and dry sub-humid environments, the amount of rainfall (low or high and erratic) is the limiting factor of rain-fed maize production (Hatibu *et al.*, 2003). Effect of water stress on maize crop has been studied by several workers. According to (Cakir, 2004) water stress occurring at different maize crop developmental stages could potentially limit biomass accumulation and consequently reduce grain yield of the maize crop. The extent of reduction in maize productivity depends not only on the severity of the water stress or drought but also on the stage of the crop development hit by stress. Short duration water deficits during the rapid vegetative growth period caused 28–32% loss of final dry matter weight according to Cakir (2004). The most critical period for water stress in maize is 10 to 14 days before and after flowering, with grain yield reduced 2 to 3 times more when water deficit coincides with flowering compared with other growing stages (Grant *et al.*, 1989). During this period, ear growth is susceptible to competition from other organs that are still growing as its growth is source limited, often leading to low grain number per ear and occasionally barren ears (Huang *et al.*, 2006).

Grain yield of maize suffering water stress at flowering and during grain fill is highly correlated with kernel number per plant (Bolanos and Edmeades, 1996) indicating the importance of adequate water supplies during flowering. Hammad *et al.* (2011) ascertained that number of grains, total dry matter, leaf area index, harvest index and grain yield were all minimum at reduced number of irrigation, where stress was imposed at six leaves and 12 leaves stage.

Application of normal irrigation (8 irrigations) significantly produced the maximum grain yield (8 tons ha^{-1}) and the lowest grain yield (4.6 tons ha^{-1}) was obtained by applying water stress at silking growth stage, while water deficit just before silking and at grain filling stages decreased yield by 12.5 and 22.5% respectively (Ghooshchi *et al.*, 2008). The total water requirement over the growing period depends on cultivar, location and the season of production. Some landraces may have developed tolerance to water stress during many years cycle of selection (Mabhaudhi, 2009). In Turkey, Mengu and Ozgurel (2008) reported that the seasonal water use for maize was between 142.19 mm and 481.91 mm in one season and between 136.25 and 499.45 mm in another season. Another study by Igbadun (2012) showed that the average daily water use of the maize crop in Nigeria increased from 2.70 mm/day at the early crop growth stages to 6.00 mm/day at mid-season and declined to 3.30 mm/day at the end of the season. Study on water requirement of maize using CROPWAT model in Karnataka India revealed that the total water requirement of maize was 116.0 mm for the early planted crop and 183.8 mm for the late planted one (Thimme *et al.*, 2013).

In respect of rainfall, maize performs well when irrigated or rain fed with about 600-900 mm per annum (Tekwa and Bwade, 2011), but Belfield and Brown (2008) established that 500 to 1200 mm per annum is the optimal range in Cambodia, with well-aerated and well-drained soil as maize crop is susceptible to water logging.

2.13.3 Solar radiation

One of the most important factors that influence plants development is the solar radiation intercepted by the crop (Campillo *et al.*, 2012). This is that part of the extraterrestrial radiation which is not absorbed and scattered when passing through the atmosphere, together with some of the scattered radiation that also reaches the earth's surface. The solar radiation provides energy to the metabolic processes of the plants. The principal process is photosynthesis by which the solar energy absorbed by the plant green pigment (chlorophyll) is utilized in various steps of reactions that involve carbon dioxide and water to produce dry matter in the form of carbohydrates. Visible radiation, between the wavelengths of 400 and 700 nanometers, is the most important part of solar energy as it relates to photosynthetically active radiation (PAR).

Several reports have shown the importance of solar radiation for maize production. Liu and Tollenaar (2009) reported that when solar radiation was reduced by 55% for 4 weeks period prior to silking the maize grain yield was reduced by 3.2%, for 3 weeks at silking the yield was reduced by 12.65% and for 4 weeks post-silking the yield was reduced by 21.4%. In another study Reed *et al.* (1988) found that reduction of solar radiation by 50% at vegetative stage reduced the grain yield by 12%, at flowering stage the yield was reduced by 20% and when reduced at grain filling stage the yield was reduced by 19%. He further reported that shading during flowering reduced yield primarily through decreasing the number of kernels per row, and shading during grain filling reduced yield primarily through decreasing kernel weight.

2.14 Soil Conditions for Maize Production

The capacity of soils to be productive depends on more than just one characteristic. The physical, biological, and chemical characteristics of a soil, such as its organic matter content, acidity, texture, soil depth, and water-retention capacity, all influence fertility and so productivity of the soil (Gruhn *et al.*, 2000). The differences of these attributes among soils bring about differences in soil quality and productivity.

2.14.1 Soil texture

Soil texture is a term commonly used to designate the proportionate distribution of the different sizes of mineral particles (sand, silt and clay) in a soil. It does not include organic matter. According to Tripathi *et al.* (2011) soil texture is a foremost requirement as it controls moisture and nutrient capacity of the soil. Texture of the soil affects plant growth by influencing soil aeration, root penetration, water holding capacity and nutrient availability in soil. Root growth reaches maximum in soils high in sand percentage as roots have to explore more volume in search of nutrients and ease of growth (Wakeel *et al.*, 2005). McKenzie *et al.* (2001) observed limited root growth in soils with high clay contents due to more soil strength. Wakeel *et al.* (2005) found that the shoot root ratio (RSR) was higher in soils with 54% sand as compared with soils that contained 45% and 38% sand; and that there was a positive correlation ($r = 0.83$) between the RSR and the total dry matter (TDM) production. According to Tripathi *et al.* (2011) loam or silt loam surface soil and brown silt clay loam having permeable sub soil are the ideal soil types for cultivation of maize.

2.14.2 Soil pH

Soil pH is an important factor in determining crop performance. Low pH levels affect nutrients by converting them into forms that are not readily available to the crop. In addition, low pH levels can increase the solubility of plant toxic metals such as aluminium (Al^{3+}) resulting in stunted growth and a general lack of plant vigour (Mallarino *et al.*, 2011). Every crop has an optimum soil pH range. Within this range production potential is maximized. The plant's critical range is the range of soil pH in which the crop will attain 80% of its maximum yield potential (Hill, 2003). Although the general idea of the optimum soil pH range for a variety of crop is used, the value may vary among crops and varieties. Hill (2003) showed that maize can be produced at pH range of 4.5 to 7.5. Tripathi *et al.* (2011) reported that pH range for maize is from 7.5 to 8.5 and that at pH beyond these extremes, problems of toxicity are found with certain elements. Mallarino *et al.* (2011) found that there was no significant or consistent increases of maize yield from pH 6.0 to 6.9, but a yield decreases for higher pH values.

2.14.3 Soil cation exchange capacity (CEC)

Cation exchange capacity (CEC) is the capacity of the soil to hold the positively charged ions such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}) hydrogen (H^{+}), aluminum (Al^{3+}), iron (Fe^{2+}), manganese (Mn^{2+}), zinc (Zn^{2+}) and copper (Cu^{2+}). These cations are held by the negatively charged clay and organic matter particles in the soil through electrostatic forces (Brady and Weil, 2004; Astera, 2007).

A soil with higher CEC has a greater capacity to maintain adequate quantities of Ca^{2+}, Mg^{2+}, K^{+} and less susceptible to nutrients leaching losses while low CEC soils are more likely to develop deficiency of potassium and magnesium and other highly mobile cations. A soil with a higher CEC may not necessarily be more fertile because a soil's CEC can also be occupied by acid cations such as hydrogen (H^{+}) and aluminum (Al^{3+}). Thus, the percentage base saturation is a good indicator of the soil fertility. However, when combined with other measures of soil fertility, CEC is too a good indicator of soil quality and productivity (Ross and Ketterings, 2011).

In maize production, better crop growth and good yields can be obtained where the soil CEC influences the soil pH to stay around 6.5 to 7.5 with good availability of nitrogen, phosphorus, calcium, magnesium and some sulphur. In low CEC soils such as in sandy soils, amendment with organic matter and incorporation of crop residues is not only for nutrient recycling but importantly for raising the soil CEC and so the retention of nutrients elements from leaching effect. In modern technology, biochar (material produced from a range of organic materials) are now commonly applied in commercial maize field to increase the soil CEC and therefore nutrient availability (Mutezo, 2013).

2.14.4 Soil organic matter

Magdoff and van Es (2009) defined soil organic matter (SOM) as the diverse organic materials, such as living organisms, slightly altered plant and animal organic residues, and well-decomposed plant and animal tissues that vary considerably in their stability and susceptibility to further degradation. It is any material produced originally by living organisms (plant or animal) that is returned to the soil through the decomposition process. At any given time, it consists of a range of materials from the intact original tissues of plants and animals to the substantially decomposed mixture of materials known as humus (Bot and Benites, 2005).

Organic matter is of great importance in soils, because it impacts on the physical, chemical and biological properties of soils. Physically, it promotes aggregate stability and therefore water infiltration, percolation and retention. It impacts on soil chemistry by increasing cation exchange capacity (CEC), soil buffer capacity and nutrient supply. Biologically, it stimulates the activity and diversity of organisms in soil (Du Preez *et al.*, 2011). In situations where moisture or soil strength is a major limitation for plant growth, the greatest impact of soil organic matter can be on the physical component of soil fertility (Craswell and Lefroy, 2001). Likewise, where soils are depleted with nutrients the chemical and biological components are more important. A typical agricultural soil has 1% to 6% organic matter (Magdoff and van Es, 2009). The chemical component consists mainly of carbon (C) and small amounts of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) magnesium (Mg) and sulphur (S) elements (Bot and Benites, 2005).

Generally, soil organic matter contains 0.5 to 2.5% N (5 to 25 g N Kg^{-1} of organic matter (Fairhurst, 2012). However, Horwath (2005) presented to a conference that soil organic matter contains 55% carbon, 5% to 6 % nitrogen and 1% of both phosphorus and sulphur and that 2% to 5% of the organic matter decomposes annually (Paul and Clark, 1996).

As regards to maize crop, organic matter is often anticipated as an alternative to mineral fertilizers. In soils of low organic matter some plant and animal materials have been used to amend the soil for increasing maize yields. Mugendi *et al.* (1999) found that application of *Calliandra* and *Leucaena* prunings with or without inorganic fertilizer resulted in higher maize grain yield. Also, Mugendi *et al.* (2007) reported that sole *Tithonia* gave the highest maize grain yield followed closely by *Tithonia* with half recommended rate of inorganic fertilizer. Baijukya *et al.* (2006) obtained higher maize yield with the application of legume residues compared to mineral nitrogen fertilizers in the second season, although it was vice versa in the previous season. Farhad (2009) reported increase in grain yield from application of different levels of poultry manure. Ikerra *et al.* (1999) reported that application of *Gliricidia sepium* prunings increased topsoil (0 to 20 cm) inorganic N and Makumba *et al.* (2006) found that with the same material (*Gliricidia sepium* prunings) applied earlier, higher N uptake and higher maize yields were obtained.

2.15 Soil Nutrients and Fertilizer Use in Maize Production

Soil is a major source of nutrients needed by plants for growth. The three main nutrients are nitrogen (N), phosphorus (P) and potassium (K) collectively known as NPK. Other important nutrients are calcium, magnesium and sulphur (Lines-Kelly, 2004). Plants also need small quantities of iron, manganese, zinc, copper, boron and molybdenum, known as trace (micro) elements (Gruhn *et al.*, 2000; Lines-Kelly, 2004). Except for carbon, hydrogen and oxygen which plants obtain from the air, the plant must get all remaining essential nutrients from the soil.

Maize crop absorbs large quantities of nutrients from the soil during different growth stages (Masood *et al.*, 2011). Therefore, profitable maize production requires an adequate soil fertility program for fully grasping of yield benefits from other management practices (Onasanya *et al.*, 2009). Insufficient nutrients will lower yields; excess nutrients will lower profit margins through increased costs of production and/or damage of the crop (nutrient toxicity).

2.15.1 Phosphorus

Phosphorus is an important nutrient in relatively short supply in most natural ecosystems and is the primary limiting nutrient for crop production in highly weathered tropical soils (Basamba *et al*., 2006). It is required in relatively large quantities by the crop, the second most crop-limiting nutrient in most soils and is the second only to nitrogen in fertilizer use (Petosic *et al*., 2003; Asghar *et al*., 2010; Masood *et al.*, 2011).

Phosphorus is highly needed for energy storage, transfer and transformation (phosphorylation) in plant biochemical processes (Ayub *et al.,* 2002). All energy-demanding processes such as photosynthesis, respiration, cell division, reproduction and utilization of other nutrients and photo-assimilates are stimulated by phosphorus (Blevins, 1999). Apart from its role in energy-transferring processes, phosphorus is a structural component of phospholipids, nucleic acids, nucleotides, coenzymes, and phosphor-proteins. In plants, phosphorus also serves as a buffer in the maintenance of cellular pH and is the main reserve in seeds (Belvins, 1999; Uchida, 1999).

According to Busman *et al.* (2009) a very large portion of soil P is fixed by inorganic phosphate compounds that are insoluble and organic compounds that are resistant to mineralization by microorganisms in the soil. Thus, a large portion of soil P may remain in soils for years without being made available to plants and has very little impact on the fertility of a soil. Therefore, adequate supplementation of P in the soil for best yields is highly necessary though it must be done based on the soil tests. Masood *et al.* (2011) reported that adequate phosphorus resulted in rapid growth and earlier maturity, improved the quality of vegetative growth and the quality of harvested grains and that phosphorus deficiency resulted in warped and missing rows in maize cobs. The effects of applied phosphorus on yield and yield components of maize were also described by Shiluli *et al.* (2003), Ali *et al.* (2002) and Ayub *et al.* (2002).

2.15.2 Potassium

Plants absorb Potassium in greater amounts than any other essential nutrient except nitrogen in most crops (Rehm and Schmitt, 1997). In order for a crop to achieve its maximum yield potential, potassium is needed in large quantities. According to White (2003), a mature maize crop can contain up to 300 kg K ha^{-1} in aboveground plant material. The K uptake pattern of maize is distinctive in that K is taken up rapidly and early in the crop's growth cycle (Prajapati and Modi, 2012), with some varieties accumulating more than 5 kg K ha^{-1} day^{-1} during the period between 4 to 7 weeks after emergence (White, 2003).

Usually the K content of the soil exceeds 20 g K kg^{-1} soil but nearly all of this is in the structural component of the soil minerals (immobile), thus, is not readily available for the plants (Rehm and Schmitt, 1997; Angima, 2008). Its availability depends on several factors such as soil moisture, soil temperature and the soil pH. Potassium is one of the most important nutrients in protecting a crop against disease. It has the ability to strengthen stalks and stems against disease, protecting the plant from lodging. It has the ability to make plant cells thicker, making it difficult for diseases to invade the plant.

Potassium is involved in over 60 enzyme systems that regulate plant growth reactions (CFF, 2013). One of these major roles is in regulating water use efficiency in the plant (Mengel and Arneke, 1982). The opening and closing of the stomata in the leaves is directly related to the concentration of Potassium in the cells that surround the stomata.

Potassium is also vital in photosynthesis. Potassium deficiency can lead to a reduction in both the number of leaves produced and the size of individual leaves. This reduces the amount of photosynthetic source material with a reduction in the photosynthetic rate per unit leaf area, and the result is an overall reduction in the amount of photosynthetic assimilates available for growth (Pettigrew, 2008). In turn, this increases the plants respiration rate and causes the plant's carbohydrate supply to decrease (Haeder and Beringer, 1981). The study by Jones (2003) showed that K deficiency severely reduces yield in maize. Mussgnug *et al.* (2006) reported that regular K applications were required to make investments in the application of other mineral nutrients profitable. Ebrahimi *et al.* (2011) reported that application of 200 kg K ha^{-1} increased grains number per row, grains weight per cob and 1000 grains weight that increased grain yield to 15.9 tons ha^{-1}.

2.15.3 Nitrogen

Nitrogen is an essential nutrient for growth and reproduction of all forms of life (Dinnes *et al.*, 2002). It is one of the most prevalent elements and a component of amino acids, proteins, nucleic acids, chlorophyll and many other metabolites essential for survival, growth and development of the plant (Alimohammadi *et al.*, 2011; Guled, 2007). It reconciles utilization of phosphorus, potassium and other plant nutrients available in the soil (Brady and Weil, 2007) and is a major yield-determining factor required for maize production (Adediran and Banjoko, 1995; Shanti *et al.*, 1997). In order for a crop to achieve its maximum yield potential, nitrogen is needed in large quantities and must be in balance with other nutrients. According to Schroder *et al.* (2000), in the first three weeks after emergence, the maize crop takes up soil mineral nitrogen (NO_3^- and NH_4^+) at a rate of less than 0.5 kg N ha^{-1} day^{-1}. During the next 75 days the rates can be as high as 3.7 kg ha^{-1} day^{-1} (Andrade *et al.*, 2002).

Only 2 – 3% of the soil nitrogen exists in the inorganic form as nitrate (NO_3^-) and ammonium (NH_4^+), the forms that are available to plants. The remaining (97 - 98%) is tied up in the organic matter and is only available to plants when organic matter is decomposed by micro-organisms through the process of mineralization (Brady and Weil, 2004; Cassman *et al.*, 2002; Tisdale *et al.*, 2004; Barbarick, 2006). Yet an opposite process (immobilization) also occurs where microorganisms feed on inorganic nitrogen and incorporate it into their living cells and deplete the soil of available nitrogen (Tisdale *et al.*, 2004). According to Coder (1997), between unusable organic nitrogen and the tree-preferred inorganic nitrogen, apart from crops there are many soil organisms (almost exclusively bacteria), which use whatever nitrogen source is accessible to live. In that process the micro organisms transform nitrogen into other forms not available for plants. As micro organisms' life declines away nitrogen is soon available to plants again but for short periods before it is again incorporated into living cells. On the other hand, ammonium nitrogen (NH_4^+) is highly susceptible to loss by volatilization while the nitrate nitrogen (NO_3^-) is highly prone to loss due to hasty nitrate leaching and poor management practices under the humid tropical environment (Osmond *et al.*, 1996). In addition to that, large quantities of N are removed from the soil and taken away along with the harvested crops. Lack of synchrony between large quantities of N required by crops and the net amounts available in the soils, has made nitrogen to be the most important nutrient limiting crop production in the tropics (Sanchez, 1976) and in particular the most off-putting nutrient for tropically produced maize (Osmond *et al.*, 1996).

Achieving synchrony between N supply and crop demand without excess or deficiency is the key to optimizing trade-offs amongst yield profit in both large-scale systems in developed countries and small-scale systems in developing countries (Cassman *et al.*, 2002). Due to limitations with soil N, the use of chemical fertilizers to supplement this nutrient for maize production has increased and a lot of research has been done in different locations around the world to determine the optimum and profitable levels of application. El-Sheikh *et al.* (1998) reported significant increase of grain yield of maize at 160 kg N ha^{-1}. Arif *et al.* (2010) found that ears m^{-2}, grains ear^{-1}, 1 000 grain weight, grain yield, biological yield and harvest index constantly increased with increase in nitrogen level from zero kg N ha^{-1} to 160 kg N ha^{-1}. Namakka *et al.* (2008) observed that 80 kg N ha^{-1} produced the highest values of cob length, cob diameter, cob weight and grain yield of 3.8 tons ha^{-1} and that further increase of nitrogen to 120 kg N ha^{-1} had no effect on grain yield. Another report by Lomer *et al.* (2012) showed that application of different levels of nitrogen had significant effects on number of days to tasseling, pollen occurrence and physiological maturity. In another study by Subedi *et al.* (2006) grain yield reached a maximum with application of 225 kg N ha^{-1} followed by 75 kg and 150 kg N ha^{-1}. However, the optimum levels always vary from one location to another, from one season to another and also depend on variety/cultivar.

2.16 Effects of Choice of Varieties on Maize Yield and Production

Maize is a crop of diverse genotypes. Still, plant breeders are continuously working to develop more cultivars with improved yield and other desirable agronomic and phenological characteristics (Bello *et al.*, 2010). As a result, there is high potential of increasing maize yields and production through selection of better varieties for a particular location. For the better variety-environment interaction and the higher yields, it is important that farmers be familiar with the varieties recommended for their ecological niche.

Several researchers have reported differences in yield among maize varieties. Kaliba *et al.* (1998) reported yield differences from 3.0 to 8.0 tons ha^{-1} with different improved varieties and hybrids in Eastern Tanzania. Mugisha and Diiro (2010) reported that the mean yield of 2941.5 kg ha^{-1} from improved maize varieties was significantly higher than the mean yield of 1694 kg ha^{-1} obtained from local varieties used by farmers in Eastern and Central regions in Uganda. Geleti *et al.* (2011) reported highly significant differences for harvest index and grain yield among three maize varieties in Ethiopia and Bello *et al.* (2011) reported a significant yield difference (of one ton ha^{-1}) between early maturing and late/intermediate maize varieties in Southern Guinea savannah, Nigeria.

2.17 Effects of Planting Density on Maize Yield and Production

The maize crop is highly sensitive to variation in plant density (Lashkari *et al.*, 2011). Different maize varieties also differ in their response to plant density (Luque *et al.*, 2006). Liu *et al.* (2004) reported that maize yield differs significantly under varying plant density levels due to differences in genetic responses to the varying densities. Plant densities affect most growth parameters of maize even under optimal growth conditions, therefore considered a major factor determining the degree of competition between plants (Sangakkara *et al.*, 2004). Plant density affects plant architecture, alters growth and developmental patterns and influences carbohydrate production.

Maize yield is low with low plant densities because of its little plasticity in leaf area per plant (do not tiller) and quite often produce only one ear per plant thus fewer cobs will be harvested from any given area. Also low plant density creates more space for vigorous growth of weeds. At highest densities the grain yield per plant is decreased in response to decreasing light, water, nutrients and other environmental resources available to each plant (Sangoi, 2000; Luque *et al.*, 2006). Also excessive higher plant densities stimulate apical dominance, induce barrenness, and in due course decrease the number of ears produced per plant and kernels set per ear (Sangoi, 2000).

