EFFECT OF INTER AND INTRA ROW SPACING ON YIELD COMPONENTS AND YIELD OF MAIZE (*Zea mays* L.) AT CHINAKSEN, EASTERN ETHIOPIA

M.Sc. THESIS

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We hereby certify that we have read and evaluated this thesis prepared under our guidance, by Tahir Daud, entitled "**Effect of Inter and Intra Row Spacing on Yield Components and Yield of Maize** (*Zea mays L.*) **at Chinaksen, Eastern Ethiopia**". We recommend that it be submitted as fulfilling the requirements.

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As members of the Board of Examiners of the M.Sc. Thesis open defence examination, we certify that we have read and evaluated the thesis prepared by Tahir Daud and examined him. We recommended that the thesis is accepted as it fulfills the requirements for the Degree of Master of Science in Agriculture (Agronomy).

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DEDICATION

I dedicate this thesis to my wife Ayan Abdi and my whole family members for they have encouraged me with care and fondness and paved me the way towards pursuing my master's degree thereby contributing enormously to the success of my study.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is a result of my own work and I have duly acknowledged all sources of materials used for thesis.
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BIOGRAPHICAL SKETCH

The author, Tahir Daud, was born in eastern Hararge, Chinaksen District in 1984. He attended his Elementary and Junior Secondary Schools at Chinaksen Primary and Junior Secondary School from 1995-2000 and High School education at Jigjig senior Secondary School from 2001-2002. After successful completion of High School education, he joined Alage Agricultural TVET College in 2003 to pursue his Diploma and graduated with Diploma in plant science on July 31, 2005. Then after, he was recruited by employed by Chinaksen District Agro-pastoral Development Office in eastern Hararge Zone, Oromia Regional state in Crop department as advisor development agents. After two year of service he joined Ambo University to continue his undergraduate study in crop production. When he graduated July16, 2009 he was employed in Chinaksen District Pastoral Development Office in eastern Hararge Zone, Oromia Regional State as head officer. After serving that position for nine years, he joined Haramaya University in October 2018, Postgraduate program, to pursue his M.Sc. degree in Agronomy.

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LISTS OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agency
CSA	Central Statistical Agency
DAP	Di-ammonium Phosphate
EARO	Ethiopian Agriculture Research Organization
EIAR	Ethiopian Institute of Agricultural Research
FAOSTAT	Food and Agriculture Organization Statistics
m.a.s.l	Meter Above Sea Level

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ABSTRACT

Maize production plays vital role for the producers of the study area in serving as staple food. However, its productivity is constrained by a number of factors out of which optimum spacing is among the most important production factors. The Objective of the experiment was to investigate the influence of inter and intra-row spacing on yield components and grain yield of maize in 2019 cropping season at Chinaksen, East Hararghe Zone, eastern Ethiopia. The experiment was arranged in a factorial combination of the four inter-rows (55, 65, 75 and 85 cm) spacing and three intra-row spacing (25, 30, and 35 cm) spacing which were laid out in RCBD with three replication using maize (Zea mays L.) Melkassa-II variety. The results obtained had shown that there was highly significant (P<0.01) main effect of inter-row spacing on plant height, leaf area, leaf area index, number of ears per plant, number of kernels per ear, above ground dry biomass yield per hectare and harvest index while thousand kernel weight was significantly (P< 0.05) affected by inter and intra-row spacing. The highest mean plant height (155.6 cm), leaf area (7287cm^{2}), number of ears per plant (1.32), number of kernels per ear (540.4) and harvest index (40.5) which were obtained from widest inter row spacing of 85 cm while the highest above ground dry biomass yield per hectare (14704 kg^{-1}) and leaf area index (3.687) were obtained from the narrowest inter row spacing of 55 cm. The highest mean thousand kernel weight (348.6) was obtained from widest inter row spacing of 85 cm while the highest mean thousand kernel weight (347) was obtained from widest intra-row spacing of 35 cm. Highly significant difference due to the main effects of intra-row spacing was observed on all the above parameters except plant height, number of ears per plant and harvest index which was significant (P< 0.05). There was highly significant interaction effect of inter-row by intra-row spacing on stand count percent, ear length and grain yield per hectare. The highest plant stand count percentage (97.87%), ear length (27.2 cm) and grain yield (5594 kg^{-1}) were recorded from 85 x 35 cm, 85 x 35 cm and 55 cm x 25 cm inter and intra-row spacing combinations respectively. In general, significantly higher grain yield was obtained due to closer spacing. Therefore it can be concluded that spacing combinations of 55 x 25 cm responded favorably in attaining higher grain yield of maize in the study area.

Keywords: Plant density, Phenology, Population, Yield, Yield components.

1. INTRODUCTION

Maize (*Zea mays* L.) is an important grain crop of the world and it ranks second, after wheat in hectarage (187,959,116 ha) and first in total production (1,060,107,470 MT) and productivity (5.64 t ha^{-1}) (FAOSTAT, 2016). It is recognized worldwide as a strategic food and feed crop that provides an enormous amount of protein and energy for humans and livestock.
Although much of the world's maize production is utilized for animal feed, human consumption in many developing and developed countries is steadily increasing. It is the most important cereal crop for food in sub-Saharan Africa and Latin America. Between 2010 and 2050, the demand for maize in the developing world will double, and by 2025, maize is likely to become the crop with the greatest production globally (Rosegrant *et al.,* 2010).

