EFFECT OF INTER AND INTRA ROW SPACING ON GROWTH, YIELD AND YIELD COMPONENT OF QUALITY PROTEIN MAIZE (*Zea mays L.*) (BHQPY 545) AT JIMMA, SOUTHWEST ETHIOPIA

M.Sc. Thesis Research

By

Diriba Adugna Biru

June, 2015

Jimma, Ethiopia

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Submitted to the School of Graduate Studies

Jimma University College of Agriculture and Veterinary Medicine

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Agronomy

By

Diriba Adugna Biru

June, 2015

Jimma, Ethiopia

DEDICATION

I dedicate this Thesis manuscript to my mother W/ro Kebene Eseta and my father Ato Adugna Biru for their dedicated partnership in the success of my life.

STATEMENT OF THE AUTHOR

First I declare that this thesis is my work and that all sources of the materials used for this thesis have been duly acknowledged. This thesis has been submitted to In partial fulfillment of the requirements for M.Sc. degree at Jimma University, College of Agriculture and Veterinary Medicine and is deposited at the University Library to be made available to borrowers under the rules of the library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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BIOGRAPHOCAL SKITCH

Diriba Adugna Biru was born on January 4, 1990 at the vicinity of Shambu town, Horro Guduru Wollega zone. He attended his education at Shambu Primary and Secondary School, Shambu Secondary High School and Shambu Preparatory School from 1998 to 2009, respectively. After successfully passing the Ethiopian School Leaving Certificate Examination, he joined Jimma University College of Agriculture and Veterinary Medicine in 2010 academic year and graduated with B.Sc degree in Agriculture (Horticulture) in June 2012. Then, after his graduation the author joined Jimma University College of Agriculture and Veterinary Medicine, School of Graduate Studies on September 2012 to pursue his M.Sc. degree in Agronomy.

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ACRONYMS AND ABBREVATIONS

AIPAR	Average Intercepted Photosynthetically Active Radiation
ARC	Agricultural Research Council
BHQPY	Bako Hybrid Quality Protein Yellow maize
CSA	Central Statistical Agency
GDP	Growth Domestic Product
HI	Harvest Index
JARC	Jimma Agricultural Research Center
KAT	Kembata Alaba Tembaro
LAI	Leaf Area Index
MoA	Ministry of Agriculture
NRC	National Research Council
PGR	Plant Growth Rate
QPM	Quality Protein Maize
RCBD	Randomized Complete Block Design
SNNP	Southern Nation Nationalities and Peoples
USDA	United States Department of Agriculture

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDIX TABLES

EFFECT OF INTER AND INTRA ROW SPACING ON GROWTH, YIELD AND YIELD COMPONENT OF QUALITY PROTEIN MAIZE (*Zea mays L.*) (BHQPY 545) AT JIMMA, SOUTHWEST ETHIOPIA

ABSTRACT

*Quality Protein Maize (BHQPY545) has been released by research center to tackle the low level protein content of other commercial maize varieties in Ethiopia. However, little has been done on the influence of different Inter and Intra row spacing on BHQPY 545 variety growth and yield under Jimma Condition. Therefore, this field experiment was conducted at Jimma Agricultural Research Center with the objective of to determine the effect of Inter and Intra row spacing on growth, yield and yield component of BHQPY 545. Factorial combinations of five Inter row spacing (55, 65, 75, 85 and 95 cm) and five Intra row spacing (20, 25, 30, 35 and 40 cm) were laid out in a randomized complete block design with three replications. Analysis of variance showed that the interaction effect of inter and intra row spacings brought about significant variation among all the traits measured except Days to 50% emergence, ear length, number of grain rows per ear and number of grains per row while the main effect brought significant variation on number of ear per plant and ear diameter. Moreover, significantly higher leaf area index, plant height, number of grain per ear, grain yield and biomass yield was recorded from 55x25cm inter and intra row spacing. Grain yield highly significant and positively correlated with leaf area index (r=0.57**), plant height (r=0.37**), number of grain per ear (r=0.33**) and biomass yield (r=0.81**). On the other hand, grain yield was highly significantly and negatively correlated with leaf area (r=-0.53**), stem diameter (r=-0.54**) and number of ear per plant (r=-0.39**). In general, significantly higher yields were obtained from treatment combination of 55x25cm while the lowest was recorded from 75x40cm inter and intra row spacing. Therefore, it could be concluded that BHQPY 545 maize could be planted at optimum spacing of 55cm x 25cm of Inter and Intra row spacing under irrigation in Jimma area to attain maximum yield. It is further recommended that these results are from only one season at one site and hence such studies may be repeated in space and time to reach at concrete recommendation.*

Keywords: *Ethiopia, Grain Yield, Harvest Index, Leaf Area Index, Quality Protein Maize*

1. INTRODUCTION

Maize (*Zea mays* L.) has a critical nutritional role to play in human as it is the third important cereal crop globally after wheat and rice with regards to cultivation area, total production and consumption (FAO, 2011). Data from the United Nations (UN) Food and Agriculture Organization (FAO) showed that in 2010 world maize production was over 840 million metric ton, with the United States and China as the leading producers. The low average yield per unit area is the main reason why Africa's share of global maize production is so small (Pingali and Pandey, 2001). Maize in Africa is grown by small and medium-scale farmers who cultivate 10 ha or less (Devries and Toenniessen, 2001). About two thirds of all African maize is produced in eastern and southern Africa and it accounts for 53% of the total cereal area (FAOSTAT, 2010) and 30- 70% of total caloric consumption (Langyintuo *et al*., 2010).

Maize is one of the most important cereals cultivated in Ethiopia. It ranks second after tef in area coverage and first in total production. Maize is cultivated in a wide range of altitudes, moisture regimes, soil types and terrains, mainly by smallholder crop producers, which comprise 80 percent of the total population, in all regional states. Maize is currently grown across 13 agro-ecological zones, which together cover about 90 percent of the country (Dawit *et al.*, 2008). Though maize is widely grown in Ethiopia, only three regional states contribute to 94% of the total annual production. These regions are Oromia (60 %), Amhara (21.6%) and SNNP (12.55%). Thus the trend of the National maize production was totally dependent on the production field of the three regions. In 2012/13 the maize production in Ethiopia was 2,013,044.93 ha, and 3059 kg / ha (CSA, 2013). Maize grain has greater nutritional value as it contains 72% starch, 10% protein, 4.8% oil, 8.5% fiber, 3.0% sugar and 1.7% ash (Chaudhary, 1983). Normal maize has 10% protein which is of poor nutritional quality due to limiting concentration of essential amino acids (lysine and tryptophan) which the human body cannot synthesize and has to be supplemented (Mbuya *et al*., 2011).

The deficiency of the essential amino acids in normal maize causes serious protein malnutrition and associated problems for people with high protein requirements, e.g., young children, pregnant or lactating women, and the ill in communities where maize is a dietary staple and often a major source of protein (Pixley and Bjarnason, 2002). Despite the large area under maize, the national average yield is about 2.95t/ha (CSA, 2012). This is by far below the world's average yield which is about 5.21t/ha (FAO, 2011). The low productivity of QPM could be attributed to many factors like frequent occurrence of drought, declining of soil fertility, plant population, poor agronomic practice, limited use of input, poor seed quality, and disease. Among all the factors, plant population is one of the problems which affect the QPM yield remarkably.QPM yield could be different under various plant populations. According to Sangoi (*2001*) there is no specific optimum population density for maize in general for all the weather conditions since it differs based on environmental conditions. The pattern of distribution of plants at variable spatial arrangement has significant effects on yield depending on the proximity of plants within and between rows (Nafziger, 2006).

The production obtained from maize in Jimma 2012/13 was 144,362.82ha with the total production of 454,755,428kg and productivity of 3,150kg/ha (CSA, 2013). The average farmers land holding of maize is 0.33ha (CSA, 2013). Ethiopia has great potential for irrigated agriculture in low moisture stress areas of the country. It is well recognized that small scale irrigation can make a significant contribution towards reducing food insecurity both in potential and drought prone areas of the country. In addition to increasing crop productivity, it can enable farmers to increase intensification of cropping systems through double cropping and application of irrigation during dry spells and short-rain growing seasons. In spite of its potential contribution to food security, low emphasis has been given to sustainability as well as identification of suitable varieties for growing condition. To fast track the identification of maize varieties for irrigated agriculture systems, most of the open-pollinated and hybrid varieties that have been released for rain-fed conditions were tested under furrow irrigation at different locations (Gezahegn *et al.*, 2011).

From the tested OPVs, Melkasa2 was suitable for production under irrigated conditions while BHQPY545 and BH540 were superior among the hybrids. Farmers growing maize under irrigation in the central rift valley have already ascertained the top performance of Melkasa2 and BH540 under irrigated conditions. There is also evidence that farmers around Melkasa produced about 8 t ha-1 of Mellkasa2 by combining high plant population (by reducing spacing between plants from 25 to 20 cm) (Gezahegn *et al*., 2011)

In mid-altitude regions of the south, west and north-west, maize is normally grown in the main rainy season starting from March to November depending on maturity groups and onset of rains for each location. These regions account for more than 80% of the maize production of the country (CSA, 2010). In these areas, as a demand on more land area for maize cultivation has increased, the production of the crop has been maintained at an increasing pace. Although farmers in these regions attempted to use improved crop management practices, continuous cropping on the same piece of land and decreasing fallow periods contributed to the lower productivity of the crop (Tesfa *et al.,* 2004).

In these precarious situations, farmers most often harvest only once in a year those varieties that take a longer period of time. Such traditional practices do not ensure the production of adequate food per household, especially under conditions where the average land holding is very small. Though the area of maize production has been steadily expanding, the aforementioned social and agronomic constraints contribute to low national productivity of the crop, which is nearly 2.3 t ha^{-1} (CSA, 2010).

Even though production under irrigation systems plays an important role in subsistence and food production in Jimma area; to solve the problem related with land shortage, for released BHQPY 545 maize cultivar in the area their performance under inter and intra row spacing system have not been tested during the off-season. Inter and intra row spacing on BHQPY 545 maize cultivar had been practiced in the studied area by farmers during the main season using the same inter and intra row spacing with normal maize but during off season there is no inter and intra row spacing practices on BHQPY 545 maize cultivar by farmers. In the absence of recommended spacing for quality protein maize, the productivity will affected and difficult to apply proper farm management practices. Therefore, this research work was designed to answer "what is the optimum Inter and Intra row spacing for quality protein maize under Jimma agro- ecology during the off season. Therefore, the objective of this research was to determine the effect of Inter and Intra row spacing on growth, yield and yield component of BHQPY 545 at Jimma.

2. LITERATURE REVIEW

2.1 Agro-Ecologies of Maize in Ethiopia

Maize is one of the most important food crops world-wide. It has the highest average yield per hectare and it is grown in most parts of the world over a wide range of environmental conditions. Maize is generally less suited to semi arid or equatorial climates, although drought-tolerant cultivars adapted to semi-arid conditions are now available. The crop requires an average daily temperature of at least 20 ºC for adequate growth and development; the optimum temperature for growth and development ranges between 25-30 ºC; temperature above 35 ºC reduces yields (Brink and Belay, 2006). Frost can damage maize at all growth stages and a frost-free period of 120 to 140 days is required to prevent damage. Leaves of mature plants are easily damaged by frost and grain filling can be adversely affected.

