EFFECT OF SPACING AND NUMBER OF PLANTS PER HILL ON GROWTH AND YIELD OF SC DUMA 43 IN THE COASTAL LOWLANDS

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DECLARATION & RECOMMENDATION

Declaration

This thesis is my original work and it has not been presented for a degree or any other award in any other University

Signature: Date: 20th September 2021

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AGR-3-0894-3/2013

Recommendation

We confirm that the work reported in this thesis has been carried out by the candidate under our Supervision.

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DEDICATION

Dedicated to my late parents Margaret Imali and James Ochami.

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To my departed Dad and Mum, my siblings, wife Rita, daughters Winfred, Prudence and Bridgette thank you for moral and financial support accorded to me throughout the years and finally to my colleagues and friends for their words of encouragement.

ABSTRACT

Maize (*zea* mays *L*.) is an important cereal grain globally as feed, and food for human and livestock respectively, rated third after wheat and rice in terms of production. The per capita consumption is 103 kg per person annually in Kenya, at the coastal lowlands it is rated first ahead of cassava and sweet potatoes. Maize is a rich source of carbohydrates, proteins, fats and minerals for the inhabitants of sub-Saharan Africa. Maize production at coast is constrained by inadequate knowledge of agronomic practices such as spacing, plants per hill, crop management, limited arable land and choice of suitable cultivar choice and climate change. This study was conducted at Sugar Research Institute farm, Kikambala sub-county, Kilifi County between May and November 2015 and 2016 cropping seasons, to evaluate the effect of four inter row spacing S1 (60 cm), S2 (70 cm), S3 (80 cm) and S4 (90 cm) and the number of plants per hill of 1, 2 and 4 as a second factor tested for effect on the growth and yields of the hybrid maize variety SC DUMA 43. Randomized complete block design (RCBD) in a split – plot arrangement was used with 3 replicates. The parameters investigated were plant height, stem diameter, cob length, weight of 1000 seeds, and grain yields per hectare. The data was summarized in MS Excel and analyzed using SPSS version 20 for ANOVA and LSD. Spacing and interaction between spacing and number of plants per hill did not show a significant effect on plant height, plant diameter and cob length. However, an inter – row spacing of 70 cm gave a significantly lower mean weight of 1000 seeds (312.48 g) against a highest mean value of 342.60 g for 80 cm which was however, not significantly different from the means obtained with 60 and 90 cm. The number of plants per hill significantly affected all growth and yield parameters with the highest grain yield recorded for 2 plants per hill (6543 kgha-^{1}) against a lowest mean value of 4575.4 kgha^{-1} obtained with 4 plants per hill. Stem diameter, cob length, weight of 1000 seeds decreased significantly as the number of plants per hill increased. Based on the findings of this study, it was concluded that for higher grain yields with the variety SC DUMA 43, planting should be done at 2 plants per hill and a spacing 80 × 30 cm.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

ASAL	Arid and Semi-Arid Lands
cm	centimeter
DM	Dry Matter
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agriculture Organization corporate Statistical Database
HI	Harvest Index
kCal	kilo Calories
LSD	Least significance difference
MoALF	Ministry of Agriculture, Livestock & Fisheries
SPSS	Statistical Packages for Social Scientists
SSA	Sub Saharan Africa
ppm	parts per million
KAPP	Kenya agriculture productivity project
KAPAP	Kenya agricultural productivity and agribusiness project

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Maize (*Zea mays* L.) is ranked third most important cereal crop after rice and wheat in the world in terms of production, due to its associated vast productivity and adaptability nature (Enujeke, 2013). On the global scale maize is grown under a wide range of environmental conditions, however it yields well under moderate temperatures provided there is satisfactory nutrients and moisture levels. Fundamentally, it is predominantly a tropical crop but currently it is being grown across diverse climatic conditions; in the temperate, sub-tropic, and tropical regions of the world. According to FAOSTAT (2014) maize is the principal cereal crop occupying approximately 20% of food crops harvested area, a principal staple food for about 1.2 billion inhabitants of Sub-Saharan Africa (SSA) and Latin America. Approximately over 300 million Africans depend on maize solely as their staple food, where it forms an estimated 30% source of dietary calories and fiber. In addition, at household level it accounts for 30 - 50% amongst the low-income family's daily food expenditure on the African continent.

In developed countries, maize acts as a source of industrial raw materials for production of finished goods for instance carbohydrates, dextrose, bio fuel and contributes a greater component (percentage) of livestock feed. Therefore, maize has become an extensively and essential commercialized crop in terms of feed, food and industrial raw material purposes playing a critical role on Global, Africa and Kenya's economies. In the Eastern

Africa, Ethiopia is the leading maize producer in the region, trailed by Tanzania and Uganda which have below to average quantities surplus while Kenya, Rwanda and Burundi are deficient (FAOSTAT, 2014).

In Kenya it's a main food crop for most households where it acts as main source of livelihood both for employment, and income especially for the majority of rural households. Its importance is emphasized since it forms a major component (percentage) of our country's national food security and strategic grain reserves, where out 3 million of the 5 million 90 kg bags of cereal grains is maize. In addition, the Kenyan government through state department of agriculture under ministry of agriculture continues to allocate approximately Ksh. 2 billion annually for purchase of this reserves both from farmers locally, and imports from abroad (Government of Kenya (Gok, 2013). Food security and general well-being of a larger rural population of Kenyans is dependent on the productive capacity of the crop especially the small holder farmers for subsistence consumption and surplus for the market. Maize alone as a crop contributes over 25% of direct agricultural employment and more than 20% of all agricultural production in the country (Ouma & De Groote, 2011). It's cultivated extensively in Kenya, where it is consumed by over 78% of the 40 million people in various forms; boiled, baked, pounded, roasted or fermented, and mixed with other food recipes. On average annual consumption is 90 kg per person, (Ministry of Agriculture, Livestock and Fisheries (MOALF), Economic review of agriculture (ERA) report, 2015). Maize is also a key ingredient of feed for livestock, the stem, foliage, grain, and immature cobs are consumed by diverse species of livestock as either fodder and silage it supplies them with energy, making entire maize plant parts useful as feed and food (Enujeke, 2013).

In Kenya, Maize is cultivated in over thirty counties, with commercial cultivation done in Trans Nzoia, Uasin Gishu, Kericho, Nandi and Bungoma counties contributing larger portion of annual maize yields. Corn is adapted for cultivation on vast agro-ecological conditions from the coastal lowlands to the central highlands of Kenya. Maize thrives best at temperatures above 15-30 ^{0}C, it grows well under annual precipitation range 600 to 800 mm per annum provided its well distributed throughout growing period. However, in areas with low precipitation (dry lands) such as lower Eastern parts of Kenya; Machakos and Kitui adaptable varieties (Katumani, DH0 4) have been developed for cultivation (Kitonyo, 2010). It can be cultivated on wide range of soils from clay loams, black cotton soils, sandy to sandy loams, but performs well on soils that are rich in nutrients, well drained and aerated with soil pH. 5.5 - 8.5. In Kenya maize is essentially cultivated under rain fed conditions on small and large portions of arable land. Small scale farmers produce approximately over 75% of the country's maize production on farm units of less than twenty (<20) acres of land mainly. While large-scale farmers, and commercial farms contribute 25% which forms a significant proportion of the marketed maize and seed production (MOALF, ERA report, 2015). However, only a small portion of maize is cultivated under irrigation especially maize meant for seed production by seed merchants and seed producing companies. Maize is produced for both subsistence and market with small scale holder selling approximately 20% of their annual produce (International Maize and Wheat Improvement Center (CIMMYT, 2015).

Kenya as a country has engages approximately 2.1 million hectares of land for maize production out of 5.3 million hectares of all crops harvested, this translates to 40% occupancy of all crop area by maize (FAOSTAT, 2014). Country's average annual total yield is estimated at 34 million 90 kg bags against a requirement of 37 million 90 kg bags leaving a deficit of 3-4 million 90 kg bags, which are met through imports from abroad and neighboring countries like Ethiopia and Tanzania (GoK, 2014). Maize yield in the last five years 2013-2018 has fluctuated with highest yield of 42.5 million 90 kg bags realized in the year 2015, cultivated on relatively reduced acreage of land compared to years 2013 and 2014 table 1.1. The high yield (2015) was due to bumper harvest attributed to favorable weather conditions (precipitation) across the country and more so in high potential areas of the country. The fluctuation in maize production in the country in last five years can be explained by factors associated with environmental conditions, crop production technologies and yielding potentials of individual varieties. It is projected that country's demand from maize will reach 50 million 90 kg bags in the year 2025 due population increase and other user related demands especially as an ingredient of livestock feed (FAOSTAT, 2014).

Table 1.1

Maize production trends in Kenya 2013 – 2018

Year	Area harvested (ha)	Yield 90 kg bags (millions)	Average yield per hectare
2013	2,123138	40.1	18.8
2014	2,116141	39.	18.4
2015	2,098240	42.5	20
2016	2,337586	37.1	15.8
2017	2,092459	32	15.2
2018	2,141743	44	20.5

Source: FAOSTAT 2018

The average maize national output is estimated at 1.8 t ha^{-1} tons per hectare (t ha^{-1}), however a potential output of over 6 t ha^{-1} is achievable especially in country's high potential areas (Schroeder et al. 2013). The national average maize yield is low compared to 3.9 t ha^{-1} in the neighboring Ethiopia and other world leading Zea *mays L.* growing countries such as Italy at 9.6 t ha^{-1}, USA 8.6 t ha^{-1} and China 5.6 t ha^{-1} respectively (Zamir et al., 2011). According to Food and Agriculture Organization (FAO, 2012), maize yield on African continent was estimated to average at approximately 2.1 t ha^{-1} which was much lower compared to other continents, Americas 6.3 t ha^{-1}, Asia and Europe at 5.0 t ha^{-1} and world's average of 4.9 t ha^{-1}. A number of factors have been linked to the low yield in Africa, these are; abiotic factors (sporadic drought, inherent low soil fertility), biotic factors (sporadic pests (locusts) and disease infestation. Social economic factors; such as unfavorable agricultural and economic policies for resource poor farmer who form the bulk of the producers, accessibility and affordability of farming inputs among others and low improved technology use and adoption. Total maize yield and production per unit area in Kenya is influenced by various components such as reduction in total area planted and productivity per unit area. This is due to fact that there is a limited extent to which land under maize cultivation can be expanded, since arable land is diminishing, while the remaining land is of marginal quality in terms of soil nutrients and precipitation, and therefore not suitable for maize growing, land subdivision due to population pressure and urbanization (Kenya Soil Survey, 1987). In Kenya maize production faces similar production challenges with fluctuating annual yields observed in period 2013-2018 (tables 1.1). Some of the main constraints include low soil nutrient fertility, pests and disease outbreaks for instance maize lethal necrosis disease (MLND) and changing rainfall patterns in country's leading maize producing agro ecological zones, low input accessibility and affordability by resource poor small holder farmers, low adoption levels of improved farming technologies and unfavorable marketing policies by government (CIMMYT, 2015).

Among the important food crops in the coastal lowlands of Kenya, maize is rated first followed by cassava and sweet potatoes (Shuma et al., 2010). Maize crop farming is spread across all coastal lowlands agroecological zones, emphasizing its importance as a preferred social and economic enterprise in the region (Wekesa et al., 2003). Two counties Kilifi and Kwale of the former Coast province account for over 50 % of the maize produced in the region (Kenya Coast Development Project (KCDP, 2015; Muli et al., 2013). Just like on the national scale, small holder farmers in region account for the production of over 75% of maize grain produced on land acreages measuring less than 20 acres purely under rainfed crop production systems in the region (Muli et al., 2013).

Wekesa et al. (2003) reported that *Zea mays L* is also cultivated semi-arid and arid lowland regions (ASAL), areas previous considered less suitable for maize production in early 1960s. More recently, maize production in the ASALS is also done using water conservation and harvesting conservation technologies (tied ridges and zai pits) though at small scale (Muli et al., 2013). The total area of Kenya's coastal region is estimated at 83,466 km^2 of which only 4,750 km^2 (approximately 6%) fall under crop production (Shuma et al., 2010) with an estimated population of 3,325,307 (POP census, 2009). According to Muli et al. (2013), annual maize requirement for the region is estimated to be 3.8 million 90 kg bags, however the region harvests less than 50% (1.5 million 90 kg bags) of maize needed leaving shortfall of 2.4 million 90 kg bags. The deficit is imported from other regions within the country and neighboring countries (Tanzania), this coupled with population increase makes availability of sufficient quantities of food to feed the growing population a major challenge. Despite maize been the most important food crop, the region only harvests an average yield of 1.06 tons/ha in contrast to a potential of 2.1 t ha^{-1} (MOALF, annual report, 2014). This translates to approximately 20 kg per person annually, while the average national maize food consumption per person in Kenya is estimated at 103 kg per person resulting in a large deficit and hunger, (CIMMYT, 2015).

The coastal lowlands are known to be comprised of diverse ecological potential ranging from the coastal lowland (CL) 2 to 6 within which soil types, soil fertility and rainfall regimes vary significantly (Wekesa et al., 2003). Given the existing maize production levels the region is rated as being self-insufficiency in terms of food production, the region is therefore characterized as food-deficient despite majority of the population investing in maize crop production for their livelihood. A number of reasons have been advanced for the low maize productivity in the coastal region; these include erratic rainfall, infertile and nutrient poor sandy soils, high temperatures, high prevalence of diseases and diseases, prohibitive input production costs, inaccessibility to inputs and technological gaps (Saha et al., 1994). Other factors associated with poor maize performance are; cultivar choice, field crop management regimes, low nutrient availability and losses emanating from sporadic pests and disease outbreaks.

The National and County governments have developed, and utilized diverse agricultural approaches under the Agricultural Sector Development Strategy (ASDP) to enhance food productivity especially in cereal crops (maize, beans, pigeon peas) with special concentration on staples; maize and beans along their production value chains. Initiatives adopted in Kilifi county to improve crop productivity include Kenya agricultural productivity program (KAPP, 2004) whose main objective was to improve dissemination and adoption of agricultural technology among the small holder and subsistence rural communities. Second follow up to KAPP (2004) initiative was the Kenya agricultural productivity and agribusiness project (KAPAP) implemented in the period 2009 - 2014 sponsored by government of Kenya and world bank, in the coast region target counties included Kilifi, Kwale, Tana River and Taita Taveta). The objective of KAPAP was to realize increased productivity and income among the small holder and subsistence farmers in rural areas, through empowering of stakeholders in the sector to transform small holder agricultural production systems. Another key initiative was the National Accelerated Agricultural Inputs Access Program (NAAIAP) a joint venture between public, private and development partners whose objective was to improve important inputs affordability and accessibility to millions of small-scale farmers to empower them so as to participate in agriculture as commercial occupation and get out of poverty (Gok, 2014).

Efforts have also been made to address research related technological challenges through local and international research organizations. Danda et al. (2015) reported research studies to address soil nutrient requirements, moisture stresses and diseases have largely been done by Kenya agricultural and livestock research organization (KALRO) and Maize and Wheat improvement Centre (CIMMYT) through collaborative research programs such as; Insect Resistant Maize for Africa (IRMA), Nutrient Use Efficiency (NUE), Water Efficient Maize for Africa (WEMA) and drought tolerant maize for Africa (DTMA) programs. Other studies have also focused on maize response to different crop management regimes such as fertilizer responses and selected varietal adaptation, maize cropping using water harvesting and conservation structures (tied ridges and Zai pits) in areas of Ganze and Bamba considered as arid and semi-arid areas within Kilifi county (Muli et al., 2013). According to Schroeder et al. (2013), Interventions to improve maize productivity in the region include increasing maize production on available land through adoption of modern farming technologies and crop management techniques. Therefore, future interventions to increase maize production in the region to bridge the deficit and meet increasing local demand will largely depend on, preferably improving grain yields per unit area of land rather than expansion of area under maize cultivation on the lands currently being cultivated, conversion of lands currently regarded as marginal and use of modern crop farming technologies such as ; adoption of climate resilient maize accessions, enhanced input use (fertilizer application) and chemicals use. Amongst these interventions, adoption of modern maize production technologies especially best agronomic management practices and choice of adapted varieties is of paramount importance.

1.2 Statement of the Problem

Maize is a cereal crop of great importance to inhabitants of coastal lowlands, however under current production and agronomic management practices maize grain yields are low. The average yields range between 1.02 -1.5 t ha^{-1} mainly harvested during the long rains season, which are far below the yield potential for the region of 2 – 3 t ha^{-1} under suitable crop management and cultivar choice (Muli et al., 2013). The low production levels create serious food deficits, region produces 149,000 metric tons annually against potential of 460,900 metric tons leaving a deficit of over 315,894 metric tons (Farm Concern International [FCI], 2015), which is sourced from other maize growing areas in the country and through imports from neighboring country Tanzania. In the coastal lowland the yield potential of maize is quite low due a number of factors including unreliable rainfall, soils are predominantly sandy in nature characterized with low moisture retention capacity and primarily low in fertility especially of major elements (Jaetzold & Schmidt, 1983). In addition, there is inadequate information on a review or improvement on current spacing and plant densities in advent of release new maize varieties. The present plant population (densities) and row spacing recommendations for the region are based on older maize varieties Pwani hybrid 4 (PH 4) 75 x 30 cm or 75 x 50 cm (53,333 plant ha^{-1}) and Coast composite (CC) 90 x 30 cm or 90 x 60 cm (37,000 ha^{-1}) at 1 and 2 plant per hill, which was released for commercial cultivation in 1995 and 1974 respectively (Saha et al., 1994). This varieties have given satisfactory grain yields though not optimum.

Previous researches have put emphasis on dissemination and adoption of new technologies especially newly released maize varieties, fertilizer rates and pest control, with little emphasis on other key agronomic components of crop yield such as spacing and planting densities in combination with other new maize production technologies (pest control) (Wekesa et al.,2003). Despite the existence of conventionally recommended spacing and plant densities for older hybrid varieties farmers continue to plant at different inter row spacing ranging 60 – 100 cm and sowing of 2- 6 plants per hill regardless of cultivar, this denies a given variety ability to yield to its full potential under given environmental conditions. Maize variety SC Duma 43 was released in 2004 and it compares favorably to older hybrids (PH1 and PH 4) in terms of period to maturity and productivity, in addition it possesses wide adaptability traits (table 3.1). It is currently sold by stockists in the region and cultivated by farming community across all coastal agroecological zones.

Significant knowledge gap exists on its appropriate row spacing and plant densities for this cultivar that gives maximum grain yield. Therefore, this study was formulated to determine the most suitable row spacing, number of plants per hill, and plant population per unit area that give maximum grain production under rainfed condition for hybrid maize variety SC Duma 43 in the coastal lowlands of Kenya.