Barten (2013) reported that when plant density was steadily increased from 57 000 to 100 000 plants ha^{-1}, the relative stover mass and grain yield were respectively reduced from 150 and 464 grams plant^{-1} to 100 and 305 grams plant^{-1} though the grain production per hectare was increased. Shariffi *et al.* (2009) found that with maize hybrids, higher plant density increased the plant height and decreased the cob length, number of kernels per cob, harvest index and number of seeds per cob row. When plant density was varied from 70 000 to 130 000 plants ha^{-1}, grain yield varied significantly from 8.45 to 9.35 tons ha^{-1} (Lashkari *et al.*, 2011). Abuzar *et al.* (2011) obtained highest grain yield (2604 kg ha^{-1}) from 60 000 plants ha^{-1} but report by Khuong *et al.* (2008) showed that significant grain yield and higher benefits were obtained from improved density of 67 000 plants ha^{-1}.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site Description

The field experiment to fulfil the objective of the study was carried out at Kangagani village in Pemba Island during the long rains (*Masika*) season from March to August 2013. This village is located half way along the length of Pemba Island on the Eastern side at latitude 5° 09′ South and longitude 39° 46′ East at about 20 meters above sea level. The area is characterized by a bimodal rainfall pattern. Long and sometimes heavy and erratic rainfall during March to June and short and normally very little rains (*Vuli*) are received during any time within September to November. Monthly rainfall during experimental period is shown in Table 1.

Table 1: Rainfall data (mm) recorded at Dodeani Agricultural centre, Pemba from January to August 2013 for the experimental site

Month	1st week	2nd week	3rd week	4th week	Total	Average/week
January	15.00	22.00	7.10	0.00	44.10	11.03
February	0.00	0.00	0.00	0.00	0.00	0.00
March	0.00	19.00	12.5	11.50	43.00	10.75
April	140.00	23.00	54.00	108.00	325.00	81.25
May	384.00	0.00	0.00	0.00	384.00	96.00
June	87.00	50.00	35.00	0.00	172.00	43.00
July	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00	0.00	0.00

Data recorded by the Tanzania Meteorological Authority station (7 km from the experimental site) showed that the mean maximum and mean minimum temperatures are 30.2 and 23.8 °C respectively. November to February is the hottest period (31 to 33°C). Average humidity is 71.5% while average evaporation is 5.72 mm day^{-1}. Sunshine duration ranges from 7 to 9 hours day^{-1}. Soil was classified as sandy clay loam with average pH of 7.6, 3% organic matter in the top 20 cm layer, 1.74% organic carbon and 0.16% total nitrogen. Other chemical characteristics were as indicated in Table 2.

Table 2: Physicochemical characteristics of the soil of the experimental site

Characteristics	Amount	Remarks
% Clay	31	
% Silt	3	
% Sand	66	
Texture	Sandy clay loam	Ideal for maize production
Organic matter (%)	2.98	Medium
Organic carbon (%)	1.74	Low
Total nitrogen (%)	0.16	Low
Extractable P (mg/kg)	3.83	Deficient
pH	7.50	High but ideal for maize crop
Electric conductivity EC (mS/cm)	0.22	
CEC (cmol/kg)	22.39	Medium
Potassium (K^+) (cmol/kg)	0.28	Low
Sodium (Na^+) (cmol/kg)	0.24	Low
Calcium (Ca^{2+}) (cmol/kg)	17.50	Medium
Magnesium (Mg^{2+}) (cmol/kg)	1.11	Sufficient
Micro nutrients:		
Cu^{2+} (mg/kg)	0.48	Low
Zn^{2+} (mg/kg)	0.49	Low
Mn^{2+} (mg/kg)	2.10	Low
Fe^{2+} (mg/kg)	1.87	Low

Cropping history showed that the experimental site had been used over years for continuous production of maize, pulses, ground nuts and sweet potatoes.

3.2 Materials

Experimental materials included three improved maize varieties (Staha, Situka and TMV-1), which were selected from the maize varieties list recommended for the Eastern zone of Tanzania, and one local variety, JKU, which is commonly grown in the semi-coral area in Pemba. Nitrogen fertilizer in four application levels was supplied using urea (46% N). Phosphorus fertilizer was used as a non-experimental material but a necessary nutrient applied uniformly to all treatment units.

3.3 Methods

3.3.1 Experimental design, field layout and treatments

The field experiment was laid out using randomized complete block design (RCBD) in a split-split-plot arrangement with three replications. Four maize varieties, Staha, Stuka, TMV-1 and JKU were assigned to the main plots. Three planting densities; 44 444, 53 333 and 66 666 plants ha^{-1} were assigned to the sub-plots and four nitrogen levels: 23 kg, 46 kg, 70 kg and 90 kg N ha^{-1} were allocated to the sub-sub-plots. The size of the treatment units (sub-sub plot) was 3m x 3m (9 m^2), each planted with four rows. Uniform inter-row spacing of 75 cm was used across all treatment units while the plant density was altered by changing intra-row spacing where 30 cm, 25 cm and 20 cm between the plants were used. There were 48 sub-sub-plots (4 varieties x 3 plant densities x 4 nitrogen levels) each replicated three times. The net experimental area was 1296 m^2. Main plots, sub plots, sub-sub plots and the replications were all spaced at one meter apart, making the total experimental plot area 2304 m^2. Two seeds per hole were planted and then thinned to one plant per hill seven days after emergence. This was done to maintain the predetermined plant densities at the beginning of the experiment and to avoid gap filling which always bring differences in maturity within the same treatment.

3.3.2 Procedures

3.3.2.1 Land preparation

Land ploughing and harrowing were done during the third week of February 2013. Tillage operations were done during the dry period purposely to help killing most of weeds prior to planting and to get suitable seed bed for best germination.

3.3.2.2 Planting

Normally the cropping season in semi-coral area starts during the onset of long rains (*Masika*) which usually starts in March. Unfortunately during the year of this study, these rains were not enough for planting until during the first week of April. Planting was done on 6 April 2013 following the adequate rain obtained one day before. The seedlings were fully emerged after one week from planting.

3.3.2.3 Fertilizer application

Prior to planting a uniform rate of phosphorus fertilizer (20 kg P ha^{-1}) using TSP 20% P was applied basally to all treatment units. Depending on the number of holes planted in each row of each experimental unit, calculated amounts of TSP 46 % P_2O_5 were placed in planting holes few centimetres below the seeds. Nitrogen fertilizer in different four levels was side dressed in 2 splits, 50% at four weeks after seedlings emergence and another 50% three weeks later. N splitting was applied because it shortens exposure time to leaching or de-nitrification, avoids early season nitrogen losses and provides available nitrogen fertilizer to the maize crop when it needs it most, mostly during the sixth to tenth week (Bundy *et al.*, 1994; Bundy and Malone, 1998; Guillard *et al.*, 1999; Gehl *et al.*, 2005)

3.3.2.4 Weed control

The land in semi coral area is highly infested with different and vigorous growing types of weeds, probably due to weed seeds distributed by freely grazing animals (cattle and goats) just after harvesting period, when the land is free from crops (visual observation). First weeding was done three weeks after seedlings emergence and the second was done at six weeks of age of the crop.

3.4 Data Collection

3.4.1 Soil data

Before ploughing, samples of soil were randomly taken from the experimental plot from zero to 20 cm depth as described by Walworth (2011). Composite soil sample was analyzed for pH, electrical conductivity, particle sizes density (texture), total nitrogen, organic carbon, extractable P as well K, Ca, Mg, Na, Mn, Zn, Fe and Cu mineral contents (Table 2). The physicochemical soil characteristics were determined according to the following methods: pH and electrical conductivity by suspension method at the ratio of 1:2.5 w/w soil-water, particle sizes density by Bouyoucos hydrometer method. Total nitrogen was determined using Micro-Kjeldahl digestiondistillation method as described by Guebel *et al.* (1991) and organic carbon by modified method of Walkely-Black (Schumacher, 2002). Extractable P was analyzed by Olsen as described by Carter and Gregorich (2006). Exchangeable bases were extracted with ammonium acetate (NH_4OAc) according to Chapman (1965).

3.4.2 Rainfall data

Rainfall data for the research period were collected from Dodeani Agricultural Station very near to the experimental site. The total rainfall for 8 months (January to August 2013) was 968.1 mm of which 881 mm was received during the exact period of the field experiment (April to July 2013). Monthly and weekly distribution of this amount is presented in Table 1.

3.4.3 Growth parameters

Days to 50% flowering was recorded when half the number of plants in a particular treatment unit had fully emerged tassels. Number of days to physiological maturity was determined and recorded by monitoring the disappearance of the milk line and formation of black layer at the base of the kernels. Data for plant height at physiological maturity was recorded by measuring five randomly selected plants in each sub-subplot, from the base of the plant to the base of the tassel.

3.4.4 Yield and yield components

Data on cob length, cob weight, grain weight per cob, 100 seeds weight, grain yield, harvest index and dry matter yield were obtained by harvesting all the plants in the 2.25 m^2 area from the central two rows of each sub-subplot. The harvests were sun dried to the constant weights before recording the predetermined variables. To obtain the actual grain yields, samples of 200 g of grain were taken from the harvest of each sub-subplot and moisture content determined. This was done by keeping the samples in an oven at 70°C for 72 hours. The yields were then adjusted to 12% moisture content. Calculations to get the actual grain yields at 12% moisture content were made based on water shrinkage factor as described by Hicks and Cloud (2001).

3.5 Data Analysis

An analysis of variance (ANOVA) was done in accordance with Gomez and Gomez (1984) to determine the response of each parameter to the treatments (response to individual factors and their interactions) using GenStat computer software and the following mathematical model:

$$Y_{ijkz} = \mu + R_i + \alpha_j + \varepsilon_{ij} + \beta_k + (\alpha\beta)_{jk} + \varepsilon_{ijk} + \gamma_z + (\alpha\gamma)_{jz} + (\beta\gamma)_{kz} + (\alpha\beta\gamma)_{jkz} + \varepsilon_{ijkz}.$$

where:-

Y_{ijkz} = each experiment unit observation. μ = general (population) mean common to all experimental units. R_i = the block effect. α_j = effect of main treatment (variety). ε_{ij} = main treatment error. β_k = effect of sub treatment (plant density). $(\alpha\beta)_{jk}$ = effect of interaction between variety and plant density. ε_{ijk} = sub treatment error. γ_z = effect of sub-sub treatment (nitrogen levels). $(\alpha\gamma)_{jz}$ = effect of interaction between variety and nitrogen level. $(\beta\gamma)_{kz}$ = effect of interaction between plant density and nitrogen level. $(\alpha\beta\gamma)_{jkz}$ = effect of interaction of all three factors (variety, plant density and nitrogen level). ε_{ijkz} = sub-sub treatment error specific to each sub-sub plot. i, j k and z are a particular block, a main plot, a sub plot and a sub-sub plot, respectively.

When F probability showed significant difference in a particular parameter, means comparison was performed using Fisher's unprotected L.S.D at 5% level of probability for treatments not exceeding five (for this study the 4 varieties, 3 plant densities and 4 nitrogen levels) and Tukey's 95% confidence limit was used to compare more than five means, in this study, the interactions of the factors. Correlations between different measured (growth and yield) parameters were determined to see how they influenced one another and the grain yield.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

4.1.1 Analysis of variance results

Table 3 presents the analysis of variance (ANOVA) results of the mean squares indicating significance (according to F-test) of the main factor (varieties), the sub-factor (plant densities), sub-sub-factor (nitrogen levels) and their interactions on growth parameters, yield and yield components. The results indicated that varieties were highly significantly ($P \leq 0.001$) different for the plant height, days to 50% silking and days to physiological maturity, cob length, grain weight cob^{-1} and grain yield. For the rest of the measured parameters (cob weight, 100 seeds weight, dry matter yield and harvest index) the varieties were significantly different at $P \leq 0.01$. Seed row cob^{-1} was not significantly affected by the varieties.

The results showed that plant densities had no significant effect on days to 50% silking, days to maturity and seed rows cob^{-1} but they were highly significantly ($P \leq 0.001$) different for the plant height, cob length, cob weight, grain weight cob^{-1}, dry matter yield and grain yield. As regard to harvest index, plant densities were significantly different at $P \leq 0.01$, while on 100 seeds weight the plant densities were significantly different at $P \leq 0.05$. Also ANOVA results revealed that nitrogen levels had no significant effect on number of seed rows cob^{-1} but caused highly significant ($P \leq 0.01$) variation on cob weight and grain weight cob^{-1} and very high significant ($P \leq 0.001$) effect on the rest of the measured parameters.

Table 3: Analysis of variance (ANOVA) results of mean squares for growth parameters, yield and yield components of maize for different varieties, plant densities, nitrogen levels and their interactions

Source of variation	Degree of freedom	Plant height (m)	Days to 50% silking	Days to maturity	Cob length (cm)	Seed rows/cob	Cob weight (grams)	Grain wt/cob (grams)	100 grains wt (grams)	Dry matter (tons/ha)	Grain yield (tons/ha)	Harvest index (%)
Blocks (reps)	2	0.010892^{ns}	9.812^{ns}	0.05^{ns}	0.2519^{ns}	0.8611^{ns}	2405^{ns}	1290.8^{ns}	23.30^{ns}	0.4379^{ns}	1.5352^{ns}	169.80^{ns}
Main factor (Varieties)	3	0.694888^{***}	3128.414^{***}	4296.43^{***}	67.8539^{***}	0.1019^{ns}	35666.1^{**}	68464.6^{***}	313.07^{**}	22.2914^{**}	34.1808^{***}	2746.46^{**}
Main factor error	6	0.004838	3.748	4.06	0.2755	0.3796	2938.	1894.8	25.392	1.1287	0.6898	224.19
Sub factor (Plant densities)	2	0.198122^{***}	9.771^{ns}	1.19^{ns}	145.9312^{***}	2.5278^{ns}	42783^{***}	25284.3^{***}	107.11^{*}	23.2908^{***}	15.0974^{***}	700.51^{**}
Varieties x Plant densities	6	0.037453^{**}	15.928^{ns}	0.87^{ns}	6.5916^{***}	1.2685^{ns}	$2776.^{ns}$	5807.9^{*}	10.87^{ns}	1.4863^{***}	1.5519^{**}	179.95^{ns}
Sub factor error	16	0.006289	8.514	4.81	0.3214	0.9167	3607.	2088.6	28.912	0.1014	0.3483	73.85
Sub-sub factor (Nitrogen levels)	3	0.288574^{***}	425.637^{***}	818.80^{***}	12.2438^{***}	0.7685^{ns}	5924^{**}	3285.6^{**}	89.47^{***}	9.8014^{***}	5.9196^{***}	481.96^{***}
Varieties x nitrogen levels	9	0.013479^{*}	17.846^{*}	44.04^{**}	0.6529^{*}	1.1883^{ns}	$2547.^{*}$	811.1^{ns}	7.58^{ns}	1.0636^{***}	1.0753^{***}	116.85^{***}
Plant densities x nitrogen levels	6	0.024034^{**}	4.789^{ns}	2.16^{ns}	0.4613^{ns}	2.1574^{**}	$1033.^{ns}$	648.4^{ns}	42.96^{***}	0.0120^{ns}	0.9400^{***}	132.98^{***}
Varieties x plant densities x nitrogen levels	18	0.002987^{ns}	5.490^{ns}	1.35^{ns}	0.8847^{***}	1.2438^{*}	$945.^{ns}$	347.9^{ns}	5.46^{ns}	0.0365^{ns}	0.2387^{**}	30.45^{ns}
Sub-sub factor error	72	0.006073	8.218	14.09	0.2900	0.7037	1221.	606.8	8.122	0.1607	0.1047	18.59
Total	143											

* indicate significant difference at $P \leq 0.05$ ** indicate significant difference at $P \leq 0.01$

*** indicate significant difference at $P \leq 0.001$ ns indicate no significant difference at $P \leq 0.05$

Variety x plant density interaction depicted significant effects on cob length and dry matter ($P \leq 0.001$), plant height and grain yield ($P \leq 0.01$) and grain weight cob^{-1} ($P \leq 0.05$). No significant effect was observed for the rest of the parameters including, days to 50% silking, days to physiological maturity, seed rows cob^{-1}, cob weight, 100 seeds weight and harvest index.

Varieties with N interaction resulted into highly significant ($P \leq 0.001$) difference on dry matter, grain weight and harvest index. For days to maturity, varieties with N interactions were significantly different at $P \leq 0.01$, while for plant height, days to 50% silking, cob length and cob weight, they were significantly different at $P \leq 0.05$. All the other parameters including number of seed rows per cob, grain weight per cob and 100 grain weight were not affected significantly by the variety with N interaction.

Interaction of plant density with N levels was highly significant ($P \leq 0.001$) on 100 seed weight, grain yield and harvest index. Results on plant height and seed showed that plant density with N interaction was significant at $P \leq 0.05$, while the rest of measured parameters were not affected significantly by the density with N interaction.

Interactions of the variety with plant density and N levels showed highly significant ($P \leq 0.001$) variation on cob length. For the grain yield, the interaction was significant at $P \leq 0.01$ and on seed rows cob^{-1} there was significant difference at $P \leq 0.05$. The rest of measured parameters were not significantly affected (Table 3).

4.1.2 Effects of varieties on growth, yield and yield parameters

Results of the mean effect of varieties on growth and yield parameters of maize are presented in Table 4. On average, TMV-1 had significantly tallest plants (1.95 m) while the shortest plants (1.64 m) were recorded from the local variety, JKU. Average days to 50 % silking ranged from 47 – 68.75 days and the period to physiological maturity ranged from 104.7 – 129.6 days. The local variety JKU was significantly earlier in both 50% silking (47.00 days) and maturity (104.7 days) than the rest of the varieties ($P \leq 0.05$). Situka took significantly longer (68.75 days) to reach 50% silking and matured significantly later (129.6 days) than all other varieties. Staha and TMV-1 were intermediate for both 50% silking and physiological maturity.

Mean comparison for cob length, cob weight, grain weight cob^{-1}, 100 seeds weight and harvest index elucidated that Staha was constantly superior over other varieties. Staha produced significantly ($P \leq 0.05$) longest (19.32 cm) and heaviest (240.7 g) cobs. The shortest cobs (16.54 cm) were produced by Situka though they were not significantly different from TMV-1 (16.64 cm). Average of cob weight showed that TMV-1 had the lightest cobs (173.6 g) but it was statistically not different from the other two varieties Situka and JKU. Data for biological yield also indicated that Staha was the best accumulator of dry matter over the growth period (7.849 tons ha^{-1}), but statistically it was similar to the local variety, JKU (7.583 tons ha^{-1}). TMV-1 and Situka produced statistically similar dry matter yields (6.146 and 6.702 tons ha^{-1} respectively) but both were significantly ($P \leq 0.05$) lower than Staha and JKU. With regard to grain weight cob^{-1}, Staha recorded the highest value (181.5 g) but

Table 4: Effects of varieties on growth, yield and yield components of maize grown in the semi-coral area of Pemba

Varieties	Plant height (m)	Days to 50% silking	Days to physiol. maturity	Cob length (cm)	Cob weight (g)	Grain weight/cob (g)	100 grains wt (g)	Dry matter (tons/ha)	Grain yield (tons/ha)	Harvest index (%)
Staha	1.878 c	63.78 c	123.6 c	19.32 c	240.7 b	181.5 b	30.27 c	7.849 b	4.953 c	63.37 c
Situka	1.749 b	68.75 d	129.6 d	16.54 a	174.2 a	102.8 a	24.56 ab	6.702 a	2.930 a	43.03 a
TMV-1	1.957 d	58.72 b	114.1 b	16.64 a	173.6 a	99.1 a	23.67 a	6.146 a	3.163 a	51.70 b
JKU	1.642 a	47.00 a	104.7 a	18.45 b	196.1 a	170.7 b	26.97 b	7.583 b	4.411 b	57.95 bc
Mean	1.806	59.56	118.0	17.74	196.1	138.5	26.37	7.070	3.864	54.01
S.E.D	0.01639	0.456	0.475	0.1237	12.77	10.26	1.188	0.2504	0.1958	3.529
L.S.D	0.041	1.117	1.162	0.303	31.260	25.100	2.906	0.613	0.479	8.636
C.V %	3.9	3.3	1.7	2.9	27.6	31.4	19.1	15.0	21.5	27.7

Means in the same column followed by the same letter(s) are not significantly different at LSD 5% level of probability.

similar to the local variety JKU (170.7 g). TMV-1 produced the least grain weight cob^{-1} (99.10 g). However, it was at par with Situka (102.8 g). TMV-1 and Situka were both significantly ($P \leq 0.05$) different from Staha and JKU in grain weight/cob.

Average 100 seeds weight demonstrated that Staha was the best in grain weight (30.27 g), which was significantly ($P \leq 0.05$) the heaviest of the rest of the varieties. TMV-1 produced lightest grains (23.67 g) but was statistically similar to Situka. Also Staha exhibited significantly ($P \leq 0.05$) greatest grain yield (4.953 tons ha^{-1}) of all the other varieties followed by JKU (4.411 tons ha^{-1}) while significantly lowest grain yield (2.93 tons ha^{-1}) was observed from Situka.

Staha also showed highest harvest index (63.37 %) but statistically similar to the local variety JKU (57.95%). Situka had the lowest harvest index (43.03%) and significantly different from the rest of the varieties (Table 4).