Currently, maize is widely grown in most parts of the world over a wide range of environmental conditions ranging between 50o latitude north and south of the equator. It is also grown from sea level to over 3000 meters above sea level (masl) elevation (Singh, 1987). In the tropics, maize does best with 600-900 mm well-distributed rainfall during the growing season (Brink and Belay, 2006). The most suitable soil for maize is one with a good effective depth, favourable morphological properties, good internal drainage, and an optimal moisture regime, sufficient and balanced quantities of plant nutrients and chemical properties that are favourable specifically for maize production. Although large-scale maize production takes place on soils with a clay content of less than 10% (sandy soils) or in excess of 30% (clay and clay loam soils), the textural classes between 10 and 30% (clay) have air and moisture regimes that are optimal for healthy maize production and productivity.

2.2 Maize Production and Uses

Globally, maize (*Zea mays* L.) is among the leading cereals in production along with rice and wheat. The diverse uses of maize in food and feed as well as its industrial products allow the crop to be utilised extensively for both human and animal consumption (Alexander, 1987). Maize is the primary food staple in most parts of SSA with the highest annual per capita consumption in southern Africa followed by eastern Africa (Smalberger and du Toit, 2004). The annual per capita consumption of maize in southern Africa ranges from 138 kg in Swaziland to 195 kg in South Africa (CIMMYT, 1999), while in eastern Africa it ranges from 40 kg in Burundi to 105 kg in Kenya (Hassan *et al*., 2001). SSA countries do not produce enough maize to meet their needs and must therefore import approximately three million tons of maize annually (FAOSTAT, 2008). South Africa leads the continent's maize production followed by Nigeria (Table 1). The productivity of maize in Africa is less than the global average which is 5.2 t ha^{-1}. The exception is Egypt where the farming system is supported by irrigation (FAOSTAT, 2010).

Table 1. The top 10 producers of maize in Africa (FAOSTAT, 2010)

Rank	Country	Production (t)	Area (ha)	Yield (t ha^{-1})
1	South Africa	12815000	2 742,000	4.67
2	Nigeria	7305530	3 335,860	2.19
3	Egypt	7041100	968,519	7.27
4	Tanzania	4475420	3 100 000	1.44
5	Ethiopia	4400000	1 772 250	2.48
6	Malawi	3800000	1 655 000	2.30
7	Kenya	3222000	2 008 350	1.60
8	Zambia	2795480	1 080 560	2.59
9	Mozambique	1878000	1 573 000	1.19
10	Ghana	1871700	991 669	1.89

Although maize is estimated to be a source of about 20% of world food calories and 15% of crop protein (Brown *et al*., 1988), the protein quality of normal maize is poor due to the deficiency of the essential amino acids, mainly lysine and tryptophan (Bhatia and Rabson, 1987).

The rate of stunting is reported to be over 40% in areas where maize is the only source of protein (Hyman *et al*., 2008). In addition, 65% of the population in the maize farming system of SSA is reported to live on United States Dollar 2 or less per day (Wood *et al*., 2010) implying the difficulty of affording animal sources of protein. Normal maize protein in comparison to milk has a biological value of 40% (Bressani, 1991) and therefore needs to be consumed with complementary protein sources such as legumes or animal products. The need to improve the nutritional value of maize has been recognized for a long time (Osborne and Mendel, 1914) and decades long research have resulted in the development of nutritionally enhanced maize germplasm.

Ethiopia is the fifth largest maize producers next to South Africa, Nigeria, Egypt and Tanzania (FAOSTAT, 2010). In Ethiopia, maize is mainly used for food and feed purpose. The stalk is also used for construction and domestic fuel. Though maize is mainly used for human consumption, its share in the total calorie intake in Ethiopia is lower when compared to other African countries. For instance in Malawi the contribution is as high as 67% where as in Ethiopia it has only a share of 19% (Berhanu *et al*., 2007).

Currently, maize production in Ethiopia is exercised using both the traditional methods and extension package. The extension package is of a green revolution type characterized by use of high yielding seed varieties, fertilizers and chemicals. Despite the efforts to expand the extension system, the distribution of improved maize seeds is at minimum stage. The number is by far the lowest when compared to that of Tanzania (24%), Kenya (70%), Zambia (77%), and South Africa (94.5%). Furthermore, farmers are only achieving on average 60 % of their potential production given modern inputs utilization (IFPRI, 2007). The potential for increasing maize production through extensive use of improved seeds is thus high in Ethiopia.

Maize is cultivated in a wide range of altitudes, moisture regimes, soil types and terrains, mainly by smallholder crop producers, which comprise 80 percent of the total population, in all regional states. Maize is currently grown across 13 agro-ecological zones, which together cover about 90 percent of the country (Dawit *et al.*, 2008). Though maize is widely grown in Ethiopia, only three regional states contribute to 94% of the total annual production. These regions are Oromia, Amhara and SNNP. According to a five years (2003/04 - 2007/08) CSA data, during the past five years, the share of Oromia region was on the average, 60% of the total Maize production in the country. This was followed by Amhara with 21.67% and SNNP with 12.55%.

2.3 Constraints to Maize Production in Sub-Saharan Africa

Maize is still considered a low yielding crop in the West and Central Africa sub-regions compared with what obtains in the USA where a yield of 10 tonnes per hectare is achievable, though a modest increase in average yield from the long standing less than 1.0 tonne per hectare to about 1.3 tonnes per hectare has occurred (Fakorede *et al*., 2003). Maize production is generally confronted with a number of biotic and abiotic stresses that are responsible for the low yields in farmers' fields. Some of these production-limiting factors include low soil nutrient supply, Striga parasitism and poor management practices, notably low plant density, late planting and late first weeding. Abiotic stresses that undermine agricultural production and particularly maize production severally include the potentially adverse effects of drought, salinity, flooding, metal toxicity, nutrient deficiency, and high and low temperatures. Others which are often sporadic and localized in their occurrence are shade, ultra-violent exposure, photoinhibition, air pollution, wind, hail, and gaseous deficiency (Shafiq-ur-Rehman *et al*., 2005). These factors portend great danger to agriculture and destroy the environment (Wang *et al*., 2003). Generally, crops attain only about 25% of their potential yield, and most crop plants suffer a yield loss of up to 50% as a result of the limiting effects of these stress factors (Bray *et al*., 2000) which are location-specific, exhibiting variation in frequency, intensity, and duration. Abiotic stresses result in a chain of morphological, physiological, biochemical and molecular changes with dramatic negative impacts on growth and productivity of crop plants (Wang *et al*., 2001a). Drought and salinity are common in a few regions, posing a major catastrophe of salinization of over 50% of agricultural lands by 2050 (Wang *et al*., 2003).

An array of diseases plagues maize growing areas in sub-Saharan Africa. These include downy mildew, rust, leaf blight, stalk and ear rots, leaf spot, and maize streak virus. Insect pests, including stem and ear borers, armyworms, cutworms, grain moths, beetles, weevils, grain borers, rootworms, and whitegrubs are also a great threat to the survival of maize in Africa. In the Nigerian savanna, for example, weed-related yield losses ranging from 65 to 92% have been recorded (IITA, 2009). The parasitic weed, known as witchweed (*Striga*), is a major pest in sub-Saharan Africa and causes an estimated cereal grain loss of up to US$7 billion. This adversely affects the lives of about 300 million people (IITA, 2009). The limited use of nitrogenous fertilizers and declining soil fertility are major maize production constraints in Sub-Saharan Africa. The effects of prolonged droughts, such as those that have struck Eastern and Southern Africa in recent years, have been disastrous (Bolanos and Edmeades, 1996). Maize in the developing world is almost exclusively grown by small scale farmers under rainfed conditions with minimal input and management (Fakorede *et al*., 2003).

In Ethiopia Soil fertility and biotic constraints account for more of the yield gap than farm management practices. Low soil fertility is the primary constraint to maize productivity in Sub-sahan Africa, accounting for an estimated 122 kilograms per hectare loss or seven percent of the total smallholder yield gap Gibbon et al. (2007). Additional soil fertility and biotic constraints such as acid soils, *Turcicum* leaf blight, weeds, grain weevils, grain borers, maize stem borer, stock borer and grey leaf spot are responsible for an estimated 272 kilograms per hectare loss, accounting for 15% of the yield gap. Management constraints, including late planting, row spacing and weeding, account for an additional three percent of the gap, resulting in an estimated loss of 54 kilograms per hectare.

2. 4 Nutritional and Economic Benefits of QPM

Quality protein maize offers significant benefits in the nutrition of monogastric animals including humans; because the essential amino acids (lysine and tryptophan) cannot be synthesized through metabolism of these groups of animals. The nutritional and biological superiority of QPM to normal maize has been amply demonstrated in rats (Gupta *et al.*, 1970), pigs (Osei *et al.*, 1994a), infants and small children (Bressani, 1995), adults (Bressani, 1992), broiler chickens (Osei *et al.*, 1994c) and dairy cattle (Glover, 1992).

QPM has superior biological value (the amount of N that is retained in the body) due to the 60 to 100% increase in concentrations of lysine and tryptophan, increased digestibility and increased N uptake which causes QPM to have a biological value of 80% compared to about 40% of normal maize (Bressani, 1992). Bressani (1995) reported that protein quality of *o2* maize is 43% higher than that of normal maize and 95% of the value of casein. QPM is 50% more effective than normal maize at fostering growth and in recovering malnourished children (NRC, 1988). Protein quality of *o2* maize is 90% of the value of milk (Bressani, 1992; 1995). Osei *et al.* (1994a) reported that pigs fed on QPM grew 2.3 times faster than pigs of the same age fed on the same quantity of normal maize. A QPM based diet is regarded as sufficient in fulfilling the energy and protein requirements of infants and children (Graham *et al.,* 1990). The health of children suffering from Kwashiorkor (a severe protein deficiency disease) was restored on a diet containing only *o2* maize as a protein source (Clark *et al.,* 1977).

Recovering malnourished children fed on QPM further showed similar growth as those fed modified cow milk formula (Graham *et al.,* 1990). QPM has a potential impact on disadvantaged populations whose maize consumption is high and access to complementary sources of protein are limited (Rahmanfer and Hamaker, 1999). Studies in China and Pakistan demonstrated that lysine fortification of cereal-based diets (wheat) improved growth in children and various health indicators for children and adults, confirming that lysine enrichment of cereal-based diets remains beneficial to improve problems associated with malnutrition (Hussain *et al.,* 2004).

Gupta *et al*. (1970) found modified *o2* maize to be nutritionally superior to normal maize in rat (*Rattus norvegicus*) feeding experiments. According to Glover (1992), US farmers who fed *o2* maize silage to dairy cattle benefited from increased milk production of their dairy cows. QPM silage may hold distinct nutritional and economic advantages in the feeding of dairy animals (Gevers, 1995). Substituting normal maize with high-lysine maize on an equal weight basis for piglets and cows can reduce the use of artificial lysine in animal feeds to maintain a proper amino acid balance (Knabe *et al*., 1992). In the USA feed industry, doubling lysine content in maize alone can add an estimated annual gross value of $360 million per year and can reach $480 million per year if protein is also increased (Johnson *et al*., 2001). These findings indicate that QPM has an added advantage of being superior in protein quality and higher in food and feed efficiency.

2.5 Factors Affecting Optimum Population Density

Maize population for maximum economic grain yield varies between 30,000 to over 90,000 plants per hectare (Olson & Sanders, 1988). There is no single recommendation for all conditions because optimum density varies depending on nearly all environmental factors, such as soil fertility, hybrid selection, planting date and planting pattern, among others. A brief summary of some of the variables that can influence optimum population follows.