1.3 General Objective

The overall objective of this experiment was to investigate effects of inter row spacing and number of plant(s) per hill on growth and yield of hybrid maize in the coastal lowlands.

1.4 Specific Objectives

i. To determine the effects of row spacing on growth and yield of hybrid maize.
ii. To determine the effects of plants per hill on growth and yield of hybrid maize.
iii. To determine interactive effects of row spacing and number of plants per hill on growth and yield of hybrid maize.

1.5 Hypotheses

The hypotheses of the study were:

I. There is significant difference in maize growth and yield due to different row spacing intervals.

II. There is significance difference in maize growth and yield due to number of plants per hill.

III. There is an interactive relationship between spacing and plants per hill on maize growth and yield.

1.6 Justification

Majority of small holder farmers in Kilifi County, Kikambala sub county are aware of improved maize production technologies such as new improved hybrid maize varieties, fertilizer use, crop management practices weeding and pest control measures. However, information on appropriate agronomic practices such as optimum plant density per given unit area of land using combination of spacing and number of plants per hill is inadequate. There exists an opportunity to improve maize yields through use of suitable hybrid variety by sowing and maintaining correct number of plants per hill at right inter-row spacing and proper crop husbandry practices. Appropriate and well packed information is useful to small holder maize farmers to realize improved maize yields in terms of grain and biomass for both subsistence use and surplus for income. The study will also form a base for further research on maize production related field issues such as post-harvest handling especially among small scale farmers and a reference material for extension workers of county government of Kilifi and coastal region. Ultimately the adoption of improved and appropriate agronomic production technologies for hybrid maize such as optimum number of plants per hill and row spacing, offers an opportunity to increase maize production per unit area of land, raise income and improve livelihoods for the rural small holder farmers in Kilifi county of the coastal lowland's region.

CHAPTER TWO

LITERATURE REVIEW

2.1 Botany, Origin and Distribution

Maize is the most widely grown cereal crop that is, and annually produced more than any other cereal grain all over the world. Due to its wide adaptability and high yielding potential, it has become one of the most versatile emerging crops on the African continent since its successful introduction and adoption. On the global arena maize is also known as queen of cereals due to its highest genetic potential and multipurpose use. Additionally, it's the only food crop among the cereals that can be cultivated in diverse environments, cropping seasons and for different target purposes (industrial and subsistence). There are many types of maize white grain, yellow grain, baby corn, waxy corn, high oil corn, popcorn and quality protein maize among others, however white brain is popular and most cultivated in sub-Saharan Africa (FAO, 2012)

Botanically maize belongs to the Maydeae tribe of the grass's family ***Poaceae*** and genus "*Zea"* which is amongst its four species, *Zea mays L* is the most sought after due to its economic benefits. Its described as a monoecious determinate annual C4 plant, a large grass with a tall thick stalk having thicker internodes at base of the stem, bears 8 - 20 leaves which are long narrow arching, borne alternately and spirally arranged on the stem, edges are evenly ruffled and tapers towards the tip end (Zamir et al., 2011). Its root system is profusely branched capable of growing to 60 cm both laterally and in depth. Amongst its three types of roots; prop roots, seminal roots, the fibrous and adventitious roots emerging at the stem's lower nodes below the soil surface are the most active and effective roots of the plant.

As described by Belfield and Brown (2008) maize can attain plant heights in the range of 1.5 – 3m depending on the cultivar, period to maturity, crop management (fertilizer application, planting patterns) and area of adaptation. Essentially late maturing verities are taller while early maturing one tend to be shorter. Gobeze et al. (2012) in the tropic where crops growing season extended to 11 months some varieties attained a height of 7 metres. The stem gives rise to floral part which is monoecious in nature bearing both the male flower (staminate) and female (pistillate), male floral part terminates into tassel while female develops into a conical cob or ear upon which the grains (kernels) are formed. At maturity, mature cobs are harvested manually either by hand on small and medium scale farms and by mechanized combine harvesters on commercial extensive farming units.

Maize (*Zea mays*), also known as corn origin can be traced to central México where it evolved from a wild grass about 7000 years ago, where Native Americans domesticated it to a better source of human food and feed (Ranum et al., 2014). Though, maize is usually mentioned as having being introduced to continent of Africa by Portuguese as one of the numerous domesticated cops, when and how this happened cannot be established with certainty. However, following its successful introduction on the African continent, maize has advanced into Africa's most favorite and dominant food crop among the cereals (Kitonyo, 2010). In Kenya, the Portuguese introduced maize at the coast in the 15th

century (Chivatsi et al., 2002) it has transformed into chief food crop across the nation forming a large percentage of strategic grain reserves.

2.2 Chemical and Nutritional Quality of Maize.

Due to corn's chemical and nutritional quality, it's been referred to as ''queen of cereal'' based on its ability to provide carbohydrates, energy and minerals required for healthy human development. Corn is a multipurpose cereal grain, utilized as food for human beings, feed and fodder for various animals (poultry, livestock) and a source raw material for agricultural allied industries. According to FAO (2012), Maize kernel is composed of carbohydrates 72% in form of simple sugars such as fructose, sucrose and glucose, followed by protein 8 -10% inform of lysine and tryptophan essential in metabolic function in the body, fat at 4% and provides approximately 365 kCal/100 energy on density basis. It is also eaten as a vegetable especially sweet corn, a good source of vitamins A, C, D, essential minerals and rich in dietary fiber.

The entire plant can be utilized in production of both non-food and food products. In developed countries, maize is used as industrial raw material where different parts of maize plant used to manufacture several products; grain into starch, sweeteners, oil, beverages alcoholic drinks, stover - paper and yarn, pith into light packaging material, inner husks to cigarette papers, cobs processed into explosives, bio fuel nylon and synthetic rubber. (Ranum et al., 2014). In Africa only 5% of the maize harvested is processed into feed and other uses since 95% of the is consumed by human beings in various forms.

In sub-Saharan Africa and larger part of South America corn is the most extensively cultivated cereal, a staple food for a population of over 1.2 billion people and absorbs 30 to 50% of low-income household's expenditure in Southern and Eastern Africa, while in Kenya 78% of population of 48 million people consume maize in various forms roasted, boiled, pounded, ground and even fermented (FAO, 2012).

2.3 Environmental Requirements of Maize

Maize grows across an array of environmental conditions and most genotypes vary terms of period to maturity, tolerance to pests and diseases and have individual yielding ability based on the environments and accompanying crop management practices applied to them.

Based on altitude maize is adapted to cultivation in literally in all altitudes ranging from zero metres above sea level at the Coast to 2,200 m above sea level. However, if established in very high altitudes poor yields will be realized.

2.4 Rainfall, Soil Type and Temperature

Different maize varieties require varying amounts of moisture, nevertheless overall maize will perform well in regions receiving 600 - 900 mm amount of rainfall per annum, provided the moisture is well distributed throughout the crops growing period. It is critical that the maize crop should receive sufficient precipitation throughout the initial five weeks after planting for higher yields to be realized. Moisture deficiency at blossoming time will affect pollination and fertilization severely and cause lower crop yields. On the other hand, dry weather conditions are essential at harvest time and drying period to avoid rotting of kernel.

Maize thrives well in soils which have a warm temperature, well aerated, have good depth and internal drainage capable of maintaining good soil moisture levels. The ideal soils for maize cultivation are those with a pH range of 5.0 - 8.0., silt loam and with satisfactory balanced nutrients reserves and chemical properties capable of sustaining maize production. For large scale maize production, soil should have less than 10% sandy soils nor in excess of 30% clay and or clay loam soils. Soils exhibiting water logging tendencies are unsuitable for maize growing, since the crop cannot endure water logging conditions for a duration exceeding two days because it will wither and die off. Therefore, for a profitable maize farming enterprise, regular soil analysis is prerequisite.

Different varieties of maize have varying temperature regimes for optimal growth and production. At higher altitudes cold conditions are likely to prolong crop cycle, 30 °C is the optimal temperature that gives satisfactory crop yields. While high temperatures are detrimental because they predispose the plants to significantly higher transpiration and respiration rates and reduce crop yields.

In the world today, corn is domicile across the world's 166 countries having wide diversity of climate, soils, biodiversity and management practices. Total are under maize is cultivation is approximately 158 million hectares of land, yielding 785 million tons, as compared to other cereals average global productivity of maize is 4.96 t ha^{-1} per annum. Leading global producers are; United States of America (USA) 42%, while Africa continent contributes only 7% from 29 million hectares of land harvested annually (FAOSTAT, 2014). In Africa maize is cultivated on approximately 24% of the farmed land area with annual grain yields averaging about 2.1 tons per hectare. Leading producers on the African continent are Nigeria producing 33 million tons, followed by South Africa and Egypt, while in Eastern Africa region Ethiopia is the highest maize producer at 8.5 million tons annually. Since Africa's annual maize production is inadequate it imports 28 % of its annual requirements from other continent, because maize farming is done primarily under rainfed conditions and more often irregular rainfall and sporadic droughts cause crop failure resulting in food shortages and famines. In year 2014 Africa's total maize harvest was estimated at 40 million hectares with Nigeria producing 16% followed by Tanzania (FAOSTAT ,2014). In Kenya maize is cultivated on approximately 2 million hectares of land with annual production of 34 million 90 kgs bags against annual requirement of 37 million 90 kg bags (MOALF annual report, 2014). Worldwide maize consumption is approximately 116 million tons out of which 30% consumed (by humans) globally and 21% of this is consumed in the Sub-Saharan Africa (FAO, 2012).

In the sub-Saharan Africa various types of maize are grown, white maize, yellow maize and colored; over 90 % of maize cultivated on continent of Africa is white maize mainly for human consumption making it as staple food. However, in the southern part of Africa while white maize fetches prime markets prices, yellow maize is mainly processed into animal feed similar to most parts of Latin America (Abdalla, 2013). Annual maize consumption in most African countries averages slightly above 100 kg per person table 2.2, it is consumed in diverse forms depending on the country. In the Western, Eastern and Southern Africa it is processed and ground into flour for preparation of porridge, paste and also fortified with other food stuffs. Alternatively, fresh green maize is either roasted or boiled on the cob and in some parts of Kenya it is shelled and mixed with legume cereals such as beans and cowpeas.

Table 2.2

Average Maize consumption in selected sub-Saharan countries

Country	Per capita consumption kgs
South Africa	195
Malawi	181
Zambia	168
Zimbabwe	153
Lesotho	149
Swaziland	138
Kenya	103
Tanzania	73
Ethiopia	52
Uganda	32

(CIMMYT, 2015)

The main maize producers in sub-Saharan Africa are resource poor small holder farmers majorly under rainfed conditions cropping systems, predisposing the crop to prevailing environmental condition that influences ultimate yield realized. Corn is produced under diverse agricultural systems which include; monocrop, mixed farming as well as an inter-crop with legumes, sugarcane and other cash crops depending on agroecological zone. Maize production in Africa is constrained by biotic and abiotic stresses; biotic factors include insect pest infestation such as maize stalk borer, fall army worm among others, diseases like blights, head smuts, maize leaf necrotic disease (MLN) and parasitic weeds striga species which have been reported to cause yield losses of 20 – 90 % in the field, during post-harvest and storage (FAO, 2012). The major abiotic constraints of maize production in Africa are associated with frequents sporadic droughts, high evapotranspiration rates, decline in soil fertility and acidity, and climate change.

Interventions to improve maize production sub-Saharan Africa can be attained through; dedicating more arable and marginal area to maize crop, increasing yields per unit area of land, intercropping, cultivation of more cropping seasons per year, adoption of improved widely adapted climate resilient hybrid maize varieties, and reduced reliance on rainfed farming through enhanced irrigated agricultural production (Gobeze et al., 2012).

Maize farming is spread across all agroecological zones of Kenya, from the central highlands to coastal lowlands including areas considered to be marginal the arid and semi-arid lands (ASALS) areas. The main maize producing counties in the country are; the so-called “grain basket” Trans-Nzoia, Bungoma, Uasin Gishu, Kakamega Nakuru, Nyeri, Embu, Kirinyaga, Kwale and Taita-Taveta (CIMMYT, 2015).

In Kenya maize production is broadly partitioned into seven agro-ecological zones, principally based on mean annual precipitation, altitude, span of growing period and adaptation of varieties suited for the various zones. These zones are; low Tropics (zone I) dry mid altitude (Zone II), dry transitional (Zone III), moist mid-altitudes (Zone IV), Highland Tropical (Zone V), Moist Transitional zone (VI) and zone seven (VI) which includes Nairobi and part of Northern Kenya contributing less than 1% of annual total maize production in the country (CIMMYT, 2015; Kitonyo ,2010). The majority of area under maize cultivation in Kenya, which is approximately 31 % of the acreage under maize falls in zone V (five) accounting for 51% of maize harvested in the country. The coastal lowlands which lie in low tropics (zone I) accounts only for 4 % of the annual maize production in Kenya (CIMMYT, 2015). However maize production in Kenya is confronted by several challenges such as; reducing land sizes, declining soil fertility, unpredictable weather due to climate change, limited fresh water supply due to shrinking water sources and population explosion.

2.5 Coastal Lowland Ago -Ecological Zones.

The coastal lowlands of Kenya are segregated into five agro-ecological zones, maize is cultivated in all the five environments from the high potential coastal lowland 2 (Cl_2) suited for production of food crops and cash crop to coastal lowland CL_5 which is described as arid and semi-arid (ASAL) and ideal for water efficient crops such as sorghum, millet and livestock ranching (Wekesa et al., 2003).

The categorization of region into five Agro-Ecological Regions (AEZ) is based on similar and closely related features such as annual average precipitation, mean temperature, humidity and vegetation coverage. These zones include the following; Zone 2: Coconut-Cassava also defined as Coastal lowland (CL_2), this is the zone with highest crop production potential in the region and runs from the hinterland to low lying coastal plains, with an altitude range of 1- 450 m above sea level. Average annual temperatures are 24 °C and mean precipitation of 1300 mm per annum. Its highly suitable for crop production and dairy farming, domicile to cash crop farming especially fruit trees citrus, mango, coconut and cashew, horticultural crops (okra, eggplant and capsicum). Food crops that perform well here include upland rice, maize, cowpeas and green grams.

Zone 4: Cashew-Coconut - Coastal Lowland (CL_4), it has agricultural potential with the same crop types as the coconut-cassava zone but with slightly lower crop production potential compared to Coconut-Cassava Zone. It runs northwards laterally along the coastal plain up to Arabuko Sokoke forest, has a mean temperature of 24 °C and average precipitation of 900 mm per annum.

Zone 5: Livestock-Millet – (Coastal lowland (CL_5) -, this zone is reported as been of lower agricultural potential compared to cashew-coconut zone, the region is appropriate for dry land farming supporting drought tolerant crops (sorghum, millet) and ranching activities such rearing of livestock for beef, mean temperatures range between 25.0 to 27.2 °C and mean precipitation range of 700 to 900 mm per annum.

Zone: 6 - Lowland Ranching (Coastal lowlands *(*CL_6) the major activities within this zone are ranching and wildlife (including conservancy). The mean temperature is 27 °C and annual precipitation of 350 mm to 700 mm. This zone lies within altitude 90 to 300 m above sea level, the entire zone is characterized with little ground vegetation cover dotted with shrubs.

Zone 3: Coconut, Cashew Nut – Cassava (Coastal lowland (CL_3) this is described as medium agricultural potential zone, and it traverses across 2 constituencies Kilifi North and South and ideally it is the smallest zone in terms of surface area coverage. It is situated at an altitude between 30 m to 310 m above mean sea level, with mean temperature of 27 °C and mean precipitation of 900 mm per annum. The area has a similar potential for the crops found in the coconut-cassava and cashew-cassava zones.

Maize yield potential is influenced by rainfall regime, availability of balanced soil nutrient levels, crop management practices and genotype adaptability to particular area in which it is cultivated. Maize is the world most significant food crop supplying 5% of dietary energy requirement. In Africa, about 300 million people rely on maize as their staple food and source of dietary carbohydrates (FAOSTAT, 2012). Its importance in Kenya is emphasized by the fact that it forms approximately 70% of the strategic food grain reserve in Kenya and neighboring eastern Africa countries. Approximately 75% of the world population lack adequate food supply compared to 47% of the Kenyan population and 71% of the inhabitants of Kilifi county at the Kenyan coast (Ndiso et al., 2013). Maize is the only major crop that determines food security of Kilifi county and by large the entire county with over 75% of the population being dependent on its productivity for food, income earnings and livelihoods (Agricultural Sector Development Program (ASDP) annual report, 2012). Therefore, tackling maize production challenges in the county is synonymous with focusing on alleviation of food insecurity and improving livelihoods of the region's population.

2.6 Constraints to Maize Production at Kenyan Coast.

The main constraints *Zea mays L.* yields in the coastal lowlands include low fertility, water stress, fast regrowth of weeds (Saha et al., 2008). The soil water stress is associated with erratic and poor rainfall distribution that is bimodal in nature (Jaetzold & Schmidt, 2012). In addition, soils are predominantly sandy in nature, and therefore exhibits low water retention capacity, implying that crops cultivated on such soils often prone moisture stress during periods of low precipitation. According to Ndiso et al. (2013), soils in region are characterized as being low in organic matter, inadequate in major nutrients nitrogen and organic carbon. The regions humid conditions and soil fertility status coupled with rapid growth of weeds further compounds water moisture deficiency affecting not only plant growth but its productive capacity. Maize as a crop in the region is also prone to infestation by diverse species of diseases and pests; especially maize stalk borer, maize streak virus disease and large grain borer due to high temperatures and humid conditions. These contributes to substantial yield losses both in the field and at post-harvest handling. Approximate 50 % of yield losses emanate from insect infestation of the maize crop in the coastal region compared other parts of country due to the favorable tropical weather (humid) conditions of the region. In addition, some farmers continue to grow local maize land races such as (Kanjerenjere et al., 2002) among others despite availability of high yielding hybrids (Pwani hybrid 4 (PH 4) and Pwani hybrid 1(PH 1), DH 04, Duma 43). Some of the reasons advanced for preference of local varieties include taste superiority, good storage quality and easy source of seed for next planting season. Other factors limiting maize production are inadequate extension services, and social economic aspects such as affordability and accessibility to farm inputs given that main maize producer in the region are resource small holder farmers (Ouma & De Groote, 2011).

Several initiatives have been made to address some of the constraints to maize production. Kilifi county like the rest of Kenya has used various agricultural extension programs such as; national agricultural extension program (NAEP), train and visit (T & V), national agricultural and livestock extension program (NALEP) and farmers field schools (FFS) to educate farmers. NALEP'S objective was enhance participatory demand driven extension, using a multicultural approach in extension services provision on the pillars of accountability and transparency of resources management in the agricultural sector (GoK, 2014).