Maize is used in many ways than any other cereals. It is used as human food, feed for livestock and industrial purposes (Dowswell *et al.*, 1996). It is also used for making local beverages. Additionally, the leaves and dry biomass are used to feed animals and the stalks are used for construction and fuel. The green fodder from thinning and topping is important source of animal feed and the dry fodder is used during the dry season. Moreover, the crop has potential uses for industrial purposes, serving as a starch, a sweetener for soft drinks, an input for ethanol fuel production and oil extraction (EARO, 2000).

In Ethiopia, maize has increasingly become a popular crop in the country with steady growth in production area and yield (Doss *et al.*, 2003). It is Ethiopia's leading cereal in produced in by about 10.9 million farmers across about 2.1 million hectares of land in 2017*Meher* season (CSA, 2017). As compared to other cereals maize can attain the highest potential yield per unit area. World average yield for maize is about 4.5 tons ha^{-1} and that of developed countries is 6.2 tons ha^{-1} while the average yield in developing countries is 2.5 tons ha^{-1}. In Ethiopia the national average yield is about 3.68 tons ha^{-1} (CSA, 2017).

It grows under a wide range of environmental conditions between 500 to 2400 meters above sea level. The mid altitude, sub-humid agro-ecology is the most important maize producing environment in Ethiopia (Birhane and Bantayehu, 1989; Kebede *et al.,* 1993). It is mainly grown in the four big regions of the country: Oromia, Amhara, Southern Nations, Nationalities and Peoples' Region and Tigray. Oromia and Amhara contribute to almost eighty percent of the maize produced.

Maize is the second important cereal crop in area coverage and production following sorghum, but first in productivity among the cereal crops in East Hararghe Zone (CSA, 2018). Maize covered an area of about 43,078.05 ha; production of grain was 110,612 tons with an average grain yield of 2.57 tons ha^{-1} in the Zone (CSA, 2018).

Even though maize has multiple purposes and high yielding potential, the national average yield (3.67 tons ha^{-1}) in general and the zonal yield (2.57 tons ha^{-1}) are low as compared to developed countries' average yield which is about 6.2 tons ha^{-1} (ATA, 2014). The low productivity of maize is attributed to many factors such as poor agronomic practices like inappropriate seed rate, row and plant spacing, poor soil fertility, drought, insects, diseases and weeds, farmers' limited access to fertilizers, and low access to seeds of improved maize varieties (Shiferaw *et al., 2*011*)*.

While significant gains have been made in maize production over the past decade, there remains large potential to increase productivity. Low productivity of maize in Ethiopia is due to several constraints: biotic (inadequate improved varieties, pests and diseases), abiotic (low soil fertility, land and water degradation, and drought) and socio-economic (input unavailability, lack of storage facility, poor access to markets and lack of appropriate agronomic practices) (CSA, 2010).

Plant density is one of the factors that affect yield by influencing yield components such as the number of ears, the number of kernels per ear, and kernel mass (Ahmadi *et al.*, 1993*)*. Moreover, grain yield of maize is more affected by variations in plant population than other members of the grass family because of its low tillering ability (Sangoi *et al.,* 2002*)*.

Therefore, plant density and arrangement of plants in a unit area greatly determine resource utilization such as light, nutrients, and water; it affects the rate and extent of vegetative growth and development of crops particularly that of leaf area index, plant height, root length and density, yield and yield components, development of important diseases and pests, and the seed cost (Jettner *et al., 1998)*. Because of this discrepancy, the establishment of required plant density is essential to get maximum yield since high plant density will deplete soil moisture and nutrients before the crop's maturity, whereas low plant density will leave nutrients unutilized. Hence, optimum density will lead to the effective utilization of soil moisture and nutrients, etc. (Chandrasekaran *et al.,* 2010*)*. 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*)*.

In order to fully explore its capacity, it is necessary to understand how plants interact morphologically and physiologically in a community of the plant and to identify management practices which allow them to maximize the use of growth resources in their environment. Among agronomic practices, spacing deserves special attention. Optimum inter- and intra-row spacing varies with soil fertility status, soil moisture, the nature of the crop and degree of weed infestation (Singh *et al.*, 1997). Andrade *et al.,* (2002) described that both too narrow and too wide spacing do affect grain yields through competition (for nutrients, moisture, air, radiation, etc) and due to the effect of shading. In the latter case (too wide spacing), yield reduction can occur due to inefficient utilization of the growth factors. Normally, as population increases yield also increases proportionally and after it reaches a certain level, the yield declines. A number of factors also influence spacing: fertility status of the soil, moisture availability, growth pattern of the crop and cultural practices; hence, optimum planting density should be determined through conducting experiments. Singh and Singh (2002) described that under Conditions of sufficient soil moisture and nutrients, higher population is necessary to utilize all the growth factors efficiently.