2.5.1 Cultivar maturity and length of the growing season

Generally speaking, early hybrids require higher plant densities for maximum yield than late hybrids (Tollenaar, 1992). This occurs because early hybrids are normally smaller, produce less leaves, have lower leaf area per plant and present fewer self-shading problems than late cultivars. Therefore, for early hybrids it is necessary to have a greater number of plants per area to generate the leaf area index that provides maximum interception of solar radiation, an essential step to maximize grain yield. The season length in any particular geographic location is a factor that interacts with cultivar maturity, affecting the optimum rate of planting for maximum yield. There is evidence that higher plant densities are required in the North central U.S. compared with locations further south (Olson & Sanders, 1988). This is expected because available light energy decreases as one proceeds further north. Hence, the smaller amount of solar radiation and the shorter growing seasons registered in the Northern Maize Belt force the utilization of early varieties, contributing to increase optimum plant densities in those regions. The same kind of trend has been observed by Almeida *et al*. (2000) in the high-lands of Southern Brazil. Late spring and early fall frosts decrease maize growing season duration in this region. Mild Spring and summer temperatures restrict maize vegetative growth. Both factors contribute to enhance maize grain yield response to higher plant populations (Almeida & Sangoi, 1996).

2.5.2 Time of planting

Holding all other factors constant, early planted maize usually requires a higher population to maximize yield, particularly in temperate and subtropical regions of the world (Anderson, 1995). Early-planted maize encounters lower soil and air temperatures during its first developmental stages. The small number of thermal units accumulated per day makes it grows slowly (Sangoi, 1993). The period between emergence and anthesis of a maize hybrid planted in August can be up to two weeks longer than when the same cultivar is planted in December in Southern Brazil (Sangoi, 1993). During this extra period, plants will uptake more solar radiation and store the energy because the lower temperatures limit their growth and consumption of this energy. As a result of this slower pattern of development, early-sowed maize plants are smaller and less leafy at anthesis (Silva *et al*., 1998). Since early planting generally results in shorter plants that have lower individual leaf area, increasing plant density by 5,000 to 7,500 plants.ha^{-1} is usually necessary to maximize yield (Aldrich *et al*., 1986). Early planted maize also silks earlier in the growing season, when the atmospheric evaporative demand is usually smaller (Matzenauer *et al*., 1998), decreasing the probability of moisture stress, which can be another reason for early-planted maize higher tolerance to increased plant population.

Ethiopia has two crop growing seasons; *belg* (from March up to August) and *Meher* (from April to February), where rain fed agriculture is the dominant practice. In most parts of the country, the *belg* rain begins around February and ends in April, where as the *meher* rain stretches from June to September. After many years of high variability and low level of cereals production, the country starts recording a better performance since 2002/03. However, there is high variability of production, which could be attributable to different factors like irregularity of weather condition, change in areas harvested, use of inputs, technology and policies (FAO/WFP 2008).

Maize growing period in Ethiopia is not uniform throughout the country (Regional Agricultural Trade Expansion Support Program, 2003). Generally, it is planted during the *belg* season which stretches from February to end of May, in semi-arid parts of the country. In the Eastern and Southeastern parts of Ethiopia, maize planting period starts in March and ends late April. Harvesting in these regions is from early November to late December. In the Northwestern and

Southwestern parts, maize planting starts in early May and ends early June. Harvesting for this period is from late December-middle of January.

2.5.3 Water availability

Water availability is probably the most important uncontrollable factor affecting optimum plant density for maize grain yield under rainfed production systems (Loomis & Connors, 1992). Precipitation, soil water and plant population interact, particularly during the rapid growth period of the crop (from 30cm height to silking). The final effect on yield of these three interacting factors is determined by the level of soil water available to plants at the beginning of rapid growth period, by the amount and distribution of precipitation during this period and by the amount of water transpired by the canopy (Matzenauer *et al*,. 1998).

Increasing plant density increases leaf area index and consequently water consumption (Tetio-Kagho & Gardner, 1988a). Therefore, the use of high plant populations under limited water supply may increase plant water stress and dramatically reduce grain yield, specially if a water shortage coincides with the period of 2-3 weeks bracketing silking (Westgate, 1994). Even though the increase in water use as plant density is raised is not proportional to the stand increase, small deficits during critical stages, especially at flowering, can drastically reduce kernel set and grain yield. Consequently, it is extremely important to consider water supply to define the optimum plant population for any particular region and cropping system. Shallow soil profiles, high atmospheric temperatures and irregular precipitation distribution favor drought stress. Under these circumstances, it is advisable to work with a lower number of individuals per area. This will decrease interplant competition for water, preventing a protandrous pattern of development that could lead to barrenness (Sangoi & Salvador, 1998b).

2.5.4 Planting density effects

Ideally, plants spaced equidistantly from each other compete minimally for nutrients, light and other growth factors (Lauer, 1994). The introduction of hybrids, the increase in fertilizer utilization, the development of new herbicides to control weeds, among other factors, stimulated the use of higher plant densities in maize (Russell, 1991) With the utilization of higher plant densities, it soon became clear that plant distribution within the row could be a limiting factor in wide rows, preventing the full expression of the yield potential of new cultivars. Narrower spacing of rows is a partial mean of achieving equidistant spacing between maize plants (Lauer, 1994). Narrow rows make more efficient use of available light and also shade the surface soil more completely during the early part of the season while the soil is still moist (Bullock *et al.*, 1998). This results in less water being lost from the soil surface by evaporation. Therefore, reducing row width to provide a more equidistant planting pattern has the potential to increase maize yield and shift optimum plant population to a higher value depending on the interactions with management and environmental factors. The utilization of row spacing ranging from 0.5 to 0.75 m may enhance maize optimum plant population especially when highly productive singlecross early hybrids are grown in soils with high fertility and under irrigation (Sangoi and Salvador, 1998a). Conversely, Buntzen (1992) and Merotto Jr. *et al*. (1997a) have shown that when any environmental factor or inappropriate management practice hinders maize growth and development, narrowing row spacing may have little effect on either improving grain yield or increasing the optimum plant population density necessary to maximize yield.

Grain yield

Maize grain yield can be described as a function of the rate and duration of dry matter accumulation by the individual kernels multiplied by the number of kernels per plant (Westgate *et al*., 1997). In simple terms, maize grain yield is a product of the number of ears produced and the average weight of the grain on the ears. Thus anything that affects one or both of these factors will significantly affect the final yield (Hatfield *et al.*, 1984). According to Hashemi *et al*. (2005), grain yield per unit area is the product of grain yield per plant and number of plants per unit area.

Maize grain yield rises with planting density to some maximum value and then declines. The rate that produces a maximum yield varies with varieties, environment, fertility and planting pattern. For a given hybrid, the yield of maize generally increases as density is raised until one or more factors such as water supply, available plant nutrients and other become limiting. According to Vega *et al*., (2001), maize grain yield is more affected by variations in plant density than other members of the grass family due to its low tillering capacity. Fancelli & Dourado-Neto, (2000) found a strong relationship between maize grain yield and plant density. They highlighted that for each production system there is a plant density that optimizes the use of available resources, thereby allowing the expression of maximum attainable grain yield in that environment.

According to Tollenaar *et al*. (1997) maize grain yield declines when plant density is increased beyond the optimum plant density, primarily because of decline in the harvest index and increased stem lodging. Such cases represent intense interplant competition for incident photosynthetic photon flux density, soil nutrients and soil water. This results in limited supplies of carbon and nitrogen and consequent increases in barrenness and decreases in kernel number per plant and kernel size (Ottman & Welch, 1989). Maize yield development is a sequential process in which the potential number of ears per plant is determined first, followed by grain number per inflorescence and by grain size. Therefore, variations in the level of carbon and nitrogen induced by different planting rates or any other factor can strongly influence yield and its components sequentially (Jacobs & Pearson, 1991).

Vega *et al*. (2000) found the direct effect of increasing plant density to enhance interplant variability in several phenotypic traits (e.g. biomass, height, anthesis-silking interval, kernel number, etc). Sangoi *et al*., (2002) supported the results of Vega *et al*. (2000), that maize grain yield is associated with the number of kernels per area, which depend on the number of plants per area, number of ears per plant and the number of kernels per ear. Tollenaar *et al*. (1992), found grain yield response to plant density to be mostly associated with number and size of kernels per unit area. Otegui (1995) found a close relationship between grain yield and kernel number for several hybrids grown under different environmental and management conditions.

Hashemi-Dezfouli & Herbert (1992) reported the response of grain yield per unit area to increase in plant density to be parabolic. At low plant density, number of plants limited the yield, while at high plant density number of barren plants limited yield as well. A reduction in grain yield at high plant densities is partly due to an increase in ear barrenness, decrease in number of kernels per ear or both. Daynard & Muldoon (1983) reported that a reduction in the number of kernels per ear might result from fewer flower initials being formed prior to flowering, poor pollination due to asynchrony of tasseling and silking, and abortion of kernels after fertilisation. They suggested that intra-row spacing and competition for water, light and nutrients to be the determinant factors on optimum plant densities for growing environment.

Kernel number per cob (KNC)

In general, kernel number accounts for most of the variation in grain yield. Echarte *et al*. (2000) found grain yield response to plant density to be positively and strongly related to number of kernels m^{2} and negatively and weakly related to weight per kernel. For instance, an increase in plant density from 5 to 14.5 plants m^{2} increased kernel number per cob by 38 to 56%. However, Andrade *et al*. (1993) reported that kernel number per plant declines sharply with increasing plant density. This response is the result of a decrease in photosynthetic rate per plant (Edmeades & Daynard, 1979) and hence plant growth rate (Andrade *et al*., 1993). Both directly reflect the reduction in Intercepted Photosynthetically Active Radiation per plant (Andrade *et al*., 1993). The greatest losses in kernel number per ear occur in plants shaded during the lag phase of grain filling (Kiniry & Ritchie, 1985).

Sangoi *et al*. (2002) reported that the number of potential grain sites per ear measured when silking commenced and before pollination, showed a decline from 550 to 474 grains per ear as population increased. Thus, although high plant density did not affect the time of initiation of the ear primordia, it decreased the number of grain sites per ear available at the time of pollination. Moreover, the decline in grain numbers indicated that under higher plant density a lack of pollination occurred for ears that were delayed in silking together with abortion of some fertile grains thereafter (Hashemi-Dzefouli & Herbert, 1992). Tokatlisdis & Koutroubas (2004) also reported that under higher plant density the reduced assimilate supply causes abortion of kernels, especially at the ear tip. Maddonni *et al*. (2004) found that maize has a distinctive response to stand density with a sharp decline in kernel number per cob (KNC) and a substantial increase in plant barrenness at plant density beyond the threshold that maximizes grain yield. This response to plant densities derives from the combined effect of: (i) a decrease in photosynthetic rate per plant and in plant growth rate (PGR) (ii) a hierarchical pattern in reproductive development in which tassel growth dominates ear growth (apical dominance). Under stress conditions (e.g., drought, high plant population), ear barrenness occurs because of lack of pollen, incomplete ear pollination and kernel abortion (Carcova & Otegui, 2001).

Maize kernel number per cob (KNC) is associated with plant growth rate (PGRs) during the period bracketing silking (Andrade *et al*., 1999). More kernels set per unit PGRs is probably related to greater dry matter partitioning to the ear and to more kernels set per unit dry matter allocated to the ear during the critical period for kernel set (Echarte *et al*., 2000). Contrarily, kernels per plant, ears per plant and kernel mass decline with increasing plant density, which could be associated with a reduction in plant dry matter accumulation from one week before silking to three weeks after silking (Tollenaar & Stewart, 1992). In addition, the higher kernel mass in an experiment involving ten plants m^2 may be attributed to a higher rate of plant dry matter accumulation per kernel during the period from three weeks after silking to physiological maturity. The final kernel number in maize is determined by the amount of photosynthate produced by the crop at flowering (Andrade *et al*., 1993). Otegui & Andrade (2000) reported that total plant growth during the period encompassing flowering is not the only factor that influences the number of reproductive sinks set per plant, since the partitioning of dry matter is also influential.