Another initiative was through Kenya agricultural productivity project, whose major purpose was to transform key systems of agricultural marketing and production among the stakeholders to enable empower small holder farmers increase agricultural productivity, with Kilifi county been one of target areas at the Kenyan coast besides Kwale, Taita Taveta and Tana River counties. Third key initiative was national accelerated agricultural input access program (NAAIP) a joint approach by private and public partnerships (PPP) with principal objective being to alleviate poverty and embrace agriculture as business venture through ensuring accessibility and affordability of primary inputs by millions of small holder farmers who form the bulk of population engaged in agricultural productivity (MAOLF GoK, 2014). Despite all these efforts targeted at raising agricultural production with specific emphasis on production of food crops (cereals), for maize which is motivated by its worth as an important economic and subsistence crop to the farmers, for accessibility of food at domestic level continued to be of a going concern. In addition, emphasis has focused on increasing crop productivity primarily based on provision of subsidized farm inputs; certified seeds of improved maize varieties, fertilizer while maintaining conventional farming methods. The liberalization of maize sector in the country, has resulted in many maize varieties being available to the farming community as supplied to the markets by seed merchants and agrovets. Some merchants even stock and sell maize seed not necessarily as per cultivar suitability for recommended agroecological region example hybrid 5 series (H513) for medium altitude are even planted in marginal environments. Also, some farming households continue to prefer local maize varieties due to diverse reasons including storage quality, taste and ease of availability of seed for next planting season (Ouma & De Groote, 2011).

Overall, many of the maize varieties in the market have generalized agronomic production guidelines (seed rate, spacing, and plant population) labeled on seed packet regardless of the region in which its marketed. Also, some farming households continue to prefer local maize varieties due to diverse reasons including storage quality, taste, ease of accessibility and availability of seed for subsequent planting season and experience that they have in its cultivation. De Groote et al. (2005) observed earlier improvement in grain yield in the coastal region was associated with adoption of improved hybrid maize cultivars and cultivation using recommended agronomic practices (fertilizers and timely weeding).

It is projected that by the year 2020 maize requirements in the sub-Saharan Africa is expected to surpass 55 million tons annually (FAOSTAT,2014). Therefore, to fulfill this anticipated high demand opportunities to improve maize production cannot be fully obtained only on already farmed land alone. Since an increase on land currently under maize is highly restricted, due to exponential population increase, environmental issues, urban development, decrease in availability of water resources and climate change (Gobeze et al.,2012). According to Mureithi (1996), maize production can be improved through; upsurge in area under maize, area extension through rehabilitation and reclamation of marginal areas, reducing areas under other cereal crops, intercropping maize with suitable crops, growing more crops per year and improving individual crop yields per unit area via planting multiple cropping seasons per year, adoption of wide adapted and early maturing hybrid maize varieties and optimization of improved maize agronomic packages.

Sustainable and successful maize production is reliant on the correct combination of production factors; correct choice of adaptable high yielding hybrid varieties, use of appropriate population densities, land preparation, fertilizer application, irrigation, chemical use, crop husbandry practices, harvesting, post-harvest handling, marketing and production technological transformations. Establishing the optimum spacing between neighboring rows and number of plants per hill offers various advantages and provides an opportunity to enhance crop productivity. It minimizes unnecessary competition between and within plants for available environmental resources; soil nutrients, soil water and solar radiation due equidistant plant arrangement (Lashkari et al., 2011).

A suitable planting arrangement resulting from narrower inter rows increases maize growth rate in the initial periods of the growing season due to a greater absorption of sunlight, better radiation use efficiency and enhanced grain yield. Grain harvested per unit area of land is an interplay of individual plant yield and population per unit area of land. At wider row spacing (low population) grain harvested is restricted by averagely low plant population, while at narrow spacing higher population (higher densities) yield reduction is majorly associated with higher number of aborted flowers and barren plants due to interspecific competition for resources at critical vegetative, development and production stages. Therefore, optimal plant density (spacing and plants per hill) ought to be sustained to effectively utilize the available resources; solar radiation, soil fertility and moisture for optimum crop yields.

2.7 Plant Spacing and Number of Plants per Hill.

In agriculture plant spacing is defined the number of crops plants planted in given unit area of land and is derived from distance between one plant and another, amongst, within and between rows.

2.8 Plant Spacing

Plant spacing has a vital function on growth and yield of maize. Appropriate plant spacing guarantees efficient utilization of sunlight and nutrients for optimum plant growth and development of above and below ground parts (Gobeze et al., 2012). Appropriate plant to plant and row spacing provides favorable environment for growth, development and yield of the crop; it minimizes plants competition for available resources nutrients in the soil, moisture and solar radiation due to equidistant plant arrangement.

According to Murányi and Pepo (2013), closer row spacing enhances maize growth rate during the initial period of the cropping season, resulting in better, higher interception and efficient utilization of solar radiation and resultant higher grain yield. Secondly, it promotes faster shading of the soil surface early in season, consequently its smoothers weeds and conserves soil moisture providing maize crop with an environment to maximize physiological processes (photosynthesis, pollination, anthesis) and growth rather than moisture been evaporated from the soil. In the contrast, closer row spacing may hinder performance of some crop cultural management practices such as weeding and other mechanical field operations (fertilizer application) especially on mechanized farms. Also, in over populated crop stands, the inter plant competition is unusually intense for light, air and available nutrients, whose outcome is mutual shading, promotion of apical growth and depressed productivity. In addition, it predisposes plants to lodging due to weak stems and it may also favor biomass yield at the expense of grain yield. In Kenya, Onyango (2009) observed reduced row spacing in *Zea mays L.* could enhance maize production per unit area of land by raising plant population provided there exist favorable weather conditions and proper crop nutrition (balanced soil nutrients). On the other hand, wide inter row spacing may not produce required plant population, which ultimately reduces grain harvest per unit area of land. Broader inter-row spacing promotes weed growth and biomass due to reduced ground cover, competition for resources moisture, and luxury availability of soil nutrients. The maximum yield that can be obtained on a given maize hybrid is dependent on appropriately spacing between and within rows complemented with right number of plants per hill in a given area. The appropriate plant spacing should be one that minimizes competition among plants for water, sunlight and nutrients, allows execution of cultural practices (weeding, fertilizer application) and creates a micro climate that minimizes the risk the associated with incidences of diseases and pests.

2.9 Plants Per Hill

Number of plants per hill coupled with intra row and inter row spacing gives plant population per unit area of land. It is important agronomic factor for successful maize production since its variation determines the total plant population per unit area. It has effects on the utilization of sunlight and nutrients for physiological processes such as;

photosynthesis and respiration which eventually affect individual yield components; cob length, seeds per cob, weight of kernel, cob yield and grain yield. Optimal number of plants per hill enables the plant to develop above and below ground components appropriately by exploiting available solar radiation, available space and water (Dahmardeh, 2011). Mashiqa et al. (2011) observed, higher number of plants per hill than optimum may cause undesirable interplant competition, mutual shading, encourage lodging due to weak stems, encourage barren panicles with a cumulative profound negative effect on grain yield. While lesser number of plants per hill may encourage luxury growth, wastage of space, underutilized growth nutrients and result in fewer number of cobs per given area resulting in reduced grain yield. Amin et al. (2014) reported that highest tonnage of maize 11.7 t ha^{-1} was reported at 3 seeds per hill at row spacing of 48 cm while lowest was recorded at same spacing at single plant per hill 6.5 t ha^{-1}, implying that grain yield reduced with decreased number of plants per hectare. Therefore, number of plants per hill is an important factor that can be manipulated to regulate the plant population per unit area required to maximize grain yield of maize genotype in a particular environment.

2.10 Plant Density

Plant density (population) may be defined as the number of individuals of a given species of plant / crop that occurs within a given unit of land. Plant density has a pronounced effect on crop growth, development and yield, often considered as an agricultural "input" in similarity other inputs such as seed (Gobeze et al., 2012). Plant density can be attained through manipulation of plant-to-plant distance within rows, distance from row to row and number of plants per hill. Plant population controls intensity for competition of available water and nutrients resources in the soil ensuring crop physiological processes are facilitated. An appropriate plant population, ensures that the crops canopy effectively covers the ground surface by overshadowing and suppressing the non-crop plants (weeds), in turn suppressing their photosynthetic ability and capacity to grow, hence making soil resources more available to the crop plants. According to Lashkari et al. (2011) number of plants per unit area tends to vary with crop farming systems, location, crop varieties and cropping patterns. Leaf surface area of genotypes influence number of plants per unit area, plants with larger leaf areas require fewer plants per unit area compared to those with smaller leaf areas. Shorter plants thrive well under closer (narrow) rows than taller plants. Based on soil fertility higher plants stands are suitable for high fertility area, while somewhat lesser plant stands are upheld in areas with low fertility and in intercrop farming systems.

Plant density is one of the most significant agronomic factors that influence crop performance in aspects of growth, development and production (yield). Amongst the member of the grass family, maize is highly sensitive to disparities in plant population than any other member of grass family (Lashkari et al., 2011; Sangoi, 2001). Plant density affects plant morphology, varies growth, developmental patterns and affects overall yield output. Maize grain yield is closely related to plant population, however there are limits to the extent to which plant density can be raised under tropics and humid environmental conditions. In the tropics, the probable plant densities that give satisfactory crop yields are in the range 65000 - 75000 plants per hectare. Plant population below 65,000 plant per hectare is not advisable since about losses of 10% are common under rainfed field conditions. on the other hand, in excess of 75,000 plants per hectare is unlikely to rise yield unless the yield potential is greater 13 t $ha^{-1}$and growing conditions (moisture, fertility, temperatures) are extremely favorable. But for environments predisposed to droughts, 60,000 plant per hectare or lower is suggested (Amin et al., 2014).

In low densities (wider spaced rows), many recent hybrid maize genotypes fail to tiller efficiently and may yield only single cob per plant. While at high densities (narrow row spacing) beyond the optimum intensifies interplant competition for water, nutrients and sunlight, which is detrimental to final yield because it promotes apical growth, initiates plant barrenness, and eventually reduce the number of cobs bared per plant and kernels set per cob (Zamir et al., 2011). According to Lashkar et al. (2011) in each cropping pattern there is often an optimal plant population that maximizes utilization of resources available, allowing the expression of optimum possible growth and yield of a variety on a given area.

2.11 Effect of Plant Density on Plant Height and Stem Diameter.

In maize plant height is a genetic trait and a key component in influencing the growth attained during the plants growing period. It is ascertained by length and the number of internodes. Depending on variety and environment under which it’s cultivated maize crop can attain a height between 0.3 m to 7 m. Sangoi (2001); Zamir et al. (2011) observed that late maturing varieties usually tend to be taller while early maturing varieties exhibited shorter stature, however in the tropics where the growing season varies between 3 - 10 months, some maize varieties (late maturing) can reach a height of 7 metres above the ground.

Previous research studies on different plant densities concluded that; planting maize at higher densities (narrow row spacing) resulted in higher mean plant height values compared to plants sown at lower plant densities (broad row spacing). Farnia et al. (2015) studying morphological traits of maize varieties under different plant densities concluded that different plant densities with different row spacing significantly regulated plant traits plant height and stem girth. Increasing plant density positively decreased stem diameter but increased plant height, cob length and weight. In Nigeria Enujeke (2013) working on effect of variety and spacing on growth characters of hybrid maize, observed plants sown at narrow intra row spacing for example 75 x 15 cm had higher growth plant heights than those sown at broader intra row spacing of 75 x 30 cm, however plants sown at wider row spacing had thicker stem girths and were of short stature in terms of height. Zamir et al. (2011) highest plant height was recorded at plant population of 111,111 (60 x 15 cm) plants per hectare and lowest on 55,555 plants ha^{-1} implying that rise in plant density positively increased plant height.

In contrast, Fanadzo et al. (2010) studying the effect of five planting densities while varying intra row spacing between 20 - 25 cm, reported that plant populations significantly affected plant height. In addition, short stature plants were observed at

narrow spacing of 50 x 20 cm equivalent to plant densities of 95,000 plant ha^{-1}, which investigators attributed to crowding effect of the plants and interspecific competition for available soil nutrients and water. Mashaqa et al. (2011) observed highest plant height (212.4 cm) on plant density 13,330 plant ha-1 and lowest 103.5cm (44,440 plants ha^{-1}) on early pearl maize variety, and concluded rise in plant density in a particular area competition amongst plants for sunlight interception and nutrient uptake also increased.
Stem diameter decreased with increase in plant density, at higher plant density stem diameters were less thick (thin) compared to lower plant density, which was associated to phenomenon called etiolation. Which is plant's growth in pursuit of solar radiation favoring apical growth and limited lateral growth. while at lower plant densities thick stem girths were linked to unrestricted lateral growth due to adequate sunlight illumination, soil nutrients and moisture. Ejuneke (2013) observed that plant sown at lower densities (75 x 35 cm) recorded higher stem girth than those sown at higher densities (75 x 15 cm), which the investigator concluded, the superior plant girth at low plant population was possibly due to availability of more resources soil nutrients, water and sunlight at lower plant population.

Kenya agricultural and livestock research organization (KALRO) has developed convectional guidelines for maize plant densities based on region that gives satisfactory yields, for the highlands 53,333 plants per hectare (spacing 75 x 25 / 50 cm), 44,444 plants per hectare (75 x 30 / 60 cm) for medium potential areas and for dry lands and coastal regions 37,850 plants per hectare (90 x 30 / 60 cm) based on 1 and 2 plants per hill respectively.

In the coastal region different plant densities continue to used and tended to vary with genotype, variety Coast composite gave satisfactory grain yield at 37,000 plants per hectare (90 x 30 /60 cm) when sown at one and 2 plants per hill respectively. While Pwani hybrid 4 (PH 4) hybrid at 53,333 (75 x 25 /50 cm) plants per hectare at similar plants per hill (Wekesa et al., 2003). Implying that hybrid maize cultivar are capable of yielding higher even at higher plant densities.

2.12 Effect of Planting Densities on Yield Components

Plant population affects yield by controlling growth and development of yield contributing traits such as; number of cobs per plant, cob length, cob diameter, number of kernels per cob, kernel weight and size. Low plant density may result in undesirable loss of yield and while higher densities than optimum may result in excessive stress on the plants per unit area. Plant density is reliant on row width and row spacing, too narrow spacing can intensify competition amongst plants and affect its yield adversely. Row width controls maize cultivation under dry conditions, as it plays an important role in defining plant density since it effects available moisture to the crop (Mashiqa et al., 2011). On the other hand, under optimum conditions of adequate moisture and nutrients supply, higher plant populations can give higher number of cobs per unit area and eventually enhanced grain yield.

Casini (2012) reported maize yield varied significantly under diverse plant population levels due to inherent genetic potentials of different cultivars and environmental conditions, for maize plant population that gave optimum economic grain yield ranged between 30,000 - 90,000 plants ha^{-1} depending on sowing date, available moisture, soil nutrients and days to maturity period of a given cultivar. Improved maize cultivars with good adaptations and endurance to high plant densities can absorb and utilize sunlight more efficiently causing noticeable rise in grain harvest. Increased plant population promote utilization of sunlight by maize canopies to great extent. At preliminary growth stages narrow spaced (dense) plants may promote utilization of solar radiation in initial vegetative stages, however in subsequent reproductive stages effective conversion of intercepted sunlight into economic yield reduces due to mutual shedding and limited growth resources (Gobeze et al., 2012).

2.13 Cob Length and Kernel (Seed) Weight

Cob length is one of the traits controlling yield in maize, cob length and diameter are principal components influencing harvested grain, change in plant population has a marked effect on cob diameter and length. Higher plant population, particularly beyond optimal level for a particular environment decreases cob length and diameter, kernel (seed) weight and finally grain yield. The variances in kernel weight at different plant population has been linked to variation in the preliminary size of the spikelet's and subsequent growth rate in the course of critical linear and exponential phases of grain accumulation.

Gobeze et al. (2012) reported at the beginning, grain mass after pollination was a determinant factor in the preliminary growth of the kernel. Thus, at high plant population seeds tended to be small due to a delay in development and a small original size of the spikelet's primordia. Implying that, ultimate seed weight was highly related to number of cells and starch particles made, especially in the endosperm tissue that develop into mature maize grains. Consequently, at high plant population yield may be affected due to restrictions in the ability of endosperm to grow either in size, number and inactivity of endosperm cells.

In Pakistan, Zamir et al. (2011) while evaluating effect of plant density and maize hybrids on yield traits of maize reported, both factors; cultivar and plant density significantly influenced number of cobs per plant, cob length and weight of 1000 seeds (gm) independently. A trend of decrease in number of cobs per plant, cob length and weight of 1000 seed (gm) was observed with increase in plant density. The authors further concluded there was a linear relationship between these traits and plant density, which they attributed to variable plant competition for soil nutrients, aeration and sunlight.

In Botswana, Mashaqa et al. (2011) working on effect of diverse plant populations on yield components and yield of early pearl maize variety, while varying intra and inter row spacing observed significant differences in cob size, grains per cob and yield. An increase in maize densities decreased number of seeds per cob and eventually grain yield.

2.14 Grain yield

Grain yield refers to economic portions of the crop reaped per unit area of land. Maize grain harvest is a sum total of yield components that comprise of plants per unit area of land, ears per plant, kernels per cob and kernel mass (Zamir et al., 2011). Therefore, yield of maize is obtained by number of cobs harvested and the mean weight of the grain on the cobs. Higher population per unit area offers an opportunity for utilization of available nutrients and moisture, and may result in increased economic grain yield of crops.

The plant population that gives maximum yield is dependent on variety choice, available soil nutrients, environment moisture and crop management practices. Depending on maize cultivar, the yield increases with increase in plant population till one or more influencing growth components becomes limiting such; as moisture, soil nutrients and other growth elements. Farnia et al. (2014) observed varying plant density significantly affected cob weight, length and mass of kernel alongside cultivar grown. In addition, authors suggested among the crop management aspects plant density strongly affected maize reproductive potential due to competitive effect exerted especially at critical reproductive (silking) and vegetative phases. It controls growth and development by influencing the numerous physiological activities plant's metabolism, interception of light by crop foliage and photosynthetic efficiency in transportation of assimilates to economic parts of the crop.

In Dera Ismail khan Iran, Abuzar et al. (2011) reported at low plant population some hybrid cultivars failed to tiller efficiently and frequently yielded a single cob per plant. However, planting at high population densities (narrow rows) resulted in increased competition amongst plants for light, nutrients and water that negatively influenced final yield. Since apical growth took prominence, induced bareness and reduced the number of cobs produced per plant and seeds/kernels per cob. Authors also observed that increase in plant density progressively and negatively impacted grain yield associated traits; number of grains per ear, individual kernel per row per ear and individual weights of grain and eventually contributed to reduced grain yield.

