2020-10-22

EFFECT OF INTER AND INTRA ROW SPACING ON YIELD AND YIELD COMPONENTS OF HYBRID MAIZE (Zea mays L.) VARIETIES AT NORTH MECHA DISTRICT, IN WEST GOJJAM ADMINISTRATIVE ZIONE, NORTHWESTERN ETHIOPIA

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M.Sc. Thesis Research Report

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August, 2020

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SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE (M.Sc.) IN "AGRONOMY"

August, 2020

Bahir Dar

THESIS APPROVAL SHEET

As member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defence examination, we have read and evaluated this thesis prepared by **Mr. Simachew Kassahun** entitled **"Effect of Inter and Intra Row Spacing on Yield and Yield Components of Hybrid Maize** (*Zea mays* L.) **Varieties at North Mecha District, in West Gojjam Administrative Zone, Northwestern Ethiopia"**. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in **"Agronomy"**.

Board of Examiners

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Name of External Examiner	Signature	Date
______________________	______________	______________
Name of Internal Examiner	Signature	Date
______________________	______________	______________
Name of Chairman	Signature	Date

DECLARATION

This is to certify that this thesis entitled **"EFFECT OF INTER AND INTRA ROW SPACING ON YIELD AND YIELD COMPONENTS OF HYBRID MAIZE** (*Zea mays* L.) **VARIETIES AT NORTH MECHA DISTRICT, IN WEST GOJJAM ADMINISTRATIVE ZONE, NORTHWESTERN ETHIOPIA"** submitted in partial fulfilment of the requirements for the award of the degree of Master of Science in **"Agronomy"** to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by **Mr. Simachew Kassahun** (ID. No. 1100653) is an authentic work carried out by him under our guidance. The matter embodied in this project work has not been submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

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1) TilahunTaddesse (PhD) -Major Advisor

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2) Dereje Ayalew (PhD) -Co-Advisor

Signature & date___________________________

ACKNOWLEDGEMENTS

I am highly thankful to my Major advisor Dr.Tilahun Taddesse for his wholehearted support, useful advice, fast comments and excellent cooperation that enabled me to complete this study with his constructive criticism and comments from the initial conception to the end of this work. I am also highly indebted to put on record my thankfulness to co-advisor Dr. Dereje Ayalew and Mr. Asaye Birhanu, Mr. Getalew Ayzengaw and Mr. Tewabe Gebeyehu for his constructive comments and suggestions during my study.

It gives me immense pleasure to express my indebtedness and deep sense of gratitude to my colleague Mr. Solomon Tilahun, Mr. Alamraw Assfaw, and Mr. Tenagne Ewunetu for their enormous contribution during the painful and laborious work of the field. I would like to express my deep sense of gratitude to Bahir Dar University College of Agriculture and Environmental Sciences Department of Plant Science for their unyielding supports. It’s my pleasure to acknowledge Gonder Agricultural Research Centre. I am proud of my family for their unforgettable support and encouragement throughout my study.

DEDICATION

This thesis is dedicated to my beloved father Mr. **Kassahun Alem** and my beloved mother Mrs. **Tsehay Dessalew.**

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agency
BH-540	Bako Hybrid 540
BH-661	Bako Hybrid 661
BNMRC	Bako National Maize Research Center
CIMMYT	Centro International de Mejoramiento de Maize y Trigo
CSA	Central Statistical Agency
CV	Coefficient of Variance
EARO	Ethiopia Agricultural Research Organization
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization
FAO STAT	Food and Agriculture Organization of United Nation
HI	Harvest Index
ICARDA	International Center for Agricultural Research in the Dry Area
LAI	Leaf Area Index
LSD	Least Significant Difference
MoA	Minister of Agriculture
MRR	Marginal Rate of Return
MT	Metric Ton
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
WoA	*Woreda* of Agriculture

EFFECT OF INTER AND INTRA ROW SPACING ON YIELD AND YIELD COMPONENTS OF HYBRID MAIZE (*Zea mays* L.) VARIETIES AT NORTH MECHA DISTRICT, IN WEST GOJJAM ADMINISTRATIVE ZONE, NORTHWESTERN ETHIOPIA

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ABSTRACT

Maize is a major staple food crop for small holder farmers in Northwestern Ethiopia, in particular to North Mecha district. However, agronomic management practices such as approperate plant spacing and use of improved varieties are quite important for enhancing maize production. Hence, a field experiment was conducted during 2019 main cropping season at North Mecha district Northwestern Ethiopia to determine the effects of inter and intra row spacing on yield and yield components of maize varieties. The experiment consisted of the factorial combinations of two hybrid maize varieties ("BH-540" and "BH-661"), three inter-row spacing (65, 75 and 85 cm) and three intra-row spacing (25, 30 and 35 cm) with a total of 18 treatments in RCBD with three replications. The results of the study had shown that there were highly significant differences due to the main effects of varieties on days to 50% tasseling, 50% silking, and 90% maturity. There was also highly significant difference due to the main effects of both variety, inter- and intra-row spacing on leaf area index, ear length and number of grains per row and ear diameter. A very highly significant interaction effect of variety, inter- and intra-row spacing on leaf area index, above ground dry biomass yield, grain yield and harvest index and highly significant in thousand grain weight. Generally, higher grain yield and above ground dry biomass were obtained from BH-661 at 65x25 cm (11.39 t·ha^{-1} and 34.1 t·ha^{-1}) respectively. The highest grain yield (11.39 t·ha^{-1}) and (10.82 t·ha^{-1}) was obtained at interaction of 65x25 cm spacing in BH-661 and BH-540, respectively while the lowest grain yield (5.71 t·ha^{-1}) was obtained from 85×35 cm spacing in BH-540. The result of economic analysis showed that the maximum net benefit (ETB 90408.75 ha^{-1}) was obtained at spacing of 65x25 cm in BH-661. Therefore, based on economic analysis it can be conclude that optimum inter and intra row spacing (65x25 cm) combinations is promising for BH-661 hybrid maize variety production in main season of North Mecha district and similar agro ecologies. For better confirmation of the result, this one year experiment needs to be repeated at multi-locations and in different seasons.

Keywords: BH-540, BH-661, Inter-row spacing, Intra-row spacing, Plant Density, Yield

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Chapter 1. INTRODUCTION

1.1 Background and Justification

Maize (*Zea mays* L.) belongs to the family of poaceae (Gramineae) and originated in Mexico and Central America and possesses 20 somatic chromosomes (Schnable *et al*., 2009). It is an annual cereal major staple crop grown in diverse agro-ecological zones, farming systems and vital for the livelihoods of many people (Hayes *et al*., 2003). Maize is the cheapest source of calorie, providing 16.7 % of per capita calorie intake nationally (Rashid *et al.,* 2010). Maize is the most important cereal crop of the world after wheat and rice, growing everywhere in the rain-fed as well as in irrigated areas (Khalil, 2002). It is the first in total production (975,587,619 MT) and productivity (5.5 t ha^{-1}) in the world and about 6.6 t ha^{-1} in developed countries (FAO STAT, 2015).

Maize has expanded rapidly and transformed production systems in Africa as a popular and widely cultivated food crop since its introduction to the continent around 1500 A.D and arrived in Ethiopia slightly later, around the late 17th century (McCann, 2005). Within the country, maize is the largest cereal commodity in terms of total production and yield and second in terms of acreage next to *tef*. In Ethiopia the national average yield is about 4.09 t ha^{-1} and in Amhara region the average yield is about 4.08 t ha^{-1} in Private Peasant Holdings (CSA, 2019). While significant gains have been made in maize production over the past decade, there still remains large potential to increase its productivity. Despite its earliest introduction to the country and agro-ecological suitability of the country compared to other African countries, maize productivity in Ethiopia is generally low (ATA, 2016).

According to Demeke Kebede (2012), compared to the 1960s, the share of maize cultivated land production and consumption among cereals increased more than double to nearly 30% in the 2000s; however, as compared to the developed countries its productivity is still low. Mismanagement of plant population, poor soil fertility, improper agronomic practices, water logging, drought, wind, disease, soil acidity, pest, lack of improved seed and weed competitions are among the key factors contributing to the present low productivity of maize in Ethiopia.

Maize yield is more affected by variations in plant population density than other members of the grass family due to its inability for tillering to adjust variation in plant stand, monoecious floral organization and the presence of a short flowering period (Vega *et al.,* 2000; Sangoi *et al*., 2002). Variations in plant density or spacing promote changes in leaf dimensions, plant height, leaf area, ear size, ear length, number of seeds and seed weight. Narrow and short leaves and small leaf area were promoted by the increase of plant density (Maddonni *et al.,* 2006). For each production system, there is a population that optimizes the use of available resources, allowing the expression of maximum attainable grain yield in that particular environment. There is no single recommendation for all conditions because the ideal plant number per unit area will depend upon several factors such as water availability, soil fertility, and nature of the variety and maturity group (Sangoi *et al.,* 2002).

Maize populations above and below the optimum level might waste plant nutrients and often result in lower total grain yields. Yield increases with increase in plant density up to a certain maximum level for a maize genotype grown under a set of particular management conditions (Plensicar and Kustori, 2005). Trenton and Joseph (2007) suggested that in a dense population most plants remain barren, ear size remains smaller and crops become susceptible to lodging, disease and pest while plant population at sub-optimum level results in lower yield per unit land area.

Plensicar and Kustori (2005) reported that the maximum biological yield was found at higher planting density. Iptas and Acar (2006) indicated that plant densities had no significant effects on leaf percentage, but stem length increased as plant densities increased (Oktem and Oktem, 2005). Seed row spacing is an agronomical management strategy used by producers to optimize the husbandry of the soil and plant ecosystem from sowing to harvest with the goal of bolstering the production of crops. Crop row spacing influences canopy architecture, which is a distinguishing characteristic that affects the utilization of light, water, and nutrients (Brenton and Denise, 2005). Optimum plant density for maximum grain yield per unit area may differ from hybrid to hybrid because of significant interactions between hybrids and densities (Tokatlidis *et al*., 2005).

Despite the importance of maize and its many uses, there are several factors affecting its productivity, among them, mismanagement of plant density is considered to be the most important factor that can highly affect crop performance and yield. Hence, there is a need to improve crop management practices like inter-and intra-row spacing of maize for getting higher maize yield (ICARDA, 2008). Although maize can grow in different arrays of inter- and intra-row arrangements, location specific and proper inter-and intra-row spacing interactions should be determined so as to maximize and attain optimum yield without competition and wastage of resources (Demeke Kebede, 2012). There are different agronomic production variables that affect the productivity of maize among them plant spacing, row spacing and hybrid variety selections are some of the key factors that a producer can manipulate their influence on the production of a given crop, in this case maize. Among all of these production variables, spacing requires due attention (Erden *et al*., 2013).

However, in Ethiopia, maize spacing recommendation of 44,444 plants ha^{-1} (75 cm × 30 cm) has been used indiscriminately for a long time without taking into account the numerous morphological differences that exist among maize varieties as well as the existence of soil and climatic differences (EARO, 2004). So, it is important to determine the optimum plant density for maize hybrids depending on environmental factors (soil fertility, moisture supply) and agronomic management practices to get maximum yield (Gonzalo *et al*., 2006).

Many research findings have indicated that the use of proper inter- and intra-row spacings was improve the utilization of growth resources and improve productivity in a unit area of land (Lakew Getaneh *et al.,* 2014). However, as briefly explained during personal communication by *Kebele* extension worker coordinator said that the majority of small holder farmers in Mecha are aware of the benefits of adopting inputs and technologies to enhance maize productivity. Yet, this awareness is mainly limited to some improved varieties and soil fertility-improving fertilizers, while the knowledge about the recommended agronomic practices/packages like optimum planting density and row spacing is not sufficient. So, the farmers in Mecha District have been using their own plant and row spacings, agronomic practices than national recommended package of practices (inter-row 75 cm X intra-row 30 cm), which results in low productivity of maize. On the other side, farmers also fear that the recommended spacing is not appropriate to favour crop growth.

At last, both the experts and farmers suggested that this confusion and variation in spacing needs to be checked-in with the national recommended spacing of 75 cm X 30 cm. Beside this North Mecha district is a potential area of producing maize crop to get a maximum yield of maize the farmer should be use optimum plant population and high yielder variety. Hence, the study was conducted to investigate the influence of varied inter- and intra-row spacings on yield and yield components of maize varieties.

1.2 Objective of the Study

1.2.1 General objective

The general objective of this study is to identify optimum inter- and intra-row spacing for better productivity of hybrid maize (*Zea mays* L.) varieties to increase production and productivity in the study area.

1.2.2 Specific objectives

- ✓ To determine the appropriate inter-and intra-row spacing for hybrid maize varieties in the study area;
- ✓ To evaluate the main and interaction effects of inter, intra-row spacing and varieties on yield and yield components of maize in the study area; and
- ✓ To evaluate the economic aspect of inter, intra-row spacing and varieties on yield and yield components of maize in the study area.

Chapter 2. LITERATURE REVIEW

2.1 Origin and Distribution of Maize

Maize (*Zea mays* L.) also known as Corn in some countries belongs to the grass family (Gramineae), is a tall, monocot annual short-day plant which is grown in many countries more than any other crops. In English speaking countries like United States, Canada, Australia, and New Zealand, Corn primarily means maize, but outside of these countries the word "Corn" refers to any of the local staple cereal crops (Hornby *et al.,* 2011). Therefore, maize is preferred in formal, scientific, and international usage because it refers specifically to this grain, unlike corn which has a complex variety of meanings that vary by context and geographic region (Ensminger, 2012). Although, there is controversy about the origin of maize, most scientific evidence indicated that maize was originated and first domesticated at least 5000 years ago in Mexico, because the great density of native forms is found in this region (Matsuoka *et al.,* 2012).

It distributed out of its origin to Europe by Columbus and introduced to Africa around 1500s, and then the crop had spread to different countries across Africa and arrived on the highlands of Ethiopia in the late sixteenth or early seventeenth century through Portuguese contacts (McCann, 2005). Since its arrival, the crop has expanded to most agro-ecologies of the country. Because of its long-term cultivations in different parts of Africa, the crop has developed adaptations to many niches and such diversity has formed land races called local varieties. Nowadays, it grows from sea level to over 2600 meters above sea level, including moisture stress semi-arid lowlands, sub-humid areas of low altitude, mid-altitude and high altitude agro- ecologies of Ethiopia (Mosisa Worku *et al.,* 2010). The predominant maize-producing areas are found mainly in the western, north western and southern parts of the country (Wende Abera, 2013).

2.2 Botany of Maize

Maize is a C_4 crop with a high rate of photosynthetic activity leading to high grain and biomass yield potential. It is a monoecious plant, having distinct male and female inflorescences for both cross- and self-pollination options. Pollen is produced entirely in the staminate inflorescence and ear, entirely in the pistillate inflorescence. The apex of the stem ends in the tassel, an inflorescence of male flowers. When the tassel is mature and conditions are suitable, anthers on the tassel dehisce and release pollen grains. Maize pollen is anemophilous (dispersed by wind). The elongated stigmas, called silks, emerge from the whorl of husk leaves at the end of the ear. They look like tufts of hair in appearance. At the end of each silk there is a carpel, which may develop into a "kernel" if fertilized by a pollen grain. Ears develop above some of the leaves in the mid-section of the plant, between the stem and leaf sheath. The establishment of distinct meristems at the shoot and root tips of the immature maize embryo is essential for continued growth and development of the plant. The maize shoot apical meristem arises early in embryogenesis and functions during stem cell maintenance and organogenesis to generate all the aboveground organs of the plant (Takacs *et al.,* 2012).