Optimum plant density is the minimum population that produces maximum yield and suitable plant arrangement per unit area allow crops to exploit resource optimally and produce high yields. However, optimum plant density varies depending on crop species or varietals differences in vigor, height and branching, time of sowing, and the nature of the season. The response of crops to plant density tended to be less in the low as compared to the high yielding environments. This also depend on soil type, management practices like seedbed conditions and soil moisture, sowing depth, sowing date, presence of weeds and seasonal rainfall (Matthews *et al.*, 2008).

Chinaksen District, where the study was conducted, is one of maize producing districts in East Hararghe Zone. Maize is the 2nd cereal crop in production next to wheat in the area.

Most of the maize producing farmers in Chinaksen District do not use the national recommendation. Realizing the importance of developing appropriate cultural practices such as plant spacing for optimum production of maize in Chinaksen District this study was envisaged. Thus, effects of different spacing on maize have to be investigated for practical purposes, as planting spacing is a major management variable.

Therefore, this study was conducted with the following objective:

- To determine the effects of inter- and intra- row spacing on yield components and yield of maize.

2. LITERETURE REVIEW

2.1. Origin, Agro-Ecologies and Maize Production in Ethiopia

Maize is a member of the grass family, Poaceae. It is believed that the crop was originated in Mexico and introduced to West Africa in the early 1500s by the Portuguese traders (Dowswell *et al.*, 1996). It has never been found growing in a wild state. There is no reliable evidence that maize reached the old world prior to 1492.

Ethiopia is among the major maize producers in Sub Saharan African countries, where smallholder farmers dominate the major share of production. Maize, which is originated from South America, is first introduced in Ethiopia in the 16th to 17^{th} Century (Abdisa *et al.*, 2001). The crop requires an average daily temperature of at least $20^{o}C$ for adequate growth and development; the optimum temperature for growth and development ranges between 25-$30^{o}C$; temperature above $35^{o}C$ reduces yields (Brink and Belay, 2006). Frost can damage maize at all growth stages and a frost-free period of 120 to 140 days is required to prevent damage. Leaves of mature plants are easily damaged by frost and grain filling can be adversely affected.

Maize can be grown from sea level to over 3000 meters above sea level (m.a.s.l) elevation (Singh, 1997). In the tropics, maize does best with 600-900 mm well-distributed rainfall during the growing season (Brink and Belay, 2006).

The most suitable soil for maize is one with a good effective depth, favorable morphological properties, good internal drainage, and an optimal moisture regime, sufficient and balanced quantities of plant nutrients and chemical properties that are favorable specifically for maize production. Although large-scale maize production takes place on soils with a clay content of less than 10% (sandy soils) or in excess of 30% (clay and clay loam soils), the textural classes between 10 and 30% (clay) have air and moisture regimes that are optimal for healthy maize production and productivity. The availability of quality seed with necessary inputs at the right time and place with a reasonable price is crucial. The maize productivity gap between stressed and high potential areas is not only an issue of technology but also differences in climatic factors. Unavailability of improved infrastructure and maize grain marketing represents major limiting factors for maize production. Wise utilization and conservation of natural resources also have a significant impact on maize grain production (Mosisa *et al.*, 2001).

2.2. Importance and Uses of Maize

Maize is one of the most important cereal crops in the world. Its worldwide economic importance is due to its use as food for human, cash crop, feed for animals, and an industrial grain crop. According to FAOSTAT (2016), 1.06 billion tons of maize was produced on 188 million hectares worldwide, with a yield of over 5.64 tons ha^{-1} in the year 2016. Maize is the most important cereal crop in eastern and southern Africa accounting for over 39.5% of the total harvested area of annual cereal crops (FAOSTAT, 2016).

In Ethiopia, about 2.1 million hectares of land was covered with maize with an estimated production of about 7.8 million tons during the 2017 cropping season (CSA, 2017). However, the national average yield, 3.68 tons ha^{-1} (CSA, 2017) is still far below the world average 5.64 tons ha^{-1}, (FAOSTAT, 2016). Such low grain yield of maize is attributable to several production constraints, which include limited improved agronomic and other cultural practices for different agro-ecological regions, weeds, diseases and insect pests, rodents, birds, moisture stress, drought and low soil fertility (Pswarayi and Vivek, 2007).

In addition to the highest total production per annum and the highest per-hectare yield, maize is also the single most important crop in terms of number of farmers engaged in cultivation.
The vast majority of Ethiopian farmers are small-scale producers estimates show about 94% of the Ethiopian farmers rely on less than 5 hectares of land, of which 55% cultivate land less than 2 hectares (Rashid and Negassa, 2010). According to data from CSA, (2017), 10.9 million smallholders were involved in maize production in the country during 2017 production season.

2.3. Principles of Plant Spacing

The spatial distribution of plants in a crop community is an important determinant of yield. Plant density defines the number of plant per unit area, which determines the size of the area available to the individual plant. Spatial arrangement is defined as the pattern of plants over the ground, which determines the shape of the area available to the individual plant (Reddy, 2000). For crops regularly arranged in rows, spatial arrangement can be concisely defined by the rectangularity, which is the ratio of the inter row spacing to the intra-row spacing (Willy and Osiru, 1972). Therefore, in this review the term plant density/population used to mean inter and intra-row spacing as it indicates the size of the area available for individual plant.