4.1.3 Effects of plant density on growth, yield and yield parameters

Mean response of growth and yield parameters to plant density are shown in Table 5. The tallest plants (1.848 m) were recorded from the highest plant density (66 666 plants ha^{-1}) followed by 1.839 m observed from the medium plant density (53 333 plants ha^{-1}). The lowest plant density (44 444 plants ha^{-1}) had significantly ($P \leq 0.05$) shorter plants (1.732 m) than any other plant density. Significantly largest value of dry matter production (7.597 tons ha^{-1}) was from the highest plant density while the lowest dry matter yield (6.280 tons ha^{-1}) was obtained from the lowest plant density ($P \leq 0.05$). Mean values for cob length, cob weight, grain weight cob^{-1} and 100 seed

Table 5: Effects of plant densities on growth, yield and yield components of maize grown in the semi-coral area of Pemba

Plant densities	Plant height (m)	Cob length (cm)	Cob weight (g)	Grain weight/cob (g)	100 grains weight (g)	Dry matter (tons/ha)	Grain yield (tons/ha)	Harvest index (%)
44 444 plants/ha	1.732 a	19.45 c	230.6 b	164.6 b	27.65 b	6.280 a	3.229 a	50.48 a
53 333 plants/ha	1.839 b	17.80 b	179.5 a	129.9 a	26.73 ab	7.333 b	4.291 b	58.07 b
66 666 plants/ha	1.848 b	15.96 a	178.3 a	121.1 a	24.73 a	7.597 c	4.073 b	53.48 a
Mean	1.806	17.74	196.1	138.5	26.37	7.070	3.864	54.01
S.E.D	0.01619	0.1157	12.26	9.33	1.098	0.0650	0.1205	1.754
L.S.D	0.034	0.245	25.990	19.780	2.327	0.138	0.255	3.719
C.V %	4.4	3.2	30.6	32.9	20.4	4.5	15.3	15.9

Means in the same column followed by the same letter(s) are not significantly different at LSD 5% level of probability.

weight showed that the lowest plant density was constantly better than the others. Significantly ($P \leq 0.05$) longest cobs (19.45 cm) were observed from the lowest plant density. Shortest cobs were from the highest density (Table 5).

Heaviest cobs (230.6 g) were recorded from the lowest plant density but the medium and highest plant densities were statistically similar in cob weight. Further, lowest plant density produced more grain weight cob^{-1} (164.6 g) ($P \leq 0.05$) than the other two densities which were statistically similar. Heaviest grains (27.65 g 100^{-1} seeds) were also recorded from the lowest plant density though not significantly different from the medium plant density (26.73 g 100^{-1} seeds). The highest plant density gave the lightest (smallest) grains (24.73 g 100^{-1} seeds) which was significantly ($P \leq 0.05$) different from the lowest plant density (Table 5).

Medium plant density (53 333 plants ha^{-1}) and the highest plant density (66 666 plants ha^{-1}) had similar grain yield. However, the medium density was found to be the optimum plant population by producing 4.291 tons ha^{-1}, that is, 0.218 tons ha^{-1} more than what was obtained from the highest plant density (4.027 tons ha^{-1}). The lowest grain yield (3.229 tons ha^{-1}) was obtained with the lowest density of 44 444 plants ha^{-1} ($P \leq 0.05$). Also, the lowest and highest densities had statistically similar effects on harvest index and both demonstrated significantly ($P \leq 0.05$) lower values compared to the medium density.

4.1.4 Effects of nitrogen levels on growth, yield and yield parameters

Mean effects of varying levels of nitrogen fertilizer on different evaluated parameters are shown in Table 6. The minimum level of nitrogen applied (23 kg N ha^{-1}) resulted into significantly ($P \leq 0.05$) and consistently lowest values in plant height (1.699 m), days to 50% flowering (55.5), days to maturity (112.7), dry matter yield (6.379 tons ha^{-1}) and grain yield (3.406 tons ha^{-1}). However, this N rate (23 kg N ha^{-1}) was statistically similar to 46 and 90 kg N ha^{-1} on cob weight, grain weight cob^{-1} and 100 seed weight. As regard to cob length, 23 kg N ha^{-1} was statistically similar to 90 kg N ha^{-1} and on harvest index it was statistically similar to 46 kg N ha^{-1}.

Increased level of nitrogen significantly and consistently increased plant height, days to 50% silking, days to maturity and dry matter yield such that 90 kg N ha^{-1} led to significantly ($P \leq 0.05$) tallest plants (1.906 m), latest 50% silking (63.28 days) and maturity (123.6 days) and highest dry matter yield (7.619 tons ha^{-1}). On the contrary, application of 90 kg N ha^{-1} resulted into significantly ($P \leq 0.05$) lowest values in harvest index (50.72%). Also, supply of 90 kg N ha^{-1} produced lowest values in cob weight (186.6 g), grain weight cob^{-1} (129.9 g) and100 seed weight (24.5 g), but the values were not consistently significantly lower.

Like a domino effect, application of 70 kg N ha^{-1} was significantly and consistently better ($P \leq 0.05$) over other N levels for cob length (18.4 cm), cob weight (214.4 g), grain weight cob^{-1} (152.1 g), grain yield (4.386 tons ha^{-1}) and harvest index (59.25%). The 70 kg N ha^{-1} was also better in 100 seeds weight (28.0 g) but was statistically similar to 27.29 g obtained from application of 46 kg N ha^{-1} (Table 6).

Table 6: Effects of nitrogen levels on growth, yield and yield components of maize grown in the semi-coral area of Pemba

Nitrogen levels	Plant height (m)	Days to 50% silking	Days to physiol. maturity	Cob length (cm)	Cob weight (g)	Grain weight/cob (g)	100 grains wt (g)	Dry matter (tons/ha)	Grain yield (tons/ha)	Harvest index (%)
23kgN/ha	1.699 a	55.50 a	112.7 a	17.21 a	187.8 a	134.9 a	25.69 a	6.379 a	3.406 a	52.95 b
46kgN/ha	1.776 b	58.14 b	115.7 b	18.06 b	195.8 a	137.2 a	27.29 b	7.020 b	3.762 b	53.13 b
70kgN/ha	1.845 c	61.33 c	120.0 c	18.40 c	214.4 b	152.1 b	28.00 b	7.261 c	4.386 c	59.25 c
90kgN/ha	1.906 d	63.28 d	123.6 d	17.29 a	186.6 a	129.9 a	24.50 a	7.619 d	3.902 b	50.72 a
Mean	1.806	59.56	118.0	17.74	196.1	138.5	26.37	7.070	3.864	54.01
S.E.D	0.01837	0.676	0.885	0.1269	8.24	5.81	0.672	0.0954	0.0763	1.016
L.S.D	0.036	1.347	1.764	0.253	16.420	11.570	1.339	0.188	0.152	2.026
C.V %	4.3	4.8	3.2	3.0	17.8	17.8	10.8	5.7	8.4	8.0

Means in the same column followed by the same letter(s) are not significantly different at LSD 5% level of probability

4.1.5 Effects of variety and plant density interaction

Table 7 presents interaction effects of variety and plant density on plant height, cob length, grain weight cob^{-1}, dry matter yield and grain yield. The results revealed that at the lowest plant density (44 444 plants ha^{-1}) all varieties, except JKU, were statistically similar in plant height. Compared with other varieties, JKU had shorter plants across all plant densities but not consistently significant. When the plant density was increased to 53 333 plants ha^{-1}, all varieties were significantly different in plant height with TMV-1 being the tallest (2.04 m) and JKU (1.654 m) still significantly the shortest ($P \leq 0.05$). At the highest plant density (66 666 plants ha^{-1}), TMV-1 had significantly tallest plants (2.039 m) but the plant height of JKU (1.619 m) was statistically similar to that of Situka (1.754 m). With regard to individual varieties, the increasing plant density from 44 444 to 66 666 plants ha^{-1} had no effect on plant height in Staha and Situka. However, there was a significant increase ($P \leq 0.05$) in plant height observed in TMV-1 between 44 444 plants ha^{-1} and the rest of the densities. Also, a significant difference in plant height existed in JKU between 44 444 plants ha^{-1} and 66 666 plants ha^{-1}.

Across different varieties and different plant densities, the interaction of Staha with 44 444 plants ha^{-1} was statistically similar to the interaction of Situka at all the three densities in plant height. The interaction of JKU with 66 666 plants ha^{-1}, the interaction of TMV-1 with 44 444 plants ha^{-1} and the interaction of Situka with all the three densities had similar effect on plant height. Also the plant height of JKU at 53 333 plants ha^{-1} was statistically similar to that of Situka at 44 444 and 66 666 plants ha^{-1} (Table 7).

Table 7: Interaction effects of varieties and plant density on growth parameters, yield and yield components

Variety x plant density	Plant height (m)	Cob length (cm)	Grain wt/cob (g)	Dry matter (tons/ha)	Grain yield (tons/ha)
Staha x 44 444 plants ha^{-1}	1.832 def	21.89 f	232.1 e	7.268 c	4.727 d
Staha x 53 333 plants ha^{-1}	1.893 ef	18.71 d	168.4 d	7.994 d	5.316 e
Staha x 66 666 plants ha^{-1}	1.909 f	17.37 c	143.9 cd	8.284 d	4.815 de
Situka x 44 444 plants ha^{-1}	1.726 bcd	18.33 d	112.2 abc	5.673 a	1.958 a
Situka x 53 333 plants ha^{-1}	1.768 cd	17.17 c	98.2 a	7.069 c	3.462 c
Situka x 66 666 plants ha^{-1}	1.754 bcd	14.13 a	98.2 a	7.363 c	3.406 c
TMV-1 x 44 444 plants ha^{-1}	1.791 cde	17.47 c	101.1 ab	5.813 ab	2.801 b
TMV-1 x 53 333 plants ha^{-1}	2.040 g	17.06 c	94.8 a	6.238 ab	3.420 c
TMV-1 x 66 666 plants ha^{-1}	2.039 g	15.39 b	101.5 ab	6.388 b	3.268 bc
JKU x 44 444 plants ha^{-1}	1.582 a	20.11 e	212.9 e	6.368 b	3.429 c
JKU x 53 333 plants ha^{-1}	1.654 ab	18.27 d	158.4 d	8.030 d	5.001 de
JKU x 66 666 plants ha^{-1}	1.691 bc	16.97 c	140.9 bcd	8.351 d	4.802 de
Mean	1.806	17.74	138.5	7.070	3.864
F. prob.	0.002	<.001	0.048	<.001	0.008
S.E.D	0.03111	0.2259	18.37	0.2720	0.2725
C.V %	4.3	3.1	32.5	9.4	17.6

Means in the same column followed by the same letter(s) are not significantiy different at Tukey's 5% level of probability.

Mean value for the dry matter yield showed that interaction of the local variety, JKU, with 66 666 plants ha^{-1} gave the greatest yield (8.351 tons ha^{-1}) but not consistently significant. This value was statistically similar to values obtained from the interactions of JKU with 53 333 plants ha^{-1} (8.030 tons ha^{-1}), Staha with 53 333 plants ha^{-1} (7.994 tons ha^{-1}) and 66 666 plants ha^{-1} (8.284 tons ha^{-1}). Interaction of Situka with 44 444 plants ha^{-1} led to the lowest quantity of dry matter yield (5.673 tons ha^{-1}) but it was at par with the interaction of TMV-1 with 53 333 plants ha^{-1} (5.813 tons ha^{-1}) and 66 666 plants ha^{-1} (6.238 tons ha^{-1}). Significantly lowest dry matter yield (5.637 tons ha^{-1}) was obtained from interaction of Situka with 44 444 plants ha^{-1}, though was not consistently lower.

Staha with 44 444 plants ha^{-1} produced longest cobs (21.89 cm) than the rest of the interactions ($P \leq 0.05$). However, at the medium density (53 333 plants ha^{-1}), Staha and JKU had statistically similar effect on cob length (18.71 cm and 17.38 cm, respectively). Also, similar effect on cob length was observed between Staha (18.27 cm) and JKU (16.97 cm) at the highest density (66 666 plants ha^{-1}). On the other hand, significantly ($P \leq 0.05$) shortest cobs (14.13 cm) were obtained from interaction of Situka with 66 666 plants ha^{-1}. At the medium plant density, however, cob length of Situka (17.17 cm) was comparable to the cob length of TMV-1 (17.06 cm). Further, at lowest plant density, cob length of Situka (18.33 cm) significantly ($p \leq 0.05$) surpassed that of TMV-1 (17.47 cm).

Interaction of Staha with 44 444 plants ha^{-1} gave the largest grain weight cob^{-1} (232.1 g), but this value was statistically similar to 212.9 g recorded from the local variety, JKU at the same plant density. Also, Staha and JKU were statistically similar for the grain weight cob^{-1} across all the three plant densities. The smallest value of grain weight cob^{-1} (94.8 g) was observed with TMV-1 at 53 333 plants ha^{-1}. At the lowest plant density (44 444 plants ha^{-1}) however, TMV-1 was statistically similar to Situka but at the highest density (66 666 plants ha^{-1}) TMV-1 had greater grain weight cob^{-1} than Situka, though not significantly different.

Highest grain yield (5.316 tons ha^{-1}) was observed from the interaction effects of Staha with 53 333 plants ha^{-1}. This value was comparable with the interactions of Staha with 66 666 plants ha^{-1} (4.815 tons ha^{-1}) and JKU with both 53 333 plants ha^{-1} (5.001 tons ha^{-1}) and 66 666 plants ha^{-1} (4.802 tons ha^{-1}). Interaction of Situka with 44 444 plants ha^{-1} was significantly ($P \leq 0.05$) the poorest grain yielder (1.958 tons ha^{-1}). However, at the medium and the highest plant density Situka and TMV-1 had similar effects on grain yield (Table 7).

4.1.6 Effects of variety and nitrogen interaction

All evaluated parameters except seed rows cob^{-1}, 100 seeds weight and grain weight cob^{-1} were significantly affected by the interaction of varieties with nitrogen levels (Table 8). Interaction effect on plant height was such that 90 kg N ha^{-1} led to consistently significantly ($P \leq 0.05$) tallest plants (2.13 m) in TMV-1. However, at 23, 46 and 70 kg N ha^{-1}, the plant heights in TMV-1 were statistically similar to those of Staha in the respective N levels. Interaction of JKU with the lowest N level (23 kg N ha^{-1}) had significantly ($P \leq 0.05$) shortest plants (1.568 m), but not consistently significant.

Table 8: Interaction effects of varieties and nitrogen levels on growth parameters, yield and yield components

Variety x nitrogen levels	Plant height (m)	Days to 50% silking	Days to maturity	Cob length (cm)	Cob weight (g)	Dry matter (tons/ha)	Grain yield (tons/ha)	Harvest index (%)
Staha x 23 kg N ha^{-1}	1.761 cdef	60.00 de	119.6 de	18.42 ef	228.2 bcd	6.464 bcd	3.966 cd	61.44 f
Staha x 46 kg N ha^{-1}	1.864 fghi	63.33 efgh	121.8 def	19.69 gh	267.2 d	7.966 ghi	4.806 e	60.90 f
Staha x 70 kg N ha^{-1}	1.931 hi	64.67 efghi	125.7 fg	20.40 h	254.8 cd	8.267 hi	6.063 f	73.37 g
Staha x 90 kg N ha^{-1}	1.957 i	67.11 ghi	127.4 fg	18.79 ef	212.4 abcd	8.698 i	4.976 e	57.74 ef
Situka x 23 kg N ha^{-1}	1.636 abc	65.00 fghi	123.9 efg	16.25 ab	148.5 a	6.253 abc	2.614 a	42.38 abc
Situka x 46 kg N ha^{-1}	1.748 cdef	67.89 hi	125.7 fg	16.68 abc	171.2 ab	6.647 bcde	2.772 a	41.10 ab
Situka x 70 kg N ha^{-1}	1.794 defg	68.56 i	129.4 g	17.11 bc	193.6 abc	6.871 def	3.489 bc	49.76 bcde
Situka x 90 kg N ha^{-1}	1.819 defgh	73.56 j	139.3 h	16.12 a	183.6 ab	7.236 efg	2.846 ab	38.90 a
TMV-1 x 23 kg N ha^{-1}	1.830 efghi	54.00 bc	107.0 bc	16.13 a	170.0 ab	5.650 a	3.068 ab	54.26 def
TMV-1 x 46 kg N ha^{-1}	1.911 ghi	56.89 cd	111.8 c	17.27 cd	164.3 ab	5.938 ab	3.174 ab	53.40 def
TMV-1 x 70 kg N ha^{-1}	1.955 i	60.89 def	118.0 d	17.06 bc	200.9 abcd	6.251 abcd	3.282 abc	52.58 cdef
TMV-1 x 90 kg N ha^{-1}	2.130 j	63.11 efg	119.6 de	16.10 a	159.0 a	6.747 cde	3.128 ab	46.54 abcd
JKU x 23 kg N ha^{-1}	1.568 a	43.00 a	100.4 a	18.02 de	204.3 abcd	7.350 efg	3.977 cd	53.73 def
JKU x 46 kg N ha^{-1}	1.580 ab	44.44 a	103.6 ab	18.59 ef	180.6 ab	7.530 fgh	4.299 de	57.12 def
JKU x 70 kg N ha^{-1}	1.701 bcd	51.22 b	106.8 bc	19.03 fg	208.2 abcd	7.656 gh	4.709 e	61.27 f
JKU x 90 kg N ha^{-1}	1.720 cde	49.33 b	108.0 bc	18.17 ef	191.4 abc	7.794 gh	4.659 de	59.68 ef
Mean	1.806	59.56	118.0	17.74	196.1	7.070	3.864	54.01
F prob.	0.030	0.034	0.003	0.028	0.042	<.001	<.001	<.001
S.E.D	0.03579	1.256	1.604	0.2523	19.15	0.2991	0.2362	3.944
C.V %	4.2	4.5	2.9	3.0	20.7	9.8	12.9	15.5

Means in the same column followed by the same letter(s) are not significantly different at Tukey's 5% level of probability

As shown in Table 8, increased nitrogen level consistently increased the periods to 50% silking and physiological maturity across the varieties. Significantly fewer days to flowering (43.0 days) were observed with local variety (JKU) at the lowest N level (23 kg N ha^{-1}). At all N levels, JKU significantly maintained its flowering earliness. Similarly, local variety JKU applied with 23 kg N ha^{-1} led to earliest maturity (100.4 days) significantly ($P \leq 0.05$) earlier over all interaction levels except for its own interaction with 46 kg N ha^{-1}. Also the local variety was at all N levels earlier in maturity, though not consistently significantly different from other varieties.

Interaction of Situka with 90 kg N ha^{-1} led to latest flowering (73.56 days). This period was significantly ($P \leq 0.05$) later than any other interaction level. In addition, at all N levels, Situka was the latest in flowering though not consistently significant. On the other side, significantly ($P \leq 0.05$) latest maturity (139.3 days) was recorded when Situka was applied with 90 kg N ha^{-1}.

Another effect of varieties with N interaction was on silking to maturity intervals. Table 9 presents results on how SMI was influenced by varieties with N interactions. Supply of 23 and 46 kg N ha^{-1} decreased the SMI of all the four varieties except in JKU with 23 kg N ha^{-1}. On the other hand, 70 and 90 kg N ha^{-1} increased the SMI in all the four varieties except in JKU with 70 kg N ha^{-1} at which, it was reduced by 2.1 days. At 90 Kg N ha^{-1} the SMI of Situka was increased by 4.9 days from its average SMI. This was the highest increase in SMI than those in the other interactions. At 23 kg N ha^{-1}, SMI of TMV-1 was 2.4 days shorter than its average SMI. Also, this was the maximum decrease in SMI compared with all the other interactions.

Table 9: **Silking to maturity interval (SMI) as influenced by the interaction of varieties with nitrogen levels**

Interaction effects of variety with N levels				Effects of variety only				Change in 50% silking	Change in maturity	Change in SMI
Interactions	50%	Maturity	SMI	Variety	50%	Maturity	SMI			
Staha x 23 kg N ha^{-1}	60.0	119.6	59.6	Staha	63.8	123.6	59.8	-3.8	-4.0	-0.2
Staha x 46 kg N ha^{-1}	63.3	121.8	58.5	Staha	63.8	123.6	59.8	-0.5	-1.8	-1.3
Staha x 70 kg N ha^{-1}	64.7	125.7	61.0	Staha	63.8	123.6	59.8	+0.9	+2.1	+1.2
Staha x 90 kg N ha^{-1}	67.1	127.4	60.3	Staha	63.8	123.6	59.8	+3.3	+3.8	+0.5
Situka x 23 kg N ha^{-1}	65.0	123.9	58.9	Situka	68.8	129.6	60.9	-3.8	-5.7	-1.9
Situka x 46 kg N ha^{-1}	67.9	125.7	57.8	Situka	68.8	129.6	60.9	-0.9	-3.9	-3.0
Situka x 70 kg N ha^{-1}	68.6	129.4	60.8	Situka	68.8	129.6	60.9	-0.2	-0.2	+0.0
Situka x 90 kg N ha^{-1}	73.6	139.3	65.7	Situka	68.8	129.6	60.9	4.8	+9.7	+4.9
TMV-1 x 23 kg N ha^{-1}	54.0	107.0	53.0	TMV-1	58.7	114.1	55.4	-4.7	-7.1	-2.4
TMV-1 x 46 kg N ha^{-1}	56.9	111.8	54.9	TMV-1	58.7	114.1	55.4	-1.8	-2.3	-0.5
TMV-1 x 70 kg N ha^{-1}	60.9	118.0	57.1	TMV-1	58.7	114.1	55.4	+2.2	+3.9	+1.7
TMV-1 x 90 kg N ha^{-1}	63.1	119.6	56.5	TMV-1	58.7	114.1	55.4	+4.4	+5.5	+1.1
JKU x 23 kg N ha^{-1}	43.0	100.4	57.4	JKU	47.0	104.7	57.7	-4.0	-4.3	-0.3
JKU x 46 kg N ha^{-1}	44.4	103.6	59.2	JKU	47.0	104.7	57.7	-2.6	-1.1	+1.5
JKU x 70 kg N ha^{-1}	51.2	106.8	55.6	JKU	47.0	104.7	57.7	+4.2	+2.1	-2.1
JKU x 90 kg N ha^{-1}	49.3	108.0	58.7	JKU	47.0	104.7	57.7	+2.3	+3.3	+1.0

\+ indicates late 50% silking, late maturity, prolonged SMI by the indicated number of days compared with average of variety

\- indicates early 50% silking, early maturity, shortened SMI by the indicated number of days compared with average of variety

At the three N levels (46, 70 and 90 kg N ha^{-1}), Staha variety exhibited statistically similar yields of dry matter (8.00, 8.27 and 8.70 tons ha^{-1} respectively). There was no any other variety to compete with Staha for dry matter yield at the highest N level (90 kg N ha^{-1}) ($P \leq 0.05$). However, at the lowest N level (23 kg N ha^{-1}), Staha was statistically similar to Situka in dry matter yield and at the medium levels (46 kg and 70 kg N ha^{-1}) Staha was statistically similar to the local variety, JKU. TMV-1 at 23 kg N ha^{-1} produced the lowest yield of dry matter (5.65 tons ha^{-1}), which was statistically poorest ($P \leq 0.05$) compared with Staha and JKU but similar to Situka.