In maize, shoot apical meristem is a domed structure, consisting of about two thousand cells in the embryonic stage (Bommineni *et al.,* 1995). Maize leaves are initiated one at a time, with consecutive leaves being initiated from opposite flanks of the shoot apical meristem, resulting in an alternating or distichous phyllotaxy (Jackson and Hake, 1999). All developing leaves consist of distal blade and proximal sheath. The sheath wraps around the stem, providing mechanical support for the blade, which projects outwards to catch the light and is optimized for photosynthesis (Foster and Timmermans, 2009).

2.3 Importance and Uses of Maize

In sub-Saharan Africa, maize is a staple food for an estimated 50 % of the population and provides 50 % of the basic calories. It is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Africans consume maize as a 5 starchy base in a wide variety of porridges, pastes, grits, and beer. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled and plays an important role in filling the hunger gap after the dry season. Maize grains have great nutritional value as they contain 72 % starch, 10 % protein, 4.8 % oil, 8.5 % fibre, 3.0 % sugar and 1.7 % ash (Chaudhary, 1983). A *Zea mays* is the most important cereal fodder and grain crop under both irrigated and rain-fed agricultural systems in the semi-arid and arid tropics (Hussan *et al*., 2003). Maize is the most popular cereal crop due to its high yielding potential, easy processing, readily digestible and also costs less than other cereals (Jaliya *et al.,* 2008). Particularly, the potential of maize to give higher grain yield per unit area attracts and shifts the farmers toward its extended cultivation. The grain of maize is composed of several important chemicals including carbohydrate (72.2%), water (13.8%), protein (8.9%), fat (3.9%) and ash (1.2%) (Jones, 2012).

The crop has a wide range of uses in Ethiopia. It is eaten in the form of green cob, *injera*, local bread, *anebabero*, porridge and boiled grain. Dry maize grains are also used for the production of local brews in the rural areas (Asrat Wondimu, 2012). In this form, maize provides calorie requirement in the traditional Ethiopian diet. The crop has been selected as one of the national commodity crops to satisfy the food self-sufficiency program of the country to feed the alarmingly increasing population (Girma Demissie *et al.,* 2008). Apart from use as a diet, maize stovers also play an important role as feed in supporting of livestock production (Ertiro *et al.,* 2013). Maize is the major staple cereal crop with total main season production of 7.85 million ton (CSA, 2017). Approximately 88% of maize produced in Ethiopia is consumed as food, both as green and dry grains (Tsedeke Abate *et al.,* 2015). Most farmers in maize producing areas of Ethiopia are engaged in maize production. According to central statistical authority, area, production and yield of crops for private peasant holdings for *meher* season 2018/19 (2011 E.C) maize are number of holders are 9,863,145, areas in hectare 2,367,797.39 and distribution are 18.50%, production in quintals 94,927,708.34 and distribution are 30.03 % and yield are 39.92 Qt/ha (CSA, 2019).

2.4 Production Status of Maize

All over the world, maize is a major food and feed source. It is considered as a **"**Queen of cereals**"** due to its excellent properties that includes; its carbon pathway (C_4), wider adaptability, higher multiplication ratio, desirable architecture, superior transpiration efficiency, easy to propagate, and harvest and high versatile use. It is also an important staple food for about 1.2 billion people around the world and provides over 20% of the total calories in human diets. In Africa, maize feeds more than 300 million peoples of the continent (Bekele Shiferaw *et al.,* 2011) and utilizes 95% of its maize production as food (Harashima, 2007).

Maize is the basis for food security in some of the world's poorest regions in Africa, Asia and Latin America. In Africa, 51 countries produced approximately 75 million tons of maize in 2014 (7.4% of the total world production) on 37 million hectares (20.44% of the total area planted worldwide). Maize occupies approximately 24% of farmland in Africa, which is more than any other staple crop, and is a food crop accounting for 73% and 64% of the total demand in Eastern and Southern Africa, and Western and Central Africa, respectively (Bekele Shiferaw *et al*., 2011).

2.5 Maize Production in Ethiopia

Ethiopia is the fourth largest maize producing country in Africa, and first in the East African region (FAO, 2012). It is also significant that Ethiopia produces non-genetically modified (GMO) white maize, the preferred type of maize in neighbouring markets. Within the country, maize is the largest cereal commodity in terms of total production and yield and second in terms of acreage next to tef. Out of the total grain crop area, 81.39% (10,358,890.13 hectares) was under cereals; among those maize took up 18.60% (about 2,367,797.39 hectares) crop area. Cereals contributed 87.97% (about 277,638,380.98 quintals) of the grain production. Maize made up 30.08% (94,927,708.34 quintals) production and yield are 40.09 Qt/ha (CSA, 2019). It is also the most important crop in terms of number of farmers engaged in cultivation.

Amhara region is one of the major producing regions, West Gojam among the top zones region and country. Other major producing areas in the country include East Wollega, Kaffa, East Shewa, West Shewa, West Arsi, Illubabor, East Gojam, West Wollega, and West Harerghe (Figure 2.1). Currently, maize is the cheapest source of calorie intake in Ethiopia, providing 20.6 % of per capita calorie nationally (IFPRI, 2010).

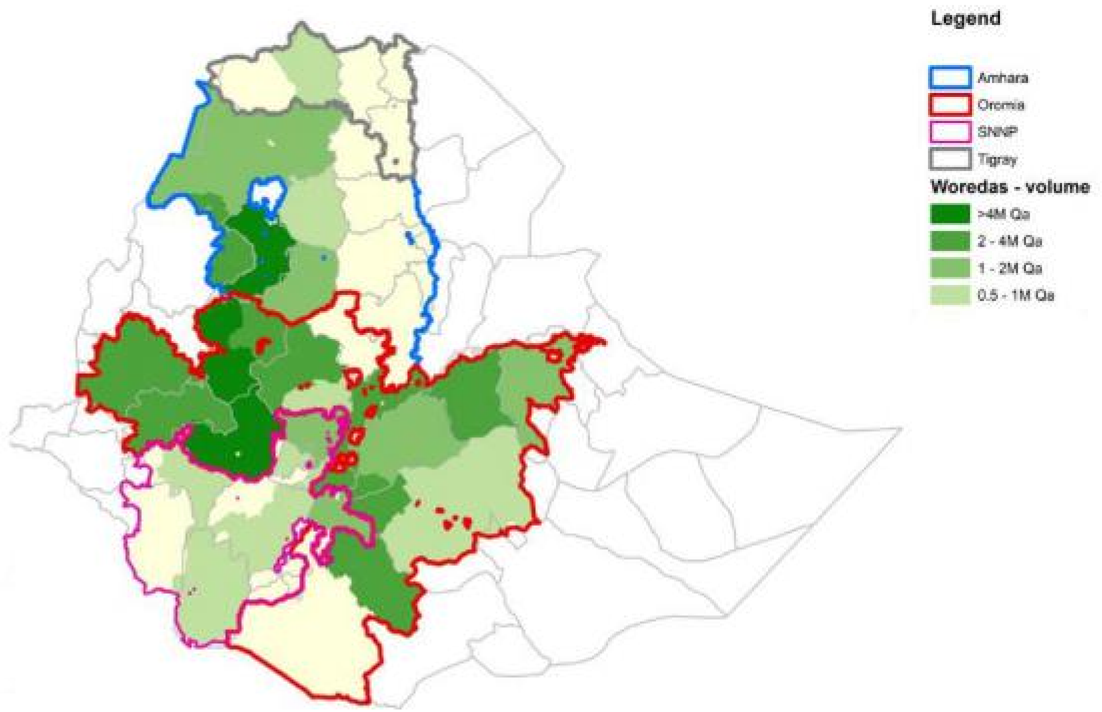

Figure 2.1. Main maize producing areas in Ethiopia

Source: CSA, 2014

2.6 Maize Production in Amhara Region and North Mecha district

Maize production in Amhara region reached 22,844,483.11 quintal in 2018/19 production season with engagement of 2,990,535 smallholder farmers (CSA, 2019). West Gojam is one of the highest potential production areas with more than 0.55 million holders engaged in maize production with about 8.7 million quintals annual production. As per WoA, in North Mecha *Woreda* there are 55,421 (4%FHH) households with a total population of 322,854 (51% Female) almost all engaged in maize production. Maize is produced in all Mecha *Woreda* (40 rural *Kebele*) almost by all households in the area (DoA, 2019).

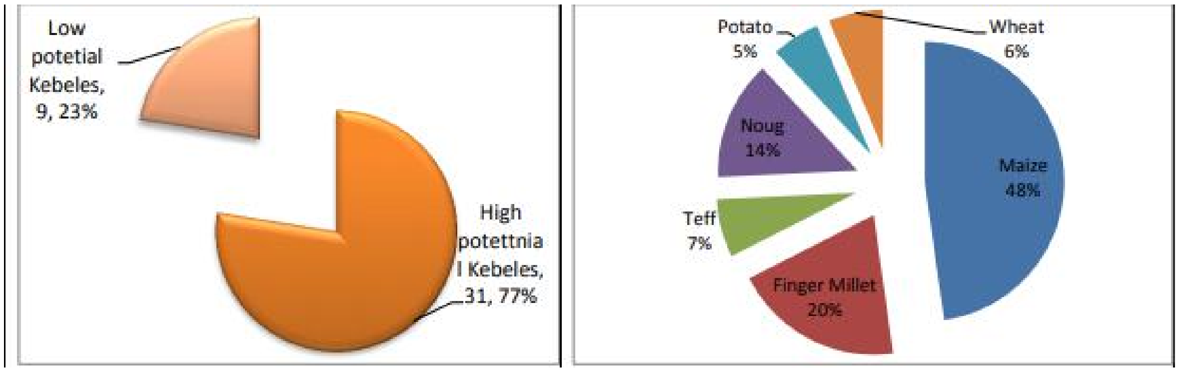

Figure 2. 2.Maize production potential and main crops area coverage (20013/14 production year)

Source: WoA, 2014

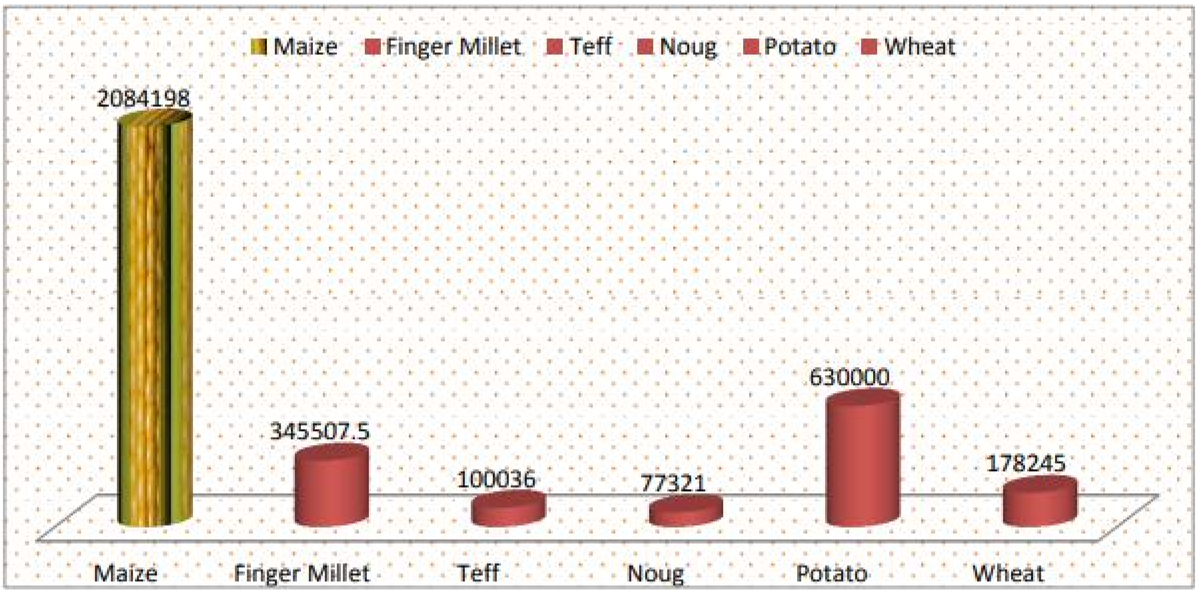

Figure 2. 3.Meher season main crops production volume in quintal (2013/14 production season)

Source: WoA, 2014

2.7 Ecology Requirement of Maize

The maize production system in Ethiopia varies from place to place. The production practices commonly found are monocropping, intercropping, and relay cropping or double cropping with different crops such as beans, horticultural crops and forage crops. The crop fits into different crop sequences and crop rotations based on soil fertility and environmental condition in different areas. It is grown mainly during the main growing season known as *meher*, which relies on May-September rainfall. The crop is also grown during the minor rainy season locally known as *belg*, which relies on January-April rainfall. During the main season, it is grown under rain-fed conditions, whereas during the off-season it is grown mostly under residual moisture at bottom lands with supplementary irrigation (Mosisa Worku *et al*., 2012).

2.8 Major Constraints of Maize Production

Crop species grown throughout the world, experience environmental stresses that limit their growth, development, and the full expression of their genetic potential for economic yield. Various factors affect maize production. Among these, the deficiency in plant nutrients and soil moisture, too low or too high, inappropriate plant population, attack by post- and pre-harvest insect pest, disease, weed infestation and poor agronomic practices are the most common problems (Badu- Apraku *et al.,* 2012).

The spatial and temporal variability of rainfall which is reflected in drought spells and floods are the most important phenomena that affect crop productivity in Sub-Saharan Africa (Laux *et al.,* 2010). Since nutrient uptake is closely linked to soil water status, it is expected that decline in available soil moisture might decrease the diffusion rate of nutrients from soil matrix to roots (Ibrahim and Hala, 2007). Maize production requires an understanding of various management practices as well as environmental conditions that affect crop performance. The effect of tillage practices, plant populations and mulches was significant on biological yield of maize (Gul *et al.,* 2009). Hoeing, weeding and mowing on crop field are the most labour-demanding phase of maize production in Ethiopia.

Maize suffers from the attack of pests from seedling to maturity and in the storage as well. Several species of stem borers (Lepidopterous), weevil (Arthropods) and termites have been recorded in Ethiopia with their significant effect on maize crop (Mosisa Worku *et al.,* 2012). Maize fungal pathogens and some viral diseases have also significant influence on maize production in Ethiopia. The major diseases identified/recognized in Ethiopia are gray leaf spot (GLS), turcicum leaf blight (TLB), common leaf rust (CLR) and maize streak virus (MSV) (Mosisa Worku *et al.,* 2012). Maize lethal necrosis disease (MLND) is also a sporadic and drastic disease which emerged recently. Weeds compete with crops for environmental resources available in limited supply that is nutrients, water and light. In addition to competition interference, weeds also interfere directly as plant parasitic species such as striga. As a consequence, weeds reduce yield significantly and impair crop quality. Among the biotic stresses, annual, perennial and noxious parasitic weeds (*Striga* species) are the most important limiting factors in maize production (Mandefro Nigussie *et al.,* 2002).