Cob number and barrenness

Sarquis *et al*. (1998) found that plant density strongly influences the rate and duration of crop growth and ultimate fate of multiple ears. They found that a 30% reduction in light interception by the canopy during the crop cycle was enough to completely suppress the development of a second ear. Apparently the reduction of light interception limits source capacity, which in turn could retard second-ear growth severely enough for the latter to be even totally repressed once the ovules in the apical ear have been fertilized (Tetio-Khago & Gardner, 1988). High plant density reduces light interception per plant and it is likely that mutual shading affect source capacity to supply a second ear with photoassimilate. Thus, apical-ear yield seemed to be sink-limited, while source capacity seemed to limit the growth of the second ear. Edmeades *et al*. (2000) demonstrated that assimilates moved preferentially from a leaf to its nearest sink. This implies that leaves above and immediately below the primary ear supply most of the assimilate for grain filling, while assimilates from the lower leaves are more likely to be translocated into the root and lower stem.

At high plant density, the equilibrium between the two ears seemed to be affected due to a stronger competition between them as evidenced by a more severe decrease in grain mass with increasing time between the two pollinations, regardless of which ear was pollinated first (Sarquis *et al*., 1998). The results indicate that in order to complete its growth, a second ear must reach a minimum stage of growth before active grain filling begins in the first ear, as has been postulated by other researchers (Tetio-Khago & Gardner, 1988). The results also supported the idea that total yield per plant would be maximum when both ears were pollinated at the same time (Sarquis *et al*., 1998).

Many researchers have reported that the plant population and the arrangement of the plants have an effect on the number and mass of the ears produced (Hatfield *et al*., 1984). Otegui (1995) found that ears per plant and ear mass are negatively correlated with plant population, while grain yield commonly varies slightly over a wide range of plant population. This suggests compensation between ear number and ear mass. Hashemi-Dezfouli & Herbert (1992) reported that increased plant density during drier periods decreases the mass and diameter of cobs, diameter and number of kernels per cob, but not the number of kernels per row as well as weight of kernels.

The failure of plants to produce ears (Barrenness) has been reported as one of the major factors limiting optimum conversion of light energy to grain in maize grown at high plant densities (Buren *et al*., 1974). Grain yield of many hybrids planted at high densities are markedly reduced by barrenness. Therefore, it is important that factors influencing barrenness be determined and understood to permit selection of genotypes that are tolerant of high plant densities (Buren *et al*., 1974). Ritchie & Alagarswamy (2003) found high maize yields at plant densities ranging from seven to ten plants m^{-2}, but barrenness occurred more frequently when plant densities exceed 10 plants m^{-2}. Thus, plant densities influence both plant growth rate (PGR) and barrenness. In relating barrenness to plant growth rate, Andrade *et al*. (1999) found that maize plants were barren when plant growth rate averaged about 1.0 g per day during the 30-d period bracketing silking. Maize genotypes appear to have major genetic differences in barrenness. Tollenaar & Aguilera (1992) found that lower barrenness in modern maize hybrids compared with older hybrids at higher plant densities was associated with higher plant growth rate from one week presilking to three weeks postsilking. Additionally, Andrade *et al*. (1999) related average intercepted photosynthetically active radiation (AIPAR) to barrenness and found a threshold AIPAR of 0.34 MJ plant d^{-1} during ear development stage was necessary to avoid barrenness.

Leaf area, leaf area index and crop growth

Watson (1997) defined leaf area index of a crop as the one-sided area of green leaf tissue per unit area of land occupied by that crop. That is the area of leaf per area of land. It is a key plant growth parameter that is frequently measured and estimated from leaf shape characteristics (Stewart & Dwyer, 1999). Leaf area index (LAI) and distribution of leaf area within a maize canopy are major factors determining total light interception, which affects photosynthesis, transpiration, and dry matter accumulation. It can be estimated and used in crop growth models to calculate photosynthesis, assimilate partitioning, gas and energy exchange (Fortin *et al*., 1994). During the early vegetative stage of growth, leaf area determines total light interception. Thus, conditions favouring maximum area per leaf should optimise Co_2 fixation during that period (Morrison *et al*., 1992). It is important to note that only 50 per cent of incident solar radiation can be used as photosynthetically active radiation (PAR). The remaining energy is of no value in photosynthesis and if absorbed, serves only to increase the temperature of the leaf (Monteith, 1981).

The efficient interception of radiant energy incident to the crop surface requires adequate leaf area, uniformly distributed to give complete ground cover and that could be achieved by manipulating stand density and distribution over the land surface (Modarres *et al.*, 1998). The capacity of the crop to intercept photosynthetically active radiation and synthesize carbohydrates for growth is a nonlinear function of LAI (Andrade *et al*., 2002). Kiniry & Knievel (1995) reported that in the absence of nutrient deficiencies, temperature extremes, or water stress, solar radiation intercepted by plant is the major limitation to growth, development and yield.

Stickler (1984) showed that the combined leaf area per plant for the primary ear leaf with the first above and below the ear decreased from 2300 cm^2 at 39500 plants ha^{-1} to 2150 cm^2 at 59500 plants ha^{-1}. However, the leaf area produced on the main stalk does not decrease in inverse proportion to an increase in plant density; thus area changes must be attributed to differences in silking with density. Major & Dynard (1972) reported that LAI of 2.6 is optimum for grain yield in hybrids while 2.0 is considered optimum for inbreds. At optimum LAI, about 90% of the incoming solar radiation is intercepted by the crop canopy (Major *et al*., 1991).

Maize grain yield tend to be linearly related to LAI at silking period. The LAI values greater than 4.0 substantially reduce the depth of light penetration into normal leaf canopies and greatly reduce yield. Dry matter produced in maize with a LAI of 3.3 by the top, middle and bottom leaves is of the ratio of 4:21:1. Thus, the low rate in the bottom leaves is probably due to shading by the above leaf canopy at a high LAI and leaf age. The high rate in the middle is probably due to close proximity of the developing grain, which provides for a large sink for photosynthates (Stickler, 1984).

The efficiency of conversion of intercepted solar radiation into economic maize yields could decrease with high plant density because of mutual shading of plants (Buren, 1974). Boyat *et al*. (1990) reported that increasing plant density accelerated leaf senescence, increased the shading of leaves, and reduced the net assimilation of individual plants. Their results also showed that an increase in plant population of 2- 13 plants per m^2 decreased the net assimilation per plant from 0.85 to 0.11 mg CO_2 m-2 s-1, but increased grain yield per area. This increase in grain yield could therefore be attributed to increase in leaf area index (LAI) and net crop assimilation (Dwyer *et al.*, 1992).

Flowering/tasseling

In maize (*Zea mays L.*), tassel initiation is the first visible sign that a plant has shifted from the vegetative to the reproductive stage of development (Russel & Stuber, 1983). Contrarily, some authors reported that, it is incorrect to say that reproductive development begins with the initiation of the tassel because the early initials of ears are visible as buds at the axils of the lower leaves before the tassel is differentiated. Approximately 30 days after planting, when the stem is only 2 cm long and the plant just knee-high, the tassel is initiated. At this stage, the growing point is switched only partly from producing leaves to producing the terminal reproductive structure, the tassel.

Tokatlidis & Koutroubas (2004) reported that high plant density affects the required interval for pollen shedding and silk emergence. The time from planting to silking increased from 84 to 95 days as density increased from five to 20 plants m^2. Additionally, they further reported that since the time gap between pollen shedding and silking increased with increase in plant density from almost zero to nine days. This in combination with the fact that plants not shedding pollen and not silking were observed only at the higher plant density of 15 and 20 plants m^2, contributed to increase in ear barrenness. Similar results were obtained under three plant densities by Hashemi-Dzefouli & Herbert (1992).

Tassel emergence was slightly affected by plant density changes. Pollen shedding and 100% silking were observed at the same time under the lower plant density of three plants m^2. Conversely, the time for 100% silking was delayed by up to five days as density increased to seven plants m^2, and under the higher plant density of 12 plants m^2 about 10% of the plants did not show any silk seven days after anthesis. The number of barren plants increased linearly as the plant density increased. The same holds true for results of Sangoi *et al*. (2002) who showed a linear elongation of the pollen-to-silking interval with increasing density from three to 10 plants m-2 of the three maize hybrids studied.

The pollen-to-silking interval increased from five to 13 days for the two older hybrids and five to 11 days for the newer hybrids. Sangoi *et al*. (2002) concluded that high plant density lengthen the gap between pollen shedding and silking, while on the other hand barrenness could be stimulated even in the case of density -tolerant hybrids, since any environmental adversity (i.e. high temperatures) may prevent pollination because of its detrimental effect on the limited pollen during silk emergence. Undoubtedly, the increased gap between pollen shedding and silking under higher plant density constitutes a key factor for increased ear barrenness and therefore influences negatively the final grain yield (Tokatlisdis & Koutroubas, 2004). Hashemi-Dzefouli & Herbert (1992) also reported that high plant densities delay silk emergence that lead to decrease in kernel number per ear, increased number of barren plants and reduction in total grain yield.

Tetio-Kagho & Gardner (1988) reported the effect of high plant densities on extension of the tasseling-to-silking interval and lack of kernel filling to be more detrimental. High plant densities enhance interplant competition for assimilates, particularly during the period bracketing silking, favouring apical dominance and decreasing the ratio of ear to tassel growth rate (Edmeades *et al*., 2000). Similar results were reported by Otegui *et al*. (1995) that at silking, the amount of dry mass partitioned to the ear to be exponentially associated with the summed intercepted photosynthetic active radiation (IPAR) prior to silking. This relationship supported the idea that during this period the ear is a dominated organ (Tollenaar, 1997), competing for photoassimilates with leaves, tassel and stem (dominating organs). As the demand from dominating organs is satisfied, then more resources are allocated to the ear with resultant ant higher proportionally increase in ear dry mass than shoot dry mass.

Plant height

Plant height is a genetic trait. Thus, the number and length of the internodes determine the height of the stalk. In this way, plant height can vary from 0.3 m to 7.0 m, depending on the variety and growing conditions (Gynes-Hegyi *et al*., 2002). Usually, early maturing varieties are shorter and late maturing ones are taller. In a tropical climate where the growing season may be as long as 11 months, some late maturing varieties can reach a height of 7 m (Koester *et al*., 1993). Yokozawa & Hara (1995) cited that the height of the final plant and the diameter of its stalk are strongly influenced by environmental conditions during stem elongation. Temperature and photoperiod may influence stalk height by affecting the number of internodes. However, there are more direct effects resulting from moisture stress, nutrition, temperature, pests and diseases and light quantity and quality (Baggett & Kean, 1989). Moisture stress could simply affect the length of internodes probably by inhibiting the elongation of developing cells.

It has often been observed in experiments involving different plant densities that maize plants are taller as mutual shading increases, although there is considerable varietal variation in this characteristic (Yokozawa & Hara, 1995). Thus, plants that grow within a dense canopy under high plant density receive a different quality of light, enriched with far red (FR) and impoverished in red (R) radiation. This high FR/R ratio triggers many morphological changes in plant architecture, stimulating stem elongation, favouring apical dominance and decrease in stem diameter (Rajcan & Swanton, 2001). In addition, Troyer & Rosenbrook (1991) reported that stalk breakage and ear droppage increase because crowded maize plants have smaller diameter stems and shanks due to mutual shading. Such changes make maize stalks more susceptible to breakage before kernels reach physiological maturity. Stalk lodging represents one of the most serious constraints to the use of high plant densities in maize (Argenta *et al*., 2001). Thus, many high-yielding hybrids are often rejected during development because of stalk lodging.