In South Africa Gobeze et al. (2012) reported maize grain yield followed a curvilinear response to plant density, maize grain yield increased upward of 75,000 per hectare and optimized at 100,000 plants per hectare, thereafter it progressively declined beyond the optimal density (10 plant m^{-2}). The decline in grain yield was not only limited to effect on agronomic traits like seed weight and number of ears per plants but also to effect on early reproductive stage such spikelet differentiation and fertilization, and dry seed weight. In addition, increased plant barrenness at high plant densities due to intense interplant competition within plants that inhibited carbon and nitrogen supply coupled with rise in barren plants reduced seed size and seeds per plant thus affecting grain yield. In Ethiopia, Abdalla (2013) investigated effect of varying plants per hill and inter row spacing, observed an increase in number of plants from 1-3 per hill, while reducing inter row spacing negatively impacted maize grain yield.

In the coastal lowland, previous researches indicated satisfactory grain yield at plant populations above 30,000 plants ha-^{1} (Wekesa et al., 2003). Saha et al. (1994) while investigating effect of nitrogen fertilizer, spacing and plant density on grain yield of hybrid maize cultivar pwani hybrid 1(PH1) (early maturing) reported yields of 2.4 tons per hectare at plant densities 67,000 plants ha-^{1} under nil fertilization, however with fertilizer application yield rose to 4.4 tha^{-1} (67,000 plants ha-^{1}) with application of 60 kg ha^{-1} of nitrogen fertilizer. Implying higher grain yield with hybrids is attainable at higher plant densities provided other inputs are not limiting.

2.15 Above Ground Biomass

Biomass comprises of dry weight of living material above or below soil surface per unit area of land at given period of time. There are four factors that determine the net biomass gain, these are the portion of that solar captured by green plant tissues, amount of incident sunlight, effective photosynthetic conversion of the captured light into biomass and losses of biomass due to respiration. According to Salisbury and Ross (1986), leaves are photosynthetic factory of plant and quantity of photosynthates accessible for biomass manufacture is controlled by surface area of the leaf and rate of photosynthesis of the crop. Gobeze et al. (2012) similarly, biomass being a product of various related genetic and environmental aspects. Its yield is directly related to growth and development potential of parameters like moisture availability, balanced nutrient supply, crop management practices and sunlight illumination. consequently, individual plants yield is reliant upon on these growth sustaining factors. In previous research satisfactory above ground biomass have been at plant densities range of 8 -10 plants per m^{-2} (80,000 - 10,0000 plants per hectare), with further increase beyond 10 plants m^{-2} resulting in leveling of biomass yield curve. Low biomass yield at plant densities less 10 plant m-^{2}, emerged due to fewer plants per unit area due to underutilization of environmental and growth resources.

Gobeze et al. (2012) indicated that biomass yield increased progressively as population increased per unit area of land and peaked at 100,000 plants ha^{-1} beyond which biomass declined at 125,000 plants ha^{-1}, this was attributed to reduced biomass production by individual plants and exhaustion of available resources. Authors further indicated for ultra-early maize with moisture levels calibrated at 10 plants per m^2, the decline in yield was attributed to moisture stress and genotype.

Casini (2012) investigating maize cultivar effect due to crop population and sowing dates on grain and biomass productivity, observed that biomass yield reduced with subsequent delays in planting dates. Highest biomass was observed on early planting with lowest yield obtained in later sowing. In addition, there was a difference in biomass yield among cultivars, and on interaction between planting dates and cultivar. Biomass yield increased gradually with consecutive increase in plant population and highest biomass observed at 120,000 plants per hectare. Implying that in certain environments in addition to plant density sowing date and cultivar choice influenced biomass yield.

However, Abuzar et al. (2011) working with different plant densities and maize variety Azam in Asia, reported biomass was significantly affected by population densities, populations of between 60,000 - 80,000 plants per hectare gave maximum biomass yield while lowest biomass was observed on population of 100,000 plants per hectare. Kaufman (2013) reported silage yields from maize increased as plant population increased so long as the amount of water and other nutrients were satisfactory. In addition, the population required to realize maximum silage dry matter yield is more than the one required to maximize grain yield, for example plant population of 88,000 plants ha^{-1} maximized grain and dry matter (DM) yield, however total DM yield was higher with a plant population of 125,000 plants ha-^{1}. Increasing plant population from 75,000 to

100,000 plants ha^1 significantly increased total DM yield, but a rise in population to 140,000 plants ha^{-1} did not raise DM yield any further. Therefore, biomass of maize is dependent on a sum of all growth factors; cultivar, plant population, row spacing and soil conditions which influence accumulation of the above-ground biomass and distribution between plant components. Implying biomass yield increased with increase in plant density but only declined when one of growth factors (nutrient, moisture) became limiting in a particular environment.

2.16 Harvest Index

Harvest index (HI)is the proportion of economic yield to above-ground dry matter (biomass), a valuable guide in identifying the biological efficiency and potential of a crop to transform total dry matter into economic yield (Abdalla, 2013). It signifies the efficacy of the plants to transform photosynthates to economically valuable form. Harvest index is a commonly used index and gives data on the association between economic and biological yields. Though, harvest index doesn't give detailed information on individual yield parameters such as; number of cobs, cobs length and diameter and grains per cob. For grain crops (maize, beans, wheat) harvest index has being defined on the basis of ratio of produced grain to entire shoot dry matter (grain and vegetative parts) and has commonly being used to estimate the productive efficiency of this crops. HI can be used to determine the variance between actual and potential yield of a given crop. Where the actual yield is maximum yield of a cultivar which could be obtained under given environmental condition and available resources. On the other hand, potential yield, is the realized yield of cultivar under an ideal environment with adequate moisture, balanced nutrients and free from disease and pests' stresses.

Generally enhanced grain yield in high yielding cultivars is attributed to the rise in their harvest index. Harvest indices of indigenous maize cultivars has been observed to range from 0.32 to 0.48 compared to mean of 0.52 in hybrids (Viorel et al., 2014). Harvest index is positively associated with grain yield and reduces with increase in plant population up to a certain optimal level due to resultant rise in plant lodging and barrenness.

Viorel et al. (2014) harvest index of corn varied due to influence of plant density in relation to location, cultivar and existing condition during growth of the crop. There was significant decrease in harvest index with increase in plant population within the locations, however different hybrid cultivars gave different harvest indices at same plant densities in different environments. Authors attributed variance in HI to existence of either favorable/ unfavorable growing conditions (adequate precipitation and nutrients) and preceding cop and tillage practices within the locations.

For Optimum grain yield of improved maize varieties to be attained, best agronomic practices must be applied amongst these plant population per unit area, row spacing and cultivar choice are prerequisite. Abdalla (2013); Zamir et al. (2011) observed plant spacing, both intra and inter row affected most growth and yield characters of maize even under optimal environmental conditions. It is regarded as a dynamic agronomic factor influencing the level of competition amongst plants and has consequences on growth, yield and on yield contributing traits of maize. Gobeze at al. (2012) observed despite the several studies done with the objective of establishing the definitive plant population for maize, there was no single recommendation which is applicable entirely to all maize varieties and across the different agroecological conditions. Since the optimal plant population differs due influence of environmental factors such as amount of precipitation, soil nutrient availability, crop husbandry practices and genetic makeup of a variety.

Therefore, this experiment was carried out to study the effect of varying row to row spacing and number of plants per hill under agro-climatic conditions of coastal lowlands on growth and yield components of hybrid maize variety SC Duma 43.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site Description

3.2 Location

The trial was carried out at sugarcane breeding station farm of the Sugar Research Institute in Mtwapa - Kilifi County, Kikambala Sub County, the research station is located 20 kilometers from Mombasa County off new Mombasa- Malindi highway. The trial was done during the long rains in 2015 cropping season. The site is located at an elevation of 15 meters above sea level, at latitudes 3° and 5° South, and longitudes 39° and 40° East.

3.3 Climate

Climatic conditions of the area are generally hot and humid with mean temperatures 23° and maximum 30°, mean relative humidity of 80%. Rainy season is experienced between April – December, with annual mean rainfall 1200 mm. The rainfall distribution is bimodal in nature with peaks in May and November respectively with low rainfall in August (Mtwapa Agromet weather station, 2015). Approximately 75% of the annual rainfall in the region is experienced during the long rains, making it most important cropping season.

3.4 Soils And Soil Analysis

The trial site was in coastal lowland zone Cl_3 also known as coconut and cassava zone. Soils are predominantly orthic ferrosols and rhodic (Jaetzold and Schmidt, 1983). Mureithi et al. (1995) described the soils to be low in organic matter and deficient in most of the critical soil nutrient elements such as; nitrogen (N), phosphorus (P) and potassium (K) due to been predisposed to leaching with soil pH range 5-7. Area is predominantly occupied by coconut trees and cassava plantation crops; however, soils are capable of supporting production of other crops such as maize, sugarcane, pulses and horticultural crops.

Soil sampling was done at depth of 0 - 15 cm using soil auger. The samples were air dried at room temperature for 7 days and analyzed for nitrogen %, available phosphorus(p), ppm, soil pH, Copper (Cu), ppm, Manganese (Mn) ppm, iron (Fe) ppm), and Organic Carbon % at KARLO - Sugar Research Institute agronomy laboratory. Soil test results (appendix 2) revealed mean soil pH 6.2 was slightly acidic, while chemical elements such as nitrogen % and organic carbon were very low and low respectively.

3.5 Experimental Procedures

The land was bush cleared, ploughed and harrowed, then the experimental area was demarcated into three blocks (replicates) of dimensions 60 m long x 4 m wide, separated by paths of 2 meter from each other (block to block). Each block was further sub divided to yield four (4) main plots measuring 15 x 4 m within the block, each main plot was further subdivided into 3 sub plots within main plot each measuring 3 x 4 m and separated with a path of 1.5 meters in between. This resulted in 4 main plots per block ,3 subplots within main plot(s) and therefore12 sub plots per block and a total of 36 subplots for the entire experiment. The experimental design employed for this study was Randomized complete block (RCBD) in split-plot arrangement of treatments and replicated three times. Factor one, which was four inter- row spacings were first randomly assigned to the main plots within the block (replicate) and thereafter factor 2 - number of plants per hill (1,2,4) were randomly assigned to the sub - plots within the main plot as designated in figure 1 below.

3.6 Experimental Plot Layout

Treatment's combinations were laid out in the experimental field as detailed in figure 1, with factor 1 (inter -row spacing) assigned to main plot (**bold border**), each row spacing was assigned a specific number and table of random numbers used to assign the treatment to main plots. Factor 2, which was number of plants per hill assigned to subplots within main plot using similar procedure as used in factor 1. Details are as illustrated in figure 3.1 1 below for example S1PH3 in plot one up to S2PH2 in plot 12 in block 1 (one).

Figure 3.1

Plot layout -spacing and plants per hill.

	Plot 1											Plot 12
R1	S1	S1	S1	S3	S3	S3	S4	S4	S4	S2	S2	S2
	PH3	PH2	PH1	PH2	PH3	PH1	PH1	PH3	PH2	PH1	PH3	PH2
					↕		Path					
R2	S3	S3	S3	S1	S1	S1	S2	S2	S2	S4	S4	S4
	PH1	PH3	PH2	PH3	PH1	PH2	PH2	PH1	PH3	PH1	PH2	PH3
R3	S4	S4	S4	S2	S2	S2	S3	S3	S3	S1	S1	S1
	PH2	PH3	PH1	PH1	PH3	PH2	PH3	PH2	PH1	PH3	PH2	PH1

Key:

R: **B**lock/replicate in this trial (R1- is block one/replicate one).
PH: Plant per hill (e.g. PH3 is 4 plants per hil)l.
S: Spacing (e.g. S3 means spacing of 80 × 30 cm).
S4PH3: Spacing 4 and 4 plants per hill.

3.7 Planting and Crop Management

Certified maize seeds bought from local agrovet shop, were sown in the experimental plots at depth of 2 - 3 cm under different plant spacing's 60 × 30 cm (S_1), 70 x 30 cm (S_2), 80 x 30 cm (S_3), 90 ×30 cm (S_4) figure 1. The hills were over sown with 3 - 6 seeds at planting and thinned out at 10 days after sowing to obtain desired number of plant (s) per hill as per treatment combination, as illustrated in (plate 1).

At planting double ammonium phosphate (DAP) basal fertilizer was applied to experimental plot as per recommended rates of 80 kg P_2O_5 ha^{-1} and calcium ammonium nitrate (CAN - 26% N) at rate of 100 kg N ha^{-1} top dressed at 6 - 8 leaf stage (knee height). The crop was weeded twice, at 4 - 5 leaf stage (3weeks after sowing) as shown in Plate 4 and second weeding at 8 - 10 leaf using a hand hoe. To prevent the attack of maize-by-maize stalk borer 2 applications of bull dock emulsifiable concentrate (EC) insecticide was applied at 3 - 4 leaf stage and repeat done at 6 - 8 leaf stage at rate 10 kg per hectare.

3.8 Cultivar Choice

The selected maize variety for this trial was SC DUMA 43 (table 3.1) it is classified as early maturity (4-5 months) white maize, yield potential 6 - 7 tons per hectare, its tolerant to drought, maize mosaic virus (MSV) maize blight and wider environmental adaptability and compares favorably) to other popular hybrid varieties Pwani hybrid 4 (PH4) and Pwani hybrid 1(PH1) in table 3.1.

Table 3.1

Hybrid maize varieties cultivated at the Kenyan Coast

No	Variety	Year of release	Maturity (months)	Yield potential (tons/ha)	Special features
1	Pwani Hybrid 1	1989	3 - 4	5 - 7	Tolerant to drought and lodging
2	Pwani Hybrid 4	1995	4 - 5	6 - 8	Heat tolerant and tolerant maize streak virus (MSV)
3	Dh 02	1995	3 - 4	4 - 6	Early and stay green
4	Dh 04	2001	3 - 5	4 - 6	Early and short
5	SC 43 Duma	2004	4 - 5	6 - 7	Early, drought resilient, ear rot MSV and blight, wide adaptability scope

Source: KEPHIS. National variety list 2015. https://www.kephis.org

3.9 Treatment and Treatment Combinations

a) Spacing

i. 60 × 30 cm - S_1

ii. 70 × 30 cm - S_2

iii. 80 × 30 cm - S_3

iv. 90× 30 cm - S_4

b) Number of plants per hill

i. 1 plant per hill - PH1

ii. 2 plants per hill - PH2

iii. 4 plants per hill - PH3

Table 3.2

Treatment and treatment combinations

Spacing (S)	Number of plants per hill		
	PH1	PH2	PH3
S1	S1PH1	S1PH2	S1PH3
S2	S2PH1	S2PH2	S2PH3
S3	S3PH1	S3PH2	S3PH3
S4	S4PH1	S4PH2	S4PH3

Key:

PH: **P**lant per hill- e.g., PH3 -is 4 plants per hill
S: **S**pacing example S3-refers to spacing 3-which is 80 x 30 cm
S4PH3: **T**reatment combination of spacing 4 and 4 plants per hill.

Table 3.3 shows treatments worked out in terms of (plant population) number of plants per unit area (per hectare) and plant density (plants per square metre), and plants per plot size in this experiment respectively.

Table 3.3

Theoretical plant populations and densities

No	**Spacing (cm)**	**Plants per hill**	**Plant density.**		**No of plant per plot.**
			Plants /ha	Plants/m^{-2}	Plants/ 12 m^{-2}
		1	55,555	5	60
1	60 x 30	2	111,111	11	132
		4	222,222	22	264
		1	47,619	5	60
2	70 x 30	2	95,238	10	120
		4	190,476	19	228
		1	41,666	4	48
3	80 x 30	2	83,333	8	96
		4	166,666	17	204
		1	37,037	4	48
4	90 x 30	2	74,074	7	84
		4	148,148	15	180

Table 3.3 illustrates the expected theoretical plants population per hectare and plant density per unit area meter square (m^2) based on the treatment combinations (spacing and number of plants per hill) in table 3.2.

3.10 Data Collection

Data was collected on plants height (cm), stem diameter (girth) cm, cob length cm, weight of one thousand kernels (grams), grain yield per hectare (kg), above ground biomass (kg) per hectare and harvest index (HI). Five plants were randomly selected plants from the middle rows per treatment for collection of data on plant height and girth using nondestructive method of sampling. Measurements were done beginning from 14 days after sowing (DAS) and thereafter at 2 fortnight intervals up to 84 days after sowing for final measurements. The plant heights were determined using meter rule from the base of plant to tip of the panicle at fourteen days interval from sowing day up to 84 days after sowing and the means per treatment determined per data collection interval. Stem diameter measurements were determined using a vernier calipers with reference to middle point of the stem beginning from 14 days after sowing (DAS) and thereafter at 14 days intervals and up to 84 days after sowing (DAS) for final measurement. Cobs per plot were obtained at harvest, five cobs selected at random per experimental unit and thereafter cob length measured as the length of the cob from the tip to the bottom using a 30 cm ruler as shown in figure 3.8. For plant height and stem diameter only final (84 das) data was analyzed.

3.11 A Thousand Seed Weight

To obtain the weight of 1000 seed (grams), shelled dried maize (12.5 % moisture content) was scooped per treatment, a thousand seeds counted and weighed using an analytical balance in the laboratory.

3.12 Grain Yield

The harvested maize cobs per plot were sundried separately, then manually threshed and kernels (grains) sun dried to attain moisture content of 12.5% determined using a moisture meter. Dry grains were weighed using spring balance to obtain yield per plot and weights converted into kg ha^{-1} using the formula:

Grain Yield (kg ha^{-1}) = yield per plot (kg) x 10000 /plot size m^2 x 1000

3.13 Above Ground Biomass

For above ground biomass, only vegetative parts of the plant above the soil surface was considered, whole dry maize stalks were cut at the base on the ground level and the weights (kg) per plot determined using calibrated spring balance weighing scale (Plate 8) until constant weight was obtained. Resultant weights per plot were converted to get biomass per hectare.

3.14 Harvest Index (HI)

Harvest index was calculated as ratio of grain weight to total above ground biomass weight using formula;

Harvest index = grain yield /above ground biomass yield (stover plus grain) x 100

3.15 Data Analysis

The data obtained from measured parameters from both first and second crops was organized using excel packages (MS excel 2013) and pooled analysis of variance done using statistical package for social scientists (SPSS) version 20.0 data analysis software and where the F values were significant, least significance difference (LSD) post hoc test at 5% level of significance was used to compare the means.