Planting arrangement in the field is very important and plays a significant role in determining plant growth and development. Arrangement of a population is altered by changing row spacing, by planting seeds singly or in groups, or by changing row direction (Robinson *et al.*, 2002). Plant spacing should be thought of as existing in two directions, within row spacing and between row spacing. At a given plant density, as row spacing decreases, the plant spacing within the row increases and results in a more equidistant plant spacing. At a fixed row width, as plant density increases the plant spacing within the row decreases and interplant competition increases. Obviously, both factors can be adjusted to provide optimal plant spacing and typically plant density increases as row spacing decreases (Adetola, 2004; Pedersen *et al.*, 2008).

For a low density of plants of a single species, increasing the density increases yield per unit area and intra specific competition becomes more intense, because greater numbers of individuals compete for the same common limited resources. In pure stands, increase in the intensity of competition manifests itself by the reduction of the performance of the individual, for example biomass of single plant and/or reduction of grain weight per plant (Sobkowicz and Podgorska, 2007). Reddy, (2000) described that both too narrow and too wide spacing do affect grain yields through competition and due to the effect of shading. There are two general concepts frequently used to explain the relationship between row spacing, plant density, and yield. First, maximum yield could be obtained only if the plant community produced enough leaf area to provide maximum light interception during vegetative growth (Shibles and Weber, 1966). Secondly, equidistant spacing between plants affects interplant competition. Hence, it will be imperative to adjust the spatial distribution of the recommended population in order to have maximum yield (Buttery, 1969).

Plant population for any given situation results in mature plants that are sufficiently crowded to efficiently use resources such as water, nutrients, and sunlight, yet not so crowded that some plants die or are unproductive. At this population, production from the entire field is optimized, although any individual plant might produce less than would have occurred with unlimited space. Many factors influence the optimum plant population for a crop; availability of water, nutrients and sunlight, length of growing season; potential plant size; and the plant's capacity to change its form in response to varying environmental conditions (morphological plasticity) (Lyon, 2009).

Spacing and plant population can be determined after considering a number of factors like variety, amount of water expected to be available during the growing season and its distribution through time, soil fertility especially nitrogen availability, planting pattern, pest and disease considerations etc (Ali *et al.*, 2010). According to Norman, (1963), it is clear that both too narrow and too wide spacing do affect grain yields through competition (for nutrients, moisture, air, radiation, etc) and due to the effect of shading. In the latter case (too wide spacing), yield reduction can occur due to in efficient utilization of the growth factors. Normally, as population increases yield also increases proportionally. After, it reached a certain level the yield declines.

The spacing between stands is largely determined by the extent of the root and shoots systems of the crop plant in question. The spacing between stands per hectare in turn determines the number of stands per hectare (Onwueme and Sinha, 1991). The number of stands per hectare and the number of plants per stand together determine the number of plants per hectare, or the plant density. A number of factors also influence spacing: such as fertility status of the soil, growth pattern of the crop and cultural practices (Martin *et al.*, 2006). Yield increases with increasing plant density up to maximum for a maize genotype grown under a set of particular environmental and management conditions and declines where plant density is increased (Gozubenli *et al.*, 2004).

2.4. Importance of Spacing and Optimum Population

Optimum number of plants is required per unit area to utilize efficiently the available production resources such as water, nutrients, light, and carbon dioxide. Normally maximum productions are obtained from plant population which does not allow plants to achieve their individual maximum potential. Thus, the entire community of plants is considered for higher production rather than the individual plant performance (Balassubramaniyan and Palaniappan, 2007). Extremely narrow spacing do affect grain yield through competition for resources and due to the effect of shading. In too wide spacing yield reduction can occur due to insufficient utilization of the growth factors. As plant population increases yield also increases proportionally then decreases after it reaches a certain level (Donald, 1963).

According to Singh and Singh (2002), establishment of optimum population per unit area of a field is essential to get maximum yield. Under conditions of sufficient soil moisture and nutrients, higher plant population is necessary to utilize all the growth factors efficiently. The level of plant population should be such that maximum solar radiation is utilized. The full yield potential of an individual plant is fully exploited when sown at wider spacing. Yield per plant decreases gradually as plant population per unit area increases. However, the yield per unit area is increased due to efficient utilization of growth factors.

High plant density brings out certain modifications in the growth of plants for example, increase in plant height, reduction in leaf thickness, alteration in leaf orientation, and leaves become erect, narrow and are arranged at longer vertical intervals to intercept more sun light (Singh and Singh, 2002). One of the most common explanations for narrow-row seed-yield enhancement is the attainment of sufficient leaf area index (LAI) to produce maximal light interception during seed formation (Shibles and Weber, 1966). As such for the proper light interception at various growth stages, optimum plant population is necessary. As plant density increases, the amount of dry matter in vegetative parts also increases. Both the biological and economic yields increase with increasing plant population up to a certain point and subsequently no addition in biological yield can be obtained and economic yield decreases (Singh and Singh, 2002).