3. MATERIALS AND METHODS

3.1 Description of the Study Area

The study was carried out at Jimma Agricultural Research Centre (JARC) during the 2014 off-season. The site was located 368 km South West of Addis Ababa. The geographical coordinate of the site were at $7^0 40'$ N latitude and 36^0 E longitudes at an altitude of 1753 meters above sea level (JARC, 2014). It was situated in the tepid to cool humid-mid highlands of south-western Ethiopia. The soil type of the experimental area is Eutric Nitsol (Reddish brown) with a pH of around 5.2. The long-term (ten years) mean annual rainfall of the area were 1639 mm with a maximum and minimum temperature of 26.6 and 13.9 ^{0}c (JARC, 2014). The trial was irrigated with a furrow irrigation system.

3.2 Planting Materials

Medium matured maize variety BHQPY 545 was used for the study. BHQPY 545 was released by Bako Agricultural Research Centre through the National Maize Research Programme in 2008, performing well in agro-ecological range of 1000-2000 m.a.s.l with rainfall range of 1000-1200 mm. It can give 9-10 and 6-7 t/ha grain yields under on-station and on-farm experiments, respectively. It was a moderately tolerant to rust, blight and gray leaf spot with maturity date of 138 and 25kg seed rate/ha.

3.3 Treatments and Experimental Design

Five levels of inter row (55, 65, 75, 85, and 95cm) and intra row spacing (20, 25, 30, 35 and 40cm) were used for the study (Table 2). The experiment was laid out in a Randomized Complete Block Design (RCBD) in 5 x 5 factorial arrangements with three replications. The seed of BHQPY 545 medium matured hybrid maize variety were obtained from Jimma Agricultural Research Center for the experiment.

Table 2**.** Details of treatment combination and plant population

Treatments	Inter- row x Intra- row spacing (cm)	Plant population per hectare
1	55x20	90909
2	65x20	76923
3	75x20	66667
4	85x20	58824
5	95x20	52632
6	55x25	72727
7	65x25	61538
8	75x25	53333
9	85x25	47059
10	95x25	42105
11	55x30	60606
12	65x30	51282
13	75x30	44444
14	85x30	39216
15	95x30	35088
16	55x35	51948
17	65x35	43956
18	75x35	38095
19	85x35	33613
20	95x35	30075
21	55x40	45455
22	65x40	38462
23	75x40	33333
24	85x40	29412
25	95x40	26316

3. 4 Experimental Procedures and Crop Management

Before sowing of the crop, the field was plowed three times. Maize was hand planted on the 16th of February 2014 on a plot size of 2.80mx5.25m =14.7m^2 Two seeds were placed per hill to assure the desired stand in each treatment and were thinned in to one plant. Thinning was done at 3-4 leaves stage. The outermost rows at both sides of plots were considered as borders. A 1.5m wide-open strip separated the blocks; whereas the plots within a block are 1m apart from each other. In accordance with specifications of the design, each treatment was assigned randomly to experimental units within a block**.** All data were determined from in the center of minimum three central rows of each plot. Basal dose of (DAP) 100kg ha^{-1} was applied at planting. Half dose of (UREA) 100kg ha^{-1} were applied at planting while the remaining half dose of urea were applied at knee height stage. Harvesting and threshing were done by hand. All other agronomic practices were applied as per the recommendation of the crop.

3. 5 Data Collected

3.5.1 Phenological parameters

3.5.1.1 Days to 50 % emergence

Days to 50% emergence were counted from the date of sowing till 50% of the seedling emerged in each plot.

3.5.1.2 Days to 50% tasseling

It was recorded from planting time to when 50% of plants in a plot started shedding pollen.

3.5.1.3 Days to 50% silking

It was recorded from planting time to when 50% of the plants produced silks in each plot.

3.5.1.4 Days to 50% maturity

Were recorded from planting time to when 50% of plants formed black layer at the base of the kernel.

3.5.2 Growth parameters

3.5.2.1 Number of green leaves

Total number of green leaves per plant at tasseling were counted from five randomly taken plants and their averages were taken as the number of green leaves per plant.

3.5.2.2 Leaf area index

It was calculated as the ratio of total leaf area per area of land (cm^2) occupied by the plant (Diwaker and Oswalt, 1992).

3.5.2.3 Stalk diameter (girth)

Were measured at 50cm from the ground level of five randomly taken plants using calliper.

3.5.2.4 Plant height (cm)

Plant height was measured from ground level to terminal stem using measuring stick at the point where the tassel starts branching.

3.5.3. Data on yield and yield components

3.5.3.1 Number of ear (per plant)

Were obtained by dividing the total number of ears per plot by the number of plants harvested.

3.5.3.2 Ear length

It was measured for five randomly selected plants from the base to the tip after dehusking the ear at harvesting.

3.5.3.3 Number of grain rows (per ear)

Five ears were selected randomly from each plot and grain rows per ear of each ear were counted and averaged at harvesting.

3.5.3.4 Number of grains (per row)

Five ears were collected randomly from each plot and number of grains per row in each ear were counted and averaged at harvesting.

3.5.3.5 Number of grains (per ear)

Were obtained by multiplying number of grain rows per ear and number of grains per row from five randomly selected ears in each plot at harvesting.

3.5.3.6 Ear diameter

Ear diameter was measured for five randomly selected plants at approximately the middle of the ear at harvesting.

3.5.3.7 Thousand-kernel weight (g)

Kernels were selected randomly from five plants and thousand seed weight was measured by counting a thousand seeds with a seed counter and weighing it with sensitive balance at harvest and adjusted at 12.5% moisture.

3.5.3.8 Grain yield (kg/ha)

Grain yield per plot were recorded using electronic balance and then adjusted to 12.5% moisture and converted to hectare basis.

3.5.3.9 Biomass yield (kg/ha)

Plants from the net plot area were harvested at physiological maturity, ears were removed then five selected plants chopped and oven dried till get uniform weight.

3.5.3.10 Harvest index

Was calculated as the ratio of grain yield to above ground biomass yield on dry weight basis.

3.6 Data Analysis

The collected data were subjected to Analysis of variance (ANOVA) using general linear model (GLM) procedure of SAS software version 9.2 software (SAS 2008) to test the significance level at 5% probability level. Data were checked for assumption of ANOVA before running the analysis. Least significant difference (LSD) was used to separate treatment means. Correlation analysis were performed to determined the association of different growth, yield and yield components obtained from the interactions of different inter and intra row spacing.

4. RESULTS AND DISCUSSION

4.1 Phenological and Growth Traits

4.1.1 Days to 50 % emergence

Analysis of variance for days to 50 % emergence showed non significant ($P>0.05$) difference among the main factors and their interaction (Appendix Table 2,). This finding is in agreement with Penuar & Sirrbie (1989) who reported that planting density has no significant effect on number of days to emergence.

4.1.2 Days to 50 % tasseling

Analysis of variance for days to 50% tasseling revealed significant difference ($P < 0.05\%$) for the interaction of inter and intra row spacing (Appendix Table 2). A treatment combination of 58824 plants ha^{-1} (85x20cm) numerically took minimum days to tasseling (74 days). But its effect was not statistically significant from the treatment combination of 55x20, 65x20, 75x25, 95x25, 55x30, 65x30, 75x30, 95x30, 55x35, 65x35, 75x35, 85x35, 55x40, 65x40 and 85x40cm while treatment combination of 95x20cm (52632 plants ha^{-1}) took maximam number of days to tasseling (77.3 days) (Table 4). Days to 50% tasseling delayed by about 3.3days in the 95x20cm inter and intra row spacing as compared with 85x20cm. This could be due to higher competition of plants for resource in the closer spacing that lead the plants to stress and ultimately the plants tassel early instead of prolonged vegetative growth. These finding are in contradict with Park *et al*. (1987) who reported that plant density did not affect days to tasseling.

4.1.3 Days to 50% silking

Analysis of variance table indicated that the interaction of inter and intra row spacing significantly affected ($P <0.05$) days to 50% silking (Appendix Table 2). Among the treatments, spacing combination of 85x20 (58824 plants ha^{-1}) numerically took maximum days to 50% silking (79.67days). But its effect was not statistically significant from the treatment combination of 55x20, 65x20, 75x25, 85x25, 95x25, 55x30, 65x30, 75x30, 95x30, 55x35, 65x35, 75x35, 85x35, 55x40, 65x40, 85x40 and 95x40cm while spacing combination of 95x20 (52632 plants ha^{-1}) took minimum days to 50% silking (76 days) (Table 4). Days to 50% silking delayed by about 3.67days in the 95x20cm inter and intra row spacing as compared with 85x20cm. This might be due to higher competition in closest spacing for resource, light and soil moisture that leads the plants produced silks early compared as with wider spacing. These finding is in contradict with Park *et al.* (1987) reported that plant density did not affect days to silking.

4.1.4 Days to 50% physiological maturity

The interaction effect of inter and intra row spacing significantly influenced days to 50% maturity (P <0.05) (Appendix Table 3). Numerically the treatments having plant population 44444 plants ha^{-1} (75x30cm) took maximum days to physiological maturity (149 days). But its effect was not statistically significant from the treatment combination of 65x20, 85x20, 75x25, 85x25, 95x25, 55x30, 65x30, 85x30, 95x30, 55x35, 65x35, 75x35, 85x35, 95x35, 55x40, 65x40, 85x40 and 95x40cm while the minimum (144.7days) was recorded from spacing combination of 55x20 (90909 plant ha^{-1}) (Table 5). Plants in the high population density matured the earliest, while plants at the lower population density matured lately because of high competition for light, soil moisture and nutrients in higher population density and days to tasseling and silking of plants were earlier in higher plant population density than lower plant population density.

The result of the present investigation has consistency with previous findings reported by Mengistu and Yomoah (2010) who concluded that closer spacing had shortened days to maturity as compared to wider spacing.

4.1.5 Leaf area index (LAI)

The analysis of the data revealed that LAI was highly significantly affected by interaction effect ($P < 0.01$) of intra and inter row spacing (Appendix Table 2). Numerically treatments having plant population of 72727 plants ha^{-1} (55x25cm) produced higher LAI (4.48). But its effect was not statistically significant from the treatment combination of 55x20, 75x30, 65x40 and 75x40cm The lowest LAI (3.33) was obtained from a population of 30075 plants ha^{-1} (95x35cm) (Table 4). The highest leaf are index recorded at closer spacing could be due to high number of plants per unit area that creates mutual shedding of leaves in closest spacing that leads to high leaf area index. According to Saberali (2007) in high maize density leaf area index was increased as compared to low maize density throughout crop growth season.

Table 3. Interaction effects of inter and intra-row spacing on growth parameters of QPM at Jimma Agricultural Research Center in 2014.