Figure 3.2

Sowing maize based on treatments combinations

Figure 3.2 illustrates sowing of maize in holes, certified maize seed were over sown in holes at three to six seeds per hole in the experimental plot.

Figure 3.3

Thinning out to attain desired plants per treatment

Excess plants were thinned out within holes 10 days after sowing in order to attain the required maize plants as per treatments as shown in figure 3.3.

Figure 3.4

Maize crop at two and four plants per hill at same spacing

In figure 3.4, At 14 days after sowing maize plants at four plants per hill appeared to be crowded compared to 2 plants per hill at same spacing of 60 x 30 cm.

Figure 3.5

Effect of plant density on growth of maize plants

In figure 3.5 single plants per hill were observed to be exhibit vigorous growth compared to 4 plants per hill. Probably due to availability of less space and environmental resources to relatively higher number of plants per unit area.

Maize is very sensitive to competition from weeds and therefore timely weeding is important to facilitate aeration, ease root development and crop establishment in its early stages of growth (figure 3.6**)**.

Figure 3.6

First weeding three weeks after sowing

Figure 3.7

Crop showing signs of moisture stress

Figure 3.7 illustrates response of maize crop to moisture stress at midday at four plants per due to crowding effect associated with plant density (number of plants per hill).

Figure 3.8

Data collection - measurements of plant height and cob length

Figure 3.8 illustrates measurement of growth (plant height) and yield (cob length) indicators respectively. To determine plants height; five plants were randomly selected from middle rows and their heights measured from base of pant on soil surface to tip of

the flower panicle, while for cob length five cobs were sampled at harvest from each treatment and their lengths measured using 30 cm ruler.

Figure 3.9

Effect of number of plants per hill on stem diameter

Two (2) plants per hill *Four (4) plants per hill*

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Plant Height

Plant height is a vital parameter that is used to determine the growth of a plant realized during its entire growth period. Plant heights were measured throughout the growth period beginning from 14 days after sowing, thereafter at fortnight intervals with final plant height determined at eighty-four days (84) after sowing. Generally, there were gradual increases in plant heights of maize throughout growth period until tasseling. The final pooled plant heights for the 2 seasons are as shown in figure 4.1.

Figure 4.1

Average plant heights at different plants densities

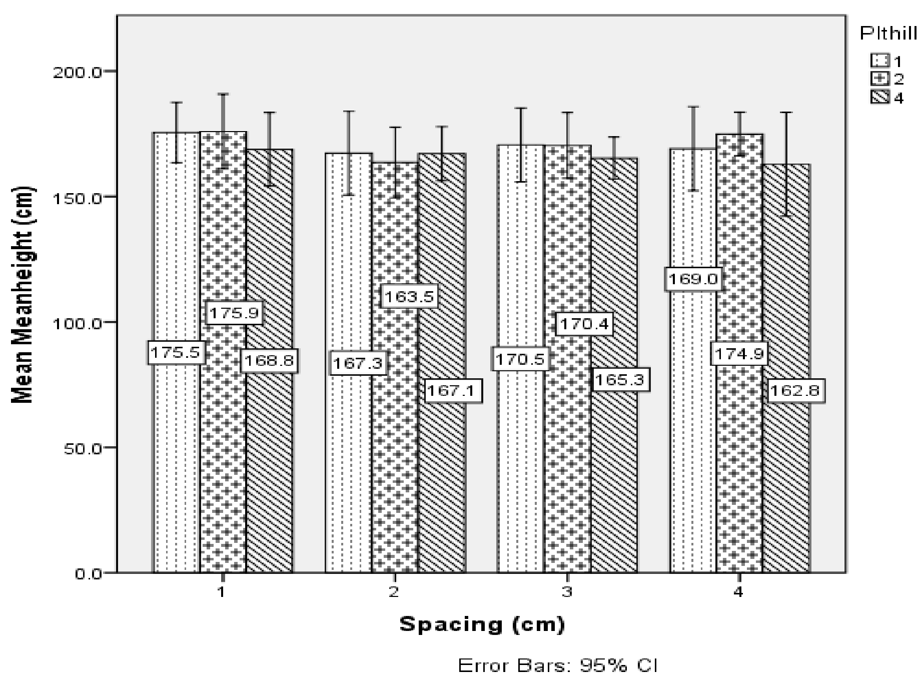


Figure 4.1, shows that based on the spacing, tallest plants were observed at lowest inter row spacing (S1 60 cm) followed by 80 cm. While least tall plants were recorded at 70 cm regardless of number of plants per hill. On the other hand, considering the number of plants per hill, tallest plant heights were recorded on a single plant per hill across all inter row spacing except for S_4 (90 x 30 cm) where 2 plants per hill gave a height 174.9 cm. Least plant heights were generally observed on 4 plants per hill regardless of row spacing. The highest plant height recorded was 175.9 followed by 175.6 on 1 and 2 plants per hill spaced at 60 x 30 cm, while the lowest was 162.2 cm at 4 plants per hill at spacing of 90 x 30 cm. The taller plants were observed on 2 plants per hill across all the four spacing except in spacing of 70 x 30 cm, while short stature plants were observed on four plants per hill across all the 4 different inter row spacing. Plant height showed a mixed response to increase in number of plants from 1 – 4 within inter row spacings. Generally, plants heights decreased with increase in numbers of plants per hill as inter row spacing increased from 60 – 90 cm. Highest reduction in plants height averaging 5 cm was recorded when number of plants per hill increased from 2 to 4 compared with 0.5 cm between single (one) to 2 plants per hill within the row spacings (figure 4.1)

Analysis of variance (table 4.1) revealed spacing, number of plants per hill and interaction of spacing and plants per hill was not significant on plant height.

Table 4.1

ANOVA - plant height

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SP	1166.041	3	388.680	0.082	0.970
PPH	1136.563	2	568.281	0.119	0.887
SP * PPH	1185.629	6	197.605	0.042	1.000
Error	1999053.337	420	4759.651		
Total	2002541.569	431			

a. R Squared = .002 (Adjusted R Squared = -0.024)

The data showed despite differences in plant height among treatments, spacing and number of plants per hill did not significantly affect plant height. The tall plants observed at one and two plants per hill could be attributed to availability of sufficient soil nutrients and moisture that facilitated optimum plant growth due low or absence of inter plant competition. In addition, plant densities emanating from one and 2 plants per hill could have resulted in efficient utilization of available solar radiation due to reduced canopy shading and absence of crowding effect of plants.

The short stature plants resulting from 4 plants per hill, could be associated with intense interspecific competition amongst plants for available but inadequate environmental resources; soil moisture and nutrients to support optimum plants growth. Secondly the treatments combination at 4 plants per hill realized higher plants populations per unit area (plant densities), that resulted in overcrowding of plants, mutual shading and therefore impeded absorption of solar radiation by plants. Therefore, creating unfavorable environmental growing conditions of the crop resulting shorter plants.

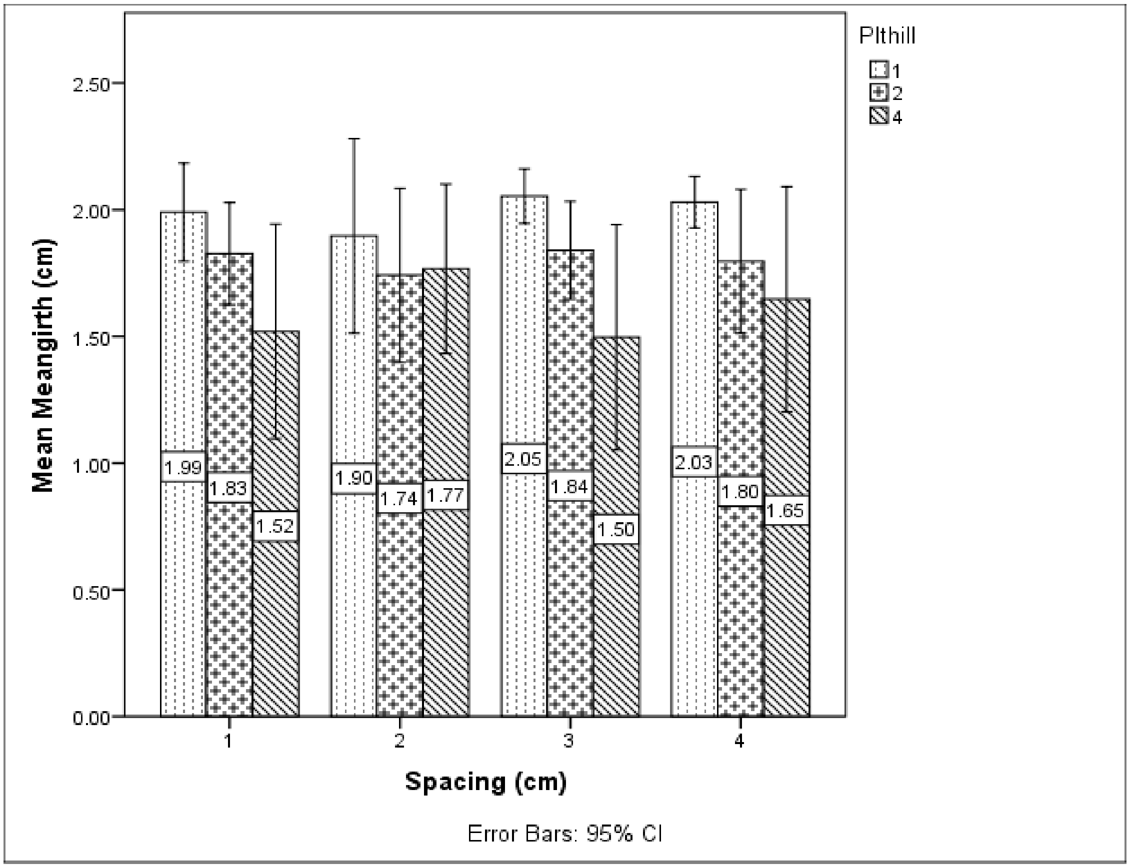
In previous studies Abuzar et al. (2011); Gobeze et al. (2012) reported similar results that at higher plant populations 140,000 plants ha^{-1} (14 plants m^{-2}) which was beyond the optimum 100,000 plants ha^{-1} (10 plants m^{-2}) often resulted in crowding of plants and caused stressful and higher interspecific plant competition for available resources of water and soil nutrients that inhibited apical growth and thus resulting in short stature plants (figure 3.9). This trend indicates that competition for nutrients uptake and sunlight interception increases with increase in number of plants per unit area, therefore affecting overall plant growth.

4.2 Stem Diameter

The stem diameter also known as stem girth is the thickness of the stem. Stem diameter was measured throughout the growth period starting from 14 days after sowing, thereafter at fourteen days (14) intervals with final stem diameter measured at 84 days after sowing. Generally, there were gradual increases in stem diameter of maize stalks throughout growth period. Figure 4.2 demonstrates response of stem diameter of the maize variety to treatments.

Figure 4.2

Response of stem diameter (cm) to treatments



The highest stem diameter 2.05 cm was recorded on single plants per hill at spacings 80 x 30 cm and lowest stem diameter 1.50 cm observed on 4 plants per hill at spacing 80 x 30 cm (Figure 4.2). Stalk thickness decreased with increase in number of plants from one single to four plants per hill within the row spacings, (figure 3.9) showed stem thickness at 2 versus 4 plants per hill 80 x 30 cm at 84 days after sowing.

Analysis of variance (table 4.2) showed that number of plants per hill significantly affected stem diameter, but row spacing and interaction of spacing and plants per hill was not statistically significant ($p \leq 0.05$).

Table 4.2

ANOVA table for stem diameter

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SP	0.902	3	0.301	1.002	0.392
PPH	14.771	2	7.386	24.608	0.000
SP * PPH	0.725	6	0.121	0.402	0.877
Error	126.054	420	0.300		
Total	142.452	431			

a. R Squared = .115 (Adjusted R Squared = .092)

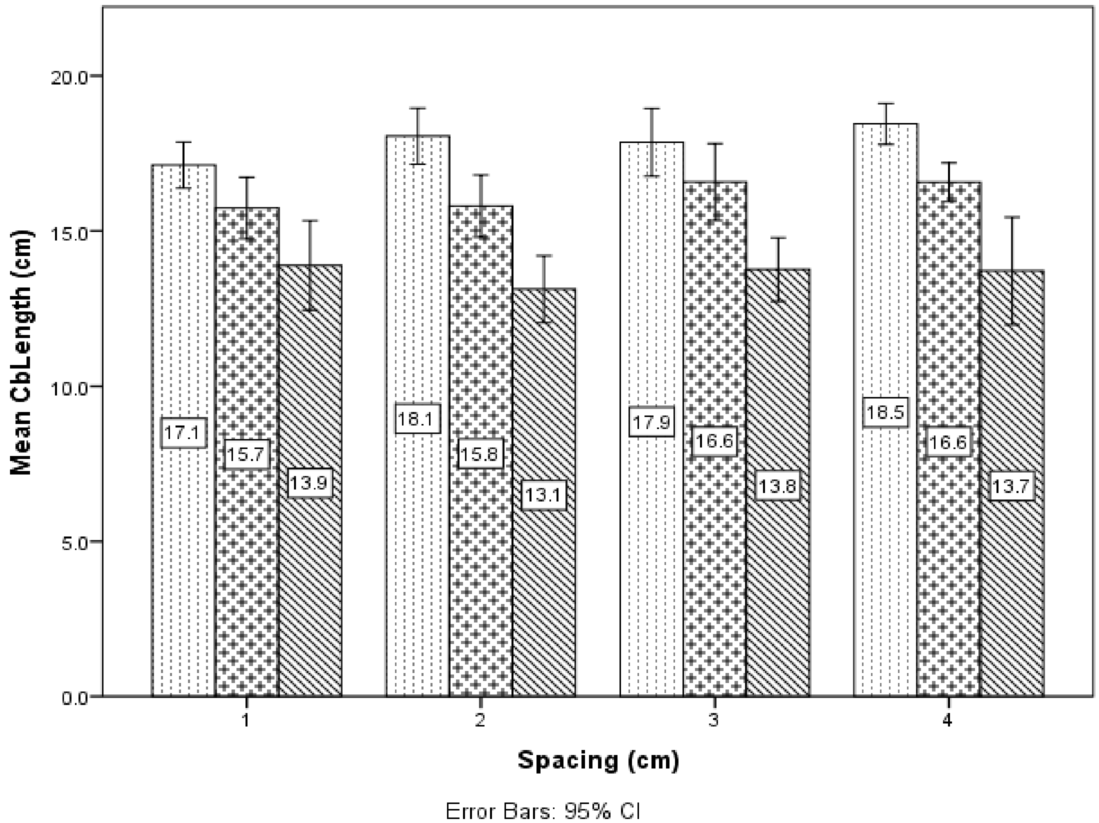
The means were separated table 4.3 and significant difference observed in the 3 levels of plants per hill, with smaller stem diameter recorded at 4 plants per hill compared to 1 and 2 plants per hill.

4.3 Cob Length

Cob length (ear length) is among the dominant traits influencing maize yield and basic components affecting kernel size, weight and grain yield. Number of plants per hill combined with row spacing has a remarkable effect on cob diameter and length. Figure 4.3 shows graphical representation of effect of spacing and plants per hill on cob length.

Figure 4.3

Cob length as influenced by treatments



The response of this variety to spacing and number of plants per hill (figure 4.3) revealed based on spacing, longer cob sizes were recorded on wider inter row spacing (90 cm and 80 cm) regardless of the number of plants per hill. While least cob lengths were observed on narrower row spacing of 60 x 30 cm (S_1).

The highest cob length 18.5 cm and 18.1 cm was observed on one plant per hill at spacing of 90 x 30 cm and 70 x 30 cm respectively. On the other hand, lowest cob length 13.1 cm was observed at 4 plants per hill at spacing of 70 x 30 cm. Generally, longer cob lengths were recorded at one plant per hill while lowest cob lengths were noted on 4 plants per hill across the four row spacings. A linear trend of decreasing cob lengths with increasing number of plant plants per hill was observed within all spacings.

Analysis of variance in table 4.3 revealed number of plants per hill significantly influenced cob length while spacing and interactive effect of spacing and plants per hill was not ($p \leq 0.05$).

Table 4.3

ANOVA table for cob length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SP	4.282	3	1.427	1.229	0.307
PPH	224.231	2	112.116	96.543	0.000
SP * PPH	6.529	6	1.088	.937	0.475
Error	69.678	60	1.161		
Total	304.720	71			

a. R Squared = .771 (Adjusted R Squared = .729)

Table 4.4

LSD summary for cob length (cm)

Plant/hill	1	2	4
1		1.767*	4.300*
2			2.533*
4			

*. The mean difference is significant at the $p \leq 0.05$.

A post hoc test table 4.4 detected significant differences in cob length between one, two and four plants per hill. One plant per hill gave longest cob length, followed by 2 plants per hill, with smallest cobs being produced at 4 plants per hill. This result shows single plant per hill on average produced cobs longer by 1.7 cm and 4.3 cm compared to cobs yielded at 2 and 4 plants per hill respectively. Also cob length decreased by 2.5 cm when number of plants were raised from 2 to 4 plants per hill. This implies the increasing number of plants per hill negatively affected ear length. The reduction in lengths of cobs doubled when number of plants per hill were further raised from 1 to 4 compared to increase to 2 plants per hill. For example, an in increase in number of plants per hill from 1 - 4 resulted in decreased cob length from 18.5 to 13.7 cm (S_4 - 90 x 30 cm) which translated to 17% reduction in cob length. The longer cob produced at single and two plants per hill can be associated with availability of unlimited growth resources; moisture and soil nutrient at critical stage of ear development. In addition, the resultant treatment combinations (spacing and number of plants per hill) at 1 and 2 plants per hill generated plant densities that allowed efficient absorption of solar radiation due to absence of plants canopy shading thus encouraging proper ear formation and development.

Reduction of cob length with increasing plant plants per hill (4 plants) might be associated with higher plant population per unit area that could not be supported by available resources and moisture, therefore affecting ear formation and development. Secondly the high plant densities at 4 plants per hill within narrow row spacings resulted in crowding of plants, caused mutual shading of plants canopy. This might have resulted in limited amount of assimilates possibly occasioned by reduced photosynthetic activity of leaves at higher plant populations, caused low availability of growth contributing factors such as solar radiation. In addition, though not quantified it can be inferred that due to limited quantity of assimilates being transported to the developing cobs after fertilization could have negatively impacted growth and development of the cobs at closer row spacing (60 cm) and at high number of plants per hill. These results indicate that number of plants per hill and ultimate plant density influenced cob length, probably caused by increased competition amid individual plants for soil nutrients, sunlight and moisture during critical ear formation and development stages.