Staha with 70 kg N ha^{-1} produced significantly ($P \leq 0.05$) longest cobs (20.4 cm). At this N level, Staha was statistically similar only to its own interaction with 46 kg N ha^{-1} (19.69 cm) but not to any other variety at any other N level. At 46 kg N ha^{-1}, Staha was still superior over other varieties in cob length but at the lowest and highest N levels (23 and 90 kg N ha^{-1}) it was statistically similar to the local variety, JKU. The shortest cobs (16.1 cm) were recorded with TMV-1 at the highest N level (90 kg N ha^{-1}) but were statistically similar to cobs recorded from interactions of Situka at all N levels except at 70 kg N ha^{-1} (Table 8).

Staha interaction with 70 kg N ha^{-1} gave the best grain yield (6.06 tons ha^{-1}), which was significantly different ($P \leq 0.05$) from all the other interactions of varieties with N levels. At the rest of N levels, Staha was statistically similar to local variety, JKU in grain yield. The lowest grain yield (2.64 tons ha^{-1}) was harvested from the interaction of Situka with 23 kg N ha^{-1} but was statistically similar to TMV-1 at all N levels. Maximum and significantly ($P \leq 0.05$) higher value of harvest index, 73.37 %, was recorded from Staha at 70 kg N ha^{-1}. However, at any N level below or above 70 kg N ha^{-1}, Staha was no longer superior in harvest index. For example, at the two lower levels of N (23 and 46 kg ha^{-1}) the harvest indices of Staha (61.44% and 60.90%) were higher in value but statistically similar to those of TMV-1(54.26% and 53.40%) and JKU (53.73% and 57.12%). At 90 kg N ha^{-1} the harvest index of Staha (57.74%) became lower than that of local variety, JKU (59.68%), though not significantly different. Interaction of Situka with 90 kg N ha^{-1} resulted into minimum harvest index (38.9 %) but not consistently significant (Table 8).

4.1.7 Effects of plant density and nitrogen interaction

Means of the effect of interaction between plant density and nitrogen (Table 10) revealed that, the highest plant density (66 666 plants ha^{-1}) and the highest N level (90 kg N ha^{-1}) led to tallest (1.967 m) plants. This value was significantly ($P \leq 0.05$) higher than all the other interactions except the interactions of 53 333 plants ha^{-1} with 70 kg N ha^{-1} and 90 kg N ha^{-1}. Interaction of lowest plant density (44 444 plants ha^{-1}) with the lowest N level (23 kg N ha^{-1}) had significantly ($P \leq 0.05$) shorter (1.598 m) plants than any of the other density with N interactions. In addition, at 46 kg N ha^{-1} all three plant densities had statistically similar effect on plant height.

Interaction of the lowest plant density (44 444 plants ha^{-1}) with 46 kg N ha^{-1} favoured the highest number of seed rows cob^{-1} (14.17). However, this value was significantly different ($P \leq 0.05$) only when compared with the interaction of 66 666 plants ha^{-1} with 46 kg N ha^{-1} (13.00) and the interaction of 53 333 plants ha^{-1} with 90 kg N ha^{-1} (12.83) which was also the least of all other interactions.

Table 10: **Interaction effects of plant density and nitrogen levels on growth parameters, yield and yield components**

Plant density x nitrogen levels	Plant height (m)	Seed rows/cob	100 grains wt (g)	Grain yield (tons/ha)	Harvest index (HI). (%)
44 444 plants ha^{-1} x 23 kg N ha^{-1}	1.598 a	14.00 bc	26.00 b	2.735 a	48.32 ab
44 444 plants ha^{-1} x 46 kg N ha^{-1}	1.737 b	14.17 c	28.23 b	3.121 ab	49.17 ab
44 444 plants ha^{-1} x 70 kg N ha^{-1}	1.751 bc	13.67 abc	29.24 b	3.652 bcd	55.17 bc
44 444 plants ha^{-1} x 90 kg N ha^{-1}	1.844 cd	13.83 abc	27.13 b	3.409 bc	49.27 ab
53 333 plants ha^{-1} x 23 kg N ha^{-1}	1.714 b	13.67 abc	25.41 b	3.764 cd	56.59 bc
53 333 plants ha^{-1} x 46 kg N ha^{-1}	1.794 bc	14.00 bc	27.17 b	4.111 de	56.22 bc
53 333 plants ha^{-1} x 70 kg N ha^{-1}	1.939 de	13.50 abc	27.63 b	4.643 ef	61.19 c
53 333 plants ha^{-1} x 90 kg N ha^{-1}	1.909 de	12.83 a	26.70 b	4.645 ef	58.28 c
66 666 plants ha^{-1} x 23 kg N ha^{-1}	1.784 bc	13.67 abc	25.67 b	3.721 cd	53.95 bc
66 666 plants ha^{-1} x 46 kg N ha^{-1}	1.796 bc	13.00 ab	26.46 b	4.056 d	54.00 bc
66 666 plants ha^{-1} x 70 kg N ha^{-1}	1.846 cd	13.83 abc	27.11 b	4.862 f	61.38 c
66 666 plants ha^{-1} x 90 kg N ha^{-1}	1.967 e	13.67 abc	19.67 a	3.653 bcd	44.60 a
Mean	1.806	13.65	26.37	3.864	54.01
F prob.	0.002	0.010	<.001	<.001	<.001
S.E.D	0.03196	0.3552	1.490	0.1661	2.324
C.V %	4.3	6.4	13.8	10.5	10.5

Means in the same column followed by the same letter(s) are not significantly different at Tukey's 5% level of probability

The least value however, was significantly ($P \leq 0.05$) lower compared with the interaction of 44 444 plants ha^{-1} with both 23 and 46 kg N ha^{-1} and the interaction of 53 333 plants ha^{-1} with 46 kg N ha^{-1} only and not other interactions.

Interaction effect of 66 666 plants ha^{-1} with 90 kg N ha^{-1} led to significantly ($P \leq 0.05$) lightest seeds (19.67 g 100^{-1} seeds). With the exception of this value, all the rest of density with N interactions were statistically similar in 100 seeds weight, but the interaction of 44 444 plants ha^{-1} with 70 kg N ha^{-1} (29.24 g 100^{-1} seeds) was better over others.

Greatest grain yield (4.86 tons ha^{-1}) was recorded from the interaction of the highest plant density (66 666 plants ha^{-1}) with 70 kg N ha^{-1}. This value was statistically similar to the yields recorded from the interaction of 53 333 plants ha^{-1} with both 70 and 90 kg N ha^{-1} but not comparable to any other density with N interaction. In all the three plant densities, the rate of 70 kg N ha^{-1} had better interaction for the grain yield but not consistently significant. Significantly lowest grain yield (2.735 tons ha^{-1}) was recorded from the lowest density (44 444 plants ha^{-1}) at the lowest N rate (23 kg N ha^{-1}). This value was significantly ($P \leq 0.05$) different from all the rest of density with N interactions except the interaction of 44 444 plants ha^{-1} with 46 kg N ha^{-1}.

The highest value of harvest index (61.38%) was recorded from the interaction of 66 666 plants ha^{-1} with 70 kg N ha^{-1}. The 70 kg N ha^{-1} was consistently better for harvest index in all the three plant densities but not consistently significantly different. On the other hand, the smallest harvest index (44.6%) was observed from the interaction of the highest plant density with the highest N level. However, this value was statistically similar to the harvest indices observed from interactions of 44 444 plants ha^{-1} with 23, 46 and 90 kg N ha^{-1} (Table 10).

4.1.8 Effects of varieties, plant densities and nitrogen interaction

It was found from the analysis of variance (Table 3) that interaction of varieties, plant densities and nitrogen levels was significant only in cob length, seed rows cob^{-1} and the grain yield. The mean effects of variety with density and N interaction on these three parameters are presented in Table 11. The effect on cob length was such that Staha in the lowest plant density (44 444 plants ha^{-1}) interacted better with all four N levels for the cob length. Interaction of Staha with 44 444 plants ha^{-1} and 46 kg N ha^{-1} produced the longest cobs (23 cm) followed by statistically similar lengths recorded from interactions of Staha with 44 444 plants ha^{-1} and 70 kg N ha^{-1} (22.81 cm) and Staha with 44 444 plants ha^{-1} and 90 kg N ha^{-1} (21.24 cm). At medium plant density (53 333 plants ha^{-1}) and same N level (46 kg N ha^{-1}), all the four varieties produced moderate and statistically similar cob lengths (Staha 18.63 cm, Situka 17.38 cm, TMV- 17.41 cm and JKU 18.53 cm). The shortest cobs (13.75 cm) were observed from the interaction of Situka with highest plant density and the lowest N level but were not consistently significantly shorter. Regardless of the N level, at the highest plant density two varieties; Situka and TMV-1 produced shorter, statistically similar cobs. Interactions of Staha with 53 333 plants ha^{-1} and JKU with 44 444 plants ha^{-1} both at 46 kg N ha^{-1}, and also the interaction of JKU with 53 333 plants ha^{-1} and TMV-1 with 66 666 plants ha^{-1} both at 70 kg N ha^{-1} resulted into largest

Table 11: Interaction effects of varieties, plant density and nitrogen levels on cob length, seed rows/cob and grain yield

Variety x plant density x nitrogen rate	Cob length (cm)	Seed rows/cob	Grain yield (t/ha)
Staha x 44 444 pl/ha x 23 kgN/ha	20.53 pq	14.0 bc	3.735 defghijklm
Staha x 44 444 pl/ha x 46 kgN/ha	23.00 r	14.0 bc	4.539 hijklmn
Staha x 44 444 pl/ha x 70 kgN/ha	22.81 r	13.3 abc	5.586 nopq
Staha x 44 444 pl/ha x 90 kgN/ha	21.24 qr	13.3 abc	5.050 mnopq
Staha x 53 333 pl/ha x 23 kgN/ha	17.50 efghijkl	14.0 bc	4.088 fghijklm
Staha x 53 333 pl/ha x 46 kgN/ha	18.63 klmno	14.7 c	4.946 mnop
Staha x 53 333 pl/ha x 70 kgN/ha	20.00 nopq	12.7 ab	6.189 pq
Staha x 53 333 pl/ha x 90 kgN/ha	18.69 klmno	13.3 abc	6.042 opq
Staha x 66 666 pl/ha x 23 kgN/ha	17.23 efghijkl	14.0 bc	4.077 fghijklm
Staha x 66 666 pl/ha x 46 kgN/ha	17.43 efghijkl	14.0 bc	4.933 mnop
Staha x 66 666 pl/ha x 70 kgN/ha	18.37 jklmn	13.3 abc	6.415 q
Staha x 66 666 pl/ha x 90 kgN/ha	16.43 cdefgh	13.3 abc	3.836 efghijklm
Situka x 44 444 pl/ha x 23 kgN/ha	17.99 hijklm	14.0 bc	1.697 a
Situka x 44 444 pl/ha x 46 kgN/ha	18.39 jklmn	14.0 bc	1.839 ab
Situka x 44 444 pl/ha x 70 kgN/ha	19.00 lmnop	14.0 bc	2.329 abcd
Situka x 44 444 pl/ha x 90 kgN/ha	17.93 ghijklm	14.0 bc	1.968 abc
Situka x 53 333 pl/ha x 23 kgN/ha	17.02 efghijk	14.0 bc	2.998 abcdefg
Situka x 53 333 pl/ha x 46 kgN/ha	17.38 efghijkl	14.0 bc	3.224 bcdefghi
Situka x 53 333 pl/ha x 70 kgN/ha	17.63 efghijklm	12.7 ab	4.093 fghijklm
Situka x 53 333 pl/ha x 90 kgN/ha	16.65 defghij	14.0 bc	3.390 cdefghijk
Situka x 66 666 pl/ha x 23 kgN/ha	13.75 a	12.7 ab	3.146 bcdefgh
Situka x 66 666 pl/ha x 46 kgN/ha	14.28 ab	12.7 ab	3.252 bcdefghi
Situka x 66 666 pl/ha x 70 kgN/ha	14.72 abc	14.0 bc	4.046 fghijklm
Situka x 66 666 pl/ha x 90 kgN/ha	13.77 a	13.3abc	3.181 bcdefgh
TMV-1 x 44 444 pl/ha x 23 kgN/ha	17.36 efghijkl	14.0 bc	2.600abcde
TMV-1 x 44 444 pl/ha x 46 kgN/ha	18.34 ijklmn	14.0 bc	2.765 abcdef

Table 11: continued

Variety x plant density x nitrogen rate	Cob length (cm)	Seed rows/cob	Grain yield (t/ha)
TMV-1 x 44 444 pl/ha x 70 kgN/ha	18.29 ijklmn	13.3 abc	2.929 abcdef
TMV-1 x 44 444 pl/ha x 90 kgN/ha	15.88 bcdef	14.0 bc	2.910 abcdef
TMV-1 x 53 333 pl/ha x 23 kgN/ha	16.15 cdefg	13.3 abc	3.344 cdefghij
TMV-1 x 53 333 pl/ha x 46 kgN/ha	17.41 efghijkl	14.0 bc	3.424 defghijkl
TMV-1 x 53 333 pl/ha x 70 kgN/ha	17.08 efghijk	14.0 bc	3.481 defghijkl
TMV-1 x 53 333 pl/ha x 90 kgN/ha	17.62 efghijklm	12.0 a	3.430 defghijkl
TMV-1 x 66 666 pl/ha x 23 kgN/ha	14.89 abcd	14.0 bc	3.261 bcdefghi
TMV-1 x 66 666 pl/ha x 46 kgN/ha	16.05 bcdef	13.3 abc	3.332 cdefghij
TMV-1 x 66 666 pl/ha x 70 kgN/ha	15.82 bcde	14.7 c	3.435 defghijkl
TMV-1 x 66 666 pl/ha x 90 kgN/ha	14.80 abc	14.0 bc	3.044 abcdefg
JKU x 44 444 pl/ha x 23 kgN/ha	19.41 mnopq	14.0 bc	2.906 abcdef
JKU x 44 444 pl/ha x 46 kgN/ha	19.99 nopq	14.7 c	3.339 cdefghij
JKU x 44 444 pl/ha x 70 kgN/ha	20.60 pq	14.0 bc	3.764 defghijklm
JKU x 44 444 pl/ha x 90 kgN/ha	20.43 opq	14.0 bc	3.709 defghijklm
JKU x 53 333 pl/ha x 23 kgN/ha	18.12 hijklm	13.3 abc	4.628 ijklmno
JKU x 53 333 pl/ha x 46 kgN/ha	18.53 klmn	13.3 abc	4.849 lmnop
JKU x 53 333 pl/ha x 70 kgN/ha	18.80 klmnop	14.7 c	4.811 klmnop
JKU x 53 333 pl/ha x 90 kgN/ha	17.64 fghijklm	12.0 a	5.718 nopq
JKU x 66 666 pl/ha x 23 kgN/ha	16.52 cdefghi	14.0 bc	4.398 ghijklmn
JKU x 66 666 pl/ha x 46 kgN/ha	17.24 efghijkl	12.0 a	4.708 jklmno
JKU x 66 666 pl/ha x 70 kgN/ha	17.68 fghijklm	13.3 abc	5.551 nopq
JKU x 66 666 pl/ha x 90 kgN/ha	16.44 cdefgh	14.0 bc	4.551 hijklmn
Mean	17.74	13.6	3.864
F. prob.	<.001	0.047	0.007
S.E.D	0.4427	0.6925	0.3597
C.V %	3.1	6.2	11.4

Means in the same column followed by the same letter(s) are not significantly different at Tukey's 5% level of probability

number of seed rows cob^{-1} (14.7) but not consistently significant. On the other hand, interaction of JKU with 53 333 plants ha^{-1} and 90 kg N ha^{-1} and the interaction of JKU with 66 666 plants ha^{-1} and 46 kg N ha^{-1} gave least number of seed rows cob^{-1} though not consistently less.

The highest grain yield (6.42 tons ha^{-1}) was observed from Staha at the highest plant density with 70 kg N ha^{-1}. At this N level, Staha was significantly better for the grain yield than all other varieties except the local variety, JKU. Lowest grain yield (1.70 tons ha^{-1}) was harvested from Situka in the lowest plant density (44 444 plants ha^{-1}) and the lowest N level (23 kg N ha^{-1}). Interaction of Situka with 44 444 plants ha^{-1} led to constantly poor grain yield regardless of the N level. When the plant density was increased to 53 333 plants ha^{-1} and the nitrogen level remaining the same (23 kg N ha^{-1}), grain yield of Situka and Staha were statistically similar. Also, at the highest plant density (66 666 plants ha^{-1}) and the highest N level (90 kg N ha^{-1}), Staha and Situka had statistically similar effects on grain yield (Table 11).

4.1.9 Correlations among yield parameters

Results of the current study showed that correlation between grain yield and cob weight, days to maturity and plant height was not significant. Number of seed rows cob^{-1} and days to 50% silking were significantly and negatively correlated with grain yield ($P \leq 0.05$). Dry matter, cob length, grain weight cob^{-1}, 100 seed weight and harvest index had highly significant ($P \leq 0.001$) and positive correlation with grain yield. Correlations between other parameters were variably significant and insignificant as indicated in Table12.

Table 12: Correlations among yield parameters of maize grown in the semi-coral area of Pemba

	Grain yield	Harvest index	100 seed wt	Grain wt/cob	Cob wt	Cob length	Seed rows/cob	Days to maturity	Days to 50%	Plant height	Dry matter
Grain yield	-										
Harvest index	0.8704^{***}	-									
100 seed wt	0.3831^{***}	0.4063^{***}	-								
Grain wt/cob	0.3633^{***}	0.3931^{***}	0.6294^{***}	-							
Cob	0.1381^{ns}	0.1971^{*}	0.5828^{***}	0.8562^{***}	-						
Cob length	0.2954^{***}	0.3780^{***}	0.5737^{***}	0.6978^{***}	0.5875^{***}	-					
Seed rows/cob	-0.2103^{*}	-0.1588^{ns}	-0.0069^{ns}	0.0093^{ns}	0.0405^{ns}	0.0754^{ns}	-				
Days to maturity	-0.1144^{ns}	-0.2533^{**}	0.0011^{ns}	-0.1747^{*}	0.0828^{ns}	-0.1026^{ns}	-0.0500^{ns}	-			
Days to 50%	-0.1858^{*}	-0.2722^{***}	-0.0291^{ns}	-0.2374^{**}	0.0523^{ns}	-0.1269^{ns}	-0.0047^{ns}	0.8956^{***}	-		
Plant height	0.0943^{ns}	0.0701^{ns}	-0.1092^{ns}	-0.2338^{**}	-0.0667^{ns}	-0.1839^{*}	-0.0339^{ns}	0.3311^{***}	0.4045^{***}	-	
Dry matter	0.7574^{***}	0.3557^{***}	0.1660^{*}	0.1788^{*}	0.0003^{ns}	0.0223^{ns}	-0.1857^{*}	0.0835^{ns}	-0.0254^{ns}	0.1058^{ns}	-

*** = significant at $P \leq 0.001$, ** = significant at, $P \leq 0.01$, * = significant at $P \leq 0.05$, ns = not significant

4.2 Discussion

4.2.1 Environmental influence

4.2.1.1 Rainfall

Rainfall varied greatly across the growing period (Table 1). Data recorded portrayed that much rainfall was received within the months of April (325 mm) and May (384 mm). Earlier in March and later in June, there were moderate amounts and beyond June the condition was completely dry till the end of the cropping season. Total amount of rainfall for the eight months period (January to August) was 968.1 mm; out of which 881 mm was received within the four months of the crop growing period of the current study (April to July).

The total water requirement over the growing period of maize depends on cultivar. Location and season influence evaporation rate and hence the water requirements. In most reports the optimum rainfall for best performance of maize crop ranges from 500 mm to 900 mm per annum (Critchley and Siegert, 1991; Belfield and Brown, 2008; Tekwa and Bwade, 2011). This should be well distributed to match the daily requirements of 2.70 mm at the early crop growth stages to 6.00 mm at mid-season and declining to 3.30 mm at the end of the season (Igbadun, 2012). Despite the total amount for the four months period (881mm) being good for crop production, the rainfall distribution was better only in April but poorly distributed during May. The whole amount of rainfall collected in May was received only within the first week and the following three weeks were completely with no rains. Also, the rainfall data (Table 1) showed that the last week of June and the whole of July received no rainfall. For early maturing varieties, like JKU, the rainfall distribution was highly favourable throughout the growth stages while for late maturing varieties such as Situka, the vegetative stage received enough rainfall but moisture stress was encountered during grain filling. In general, this condition favoured only some stages of crop growth and handicapped others. As reported by Cakir (2004) and Huang *et al.* (2006), such trend might have negatively impacted upon biomass accumulation and grain filling and consequently reduced the grain yield in the late maturing variety (Situka).

4.2.1.2 Soil characteristics

Soil texture

According to Tripathi *et al.* (2011), soil texture is a foremost requirement as it controls moisture and nutrient capacity of the soil. Texture of the soil affects plant growth by influencing soil aeration, root penetration, water holding capacity and nutrient availability in the soil. The texture determines the root growth and root mass and hence, the extent to which plants are able to scavenge for water and nutrients (Wakeel *et al.*, 2005). Since it influences the field capacity, soil texture is more important in rain fed and free-draining areas where water runoff cannot be controlled. Soil texture of the experimental site (Table 2) was sandy clay loam. According to Tripathi *et al.* (2011), such texture is suitable for production of most crops including maize.