Treatmants	Days to 50% tasseling	Days to 50% silking	Days to 50% maturity	LAI
55x20	76.00^{abcd}	78.00^{abcd}	144.70^{e}	4.42^{ab}
65x20	76.33^{abc}	78.33^{abcd}	147.70^{abc}	4.01^{defg}
75x20	75.33^{bcde}	77.33^{bcde}	146.70^{cd}	4.14^{cdef}
85x20	74.00^{e}	76.00^{e}	148.70^{ab}	3.88^{fg}
95x20	77.33^{a}	79.67^{a}	146.00^{de}	3.79^{g}
55x25	74.67^{de}	76.67^{de}	146.70^{cd}	4.48^{a}
65x25	75.33^{bcde}	77.33^{bcde}	147.30^{bcd}	4.18^{bcd}
75x25	76.00^{abcd}	78.00^{abcd}	148.00^{abc}	4.15^{bcdef}
85x25	76.00^{abcd}	78.00^{abcd}	148.00^{abc}	3.90^{efg}
95x25	76.00^{abcd}	78.00^{abcd}	148.00^{abc}	4.14^{cdef}
55x30	76.67^{ab}	78.33^{abcd}	148.30^{ab}	4.13^{cdef}
65x30	76.00^{abcd}	78.00^{abcd}	148.00^{abc}	3.98^{defg}
75x30	76.33^{abc}	78.67^{abc}	149.00^{a}	4.39^{abc}
85x30	75.33^{bcde}	77.33^{bcde}	147.70^{abc}	3.99^{defg}
95x30	76.33^{abc}	78.33^{abcd}	148.30^{ab}	4.17^{bcde}
55x35	76.67^{ab}	79.00^{ab}	148.70^{ab}	4.16^{bcdef}
65x35	76.33^{abc}	78.33^{abcd}	148.30^{ab}	4.02^{defg}
75x35	76.00^{abcd}	78.00^{abcd}	147.70^{abc}	4.17^{bcde}
85x35	76.33^{abc}	78.33^{abcd}	148.30^{ab}	3.94^{defg}
95x35	75.33^{bcde}	77.33^{bcde}	147.70^{abc}	3.33^{h}
55x40	76.67^{ab}	79.67^{a}	148.70^{ab}	3.98^{defg}
65x40	76.67^{ab}	79.00^{ab}	148.70^{ab}	4.40^{abc}
75x40	75.00^{cde}	77.00^{cde}	147.30^{bcd}	4.32^{abc}
85x40	76.00^{abcd}	78.00^{abcd}	148.00^{abc}	3.93^{defg}
95x40	75.33^{bcde}	78.00^{abcd}	148.00^{abc}	3.79^{g}
Mean	75.92	78.06	147.77	4.07
LSD (0.05)	1.549	1.746	1.592	0.2753
CV (%)	1.2	1.4	0.7	4.1

LSD = Least Significant Difference; CV = Coefficient of Variation; Values following by the same letter within the column are not significantly different at 0.05 probability level.

4.1.6 Number of green leaves

The interaction of inter and intra row spacing significantly affected ($P < 0.05$) leaf number (Appendix Table 2). Numerically the maximum leaf number of 14.67 was produced from treatment combination of 85x30cm (39216 plants ha^{-1}). But its effect was not statistically significant from the treatment combination of 75x20, 85x20, 95x20, 65x25, 95x25, 65x30, 75x30, 75x35, 95x35, 75x40 and 95x40cm while the minimum (12) was produced at spacing combination of 85x25cm (47059 plants ha^{-1}) (Table 4). The reduction of leaf number with higher plant density might be due to more number of plants compete for available resources and it’s well known that plants grown under less competition have maximum leaf number than those from dense plantings. These findings are contradicted with Ali *et al.* (2003) who reported that maize plant sown on narrow spacing had higher number of leaves.

4.1.7 Stalk diameter (Stem girth)

Analysis of variance for stem girth revealed that there was highly significant interaction effect ($P < 0.05$) of intra and inter row spacing (Appendix Table 3). Numerically the treatments having plant population 26316 plants ha^{-1} (95x40cm) produced maximum stem diameter of 3.01cm. But its effect was not statistically significant from the treatment combination of 75x20, 75x25, 85x25, 85x30, 95x30, 75x35, 85x35, 95x35, 55x40 and 75x40cm while the minimum (2.08) was obtained with plant population of 90909 plants ha^{-1} (55x20cm) (Table 5). It means with decreased in plant population the plants obtained more soil moisture and nutrients than narrower-spaced plants and have more stem diameter as compared to high plant population. This is similar to the findings of Barbier *et al.* (2000); Hamayan (2003); Dalley *et al.* (2006) and Azam *et al.* (2007) who reported that wider-spaced maize plants obtained more soil moisture and nutrients than narrower plants and result in more stem girth development.

4.1.8 Plant height

Statistical analysis of the data revealed that the interaction of inter and intra row spacing significantly affected ($P < 0.05$) plant height of maize (Appendix Table 3). Numerically among the treatments, the highest plant height was recorded from plant population of 76923 plants ha-1(65x20cm) and 72727 plants ha^{-1} (55x25cm) (260.7cm). But its effect was not statistically significant from the treatment combination of 55x20, 65x20, 75x20, 85x20, 85x25, 55x30, 65x30, 95x30, 55x35, 65x35, 75x35 and 75x40cm while the shortest plant height was produced at spacing combination of 52632 plats ha^{-1} (95x20cm) (238.3cm). But its effect was not statistically significant from the treatment combination of 65x20, 95x25 and 85x40cm (Table 5). Highest plant height in closer inter and intra row spacing there might be due to the presence of higher competition for sun light, crowding effect of the plant and other resources that decrease in the stem diameter and number of green leaves. Earlier results explained that the number of plants increased in a given area, the competition among the plants for nutrients uptake and sunlight interception also increased (Sangakkara *et al*., 2004). These finding is in agreement with Hassan (2000) who revealed that plant height increased with increasing plant density from 47600 to 71400 plants ha$^{-1.}$

Table 4. Interaction effects of inter- and intra-row spacing on growth parameters of QPM at Jimma Agricultural Research Center in 2014.

Treatments	Number of leaves	Stem diameter	Plant height (cm)
55x20	13.00^{bcde}	2.09^{m}	252.30^{abcd}
65x20	12.67^{cde}	2.34^{klm}	260.70^{a}
75x20	13.33^{abcde}	2.82^{abcdef}	252.30^{abcd}
85x20	13.33^{abcde}	2.54^{ghijk}	248.00^{abcde}
95x20	13.67^{abcd}	2.45^{ijkl}	238.30^{e}
55x25	12.67^{cde}	2.27^{lm}	260.70^{a}
65x25	14.00^{abc}	2.39^{jkl}	236.30^{e}
75x25	12.67^{cde}	2.79^{abcdefg}	246.00^{bcde}
85x25	12.00^{e}	2.80^{abcdef}	253.00^{abcd}
95x25	14.33^{ab}	2.68^{cdefghi}	237.30^{e}
55x30	12.33^{de}	2.48^{hijkl}	257.00^{ab}
65x30	13.67^{abcd}	2.60^{efghij}	247.30^{abcde}
75x30	13.33^{abcde}	2.59^{efghijk}	240.70^{de}
85x30	14.67^{a}	2.83^{abcde}	245.00^{bcde}
95x30	12.33^{de}	2.81^{abcdef}	248.00^{abcde}
55x35	12.67^{cde}	2.63^{defghij}	252.70^{abcd}
65x35	12.33^{de}	2.58^{efghijk}	248.70^{abcde}
75x35	13.33^{abcde}	2.97^{ab}	256.00^{abc}
85x35	13.00^{bcde}	2.86^{abcd}	243.30^{cde}
95x35	14.00^{abc}	2.88^{abcd}	239.70^{de}
55x40	13.00^{bcde}	2.87^{abcd}	244.00^{bcde}
65x40	12.33^{de}	2.57^{fghijk}	242.30^{de}
75x40	14.33^{ab}	2.91^{abc}	247.30^{abcde}
85x40	12.67^{cde}	2.72^{bcdefgh}	236.00^{e}
95x40	13.33^{abcde}	3.01^{a}	241.70^{de}
Mean	13.16	2.66	246.99
LSD (0.05)	1.634	0.2583	13.492
CV (%)	7.6	5.9	3.3

LSD = Least Significant Difference; CV = Coefficient of Variation; Values following by the same letter within the column are not significantly different at 0.05 probability level.

4.2. Yield and Yield Related Variables

4.2.1 Number of ear per plant

Analysis of the data revealed that the main effect of inter and intra row spacing highly significantly ($P < 0.01$) influenced the number of ear per plant while their interaction effect was not significant ($P > 0.05$) (Appendix Table 3). The maximum number of ear per plant (1.76 and 1.90) was recorded at 75 and 95cm inter row spacing respectively while the minimum number was recorded at 55cm (1.48). On the other hand, the maximum number of ear per plant (1.87) was recorded at 35cm intra row spacing while the minimum (1.51) was recorded at 20cm (Table 6). This might be due to in the closest spacing there were high inter stem competition to nutrients and sun light so, it caused lack of nutrient for each plant and consequently compelling the plants to undergo less reproductive growth. These finding are in agreement with Hashemi-Dezfouli and Herbert (1992) who reported a significantly higher number of ear per plant at lower plant density as compared to higher plant density.

4.2.2 Ear length

Statistical analysis of the data revealed that the effect of inter row, intra row and their interaction effect had not significant effect ($P > 0.05$) on ear length (Appendix Table 4 and Table 6). These results are also in contrary with Shafi *et al.* (2012) who announced that because of interplant competition ear length was decreased at higher plant populations. Al-Rudh and Al-Younis (1978) also reported that row spacing had significantly affected ear length while Moraditochaee *et al*. (2012) indicated that ear features were adversely affected by increases in plant densities.

4.2.3 Number of grain row per ear

Statistical analysis of the data revealed that the effect of inter row, intra row and their interaction effect had no significant effect (P>0.05) on number of grain row per ear (Appendix Table 4 and Table 6). Similar findings were indicated by (Moraditochaee *et al*., 2012) who reported that plant density have no significant effect on kernel grain row number.

4.2.4 Number of grains per row

The data analysis showed that the effect of inter row, intra row and their interaction effect was not significant (P >0.05) on the number of grains per row (Appendix Table 4 and Table 6).
This might be due to the length of the ear uniform for all treatments also number of grains per row didn't show significant difference between treatments. The obtained results were contrary with those of Shafi *et al.* (2012) and Abuzar *et al.* (2011) who showed that the effect of plant density was significant effect on kernel number per row.

4.2.5 Ear diameter

Statistical analysis of the data revealed that inter row spacing had highly significant effect (P <0.01) on ear diameter while the intra row spacing and their interaction had no significant (P >0.05) effect on ear diameter (Appendix Table 4). Numerically mean thickest value of ear diameter (5.06) were recorded from 95cm inter row spacing. But its effect was not statistically significant from inter row spacing of 75 and 85cm while the thinnest was (4.91) recorded from 65cm inter row spacing (Table 6). Wider inter row spacing had maximum ear diameter because of availability of more resources and competition is less when we compared with narrow row spacing for nutrients, sunlight and soil moisture. These finding was in agreement with Arif *et al*. (2010) and Zamir *et al*. (2010) who reported that inter and intra row spacing interaction did not show significant difference on ear diameter.

Table 5. Main effects of inter- and intra-row spacing on growth and yield component parameters of QPM at Jimma Agricultural Research Center in 2014.

Treatments	Number of Ear/plant	Ear diameter
Intra row spacing (cm)		
20	1.51^{c}	4.98
25	1.59^{bc}	5.03
30	1.72^{b}	4.96
35	1.87^{a}	5.02
40	1.72^{b}	4.96
Mean	1.68	4.99
LSD (0.05)	0.148	ns
Inter row spacing (cm)		
55	1.48^{d}	4.96^{bc}
65	1.57^{cd}	4.91^{c}
75	1.76^{ab}	5.01^{ab}
85	1.71^{bc}	5.03^{ab}
95	1.90^{a}	5.06^{a}
mean	1.68	4.99
LSD (0.05)	0.128	0.083
CV (%)	11.8	2.3

LSD = Least Significant Difference; CV = Coefficient of Variation; Ns= Non significant, Values following by the same letter within the column are not significantly different at 0.05 probability level.

4.2.6 Number of grains per ear

The interaction effect of inter and intra row spacing was significantly ($p<0.05$) influenced number of grains per ear (Appendix Table 4). Numerically maximum (555.5) number of grains ear-1 was recorded from spacing combination of 55x25cm (72772 plants ha^{-1}). But its effect was not statistically significant from the treatment combination of 75x20, 95x20, 65x25, 95x30, 55x35, 65x35, 75x35, 95x35, 55x40 and 85x40cm while minimum (501.3) number of grains ear-1 was recorded from 75x30cm (44444 plants ha^{-1}) (Table 7). The highest number of grain per ear recorded at closer spacing could be due to high number of plants per unit area that creates mutual shedding of leaves and high photosynthetic in closest spacing that leads to higher number of grains per ear. This result was also in agreement with Roy and Biswas (1992) who concluded that grain number per cob was highest at 33300 plants/ha.