Among agronomic practices, which affect the yield, inter row spacing has a special significance since it is ultimately related with plant population, root development, plant growth and fruiting (Davi *et al.*, 1995; Adetola, 2004). Generally, the most appropriate spacing is one, which enables the plants to make the best use of the conditions at their disposal (Malik *et al.*, 1993). Too close spacing interferes with normal plants development and increase competition resulting in yield reduction, while too wide spacing may result in excessive vegetative growth of plant and abundant weed population due to more area available. Therefore, use of optimum plant population per unit area without exceeding the economic threshold can increase the competitive ability of the crop plants in weed-infested field (FAO, 1989; Murphy *et al.*, 1996). However, growing crops in narrower row spacing can reduce weed growth although the degree of reduction will depend on the crop (Alford *et al.*, 2004).

In addition to improving crop yields, reduced row spacing can also provide the crop with a competitive advantage over weeds. Although maize plant is vigorous and tall growing in nature, yet it is very sensitive to weed competition at early stages of growth (Mabasa *et al*, 1996). Wider spacing encourages growth of weed and thus, more labor and increase cost of production. Crop plants and weeds interfere with growth activities of each other to a varying degree and compete for moisture, mineral nutrients and light and hinder harvest operations (Ratta *et al.*, 1991).

2.5. Effects of Plant Density on Phenology of Maize

High plant densities appear to affect the required period for pollen shedding and silk emergence. Higher plant density (more than 12 plants per m^2) delay time of silking and widen the time gap between silking and pollination (Carcova and Otegui, 2001). Edmeades and Daynard, (2001) stated that the required time for pollen shedding and maturity time was not influenced appreciably by plant density. However, time from sowing to silking increased from 84 to 95 days as densities increased from 5 to 20 plants m^2. Thus the duration between pollen shedding and silking increased by increasing the plant density from almost 0 to 9 days in combination with the reality that plants not shedding pollen and not silking was observed only at the higher densities of 15 and 20 plants m^2 of sterility from 0 to 26.7 %. Similar results were obtained under the same plant densities by Kgasago, (2006).

2.6. Effect of Spacing and Plant Density on Growth and Development of Maize

Plants that grow under high plant density receive a different quality of light, enriched with far red (FR) and impoverished in red (R) radiation. This high FR/R ratio triggers many morphological changes in plant architecture, stimulating stem elongation, favoring apical dominance and decrease in stem diameter (Rajcan and Swanton, 2001). Such changes make maize stalks more susceptible to breakage and lodging. Plant density exerts a strong influence on maize growth and yield as a result of different competitive ability of plants at variable densities. Thus, balanced growth and development of plants need optimum plant density because optimum density enables plants efficient utilization of available nutrients, soil water and better light interception coupled with other growth influencing factors (Tinau, *et al.*, 1993; Gobeze *et al.*, 2012).

Plant height increased as population increase up to a certain point. Taller plants (221cm) were observed when maize crop was raised at 60 x 15 cm spacing, which was statistically at par (218.83 cm) when the crop was grown at 60 x 20 cm. Similarly short plant (209.33cm) was recorded from the plots planted at 60 x 30 cm (Zamir *et al.*, 2011). Matthews *et al.*, (2008) reported that maize planted with spacing of 50 x 30 cm had significantly taller plants than those spaced 75 x 25 cm and 100 x 50 cm. Leaf and leaf area index determines total light interception.

Leaf area is an important parameter in many agronomic and ecological processes, including photosynthesis, transpiration and field energy balance. Leaf area can be increased by increasing leaf area per plant or population density by narrow spacing (Major *et al.*, 1972).
The efficient interception of radiant energy incident to the crop surface requires adequate leaf area; uniformly distributed to give complete ground cover and that could be achieved by manipulating stand density and distribution over the land surface. Thus conditions favoring maximum area per leaf should optimize CO_2 (Kgasago, 2006). One of the most common explanations for narrow-row seed yield enhancement is the attainment of sufficient leaf area index (LAI) to produce maximal light interception during seed formation (Shibles and Weber, 1966; Goldsworthy and Taylor, 1990). Hussain *et al.*, (2011) reported that increasing plant density increased leaf area index on account of more area occupied by green canopy of plants per

unit area. Plant population of 140,000 and 120,000 plants ha^{-1} produced higher LAI of 4.77 and 4.52 respectively and the lowest LAI was obtained with population of 40,000 plants ha^{-1}.

2.7. Relationship between Plant Density and Yield of Maize

To increase yield, we must plant maize at proper plant population. If plant population is too high, then crop net photosynthesis process will be affected due to less light penetration in the crop canopy as well as increase in the competition for available nutrient which will affect grain yield and forage production. On the other hand, if plant population is lower than optimum plant population then per hectare production will be low and weeds will also be more (Khan, 1972).

According to Singh and Singh (2002), establishment of optimum population per unit area of a field is essential to get maximum yield. Many experiments have been conducted to determine the spacing between rows and between plants within the row that maximizes yield. Muhammad *et al.* (2006) indicated that there was maximum grain yield 6.6 t ha^{-1} of maize against the minimum 3.28 t ha^{-1} at narrow spacing, although narrow plant spacing (10-15 cm) caused substantial reduction in yield components such as grain cob^{-1} and 1000 kernel weight compared to the wide plant spacing, accordingly they recommend 60 cm by 10 or 15 cm plant spacing for maximum yield.