2.9 .Effect of Maize Hybrid Varieties of Inter- and Intra-row Spacing's on Phenology, Growth and Yield Parameters of Maize

Maize responds more effectively to plant spacing than any other cereal crops because maize is a plant that exhibits an individual productivity (Pepó and Sárv, 2013). It is one of the most sensitive grass species to intra- and inter-specific competition (Maddonni and Otegui, 2006). For most other cereals, tillers are one of the most important components (production units) for the whole biological and grain yields. However, maize lacks this tillering capacity, so the final yield of maize is obtained from each single stand (Sangoi *et al*., 2001). However, maize is individually highly productive if it is managed well. A maize plant can produce more than 600 grains on each single ear (Qian *et al.,* 2016) which exceeds grain numbers per spike of most cereals by several folds. In addition to the highest number of grains per ear, the size of maize grain is also biggest compared to those of other cereals. These two important yield components of maize are highly sensitive to plant spacing. The number of grain per ear and weight of grain can be increased with increasing inter-and intra-row spacing (Azam *et al.,* 2017). However, yield per unit area can be reduced due to underutilization of available resources (Farina *et al.,* 2015).

On the other hand, reducing intra-row spacings hastens interplant competition for light, water and nutrients. Maize grain yield declines when intra-row spacing is decreased beyond the optimum (Mahmood *et al.,* 2001). Although the trait of prolificacy is genetically programmed, the number of functional ears (ears with grains) per plant is highly influenced by management and agronomic traits. Maize crop in dense populations highly competes for assimilates between the ear and the rest of the plant that leads to reduction in absolute growth rate of ears. Further, crop phenology is one of the most important aspects of maize yield determination which is highly influenced by plant density. High plant population influences synchrony of flowering, delays ear initiation, slows silk development, aggravates abortion of lately fertilized ovaries, and promotes barrenness and production of nubbin ears that leads to substantial reduction of final grain yield of maize (Sangoi *et al*., 2001). Similarly, growth parameters of maize are also significantly affected by plant density as interception of solar radiation depends on the leaf area index which is varied by increasing or decreasing plants per unit area (Abuzar *et al.,* 2011). The increments in plant height and reduction in stem diameter under high plant density (with less inter- and intra-row spacing) have also been observed by many previous researchers (Carpici *et al.,* 2010; Sharifi and Namvar, 2016). Adjusting the intra-row spacing in a way that results in higher grain yield per unit area is necessary to increase crop production.

Maize produces two morphologically distinct inflorescences that bear separate male (tassels) and female (silks) flowers. Silk emergence is normally delayed in relation to the male organ appearance, resulting in a temporal interval between the pollen-shedding and silking stages of the plants (Hall *et al.,* 1980). Pollen viability is seldom affected by crowding stress, but silk emergence is often delayed, thereby increasing the temporal interval between male and female development patterns (Uribelarrea *et al.,* 2002), which lead to a reduced kernel set, especially when a pollination gap of 2–4 days between early- and late-pollinated silks occurs(Ca´rcova and Otegui, 2001). Plant population influences synchrony of flowering and hence grain yield by restricting growing factors through competition. Better synchrony between silk emergence and pollen shed is critical in maize production as pollen remains viable for a short period of time. Adverse conditions such as high plant population, water stress and nitrogen deficiency slow silk development with the result that little or no pollen is available for fertilization as well as some late developing distal spikelet's fail to set kernels. Maize sown in closer plant spacing is subjected to high competition for various growth factors that result in delayed tasseling, silking and physiological maturity period (Shrestha, 2013; Imran *et al.,* 2015; Sharifi and Namvar, 2016). The growth parameters like leaf area, plant height, and stalk diameter of maize are well influenced by the effects of plant number (Berzsenyi and Lap, 2006).

Plant height is increased with close intra-row spacings due to competition for light (Mahmood *et al.,* 2001; Sener *et al.,* 2004; Khan *et al.,* 2017). In contrast, stem diameter increased with the increasing intra-row spacing (Carpici *et al.*, 2010; Farnia *et al.,* 2015). This means higher plant densities produced taller plants with lower stem diameter (Gözübenli, 2010). However, Abuzer *et al.* (2011) reported that plant height increased with decreases in intra-row spacing's up to 13.5 cm and further decrease in intra-row spacings reduced plant height. Plant density is an efficient management tool for maximizing grain yield by increasing the capture of solar radiation within the canopy (Monneveux *et al.,* 2005). Modern maize hybrids withstand stresses better than earlier cultivars and are grown at higher plant populations to increase the interception of solar radiation (Tollenaar, 1991). Leaf area index in maize increased with the increase in plant population. The highest LAI was obtained from treatment having plant population of 120,000 and lowest LAI from 40000 plants ha^{-1} (Abuzer *et al.,* 2011). Similar trend of increasing LAI with increasing plant density was also found by (Amanullah *et al.,* 2007). In contrast, Imran *et al.* (2015) reported that the lowest planting density (65,000 plants ha^{-1}) produced maximum LAI, whereas plant density of 95,000 plants ha^{-1} gave the minimum LAI.

Seed spacing is an agronomical management strategy used by producers to optimize the husbandry of the soil and plant ecosystem from sowing to harvest with the goal of bolstering the production of crops. Crop row spacing influences canopy architecture, which is a distinguishing characteristic that affects the utilization of light, water, and nutrients (Brenton and Denise, 2005). Amanullah *et al.* (2009) noted that there was not much synchrony in flowering with higher density and they reported that higher plant density delayed days to 50% silking of maize crop. Ritchie and Alagarswamy (2003) stated that lengthening of the time interval between anthesis and barrenness occurred more frequently when plant densities exceeded 10 plants m^2. Hamidi and Nasab (2001) also reported that increases in plant densities significantly delayed the duration of the vegetative and reproductive periods. Edmeades *et al.* (2000) showed that close synchrony between male and female inflorescence was desirable to improve kernel set and yield of maize.

The pattern of plant distribution at different spacing's has significant effects on yield and yield components depending on the proximity of plants within and between rows. Particularly, maize grain yield is affected by spatial arrangement of row spacing and plant spacing due to its monoecious floral organization, low tillering ability and presence of brief flowering period (Vega *et al.,* 2001). Plant reduction per unit area prevents maximum usage of production parameters while excessive density can increase the competition and decrease the yield (Farnia *et al.,* 2015). The efficiency of grain production in crop plants is also significantly influenced by plant density. The ratio of the yield of grain to the biological yield harvest index (HI) is decreased with increasing plant density (Nik *et al.,* 2011; Akhtar *et al.,* 2015). However this reduction occurs when plant density increases above the critical plant population (Gözübenli, 2010). But another study indicated that higher harvest index (HI) was obtained from higher plant density (narrowest plant spacing) and the lower harvest index (HI) at the lowest plant density or widest plant spacing (Arif *et al.,* 2010). Several studies showed that decreasing intra-row spacing has a negative impact on number of ear per plant (NEPP), ear length (EL), ear diameter (ED), number of grain rows per ear (NGRPE) and number of grains per ear (NGPE) so that the maximum values of these parameters were obtained from widest intra-row spacing (lowest density) (Abuzar *et al.,* 2011; Zamir *et al.,* 2011; Azam *et al.,* 2017). Plant density affects grain yield by influencing source: sink ratio, number of kernels per plant and kernel weight (Borras *et al.,* 2003). Reducing plant spacing induced competition for growth factors that resulted in reduction of number of ear per plant (NEPP) (Muniswamy *et al.,* 2007; Dawadi and Sah, 2012; Gobeze Yada *et al.,* 2012;Karasu, 2012). Number of kernels per ear is increased with increase in intra-row spacing due to decrease in competition under low plant population (Maddonni and Otegui, 2006). On the other hand, a plant density lower than optimum leads to lower dry matter production per unit area due to less number of plants per unit area (Gobeze Yada *et al.,*2012).

Therefore, optimum plant density is necessary to obtain maximum yield per unit area. Maize biomass yield increases with increase in plant density and nitrogen rate (NiK *et al.,* 2011; Imran *et al.,* 2015; Sharifi and Namvar, 2016). However, plant populations above the optimum for maximum economic yield waste plant nutrients and water and often result in lower total grain yield (Bruns and Abbas, 2005). Such reductions are often the result of fewer kernels per ear and less kernel weight (Zamir *et al.,* 2011; Azam *et al.,* 2017). This effect of grain yield and yield components reduction is primarily related to competition between plants for resources such as sunlight, soil water and nutrients (Nafziger, 2006). Stalk lodging which can decrease maize yield and increases with increase in plant population above the optimum level (Bruns and Abbas, 2005). Optimizing plant densities is also crucial in areas where crop growth is constrained by shortage of rainfall. Because high plant densities may deplete most of available water before a crop reaches maturity while, low plant densities may leave water unutilized in the soil (Wendimu Bayu *et al.,* 2005). Thus, optimum spatial arrangement of row spacing and plant density is needed in order to exploit natural resources such as nutrients, sunlight and soil water to ensure satisfactory maize yield.

Number of plants per unit area influences yield quantity to the greatest extent. Kernel numbers per plant and kernel weight which are the major components of grain yield are always reduced when stand density is increased (Echarte *et al.,* 2000). However, grain-yield per unit area of a maize crop shows a curvilinear response to plant population density, with a maximum yield at the optimum plant population density. Below optimum density, kernel number per plant can increase but it cannot compensate the reduction in the number of plants per unit land area, while substantial barrenness occurs above the optimum density (Gardner, 1988). Increases in plant density increased competition within plants and affect kernel weight and kernel number per ear (Hamidia *et al.,* 2010). Increasing plant density up to the optimum rate allows maize to intercept and use solar radiation more efficiently (Aghdam *et al.,* 2014).

2.10 .Effect of Maize Varieties on Phenology, Growth and Yield and Yield Components

The differential growth with respect to plant height and ear height observed between the varieties might be attributed to differences in genetic characteristics of the individual varieties, including the height of the varieties. Azam *et al.* (2007) reported that various varieties of maize have genotypic differences for plant height where the tallest plant height (145 cm) was recorded for variety Cargill 707 and the shortest plant height (134 cm) was recorded for variety Baber. Karasu (2012) also reported that ear heights of maize cultivars were significantly different and the greatest ear height (144.1 cm) was obtained from LG 2687 cultivar and the lowest ear height (131.5 cm) was obtained from a GH2547 cultivar. Anjorin, and Ogunniyan (2014) also reported that plant and ear heights are important yield determinant features in maize, the higher the ear height the more the number of ears that can develop from the nodes beneath.

The reports of Mekuannet Belay (2019) indicated that higher ear length (16.71 cm) was produced from variety BH-661 while shorter ear length (14.77 cm) was produced from BH-QPY-545. Variations in ear length observed might be due to maize hybrids could have different varietal characteristics for this trait Rangarajan (2002) reported a significant difference among the varieties of maize on ear length. Dalley *et al*. (2006) also reported that the longest ear length (18.87 cm) was found from hybrid 31 R 88 and followed by 30 Y 87 (17.52 cm). Ear diameter was differed according to hybrids and the thickest ears (4.9 cm) were obtained from Pioneer 3223 and the thinnest one (4.4 cm) was obtained from DeKalb 711. Mekuannet Belay (2019) reported highest aboveground dry biomass of variety BH-661 might be due to the late maturity of the variety that took more days to maturity and, hence had a better chance to utilize more nutrients and more photosynthetic activity, which ultimately resulted in higher biomass production**.** Similarly, Borras *et al*. (2003) found that the highest aboveground dry biomass yield (21.54 $t \cdot ha^{-1}$) for late maturing cultivar Ehsan, while the lowest aboveground dry biomass yield (16.83 $t \cdot ha^{-1}$) was obtained from early maturing cultivar Pahari of maize. Bismillah *et al*. (2002) reported that the harvest index varied significantly among different cultivars of maize. Moreover, Iptas, and Acar (2006) found that harvest index of the early maturating hybrid maize was higher (41.3%) than the mid (40.3%) and late (30.1%) maturities of maize, due to the late maturing maize hybrid might have produced more biomass yield than the grain yield.

2.11 .Effects of Hybrid Maize Varieties and Plant Spacing (Inter and Intra Row Spacing) on Growth, Yield and Yield Components of Maize

Plant variety and planting spacing usually affect crop environment, which influence crop growth and yield. Maize varieties have great impact on yield. Hybrid varieties produce more than double than local varieties. Cultivation of hybrid varieties along with various planting spacing can increase production of maize. Adjustment of proper plant spacing in the maize field is important to ensure maximum utilization of solar energy by the crop and reduce evaporation of soil moisture (FAO, 2012).

Radiation intercepted by the leaf surface and the efficiency or its use in developing biomass govern the total dry matter production. Population levels should be sustained to exploit maximum natural resources, such as nutrients, sunlight, soil moisture etc. and to ensure satisfactory yield. Very closest planting is undesirable because it encourages inter-plant competition for resources. Biomass production of a crop largely depends on the function of leaf area development and consequential photosynthetic activity (Natr, 1992). Thus different varieties and appropriate plant spacing have to be ensured with a view to maximizing maize yield.

Iken and Anusa (2004) recommended an optimum plant population of 53,333 plants/ha for maximum yield of maize. Their report indicated that this is obtainable using a spacing of 75cm x 25cm at 1 plant per stand or 75cm x 50cm at 2 plants per stand. Azam *et al.* (2007) reported that spacing of 75cm x 35cm resulted in increased grain yield of maize while 75cm x 15cm gave maximum cob weight. Similar report by Allessi and Power (2004) revealed that maize cob weight decreased with increased plant population. Tolera *et al.* (1999) suggested that breeders should select maize varieties that combine high grain yield and desirable stover characteristics because of large differences that exist between cultivars. Odeleye and Odeleye (2001) reported that maize varieties differ in their growth characters, yield and its components, and therefore suggested that breeders must select most promising combiners in their breeding programmes.

Chapter 3. MATERIALS AND METHODS

3.1 Description of the Study Area

The field experiment was conducted at kudmi *kebele* administration in North Mecha district Amhara Regional State in 2019 main cropping season. Kudmi *Kebele* is found at North Mecha district West Gojam Zone which is located about 42 km South of Bahir Dar town (Figure 3.1). The *kebele* lies between the coordinates of 11°19' to 11°29' N latitude; 37° 02' to 37° 13' E longitudes and situated at an altitude 1960 meters above sea level with total area coverage of 159,898 ha. According to Merawi Metrological Station in 2019, the minimum and maximum temperatures of the area range between 8 and 15 and 22.5 and 30.6 ^{O}C, respectively. The average annual rainfall of the area is reported to be 1679.4 mm. The soil is silty clay with 36 cmol (+)/kg of CEC and 23.6 ppm available phosphorus. The pH value (6.58) with total nitrogen of 1.21% and 0.06% of organic matter. Maize is one of the major cereal crops grown in the main cropping season and during the off dry season under irrigation and the major crops grown in the area are maize, wheat, millet and *teff* (DoA, 2019).