4.2.7 Thousand grain weight

Statistical analysis of the data revealed that both the main factors and their interaction showed significant difference ($P < 0.05$) for thousand grain weight (Appendix Table 5). Numerically, the treatment combination having population of 51282 plants ha^{-1} (65x30cm) produced the highest thousand grain weight of 403.9g. But its effect was not statistically significant from the treatment combination of 75x20, 95x20, 65x25, 75x25, 95x25, 55x30, 75x30, 85x30, 95x30, 55x35, 65x35, 95x35, 65x40, 75x40, 85x40 and 95x40cm (Table 7). The increment in thousand grain weight might be due to availability of more resources for comparatively less number of plants. The lowest grain weight 354.4g was recorded in treatment combination having plant population of 76923 plants ha^{-1} (65x20cm). From this study it has been observed that decreased plant densities from 55x20cm to 65x30cm spacing increased thousand kernel weight significantly. This implies that maize plants planted at 65x30 inter and intra row spacing developed wider canopy due to enough inter and intra row spacing, low inter stem competition to resources like light and nutrients. As the plant increase in their canopy they have the chance to intercept light, high net assimilation rate that increase thousand kernel weight. This finding is in agreement with (Arif, *et al.,* 2010), who reported that corresponding reduction of TSW with increasing plant density was due to unfavorable growing conditions such as less aeration, light penetration and mineral nutrient availability at a high plant density.

4.2.8 Grain yield (kg ha^{-1})

Analysis of variance for grain yield showed that there was significant interaction effect ($P < 0.05$) among inter and intra row spacing (Appendix Table 5) on grain yield. Plant population of 72727 plants ha^{-1} (55x25cm) had significantly produced higher grain yield (13807 kg ha^{-1}) as compared to the others. On the other hand, the lowest mean yield of 7366kg ,7874kg and 8169kg ha^{-1} were recorded from plant population of 33333 plants ha^{-1} (75x40cm), 29412 plants ha^{-1} (85x40) and 26316 plants ha^{-1} (95x40) respectively (Table 7) . Generally, in the closest inter and intra row spacing resulted in higher grain yield ha^{-1}. This is due to higher number of plants harvested in closer spacing as compared to wider spacing. It is clear from the result that grain yield ha^{-1} increased in response to increasing plant density and also possibly due to higher LAI, plant height, number of grain per ear and biomass yield in the treatment of high plant population density of 72727 plants ha^{-1} (55x25cm). As spacing increased from 55x25cm to 75x40cm grain yield ha^{-1} decreased from 13807kg ha^{-1} to 7366kg ha^{-1}. This is due to low plant population harvested ha^{-1} in wider spacing. Thus, balanced growth and development of plants need optimum plant density because optimum density enables plants efficient utilization of available nutrients, soil water and better light interception coupled with other growth influencing factors. Therefore, results of this contradicted the previous recommendation 75x30cm inter and intra row spacing resulted in the production of grain yield. These finding was in agreement with Farnham (2001) who reported that maize grain yield increased as plant density increased from 59,000 to 89,000 plant ha^{-1} and contrary with Abuzar *et al*. (2011) who observed the minimum grain yield at the highest population.

4.2.9 Biomass yield (kg ha^{-1})

Statistical analysis of the data revealed that inter row, intra row and their interaction had highly significantly ($p < 0.01$) affected biomass yield (Appendix Table 5). Maximum biomass yield 13754kg ha^{-1} and 13544kg ha^{-1} were produced by plant population of 72727 plants ha^{-1} (55x25cm) and 61538 plants ha^{-1}(65x25) respectively (Table 9). On the other hand, the minimum biomass yield was obtained from plant population of 29412 plants ha^{-1}) (85x40cm) (5649kg ha-1and 33333 plants ha^{-1}(75x40cm) (6456kg ha^{-1}) (Table 7). The result showed that biological yield was increased by increasing plant density due to high grain yield, LAI, number of grain per ear and plant height in the treatment of high plant population density of 72727 plants ha^{-1} (55x25cm). These results were in agreement with Bullock *et al*. (1998) who reported that narrow row spacing made more efficient use of available light and shaded the surface soil more completely during the early part of the growing season while the soil is still moist and therefore, narrow row spacing are more effective in producing biomass.

4.2.10 Harvest index (HI)

The interaction of inter and intra row spacing had a significant effect ($p < 0.05$)) on harvest index (Appendix Table 5). Numerically the highest harvest index was observed in the treatment combination of 85x40cm (29412 plants ha^{-1}) (58.16). But its effect was not statistically significant from the treatment combination of 85x20, 95x30 and 95x35cm while the lowest was observed in the treatment combination of (55x35cm) 51948 plants ha-1 (46.73) and (65x25cm) 61538 plants ha^{-1} (47.28) (Table 7). The higher HI in the decreased plant population density was not only due to poor yield but also due to vegetative growth of the plant. The lower harvest index in the increased plant population density might be due to minimum nutrient uptake and transform when we compared with decreased plant population density. The obtained results were in agreement with the findings of Valadabadi and AliabadiFarahani (2010), Zamir *et al*. (2011), Moraditochaee *et al* (2012), and Anafjeh and Chaab (2012), who claimed that with increasing the plant population, the harvest index was decreased. However, Iptas and Acar (2006) and Abouziena *et al.* (2008) found that row spacing and plant density did not have a significant effect on the harvest index. Ahmad & Khan (2002) reported that increase in plant density significantly increased harvest index.

Table 6 Interaction effects of inter-and intra-row spacing on yield parameters at Jimma Agricultural Research Center in 2014.

Treatments	Number of grain per ear	Thousand grain weight (g)	Grain yield (Kg ha-1)	Biomass yield (kg ha-1)	Harvest index
55x20	524.80^{cdefg}	366.80^{efgh}	12410^{b}	10503^{f}	54.23^{bcd}
65x20	520.30^{defg}	354.40^{h}	11545^{bcd}	12076^{cd}	48.93^{cd}
75x20	535.90^{abcde}	390.30^{abcde}	10808^{defgh}	9111^{ghi}	54.24^{bcd}
85x20	519.20^{defg}	357.00^{gh}	11468^{bcde}	8860^{ghij}	56.42^{abcd}
95x20	543.70^{abcd}	401.30^{ab}	11374^{cdef}	10895^{ef}	51.09^{cd}
55x25	555.50^{ab}	372.20^{defgh}	13807^{a}	13754^{a}	50.13^{cd}
65x25	553.10^{ab}	$380.30^{abcdefg}$	12146^{bc}	13544^{ab}	47.28^{d}
75x25	501.30^{g}	384.20^{abcdef}	10904^{defg}	9538^{g}	53.30^{bcd}
85x25	532.00^{bcdef}	361.80^{fgh}	10860^{defg}	9421^{gh}	53.52^{bcd}
95x25	530.70^{bcdef}	393.60^{abcd}	11316^{cdef}	9427^{g}	54.55^{bcd}
55x30	510.40^{efg}	390.90^{abcd}	12322^{b}	11567^{de}	51.59^{bcd}
65x30	512.70^{efg}	403.90^{a}	10977^{def}	10936^{ef}	50.12^{cd}
75x30	506.50^{fg}	394.70^{abcd}	9368^{ijk}	8088^{jkl}	53.71^{bcd}
85x30	532.00^{bcdef}	401.50^{a}	10027^{ghi}	8532^{hijk}	54.02^{bcd}
95x30	536.90^{abcde}	400.90^{ab}	10433^{fgh}	7731^{kl}	57.43^{abc}
55x35	536.90^{abcde}	386.10^{abcde}	11192^{def}	12708^{bc}	46.73^{d}
65x35	550.10^{abc}	398.50^{abc}	10573^{efgh}	8842^{ghij}	54.46^{bcd}
75x35	550.70^{abc}	375.30^{cdefgh}	10012^{ghi}	9281^{ghi}	51.91^{bcd}
85x35	524.10^{cdefg}	$377.80^{bcdefgh}$	8497^{klm}	7392^{lm}	53.48^{bcd}
95x35	560.40^{a}	381.30^{abcdef}	9041^{jkl}	6678^{mn}	57.55^{ab}
55x40	533.50^{abcdef}	371.90^{defgh}	9891^{hij}	8415^{ijk}	53.83^{bcd}
65x40	527.90^{bcdefg}	391.70^{abcd}	8825^{kl}	9287^{ghi}	48.76^{cd}
75x40	517.30^{defg}	394.60^{abcd}	7366^{n}	6456^{no}	53.26^{bcd}
85x40	536.90^{abcde}	395.40^{abcd}	7874^{mn}	5649^{o}	58.16^{a}
95x40	528.30^{bcdefg}	385.10^{abcdef}	8169^{lmn}	6807^{mn}	54.56^{bcd}
Mean	531.26	384.46	10448	9420	52.93
LSD (0.05)	28.15	23.68	945	894.1	2.99
CV (%)	3.2	3.8	5.5	5.8	3.4

LSD = Least Significant Difference; CV = Coefficient of Variation; Values following by the same letter within the column are not significantly different at 0.05 probability level.

4.3 Correlation Analysis

Generally, Pearson's moment correlation coefficients between grain yield and eighteen other agronomic traits considered in the study are shown in Table 8. The simple correlation analysis showed that leaf area index was highly significant (P <0.01) and positively correlated with grain yield (r=0.57) and biomass yield (r=0.33) and negatively correlated with number of leaves (r=0.7) and number of ear per plant (r=0.34). Leaf are index had negative and significant correlation with stem girth (r=0.26) and positively correlated with plant height (r=0.23).

Girth (stem diameter) was highly significant (P <0.01) and negatively correlated with plant height (r=0.32), biomass yield (r=0.59) and grain yield (r=0.54). Girth had positive and significant correlation with number of ear per plant (r=0.57) and ear length (r=0.23). Plant height was highly significant (P <0.01) and positively correlated with biomass yield (r=0.35) and grain yield (r=0.37). Plant height had negative and significant correlation with thousand seed weight (r=0.28). Number of ear per plant was highly significant (P <0.01) and positively correlated with ear length (r=0.31) and negatively correlated with biomass yield (r=0.39) and grain yield (r=0.39). Number of ear per plant had positive and significant correlation with ear diameter (r=0.25).

Ear length was highly significant (p <0.01) and positively correlated with number of grain per row (r=0.72) and ear diameter (r=0.51). Ear length had positive and significant correlation with number of grain per ear (r=0.28) and thousand seed weight (r=0.28). Number of grain row per ear was highly significant (P <0.01) and positively correlated with number of grain per ear (r=0.49) and ear diameter (r=0.36). Number of grain per row was highly significant (P <0.01) and positively correlated with number of grain per ear (r=0.34) and ear diameter (r=0.33). Number of grain per ear was highly significant (p <0.01) and positively correlated with grain yield (r=0.33). Ear diameter was positive and significant correlation with thousand seed weight (r=0.24) and showed non significant association with biomass yield, Harvest Index and grain yield. Biomass yield was highly significant (P <0.01) and positively correlated with grain yield (r=0.81).

Highly significant negative correlations with yield were observed for stem diameter and number of ear per plant. Highly significant positive correlation with grain yield ($P<0.01$) was observed for leaf area index, plant height, number of grains per ear and biomass yield. The current investigation was contrary with the previous studies made by Pearl**,** (2012) that certain plant characters such as thousand kernel weight and ear length highly significant and positively correlated with grain yield. Correlations for number of green leaves, ear number of grain row per ear, number of grains per row, ear diameter, and thousand kernel weight and harvest index were not significant. Therefore, significant and positively correlated parameters moves in the same direction this means that as one variable increases, so does the other one while significant and negatively correlated parameters moves in the inverse or opposite direction. In other words as one variable increases the other variable decreases.