Turgut *et al.* (2005) also reported that narrow-row maize production is more efficient in utilizing soil nutrient and contributes to increased yield. Grain yield increased linearly with increasing plant density until production factors were not limiting (Anjum *et al.,* 1992). Optimum plant population increased number of grains cob^{-1}, 1000 grain weight and grain yield of maize (Sabir *et al.,* 1987). Rowland (1993) viewed that widely spaced maize tends to have excessive vegetative growth during early stage which may result in severe competition for water and further observed that spacing and plant population can be determined after considering a number of factors like variety, amount of water expected to be available during the growing season and its distribution through time, soil fertility especially nitrogen availability, planting, pest and disease considerations etc. Wider spacing encourages growth of weed and thus, more labor and increase cost of production.

Many crops are grown in wide rows to reduce seed costs, enable better stubble management, provide less soil disturbance, and facilitate weed control between rows. The disadvantages of wide rows include reduced competition with weeds and reduced yield in some situations. Furthermore, there is a large gap between the theoretical benefits of high crop densities and actual practice because farmers are reluctant to adopt higher seeding rates due to concerns about reduced yield or quality (Eddows, 1967). Generally, closer row spacing will improve crop competition for light, soil moisture and soil-borne nutrients. Time to canopy closure is an inverse function of row spacing and plant population and is also influenced by crop species and cultivar.

Among various biotic and a biotic factors that affect maize yield considerably; variations in plant density affects maize yield than other members of the grass family (Vega *et al.,* 2001). Maize differs in its responses to plant density (Luque *et al.*, 2006). Liu *et al.*, (2006) also reported that maize yield differs significantly under varying plant density levels due to difference in genetic potential. Plant populations affect most growth parameters of maize even under optimal growth conditions and therefore it is considered a major factor determining the degree of competition between plants (Sangakkara *et al.*, 2004). The grain yield per plant is decreased in response to decreasing light and other environmental resources available to each plant (Ali *et al.*, 2012).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The field experiment was conducted at Chinaksen District, Marar Kebele in farmers training center. It is located between 9° 30' N latitude and 42° 40' E longitude and an altitude of 1857 m a. s. l. It is situated in the semi-arid tropical belt of eastern Ethiopia and is characterized by a sub-humid type of climate with an average annual rainfall of about 600 mm, annual mean temperature of 20°C with mean minimum and maximum temperature of 12 and 28°C, respectively (BoA of Chinaksen District, 2017). The rainy season of the area is bimodal; the short rainy season stretches from March to May and the main rainy season from July to September.