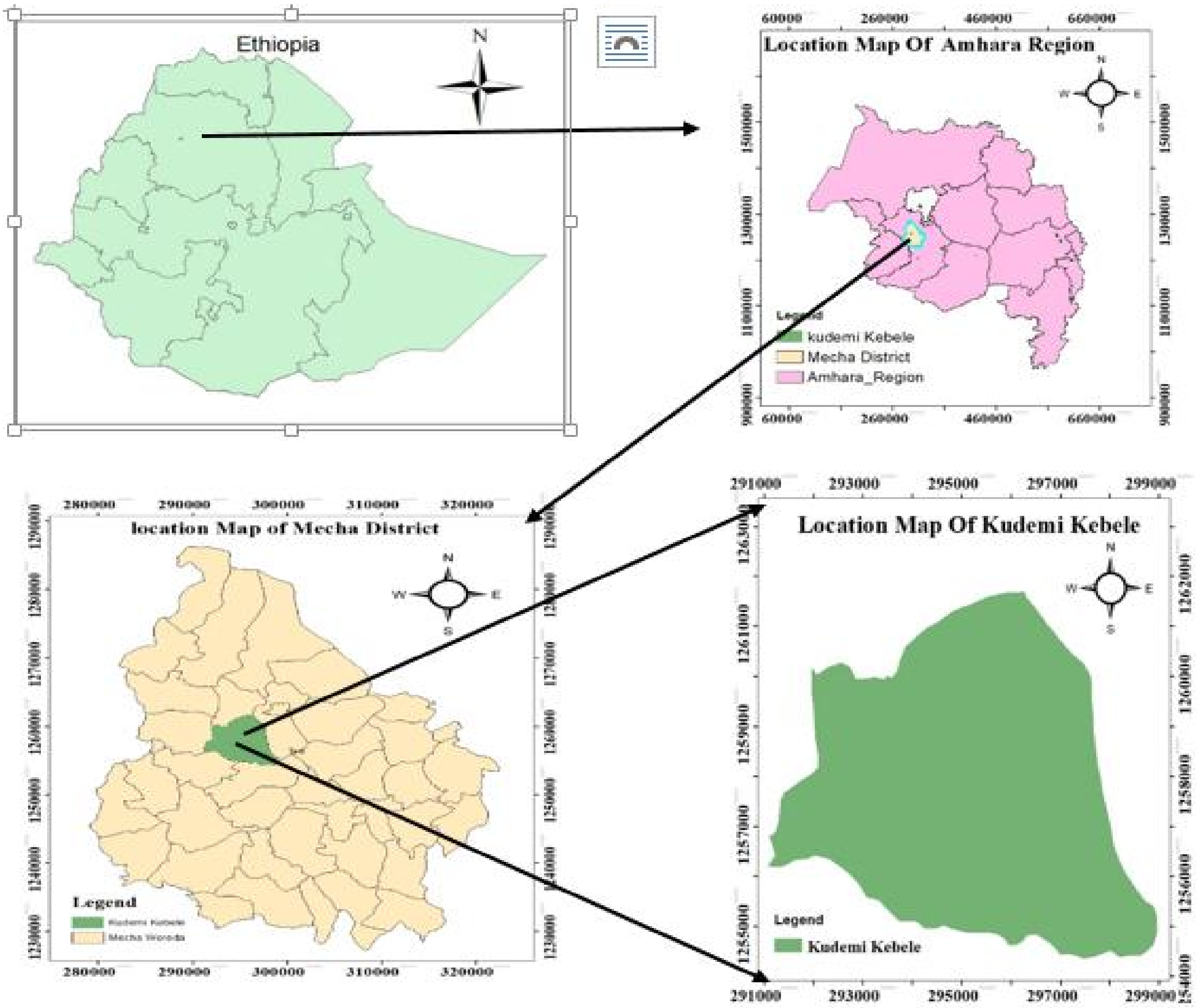

Figure 3. 1.Map of the study area (DoA, 2019)

3.2 Experiment Materials used for the Experiments

Hybrid maize varieties named BH-540 and BH-661 were used for the study.

Table 3.1.Description of hybrid maize used in the experiment

Variety	Year of release	Altitude (m)	Rainfall (mm)	Maturity (days)	Yield (t/ha)	
					On research	On farm
BH-540	1995	900-2000	900-1200	145	8-10	5-7
BH-661	2011	1600-2200	1000-1200	160	9.5-12	6.5-8.5

Source: MoA, 2011; BNMRC, 2014

3.3 Treatments and Experimental Design

The experimental treatments consisted of factorial combinations of three levels of inter-row spacing (65 cm, 75 cm and 85 cm) and three levels of intra-row spacing (25 cm, 30 cm and 35 cm) and two levels of maize varieties (BH-540 and BH-661). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications making a total of 18 treatments (Appendix Table 16). Each treatment was randomly assigned to experimental unit within a block or replications (Appendix Table 16).

The gross plot size was (4.5m x 2.5m) = (11.25 m^2) the length and width has 2.5 m and 4.5 m, respectively and accommodating 6, 6 and 5 rows for all 65 cm, 75 cm and 85 cm inter rows, respectively and 10, 8, and 7 number of plants for all 25 cm, 30 cm and 35 cm intra rows, respectively. The net plot area was delineated by leaving two border rows at both sides of each plot. As the inter- and intra-row spacing varied the net plot area also varied. The numbers of central plants left aside for data recording were 8, 6 and 5 for 25 cm, 30 cm, and 35 cm intra-row spacing, respectively. Hence, the corresponding lengths of net plot for intra-row spacings of 25 cm, 30 cm and 35 cm were 2 m, 1.8 m and 1.75 m, respectively. The numbers of central rows left aside for data recording were 4, 4 and 3 for

65 cm, 75 cm and 85 cm inter-row spacing, respectively. The net widths for 65 cm, 75 cm and 85 cm inter-row spacing's were 2.6 m, 3m and 2.55 m, respectively.

Field Management Practices

Land preparation and sowing

Prior to sowing the land was finely prepared following conventional tillage practices and ploughed three times from March to May 2019 by using oxen-driven local plough (*maresha*). The last ploughing as done for sowing and planting was done in June/3/2019, using the required rate of seeds for each treatment and proposed spacing's, and seeds were planted in furrows. To ensure uniform stand and less missing hills, initially two seeds per hill (hole) were planted. After 13 days of sowing (before plant competition starts) seedlings were thinned to one plant per hole to keep a good stand of seedlings growing up to maturity.

Fertilizer application

Fertilizer levels for different treatments based on the gross plot size and the number of plants per plot were calculated as per the national recommended rate. Full dose of blended fertilizer in the form of NPS at national recommended rate of 200 kg ha^{-1} was applied uniformly to all plots at a depth of 2-3 cm and 3-5 cm away from the seeds at the time of sowing by side-banding method. In addition, all plots were top dressed with urea fertilizer (46% N) using national recommendation rate of 200 kg ha^{-1} in three split doses that is, 1/3 at knee high stage (4 weeks after sowing), 1/3 at tassel initiation/tasseling stage and 1/3 at advanced silking stage/grain filling by the same method of side- dressing after all the weeds had been removed from the plots. As urea releases ammonia within a few hours after application which can be toxic to seedlings and also has high volatile effect resulting in some loss of nutrients, the specified rate of urea was placed approximately 5-7 cm away from the plants and immediately covered with soil (McKenzie, 2013).

Weeding and harvesting

Hand weeding, hoeing and other crop management practices were applied uniformly to all plots as per the recommendations for maize. Finally, maize plants in the net plot area were harvested at harvest maturity.

3.4 Data Collection

Data were collected from the net plot area. In this experiment data were taken on five representative randomly selected sample plants from the net plot and then averaged.

3.4.1 Phenological parameters

Days to 50% tasseling: Days were counted from sowing to the day when 50% of the maize plants shed pollen grains from the main branch of the tassel and from a few other branches in each plot by visual observation.

Days to 50% silking: It was recorded as the number of days required from sowing to the silk emergence on 50% of the plants or when 50% of the maize plants showed extrusion of silking each plot by visual observation.

Days to physiological maturity: The days to physiological maturity were recorded as the duration from the date of sowing up to a stage when 90% of plants formed black layer at the base of the kernel (at the point where the kernel attaches with the cob) and kernels were difficult to be broken by thumb nail.

3.4.2 Growth parameters

Leaf area index (LAI): The leaf area, at the stage of tasseling, was determined first from five randomly selected plants from the net plot by multiplying leaf length and maximum leaf width at the middle section of the leaf and adjusted by a correction factor of 0.75 (0.75 x leaf length x leaf width) as suggested by Francis *et al.* (1969) and Daughtry *et al.* (2004). Then leaf area index was determined by dividing the total leaf area of a plant to the ground area covered by single plant (Radford, 1967).

$$\text{LAI} = \frac{\text{Area of green leaf per plant}}{\text{Area occupied by plant}}$$

Plant height: It was measured as the height from the soil surface to the tip excluding the tassel of five randomly selected plants from the net plot area at physiological maturity.

Ear height: was recorded from five randomly selected plants from each net plot area and measured their ear height from the ground level to the node bearing the top useful ear with a meter rod at physiological maturity.

3.4.3 Yield and yield components

Stand count percentage: It was recorded by counting the number of plants reached to harvesting from the net plot area and calculated as the ratio of actual plant stand to the number of seedlings left after thinning multiplied by 100 (Donald and Hamblin, 1976).
Plant stand count %:(Actual plant stand/ Number of seedlings after thinning) x 100

Number of ears per plant: The number of ears per plant was recorded from the count of five randomly sampled plants per net plot at harvest.

Ear length: It was measured from the base to the tip of the ear from randomly taken five ears in the net plot area at crop harvest. The ear length was measured after removing the husk cover and the average values were computed for each plot.

Ear diameter: It was measured from vernier calipers in the centre of ear by taking five randomly selected ears at harvesting.

Number of grain rows per ear: The numbers of rows were counted on five randomly selected ears and the average values were computed for each plot.

Number of grain per row: It was determined by counting the number of kernels in each grain row of five randomly taken ears from the net plot area at crop harvest and average it.

Number of grain per ear: This represented the average number of kernels obtained from ears of five plants randomly taken from the net plot area at crop harvest.

Thousand –grain weight: It was determined from 1000 randomly taken grains (by hand counting) from each plot and weighed using a digital balance.

Grain yield: The total number of plants in the net plot was harvested. After that, grains were shelled from the ears of each plot. Then, the field weight of grains and the moisture content thereof were immediately measured using electronic balance and moisture tester, respectively in each plot. The measured values were adjusted to the standard moisture content of 12.5 % (Biru Abebe, 1976), then it was multiplied by the field weight of the actual yield of each plot to determine the adjusted yield of the plot and finally converted in to hectare basis using the following formulas:

$$\text{Correction factor} = \frac{100 - \text{Actual moisture content}}{100 - \text{Stanadard moisture content}}$$

$$\text{Grain yield (kg plot}^{-1}) = \frac{100 - \text{Actual moisture content}}{100 - \text{Stanadard moisture content}} x\mathit{Field\ weight}$$

$$\text{Grain yield (kg ha}^{-1}) = \frac{\text{Yield(kg)/plot x 10000}}{\text{Plot size}}$$

$$\text{Grain yield (ton ha}^{-1}) = \text{Grain yield (kg ha}^{-1})/\ 1000$$

Above ground dry biomass yield: All plants with ears attached from the net plot were harvested at harvest maturity and weighed after sun drying which defined it as above ground dry biomass (biological yield).

Harvest index: It was calculated as the ratio of grain yield to total above ground dry biomass yield multiplied by 100 at harvest from the respective treatments (Donald and Hamblin, 1976).

$$\text{Harvest index (HI \%)} = \frac{\text{Grain yield}}{\text{Aboveground biological yield}} \text{X 100}$$

3.5 Statistical Data Analysis

Analyses of variances for the collected data were carried out using the General Linear Model (GLM) procedures of SAS Version 9.1.3 (SAS Institute Inc., 2002). Least significant difference (LSD) test at 5% probability level (Gomez and Gomez, 1984) was used for mean separation if the analysis of variance indicated the presence of significant treatment differences. Correlation analysis was made to examine the association among yield and yield-related components. Simple cost-benefit analysis of each combination was performed to evaluate the economic benefits expected using the farm gate price of maize at the time of harvest.

3.6 Partial Budget Analysis

To assess the costs and benefits associated with different treatments (inter and intra row spacing on hybrid maize's), the partial budget technique as described by CIMMYT (1988) was applied. Economic analysis was performed to investigate the economic feasibility of different variety, inter- and intra-row spacing combinations or treatments. The total variable costs (TVC) are seed and labour for planting cost were calculated based on the current price at the locality during production time. The price of maize was also calculated based on the local market price of maize at Merawi town. The net return was calculated by subtracting total variable cost from the gross benefit. The gross benefit was calculated with that of the grain yield (kg ha^{-1}) and stalk yield (kg ha^{-1}) multiplied by local market price, which is the money gained from sale of the grain and stalk. Finally, to assess the cost and benefit associated with different treatments the partial budget analysis technique (CIMMYT, 1988) was applied. The current local price of labour was birr 100 per day per person and the labours required for the total variable cost used are different between treatments for planting cost were 35-60 persons ha^{-1} costing birr 3500-6000 and the price of improved BH-540 and BH-661 seed was birr 33 kg^{-1} and 27.7 kg^{-1} respectively and also different amount of seeds used between treatments.

The price of maize grain that was valued at an average open market price of 9 birr kg^{-1} at Merawi town in November 2019 and the price of stalk was estimated to be 0.25 birr kg^{-1} during harvest and changed into hectare basis. The actual average yield was adjusted by 10% down to reflect the difference between the experimental yield and farmers field yield that expected to get from the same treatment as described by (CIMMYT, 1988). Adjusted yield was multiplied by market price to obtain gross field benefit. Costs and benefits were calculated for each treatment. All variable costs were summed up and subtracted from gross benefits to obtain the net benefit of each treatment.

$$\text{MRR (\%)} = \frac{\text{Change of net benefit}}{\text{Change of total variable cost}} * 100$$

The dominance analysis procedure as detailed in CIMMYT (1998) was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using this technique were referred to as dominated and undominated treatments, respectively. The undominated treatments were ranked from the lowest to the highest cost. For each pair of ranked treatments, the percent marginal rate of return (MRR) was calculated. In economic analysis, it is assumed that farmers require a minimal rate of return of 100%, representing an increase in net return of at least 1 ETB for every 1 ETB invested, to be sufficiently motivated to adopt a new agricultural technology (CIMMYT, 1988). A treatment having above 100% MRR and highest net benefit is recommended as the most profitable one.