Soil pH

Nutrients deficiency and mineral toxicity are two undesirable effects for crop production. Soil pH is an important factor in determining these two soil conditions and therefore the crop performance. Low pH levels (acidic condition) converts some of the important nutrients into forms not readily available to the crops while dissolving other minerals such aluminium (Al^{3+}) to the toxic amounts (Mallarino *et al.*, 2011). Reports on the pH range for maize production differ from one researcher to another and from one location to another. However, in most reports the range starts from slightly acidic to neutral. The soil of the experimental site's pH 7.6 falls within the range (7.5 – 8.5) reported by Tripathi *et al.* (2011) as optimum and slightly above the ranges reported by Hill (2003) and Mallarino *et al.* (2011). According to Landon (1991), Gale *et al.* (2001) and Fernandez and Hoeft (2009), at higher soil pH the solubility of phosphorus (P) and some micro nutrients especially zinc (Zn^{2+}), copper (Cu^{2+}), manganese (Mn^{2+}) and iron (Fe^{2+}) is reduced. At pH above 7.5, phosphorus is precipitated by calcium ions (Ca^{2+}) and the micro elements are limited by reactions that form insoluble solids (Gale *et al.*, 2001; Fernandez and Hoeft, 2009). Possibly low content of P, Zn^{2+}, Cu^{2+}, Mn^{2+} and Fe^{2+} in the soil of the semi-coral area was the effect of high soil pH. This could have negatively affected the growth and yield of the maize crop in the research plot, especially the micro nutrients.

Soil organic matter

Soil at the experimental site contained 3% organic matter (30 g Kg^{-1} of soil). This value is ranked as medium. Anything higher than this content is likely to increase the soil pH and bring about deficiency of other nutrients mainly micro elements. With reference to the results of soil pH in the semi-coral area (7.6), the organic matter content of 3% can be regarded as adequate for maize production in this area.

Cation exchange capacity (CEC)

In maize production, better crop growth and good yields can be obtained where the soil CEC influences the soil pH to stay around 5 to 7.5 with balanced levels of nitrogen, phosphorus, calcium, magnesium and some sulphur. Cation exchange capacity (CEC) of the soil of the experimental area was found to be 22.39 cmol/kg of soil. According to Landon (1991), this value is considered as medium. Analysis of individual exchangeable bases indicated that the large proportion of this soil CEC was contributed by high percentage of exchangeable Ca^{2+} (17.5 cmol/kg of soil).

Exchangeable Mg^{2+} and K^+ were respectively 1.11 and 0.28 cmol/kg of soil (264.6 and 109.2 ppm) while exchangeable Na^+ was 0.24 cmol/kg of soil (55.2 ppm). Based on soil test criteria, the soil of the experimental site contained satisfactory level of Mg^{2+} and was medium in K^+ fertility (London, 1991). Sodium (Na^+) signified that the content was lower compared with the critical levels for most soils, a condition that was good for the salt susceptible crops like maize. High CEC of soil in the experimental site was not a good indicator of the soil fertility. Mutezo (2013) ascertained that, a soil with high CEC may not necessarily be more fertile because of other factors. In this soil, the four micronutrients contents (zinc 0.49, iron 1.87, manganese 2.1 and copper 0.48 mg kg^{-1} of soil) were very low based on soil test criteria (London, 1991) and therefore very infertile in terms of micronutrients. Ball (2013) recommended that in a fertile soil the range for the base cation saturation ratios (BCSR) need to be 65 – 85% for Ca^{2+}, 6 – 12% for Mg^{2+} and 2 – 5% for K^+. Except for Ca^{2+} the rest of base cations were present in less than the recommended ratios and thus the soil fertility was poor with regards to nutrients balance.

Extractable phosphorus

Soil of the experimental site was found to have 3.83 mg P kg^{-1} of soil (3.83 ppm). This low content of P was likely caused by intensive land use for annual crops production without use of P fertilizers. High soil pH (7.6) and high Ca^{2+} content (17.5 cmol/kg of soil) was possibly another reason for the P deficiency as under such conditions, P is precipitated by Ca^{2+} and other elements to insoluble compounds (Gale *et al.*, 2001; Fernandez and Hoeft, 2009). Landon (1991) established that the adequate amount of available soil phosphorus for maize is anything greater than 8 ppm (> 8 mg P kg^{-1} of soil). The result indicated that amendment of the soil with P fertilizer was necessary for better maize establishment. Though it was not a factor of varying levels, uniform application of 20 kg P ha^{-1} (10 ppm) was applied to build up the P level in the experimental plot and possibly this could increase the efficiency of uptake and utilization of other soil nutrients and reduced experimental errors.

Total nitrogen

Nitrogen deficiency is a common factor for declining of maize yield in humid tropical areas. One of the reasons is poor management practices (Osmond *et al.*, 1996). Similar characteristic of low soil nitrogen was found in the semi-coral area. The soil sampled from the experiment site contained only 0.16 % nitrogen. According to Landon (1991), this value was low and inadequate whereby applied N levels showed significant responses in both growth and yield components.

4.2.2 Effects of varieties on growth, yield and yield components

Results from the present study enlightened significant differences among four maize varieties in growth, yield and yield parameters (Table 4). Variations must have been due to genetic differences among these varieties though weather condition during the growing period could have played some role. Same reason was reported by Critchley and Siegert (1991) and Igbadun (2012).

In this study, early silking and physiological maturity were recorded by the local variety, JKU, compared with the three improved varieties (Staha, Situka and TMV-1). The earliness in flowering of the local variety possibly was due to its genetic adaptability and stability to the semi-coral environment after many cycles of its production in this area. Such possibility was also reported by Mabhaudhi (2009). Borras *et al.* (2007) explained that significant variation in flowering and maturity was directly from the natural variation in plant growth within the population and the inherent genetic variation among genotypes in partitioning the dry matter to the emerging ears. This was also supported by Idris and Mohammed (2012) who reported that days to 50% flowering had maximum heritability (79.1%) and that maize flowering and maturity are highly influenced by genotype. Because of its earliness in flowering, the local variety, JKU, efficiently completed all its growth stages within the rainy period and is expected to have highly expressed its genotypic potential in most parameters compared with the other three varieties and so was more competitive than Staha, which was the best overall. On the other hand, Situka which flowered and matured later was to a certain extent hit by the dry spell and so suffered moisture stress during the later stage of grain filling. Results of this study have shown that both days to 50% silking and days to maturity had negative correlations with most of the yield parameters. This indicated that overall poor performance of Situka was possibly attributable to delay in flowering and maturity.

Plant height is another parameter which showed that the tested varieties were significantly different (Table 4). Similar results were reported by Dudley *et al.* (1996) who showed that significant difference in plant height among varieties was probably due to differences in dominant alleles controlling plant height and hence it was due to genotypic differences. Importance of plant height (as part of the plant morphology and canopy structure) in the improvement of maize yield and yield components has been studied by many researchers. Sadler *et al.* (2000) found that plant height showed significant variability during vegetative development. Katsvairo *et al.* (2003) reported that plant height correlated well with maize yields at one out of three sites. Machado *et al.* (2002) observed that plant height at V12 contributed 61% of the variations of maize yield in the dry season but this relationship did not exist in the wet season. However, none of these authors explained the relationship between grain yield and plant height measured near maturity (when plants had stopped growing).

Results of this study showed no significant correlation between plant height and grain yield and therefore do not suggest tallest or shortest plants as a criterion for increasing grain yield. These results agree with those obtained by Liu and Wiatrak (2011) who also found that maize grain yield was not significantly affected by the plant height.

The present study showed significant variation in dry matter production among the tested varieties. Staha and JKU recorded higher values while TMV-1 and Situka had lower values. Significant differences in dry matter yield among maize genotypes have also been reported by Yilmaz *et al.* (2007), Kuzaksiz (2010) and Randjelovic *et al.* (2011). Based upon correlations (Table 12), it was found from the present study that, dry matter yield is a suitable marker for selecting a maize variety for more grain weight cob^{-1}, heavy seeds, high value of harvest index and higher grain yield. Staha and JKU, which had greater yield in dry matter, also had greater values in yield components and grain yield. Significant and positive correlations between dry matter yield and grain weight cob^{-1}, 100 seed weight, harvest index and grain weight were also reported by Wajid *et al.* (2007) and Inamullah *et al.* (2011) and both agree with the results of this study.

Also the results of the present study revealed that except the cob weight, all other evaluated yield components (cob length, grain weight cob^{-1}, 100 seed weight and harvest index) had significantly positive correlations with the grain yield. This made the two varieties, Staha and JKU that had higher values of cob length, grain weight cob^{-1}, 100 grain weight and harvest index, better for the grain yield. Turi *et al.* (2007), Idris and Mohammed (2012) and Charles *et al.* (2013) reported highest grain yield from varieties that had longer cobs, higher values of grain weight cob^{-1}, heavy seeds and higher values of harvest index and therefore agreed with the current results. Further, the results revealed that overall better performance of the local variety JKU over two improved varieties (Situka and TMV-1) is an indication that this variety may actually have been an improved variety that had been adopted long ago or farmers may have forgotten its name or origin.

4.2.3 Effects of plant density on growth, yield and yield components

Plant density is one of the important yield determinants of crops and an efficient management tool for maximizing grain yield by increasing the capture of solar radiation within the canopy (Monneveux *et al.*, 2005). Maize is more sensitive to variation in plant density than any other grass family (Sangoi, 2000; Lashakari *et al.*, 2011). Important effects of plant density are on both, vegetative and reproductive development of maize. The results of this experiment showed that plant density significantly influenced all evaluated parameters except days to 50% silking and days to maturity (Table 5).

Data for growth parameters showed that plant height and plant density were directly related. The tallest plants were recorded from the highest density (66 666 plants ha^{-1}) and the shortest plants from the lowest density (44 444 plants ha^{-1}). Experimental results by Kunjir *et al.* (2007), Sharifi *et al.* (2009) and Lashkari *et al.* (2011) indicated that plant height was usually increased with an increase in plant density and therefore conforming to the current results. Similarly, Shafi *et al.* (2012) reported the tallest maize plants from the highest plant density of 65 000 plants ha^{-1} and the shortest plants from the lowest plant density of 45 000 plants ha^{-1} (very close to the highest and lowest plant densities of the present study). Lashkari *et al.* (2011) further explained that, intense crowding of plants increased the far-red/red (FR/R) ratio triggering physiological events that lead to prioritization in the allocation of new assimilates to the main stem hence increased plant height. Surprisingly, opposite results have been reported by Abuzar *et al.* (2011) that, highest plant density (140 000 plants^{-1}) had shortest plants. They concluded that due to crowding effect of the plants and higher intra-specific competition for resources in highest densities, the plant height was reduced, which totally disagreed with the results of this study and also the results of other reporters. However, in the same results, Abuzar *et al.* (2011) showed that there was a significant increase in plant height between 40 000 and 100 000 plants ha^{-1} and an immediate decline above this range. This indicated that, 140 000 plants ha^{-1} which they referred as the highest density in their study, was extremely higher than the highest density in the current study (66 666 plants ha^{-1}). Possibly, the highest density in their study (140 000 plants ha^{-1}) was over and above the optimum density such that it created excessive intra-plants competition, weakening of the entire crop and declining of the plant height.

Highest dry matter yield was produced from the highest plant density (66 666 plants ha^{-1}) and the lowest biomass yield was recorded from the lowest plant density (44 444 plants ha^{-1}). However, Abuzar *et al.* (2011) reported differently. They got higher dry matter yield in the lower plant densities (60 000 and 80 000 plants ha^{-1}) which mean that the highest density in the current study was in this range. Further, Abuzar *et al.* (2011) made argument that with higher plant densities the individual plant dry matter production is reduced; therefore the total dry matter yield is also reduced. But it has appeared in this experiment and other studies by Yilmaz *et al.* (2007), Aziz *et al.* (2007) and Carpici *et al.* (2010) that, so long as the optimum density is not exceeded, dry matter yield increased with increasing plant density and that, in increasing density, the reduction of dry matter yield due to the reduction in dry matter production of individual plants was significantly and positively compensated by the increased number of plants ha^{-1} up to the optimum density. Also, Sadeghi (2013) reported highest dry matter yield from the highest plant density except that the highest plant density in his study (100 000 plants ha^{-1}) was higher than the highest plant density in the current experiment. In general, the current results and those of Abuzar *et al.* (2011) and Sadeghi (2013) have shown that optimum density for dry matter production lies between 60 000 and 100 000 plants ha^{-1} and that 60 000 plants ha $^{-1}$ should not be considered the lowest density.

Contrary to plant height and dry matter yield, cob length, cob weight, grain weight cob^{-1} and 100 seeds weight were inversely related to the plant density. Lower plant density of 44 444 plants ha^{-1} was the best for all these parameters. The higher plant density had lower values of all these yield attributes. Study by Sharifi *et al.* (2007) and Abuzar *et al.* (2011) showed similar results and therefore are in conformity with the results of the present study.

Comparatively, less number of plants in the lower plant density probably utilized the solar radiation and soil resources efficiently resulting into long cobs, heavy cobs and heavy grains, while low values of these yield components in higher plant density were probably due to enhanced mutual shading, high inter-plants competition for solar radiation, moisture and soil nutrients and reduced per plant production of photo-assimilates (Sangakkara *et al.*, 2004). Same reason was suggested by Abuzar *et al.* (2011) and Zamir *et al.* (2011).

The present study showed that decreased grain yield of individual plants due to increased plant density must have been compensated by increased number of plants and therefore grain yield increased with increased plant density but only to a certain level. Results indicated that medium plant density (53 333 plants ha^{-1}) recorded the maximum grain yield and can be regarded as the optimum plant density. The results also revealed that further increase in plant density had negative effects on grain yield. Carena and Cross (2003) obtained maximum grain yield from 56 000 plants ha^{-1}, very close to the results of this study. Similar results were reported by Abuzar *et al.* (2011) and Lashkari *et al.* (2011). Further, results indicated that despite longer and heavier cobs at the lowest plant density, grain yield was less because of fewer plants and therefore fewer cobs harvested per area. On the other hand, highest plant density above the optimum, had shorter and lighter cobs with increased number of barren plants, thus resulting in reduced grain yield. A similar effect was also reported by Sangakkara *et al.* (2004), Yilmaz *et al.* (2007), Carpici *et al.* (2010) and Zamir *et al.* (2011).

4.2.4 Effects of nitrogen fertilizer on growth, yield and yield components

Various studies have shown that maize responds well to nitrogen under various edapho-climatic conditions. Response of added N fertilizer depends upon the variety or hybrid, initial fertility status of the soil and climatic conditions (Amanullah *et al.*, 2008). The results of the present study have shown that plant height, days to 50% silking, days to physiological maturity and dry matter accumulation increased significantly with increased nitrogen level and reached maximum at the highest level of N (90 kg N ha^{-1}). Findings of this experiment on plant height agreed with the findings reported by Monneveux *et al.* (2005), Onasanya *et al.* (2009), Carpici *et al.* (2010) and Bozorgi *et al.* (2011). These authors suggested that increased nitrogen availability to plants increased chlorophyll content of leaves, impacted on utilization efficiency of other nutrients and increased rate of photosynthesis, hence more biomass production and translocation to the stem. This could have triggered rapid growth and elongation of internodes, resulting in taller plants.

Increase in N level significantly and consistently increased the duration to flowering and physiological maturity. The longest periods were observed with the highest N level (90 kg N ha^{-1}). The same trend of effect of nitrogen was also reported by Hammad *et al.* (2011). Possibly, with higher N rates, plants became more succulent, leaves enlarged with more chlorophyll content and increased photosynthesis. This triggered extra vegetative growth, which caused delay in flowering (Gungula *et al.*, 2003). Opposite and surprising results have however been reported by Shrestha (2013) who found that with increased N level the plants flowered earlier but matured later. According to Shrestha (2013) report, the time interval from silking to maturity is always too wider at higher N rates. But with the current experiment's results, the period from silking to maturity was not so widened by variation in N levels. The delay in maturity was highly a reflection of delay in silking but not an effect of significant increase of grain filling period.

This study also revealed that dry matter increased significantly in a linear relationship with increasing N ($R^2 = 0.96$) to the highest N level (90 Kg N ha^{-1}). These results are in conformity with those reported by Evans *et al.* (2003), Hokmalipur *et al.* (2010) and Bozorgi *et al.* (2011). Haque *et al.* (2001) explained that maize is a crop with high response to nitrogen fertilizer, hence when nitrogen is sub-optimal, growth is reduced and enhanced at increased levels. It is possible that, during this experiment, availability of more nitrogen at higher N levels resulted into vigorous plants with excessive vegetative growth which increased the rate of photosynthesis and hence greater dry matter production.

Similarly, yield components (cob length, cob weight, grain weight cob^{-1}, 100 seeds weight) and grain yield increased significantly with increasing N level but only up to 70 Kg N ha^{-1}. Thereafter, values of these parameters decreased. Generally, these results agree with those reported by Namakka *et al.* (2008), Di Paolo and Rinaldi (2008), Arif *et al.* (2010) and Moraditochaee *et al.* (2012) except for the optimum levels of N for these parameters. Namakka *et al.* (2008) reported 80 kg N ha^{-1} as the optimum level for cob length, cob weight and grain yield. The optimum N level for cob weight, 100 seeds weight, grain yield and harvest index as reported by Arif *et al.* (2010) was 160 kg N ha^{-1}. It is important that in all these reports there was an optimum level beyond which the values of yield and yield parameters decreased. In the present study, 70 kg N ha^{-1} was found to be optimum across all the evaluated yield parameters. According to Cassman (2002), in order for a crop to achieve its maximum yield potential, nitrogen is needed in large quantities but must be in balance with other nutrients. Under- as well as over- fertilization with nitrogen will result in reduced yield due to vegetative over growth, and reduced quality of products (Olfs *et al.*, 2005). Mengel (1992) stated that the very first effect of N fertilization of the field was the increase in size and number of leaves. N fertilization results in the increase in the number of mature leaves which in turn, results in higher photosynthesis/respiration ratio, assimilation and yield. However, its overdose brings about excessive increase in shoot development. Then, more leaves are shaded, photosynthesis/respiration ratio is lost, less assimilates are mobilized to grains and more assimilates are consumed by already consuming shaded mature and immature leaves (Emam and Niknejad, 2005)

4.2.5 Effects of variety and plant density interaction

Growth and yield characteristics of a crop are controlled by many genes and by the interactions between these genes within the crop genotype. However, many environmental and agronomical factors (e.g. plant density, light intercepted by the canopy, fertilizers, pests and diseases) have great influence on the expression of genotypic characteristics (Doku, 1977). The current research has shown that interaction of variety with plant density had significant effect on plant height, cob length, grain weight cob^{-1}, dry matter yield and grain yield.

Interactions of TMV-1 with 53 333 plants ha^{-1} and 66 666 plants ha^{-1} recorded the tallest plants. None of the other varieties was statistically similar to TMV-1 at highest or medium density. At lower plant density (44 444 plants ha^{-1}), TMV-1 was similar to Staha and Situka in plant height.

On the other hand, interaction of local variety, JKU with 44 444 plants ha^{-1} resulted into shortest plants. At medium and highest plant densities the plant height of JKU was statistically similar to that of Situka. This indicated that vegetative growth in

TMV-1 and JKU was highly responsive to increases in plant density compared with Staha and Situka. A similar trend of results was obtained by Gollar and Patil (2000). Ibeawuchi *et al.* (2008) reported that, with closer spacing (higher plant density), plants compete for nutrients and other growth factors; therefore tend to grow taller than those within lower plant density. But he further reported that variation in intensity of interaction of the variety with plant density depends on the variety concerned. This fact was evident in this experiment. Sangoi and Salvador (1997) reported that plant height may be an advantage when competition with weeds is severe. Therefore among the varieties tested in this study, TMV-1 at medium plant density was most likely the best in weed suppression. Interaction of JKU with 53 333 led to greatest dry matter yield which was comparable only to its own interaction with 66 666 plants ha^{-1} and Staha at same plant densities (44 444 and 66 666 plants ha^{-1}). Shafi *et al.* (2012) obtained maximum dry matter yield from the interaction of one variety (Sarhad white) with the highest plant density of 65 000 plants ha^{-1}, the results of which were very close to the results of the current study. At the lowest density (44 444 plants ha^{-1}), Staha produced significantly greater dry matter yield than JKU but Situka produced significantly less dry matter yield compared with other varieties except TMV-1. However, at higher plant densities (53 333 and 66 666 plants ha^{-1}) Situka had statistically greater dry matter yield than TMV-1. These results suggested that JKU and Situka responded rapidly and positively to the increase in plant density in terms of dry matter accumulation compared with Staha and TMV-1.

Experimental results by Sangoi and Salvador (1997) suggested that maize varieties reacted differently to increases in plant density in dry matter production and that some varieties were less sensitive to shifts in plant population. This fact is manifested in the results of the current study. The same authors explained that dry matter provides stem material for feed, meal, bedding, building and thatching purposes. The present study has shown that the local variety JKU planted at high density (66 666 plants ha^{-1}) provided the best interaction for production of feed/forage material apart from grain yield.

Generally, the cob length and grain weight cob^{-1} decreased across all varieties as the plant density increased but in different decreasing rates. Results showed that interaction of Staha with lower plant density (44 444 plants ha^{-1}) produced the longest cobs and highest value of grain weight cob^{-1}. These results suggest that, at 44 444 plants ha^{-1}, Staha was very efficient in the utilization of soil plant nutrients and other growth factors compared with the rest of interactions. Also, the results agree with the previous studies (Sangoi and Salvador, 1997; Sharifai *et al.*, 2012) that, at the same density, varieties responded differently in the same yield parameter. Thus, for each yield component, the optimum plant density is different form one variety to another. This was evident in the current results. Sangoi and Salvador (1997) and Sharifai *et al.* (2012) further explained that, probably, these results were due to the intense intra-plant competition for limited nutrients, moisture and light. In such a competition, some varieties loose stability earlier in slightly higher densities with the consequence of decreased cob length and increased barrenness.

However, Carena and Cross (2003) observed that the interaction of variety with plant density was significant only for ear height (position of the cob from the base of the plant) and for the rest of the growth parameters including yield components, varieties responded similarly to variations in plant density. These observations disagreed with the current results and those of Sangoi and Salvador (1997) and Sharifai *et al.* (2012).

Highest grain yield was observed with the interaction of Staha and medium density. However, the local variety, JKU, was very competitive such that it produced better yield compared with Situka and TMV-1 at both medium and highest densities. Yoshida (1993) stated that, the longer the crop is able to grow in a particular site or season, the greater the biomass production and the greater the yield. Evans (1993) argued that, no single process holds the key to greater crop yield. He further explained that, for grain crops, grain yield will often increase with duration up to a certain point but what happens beyond that point depends on environmental and agronomic conditions. This could be the reason why in the current experiment, early matured local variety (JKU), despite having short duration for growth, it produced statistically similar yield compared with the highest grain yield recorded by the interaction of an improved, medium maturing variety (Staha) at all levels of plant density except at lowest density (44 444 plants ha^{-1}).