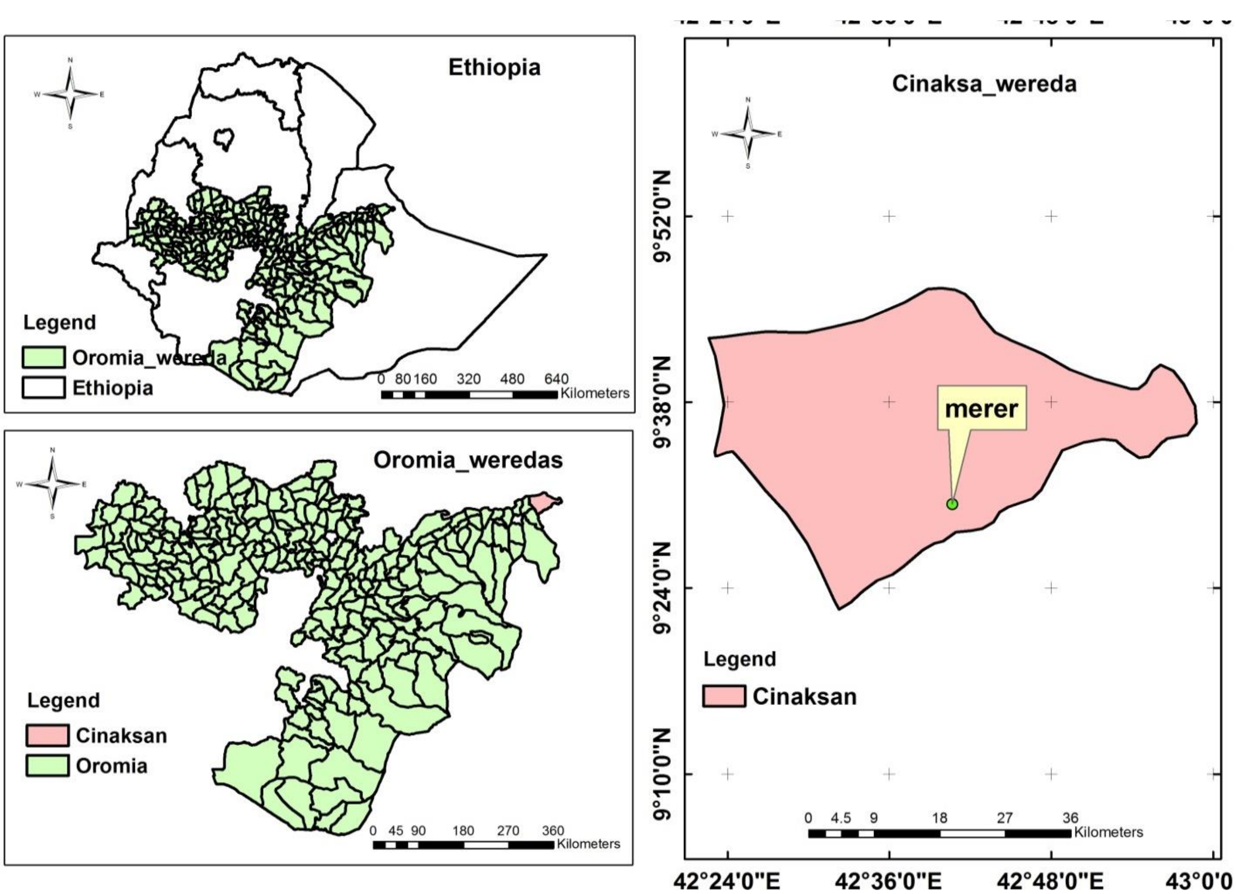

Figure 1: Map of the Study Area

3.2. Description of Experimental Materials

Maize variety, Melkassa-II was used in the experiment. Melkassa-II is early and intermediate maturing variety adapted to low-mid altitude (1200-2600 m.a.s.l) areas with high protein. It was released in the year 2004 by Melkassa Agricultural Research Center (EIAR, 2008).

3.3. Soil Sampling and Analysis

Before planting, soil sample from the experimental site was collected in a zigzag pattern from the depth of 0-30cm and composited. Uniform volume of soil was obtained in each sub- sample by vertical insertion of an auger. The soil was air dried to constant weight, ground by using a pestle and mortar and allowed to pass through a 2 mm sieve. Working samples was obtained from each submitted samples and analyzed for textural analysis, organic carbon, total N, soil pH, available phosphorus and cation exchange capacity (CEC) using standard laboratory procedures at Haramaya University's soil Laboratory.

Analysis of particle size distribution was done by hydrometer method (differential settling within a water column) according to FAO (2008) and classified in to clay, silt and sand. The pH of the soil was determined according to FAO (2008) using 1:2.5 (weight or volume) soil sample to water ratio using a glass electrode attached to a digital pH meter. Organic carbon content was determined using Walkley and Black's (1934) method. Soil organic matter was calculated indirectly from the organic carbon determination (OM%=1.72×% OC).Total nitrogen (TN) was analyzed by Micro-Kjeldhal digestion method with sulphuric acid (Dewis and Freitas, 1975). Available phosphorus was determined by the Olsen's method using a spectrophotometer (Olsen *et al.*, 1954). Cation exchange capacity (CEC) was determined after saturating the soil with 1N ammonium acetate (NH_4OAc) and displacing it with 1N NaOAc (Chapman, 1965).

3.4. Treatments and Experimental Design

The treatments consisted of four inter-rows spacing (85, 75, 65 and 55 cm) and three intra-rows spacing (35, 30 and 25 cm). The gross plot size was 4.55 x 3 m = (13.65m^2) accommodating 5, 6, 7 and 8 rows for 85, 75, 65, and 55 cm inter-rows, respectively. The experiment was laid out in randomized complete block design (RCBD) in factorial arrangement with three replications. The blocks were separated by 1.5 m wide space and each plot was separated by 1 m space. As inter and intra-row spacing varied the net plot area also varied.

Therefore, the corresponding length of net plot for intra-row spacing of 35 cm, 30 cm and 25 cm was 1.6 m, 1.8 m and 2 m, respectively and the width for inter-row spacing of 85, 75, 65 and 55 cm was 2.55 m, 3 m, 2.6 m, and 2.75 m respectively. The central rows left aside for data recording was 3, 4, 4, and 5 rows for 85, 75, 65, and 55cm inter-row spacing respectively.

Table 1: Details of Treatment Combination and Plant Population

Treatments	Inter and intra-row spacing (cm)	plant population h^{-1}
T1	55 x 25	72,727
T2	55 x 30	60,606
T3	55 x 35	51,766
T4	65 x 25	61538
T5	65 x 30	51,282
T6	65 x 35	43,955
T7	75 x 25	53,333
T8	75 x 30	44,444
T9	75 x 35	39,094
T10	85 x 25	47,058
T11	85 x 30	39,215
T12	85 x 35	33,612

3.5. Management of the Experimental Field

Prior to sowing, the land was well prepared by repeated ploughing using oxen plough. Maize seeds were planted as per proposed inter and intra-row spacing. Initially two seeds per hill were planted and latter thinned to one plant at the stage of 3 to 4 leaves. At time of planting, all plots were received a basal application of NPS (19% N, 38% of P2O5 and 7% S). In addition all plots were top dressed with urea (46% N ha^{-1}) in split (at knee height and at boot stage). All other agronomic and cultural practices like hoeing, weeding, etc were applied to all treatments as per recommended.

3.6. Data Collection

3.6.1. Crop phonological data

Days to 50% anthesis (DA): Days to 50% tasseling (the number of days required from planting to the start of shedding of pollen by 50% of the maize plants) was recorded when 50% of plants in a net plot reached the respective phenological stage.

Days to silking (DS): The number of days taken from the date of planting to the stage when 50% of plants shows extrusion of silk.