Chapter 4. RESULTS AND DISCUSSION

4.1 Phenological Parameters of Maize

4.1.1 Crop phenology

Results from analysis of variance revealed that both main effect and their interactions effect inter and intra-row spacing were not significant on days to 90% maturity, days to 50% tasseling and days to 50% silking of maize but the main effect was highly significant ($p<0.01$) on varieties (Appendix Table 1). The present results, is in line with Gozubenli *et al*. (2004) reported that the effect of inter and intra-row spacing did not significantly affect the tasseling and maturity period of maize. The longest days (88.51) to 50% tasseling was recorded at BH-661 while the shortest days (83.18) to 50% tasseling was recorded at BH-540 (Table 4.1). The longest days (93.88) to 50% silking was recorded BH-661 while the shortest days (89.7) to 50% silking was recorded in BH-540 (Table 4.1). The longest days (159.92) to 90% maturity was recorded BH-661 while the shortest days (143.59) to 90% maturity was recorded in BH-540 (Table 4.1). The differential with respect to days to 90% maturity, number of days to 50% tasseling and number of days to 50% silking were observed between the varieties these might be attributed to differences in genetic characteristics of the individual varieties. Gozubenli *et al*. (2001) and Thiraporn *et al*. (1983) reported that tasseling period was variable in maize and longer season cultivars took more time to reach tassling and maturation than did the shorter seasonal cultivar.

Table 4.1.The main effects of varieties on phenological parameters of maize

Variety	Days to 50% tasseling	Days to 50 % silking	Days to 90% physiological maturity
BH-540	83.18[b]	89.70[b]	143.59[b]
BH-661	88.51[a]	93.88[a]	159.92[a]
LSD	1.26**	1.07**	1.48**
CV	2.65	2.12	1.76
SE±	1.86	1.59	2.18

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error, **=highly significant at 1% (p<0.01).*

4.2 .Growth Parameters of Maize

4.2.1 Plant height

The analysis of variance showed that the main effect of inter and intra-row spacings was significant ($p<0.05$) and varieties on plant height was highly significant ($p<0.01$). However, the interaction effect was not significant (Appendix Table 2). Plant height increased with decreasing the inter-row spacing from 85 cm to 65 cm and the taller plant height (233.36 cm) was recorded in a treatment having the narrowest inter-row spacing of 65 cm, while the shorter plant height (221.3 cm) was recorded under treatment consisting of the widest inter-row spacing of 85 cm, but it is statistically at par with that obtained under (223.23 cm) 75 cm, respectively (Table 4.2). This increase in plant height at narrowest inter-row spacing might be due to overcrowding effect of plants and higher inter-specific competition for growth-limiting resources, particularly for light. This competition for light probably attributed to relatively low solar radiation interception through leaf canopy of plant that might be responsible for the formation of longer internodes resulting in increased plant height. While sparsely populated plants intercepted sufficient sunlight that enhanced lateral growth.

In conformity with this result, Matthews *et al*. (2008) reported that maize planted with 75 cm row-spacing had significantly shorter plants than those planted with 50 cm row-spacing. Similarly, Miko and Manga (2008) also reported that sorghum height was significantly affected by inter-row spacing and 50 cm inter-row spacing was observed to have given significantly higher plant height than 75 cm inter-row spacing.

With regard to the effect of intra-row spacings, plant height increased with decreasing intra-row spacing from 35 cm to 25 cm. The tallest plant height (231.36 cm) was observed under the narrowest intra-row spacing of 25 cm, while the shortest plant height (220.35 cm) was recorded at the widest intra-row spacing (35 cm) (Table 4.2). This increase in plant height at narrowest plant spacing (higher plant density) may be due to strong intra-specific competition among plants for light that might be attributed to more vegetative development resulting in increased plant height due to mutual shading with intermodal extension being responsible for increasing the plant height.

The result is supported by the previous findings of Khan *et al.* (2017), who reported that increasing plant population density increased the plant height and similarly, Matthews *et al*. (2008) also reported that maize planted with plant spacing of 25 cm had significantly taller plants than those planted with 30 cm plant spacing. The result also agreed with the previous findings of Abuzer *et al.* (2011) who reported that plant height increased with decreasing intra-row spacing.

Accordingly, significantly taller plant height (242.67 cm) was obtained from the variety BH-661 than variety BH-540 (209.25 cm) (Table 4.2). The differential growth with respect to plant height observed between the varieties this might be attributed to differences in genetic characteristics of the individual varieties, including the height of the varieties. Similarly, Azam *et al.* (2007) stated that various varieties of maize have genotypic differences for plant height where the tallest plant height (145 cm) was recorded for variety Cargill 707 and the shortest plant height (134 cm) was recorded for variety Baber. In conformity with this result, Abuzar *et al.* (2011) who reported considerable varietal variation among plant height of maize cultivars.

Table 4.2.The main effects of intra row, inter row spacing,s and varieties on plant height of maize

Treatments	Plant height (cm)
Variety	
BH-540	209.25[b]
BH-661	242.67[a]
LSD	6.77**
Inter row spacing (cm)	
85	221.3[b]
75	223.23[b]
65	233.36[a]
LSD	10.003*
Intra row spacing(cm)	
35	220.35[b]
30	226.18[ab]
25	231.36[a]
LSD	10.003*
SE±	9.99
CV	5.41

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error, **=highly significant at 1% (p<0.01),*=significant at 5% (p<0.05).*

4.2.2 Ear height

The analysis of variance revealed that the main effect due to varieties on ear height was highly significant ($p < 0.01$) and intra-row spacings was significant ($p<0.05$), while the interaction effect was not significant ($p > 0.05$) on ear height (Appendix Table 2). The highest ear height (127.14 cm) was obtained from the variety BH-661, while the lowest ear height (90.51 cm) was obtained at the variety BH-540 (Table 4.3). The differential growth with respect to ear height observed between the varieties might be attributed to differences in genetic characteristics of the individual varieties. Karasu (2012) also reported that ear heights of maize cultivars were significantly different and the greatest ear height (144.1 cm) was obtained from LG 2687 cultivar and the lowest ear height (131.5 cm) was obtained from a GH2547 cultivar. Anjorin and Ogunniyan (2014) also reported that plant and ear heights are important yield determinant features in maize, the higher the ear height the more the number of ears that can develop from the nodes beneath.

Regarding the effect of intra-row spacing, ear height increased with decreasing intra-row spacing from 35 cm to 25 cm. The tallest ear height (117.45 cm) was recorded under the narrowest intra-row spacing of 25 cm, while the shortest ear height (101.62 cm) was recorded at the widest intra-row spacing of 35 cm (Table 4.3). This increase in ear height at narrowest plant spacing may be due to strong intra-specific competition among plants for light that might be attributed to more vegetative development resulting in increased ear height due to mutual shading with intermodal extension being responsible for increasing the ear height. Generally, ear height showed a linear increase with an increase in planting density increase due to high density resulted in competition for resources. The current result was in agreement with Abuzar *et al*. (2011) the main effect of planting density showed that ear height was relatively responsive to the change in planting density than N levels.

Table 4.3.The main effects of intra row spacing's and varieties on ear height of maize

Treatments	Ear height(cm)
Varieties	
BH-540	90.51^{b}
BH-661	127.14^{a}
LSD	9.05**
Intra row spacing	
35	101.62^{b}
30	107.39^{ab}
25	117.45^{a}
LSD	13.36*
SE±	13.36
CV	15.03

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error, **=highly significant at 1% (p<0.01),*=significant at 5% (p<0.05).*

4.2.3 Leaf area index

The analysis of variance showed that the main effects due to inter, intra-row spacings and varieties on leaf area index (LAI) were highly significant ($p < 0.01$), while the interaction effect was very highly significant ($p < 0.001$) on leaf area index (Appendix Table 2). Analysis of variance depicted that the highest leaf area index (5.17) was obtained from variety BH-661 at closer inter (65 cm) and intra (25 cm) row spacing. The lowest leaf area index (2.34) were attained from variety BH-540 at wider inter (85 cm) and widest intra (35 cm) row spacing (Table 4.4). The possible reasons for the highest leaf area index for variety BH-661 at the narrowest inter and intra-row spacing might be due to more number of leaves produced owing to more number of plants per unit area. Leaf area index is in reverse to leaf area per plant, that is the maximum leaf area per plant occurred at wider spacing and at the same time, the minimum leaf area index occurred at the widest spacing.

In line with this result, Ahmad *et al*. (2010) who reported the highest leaf area index (5.82) was obtained from variety Pioneer-30D55, while the lowest leaf area index (5.55) was obtained from variety pioneer-3012 due to a smaller number of leaves per plant and less leaf breadth. Similarly, Abuzar *et al*. (2011) who revealed that leaf area index was significantly affected and increased in a linear fashion from 1.21 to 2.77 when plant population increased from 40,000 to 120,000 plants·ha^{-1} of maize, respectively. This was in agreement with Shafi *et al*. (2012) who showed that the leaf area index of maize was significantly affected by planting density and varieties, leaf area index increased from 2.5 to 3.5 as plant population increased from 45,000 to 65,000 plants·ha^{-1}. Amona Tolka (2014) also showed that the highest leaf area index (4.19) was obtained at the narrowest plant spacing (55 cm X 25 cm) and the lowest leaf area index (2.67) was registered at the widest plant spacing (75 cm X 30 cm) of maize.

Table 4.4.The Mean leaf area index of maize as affected by the three ways interaction effect of variety, inter and intra row spacing

Variety	Inter row spacing	Intra row spacing		
		25	30	35
BH-540	65	3.73^{abc}	4.01^{abc}	3.18^{bc}
	75	3.56^{abc}	2.75^{bc}	2.95^{bc}
	85	3.87^{abc}	2.34^{c}	2.34^{c}
BH-661	65	5.17^{a}	4.02^{abc}	3.74^{abc}
	75	4.57^{ab}	4.16^{abc}	4.13^{abc}
	85	3.42^{abc}	2.66^{bc}	2.88^{bc}
LSD	1.92***			
CV	17.7			
SE±	0.5			

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, LSD=least significance difference, SE= standard error,***= very highly significant at (p<0.001).*

4.3 Yield and Yield Components of Maize

4.3.1 Stand count percent

In the result of this study, the main effect of inter -row spacing on the stand count was significant ($p < 0.05$). However, the interaction effect had no significant ($p > 0.05$) on stand count percent (Appendix Table 3). The plant stand count increased as inter-row spacing increased from 65 cm to 85 cm. The highest stand count percent (93.61%) was recorded at widest inter row spacing 85 cm and the lowest stand count percent (87.21%) was recorded at the narrowest inter row spacing 65 cm (Table 4.5). This increase in stand count percent at wider inter- row spacing might be because, at wider row spacing there would be low plant population and relatively each plant could have a chance to get more space and might have resulted in less competition for resources that resulted for increasing plant stand count percent.

In general, plant stand count percent decreased as plant population increased and that might be due to crowding effect. There is a possibility that at narrower inter row spacing (with higher population density) smaller plants crowded out and disappear. This might be due to at lower population comparatively availability of more space might have resulted in less competition for resources (nutrients, moisture and light) whereas at high density due to more intra-specific competition. This self-thinning effect can also be attributed to increased interplant competition for space, light, moisture and nutrients at the higher populations. This result was in line with that of Sangoi *et al.* (2001) reported that wider inter and intra-row spacing of 75 cm x 26.6 cm had greater plant stand count percent of maize as compared to the initial count than that of narrow inter and intra spacing of 50 cm x 17.7 cm. Similarly, Eskandarnejada *et al*. (2013) reported that higher plant stand count percent was achieved due to the wider spacing combinations of 75 cm x 30 cm than narrower spacing of 55 cm x 20 cm.

Table 4.5.The main effects of inter row spacing's on stand count percent of maize

Treatments	Stand count (%)
Inter row spacing	
85	93.61[a]
75	89.21[ab]
65	87.21[b]
LSD	5.026*
SE±	5.02
CV	6.83

Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error,=significant at 5% (p<0.05).*

4.3.2 Ear length

The analysis of variance revealed that the main effect of inter row spacing and variety on ear length was very highly significant ($p<0.0001$) and intra-row spacing's was significant ($p<0.05$). However, the interaction effect had no significant ($p>0.05$) on ear length (Appendix Table 3). Ear length increased with increased row-spacing from 65 cm to 85 cm.

The longest ear length (22.8 cm) was recorded from the widest row-spacing (85 cm), while the shortest ear length (21.30 cm) was recorded from row-spacing of 75 cm but it is statistically at par with that obtained under 65 cm (21.55 cm) in narrow inter row spacing (Table 4.6). This increase in ear length in response to wider inter-row spacing might be due to easy availability of growth-limiting factors, both in the soil system and the aboveground of the soil. This could be responsible for maize plants to express fully its yield potential and effective translocation of assimilates from the source to sink might have further improved yield attributes resulting in the longest ear length under wider inter-row spacings. This result is in agreement with the findings of Zamir *et al.* (2011) reported that there was a positive relationship between row-spacing and cob length. In low planting density, each plant would have a chance to obtain adequate resources for optimum growth that might have been responsible for setting up early sink with accumulated photosynthesis due to early formation of reproductive structures which was evident from the advancement of silking due to cob's greater size.

Regarding the effect of intra- row spacing, ear length decreased with decreasing plant spacing from 35 cm to 25 cm. The highest ear length (22.4 cm) was recorded from the widest-spaced plants (35 cm), while the lowest ear length (21.49 cm) was recorded from the narrowest row-spacing of 25 cm (Table 4.6). This reduction of ear length in narrowly-spaced plants might be attributed to inefficient supply of assimilates from source to sink as a result of mutual shading or low photosynthetic process of leaves. This result is in line with the findings of Azam *et al.* (2017) who reported that intra-row spacing significantly affected cob length due to intense competition for growth-limiting factors like nutrient, moisture, air and light.

Regarding the effect of varieties in ear length, higher ear length (22.83 cm) was produced from variety BH-661 while shorter ear length (20.93 cm) was produced from BH-540 (Table 4. 6). Variations in ear length observed might be due to maize hybrids could have different varietal characteristics for this trait. This result is in line with the findings of Konuskan (2000) and Gozubenli *et al.* (2001) who reported that variations in ear characteristics of maize depend upon genotype and environmental conditions. Rangarajan *et al.* (2002) reported a significant difference among the varieties of maize on ear length. Dalley *et al.* (2006) also reported that the longest ear length (18.87 cm) was found from hybrid 31 R 88 and followed by 30 Y 87 (17.52 cm).

Table 4.6.The main effects of inter row spacing's, intra row spacing's and variety on ear length of maize

Treatments	Ear length (cm)
Variety	
BH-540	20.93[b]
BH-661	22.83[a]
LSD	0.53***
Inter row spacing (cm)	
85	22.8[a]
75	21.3[b]
65	21.55[b]
LSD	0.79***
Intra row spacing (cm)	
35	22.4[a]
30	21.76[ab]
25	21.49[b]
LSD	0.91*
SE±	0.78
CV	4.42

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error, ***=very highly significant at 0.1% (p<0.001), ***=very highly significant at 1% (p<0.01), *=significant at 5% (p<0.05).*

4.3.3 Number of ears per plant

The analysis of variance showed that there was significant difference (p< 0.05) in number of ears per plant due to the main effects of inter -row spacing's . However, interaction of the factors did not show significant difference (p>0.05) on number of ears per plant (Appendix Table 3). Number of ears per plant increased with increased inter-row spacing from 65 cm to 85 cm. The highest number of ears per plant (1.50) was recorded from the widest inter-row spacing (85 cm), while the lowest number of ears per plant (1.33) was recorded from the narrowest inter-row spacing (65 cm) but it is statistically at par with that obtained under number of ear per plants (1.35) 75 cm (Table 4.7). This increase in number of ears per plant with the increase in inter-row spacing might be due to the availability of growth-limiting resources with less competition, higher net assimilation and partitioning than the narrowest spacing. In addition, the reduced competition for light and reduced overlapping from adjacent maize plants could have enabled the plants grown at wider spacing to utilize its energy for more horizontal growth (Abdel and Idris*,* 2008). This result is in agreement with the findings of Ahmad *et al.* (2006) who recorded that, the highest number of ears per plant in maize crop sown in 75 cm spaced rows than crops sown at 55 cm and 45 cm spaced rows.