Table 7 Pearson Correlation Coefficients of different growth, yield and yield component parameters.

	LAI	LN	GIR	PH	EP	EL	GRE	GR	GE	ED	TSW	BIO	HI	GY
LAI	1	-0.7^{**}	-0.26^{*}	0.23^{*}	-0.34^{**}	-0.2^{ns}	-0.14^{ns}	-0.093^{ns}	-0.21^{ns}	-0.16^{ns}	-0.04^{ns}	0.33^{**}	-0.19^{ns}	0.57^{**}
LN		1	0.06^{ns}	-0.14^{ns}	0.11^{ns}	-0.11^{ns}	0.054^{ns}	-0.18^{ns}	-0.02^{ns}	-0.04^{ns}	0.025^{ns}	-0.09^{ns}	0.09^{ns}	-0.14^{ns}
GIR			1	-0.32^{**}	0.57^{*}	0.23^{*}	0.012^{ns}	0.054^{ns}	0.049^{ns}	0.22^{ns}	0.19^{ns}	-0.59^{**}	0.02^{ns}	-0.54^{**}
PH				1	-0.9^{ns}	-0.16^{ns}	0.14^{ns}	-0.08^{ns}	0.01^{ns}	-0.02^{ns}	-0.28^{*}	0.35^{**}	0.14^{ns}	0.37^{**}
EP					1	0.31^{**}	0.15^{ns}	0.03^{ns}	0.19^{ns}	0.25^{*}	0.22^{ns}	-0.39^{**}	0.01^{ns}	-0.39^{**}
EL						1	0.17^{ns}	0.72^{**}	0.28^{*}	0.51^{**}	0.28^{*}	-0.14^{ns}	0.04^{ns}	-0.06^{ns}
GRE							1	0.03^{ns}	0.49^{**}	0.36^{**}	-0.19^{ns}	-0.01^{ns}	0.01^{ns}	0.03^{ns}
GR								1	0.34^{**}	0.33^{**}	0.21^{ns}	0.06^{ns}	0.11^{ns}	0.08^{ns}
GE									1	0.21^{ns}	0.004^{ns}	0.09^{ns}	-0.02^{ns}	0.33^{**}
ED										1	0.24^{*}	-0.15^{ns}	-0.05^{ns}	-0.04^{ns}
TSW											1	-0.2^{ns}	0.07^{ns}	-0.2^{ns}
BIO												1	-0.05^{ns}	0.81^{**}
HI													1	0.004^{ns}
GY														1

** and * = Correlation significant at 1% and 5% level of significance, respectively; ns=non significant; LAI=leaf area index; LN=leaf number; GIR=girth; PH=plant height; EP= number of ear per plant; EL=ear length; GRE=number of grain row per ear; GR=number of grain per row; GE=number of grain per ear; ED=ear diameter; TSW=thousand seed weight; BIO=biomass yield and GY=grain yield

5. SUMMARY AND CONCLUSIONS

The study on Inter and Intra row spacing indicated that emergency date, ear length, number of grain row per ear and number of grain per row were not significantly affected by main effect and interaction effect while significant variations due to inter and intra row spacing were recorded in number of ear per plant and ear diameter due to the main effects. The maximum number of ear per plant of 1.9 was recorded from inter row spacing of 95cm while the minimum number of ear per plant of 1.48 was recorded from 55cm and the maximum number of ear per plant of 1.87 was recorded from intra row spacing of 35cm while the minimum number of ear per plant 1.51 was recorded from 20cm. The thickest ear diameter 5.06 was recorded from inter row spacing of 95cm while the thinnest ear diameter 4.91 was recorded from 65cm.

The analysis of variance indicated that interaction effect of inter and intra row spacing on days to 50% tasseling, days to 50% silking, leaf number, leaf area, leaf area index, stem girth, days to 50% maturity, plant height, number of grains per ear, thousand grain weight, grain yield per hectare, biomass yield per hectare and harvest index. Therefore, the experimental result indicated that interaction of inter and intra row spacing had a significant effect on growth, yield and yield components. The maximum number of days to 50% tasseling (77.3), days to 50% silking (79.67) and days to 50% physiological maturity (149) was recorded at 95x20, 95x20 and 75x30cm respectively while their minimum value recorded at 85x20, 85x20 and 55x20cm respectively. The highest leaf area index (4.48), plant height (260.7cm), number of grain per ear (555.5), grain yield (13807 kg ha^{-1}) and biomass yield (13754kg ha^{-1}) was recorded at the closest 55x25cm inter and intra row spacing as compared with results of lower value of leaf area index (3.33), plant height (236.3), number of grain per ear (501.3) grain yield (7366kg ha^{-1}) and biomass yield (5649kg ha^{-1}) at the interaction effect of 95x35, 95x20, 75x25, 75x40 and 85x40cm inter and intra row spacing respectively.

Grain yield highly significant and positively correlated with leaf area index (r=0.57**), plant height (r=0.37**), number of grain per ear (r=0.33**) and biomass yield (r=0.81**). On the other hand highly significant and negatively correlated with stem diameter (r=-0.54**) and number of ear per plant (r=-0.39**).

Biomass yield highly significant and positively correlated with leaf area index (r=0.33**) and plant height (r=0.35**) where as highly significant and negatively correlated with stem diameter (r=-0.59**) and number of ear per plant (r=-0.39**)

The result of study indicated that increasing spacing further from 55x25cm to 75x40cm decreased grain yield significantly and from 55x25cm to 85x40cm decreased biomass yield significantly similarly decreasing spacing from 55x25cm to 55x20cm decreased leaf area and days to 50% maturity significantly. From this experimental result it can be concluded that the maximum grain yield and biomass yield per hectare was recorded with 55x25cm inter and intra row spacing treatment combination using BHQPY 545 maize variety which contradicted the previous recommendation 75x30cm inter and intra row spacing resulted in the production of grain yield. Therefore, it is advisable for farmers in the study area to produce BHQPY 545 maize variety under irrigation using 55x25cm inter and intra row spacing to achieve maximum grain yield and biomass yield than the other treatment combination. Future line of work, since the experiment was conducted for one season, off season and in one location using one variety additional one to two seasons under rain fed condition, different growing season, involving different varieties and Promoting action research and increasing awareness through training and demonstration of BHQPY-545 maize is suggested to come up with conclusive result.

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7. APPENDIX

Appendix Table 1. Meteorological data during crop growth period

Month	Rainfall (mm)	Min. Temp. (^{o}C)	Max. Temp. (^{o}C)	Mean Temp. (^{o}C)
January	6.1	11.3	25.6	18.45
February	21.3	11.4	26.2	18.8
March	138.9	10.5	26.3	18.4
April	258.5	10.4	25.6	18.0
May	262.2	11.6	25.5	18.55
June	142.8	10.9	26.0	18.45
July	229.4	11.3	25.0	18.15
August	235.7	11.7	25.7	18. 7
September	159.8	11.3	25.3	18.3
October	186.4	10.8	25.7	18.25
Mean	164.11	11.12	25.69	18.37

Appendix Table 2. Analysis of variance table showing mean square values of growth parameters as influenced by inter and intra-row spacing and their interaction at Jimma Agricultural Research Center in 2014.

		Mean Square				
Source	Df	Emer. day	TD	SD	MD	LAI
PS	4	0.0133^{ns}	0.7800^{ns}	1.567^{ns}	6.0533^{***}	0.13581^{***}
RP	4	0.1467^{ns}	1.7800^{ns}	2.367^{ns}	1.3200^{ns}	0.47691^{***}
PS*RS	16	0.3717^{ns}	1.7883^{*}	2.517^{*}	2.2700^{**}	0.12022^{***}
Error	48	0.2428	0.8906	1.132	0.9406	0.02811
CV (%)		6.5	1.2	1.4	0.7	4.1

DF = degree of freedom, %CV = % coefficient of variation, *** highly significant (P < 0.001), *Significant (P < 0.05), ns = non-significant difference, PS= Plant spacing, RP= Row spacing, PS*RS= Interaction of plant spacing and row spacing, Emer. Day= Days to 50 % emergency, TD = Days to 50% tasseling, SD = Days to 50% silking, MD= Days to 50% maturity, LAI = Leaf Area Index.

Appendix Table 3. Analysis of variance table showing mean square values of growth parameters as influenced by inter and intra-row spacing and their interaction at Jimma Agricultural Research Center in 2014.

		Mean Square			
Source	Df	LNo.	SD	PH	EP
PS	4	0.0867 ^{ns}	0.33696***	131.71 ^{ns}	0.27987***
RP	4	1.5200 ^{ns}	0.40613***	307.51**	0.39947***
PS*RS	16	1.9367*	0.05906**	126.34*	0.03150^{ns}
Error	48	0.9906	0.02475	67.54	0.03960
CV (%)		7.6	5.9	3.3	11.8

DF = degree of freedom, %CV = % coefficient of variation, ******* highly significant (P < 0.001), ** highly significant (p<0.01), *****Significant (P < 0.05), Ns = non-significant difference, PS= Plant spacing, RP= Row spacing, PS*RS= Interaction of plant spacing and row spacing, LNo. = Leaf Number, SD = Stem Diameter (girth), PH = Plant Height, EP = Number of ear per plant

Appendix Table 4. Analysis of variance table showing mean square values of yield component as influenced by inter and intra-row spacing and their interaction at Jimma Agricultural Research Center in 2014.

		Mean Square				
Source	Df	EL	GRE	GR	GE	ED
PS	4	0.3671 ^{ns}	0.8245^{ns}	0.977^{ns}	1239.2**	0.01858^{ns}
RP	4	0.7358 ^{ns}	0.2165^{ns}	1.199^{ns}	618.4^{ns}	0.04810**
PS*RS	16	0.2087 ^{ns}	0.2952^{ns}	1.966^{ns}	620.1*	0.01038^{ns}
Error	48	0.4654	0.3607	4.197	294.0	0.01264
CV (%)		3.8	4.2	5.6	3.2	2.3

DF = degree of freedom, %CV = % coefficient of variation, ******* highly significant (P < 0.001), ** highly significant (p<0.01), *****Significant (P < 0.05), Ns = non-significant difference, PS= Plant spacing, RP= Row spacing, PS*RS= Interaction of plant spacing and row spacing, EL = Ear length, GRE = Number of grain row per ear, GR = Number of grain per row, GE = Number of grain per ear, ED = Ear diameter

Appendix Table 5. Analysis of variance table showing mean square values of yield parameters as influenced by inter and intra-row spacing and their interaction at Jimma Agricultural Research Center in 2014.

Source	df	Mean Square			
		TSE	BY	GY	HI
PS	4	1315.1^{***}	31112456^{***}	27991873^{***}	178.75^{*}
RP	4	590.1^{*}	38900534^{***}	13213400^{***}	1567.3^{***}
PS*RS	16	443.3^{*}	3608009^{***}	633700^{*}	396.57^{***}
Error	48	208.1	296607	331530	64.94
CV (%)		3.8	5.8	5.5	7.1

DF = degree of freedom, %CV = % coefficient of variation, ** highly significant ($p<0.01$), *****Significant ($P < 0.05$), Ns = non-significant difference, PS= Plant spacing, RP= Row spacing, PS*RS= Interaction of plant spacing and row spacing, TSW = Thousand seed weight, BY = Biomass yield kg ha^{-1}, GY = Grain yield kg ha^{-1}, HI = Harvest Index