Another observation in grain yield was that, interaction of Situka with lowest plant density produced statistically lowest grain yield but at the highest plant density it was similar to TMV-1 in grain yield. These results suggest that at lowest plant density where competition between plants is reduced, per hectare grain yield is determined by the grain yield per plant, but as density increases, grain yield is determined by the yield stability of a variety to a particular plant density. These results also indicated that interaction of Staha and JKU with medium plant density could have resulted in production of crop architecture that influenced utilization of solar radiation, moisture and nutrients more efficiently and hence better carbohydrate production. The results agree with Sangoi (2000) who reported that maize yield is low with low plant densities because of its little plasticity in leaf area per plant (do not tiller) and quite often produce only one ear per plant, excessively high plant densities stimulate apical dominance, induce barrenness, and in due course decrease the number of ears per plant and kernels set per cob.

4.2.6 Effects of variety and nitrogen interaction

Significant interaction between varieties and nitrogen was evident in numerous parameters. This showed the importance of nitrogen on improving yield of maize crop. Interaction of the TMV-1 with 90 kg N ha^{-1} was the best of all the other interactions in terms of plant height. On the other hand, shortest plants were observed from the interaction of JKU with the lowest N level (23 kg N ha^{-1}).

Results showed that, in Staha, Situka and JKU, significant increase in plant height was observed between 23 and 70 kg N ha^{-1}, while for TMV-1, rapid growth and significant increase in plant height was between 70 and 90 kg N ha^{-1} (Table 8). These results provided an indication that the plant growth of Staha, Situka and JKU responds better from low to medium rates of N, while that of TMV-1 needs higher levels of N for the plant growth to respond significantly. Interaction of Situka with 90 kg N ha^{-1} led to latest flowering and maturity times. These periods were respectively 4.8 and 9.7 days more than the overall effect of Situka on flowering (50% silking) and maturity (Table 9). Further, interaction of Situka with 90 kg N ha^{-1} had increased the SMI of this variety by 4.9 days. Conversely, interaction of JKU with 23 kg N ha^{-1} was significantly earliest in flowering (50% silking) and maturity with 4.0 and 4.3 days earlier than the overall averages observed with JKU alone regardless of N supply. At this rate of N the SMI of JKU was not much affected, it was reduced for only few hours (0.3 day).

Application of 23 and 46 kg N ha^{-1} reduced the period to flowering and maturity across all varieties. The SMI was also reduced except in JKU at 46 kg N ha^{-1}. Contrary, 70 and 90 kg N ha^{-1} resulted into late flowering and maturity in all varieties, with small changes in SMI except Situka with 90 kg N ha^{-1} where the change in SMI was 4.9 days (Table 9). From these results, it can be explained that, the latest flowering of Situka with 90 kg N ha^{-1} was probably because of high response of vegetative growth to N rates, while the latest maturity observed with N increase was probably attributable to both late flowering and increased grain filling period. These results are in agreement with Lomer *et al.* (2012) who found that interaction effects of variety and nitrogen fertilizer on days to silks emergence, days to dough stage and days to physiological maturity were significant. Daynard *et al.* (1971) observed a difference of 4 days in SMI among maize varieties and claimed that, probably nitrogen increase had provided the possibility of increased period of grain filling. Depending on other environmental and agronomic factors, increased grain filling period is an advantage for the grain yield (Yoshida, 1983). However, in the current study, interaction of Situka with 90 kg N ha^{-1} had longer grain filling period but less grain yield. Probably, Situka was negatively affected by the excessive vegetative growth at early stages and moisture stress encountered during the last days of grain filling.

Interaction of Staha with the highest N level (90 kg N ha^{-1}) produced the highest dry matter yield but was not better at other N levels. At 23 kg N ha^{-1}, Staha and Situka were statistically similar in the dry matter production. At 46 kg N ha^{-1} and 70 kg N ha^{-1}), Staha was statistically similar to the local variety, JKU. Further, results revealed that for the three varieties: Staha, Situka and JKU, supplying between 23 and 70 kg N ha^{-1}, dry matter increased at a decreasing rate but increased at an increasing rate from 70 to 90 kg N ha^{-1}. Conversely, TMV-1 responded increasingly throughout the N levels in dry matter from 23 to 90 kg N ha^{-1}. Hokmalipour and Darbandi (2011) reported that significant interaction effect of variety and nitrogen on dry matter production depends on the efficiency at which a variety remobilizes the dry matter at a particular N level. Thus, the results of the present study suggest that TMV-1 has high efficiency of total dry matter remobilization across all N levels while the rest of the tested varieties had high efficiency of total dry matter remobilization only at higher and highest N levels. Thus TMV-1 can be used with minimum nitrogen for production of feed/fodder maize.

Results for the cob length showed that, varieties responded differently with each N level so that significant difference existed among varieties with the same N level as well as between the interactions of the same variety with different N levels. Interaction of Staha with 70 kg N ha^{-1} produced longest cobs while interaction of TMV-1 with 90 kg N ha^{-1} recorded the shortest cobs. The trend for the cob weight was different from that of cob length. Significant difference in cob weight existed only among interactions of N with different varieties and not among N levels with the same variety. Yet, the only difference was between Staha with 46 kg N ha^{-1} and the two varieties, Situka and TMV-1 at all N levels except TMV-1 at 70 kg N ha^{-1}.

However, in each variety, maximum values for both, cob length and cob weight were obtained from the interaction of the variety with 70 kg N ha^{-1} except the cob length of TMV-1 and the cob weight of Staha where the highest values were recorded from their interaction with 46 kg N ha^{-1}. These results indicated that below 46 kg N ha^{-1} the plants probably suffered deficiency of N whereby further increase of N beyond 70 kg ha^{-1} increased excessive vegetative growth at the expense of dry matter allocation to the reproductive parts. Thus, 70 kg N ha^{-1} can be generalized as the optimum nitrogen level for cob length and cob weight. Akmal *et al.* (2010) and Kanton *et al.* (2013) found that cob length, cob weight were significantly affected by variety x N interaction, therefore agreed with the results of the current study. According to Hokmalipour and Darbandi (2011), despite increase in total dry matter with increasing N, the efficiency of dry matter remobilization from stem to the reproductive parts was reduced at highest N levels. This fact was evident in the current study, of which the results showed that, beyond 70 kg N ha^{-1} cob length and cob weight declined.

The trend of effect of varieties with N interaction on grain yield was similar to that observed on cob length and cob weight. In each variety, maximum grain yield was obtained from the interaction with 70 kg N ha^{-1} and declined thereafter. Highest grain yield was recorded from the interaction of Staha with 70 kg N ha^{-1}, whereas interaction of Situka with 23 kg N ha^{-1} had the lowest grain yield but comparable with TMV-1 at all N levels. Likewise, the trend of effect on harvest index was similar to that on grain yield except in Situka where the maximum harvest index was observed at 46 kg N ha^{-1}. Interaction of Staha with 70 kg N ha^{-1} led to largest value of harvest index but Situka with 90 kg N ha^{-1} had the smallest value. Akmal *et al.* (2010) and Kanton *et al.* (2013) found that cob length, cob length and grain yield were significantly affected by variety x N interaction. Khan *et al.* (2011) obtained greatest grain yield from the interaction of one variety (FH-810) and the highest N level (300 kg ha^{-1}) but harvest index was not significantly affected, thus partly agreeing with the current results. Ali *et al.* (2011) reported no significance in variety x N interaction for all yield parameters, thus disagree with the results of the current research. Bertin and Gallais (2000) found that significant difference in varieties with N interaction was due to genetic variability being differently expressed under high and low N inputs. They further explained that, low N (nitrogen stress) may allow the expression of variability controlled by specific genes involved in N-remobilization while high N input would favour the expression of variability controlled by specific genes involved in post-anthesis N uptake.

4.2.7 Effects of plant density and nitrogen interaction

Interaction of plant density and nitrogen fertilizer showed that, 90 kg N ha^{-1} was better for plant height across all the three plant densities with highest density (66 666 plants ha^{-1}) and highest N level (90 kg N ha^{-1}) resulting in tallest plants. However, this effect was similar to that of 53 333 plants ha^{-1} with 90 kg N ha^{-1}. This showed that, at 90 kg N ha^{-1}, increasing density from 53 333 to 66 666 plants ha^{-1} did not increase the plant height significantly.

On the other hand, interaction of lowest density (44 444 plants ha^{-1}) with lowest N level (23 kg N ha^{-1}) resulted into significantly shortest plants. At the same level of N, increasing density to 53 333 plants ha^{-1} resulted into significant increase in plant height. Within all N levels, maximum plant height was obtained from the highest density. These results suggest that the crowding effect at the highest density induced excessive stem elongation in plants competing for sun light. This probably was accompanied by the effect of excessive N supply which also might have caused vigorous plant growth. Similar results were obtained by Moraditochaee *et al.* (2012) who also found maximum plant height from interaction of highest N level with closest spacing (highest plant density).

Interaction of lowest density (44 444 plants ha^{-1}) and 46 kg N ha^{-1} gave largest number of seed rows cob^{-1}, and the least seed rows cob^{-1} were recorded from interaction of 53 333 plants ha^{-1} with 90 kg N ha^{-1}. Further, the results showed that in lowest and medium plant densities, the medium rate of nitrogen (46 kg N ha^{-1}) was better for the number of seed rows cob^{-1}. Interaction of the highest plant density and highest rate of nitrogen (90 kg N ha^{-1}) produced number of rows cob^{-1} similar to the largest numerical value obtained from lowest density with medium N level but the seeds harvested from the interaction of highest density with highest N level were the lightest of all such that they could not improve the grain yield significantly. Maximum 100 seed weight was obtained from the interaction of the lowest density (44 444 plants ha^{-1}) with higher N level (70 kg N ha^{-1}). Similarly, Moraditochaee *et al.* (2012) found maximum number of seed rows per cob at the highest plant density with highest N level and also they found that maximum 100 grain weight was from the interaction of lower plant density with highest N level, thus agreed with the current results. Bozorgi *et al.* (2011) reported that there was no significant effect in density with N interaction on both, seed rows cob^{-1} and 100 seed weight and therefore disagreed with the current results. However, other authors (Mengel, 1992; Sangakkara *et al.*, 2004; Emam and Niknejad, 2005; Malaviarachchi *et al.*, 2007) agree with the current results that lightest seeds from the interaction of highest density with highest N level could be due to excessive vegetative growth, excessive mutual shading of leaves, low light distribution among leaves and hence reduced photosynthesis/respiration ratio.

In all the three plant densities, N rate of 70 kg N ha^{-1} enhanced grain yield and harvest index though not consistently significant. Interaction of 66 666 plants ha^{-1} with 70 kg N ha^{-1} produced the highest grain yield. Significantly lower grain yield was recorded from interaction of the lower plant density (44 444 plants ha^{-1}) with the lowest nitrogen level (23 kg N ha^{-1}). The highest value of harvest index was also recorded from highest plant density (66 666 plants ha^{-1}) applied with 70 kg N ha^{-1}.

These results are comparable to Bozorgi *et al.* (2011) and Hoshang (2012). On the other hand 66 666 plants ha^{-1} and 90 kg N ha^{-1} divulged the lowest harvest index. Nitrogen and plant density are considered some of the most important factors affecting the grain yield (Hoshang, 2012). Nitrogen determines the amount of plant chlorophyll, plant health, other nutrients absorption and a number of plant's metabolic functions. Plant density on the other side, decides how sufficient are the soil and atmospheric resources in relation to the number of plants within a given area of land. Results of the present study indicated that whenever plant density was increased, more nitrogen was required to maintain plants in their normal growth.

Despite previous observation that lower plant density had greater yield plant^{-1}, due to less number of plants per area and less number of harvested cobs, yield remains lower at lower densities. In the current study, yield could be improved through increasing density with moderate level of N (70 kg ha^{-1}) whereas in lower and medium densities highest rate of N (90 N ha^{-1}) was necessary to increase grain yield.

4.2.8 Effects of variety, plant densities and nitrogen interaction

Despite individual effects of each of these factors, interaction effects among them have also been reported to influence yield and yield parameters in maize (Aziz *et al.*, 2007). However, the present study revealed that variety, plant density and nitrogen interaction was significant only for cob length, seed rows cob^{-1} and the grain yield.

Interaction of Staha with lowest plant density (44 444 plants ha^{-1}) and 46 kg N ha^{-1} resulted into longest cobs (23 cm). Results revealed that, by maintaining plant density at 44 444 plants ha^{-1}, increasing N form 46 to 90 kg ha^{-1}, decreased the cob length of Staha but not significantly. At lowest plant density Staha was similar with JKU in cob length at 23 and 90 kg N ha^{-1} only and not other interactions. At increased plant density however, cob length of Staha was moderate and similar with Situka and TMV-1 in different N levels. It was also observed that, within any variety, increasing density at the same level of N decreased the cob length and possibly, this was due to deficiency in N. Similar effect was observed at increased N level within the same density, showing possibility of plants overgrowth and utilization of assimilates by an increased number of shaded leaves. These results suggest the need for balancing plant density with N rates for maximizing cob size.

Interaction of Staha with highest density (66 666 plants ha^{-1}) and 70 kg N ha^{-1} gave greatest grain yield. However, local variety, JKU well competed with Staha except at lowest density (44 444 plants ha^{-1}) with 70 kg N ha^{-1}. Poorest grain yield was recorded from Situka with the lowest density (44 444 plants ha^{-1}) at the lowest N level (23 kg N ha^{-1}). Likewise, all Situka interactions with the lowest plant density resulted in low grain yield across all the four N levels. On the other hand, results showed that, increasing density could improve the grain yield of Situka such that at medium plant density (53 333 plants ha^{-1}) and the lowest N level (23 kg ha^{-1}), and at highest plant density (66 666 plants ha^{-1}) with highest N level (90 kg N ha^{-1}) Situka well competed with Staha. Also, with medium plant density (53 333 plants ha^{-1}) the N levels of 23, 46 and 90 kg N ha^{-1} improved the grain yield of TMV-1 and therefore well competed with Staha. Likewise, Staha and TMV-1 were similar in grain yield at 66 666 plants ha^{-1} with 46 and 90 kg N ha^{-1}. However, in all these results, Staha was still better than the other varieties. Overall better performance of Staha could be attributable to the inherent yield potential, its better stability to the environmental stress created by increased plant density and better response to changing nitrogen levels. Such possible reason was also suggested by Doku (1977), Sangakkara *et al.* (2004) and Aziz *et al.* (2007).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Findings of this study have shown that individual as well as interactive effects of varieties, plant density and nitrogen soil fertility were quite significant. Of the three improved varieties, Staha was statistically better over the local variety for cob length, cob weight, 100 seeds weight and grain yield. The local variety, JKU was the earliest in flowering and maturity and better for yield and yield components than Situka and TMV-1, and nearly performed as well as Staha. It is concluded from these results that the local variety, JKU may actually be an improved variety that had been adopted long ago or farmers may have forgotten its name or origin.

For maximizing interception of solar radiation and grain yield, the maize crop must be grown in a relatively high but optimum plant density. This study revealed that a lowest plant density of 44 444 plants ha^{-1} was better for some yield components parameters: cob length, cob weight, grain weight cob^{-1} and 100 seeds weight but produced minimum grain yield due to the small number of plants per area with this density. The medium plant density of 53 333 plants ha^{-1} was an optimum density for grain yield. Increase in nitrogen level increased the plant height, duration to flowering, duration to maturity and dry matter yield up to the highest N level (90 kg N ha^{-1}). But for the grain yield and yield components the values increased up to 70 kg N ha^{-1}. Above that level the values of the yield components parameters decreased. Interaction of variety with plant density significantly affected plant height, cob length, grain weight cob^{-1}, dry matter and grain yield and but other parameters. Staha planted at 44 444 plants ha^{-1} had the longest cobs and more grams of grains per cob but Staha at 53 333 plants ha^{-1} was the optimum combination for grain yield.

Interaction of variety with nitrogen indicated that the local variety, JKU at 23 kg N ha^{-1} was the best combination for early flowering and early maturity while Staha at 70 kg N ha^{-1} was better for the cob length and grain yield.

Interaction of plant density with nitrogen levels resulted in tallest plants at 66 666 plants ha^{-1} and 90 kg N ha^{-1} and the heaviest grains at 44 444 plants ha^{-1} with 70 kg N ha^{-1}. But 66 666 plants ha^{-1} with 70 kg N ha^{-1} was best for the grain yield and harvest index. Interaction of varieties, plant densities and nitrogen levels was significantly effective on cob length, seed rows cob^{-1} and grain yield but not other parameters. Staha with 44 444 plants ha^{-1} and 46 kg N ha^{-1} was best for cob length while Staha with 66 666 plants ha^{-1} and 70 kg N ha^{-1} was an optimum combination for enhanced grain yield under the semi-coral conditions of Pemba. The local variety, JKU with 53 333 plants ha^{-1} and 90 kg N ha^{-1}, and JKU with 66 666 plants ha^{-1} and 70 kg N ha^{-1} were, however, competitive combinations for grain yield.

5.2 Recommendations

Based on the results of the present research, recommendations are made as follows:

i. Regarding the rainfall pattern in the semi-coral area, maize varieties that combine earliness and high yields should be used by farmers to increase maize production and improve food security.

ii. Staha variety that was found moderate in maturity and best in grain yield is recommended against other two improved varieties Situka and TMV-1

iii. The local variety JKU can be used parallel with Staha for its earliness in maturity and good yield provided that recommended plant densities and nitrogen levels from this study are adopted.

iv. For maximizing yield, farmers need to adopt a combination of Staha variety, 66 666 plants ha^{-1} and 70 kg N ha^{-1} although a combination of Staha, 53 333 plants ha^{-1} and 70 kg N ha^{-1} can be used to reduce the cost of seeds and the risk of interplant competition.

v. For the risk avoiding farmers (when rainfall is considered a threat), combinations of local variety, JKU with 53 333 plants ha^{-1} and 90 kg N ha^{-1} or JKU with 66 666 plants ha^{-1} and 70 kg N ha^{-1} are also recommended.

vi. Experiments to determine the agronomic and economic benefits of recommended rates of N fertilizer and seed required for the recommended plant densities are still necessary.

vii. More experiments to confirm these finding in different seasons as these results were based on a single cropping season have to be done.

viii. Due to its performance the local variety, JKU should be traced for its origin so that it can be improved or used in breeding programmes to improve other cultivars.

REFERENCES

AATF. (2010). *Mitigating the Impact of Drought in Tanzania: WEMA Intervention.* Policy Brief. 4pp.

Abuzar, M. R., Sadozai, G. U., Baloch, M. S., Baloch, A. A., Shah, I. H., Javaid, T. and Hussain, N. (2011). Effect of plant population densities on yield of maize. *Journal of Animal and Plant Sciences* 21(4): 692 – 695.

Adediran, J. A. and Banjoko, V. A. (1995). Response of maize to nitrogen, phosphorus and potassium fertilizers in the savanna zone of Nigeria. *Communication in Soil Science and Plant Analysis* 26: 593 – 606.

Akmal, M., Ur-Rehman, H., Asim, F. M. and Akbar, H. (2010). Response of maize varieties to nitrogen application for leaf area profile, crop growth, yield and yield components. *Pakistan Journal of Botany* 42(3): 1941 – 1947.

Ali, H. M., Walsh, M. and Woods, R. (Eds) (1995). *Farming System Zones in Agricultural Research and Planning:* A Paper Presented at the ZARC Annual Research Review Meeting, Zanzibar, 14 – 15 November, 1995. 15pp.

Ali, J., Bakht, J., Shafi, M., Khan, S. and Shah, W. A. (2002). Uptake of nitrogen as affected by various combinations of nitrogen and phosphorus. *Asian Journal of Plant Science* 1: 367 – 369.

Ali, K., Munsif, F., Zubair, M., Akbar, H., Hussain, Z., Shahid, M., Din, I. U. and Khan, N. (2011). Management of organic and inorganic nitrogen for different maize varieties. *Sarhad Journal of Agriculture* 27(4): 525 – 529.

Alimohammadi, M., Yousefi, M. and Zandi, P. (2011). Impact of nitrogen rates on growth and yield attributes of sweet corn grown under different phosphorus levels. *Journal of American Science* 7(10): 201 – 206.

Amani, H. K. R. (2004). Agricultural Development and Food Security in Sub-Saharan Africa Tanzania Country Report. In: AATF (2010). *Mitigating the impact of Drought in Tanzania: WEMA Intervention.* Policy Brief, 4pp.

Amanullah, M. M., Srikanth, M., Muthukrishnan, P. and Ponnuswamy, K. (2008). Response of hybrid maize to plant density and fertilizer levels – a review. *Agricultural Review* 29 (4): 248 – 259.

Amare, M., Asfaw, S. and Shiferaw, B. (2012). Welfare impacts of maize–pigeonpea intensification in Tanzania. *Agricultural Economics* 00: 1 – 17.

Andrade, F. H., Echarte, L., Rizzalli, R., Della-Maggiora, A. and Casanovas, M. (2002). Kernel number prediction in maize under nitrogen or water stress. *Crop Science* 42:1173 – 1179.

Angima, S., (2008). Potassium Deficiency: Listening to your ears of corn. [http://smallfarms.oregonstate.edu/book/export/html/175629]. Site visited on 5/3/2013.

Arif, M. M., Tariq, J., Naqibullah, K., Habib, A., Shad, A. A., Khan, M. J., Khan, A., Iqbal, M., Muhammad, S. and Iqbal, A. (2010). Impact of plant population and nitrogen levels on maize. *Pakistan Journal of Botany* 42(6): 3907 – 3913.

Asare, D. K., Frimpong, J. O., Ayeh, E. O. and Amoatey, H. M. (2011). Water use efficiencies of maize cultivars grown under rain-fed conditions. *Agricultural Sciences* 2(2): 125 – 130.