Table 4.7.The main effects of inter row spacing,s on number of ears per plant of maize

Treatments	Number of ears per plant
Inter row spacing	
85	1.5[a]
75	1.35[b]
65	1.33[b]
LSD	0.13*
SE±	0.13
CV	11.76

Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error,=significant at 5% (p<0.05).*

4.3.4 Number of grain rows per ear

The analysis of variance indicated that the main effect of inter-row and variety was highly significant effect ($p< 0.01$) on the number of grain rows per ear while significant ($p < 0.05$) effect on number of grains rows per ear. However, their interaction was not significant (Appendix Table 3). The number of grain rows per ear increased with increasing the row-spacing from 65 cm to 85 cm. The highest number of grain rows per ear (13.94) was obtained from the widest inter-row spacing (85 cm), while the lowest number of grain rows per ear (13.08) was recorded from the narrowest row-spacing (65 cm) but it is statistically at par with that obtained under number of grain rows per ear (13.15) with medium row spacing (75) cm (Table 4.8). This increase in number of grain rows per ear in response to increasing inter-row spacing might be due to better availability of growth-limiting resources both in the soil and outside the soil system that perhaps enabled plants to grow vigorously and produce fully viable big ears that can carry several number of grain rows on it. This result is in line with the previous findings of Aghdam *et al.* (2014) who reported that increasing row space increased corn growth and development, which increased number of grain rows per ear.

Regarding the effect of number of grain rows per ear, the highest number of grain rows per ear (13.62) was obtained in variety BH-661, while the lowest number of grain rows per ear (13.17) was recorded in variety BH-540. This is due to the effect of the corn growth and development is BH-661 good performing than BH-540. Similar result was reported by Abdulatif (2002) who observed significant variation at row spacing and maize varieties on number of kernel rows per ear.

Table 4.8.The main effects of intra row spacing's and varieties on number of grain rows per ear of maize

Treatments	Number of grain rows per ear
Varieties	
BH-540	13.17[b]
BH-661	13.62[a]
LSD	0.32*
Inter row spacing	
85	13.94[a]
75	13.15[b]
65	13.08[b]
LSD	0.48**
SE±	0.47
CV	4.4

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error, **=highly significant at 1% (p<0.01), *=significant at 5% (p<0.05).*

4.3.5 Number of grains per row

The analysis of variance showed very highly significant ($p < 0.001$) effect of variety and inter-row spacing and highly significant ($p<0.01$) intra-row spacings on the number of grains per row, but their interaction had no significant effect (Appendix Table 3). The number of grains per row showed consistent reduction with decreasing row-spacing from 85 cm to 65 cm. The highest mean number of grains per row (42.99) was recorded from the widest inter row-spacing (85 cm), while the lowest mean number of grains per row (38.05) was recorded from the narrowest inter row-spacing (65 cm) (Table 4.9). The decrease in inter row-spacing which led to reduction in the number of grains per row might be due to increased inter-plant competition and mutual shading of lower leaves where light and air could not penetrate throughout and distribute to all leaves for efficient photosynthesis. This result coincides with the findings of Sabri *et al.* (2001) reported that the kernel numbers per row increased by about 4% when row-spacing increased from 55 cm to 80 cm.

With regard to intra-row spacing,s, the number of grains per row increased with increasing plant spacing from 25 cm to 35 cm. The highest grains per row (41.07) was recorded at the widest plant spacing (35 cm), but it is statistically at par with that obtained under (30 cm) (40.66) and the lowest number of grains per row (39.31) was recorded from the narrowest plant spacing (25 cm) (Table 4.9). This increased number of grains per row with increasing plant spacing might be due to the availability of growth-limiting factors that encouraged better plant growth and development attributing to more interception and conversion of light through leaves and set early sink for the accumulation of assimilates. This result is in tune with the findings of Kumar (2009) reported that increasing plant spacing reduced inter-plant competition and increased photosynthetic efficiency favouring better source-sink relationship which might have been responsible for increased cob size, number of rows per ear and number of grains per ear.

With regard to varieties, the highest number of grains per row (41.32) was recorded in BH-661 while the lowest number of grains per row (39.37) was recorded in BH-540 (Table 4.9). Esayas Eyasu *et al.* (2018) reported that decreasing row spacing led to reduction in number of seeds per row due to increased interplant competition and mutual shading of lower leaves where light could not penetrate throughout and distribute to all leaves for efficient photosynthesis.

Table 4.9.The main effects of intra row; inter row spacing's and varieties on numbers of grains per row of maize

Treatments	Numbers of grains per row
Variety	
BH-540	39.37[b]
BH-661	41.32[a]
LSD	0.88***
Inter row spacing (cm)	
85	42.99[a]
75	40.0056[b]
65	38.05[c]
LSD	1.3***
Intra row spacing (cm)	
35	41.07[a]
30	40.66[a]
25	39.31[b]
LSD	1.3**
SE±	1.3
CV	3.94

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, ** highly significant at 1%,*** highly significance at 0.1% (p<0.0001), SE= standard error.*

4.3.6 Number of grain per ear

In the present study, number of kernels per ear was very highly significantly ($p< 0.0001$) affected by the main effects of variety and highly significantly ($p<0.01$) affected by inter row spacings but there were no two or three-way interactions effects ($p> 0.05$) between or among the experimental variables (Appendix Table 3). Significantly, a higher number of kernels per ear (550.27) were recorded from variety BH-661 while the lower (500.32) was recorded BH-540 (Table 4.10). The difference in number of kernels per ear observed between two varieties might be due to the fact that number of kernels per ear depends on traits like ear length. Similarly, Amona Tolka (2014) reported that the variety BH-140 gave the highest number of kernels per ear (502) than varieties BHPQY-545 and BH-540 owing to the difference in genetic makeup among the cultivars.

Regarding to the effect of inter row spacing's, the highest number of kernels per ear (552.2) was recorded at 85 cm inter-row spacing and the lowest number of kernel (510) was recorded at 75 cm inter-row spacing, but it is statistically at par with that obtained under 65 cm (513.67 cm) (Table 4.10). In wider spacing there is enough resources in case no competition so the amount of kernel is high. Increasing inter-row spacing from 65 cm to 85 cm showed linear and consistent kernels increment. In agreement with this result, Eskandarnejada *et al.* (2013) reported that the inter-row spacing of 30 cm produced a greater number of grains per ear than that of 20 cm. Similarly, Mukhtar *et al.* (2012) observed decreased number of grains per ear with increase in plant density in maize.

Table 4.10.The main effects of inter row spacing's and varieties on numbers of grain per ear of maize

Treatments	Numbers of grain per ear
Varieties	
BH-540	500.32[b]
BH-661	550.27[a]
LSD	15.74***
Inter row spacing	
85	552.209[a]
75	510.006[b]
65	513.678[b]
LSD	23.245**
SE±	23.23
CV	5.41

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error, ***=highly significant at 0.1% (p<0.001), **=significant at 1% (p<0.01).*

4.3.7 Ear diameter

The analysis of variance indicated that the main effect of inter-row, intra-row spacing and variety had very highly significant ($p<0.001$) effect on ear diameter, but their interaction was not significant (Appendix Table 4). Ear diameter increased with the increasing of both inter- and intra-row spacing. The thickest ear diameter (4.4 cm) was recorded from the widest row-spacing (85 cm), and the thinnest ear diameter (4.28 cm) was recorded from the narrowest row-spacing (65 cm) (Table 11). Similarly, the thickest ear diameter (4.36 cm) was recorded from the widest intra-plant spacing (35 cm), while the thinnest ear diameter (4.32 cm) was recorded from the narrowest intra-row spacing (25 cm) (Table 4.11). This increase in ear diameter in both wider inter- and intra-row spacing might be ascribed to the reduction in influential competition and efficient utilization of the growth-limiting factors, high net assimilation rate and favourable assimilate partioning from the source to the sink resulting in enhanced healthy, thick cobs and high seed production. This result is in agreement with the previous findings of Abuzer *et al.* (2011) who reported that increasing row and plant spacings had a positive effect on ear diameter. Because at lower planting density with less inter- and intra-plant competition, ample availability of growth-limiting resources and early formation of reproductive structures might have increased the grain filling period and cob size (Reddy *et al.,* 2010).

Thickest ear diameter (4.46 cm) was obtained from variety BH-661 and the thinnest (4.21 cm) diameter was recorded in variety BH-540 (Table 4.11). The possible reason for observed thicker ear diameters for variety BH-661 might be due to large kernel size for variety BH-661 as compared to variety BH-540 and differed according to hybrids. In line with this result, Sener *et al*. (2004) reported that ear diameter was differed according to hybrids and the thickest ears (4.9 cm) were obtained from Pioneer 3223 and the thinnest one (4.4 cm) was obtained from DeKalb 711. Similarly, Sharifi *et al*. (2009) revealed that the thickest ear diameter (4.5 cm) was obtained from SC-504 hybrid and the thinnest ear diameter (3.8 cm) was attained from a DC-370 hybrid.

Table 4.11.The main effects of intra row; inter row spacing's and varieties on ear diameter of maize

Treatments	Ear Diameter (cm)
Variety	
BH-540	4.21[b]
BH-661	4.46[a]
LSD	0.0088***
Inter row spacing (cm)	
85	4.4[a]
75	4.33[b]
65	4.28[c]
LSD	0.013***
Intra row spacing (cm)	
35	4.36[a]
30	4.34[b]
25	4.32[c]
LSD	0.013***
SE±	0.013
CV	0.36

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error, ***=highly significant at 0.1% (p<0.001).*

4.3.8 Thousand grain weight

The analysis of variance showed that the main effects of variety and interactions were highly significant ($p<0.01$) and inter-row spacing's was significant ($p<0.05$) on thousand grain weight (Appendix Table 4). The highest mean thousand grain weight (503.33 g) was recorded from the combination of 85 cm X 30 cm spacing of variety BH-540 and statistically at par 85 cm X 25 cm spacing of variety BH-540, while the lowest mean thousand grain weights (321 g) was recorded from 65 cm X 35 cm spacing of variety BH-661 (Table 4.12). This might be due to wider spacing provided better opportunity for crop to utilize available resources with less competition leading to increased plant capacity for building large amounts of metabolites to be used in increasing this yield component. In addition, wider spaced plants that improved the supply and partioning of assimilates from source to sink to be stored in the grains might be the reason for producing higher seed weight. This result is in tune with the findings of Azam *et al.* (2017) who observed maximum 1000-seed weight (339 g) at plant spacing of 30.5 cm and minimum 1000-seed weight of (315.44 g) at 15.24 cm, and also agreed with the findings of several workers (Arif *et al.,* 2010; Khan *et al.,* 2017; Mukhtar *et al.,* 2012 and Zamir *et al.,* 2010) who reported that the lowest plant population increased 1000-seed weight.

Table 4. 12.Mean thousand grain weight (g) of maize as affected by the three ways interaction effect of varieties, inter and intra row spacing

Variety	Inter row spacing	Intra row spacing		
		25	30	35
BH-540	65	475^{ab}	367.67^{ab}	399^{ab}
	75	380^{ab}	424^{ab}	418^{ab}
	85	496.67^{a}	503.33^{a}	386^{ab}
BH-661	65	389.33^{ab}	369^{ab}	321^{b}
	75	379.33^{ab}	360^{ab}	373.67^{ab}
	85	398.67^{ab}	402.67^{ab}	439.67^{ab}
LSD	149.68**			
CV	11.98			
SE±	39.91			

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, LSD=least significance difference, SE=standard error, **=significant at 1% (p<0.01).*

4.3.9 Aboveground dry biomass yield

Analysis of variance to above ground dry biomass yield revealed that main effect and interaction effect of inter row spacing × intra row spacing and variety× intra row spacing's was significant ($p<0.01$) and three ways of interaction variety × inter× intra row spacing ($p<0.001$) was very highly significant (Appendix Table 4).

Accordingly, the highest aboveground dry biomass yield (34.10 $t \cdot ha^{-1}$) was obtained at narrow inter (65 cm) and intra (25 cm) row spacing in variety BH-661 and statistically at par under narrow inter (65 cm) and intra (30 cm) row spacing in variety BH-661 while the lowest aboveground dry biomass (21.096 t·ha^{-1}) was attained at wider inter (85 cm) and medium intra (30 cm) row spacing in variety BH-661 (Table 4.13). The highest aboveground dry biomass might be due to the presence of high number of plant stand per unit area and the late maturity of the variety that took more days to maturity and, hence had a better chance to utilize more nutrients and more photosynthetic activity, which ultimately resulted in higher biomass production.

The result shows that an increase in biomass yield with increasing plant population density and plant height also directly contribute to biomass yield increment. This result was in line with Borras *et al.* (2003) found that the highest aboveground dry biomass yield (21.54 t·ha^{-1}) for late maturing cultivar Ehsan, while the lowest aboveground dry biomass yield (16.83 t·ha^{-1}) was obtained from early maturing cultivar Pahari of maize. Similarly, Amona Tolka (2014) who reported the highest dry biomass (28.4 t·ha^{-1}) of maize at the plant density of 61,538 plants·ha^{-1} (65 cm X 25 cm), but the lowest dry biomass (21.19 t·ha^{-1}) at plant density of 44,444 plants ha^{-1} (75 cm X 30 cm) which might be due to the result of variation in the crop stand per unit area. Aslam *et al.,* (2011) reported that dry matter accumulation was much in high plant densities compared to low plant densities.

Table 4.13.Mean aboveground dry biomass yield ($t{\cdot}ha^{-1}$) of maize as affected by the three ways interaction effect of varieties, inter and intra row spacing

		Intra row spacing		
Variety	Inter row spacing	25	30	35
BH-540	65	32.26^{ab}	31.45^{ab}	30.89^{ab}
	75	30.8^{ab}	31.51^{ab}	29.13^{bc}
	85	24.76^{de}	25.4^{de}	23.87^{def}
BH-661	65	34.10^{a}	34.02^{a}	25.22^{de}
	75	30.61^{b}	26.56^{cd}	22.62^{ef}
	85	24.24^{def}	21.096^{f}	22.99^{ef}
LSD	3.35***			
CV	3.93			
SE±	0.89			

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error, ***= very highly significant (p<0.001).*

4.3.10 Grain yield

Grain yield is the ultimate goal of any crop production system aimed at increasing the economic yield. Grain yield is the end product of all metabolic processes of crop plants over the growing season. The analysis of variance showed that both main effect was very highly significant ($p<0.001$) and also interaction effect of inter× intra row spacings and variety × inter× intra row spacings were very highly significant ($p<0.001$) (Appendix Table 4).