Results of this experiment are in agreement with findings of Manan et al. (2016) who reported that cob length was longer at wider row spacing and declined with decreased row spacing, which they attributed to crowded plant populations that led low photosynthetic efficiency of leaves caused by mutual shading of ears resulting in formation of smaller ears(cob). Similarly, Violeta et al. (2016) reported reduced ear length (cob length) and width with increase in densities from 50,000 – 75,000 plants per hectare.

Similar findings were also reported by Lashkari et al. (2011), Ukonze et al. (2016) and Zamir et al. (2011) that cob length reduced linearly with rise in plant population per unit area of land. In Nigeria Enujeke (2013) observed wider spaced crops encountered less competition for sunlight and plant nutrients and therefore gave higher values of ear length, kernel weight and grain indices. It can be concluded from the results of this study, that there exists a positive relationship between resultant cob length and number of plants per hill, possibly owing to varied interplant competition at specific row spacing of this cultivar.

Cob size (length and diameter) tend to influence other yield contributing components such as grain size, kernel weight that contribute to final grain yield per unit area. Therefore, the reduced cob length is likely to negatively affect crop yield since shorter cob length tend to have lighter and fewer grains per cob.

4.4 Weight of a Thousand Seeds

Seed mass is a yield controlling factor, it plays an important part in indicating the potential yield of a variety. Graphical representation of effect of spacing and plants per hill is shown in figure 4.4.

Figure 4.4

Effect of spacing and plants per hill on weight of thousand seeds

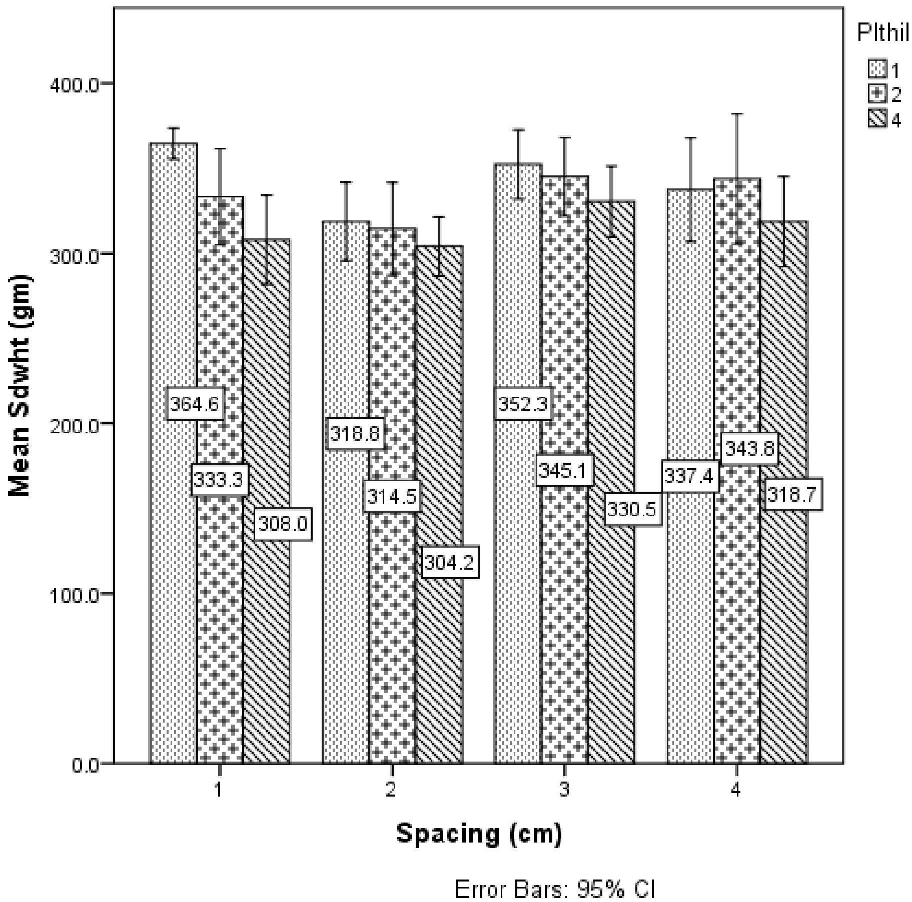


Figure 4.4 illustrates that number of plants per hill influenced seed weight, highest 1000 seed weight was recorded on one plant per hill, followed by 2 plants per hill. While the least seed weights were observed on four plants per hill. In addition, generally seed weights decreased with rise in number of plants per hill from 1 to 4 regardless the inter row spacing except for S_4 (90 x 30 cm). Data also revealed that spacing influenced seed

weight (gm), which decreased with increase in row spacing at 1, 2 and 4 plants per hill respectively.

The highest seed weight (364 g) was recorded at spacing of 60 x 30 cm followed by (352 g) at spacing of 80 x 30 cm at single plant per hill (figure 4.4). While lowest seed weight (304 g) was observed at four (4) plants per hill spaced at 70 x 30 cm, generally lower seed weights were observed at 4 plants per hill regardless of the inter row spacing.

Table 4.5

ANOVA table for weight of a thousand seeds (g)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SP	9024.645	3	3008.215	5.211	0.003
PPH	9785.397	2	4892.698	8.476	0.001
SP * PPH	4083.973	6	680.662	1.179	0.330
Error	34636.245	60	577.271		
Total	57530.260	71			

a. R Squared = .398 (Adjusted R Squared = .288)

Analys is of variance table 4.5 revealed effect of spacing and plants per hill resulted in high significant difference in weight (g) of 1000 seeds, however interactive effect of spacing and plants per hill did not significantly influence a thousand seed weight ($p \leq 0.05$).

Table 4.6

LSD summary for a thousand weight(grams)

Plant/hill	1	2	4
1		9.0833	27.9875*
2			18.9042*
4			

* The mean difference is significant at the 0.05 level.

Separation of means using least significance difference test was done (table 4.6), where it detected differences existed among the treatments in terms of weight of 1000 seeds (g) between 1, 2 and 4 plants per hill. It also revealed weight of 1000 seed at 1 and 2 plants per hill was statistically at par ($p \leq 0.05$). This demonstrates that sowing at either 1 or 2 plants per hill resulted in difference of 9.8 grams in seed weight regardless of the row spacing, however this was not significant. Implying there was little gain in seed weight when varying number plant per hill from 1 to 2 for this cultivar under study conditions.

The heavy seed weights at 1 and 2 plants per hill compared to 4 plants per hill could be associated with availability of more growth resources; soil nutrients and water to relatively fewer number of plants per unit area which they utilized more effectively. In addition, plant densities resulting from 1 and 2 plants per hill did probably did not heavily affect photosynthetic activity of the crop thus facilitating efficient photosynthesis assimilates conversion and translocation for effective filling of kernels.

On the other hand, the low seed weight at higher number of plants per hill was probably due to availability of less amounts of environmental resources (soil nutrients and soil moisture) to comparatively against higher number of plants per unit area creating higher interspecific plants competition nutrients and soil moisture that could have caused stressful growing conditions for the crop during important periods of seed development and kernel filling phases.

It was also observed that weight of 1000 seeds declined with increase in number of plants per hill within the row spacing (figure 4.4). For instance, weight of 1000 seeds declined by 15% (from 364.57gms to 307.98 grams) at spacing of 60 x 30 cm with increase in number of plants per hill from one (11 plant m^{-2}) to four (22 plants per m^{-2}) which was double compared to increase in plants per hill from 1(6 plants m^{-2}) to 2 (11plants m^{-2}) at 8% (from 364.57 to 333.3 grams) and similar trend replicated with increase within row spacings (60, 70, 80 cm) in this study.

Another factor contributing to the low seed weight at four plants per hill could be attributed to plant densities emanating from treatments combination at four plants per hill. Crowding effect and overlapping of plants canopies resulted in limited amount of photosynthates for grain development, due to elevated interspecific plant competition which could have caused reduced rate of photosynthesis and encouraged a higher rate of crop respiration because of increased mutual shading. In this experiment plant density affected seed weight, for example, a decrease in row spacing from 90 cm (15 plant m^{-2}) to 60 cm (22 plant m^{-2}) employing four plants per hill resulted in decline of weight of 1000 seeds from 318.67 to 307.98 grams (figure 4.4). This results also showed that planting at 4 plant per hill, which is planting at high plant population irrespective of row spacing is likely to result in low seed weight and eventually affect grain yield. Violeta et al. (2016) in their studies observed increase in plant density not only reduced ear length (cob length) and width but also negatively affected both number of rows per cob, grains per ear and weight of 1000 seeds.

The findings are in agreement with Abuzar et al. (2011) and Zamir et al. (2011) who reported planting at lower densities resulted in heavier kernel mass compared to planting at higher densities, and that rise in plant density caused a decrease in weight of kernels caused by unfavorable environmental conditions such as reduced aeration and available sunlight for photosynthesis. Results from this study imply planting this variety at one or two plants per hill would result in different crop yield though not significant. However, at higher plant populations (4 plants per hill) in combination with narrow row spacing, negatively affected seed weight which is a contributing component to grain yield.

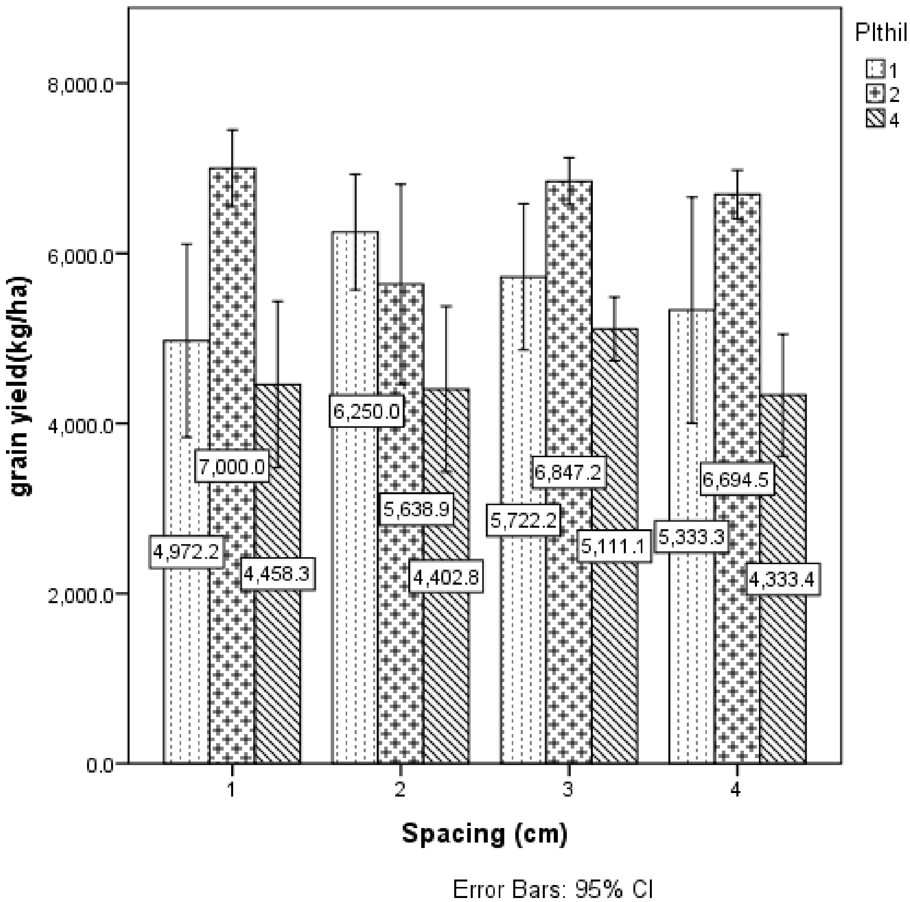
4.5 Grain Yield

Grain yield in maize is an combined function of interface of genetic composition of cultivars and environmental conditions in which its cultivated. An end result of several complex physiological, morphological and chemical processes taking place during the entire growth and development phases of the crop. The grain yield of maize crop is influenced by interactions of several factors including environmental growing conditions, row spacing, soil fertility, plant population, inherent genetic factors of the cultivar and crop management aspects. For this study factors considered were varied inter row spacing and number of plants per hill.

The data on grain yield as illustrated in figure 6 revealed that grain yield was strongly regulated by number of plants per hill within the row spacing.

Figure 4.5

Effect of spacing and plants per hill on grain yield



Based on data, number of plants per hill (figure 4.5) gave the highest grain yield as recorded on 2 plants per hill, followed by single plant per hill and the least grain yield reported on 4 plants per hill. A trend of increasing grain yield with increase in number per hill within inter row spacings was reported in all inter row spacing except for S_3 (70 x 30 cm) which was not expected.

Generally higher grain yield was observed at 2 plants per hill in across different row spacing with exception row spacing 70 x 30 cm. while lowest grain yield observed on 4 plants per hill regardless of the spacing. The highest grain yield was 7000 kg ha^{-1}, followed by 6847 kg ha^{-1} as recorded on two plants per hill spaced at 60 x 30 cm and 80 x 30 cm respectively. While lowest grain yield was 4333 kg ha^{-1} at 4 plants per hill on spacing 90 x 30 cm. It was observed that a trend emerged where grain yield increased with rise in number of plants per hill from one to two, followed by decline with further increase to 4 plants per hill was across all treatments combination except at spacing 70 x 30 cm which posted a mixed response.

Analysis of variance in table 4.7 indicated number of plants per hill and interaction of spacing and plants per hill significantly influenced grain yield, while row spacing did not.

Table 4.7

ANOVA Table for Grain Yield

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SP	2630473.772	3	876824.591	1.353	0.266
PPH	46512136.500	2	23256068.250	35.882	0.000
SP * PPH	11947862.581	6	1991310.430	3.072	0.011
Error	38887354.673	60	648122.578		
Total	99977827.526	71			

a. R Squared = .611 (Adjusted R Squared = .540)

Table 4.8

LSD summary for grain yield

Plant/hill	1	2	4
1			993.046*
2	975.688*		1968.733*
4			

*The mean difference is significant at the 0.05 level

Post hoc test was done showed the grain yield was significantly different at all 3 levels of number of plants per hill table 4.8. Planting at single and 2 plant(s) per hill compared to 4 plants per hill yielded significantly more by 993 kg ha^{-1} and 1968 kg ha^{-1} of grain respectively ($p \leq 0.05$). Similarly, 2 plants per hill gave higher yield than single plant per hill.

Higher grain yield realized at 2 plants per hill compared to 1 plant per hill can be attributed higher number of harvested cobs due to plant population per unit, and secondly the resultant plant population at 2 plant per hill ensured that the plants were equidistantly distributed enabling efficient utilization of available resources (soil moisture and nutrients) for growth and development of ears and grain filling. In addition, plant densities at 2 plant per hill (spacing 60 and 80 cm) did no favor shading thus enabling the crop efficiently absorb solar radiation reaching crop foliage.

Contrastingly, the low number of plants per unit area (population) emanating from single plants per hill at wider row spacing contributed to low grain yield due to fewer number of cobs harvested per unit area of land. In addition, the availability of more growth resources to relatively fewer number of plants per unit area(population) did not result in higher grain yield, rather it could have promoted higher vegetative growth (wider stem girth) of the plants at expense of grain formation. Overall, single plants per hill across all inter-row spacings gave low grain yield per unit area of land, more so due to low plant population rather than reasons associated with genotype its performance in the environment in which it was cultivated. Violeta et al. (2016) among the dominant traits influencing grain yield in maize are cob diameter and cob length, subsequently these traits are also basic components that affect kernel yield (size and weight). Consequently, since increasing plant density in particular area affects cob length and therefore indirectly impacts on kernel weight and ultimately grain yield. This scenario could account for decline in grain yield (figure 4.5) at high plant densities associated with decreased in cob length (figure 4.3) for this experiment, implying that shorter cob length probably contained fewer and lighter kernel contributing to low grain yield at 4 plants per hill within the row spacing.

In addition, there was decline in grain yield with increase in number of plants per hill, for example a 36% decline in grain yield was observed at spacing 60 x 30 cm from 7000 kg ha^{-1} to 4458 kg ha^{-1} as number of plants per hill rose from 2 (111,111 plants ha^{-1}) to 4 (222,222 plants ha^{-1}) compared to 28% increase when plants per hill increases 1 (55,555 plants ha^{-1}) to 2 (111,111 plants ha^{-1}). Higher plant densities increased competition for relatively lower amounts of available environmental resources (soil moisture and crop nutrients) that were limited at critical physiological crop stages of ear formation, development and creating a stressful growing condition during grain formation and kernel filling stages. Also, at higher plant population the overcrowding effect of plant encourages shading of crop foliage, impeding absorption of solar radiation, encourages lower rate of photosynthetic activity and assimilation of available photosynthates for ear development and kernel. Availability of less photosynthates for grain development, occasioned by low rate of photosynthesis due to mutual shading further aggravates the situation under limited soil moisture and nutrients especially at higher plant densities. At higher plant densities, another phenomenon exhibited in such crop stands is higher number of individual plant barrenness; which is defined as inability of plants to bear ear (to cob). It has been reported as one of the key factors contributing to low grain yield due to inhibited optimal conversion of solar radiation to grain in *Zea mays L.* (Gobeze et al., 2012). Though not measured, the higher plant densities (table 3.3) could have encouraged plant barrenness thus reducing overall number cobs harvested and contributed to lower grain yield. Therefore, it is suggested that increase in plant density across row spacing beyond cultivar optimal contributed to the observed decline in grain yield. This can be collaborated with previous studies by Gobeze et al. (2012) who reported that plant densities of below 75,000 plants per hectare (8 plants per m^2) had insignificant number of bareness plants. However, at closer row spacing and plant densities above 120,000 plants per hectare (12 plants per m^2) number of barren plants increased significantly. This affected final grain yield due to variation of crops physiological process at reproduction phase (fertilization, silking) due to suppressed supply of photosynthetic assimilates causing ear and seed abortion in dense crop stands.