Asghar, A., Ali, A., Syed, H., Asif, M., Khaliq, T. and Abid, A. A. (2010). Growth and yield of maize (*Zea mays* L.) cultivars affected by NPK application in different proportion. *Pakistan Journal of Science* 62(4): 211 – 216.

Astera, M., (2007). Cation Exchange Capacity in Soils, Simplified. [http://www.soilminerals.com/Cation_Exchange_Simplified.htm]. Site visited on 19/4/2013.

Ayub, M., Nadeem, M. A., Sharar, M. S. and Mahmood, N. (2002). Response of maize (*Zea mays* L.) fodder to different levels of nitrogen and phosphorus. *Asian Journal of Plant Science* 1: 352 – 354.

Aziz, A., Ur-Rehman, H. and Khan, N. (2007). Maize cultivars response to population density and planting date for grain and biomass yield. *Sarhad Journal of Agriculture* 23(1): 25 – 30.

Badu-Apraku, B., Hunter, R. B. and Tollenaar, M. (1983). Effect of temperature during grain filling on whole plant and grain yield in maize (*Zea mays* L.). *Canadin Journal of Plant Science* 63: 357 – 363.

Baijukya, F. P., de Ridder, N. and Giller, K. E. (2006). Nitrogen release from decomposing residues of leguminous cover crops and their effect on maize yield on depleted soils of Bukoba district, Tanzania. *Plant and Soil* 279: 77 – 93.

Ball, B. (2013). Fertilizer recommendations and approaches. *Crop Talk* 13 (1): 9 – 10.

Barbaric, K. A., (2006). Nitrogen Sources and Transformations. [http://www.ext.colostate.edu/pubs/crops/00550.html]. Site visited on 3/11/2012.

Barten, T., (2013). Evaluation of Plant Density and Row Spacing to Optimize Hybrid Performance. [http://imbgl.cropsci.illinois.edu/school/2013/12_TY _BARTEN.pdf]..Site visited on 19 April, 2013.

Basamba, T. A., Barrios, E., Ame'zquita, E., Rao, I. M. and Singh, B. R. (2006). Tillage effects on maize yield in a Colombian savanna oxisol: soil organic matter and P fractions. *Soil and Tillage Research* 91: 31–142.

Belfield, S. and Brown, C. (2008). *Field Crop Manual: Maize - A Guide to Upland Production in Cambodia.* Cambodian Agricultural Research and Development Institute and the State of New South Wales (NSW) Department of Primary Industries. 43pp.

Bello, O. B., Abdulmaliq, S. Y., Afolabi, M. S. and Ige, S. A. (2010). Correlation and path coefficient analysis of yield and agronomic characters among open pollinated maize varieties and their F1 hybrids in a diallel cross. *African Journal of Biotechnology* 9 (18): 2633 – 2639.

Bello, O. B., Azeez, M. A., Mahmoud, J., Afolabi, M. S., Ige, S. A. and Abdulmaliq, S. Y. (2011). Evaluation of grain yield and agronomic characteristics in drought tolerant maize varieties belonging to two maturing groups. *Scholarly Journal of Agricultural Science* 2(4): 70 – 74.

Bertin, P. and Gallais, A. (2000). Genetic variation for nitrogen use efficiency in a set of recombinant maize inbred lines I. Agrophysiological results. *Maydica* 45(1): 53 – 66.

Belvins, D. G. (1999). Why plants need phosphorus. *Better Crops* (8)2: 29 – 30.

Bolanos, J. and Edmeades, G. O. (1996). The importance of the anthesis-silking inteval in breeding for drought tolerance in tropical maize. *Field Crops Reearch* 48: 65 – 80.

Borras, L., Westgate, M. E. and Astini, J. P. (2009). Physiological Processes to Understand Genotype × Environment Interactions in Maize Silking Dynamics. In: *Scale and Complexity in Plant Systems Research: Gene-Plant-Crop Relations*. (*Edited by Spiertz, J. H. J., Struik, P. C. and van Laar, H. H.*), Springer, German. pp. 105 – 113.

Bot, A. and Benites, J. (2005). *The Importance of Soil Organic Matter: Key to Drought-Resistant Soil and Sustained Food Production.* Publishing Management Service, Information Division, Food and Agricultural Organization (FAO), Rome, Italy. 78pp.

Bozorgi, H. Z., Doustan, H. Z., Sadeghi, S. M., Keshavarz, A., Faraji, A., Tarighi, F. and Azarpour, E. (2011). Study effect of plant density and nitrogen fertilizer on yield and yield components of maize. *World Applied Science Journal* 13(1): 147 – 151.

Brady, N. C. and Weil, R. (Eds.) (2004). *Elements of the Nature and Properties of Soils*. Prentice Hall, Upper Saddle River, New Jersey. 624pp.

Brady, N. C. and Weil, R. (Eds.) (2007). *The nature and properties of soils*. Prentice Hall, Upper Saddle River, New Jersey. 980pp.

Bundy, L. G., Kelling, K. A., Shulte, E. E., Combs, S. M., Wolkowski, R. P. and Sturgul, S. J. (1994). Nutrient Management Practices for Wisconsin Corn Production and Water Quality Protection. Extension Publication. A3557, Wisconsin Cooperative Extension, University of Wisconsin, Madison.

Bundy, L. G. and Malone, E. S. (1988). Effect of residual profile nitrate on corn response to applied nitrogen. *Soil Science Society of America Journal* 52: 1377 – 1383.

Busman, L., Lamb, J., Randall, G., Rehm, G. and Schmitt, M., (2009). The Nature of Phosphorus in Soils. University of Minnesota. [http://www.extension.umn.edu/distribution/cropsystems/dc6795.html]. Site visited on 18/11/2012.

Cakir, R. (2004). Effect of water stress at different development stages on vegetative and reproductive growth of corn. *Field Crops Research* 89 (1): 1 – 16.

Campillo, C., Fortes, R. and del Henar, M. P. (2012). Solar Radiation Effect on Crop Production. In: *Solar Radiation* (Edited by Babatunde, E. B.), InTech, Slavka Krautzeka 83/A, 51000 Rijeka, Croatia. pp. 167 – 194.

Carena, M. J. And Cross, H. Z. (2003). Plant density and maize germplasm improvement in the northern corn belt. *Mydica* 48: 105 – 111.

Carpici, E. B., Celik, N. and Bayram, G. (2010). Yield and quality of forage maize as influenced by plant density and nitrogen rate. *Turkish Journal of Field Crops* 15(2): 12 8 – 132.

Carter, M. R. and Gregorich, E. G. (Eds.) (2006). *Soil Sampling and Methods of Analysis.* CRC Press, Taylor and Francis Group, Broken Sound Parkway NW. 198 pp.

Cassman, K. G., Dobermann, A. and Walters, D. T. (2002). Agroecosystems, nitrogen-use efficiency and nitrogen management. *Journal of the Human Environment* 31(2):132 – 140.

CFF. (2013). Plant nutrients: Potassium. In: *Natural resource fact sheet* Issue No. 04/13. pp 1 – 2.

Chapman, H. D. (1965). Total Exchangeable Bases. In: *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties* (Edited by Norman, A. G.), 1965, American Society of Agronomy, Soil Science Society of America, Madison, USA. pp. 902 – 904.

Charles, M. K., Fredrick, N. M., George, O. A. and Odongo, O. M. (2013). Genetic variability analysis for growth and yield parameters in double cross maize (*Zea mays* L.) genotypes in Kitale county of Kenya. *Journal of Plant Breeding and Genetics* 1: 7 – 11.

CIMMYT and IITA. (2011). Maize: Global Alliance for Improving Food Security and Livelihoods of the Resource-poor in Developing Countries. *Proposal Submitted by CIMMYT and IITA to the Consortium Board of the Consultative Group on International Agricultural Research (CGIRA), June 2011.* 176pp.

Coder, K. D., (1997). Nitrogen Transformations in Soils. [http://warnell.forestry.uga.edu/service/library/for97-012/for97-012.pdf]. Site visited on 4/3/2013.

Craswell, E. T. and Lefroy, R. B. D. (2001). The role and function of organic matter in tropical soils. *Nutrient Cycling in Agroecosystems* 61: 7 – 18.

Critchley, W. and Siegert, K. (1991). *Water Harvesting: A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production.* Food and Agricultural Organization of the United Nations, Rome. 149pp.

Daynard, T. B., Tanner, J. W. and Duncan, W. G. (1971). Duration of the grain filling period and its relation to grain yield in corn (*Zea mays* L.). *Crop Science* 11: 45 – 48.

Di Paolo, E. and Rinaldi, M. (2008). Yield response of corn to irrigation and nitrogen fertilization in a Mediterranean environment. *Field Crops Research* 105(3): 202 – 210.

Dickau, R., Ranere, A. J. and Cooke, R. G. (2007). Starch grain evidence for the preceramic dispersals of maize and root crops into tropical dry and humid forests of Panama. In: *Proceedings of the National Academy of Science* Vol. 104, No 9. (Edited by Piperno, D. R.), 27 December 2006, Smithsonian Institution, Washington, DC, and Balboa, Panama. pp. 3651 – 3656

Dinnes, D. L., Karlen, D. L., Jaynes, D, B., Kaspar, T. C. and Hatfield, J. L. (2002). Review and interpretation: Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. *Agronomy Journal* 94: 153 – 171.

Doebley, J., Stec, A. and Gustus, C. (1995). *Teosinte* branched1 and the origin of maize: Evidence for epistasis and the evolution of dominance. *Genetics* 141: 333 – 346.

Doebley, J., Stec, A., Wendelt, J. and Edwardst, M. (1990). Genetic and morphological analysis of a maize-teosinte F2 population: Implications for the origin of maize. In: *Proceedings of National Academy of Science* Vol 87. (Edited by Goodman, M. M.), 29 September 1990, *USA*. pp. 9888 – 9892.

Doku, E. V. (1977). Some concepts of crop yield. *Ghana Journal of Agricultural Science* 10(1): 53 – 60.

Dowswell, C. R., Paliwal, R. L. and Cantrell, R. P. (1996). Maize in the third world. In: Nuss, E. T. and Tanumihardjo, S. A. (2011). Quality protein maize for Africa: Closing the protein inadequacy gap in vulnerable populations. *Advances in Nutrition* 2: 217 – 224.

Du Plessis, J. (2003). *Maize Production.* Department of Agriculture, Republic of South Africa. 35pp.

Du Preez, C. C., Van Huyssteen, C. W. and Mnkeni, P. N. S. (2011). Land use and soil organic matter in South Africa 2: A review on the influence of arable crop production. *South African Journal of Science* 107 (5/6): 1 – 8.

Dudley, J. W., Lamrey, K. R. and Geadelmann, J. L. (1996). Evaluation of populations for their potential to improve three maize hybrids. In: Golam, F., Farhana, N., Zain, M. F., Majid, N. A., Rahman, M. M., Rahamn, M. M. and Kadir, M. A. (2011). Grain yield and associated traits of maize (*Zea mays* L.) genotypes in Malaysian tropical environment. *African Journal of Agricultural Research* 6(28): 6147 – 6154.

Ebrahimi, S. T., Yarnia, M., Benam, M. B. K. and Tabrizi, E. F. M. (2011). Effect of potassium fertilizer on corn yield under drought stress condition. *American-Eurasian Journal of Agriculture and Environmental Science* 10(2): 257 – 263.

Ejigui, J., Savoie, L., Marin, J. and Desrosiers, T. (2007). Improvement of the nutritional quality of a traditional complementary porridge made of fermented yellow maize (*Zea mays*): Effect of maize-legume combinations and traditional processing methods. *Food Nutrition Bulletin* 28(1): 23 – 34.

El Sheikh, T., Hago, M. and Sawi, S. M. A. (1995). The Effects of nitrogen and phosphorus on yield and yield components of maize (*Zea mays* L.) under irrigation. *University of Khartoum Journal Agricultural Science* 3(2): 22 – 31.

Emam, Y. and Niknejad, M. (Eds) (2005). *An Introduction to the Physiology of Crops Yield.* Shiraz University Press, Iran. 551pp.

Evans, L. T. (1993). *Crop Evolution, Adaptation and Yield.* Cambridge University. Press. Cambridge, UK. 500 pp.

Evans, S. P., Knezevic, S. Z., Lindquist, J. L. and Shapiro, C. A. (2003). Influence of nitrogen and duration of weed interference on corn growth and development. *Weed Science* 5(4): 546 – 556.

Fairhurst, T. (Eds.) (2012) *Handbook for Integrated Soil Fertility Management.* Africa Soil Health Consortium, Nairobi. 151pp.

FAO, (2010). Food Outlook: Global market analysis. [http://www.fao.org/docrep/013/al969e/al969e00.pdf]. Site visited on 12/9/2012.

FAOSTAT, (2011). Agricultural Production Statistics for 2010. [http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E]. Site visited on 8/9/2012.

FAOSTAT, (2012). Agricultural Production Statistics for 2011. [http://faostat3.fao.org/faostat-gateway/go/to/download/Q/QC/E]. Site visited on 11/6/2013.

FARA. (2009). *Patterns of Change in Maize Production in Africa: Implication for Maize Policy Development*. Ministerial Policy Brief Series No.3. 8pp.

Farhad, W., Saleem, M. F., Cheema, M. A. and Hammad, H. M. (2009). Effect of poultry manure levels on the productivity of spring maize (*Zea mays* L.). *Journal of Animal and Plant Sciences* 19(3): 122 – 125.

Fernandez, F. G. and Hoeft, R. G. (2009). Managing Soil pH and Crop Nutrients. In: *Illinois Agronomy handbook.* (Edited by Nafziger, E. D.), University of Illinois, Urbana. pp. 91 – 112.

Gale, J., Koenig, R. and Barnhill, J., (2001). Managing Soil pH in Uttah. [http://extension.usu.edu/files/publications/publication/AG-SO-07.pdf]. Site visited on 28/11/2012.

Gaut, B. S. and Doebley, J. F. (1997). DNA sequence evidence for the segmental allotetraploid origin of maize. In: *Proceedings of National Academy of Science Vol. 94.* (Edited by Goodman, M. M.), 17 April 1997, North Carolina State University, Raleigh, NC. pp. 6809 – 6814.

Gehl, R. J., Schmidt, J. P., Maddux, L. D. and Gordon, W. B. (2005). Corn yield response to nitrogen rate and timing in sandy irrigated soils. *Agronomy Journal* 97: 1230 – 1238.

Geleti, D., Tolera, A., Mengistu, A. and Hailemariam, M. (2011). Effect of variety of maize on yield of grain, residue fractions and the nutritive value of the whole stover. *Ethiopian Journal of Applied Science and Technology* 2(2): 91 – 96.

Ghooshchi, F., Seilsepour, M. and Jafari, P. (2008). Effects of water stress on yield and some agronomic traits of maize. *American-Eurasian Journal of Agriculture and Environmental Science* 4 (3): 302 – 305.

Golam, F., Farhana, N., Zain, M. F., Majid, N. A., Rahman, M. M., Rahamn, M. M. and Kadir, M. A. (2011). Grain yield and associated traits of maize (*Zea mays* L.) genotypes in Malaysian tropical environment. *African Journal of Agricultural Research* 6(28): 6147 – 6154.

Gollar, R. G. and Patil, V. C. (2000). Effect of plant density on yield of maize genotypes during Rabi season. *Karnataka Journal of Agricultural Science* 13(1): 1 – 6.

Grant, R. F., Jackson, B. S., Kiniry, J. R., and Arkin, G. F. (1989). Water deficit timing effects on yield components in maize. *Agronomy Journal* 81: 61 – 65.

Gruhn, P., Goletti, F. and Yudelman, M. (Ed.) (2000). *Integrated Nutrient Management, Soil Fertility and Sustainable Agriculture: Current Issues and Future Challenges.* Food, Agriculture and the Environment Discussion Paper 32, International Food Policy Research Institute, Washington, D.C, September, 2000. 31pp.

Guebel, D. V., Nudeland, B. C. and Giulietti, A. M. (1991). Simple micro-Kjeldahl method for total nitrogen analysis. *Biotechnology Techniques* (5) 6: 42 – 430.

Guillard, K., Morris, T. F. and Kopp, K. L. (1999). The pre-sidedress soil nitrate test and nitrate leaching from corn. *Journal of Environmental Quality* 28: 1845 – 1852.

Guled, S. M. (2007). Integrated nitrogen management in maize under rain fed condition. Thesis for Award of MSc Degree at Dharwad University of Agricultural Science, Dharwad-580 005, Karnataka, India, 112 pp.

Gungula, D. T., Kling, J. G. and Togun, A. O. (2003). CERES-Maize predictions of maize phenology under nitrogen-stressed conditions in Nigeria. *Agronomy Journal* 95: 892 – 899.

Haeder, H. E. and Beringer, H. (1981). Analysis of yield of winter wheat grown at increasing levels of potassium. *Journal of the Science of Food and Agriculture* 32: 547 – 551.

Hammad, H. M., Ahmad, A., Azhar, F., Khaliq, T., Wajid, A., Nasim, W. and Farhad, W. (2011). Optimizing water and nitrogen requirement in maize (*Zea mays* L.) under semi arid conditions of Pakistan. *Pakistan Journal of Botany* 43(6): 2919 – 2923.

Haque, M. M., Hamid, A. and Bhuiyan, N. I. (2001). Nutrient uptake and productivity as affected by nitrogen and potassium application levels in maize/sweet potato intercropping system. *Korean Journal of Crop Science* 46(1): 1 – 5.

Hassan, R. M., Muriithi, F. and Kamau, G. (1998). Determinants of fertilizer use and the gap between farmers' maize yields and potential yields in Kenya. In: *Maize Technology Development and Transfer in Kenya*. (Edited by Hassan, R. M.), CAB International, London. pp. 137 – 161.

Hatibu, N., Young, M. D. B., Gowing, J. W., Mahoo, H. F. and Mzirai, O. B. (2003). Developing improved dry land cropping systems for maize in semi-arid Tanzania. Part 1: Experimental evidence of the benefits of rainwater harvesting. *Journal of Experimental Agriculture* 39 (3): 279 – 292.

Hicks, D. R. and Cloud, H. A., (2001). Calculating grain weight shrinkage in corn due to mechanical drying. [http://corn.agronomy.wisc.edu/Management/pdfs/NCH61.pdf]. Site visited on 17 May 2012.

Hill, P., (2003). Optimum Soil pH for Crop Plants. [http://www.agric.wa.gov.au/objtwr/imported_assets/content/fcp/fn047_2002.pdf]. Site visited on 5/12/2012.

Hokmalipour, S. and Darbandi, M. H. (2011). Investigation of nitrogen fertilizer levels on dry matter remobilization of some varieties of corn (*Zea mays* L.). *World Applied Sciences Journal* 12 (6): 862 – 870.

Hokmalipour, S., Seyedsharifi, R., Somarin, S. J., Hassanzadeh, M., Janagard, M. S. and Mahmoodabad, R. Z. (2010). Evaluation of plant density and nitrogen fertilizer on yield, yield components and growth of maize. *World Applied Sciences Journal* 8 (9): 1157 – 1162.

Horwath. W. R. (2005). The Importance of Soil Organic Matter in the Fertility of Organic Production Systems. *Western Nutrient Management Conference*, 2005, Salt Lake City, UT, 6: 244 – 249.

Hoshang, R. (2012). Effect of plant density and nitrogen rates on morphological characteristics of grain maize. *Journal of Basic and Applied Science Research* 2(5): 4680 – 4683.

Huang, R., Birch, C. J. and George, D. L. (Ed.) (2006). *Water use efficiency in maize production – The Challenge and Improvement Strategies.* 6th Triennial Conference of the Maize Association of Australia, 2006. 7pp.

Ibeawuchi, I. I., Edna, M. N., Ofor, M. O., Anyanwu, C. P. and Onyia, V. N. (2008). Plant spacing, dry matter accumulation and yield of local and improved maize cultivars. *The Journal of American Science* 4(1): 11 – 20.

Idris, A. E. and Mohammed, H. I. (2012). Screening maize genotypes by genetic variability of vegetative and yield traits using compromise programming technique. *British Biotechnology Journal* 2(2): 102 – 114.

Igbadun, H. E. (2012). Estimation of crop water use of rain-fed maize and groundnut using mini-lysimeters. *Pacific Journal of Science and Technology* 13(1): 527 – 535.

Ikerra, S. T, Maghembe, J. A., Smithson, P. C. and Buresh, R. J. (1999). Soil nitrogen dynamics and relationships with maize yields in *Gliricidia*-maize intercrop in Malawi. *Plant and Soil* 211: 155 – 164.

Inamullah, N. R., Shah, N. H., Arif, M., Siddiq, M. and Mian, I. A. (2011). Correlations among grain yield and yield attributes in maize hybrids at various nitrogen levels. *Sarhad Journal of Agriculture* 27(4): 532 – 538.

IGC (2012). Grain Market Report. No.421. [www.igc.int]. Site visited on 4/6/2012.

IITA, (2012). Maize Production. [http://www.iita.org/maize]. Site visited on 01/06/2013.

Isinika, A., Ashimogo, G. and Mlangwa, J. (2003). Africa in Transition: AFRINT Country Report. In: AATF (2010). *Mitigating the impact of Drought in Tanzania: the WEMA Intervention.* Policy Brief. 4 pp.

Jones, J. B. (Eds.) (2003). *Agronomic Handbook: Management of Crops, Soils, and Their Fertility.* Boca Raton, Fla. CRC Press. 450 pp.

Kaliba, A.R.M., Verkuijl, H., Mwangi, W., Moshi, A. J., Chilagane, A., Kaswende, J. S. and Anandajayasekeram, P. (1998). *Adoption of Maize Production Technologies in Eastern Tanzania.* Mexico D.F: International Maize and Wheat Improvement Centre (CIMMYT), The United Republic of Tanzania, and the Southern African Centre for Cooperation in Agricultural Research (SACCAR). 32pp.

Kanton, R. A. L., Larbi, A., Buah, S., Kombiok, J. M., Ansoba, E., Asungre, A. P., Lamini, S. and Prasad, P. V. V., (2013). Effect of Nitrogen Fertilizer on Growth and Yield of Maize Varieties with Different Maturities in a Dry Agro-Ecology of Northern Ghana. [https://scisoc.confex.com/crops/2013am/webprogram/Paper81739.html]. Site visited on 26/12/2013.