Accordingly, the highest grain yield (11.39 $t{\cdot}ha^{-1}$) was obtained in combination of 65 cm × 25 cm at BH-661 variety while the lowest grain yield (5.71 $t{\cdot}ha^{-1}$) was obtained at wider inter and intra row spacing combination (85 cm X 35 cm) in BH-540 (Table 4.14). A statistically at par to the highest grain yield (10.9 $t{\cdot}ha^{-1}$) which was obtained in BH-661 with spacing of 65 cm X 30 cm (Table 4.14). The result observed for the two varieties revealed that the blanket recommendation of 75 cm X 30 cm is not an appropriate to insure better grain yield of maize. The higher grain yield for variety BH-661 could be due to its tallness as well as its late maturity which had a better chance to utilize more nutrients and more photosynthetic activity, which ultimately resulted in higher yield production. The possible reason for the lowest grain yield at widest spacing might be due to the presence of less number of plants per unit. This indicated that low plant density per unit area that could get better available growth factors like moisture, nutrients, light, and space could not offset the grain yield obtained from high plant density per unit area. This might be due to the fact that high plant population ensured early canopy coverage and maximized light interceptions facilitating better crop growth, development and biomass resulting in increased yield of maize. Previous research findings also indicated that plants grown on wider spacing absorb more nutrients and solar radiation for improved photosynthesis and hence produce better grain yield on an individual basis but yield per unit area reduced due to a low plant stand (Borras *et al.,* 2003).

In addition, this increase in maize grain yield under decreased inter- and intra-row spacings might be due to the efficient utilization of available resources and also because of planting density-induced increase of leaf area index, light interception and photosynthesis (Farina *et al.,* 2015). This findings, is in agreement with Eskandarnejada *et al.* (2013) reported that higher grain yield of maize (15.25 t ha^{-1}) was obtained from narrower (55 cm X 20 cm) spacing combination than the wider (75 cm X 30 cm) spacing combination which yielded 11.43 t ha^{-1}. Shrestha (2013) also reported that grain yield (5.11 t. ha^{-1}) under 60 cm X 25 cm spacing was significantly higher than that of 60 X 30 cm spacing but that was at par with the yield obtained from 60 X 20 cm spacing. A similar trend in yield increments with increasing plant density has been observed by Mukhtar *et al.* (2012) reported that the highest grain yield of 8.37 t.ha^{-1} produced under narrower spacing of 12.5 cm X 70 cm, while the lowest grain yield of 6.65 t ha^{-1} was recorded from 17.5 cm X 70 cm spacing combination.

Table 4.14. Mean grain yield (t. ha^{-1}) of maize as affected by the three ways interaction effect of varieties, inter and intra row spacing

		Intra row spacing		
Variety	Inter row spacing	25	30	35
BH-540	65	10.82^{ab}	10.26^{bc}	8.73^{de}
	75	9.72^{d}	7.85^{fgh}	8.03^{fg}
	85	7.45^{hi}	7.03^{i}	5.71^{j}
BH-661	65	11.39^{a}	10.9^{a}	10.046^{c}
	75	10.046^{c}	8.69^{de}	9.033^{d}
	85	7.52^{ghi}	8.32^{ef}	7.58^{ghi}
LSD	0.56***			
CV	2.1			
SE±	0.15			

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance. LSD= least significance difference, SE= standard error, ***=very highly significant (p<0.001).*

4.3.11 Harvest index (%)

The analysis of variance revealed the harvest index significantly affected by the main effect was very highly significant ($p<0.001$) and their interaction effects of inter and intra row spacings, variety × intra row spacing and variety × inter× intra row spacing were very highly significant ($p<0.001$) (Appendix Table 4).

The highest harvest index (39.92%) was obtained from variety BH-661 in 75 cm X 35 cm while statistically equivalent harvest indices were observed from combinations of 85 cm X 30 cm and 65 cm X 35 cm while the lowest harvest index (23.95%) was attained from variety BH-540 in 85 cm X 35 cm (Table 4.15). The highest harvest index for variety BH-661 could be due to the fact that variety BH-661 had effective utilization of growth factors like moisture, nutrients, light, and space when there is adequate rainfall resulted in high photosynthesis activity and thereby to high partitioning of photosynthate into grain yield as compared to variety BH-540. In agreement with this result Bismillah *et al.* (2002) reported that the harvest index varied significantly among different cultivars of maize.

Table 4. 15.Mean harvest index of maize as affected by the three ways interaction effect of varieties, inter and intra row spacing

Variety	Inter row spacing	Intra row spacing		
		25	30	35
BH-540	65	33.57[b]	32.66[bc]	28.32[cde]
	75	31.58[bcd]	24.94[e]	27.63[de]
	85	30.12[bcd]	27.7[de]	23.95[e]
BH-661	65	33.40[b]	32.05[cbd]	39.86[a]
	75	32.9[b]	32.75[b]	39.92[a]
	85	31.04[cbd]	39.5[a]	33.06[b]
LSD	4.41***			
CV	4.51			
SE±	1.17			

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV= coefficient of variance, LSD= least significance difference, SE= standard error, ***=highly significant (p<0.001).*

4.4 Pearson's Correlation Analysis among Phenology, Growth Parameters and Yield Components of Maize

Grain yield is the end result of many complex morphological and physiological processes occurring during the growth and development of the crop. Correlation is used to describe and measure the strength and direction of relationship between variables. The correlation coefficient (r) analysis indicated that grain yield was significantly and positively correlated with plant height (r = 0.47**), leaf area index (r = 0.63***), thousand grain weight (r=0.3*), harvest index (r = 0.5***) and above ground dry biomass yield (r = 0.65***) (Table 4.16). In line with these results, Saleem *et al.* (2007) also reported a positive and significant correlation between plant height and biomass yield. However, it was significantly and negatively correlated with stand count percent (r = -0.41**), number of ear per plant (r=-0.32**), number of grain rows per ear (r = -0.34*) and number of grains per row (r =-0.59***). It was also observed that leaf area index (r = 0.41**) showed positive and significant correlation with the above ground dry biomass yield. This might be due to the fact that increasing row and plant spacing,s decreased plant population and provided better opportunity for crops to utilize available resources with less competition.

Phenological parameters like days to 50% tasseling (r =0.54***), days to 50% silking (r = 0.52***) and days to 90 % physiological maturity (r=0.72***) exhibited a positive and significant correlation with plant height. In tune with the findings of Beyene Yoseph *et al*. (2005) reported a positive and significant correlation between days to tasseling, days to silking and days to physiological maturity. Generally, grain yield in maize production is highly influenced by growth and yield related parameters which can be enhanced by optimizing proper inter- and intra-row spacing and also better variety selection that ultimately would increase grain yield of maize.

Table 4. 16.Pearson's Correlation coefficient (r) among phenology, growth and yield related parameters of maize during 2019 cropping season

	DT	DS	DPM	PH	LAI	SCP	EH	ED	NEPP	NGRPE	NGPR	NKPE	EL	TSW	GY	DB	HI
DT	1																
DS	0.91***	1															
DPM	0.73***	0.65***	1														
PH	0.54***	0.52***	0.72***	1													
LAI	0.34**	0.43**	0.36**	0.45**	1												
SCP	0.12^{ns}	0.05^{ns}	0.27*	0.047^{ns}	-0.21^{ns}	1											
EH	0.54***	0.52***	0.67***	0.77***	0.44**	0.022^{ns}	1										
ED	0.71***	0.62***	0.9***	0.59***	0.11^{ns}	0.37**	0.61***	1									
NEPP	0.1^{ns}	0.022^{ns}	0.1^{ns}	0.029^{ns}	-0.065^{ns}	0.26^{ns}	0.092^{ns}	0.25^{ns}	1								
NGRPE	0.11^{ns}	0.091^{ns}	0.32*	0.2^{ns}	-0.25^{ns}	0.36**	0.19^{ns}	0.48**	0.17^{ns}	1							
NGPR	0.3*	0.28*	0.35**	0.12^{ns}	-0.35**	0.45**	0.15^{ns}	0.59**	0.31*	0.53***	1						
NKPE	0.4**	0.31*	0.59***	0.37**	-0.03^{ns}	0.36**	0.37**	0.67***	0.38**	0.63***	0.45**	1					
EL	0.4**	0.33*	0.57***	0.45**	-0.14^{ns}	0.35**	0.33*	0.7***	0.46**	0.51***	0.53***	0.58***	1				
TSW	-0.43**	-0.47**	-0.33*	-0.16^{ns}	-0.35**	0.15^{ns}	-0.2^{ns}	-0.28*	0.33*	0.01^{ns}	0.048^{ns}	-0.15^{ns}	0.052^{ns}	1			
GY	0.21^{ns}	0.25^{ns}	0.22^{ns}	0.47**	0.63***	-0.41**	0.38**	-0.075^{ns}	-0.32*	-0.34*	-0.59***	-0.15^{ns}	-0.14ns	0.3*	1		
DB	-0.14^{ns}	-0.063^{ns}	-0.28*	0.12^{ns}	0.41**	-0.5***	0.026^{ns}	-0.53***	-0.29*	-0.43**	-0.67***	-0.43**	-0.46**	-0.057^{ns}	0.65***	1	
HI	0.45**	0.41**	0.6***	0.45**	0.3*	0.033^{ns}	0.43**	0.51**	-0.077^{ns}	0.038^{ns}	0.032^{ns}	0.28*	0.34*	-0.32*	0.5***	-0.3*	1

DT=days of50% tassling, DS=days of 50% silking, DPM= days of 90% physiological maturity, PH=plant height, LAI=leaf area index, SCP=stand count percent, EH=ear height, ED=ear diameter NEPP= number of ear per plant, NGRPE=number of grain rows per ear, NGPR=number of grains per row, NKPE=number of kernels per ear, EL=ear length, TSW=thousand seed weight, GY=grain yield, AGDBMY=above ground dry biomass yield, HI=harvest index and ns=non -significant.

4.5 Economic Analysis

Economic analysis was performed to know the economic feasibility of different variety, inter- and intra-row spacing combinations (treatments). The analysis of budget summary indicated that the highest net return (Birr 90408.75 ha^{-1}) was obtained from BH-661 at 65 cm× 25 cm spacing, with marginal rate of return greater than one hundred (MRR > 100), while the minimum net return (Birr 60841.25ha^{-1}) was recorded from BH-661 at 85 cm *X* 35 cm spacing (Table 4.17).

Table 4. 17. Partial budget analysis of variety, inter- and intra-row spacings of maize production

Variety	Spacing	AGY ton/ha	ASTY ton/ha	AGY birr/ha	ASTY birr/ha	SC ETB	PC ETB	TVC	TR	NR	MRR
BH661	85*35	6.82	13.87	61398	3467.25	524	3500	4024	64865.25	60841.25	
BH540D	85*35	5.14	16.34	46251	4086.00	624	3500	4124	50337.00	46213.00	
BH661	75*35	8.13	12.23	73167.3	3057.08	594	4000	4594	76224.38	71630.38	5407.95
BH540D	75*35	7.23	18.99	65043	4747.50	707	4000	4707	69790.50	65083.50	
BH661D	85*30	7.49	11.49	67392	2873.25	611	4100	4711	70265.25	65554.25	
BH540D	85*30	6.33	16.53	56943	4133.25	728	4100	4828	61076.25	56248.25	
BH661	65*35	9.04	13.66	81324	3415.50	683	4400	5083	84739.50	79656.50	9179.70
BH661D	75*30	7.82	16.08	70389	4020.75	693	4500	5193	74409.75	69216.75	
BH540D	65*35	7.86	19.94	70713	4986.00	816	4400	5216	75699.00	70483.00	
BH540D	75*30	7.07	21.29	63585	5323.50	852	4500	5352	68908.50	63556.50	
BH661D	85*25	6.77	15.05	60912	3762.00	734	4900	5634	64674.00	59040.00	
BH540D	85*25	6.71	15.58	60345	3894.75	874	4900	5774	64239.75	58465.75	
BH661	65*30	9.81	20.81	88290	5202.00	800	5100	5900	93492.00	87592.00	23116.07
BH540D	65*30	9.23	19.07	83106	4767.75	952	5100	6052	87873.75	81821.75	
BH661D	75*25	9.04	18.51	81324	4628.25	832	5300	6132	85952.25	79820.25	
BH540D	75*25	8.75	18.97	78732	4743.00	990	5300	6290	83475.00	77185.00	
BH661	65*25	10.25	20.44	92259	5109.75	960	6000	6960	97368.75	90408.75	1973.69
BH540D	65*25	9.74	19.30	87642	4824.00	1143	6000	7143	92466.00	85323.00	

AGY=adjusted grain yield, ASTY=adjusted stover yield, SC=seed cost, PC=planting cost, TVC=total variable cost, TR= total revenue, NR=net revenue, MRR= marginal rate of return, D=dominance, ETB= Ethiopia birr.

Chapter 5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The results depicted that the main effect of variety had a significant effect on all parameters of maize hybrids except stand count percent and number of ears per plant. The results obtained from the experiment had showed that maize crop phenological parameters like days to 50% tasseling, days to 50% silking and days to 90% physiological maturity was highly significantly affected by the main effects of variety. However, their interaction effect was not significant. The analysis of variance revealed that the main effects due to varieties and intra-row spacings on ear height was highly significant, while the interaction effect of the two factors was not significant. Similarly, the results showed highly significantly differences on growth parameters such as plant height and leaf area index due to the main effects of variety, inter- and intra-row spacing. Both growth parameters were increased with decreasing inter- and intra-row spacing from 85 cm to 65 cm, and from 35 cm to 25 cm, respectively. The maximum mean plant height and leaf area index were obtained from the narrowest (65 cm and 25 cm) inter- and intra-row spacing, respectively, while the minimum was at the widest, i.e. 85 cm and 35 cm inter- and intra-row spacing, respectively. The maximum mean plant height and leaf area index was obtained from variety BH-661.

Variety and inter- row spacing had highly significant effect on ear length, number of grain rows per ear and number of kernels per ear. All these yield parameters were increased with increasing inter-row spacing. The maximum mean values of these yield parameters were recorded at the widest inter- row spacing of 85 cm, while the minimum mean values of these parameters were recorded from the narrowest inter- row spacing of 65 cm. Variety, inter- row spacing and intra row spacings had highly significant effect on number of grains per ear, ear diameter, above dry biomass yield and grain yield. Harvest index also highly significant affected by variety and inter row spacings and significantly by intra row spacings.

The highest grain yield and above ground dry biomass was recorded from BH-661 at 65 cm *X* 25 cm spacing, while the lowest mean grain yield and above ground dry biomass was recorded at 85 cm *X* 35 cm and 85 cm *X* 30 cm spacing combinations of variety BH-540 and BH-661, respectively. The analysis of budget summary indicated that the highest net return was obtained from BH-661 at spacing of 65 cm *X* 25, with marginal rate of return greater than 100%, while the minimum net return was recorded from BH-661 at 85 *X* 35 cm spacing.

Overall results from the present finding indicated that it can be concluded that optimum inter and intra row spacing combination for the maximum grain yield was 65 cm *X* 25 cm at BH-661 variety in the study area.