Gobeze et al. (2012) and Sangoi (2001) indicated that increasing plant densities increased grain yield and optimum grain yield was realized at plant populations of 100,000 plants ha^{-1} (10 plant m^{-2}) beyond which grain yield declined. These conclusions are in agreement with the findings of those in this experiment, where higher grain yields were realized at 2 plants per hill spaced at 60 x 30 cm (92,000 plants ha^{-1} / 9 plant m^{-2}) and 80 x 30 cm (83,333 plants ha^{-1}/ 8 plant $m^{-2)}$ respectively. Thereafter yield declined when plant increased density rose beyond optimum (100,000 plants ha^{-1} /10 plant/m^2), in this experiment which was at 4 plants per hill across all spacings, S_1 60 x 30 cm (222,222 plants ha^{-1}/22 plant m-$^{2)}$, S_2 70 x 30 cm (190,500 plants ha^{-1}/19 plant $m^{-2)}$, S_3 80 x 30 cm (167,000 plants ha^{-1}/ 17 plant m^{-2}) and S_4 90 x 30 cm (148,000 plants ha^{-1}/15 plants m^{-2}) as detailed in table 3.3. It can be concluded that cultivar SC duma 43 gave satisfactory grain yield in plant populations 37,000 – 111,111 plants ha^{-1}, thereafter the yield decline set in due to competition for inadequate availability of growth resources associated with higher plant densities. Similar findings by Abuzar et al. (2011); Violeta et al. (2016) and Zamir et al. (2011) reported low grain yield at high plant population per unit area, was associated with declining yield of individual plant (number of ears per plant, ear length and diameter) due to competition for environmental resources soil water and nutrients and solar radiation.

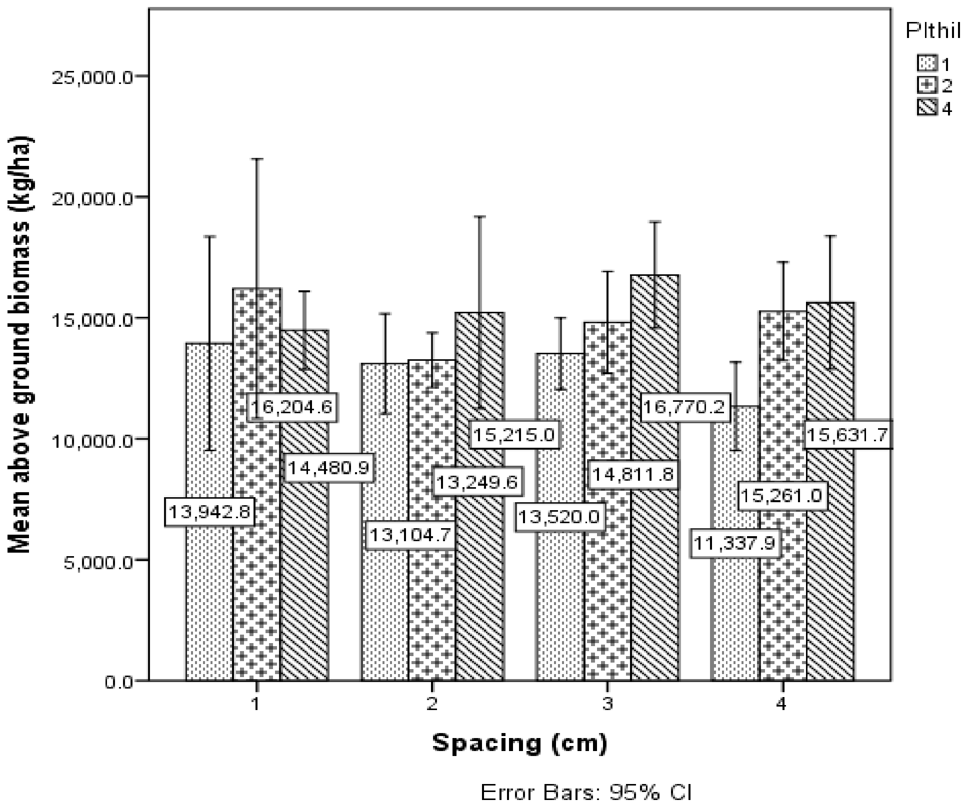
Based on the results of the study planting at single plant per hill regardless of the inter row spacing, would result in lower grain yield regardless of row spacing due to low plant densities, than the potential optimum for hybrid variety SC duma 43. Similarly, under treatments combination of 4 plants per hill the scenario of lower grain yield would be occasioned by high plant population per unit area beyond its carrying capacity necessitating unwarranted competition for growth resources and solar radiation thus affecting individual plants yield and their contribution to overall crop grain yield.

4.6 Above Ground Biomass

It is a mass of dry organic living material obtained from above or below ground surface of given predetermined area of land at a particular period of time. During this study only above ground biomass was considered and graphical representation of results due to treatments is presented in figure 4.6.

Figure 4.6

Above ground biomass as influenced by treatments



Data on figure 4.6 revealed a linear relationship between number of plants per hill and biomass produced among treatment combinations (spacing and plants per hill). A trend of increasing above ground biomass with increasing number of plants per hill within spacing except at spacing S_1 60 x 30 cm which was not expected. Generally, the lowest above ground biomass was harvested on treatments combination of single plants per hill irrespective of row spacing. While on the other hand highest biomass was produced at across spacing treatments with 4 plants per hill.

The highest above ground biomass was 16,770.2 kg (16.7 tons) ha^{-1} recorded on 4 plants per hill at spacing of 80 x 30 cm, followed by 16,204.6 kg ha^{-1} at 2 plants per hill at spacing (60 x 30 cm), on the other hand lowest biomass weight was 11337.9 kg ha^{-1} (90 x 30 cm) at 4 plants per hill. It was also noted that biomass increased within row spacings with increase in number of plants per hill (figure 4.6) with exception of spacing 60 x 30 cm which posted mixed response. Analysis of variance results (table 4.10) revealed above ground biomass was statistically significantly different at the three levels of number of plants per hill, but spacing, and interaction of spacing and number of plants per hill was not significantly different at ($p \leq 0.05$). the above ground biomass generally increased with increase in row spacing and number of plants per hill, optimizing at 80 cm row spacing (16770.2kg ha^{-1}), further increase to 90 cm resulted in a decline in plant density

Table 4.9

ANOVA table for above ground biomass

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SP	20.928	3	6.976	0.647	0.588
PPH	113.701	2	56.851	5.275	0.008
SP * PPH	71.282	6	11.880	1.102	0.372
Error	646.675	60	10.778		
Total	852.586	71			

a. R Squared = .242 (Adjusted R Squared = .102)

Data

was further subjected to a least significance difference post hoc test (table 4.11) to determine where differences existed among the treatments means.

Table 4.10

LSD summary for above ground biomass

Plant/hill	1	2	4
1			
2	2.223*		0.733
4	2.955*	0.733	

*. The mean difference is significant at p≤0.05 level

Significant differences in above ground biomass were observed between 1 versus 2 per hill, and 2 versus 4 plants per hill respectively. However above ground biomass was statistically at par (733 kg ha^{-1}) at 2 and 4 plants per hill regardless of the spacing. implying that while difference in biomass yield between 4 and 2 plants per hill averaged 733 kg ha^{-1}, though not statistically significant.

The separation of means (LSD) posts hoc test also revealed that sowing at 2 plants per hill significantly produced 2223 kg ha^{-1} more of biomass compared to sowing at single plant per hill (table 4.11), which could be attributed to availability of more plants per unit area (plant population) emanating from sowing 2 plants per hill, rather that the availability of adequate environmental resources (soil moisture and nutrients). A similar trend could be inferred to account for rise in biomass yield of 2955 kg ha^{-1} when number of plants per hill increased from one to four.

The higher biomass values at 4 plants per hill across the three spacings could be attributed to increased number of plants per unit area of land. Similarly, comparatively high biomass values at 2 plants per hill compared to 1 plant per hill may be due to more plant per unit area and probably efficient utilization of available resources; water and soil nutrients.

One the other hand the low biomass posted at single plant per hill irrespective of row spacing could be credited to a lesser number of plants per unit area (low plant population) and low plant density. This implied there were more resource to relatively lower number of plants resulting in underutilization of available resources of soil moisture and nutrients.

Regarding the above results, plant biomass increased with increasing levels of plant per hill and plant density per unit area, which may be due to optimum utilization of soil nutrients and solar radiations by the crop in initial stages of growth (vegetative growth). Generally, it was noted that biomass increased progressively with increase in number of plants per hill within spacings investigated except for S_1 60 x 30 cm where, initially biomass yield increased with increase in number of plants per hill from one (13.9 t ha^{-1}) to two, (16.2 t ha^{-1}) but further rise in number of plants (4) resulted in yield decline (13.9 t ha^{-1}). This could probably be explained by decline in stover weight of individual plants at due to doubling of plant population (222,222 plants ha^{-1}) which was extremely higher compared optimal level for this trial at 166,666 plants ha^{-1}, creating intense competition for available and unfavorable stressful conditions for accumulation of biomass.

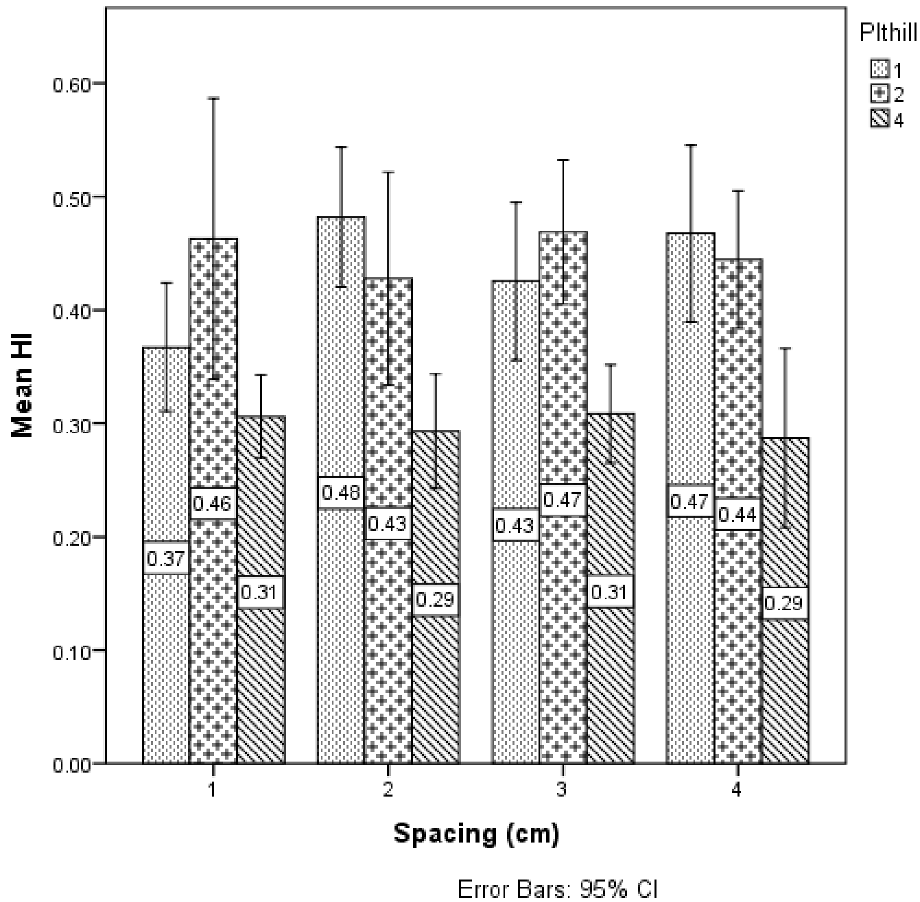
The findings are similar to those of Zamir et al. (2011) reported biomass yield decreased progressively as number of plants decreased in given area, due to difference in crop stand per unit area. The results of this experiment could be postulated to mean that for fodder production livestock farmers could be advised to grow this cultivar at 2 and 4 plants per hill at spacings of 60 x 30 cm and 80 x 30 cm respectively since biomass yield was statistically at par.

4.7 Harvest Index

Harvest index (HI) is a proportion of two components economic yield to above ground biomass, a valuable index in describing the functional efficacy and potential of a crop to convert the total dry matter into economic yield. It indicates relative portion of assimilates dispersion between economic and total biomass yield. In addition, for grain crops harvest index can also be used as measure of reproductive efficiency of genotype. Figure 4.7 shows HI ratios of duma variety as influenced by spacing and plants per hill. Higher HI was reported at 1 and 2 plants per hill with lower HI at 4 plants per hill across spacing treatments. While lowest ratio of harvest index was recorded at four plants per hill across inter row spacing.

Figure 4.7

Harvest index ratios at various spacings and number of plants per hill



The highest harvest index 0.48 was observed on single plant per hill at spacing of 70 x 30 cm, followed by 0.47 at 2 plants per hill spaced at 80 x 30 cm. Harvest index increased with rise in number of plants per hill within all row spacings tested except at spacing 70 x 30 cm up to 2 plants per hill and declined with further increment in number of plants to 4 per hill across all the spacings (figure 4.7).

Analysis of variance revealed number of plants per hill resulted in significant differences on harvest index, while spacing and interaction spacing and number of plants per hill was not significant (table 4.12).

Table 4.11

ANOVA table for harvest index (HI)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SP	0.006	3	0.002	0.460	0.711
PPH	0.337	2	0.169	36.084	0.000
SP * PPH	0.049	6	0.008	1.761	0.123
Error	0.281	60	0.005		
Total	0.674	71			

R Square

d = .584 (Adjusted R Squared = .507)

Separation of means revealed that harvest index was significantly different with number of plants per hill table 4.13

Table 4.12

LSD summary for harvest index

Plants/hill	1	2	4
1		-0.0155	0.1368*
2	0.0155		0.1523*
4	-0.1368*	-0.1523*	

*. The mean difference is significant at the 0.05 level

Significant differences in harvest index were observed between 1 and 4 plants per hill, harvest index decreased with increase in number of plants from 1 - 4 (0.15) and 2 - 4 plants per hill by 0.13 (table 4.13) respectively. While HI between 1 and 2 plants per hill was statistically at par ($p<0.05$). It was observed that an increase in number of plants per hill resulted in decreased harvest index across row spacings investigated. Further Perusal of the results also established positive correlation between grain yield and harvest index (HI) values on per treatment basis, as demonstrated in figures 4.6 and 4.7 respectively.

Harvest index represents the amount of plant dry matter apportioned to grain. it is determined by crop management practices, environmental factor, climatic and genotype. Soils condition and climate factors primarily affect harvest index, while among crop management aspect; row spacing and plant density affect harvest index. The low harvest index ratios recorded on 4 plants per hill could be due to plant densities higher than optimum for this cultivar. In addition, having low harvest indices at 4 plants per hill compared to 1 and plants pe hill across row spacing could imply there was reduced efficiency of distribution of assimilates between biomass and grain yield at 4 plants per hill. Findings are in agreement Mohsen et al. (2011) who reported harvest index decreased with increasing plant density.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

In any crop production system, the ultimate goal is to attain maximum productivity while integrating suitable agronomic practices which address crop production challenges in a given area. Sustainable maize production is dependent on correct combination of suitable crop genotype for a given environment, appropriate agronomic practices and related crop management aspects. Among the key factors influencing maize growth and yield is spacing and plant population per unit area. Plant population is a function of number of plants per unit area, and can be realized through manipulation of row-to-row distance, plant to plant distance and number of plants per hill. Therefore, inter row spacing and population (number of plants per hill) are important agronomic components that affect growth and yield of maize. Appropriate inter row spacing combined with correct number of plants per hill (plant density) helps determine yield potential of given variety of maize without compromising both its quantity and quality in a given environment. Many studies have been carried out with the aim of defining the optimal spacing and plant population (plant per unit area) for various maize hybrids. Nevertheless, there is no single recommendation applicable across all agro ecological conditions and to all maize varieties, since optimal spacing and plants per hill differs due to environmental factors; soil fertility, hybrid selection, planting date, crop management and harvest time.

This study aimed at investigating effect of varying inter row spacing and number of plants per hill on growth and yield of hybrid maize variety SC Duma 43 under coastal lowlands conditions. Based on analyzed data, first factor spacing significantly affected thousand seed weight, but on had no significant effect on growth, other yield components and yield of cultivar under investigation. Second factor which was number of plants per hill significantly affected growth, yield traits and yield of cultivar SC duma 43 ($p < 0.05$), with significant effects observed on stem diameter, cob length, and mass of 1000 seeds, harvest index, above ground biomass and grain yield. Interaction of factor 1 and 2 had significant effect on grain yield but was not on all other parameters investigated.

For growth parameters stem diameter 2.05 cm being highest was recorded on single (one) and lowest stem diameter 1.50 at 4 plants per hill at S_3 (80 x 30 cm). On yield components, longest cob length 18.5 cm S_4 (90 x 30 cm), observed on one plant per hill and least cob length 13.1cm at S_2 (70 x 30 cm) on 4 plants per hill. The highest seed weight (1000 seeds) was 364 g S_1 (60 x 30 cm) followed by (352 g) recorded at single plant per hill at a spacing S_1 (60 x 30 cm) and of S_3 (80 x 30 cm) respectively. While lowest seed weight (304.1g) was recorded on 4 plants per hill at S_2 (70 x 30 cm).

The highest above ground biomass was on 4 plants per hill which yielded 16.7 tha^{-1} (80 x 30 cm) followed by 2 plants per hill which gave 16.2 tha^{-1} tons (60 x 30 cm), lowest tonnage 11.3 tha^{-1} (90 x 30 cm) at 4 plants per hill. Two plants per hill gave higher grain yield of 7000 $kgha^{-1}$(60 x 30 cm) and 6847 $kgha^{-1}$(80 x 30 cm) while lowest was 4333 $kgha^{-1}$ (90 x 30 cm) at 4 plants per hill. Harvest index increased as number of plants per hill increased but declined with further increase in number of plants to 4 per hill within spacings. Highest harvest index 0.48 was observed on single plant per hill (70 x 30 cm), followed 0.47 at 2 plants per hill (80 x 30 cm) and least 0.29 was recorded 4 plants per hill at 90 x 30 cm spacing.

This study revealed that;

i. Cob length, stem diameter and weight 1000 seeds(g) decreased progressively with increase in number of plants per hill from one to four (1- 4) within spacings.
ii. Grain yield and harvest index increased progressively within spacing with increase in number of plants per hill from 1- 2 but declined with further increase to 4 plants per hill.
iii. Above ground biomass increased as number of plants per hill rose from 1 – 4 within spacing with exception of spacing 60 x 30 cm, low biomass at 4 plants per hill could be due to higher number plant per hill this impacted negatively on biomass production.

5.2 Recommendations

The most important concern of farmers is to use optimal spacing and plant per hill that gives optimum grain yield or biomass. Based on the findings of this trial, it is recommended that maize hybrid SC duma 43 could be sown at 2 plants per hill at spacings of 60 x 30 cm and 80 x 30 cm for grain production. For biomass production sowing at 4 plants per hill at spacing of at spacing 80 x 30 cm would give optimum yield. However, spacing of 60 x 30 cm is impracticable for maize grain production due to challenges associated with crop management practices such as weeding and additional costs of farm inputs such as fertilizer and seed. It is therefore recommended maize variety SC duma 43 be planted at 2 plants per hill employing spacing 80 x 30 cm for optimum grain yield under agro- climatic condition of area of study.