Katsvairo, T. W., Cox, W. J. and Van Es, H. M. (2003). Spatial growth and nitrogen uptake variability of corn at two nitrogen levels. *Agronomy Journal* 95: 1000 – 1011.

Kean, E. G., Hamaker, B. R. and Ferruzzi, M. G. (2008). Carotenoid bioaccessibility from whole grain and degermed maize meal products. *Journal of Agriculture and food chemistry 56(21)*: 9918 – 9926.

Khan, H. Z., Iqbal, S., Iqbal, A., Akbar, N. and Jones, D. L. (2011). Response of maize (*Zea mays* L.) varieties to different levels of nitrogen. *Crop and Environment.* 2(2): 15 – 19.

Khuong, T. Q., Tan, P. S. and Witt, C. (2008). Improving of maize yield and profitability through site-specific Nutrient management (ssnm) and planting density. *Omonrice* 16: 88 – 92.

Kunjir, S. S., Chavan, S. A., Bhagat, S. B. and Zende, N. B. (2007). Effect of planting geometry, nitrogen levels and micronutrients on the growth and yield of sweet corn. *Crop Protection and Production* 2(3): 25 – 27.

Kuzaksiz, T. (2010). Adaptability of some new maize (*Zea mays* L.) cultivars for silage production as main crop in mediterranean environment. *Turkish Journal of Field Crops* 15(2): 193 – 197.

Landon, J. R., (Eds.) (1991). *Booker Tropical Soil Manual. A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics.* Longman, Inc., New York. 450 pp.

Lashkari, M., Madani, H., Arkadani, M. R., Golzardi, F. and Zargari, K. (2011). Effects of plant density on yield and yield components of different corn (*Zea mays* L.) hybrids. *American-Eurasia Journal of Agriculture and environmental Science* 10(3): 450 – 457.

Lines-Kelly, R., (2004). Plant Nutrients in the Soil. [http://www.dpi.nsw.gov.au/agriculture/resources/soils/improvement/plant-nutrients]. Site visited on 9/11/2012.

Liu, K. and Wiatrak, P. (2011). Corn (*Zea mays* L.) plant characteristics and grain yield response to N fertilization programs in no-tillage system. *American Journal of Agricultural and Biological Sciences* 6 (1): 172 – 179.

Liu, W. and Tollenaar, M. (2009). Physiological mechanisms underlying heterosis for shade tolerance in maize. *Crop Science* 49: 1817 – 1826.

Liu, W., Tollenaar, M. and Smith, G. (2004). Within row plant spacing variability does not affect corn yield. *Agronomy journal* 96: 275 – 280.

Lobell, D. B., Banziger, M., Magorokosho, C. and Vivek, B. (2011). Nonlinear heat effects on African maize as evidenced by historical yield trials. *Nature Climate Change* 1: 42 – 45.

Lomer, A. M., Ali-zade, V., Chogan, R. and Amiri, E. (2012). Effect of nitrogen on the growth levels and development of maize hybrids in the condition of amino acids application. *International Journal of Agriculture and Crop Sciences*. 4(14): 984 – 992.

Luque S. F., Cirilo, A. G. and Otegui, M. E. (2006). Genetic gains in grain yield and related physiological attributes in Argentine maize hybrids. *Field Crops Research* 95(2-3): 383 – 397.

Mabhaudhi, T. (2009). Responses of maize (*Zea mays* L.) landraces to water stress compared with commercial hybrids. Dissertation for Award of MSc Degree at University of Kwazulu-Natal, Pietermaritzburg, South Africa. 176pp.

Machado, S., Bynum, E. D., Archer, T. L., Lascano, R. J., Wilson, L. T., Bordovsky, J., Segarra, E., Bronson, K., Nesmith, D. M. and Xu, W. (2002). Spatial and Temporal variability of corn growth and grain yield: Implications for site-specific farming. *Crop Science* 42: 1564 – 1576.

Magdoff , F. and van Es, H. (Eds,) (2009). *Building Soils for Better Crops: Sustainable soil management*. Sustainable Agriculture Research and Education (SARE) Program and the United States Department of Agriculture. 294pp.

Makumba, W., Janssen, B., Oenema, O. and Akinnifesi, F. K. (2006). Influence of time of application on the performance of *Gliricidia* prunings as a source of nitrogen for maize. *Experimental Agriculture* 42: 51 – 63.

Malaviarachchi, M. A. P. W. K., Karunarathne, K. M. and Jayawardane, S. N. (2007). Influence of plant density on yield of hybrid maize (*Zea mays* L.) under supplementary irrigation. *The Journal of Agricultural Sciences* (3)2: 58 – 66.

Mallarino, A. P., Pagani, A. and Sawyer, J. E. (2011). Corn and Soybean Response to Soil pH Level and Liming. In: *Proceedings of the Integrated Crop Management Conference*. (Edited by Pringnitz, B. A.), 30 November – 1 December, 2011, Iowa State University, Ames, Iowa. pp. 93 – 102.

Mangelsdorf, P. C. and Reeves, R. G. (1938). The Origin of Maize. In: *Proceedings of the National Academy of SciencesVol.24, No.8.* (Edited by Wilson, E. B.), August 1938, Texas Agricultural Experiment Station and A. & M. College of Texas. pp. 303 – 312.

Masood, T., Gul, R., Munsif, F., Jalal, F., Hussain, Z., Noreen, N., Khan, H., Nasiruddin and Khan, H. (2011). Effect of different phosphorus levels on the yield and yield components of maize. *Sarhad Journal of Agriculture* 27 (2): 167 – 170.

McCann, J. (2001). Maize and grace: History, corn, and Africa's new landscapes, 1500-1999. *Society for Comparative Study of Society and History* 43(2): 246 – 272 pp.

McKenzie, D. C., Greenhalgh, S. E., Koppi, A. J., MacLeod, D. A. and McBratney, A. B. (2001). Cotton root growth in a compacted vertisol (grey vertisol) II: Correlation with image analysis parameters. *Australian Journal of Soil Research* 39: 1169 – 1181.

Mengel, K., and Arneke, W. W. (1982). Effect of potassium on the water potential, the pressure potential, the osmotic potential and cell elongation in leaves of *Phaseolus vulgaris*. *Physiology of Plant* 54: 402 – 408.

Mengel, K. (1992). Agricultural Productivity and Environmental Problems. In: *Nitrogen Metabolism of Plants*. (Edited by Mengel, K. and Pillbeam, D. J.), Oxford University Press, United Kingdom. pp. 1 – 16.

Mengu, P. G. and Ozgurel, M. (2008). An evalution of water-yield relations in maize (*Zea mays* L.) in Turkey. *Pakistan Journal of Biological Science* 11: 517 – 524.

Minot, N. (Ed.) (2010). *Staple Food Prices in Tanzania*. Proceedings of COMESA workshop, Maputo, Mozambique, 25 – 26 January, 2010. 15pp.

Miracle, M. P. (1965). Introduction and spread of maize in Africa. *Journal of African History* 6(1): 39 – 55.

Miracle, M. P. (1966). Maize in Tropical Africa. In: Smale, M. and Jayne, T. (2003). *Maize in Eastern and Southern Africa: Seeds of Success in Retrospect. Environment and Production Technology Division (EPTD) Discussion Paper No. 97.* International Food Policy Research Institute. 2033 K Street, N.W. Washington, D.C. 79pp.

Mkamilo, G. S. (2004). Maize-sesame intercropping in Southeast Tanzania: Farmers' practices and perceptions, and intercrop performance. Thesis for Award of PhD Degree at Wageningen University, Netherlands.

Monneveux, P., Zaidi, P. H. and Sanchez, C. (2005). Population density and low nitrogen affects yield-associated traits in tropical maize. *Journal of Crop Science* 5(2): 535 – 545.

Moraditochaee, M., Motamed, M. K., Azarpour, E., Danesh, R. K. and Bozorgi, H. R. (2012). Effects of nitrogen fertilizer and plant density management in corn farming. *ARPN Journal of Agricultural and Biological Science* 7(2): 133 – 137.

Mugendi, D. N., Mucheru-Muna, M., Mugwe, J., Kung'u, J. B. and Batiano, A. (2007). Improving food production using "best bet" soil fertility technologies in the central highlands of Kenya. In: *Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities*. (Edited by Batiano, A., Waswa, B., Kihara, J. and Kimetu, J.), Springer, Berlin. pp. 345 – 351.

Mugendi, D. N., Nair, P. K. R., Mugwe, J. N., O'Neill, M. K. and Woomer, P. L. (1999). *Calliandra* and *Leucaena* alley cropped with maize Part I. Soil fertility changes and maize production in the sub humid highlands of Kenya. *Agroforestry Systems* 46: 39 – 50.

Mugisha, J. and Diiro, G. (2010). Explaining the adoption of improved maize varieties and its effects on yields among smallholder maize farmers in Eastern and Central Uganda. *Middle-East Journal of Scientific Research* 5(1): 06 – 13.

Mussgnug, F., Becker, M., Son, T. T., Buresh, R. J. and Vlek, P. L. G. (2006). Yield gaps and nutrient balances in intensive, rice-based cropping system on degraded soils in the Red River Delta of Vietnam. *Field Crop Research* 98:127 – 140.

Mutezo, W. T. (Ed.) (2013). *Early crop growth and yield response of maize (Zea mays) to biochar applied on soil.* International Working Paper Series, No. 13/03, Natural Resource, Agricultural Development and Food Security International Network, 2013. 48pp.

Mwakalinga, H. A. and Massawe, W. (2007). *Report on Output Market Support.* Agricultural Council of Tanzania. 83pp.

Namakka, A., Abubakar, I. U., Sadik, I. A., Sharifai, A. I. and Hassas, A. H. (2008). Effect of sowing date and nitrogen level on yield and yield components of two extra early maize varieties (*Zea mays L.*) in Sudan Savanna of Nigeria. *ARPN Journal of Agricultural and Biological Science* 3(2): 1 – 5.

NBS. (2010). *National Sample Census of Agriculture: 2007/2008 Preliminary Report*. Tanzania Ministry of Finance, Dar es Salaam 27pp.

Nielsen, R. B., (2000). Corn growth and Development: What goes on from planting to harvest? [http://www.kingcorn.org]. Site visited on 10/3/2012.

Nuss, E. T. and Tanumihardjo, S. A. (2011). Quality protein maize for Africa: Closing the protein inadequacy gap in vulnerable populations. *Advances in Nutrition* 2: 217 – 224.

O'Brien, D., (2011). World Corn Supply-Demand Trends: An "At Risk" position. [http://www.agmanager.info/marketing/outlook/newletters/archives/GRAIN-OUTLOOK_05-03-11.pdf.]. Site visited on 12/11/2012.

O'Keeffe, K. (Eds.) (2009). *Maize growth and Development*. Department of Primary Industries, State of New South Wales (NSW). 50pp.

Olfs, H. W., Blankenau, K., Brentrup, F., Jasper, J., Link, A. and Lammel, J. (2005). Soil and plant-based nitrogen fertilizer recommendations in arable farming. *Journal of Plant Nutrition and Soil Science* 168(4): 414 – 431.

Onasanya, R. O., Aiyelari, O. P., Onasanya, A., Oikeh, S., Nwilene, F. E. and Oyelakin, O. O. (2009). Growth and yield response of maize (*Zea mays* L.) to different rates of nitrogen and phosphorus fertilizers in Southern Nigeria. *World Journal of Agricultural Sciences* 5 (4): 400 – 407.

Osmond, D. L. and Riha, S. J. (1995). Nitrogen fertilizer requirements for maize produced in the tropics: A comparison of three computer-based recommendation systems. *Agriculture System* 50: 37 – 50.

Oyarekua, M. A. (2013). Effect of co-fermentation on nutritive quality and pasting properties of maize/cowpea/sweet potato as complementary food. *African Journal of Food, Agriculture, Nutrition and development* 13(1): 7171 – 7197.

Paul, E. A. and Clark, F. E. (Eds.) (1996). *Soil Microbiology and Biochemistry.* Academic Press, San Diego, California. 340pp.

Petosic, D., Kovacevic, V. and Josipovic, M. (2003). Phosphorus availability in hydromorphic soils of Eastern Croatia. *Plant Soil Environment* 49(9): 394 – 401.

Pettigrew, W. T. (2008). Potassium influences on yield and quality production for maize, wheat, soybean and cotton. *Physiologia Plantarum* 133: 670 – 681.

Prajapati, K. and Modi, H. A. (2012). The importance of potassium in plant growth: A review. *Indian Journal of Plant Sciences* 1(2-3): 177 – 186.

Prasanna, B. M. (2012). Diversity in global maize germplasm: Characterization and utilization. *Journal of Bioscience* 37(5): 843 – 855.

Randjelovic, V., Prodanovic, S., Tomic, Z., Bijelic, Z. and Simic, A. (2011). Genotype and year effect on grain yield and nutritive values of maize. *Journal of Animal Science and Veterinary Advances* 10(7): 835 – 840.

Reed, A. J., Singletary, G. W., Schussler, J. R., Williamson, D. R. and Christy, A. L. (1988). Shading effects on dry matter and nitrogen partitioning, kernel number and yield of maize. *Crop Science* 28 (5): 819 – 825.

Rehm, G. and Schmitt, M. (1997). *Potassium for Crop Production.* Minnesota extension service publication No. FO-6794-C, University of Minnesota, College of agriculture, food and environmental science. 6pp.

Rockstrom, J., Karlberg, L. and Falkenmark, M. (2011). Global Food Production in a Water-Constrained World: Exploring 'Green' and 'Blue' Challenges and Solutions. In: *Water Resource Planning and Management* (Edited by Grafton, R. Q. and Hussey, K.), Cambridge University Press. pp. 131 – 152.

Ross, D. S. and Ketterings, Q. (2011). Recommended Methods for Determining Soil Cation Exchange Capacity. In: *Recommended Soil Testing Procedures for the Northeastern United States.* Cooperative Bulletin 493, University of Delaware. pp. 75 – 86.

Sadeghi, M. (2013). The determination of plant density on dry matter accumulation, grain yield and yield components of four maize hybrids. *International Journal of Agriculture and crop Science* 5(2): 109 – 114.

Sadler, E. J., Bauer, P. J. and Busscher, W. J. (2000). Site-specific analysis of a droughted corn crop: I. Growth and grain yield. *Agronomy Journal* 92 (3): 395 – 402.

Sanchez, P. A. (Eds.) (1976). *Properties and Management of Soils in the Tropics.* John Wiley and Sons, New York. 618pp.

Sangakkara U. R., Bandaranayake, P. S. R. D., Gajanayake, J. N. and Stamp, P. (2004). Plant populations and yield of rainfed maize grown in wet and dry seasons of the tropics. *Maydica.* 49: 83 – 88.

Sangoi, L. (2000). Understanding plant density effects on maize growth and development: An important issue to maximize grain yield. *Ciencia Rural.* 31(1): 159 – 168.

Sangoi, L. and Salvador, R. (1997). Dry matter production and partitioning of maize hybrids and dwarf lines at four plant populations. *Ciencia Rural* 27(1): 1 – 6.

Save the Children. (2003). *Report on Zanzibar Household Economy.* 456pp.

Schroder, J. J., Neeteson, J. J., Oenema, O. and Stuik, P. C. (2000). Does the crop or soil indicate how to save nitrogen in maize production? Reviewing the state of the art. *Field Crops Researches.* 66: 151 – 164.

Schumacher, B. A. (Eds.) (2002). *Methods for the Determination of Total Organic Carbon (TOC) in Soils and Sediments.* United States Environmental Protection Agency, Las Vegas. 25pp.

Shafi, M., Bakht, J., Ali, S., Khan, H., Khan, M. A. and Sharif, M. (2012). Effect of planting density on phenology, growth and yield of maize (*Zea mays* L.). *Pakistan Journal of Botany* 44(2): 691 – 696.

Shanti, K. V. P., Rao, M. R., Reddy, M. S. and Sarma, R. S. (1997). Response of maize (*Zea mays* L.) hybrid and composite to different levels of nitrogen. *Indian Journal of Agricultural Science* 67: 424 – 425.

Sharifai, A. I., Mahmud, M., Tanimu, B. and Abubakar, I. U. (2012). Yield and yield components of extra early maize (*Zea mays* L.) as influenced by intra-row spacing, nitrogen and poultry manure rates. *Bayero Journal of Pure and Applied Sciences* 5(1): 113 – 122.

Sharifi, R. S., Sedghi, M. and Gholipouri, A. (2009). Effect of population density on yield and yield attributes of maize hybrids. *Research Journal of Biological Sciences* 4(4): 375 – 379.

Shiferaw, B., Kebede, T. A. and You, L. (2008). Technology adoption under seed access constraint and the economic impacts of improved pigeonpea varieties in Tanzania. *Agricultural Economics* 39: 1 – 15.

Shiluli, M. C, Macharia, C. N. and Kamau, A. W. (2003). Economic analysis of maize yield response to nitrogen and phosphorus in the sub-humid zones of Western Kenya. *African Crop Science Journal* 11(3): 181 – 187.

Shin-Gu, K., Yussuf, J. K., Mariam, J. A., Soon-Kwon, K. and Tae-Seon, P. (2011). Introduction and selection of improved open-pollinated maize varieties in Zanzibar. *Korean Journal of International Agriculture* 23(1): 102 – 108.

Shrestha, J. (2013). Effect of nitrogen and plant population on flowering and grain yield of winter maize. *Sky Journal of Agricultural Research* 2(5): 64 – 68.

Subedi, K. D., Ma, B. L. and Smith, D. L. (2006). Response of a leafy and non-leafy maize hybrid to population densities and fertilizer nitrogen levels. *Crop Science* 46: 1860 – 1869.

TFSNAS (2012). *Comprehensive Food Security and Nutrition Assessment Report of the April, 2012 Main (Masika) Season.* Disaster Management Department, Prime Minister's Office and The National Food Security Division, Ministry of Agriculture Food Security and cooperatives, Dar es Salaam. 30pp.

Tekwa, I. J. and Bwade, E. K. (2011). Estimation of irrigation water requirement of maize (*Zea mays* L.) using pan evaporation method in Maiduguri, North Eastern Nigeria. *CIGR Journal* 13(1): 1 – 7.

Thimme, G. P., Manjunaththa, S. B., Yogesh, T. C. and Satyareddi, S. A. (2013). Study on water requirement of maize (*Zea mays* L.) using CROPWAT Model in Northern Transitional Zone of Karnataka. *Journal of Environmental Science, Computer Science and Engineering and Technology* 2(1): 105 – 113.

Tisdale, S. L., Nelson, W. L., Beaton, J. D. and Havlin, J. L. (Eds.) (2004). *Soil Fertility and fertilizers: An introduction to nutrient management.* Prentice Hall. 528pp.

Tripathi, K. K., Warier, R., Govila, O. P. and Ahuja, V. (Eds) (2011). *Biology of Zea mays.* Indian Ministry of Environment and Forests and Indian ministry of Science and Technology. 27 pp.

Tuaeli, E., Mmbaga, and Friesen, D. (2003). Adoptable maize/legume systems for improved maize production in northern Tanzania. *African Crop Science Conference Proceedings* 6: 649 – 654.

Turi, N. A., Shah, S. S., Ali, S., Rahman, H., Ali, T. and Sajjad, M. (2007). Genetic variability for yield parameters in maize (*Zea mays* L.) genotypes. *Journal of Agricultural and Biological Science* 2(4): 1 – 3.

Uchida, R. (1999). Essential Nutrients for Plant Growth: Nutrient Functions and Deficiency Symptoms. In: *Approaches for Tropical and Subtropical Agriculture* (Edited by Silva, J. A. and Uchida, R.), 2000, College of Tropical Agriculture and Human Resources, University of Hawaii, Manoa. pp. 30 – 55.

Van Heerwaardena, J., Doebley, J., Briggs, W. H., Glaubitz, J. C., Goodman, M. M., Gonzalez, J. J. S. and Ross-Ibarra, J. (2010). Genetic signals of origin, spread, and introgression in a large sample of maize landraces. In: *Proceedings of National Academy of Science Vol. 108, No. 3.* (Edited by Piperno, D. R.), 9 December 2010, Smithsonian National Museum of Natural History and Smithsonian Tropical Research Institute, Fairfax, VA. pp. 1088 – 1092.

VerEcke, D. H., (2011). What is the Nutrition Value of Corn? [http://www.livestrong.com/article/18783-nutritional-value-corn/#ixzz 2X7PVlSR7]. Site visited on 6/8/2012.

Wajid, A., Ghaffar, A., Maqsood, M., Hussein, K. and Nasim, W. (2007). Yield response of maize hybrids to varying nitrogen rates. *Pakistan Journal of Agricultural Science* 44(2): 217 – 220.

Wakeel, A., Aziz, T., Aziz, T. and ul-Hassan, A. (2005). Growth and potassium uptake by maize (*Zea mays* L.) in three soils differing in clay contents. *Emirates Journal of Agricultural Science* 17 (1): 57 – 62.

Walworth, J. L., (2011). Soil Sampling and Analysis. [cals.arizona.edu/pubs/crops/az1412.pdf]. Site visited on 19 May, 2012.

White, J. (Ed.) (2003). Potassium Nutrition in Australian High-Yielding Maize Production systems. *Review Paper Presented at the 5th Australian Maize Conference,* Toowoomba, Queensland, Australia, 18 - 20 February, 2003. 16pp.

Yilmaz, S., Gozubenli, H., Konuskan, O. and Atis, I. (2007). Genotype and plant density effects on maize yield. *Asian Journal of Plant Science* 6(3): 538 - 541.

Yoshida S. (1993). Rice. In: *Potential Productivity of Field Crops Under Different Environments* (Edited by IRRI), Los Banos, Philippines. pp 103 – 127.

Zamir M. S. I., Ahmad, A. H., Javeed, H. M. R. and Latif, T. (2011). Growth and yield behaviour of two maize hybrids (*Zea mays* L.) towards different plant spacing. *Cercetari Agronomice in Moldova* 2(146): 33 – 40.

Zanzibar Ministry of Agriculture and Natural Resources. (2012). *Zanzibar Food Balance Sheet Report 2007 – 2011.* 35 pp.