5.2 Recommendations

- ✓ From the results obtained it is clear that the national or blanket recommended inter-row spacing of 75 cm and intra-row spacing of 30 cm is not satisfactory for the maize hybrid BH-540 and BH-661 productivity. Therefore, 65 cm X 25 cm inter- and intra-row spacing combination is suitable and recommendable for achieving maximum profit of maize hybrid BH-661 in the study area and similar agro-ecologies.
- ✓ However, as these results was based on only one growing season and single location, it requires confirmation with further studies to be conducted across different seasons at multi locations with different varieties to come up with more reliable a conclusive recommendation.

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APPENDICES

LIST OF APPENDIX TABLES

Appendex Table 1.Mean square values of ANOVA for phenological parameter of maize as affected by inter, intra-row spacing and varieties

Source of variation	DF	Mean squares		
		Days to 50% tassling	Days to 50% silking	Days to 90% maturity
Replication	2	10.12	23.90	10.90
PS	2	4.24^{ns}	1.79^{ns}	0.074^{ns}
RS	2	2.57^{ns}	2.29^{ns}	10.01^{ns}
V	1	384.00 **	236.46**	3601.50**
RS*PS	4	1.29^{ns}	2.10^{ns}	1.96^{ns}
V*PS	2	9.05^{ns}	7.01^{ns}	3.55^{ns}
V*RS	2	13.38^{ns}	6.74^{ns}	4.05^{ns}
V*RS*PS	4	0.44^{ns}	4.71^{ns}	6.44^{ns}
Error	34	5.20	3.80	7.16
CV		2.65	2.12	1.76
SE±		1.86	1.59	2.18

*PS=plant spacing, RS=row spacing, V=variety, DF= degree of freedom, CV=coefficient of variance, SE=standard error, ns=Non significant, ** Significant at 1% of probability (p<0.01).*

Appendex Table 2.Mean square values of ANOVA for growth parameter of maize as affected by inter, intra row spacing and variety

		Mean square		
Source of variation	DF	Plant height(cm)	Ear height(cm)	Leaf area index
Replication	2	497.32	108.73	3.82
PS	2	755.8*	1155.14*	3.79**
RS	2	546.22*	104.82^{ns}	5.38**
V	1	15076.76**	18114.08**	6**
RS*PS	4	317.76^{ns}	616.77^{ns}	0.35^{ns}
V*PS	2	206.63^{ns}	25.36^{ns}	0.035^{ns}
V*RS	2	74.42 ^{ns}	635.44^{ns}	1.27*
V*RS*PS	4	313.3^{ns}	116.06^{ns}	0.6***
Error	34	149.98	267.83	0.39
CV		5.41	15.03	17.7
SE±		9.99	13.36	0.5

*PS=plant spacing, RS=row spacing, V=variety, DF= degree of freedom, CV=coefficient of variance, SE=standard error, ns=Non significant, ** Significant at 1% of probability (p<0.01), *Significant at 5% probability (p<0.05).*

Appendex Table 3.Mean square values of ANOVA for yield components of maize as affected by inter, intra row spacing and variety

Source of variation	DF				Mean square		
		SCP	NEPP	NGRPE	NGPE	NKPE	EL
Block	2	5.04	0.13	0.153	1.17	740.28	3.18
PS	2	36.14^{ns}	0.011^{ns}	0.02^{ns}	15.38**	327.36^{ns}	3.87*
RS	2	192.96*	0.15*	4.1**	111.38***	9837.75**	11.57***
V	1	71.87^{ns}	0.015^{ns}	2.72*	51.23***	33680.036***	48.46***
RS*PS	4	6.69^{ns}	0.035^{ns}	0.8^{ns}	1.1^{ns}	1799.65^{ns}	1.61^{ns}
V*PS	2	8.72^{ns}	0.00055^{ns}	0.23^{ns}	3.089^{ns}	674.94^{ns}	1.65^{ns}
V*RS	2	8.5^{ns}	0.0038^{ns}	0.25^{ns}	8.29^{ns}	428.033^{ns}	0.98^{ns}
V*RS*PS	4	7.32^{ns}	0.021^{ns}	0.12^{ns}	0.48^{ns}	1348.73^{ns}	1.87^{ns}
Error	34	37.86	0.026	0.34	2.53	809.87	0.93
CV		6.83	11.76	4.4	3.94	5.41	4.42
SE±		5.02	0.13	0.47	1.30	23.23	0.78

*PS=plant spacing, RS=row spacing, V=variety, DF= degree of freedom, SCP= stand count percent, NEPP=number of ear per plant, NGRPE=number of grain rows per ear, NGPE= number of grains per ear, NKPE=number of kernel per ear, EL= ear length, CV= coefficient of variance, SE=standard error, ns=Non significant, *** Highly significant at 0.1% of probability (p<0.0001), ** Significant at 1% of probability (p<0.01), *Significant at 5% probability (p<0.05).*

Appendex Table 4.Mean square values of ANOVA for yield and yield components of maize as affected by inter, intra row spacing and variety

Source of variation	DF	Mean square				
		TGW	ED	GY	AGDBY	HI
Replication	2	12190.38	0.00082	0.0068	0.58	1.22
PS	2	2015.72^{ns}	0.0068***	7.63***	63.76**	1.59^{ns}
RS	2	12744.66*	0.061***	43.00***	266.053**	27.77***
V	1	37815.57**	0.81***	10.42***	57.66**	486.96***
RS*PS	4	6809.88*	0.000018^{ns}	1.65***	11.69**	40.39***
V*PS	2	395.12^{ns}	0.000096^{ns}	1.30^{ns}	25.257**	119.17***
V*RS	2	76.74^{ns}	0.00066^{ns}	0.15^{ns}	13.61^{ns}	19.53^{ns}
V*RS*PS	4	9444.29**	0.00022^{ns}	0.20***	14.39***	22.83***
Error	34	2389.27	0.000251	0.034	1.2	2.08
CV		11.98**	0.36	2.1	3.93	4.51
SE±		39.91	0.013	0.15	0.89	1.17

*PS=plant spacing, RS=row spacing, V=variety, DF=degree of freedom, TGW=thousand grain weight, ED=ear diameter, GY=grain yield, AGDBY=above ground dry biomass, HI=harvest index, CV= coefficient of variance, SE=standard error, ns=non significant, *** Highly significant at 0.1% of probability (p<0.0001), ** Significant at 1% of probability (p<0.01), *Significant at 5% probability (p<0.05).*

Appendex Table 5.The main effects of intra row, inter row spacing and varieties on leaf area index parameters of maize

Treatments	Leaf area index
Variety	
BH-540	3.19[b]
BH-661	3.86[a]
LSD	0.24**
Inter row spacing (cm)	
85	2.91[b]
75	3.69[a]
65	3.97[a]
LSD	0.35**
Intra row spacing (cm)	
35	3.20[b]
30	3.32[b]
25	4.05[a]
LSD	0.35**
SE±	0.35
CV	12.41

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, SE=standard error, ** Significant at 1% of probability (p<0.01), LSD=least significant difference.*

Appendex Table 6.The main effects of inter row spacing and varieties on thousand seed weight component parameters of maize

Treatments	Thousand grain weight
Varieties	
BH-540	434.41[a]
BH-661	381.48[b]
LSD	23.54**
Inter row spacing	
85	437.83[a]
75	399.17[b]
65	386.83[b]
LSD	34.77*
SE±	34.76
CV	10.43

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, SE=standard error, ** Significant at 1% of probability (p<0.01), *Significant at 5% probability (p<0.05), LSD=least significant difference.*

Appendex Table 7.The main effects of intra row, inter row spacing and varieties on yield and yield components parameters of maize

Treatments	Grain yield	Aboveground dry biomass yield	Harvest index
Variety			
BH-540	8.4[b]	28.9[a]	28.94[b]
BH-661	9.28[a]	26.83[b]	34.94[a]
LSD	0.1***	0.61**	0.8***
Inter row spacing (cm)			
85	7.27[c]	23.72[c]	30.89[c]
75	8.89[b]	28.54[b]	31.62[b]
65	10.36[a]	31.32[a]	33.31[a]
LSD	0.15***	0.9**	1.19***
Intra row spacing (cm)			
35	8.19[c]	25.79[c]	32.12[a]
30	8.84[b]	28.34[b]	31.6[a]
25	9.49	29.46[a]	32.11[a]
LSD	0.15***	0.9**	1.19[ns]
SE±	0.33	0.9	0.017
CV	2.15	3.99	4.57

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, SE=standard error, ** Significant at 1% of probability (p<0.01), LSD=least significant difference.*

Appendex Table 8. Mean leaf area index of maize as affected by the interaction effect of varieties and inter row spacing

Variety	Inter row spacing (cm)		
	65	75	85
BH-540	4.28^{a}	3.09^{ab}	2.84^{b}
BH-661	4.30^{a}	3.64^{ab}	2.98^{ab}
LSD	1.38*		
CV	17.7		
SE±	1.68		

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, SE=standard error, *Significant at 5% probability (p<0.05), LSD=least significant difference.*

Appendex Table 9.Mean of thousand seed weight maize as affected by the interaction effect of inter and intra row spacing

	Intra row spacing(cm)		
Inter row spacing (cm)	25	30	35
65	432.17^{ab}	368.33^{ab}	360.00^{b}
75	379.67^{ab}	392.00^{ab}	425.83^{ab}
85	447.67^{ab}	503.00^{a}	412.83^{ab}
LSD	125.23*		
CV	11.98		
SE±	41.02		

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, SE=standard error, *Significant at 5% probability (p<0.05), LSD=least significant difference.*

Appendex Table 10.Mean of grain yield maize as affected by the interaction effect of inter and intra row spacing

	Intra row spacing (cm)		
Inter row spacing (cm)	25	30	35
65	11.09[a]	10.08[b]	9.38[cd]
75	9.88[bc]	8.27[ef]	8.53[de]
85	7.48[fg]	7.67[ef]	6.64[g]
LSD	1.021***		
CV	2.17		
SE±	0.37		

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, SE=standard error, *** Significant at 0.01% of probability (p<0.0001), LSD=least significant difference.*

Appendex Table 11.Mean of above dry biomass yield maize as affected by the interaction effect of inter and intra row spacing

	Intra row spacing (cm)		
Inter row spacing (cm)	25	30	35
65	33.18[a]	32.74[ab]	28.06[de]
75	30.7[bc]	29.04[dc]	25.87[ef]
85	24.5[fg]	23.24[g]	23.43[g]
LSD	2.35**		
CV	3.93		
SE±	0.86		

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, SE=standard error, ** Significant at 1% of probability (p<0.01), LSD=least significant difference.*

Appendex Table 12.Mean of harvest index maize as affected by the interaction effect of inter and intra row spacing

	Intra row spacing (cm)		
Inter row spacing (cm)	25	30	35
65	28^{c}	32^{bc}	34^{ab}
75	32^{bc}	28^{bc}	33^{ab}
85	30^{bc}	33^{abc}	38^{a}
LSD	5.1***		
CV	4.9		
SE±	0.21		

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, SE=standard error, *** Significant at 0.01% of probability (p<0.0001), LSD=least significant difference.*

Appendex Table 13. Mean above dry biomass yield of maize as affected by the two ways interaction effect of varieties and intra row spacing

	Intra row spacing (cm)		
Variety	25	30	35
BH-540	31.53^{a}	30.48^{a}	24.67^{c}
BH-661	31.12^{a}	26.6^{b}	22.77^{d}
LSD	1.51**		
CV	3.81		
SE±	0.81		

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, SE=standard error, ** Significant at 1% of probability (p<0.01), LSD=least significant difference.*

Appendex Table 14. Mean harvest index of maize as affected by the two ways interaction effect of varieties and intra row spacing

	Intra row spacing (cm)		
Variety	25	30	35
BH-540	32^{b}	27^{c}	27^{c}
BH-661	37^{a}	35^{ab}	34^{ab}
LSD	3.6***		
CV	3.5		
SE±	0.34		

*Means in columns followed with the same letter(s) are not significantly different at 5% level of probability. CV=coefficient of variance, SE=standard error, ** Significant at 1% of probability (p<0.01), LSD=least significant difference.*

Appendex Table 15. Factorial combinations of inter, intra-row spacing and varieties which combined to evaluate yield and yield components of maize

Treatment	Variety	Inter row spacing (cm)	Intra spacing (cm)	Inter row spacings by intra row spacings (cm)	Plant populations number
T1	BH-540	65	25	65 X 25	61538
T2	BH-540	65	30	65 X 30	51282
T3	BH-540	65	35	65 X 35	43956
T4	BH-540	75	25	75 X 25	53333
T5	BH-540	75	30	75 X 30	44444
T6	BH-540	75	35	75 X 35	38095
T7	BH-540	85	25	85 X 25	47058
T8	BH-540	85	30	85 X 30	39215
T9	BH-540	85	35	85 X 35	33613
T10	BH-661	65	25	65 X 25	61538
T11	BH-661	65	30	65 X 30	51282
T12	BH-661	65	35	65 X 35	43956
T13	BH-661	75	25	75 X 25	53333
T14	BH-661	75	30	75 X 30	44444
T15	BH-661	75	35	75 X 35	38095
T16	BH-661	85	25	85 X 25	47058
T17	BH-661	85	30	85 X 30	39215
T18	BH-661	85	35	85 X 35	33613

Appendix Table 16.Layout and randomization of treatments

1 m

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
T9	T8	T4	T14	T17	T7	T1	T13	T5	T3	T2	T12	T16	T11	T6	T10	T18	T15

Replication -1-

1.5 m

16.5m

36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19
T1	T9	T15	T8	T4	T6	T14	T12	T17	T2	T7	T18	T3	T10	T16	T5	T11	T13

Replication-2-

1.5 m

37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
T3	T9	T12	T13	T8	T4	T11	T14	T18	T16	T5	T15	T10	T1	T7	T17	T6	T2

Replication-3-

63 m

Gross plot: 4.5 m x 2.5 m=11.25m²

Plot23

(Treatment 10)

LIST OF APPENDIX FIGURES

Appendix Figure 1.Pictures taken during planting

Appendix Figure 2.Pictures taken during the growing season of maize BH-540

Appendix Figure 3. Pictures taken during the growing season of maize BH-661

Appendix Figure 4.Pictures taken at fertilizer application

Appendix Figure 5.Pictures taken at maturity stage of maize

Appendix Figure 6.Pictures taken at harvesting of maize

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The author, Simachew Kassahun, was born on January 23, 1995 in Guagusa shikudad district, Awi Administration Zone of Amhara Region, Ethiopia. He attended his elementary and Junior Secondary education at Askuna, Kili mesk and Hibret from 2002 to 2009. He completed secondary and preparatory education at Tilili Secondary and Preparatory School from 2010 to 2013. In 2014, he joined Bahir Dar University and graduated in Bachelor of Science degree in Agriculture (Plant Science) on July 2, 2016. Upon graduation, he was join to Duruman Private College in Benshangul Gumez Region as a lecturer in crop production for one year, after that unemployed for a month and in the scholarship sponsor of Bahir Dar University he joined on October 2018 Bahir Dar University to study the Degree of Master Science in Agronomy. Now he joins Gonder Agricultural Research Center in June 2019 and working as junior researcher.