5.3 Recommendations for Further research

It is recommended that future studies on this variety in respect to spacing and plants per hill should consider following;

1. Studies on yield of this variety under different cropping seasons, short and long rains season in the coastal lowlands to establish optimum season for growing this cultivar.

2. Multi-locational adaptability trials in the larger coastal lowland agro ecological zones to establish areas most suitable for growing of this variety.

3. Conduct agronomic studies of the variety Duma SC 43 such as fertilizer regimes, response to chemical herbicides, pesticide and insecticides dosages.

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APPENDICES

Appendix 1:

Agro-meteorological data (9 years) for the experimental site.

Rainfall (mm) per month													
Year	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Total**
2007	39	0	51	228.9	222.5	142.5	47.5	71.9	42.4	30.4	93	4.6	**973.1**
2008	1.0	2.4	49.7	348.9	305.7	158.6	103	88.3	142.6	282.6	368.7	49.7	**1901.2**
2009	3.2	1.4	21	228.8	802.7	141.9	116.4	161.1	131.1	54.8	54.8	149.8	**1867**
2010	12.2	0	82.6	133.9	228.8	161.0	96	39.4	57.8	75.3	51.7	21.9	**960**
2011	5.5	43.7	59.4	43.6	171.1	227.2	53.6	60.7	9.4	321.8	15.5	71.5	**1083**
2012	7.7	14.7	30.9	222.5	513.9	136.6	91.3	30.7	45.1	22.9	123.5	11.6	**1551**
2013	2.0	12.3	8.6	119.6	212.2	62.1	28.4	42	65.4	317.6	64.9	0.4	**935.5**
2014	150.5	0.6	0	60.9	187.1	35.8	35.7	80.7	24	112.8	184.1	78.1	**950.3**
2015	8.9	0	260.2	115.1	390.5	111.3	46.5	59.9	47.5	132.6	74.3	45.5	**1292.3**
Avg	**25.5**	**8.3**	**62.6**	**166.9**	**337.1**	**130.8**	**68.7**	**70.5**	**62.8**	**150.1**	**114.5**	**48.1**	**1246.1**
Temperature (°C) from 2007-2015													
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**Mean**
Maximum	31.9	32.1	32.6	31.3	29.7	28.7	28.1	28.1	28.9	30.2	30.7	31.6	**30.3**
Minimum	23.6	23.6	24.4	25.0	23.7	19.8	22.1	21.9	22.7	23.8	24.4	21.5	**23.0**

Source: Mtwapa Agro- Metrology Station (2015)

Appendix 2.

Soil analysis report of the experimental site

LAB N°	Block No	N %	pH	Phosphorus (P) ppm	Iron (Fe) ppm	Copper (Cu) ppm	Manganese (Mn) ppm	Organic Carbon (C), %
53/16	1	0.05	7.02	32.9	21.4	0.8	77.2	0.41
54/16	1	0.02	6.71	34.2	33.4	1.4	78.4	0.34
55/16	1	0.03	5.96	29.7	28.9	1.4	78.4	0.37
56/16	1	0.04	5.80	21.7	22.6	1.1	77.4	0.32
57/16	2	0.03	6.89	27	24.2	1.6	77.2	0.27
58/16	2	0.03	6.37	38.9	24.4	1.2	77.1	0.30
59/16	2	0.05	5.84	29.3	30.8	1.1	77.7	0.27
60/16	2	0.01	6.24	36.3	32.0	1.2	77.8	0.21
61/16	3	0.05	6.33	19.7	5.7	0.7	76.1	0.66
62/16	3	0.02	5.91	20.4	24.3	0.9	76.9	0.30
63/16	3	0.05	5.63	26.1	23.5	0.9	76.9	0.26
64/16	3	0.06	5.89	18.4	22.4	0.8	77.3	0.40
Mean		0.04	6.22	27.7	24.47	1.03	77.37	0.34
Interpretation		Very low	Slightly acidic	Adequate	Very high	Medium	Low	Low

Abbreviations:

Lab No.: Laboratory identification number, N -nitrogen percent, ppm -parts per million.
Note: Interpretation of elements based on chemical test levels (available nutrients by Mehlich 1 extraction method)

Appendix 3.

Summary of ANOVA table -parameters.

Parameter	Factors	Type III Sum of Squares	df	Mean Square	F	Sig.
P/height	SP	1166.041	3	388.680	0.082	0.970
	PPH	1136.563	2	568.281	0.119	0.887
	SP * PPH	1185.629	6	197.605	.042	1.000
S/diameter	SP	.902	3	0.301	1.002	0.392
	PPH	14.771	2	7.386	24.608	0.000*
	SP * PPH	.725	6	0.121	0.402	0.877
Cob length	SP	4.282	3	1.427	1.229	0.307
	PPH	224.231	2	112.116	96.543	0.000*
	SP * PPH	6.529	6	1.088	0.937	0.475
W/1000seed	SP	9024.645	3	3008.215	5.211	0.003*
	PPH	9785.397	2	4892.698	8.476	0.001*
	SP * PPH	4083.973	6	680.662	1.179	0.330
Grain yield	SP	2.153	3	0.718	0.762	0.520
	PPH	63.361	2	31.681	33.643	0.000*
	SP * PPH	16.306	6	2.718	2.886	0.015*

Value followed by asterisk (*) are significant at 5%

Appendix 4.

Raw Experimental Data

TITLE: Effect of spacing and number of plants per hill on growth and yield of sc duma 43 in coastal lowlands											
S	**DAS-**	**BK**	**SPAC cm**	**Pphill**	**Hgt (cm)**	**S/dia (cm)**	**Cob length**	**Sdwht (gm)**	**Bmass kgs**	**HI**	**ykgsha**
1	84	1	1	1	160.2	2.26	0	0	0.0	0.00	0.0
1	84	1	1	2	179.2	1.70	0	0	0.0	0.00	0.0
1	84	1	1	4	164.8	1.58	0	0	0.0	0.00	0.0
1	84	1	2	1	178.6	2.14	0	0	0.0	0.00	0.0
1	84	1	2	2	162.2	1.62	0	0	0.0	0.00	0.0
1	84	1	2	4	168.2	1.6	0	0	0.0	0.00	0.0
1	84	1	3	1	189	2.34	0	0	0.0	0.00	0.0
1	84	1	3	2	188	1.86	0	0	0.0	0.00	0.0
1	84	1	3	4	176.2	2.38	0	0	0.0	0.00	0.0
1	84	1	4	1	174	2.36	0	0	0.0	0.00	0.0
1	84	1	4	2	180.2	1.74	0	0	0.0	0.00	0.0
1	84	1	4	4	184.4	1.6	0	0	0.0	0.00	0.0
1	84	2	1	1	171.4	2.08	0	0	0.0	0.00	0.0
1	84	2	1	2	168.8	1.5	0	0	0.0	0.00	0.0
1	84	2	1	4	155.4	1.32	0	0	0.0	0.00	0.0

1	84	2	2	1	160.2	2.28	0	0	0.0	0.00	0.0
1	84	2	2	2	164.2	1.64	0	0	0.0	0.00	0.0
1	84	2	2	4	181.4	1.58	0	0	0.0	0.00	0.0
1	84	2	3	1	175.2	2.22	0	0	0.0	0.00	0.0
1	84	2	3	2	169.2	1.9	0	0	0.0	0.00	0.0
1	84	2	3	4	156.8	1.7	0	0	0.0	0.00	0.0
1	84	2	4	1	183.6	2.22	0	0	0.0	0.00	0.0
1	84	2	4	2	177.8	1.96	0	0	0.0	0.00	0.0
1	84	2	4	4	170.8	1.62	0	0	0.0	0.00	0.0
1	84	3	1	1	181	1.9	0	0	0.0	0.00	0.0
1	84	3	1	2	190.8	1.94	0	0	0.0	0.00	0.0
1	84	3	1	4	157.6	1.54	0	0	0.0	0.00	0.0
1	84	3	2	1	169.2	2.36	0	0	0.0	0.00	0.0
1	84	3	2	2	156	1.8	0	0	0.0	0.00	0.0
1	84	3	2	4	173.2	1.6	0	0	0.0	0.00	0.0
1	84	3	3	1	159.6	2.22	0	0	0.0	0.00	0.0
1	84	3	3	2	165.8	1.96	0	0	0.0	0.00	0.0
1	84	3	3	4	172.8	1.22	0	0	0.0	0.00	0.0
1	84	3	4	1	160	2.28	0	0	0.0	0.00	0.0
1	84	3	4	2	171	2.02	0	0	0.0	0.00	0.0
1	84	3	4	4	160.8	1.66	0	0	0.0	0.00	0.0
1	135	1	1	1	0	0	16	356.94	9539.0	0.44	4166.7

1	135	1	1	2	0	0	16.3	347.54	11250.0	0.58	6500.0
1	135	1	1	4	0	0	13.09	341.28	12915.8	0.29	3750.0
1	135	1	2	1	0	0	18.08	326.2	12248.1	0.54	6666.7
1	135	1	2	2	0	0	15.37	361.07	13333.3	0.53	7083.3
1	135	1	2	4	0	0	14.64	307.85	14421.3	0.35	5000.0
1	135	1	3	1	0	0	18.27	337.54	12221.7	0.48	5833.3
1	135	1	3	2	0	0	16.38	376.35	14344.8	0.49	7083.3
1	135	1	3	4	0	0	13.74	357.91	14166.7	0.38	5416.7
1	135	1	4	1	0	0	18.28	324.1	10504.0	0.56	5833.3
1	135	1	4	2	0	0	16.96	400.43	12500.0	0.53	6666.7
1	135	1	4	4	0	0	13.88	359.2	13625.4	0.31	4166.7
1	135	2	1	1	0	0	17.57	377.3	13503.0	0.37	5000.0
1	135	2	1	2	0	0	14.17	323.4	14412.8	0.52	7500.0
1	135	2	1	4	0	0	14.37	334.37	13269.6	0.31	4166.7
1	135	2	2	1	0	0	19.29	292.26	15833.3	0.42	6666.7
1	135	2	2	2	0	0	16.21	314.33	11578.6	0.47	5416.7
1	135	2	2	4	0	0	12.94	317.66	12696.6	0.26	3333.3
1	135	2	3	1	0	0	18.52	364.23	12595.8	0.36	4583.3
1	135	2	3	2	0	0	18.63	353.8	16544.0	0.43	7083.3
1	135	2	3	4	0	0	13.96	338.4	14460.6	0.31	4500.0
1	135	2	4	1	0	0	19.66	387.95	12719.5	0.49	6250.0
1	135	2	4	2	0	0	16.37	361.01	15823.2	0.45	7083.3

1	135	2	4	4	0	0	15.81	337.4	13167.6	0.35	4666.7
1	135	3	1	1	0	0	17.17	369.13	19031.6	0.31	5833.3
1	135	3	1	2	0	0	15.97	371.61	21815.3	0.34	7500.0
1	135	3	1	4	0	0	13.61	307.24	14950.0	0.28	4166.7
1	135	3	2	1	0	0	16.95	347.61	14296.6	0.43	6166.7
1	135	3	2	2	0	0	16.12	283.6	12668.7	0.36	4583.3
1	135	3	2	4	0	0	14.18	327.47	22505.6	0.24	5416.7
1	135	3	3	1	0	0	19.12	384.05	14635.5	0.43	6250.0
1	135	3	3	2	0	0	15.87	356.71	17148.7	0.41	7083.3
1	135	3	3	4	0	0	14.56	346.47	19077.3	0.28	5416.7
1	135	3	4	1	0	0	18.44	333.69	10137.0	0.41	4166.7
1	135	3	4	2	0	0	16.57	332.37	14492.8	0.43	6250.0
1	135	3	4	4	0	0	15.47	297.16	14497.3	0.32	4666.7
2	84	1	1	1	188.2	2.26	0	0	0.0	0.00	0.0
2	84	1	1	2	192.6	1.68	0	0	0.0	0.00	0.0
2	84	1	1	4	187.4	1.28	0	0	0.0	0.00	0.0
2	84	1	2	1	191.6	2.24	0	0	0.0	0.00	0.0
2	84	1	2	2	184	1.78	0	0	0.0	0.00	0.0
2	84	1	2	4	168.4	1.36	0	0	0.0	0.00	0.0
2	84	1	3	1	173.4	2.26	0	0	0.0	0.00	0.0
2	84	1	3	2	182	1.78	0	0	0.0	0.00	0.0
2	84	1	3	4	163	1.22	0	0	0.0	0.00	0.0

2	84	1	4	1	187	2.18	0	0	0.0	0.00	0.0
2	84	1	4	2	185.4	1.78	0	0	0.0	0.00	0.0
2	84	1	4	4	181.2	1.58	0	0	0.0	0.00	0.0
2	84	2	1	1	186.4	2	0	0	0.0	0.00	0.0
2	84	2	1	2	166.8	1.68	0	0	0.0	0.00	0.0
2	84	2	1	4	185	1.46	0	0	0.0	0.00	0.0
2	84	2	2	1	149.4	1.18	0	0	0.0	0.00	0.0
2	84	2	2	2	170.8	1.326	0	0	0.0	0.00	0.0
2	84	2	2	4	161.2	1.88	0	0	0.0	0.00	0.0
2	84	2	3	1	149	2.04	0	0	0.0	0.00	0.0
2	84	2	3	2	154.6	1.66	0	0	0.0	0.00	0.0
2	84	2	3	4	165.6	1.24	0	0	0.0	0.00	0.0
2	84	2	4	1	164.6	1.9	0	0	0.0	0.00	0.0
2	84	2	4	2	173.2	1.32	0	0	0.0	0.00	0.0
2	84	2	4	4	136.2	1.04	0	0	0.0	0.00	0.0
2	84	3	1	1	166.4	1.68	0	0	0.0	0.00	0.0
2	84	3	1	2	157	1.6	0	0	0.0	0.00	0.0
2	84	3	1	4	162.4	1.38	0	0	0.0	0.00	0.0
2	84	3	2	1	154.6	1.96	0	0	0.0	0.00	0.0
2	84	3	2	2	144.4	1.34	0	0	0.0	0.00	0.0
2	84	3	2	4	150.8	1.36	0	0	0.0	0.00	0.0
2	84	3	3	1	176.8	2.02	0	0	0.0	0.00	0.0

2	84	3	3	2	162.6	1.6	0	0	0.0	0.00	0.0
2	84	3	3	4	157	1.52	0	0	0.0	0.00	0.0
2	84	3	4	1	144.6	2.1	0	0	0.0	0.00	0.0
2	84	3	4	2	161.6	1.68	0	0	0.0	0.00	0.0
2	84	3	4	4	143.6	1.26	0	0	0.0	0.00	0.0
2	135	1	1	1	0	0	18	356	9500.0	0.42	4000.0
2	135	1	1	2	0	0	15.8	310	12083.3	0.55	6666.7
2	135	1	1	4	0	0	12.36	289	13666.7	0.30	4166.7
2	135	1	2	1	0	0	17.6	327.8	11250.0	0.56	6333.3
2	135	1	2	2	0	0	16.3	311	13166.7	0.51	6666.7
2	135	1	2	4	0	0	12.36	287	15833.3	0.31	4833.3
2	135	1	3	1	0	0	17.24	347	12916.7	0.53	6833.3
2	135	1	3	2	0	0	16	342	11666.7	0.57	6666.7
2	135	1	3	4	0	0	12.2	313	18750.0	0.27	5000.0
2	135	1	4	1	0	0	18	301	14166.7	0.47	6666.7
2	135	1	4	2	0	0	16.84	356	16666.7	0.40	6666.7
2	135	1	4	4	0	0	12.04	319	17500.0	0.24	4166.7
2	135	2	1	1	0	0	17.3	359	13333.3	0.31	4166.7
2	135	2	1	2	0	0	16.92	300	14333.3	0.49	7083.3
2	135	2	1	4	0	0	16.34	279	15000.0	0.28	4166.7
2	135	2	2	1	0	0	18.8	292.26	14166.7	0.47	6666.7
2	135	2	2	2	0	0	16.76	298.8	14583.3	0.40	5833.3

2	135	2	2	4	0	0	12.54	298	12500.0	0.25	3166.7
2	135	2	3	1	0	0	16.16	351	12916.7	0.39	5000.0
2	135	2	3	2	0	0	17.26	315.8	15416.7	0.42	6500.0
2	135	2	3	4	0	0	13.18	312.5	17500.0	0.29	5000.0
2	135	2	4	1	0	0	18.04	347.5	10833.3	0.52	5666.7
2	135	2	4	2	0	0	17.12	312	14166.7	0.48	6833.3
2	135	2	4	4	0	0	12.04	302	15000.0	0.34	5166.7
2	135	3	1	1	0	0	16.66	369.13	18750.0	0.36	6666.7
2	135	3	1	2	0	0	15.2	347.5	23333.3	0.29	6750.0
2	135	3	1	4	0	0	13.56	297	17083.3	0.37	6333.3
2	135	3	2	1	0	0	17.54	326.3	10833.3	0.46	5000.0
2	135	3	2	2	0	0	14.08	318	14166.7	0.30	4250.0
2	135	3	2	4	0	0	12.14	287	13333.3	0.35	4666.7
2	135	3	3	1	0	0	17.84	330	15833.3	0.37	5833.3
2	135	3	3	2	0	0	15.32	326.1	13750.0	0.48	6666.7
2	135	3	3	4	0	0	14.88	314.4	16666.7	0.32	5333.3
2	135	3	4	1	0	0	18.28	330.2	9666.7	0.35	3416.7
2	135	3	4	2	0	0	15.48	301	17916.7	0.37	6666.7
2	135	3	4	4	0	0	13.02	297.16	20000.0	0.16	3166.7

KEY:

S- season

DAS – DAYS AGFTER SOWING

SPAC -SPACING

BK -BLOCK

Pphill- number of plants per hill.

Hgt -plant height

S/dia- stem diameter

Sdwt- a thousand seed weights

Bmass -above ground biomass

Hi- harvest index (ratio)

Ykgsha- yield in kilograms per hectare

Appendix 5.

The paper from this thesis titled, Effect of spacing and number of plants per hill on growth and yield of Sc duma 43 in the coastal lowlands authored by Fredrick Ochami[1]*, David Mushimiyimana[2], Mwaoria Mugambi[3], School Science and Technology, Department of Agriculture. Kenya Methodist University, P.O Box 267 Meru, Kenya. Published in International Journal of Multidisciplinary Research and Development Online ISSN: 2349-4182, Print ISSN: 2349-5979; Impact Factor: RJIF 5.72 Received: 21-07-2020; Accepted: 08-08-2020; Published: 17-08-2020 www.allsubjectjournal.com Volume 7; Issue 8; 2020; Page No. 152-156.