Days to 90% physiological maturity (DPM): It was recorded as the number of days after planting to the formation of a black layer at the point of attachment of the kernel with the cob by 75% of the maize plants in the plot.

3.6.2. Growth parameters

Leaf area and Leaf Area Index: It was determined at 50% silking from five plants randomly taken per net plot by multiplying leaf length and maximum width adjusted by a correction factor of 0.75 (i.e. 0.75 x leaf length x maximum leaf width) as suggested by Francis *et al.* (1969). Leaf area index was then calculated by dividing leaf area per plant sampled ground area (Radford, 1967).

Plant height: It was measured as the height from the soil surface to the base of the tassel of five randomly taken plants from the net plot area at 75% physiological maturity.

3.6.3. Yield components and yield

Stand count: Stand count per plot was recorded after thinning and at harvest from the net plot area. The final plant stand percentage (final plant stand count at maturity/population established after thinning x 100) of the respective treatments were used to determine the stand loss due to lower spacing treatments.

Number of ears per plant: It was recorded from the count of five randomly taken plants in the central net plot area at crop harvest.

Ear length: It was measured from the point where the ear attached to the stem to the tip of the ear from randomly taken ten ears in the central net plot at crop harvest.

Number of kernels per ear: It was recorded from average of five randomly taken ears per plot. This will be done by manually shelling and counting the kernels.

Dry biomass of stover: It was determined after harvest on the basis of the samples from which the grain yield was taken. This was done after the harvested stover was air dried to a constant weight for 20 days.

Thousand kernel weight (TKW) (g): Thousand kernels were counted from a bulk of shelled grains from net plot and weighed using sensitive balance adjusted to 12.5% moisture level.

Grain yield: It was recorded from the net plot area and adjusted to 12.5% moisture level.

Harvest index (%): It was calculated as the ratio of grain yield to above ground dry biomass per net plot and multiplied by 100.

3.7. Statistical Data Analysis

The measured related data were subjected to the analysis of variance using GenStat Release 15 (GenStat, 2012). The differences between treatment means were compared using Least Significant Difference (LSD) test at 5% level of significance when the ANOVA show the presence of significant difference.

4. RESULTS AND DISCUSSION

4.1. Physical and Chemical Properties of Experimental Site

Physical and chemical properties of the soil were analyzed for the surface soil sample at 0-30 cm taken from the experimental field. The soil analysis results indicated that texture of the soil was sandy loam with particle size distribution of 68% sand, 16% clay and 16% silt (Table 2).
According to Rao *et al*., (1995) maize is best adapted to well-drained sandy loam to silty loam soil. Thus, the analysis result showed that the soil texture is suitable for maize production. The texture indicates the degree of weathering, nutrient, and water holding capacity of the soil. The high sand content might indicate less water and nutrient holding capacity of the soil in the experimental site. The chemical analysis of the experimental soil also showed pH of 8.05. Landon (1991) provided guidelines for interpreting soil pH values for environmental evaluation as pH >9.0, 9.0–8.5, 8.4–7.9, 7.8–7.4, 7.3–6.6, 6.5–6.1, 6.0–5.6, 5.5–5.1, 5.5–5, 5.0-4.5 very strongly alkaline, strongly alkaline, moderately alkaline, mildly alkaline, neutral, slightly acid, moderately acid, strongly acid, strongly acid, and very strongly acid respectively. Thus, the chemical reaction of the experimental site is moderately alkaline (Table2).
Maize has been found to grow and yield well in pH values of 6.5-8 but the optimum growth is attained at pH 5.5-7 and any pH below these values will affect its growth. Cation exchange capacity **(**CEC**)** is the capacity of the soil to hold and exchange cations. The result showed that the CEC of the experimental soil was 33.2 cmol (+) kg^{-1} (Table 2).

Landon (1991) classified CEC of <6, 6-12, 12-25, 25-40, >40 Cmol (+)/kg very low, low, moderate, high and very high. Thus, the CEC of the experimental site is rated as high.
The analysis result revealed that available P of the experimental site soil was 18.7 ppm.
Tekalign *et al.,* (1991) described soils with available P <10, 11-31, 32-56, >56 ppm as low, medium, high and very high, respectively. Thus, the soil of the experimental site is considered having medium available P content (Table 2).

Total nitrogen measures the total amount of nitrogen present in the soil, much of which is held in organic matter. The soil analysis result showed that the total nitrogen percentage was 0.152% (Table 2).

Tekalign, (1991) classified soil total N availability of <0.1% as very low, 0.1-0.2% low, 0.2-0.5% as moderate, 0.5-1 high and >1% as very high. Thus, the soil of the experimental site has low nitrogen. The results of the soil analysis of the experimental site showed that the soil carbon content of 1.81% (Table 2). Hazelton and Murphy, (2007) classified soil organic carbon percentages of <0.6, 0.6–1.0, 1.0–1.80, 1.80–3.0, and >3 as very low, low, medium, high, and high, respectively. Therefore, the soil has high organic carbon content.

Table 2: Major Characteristics of experimental soil

SN	Soil Characteristics	Values	Rating	References
	1. Physical Properties			
1	Sand (%)	68		
2	Silt (%)	16		
3	Clay (%)	16		
4	Textural classes	sandy loam		Rao *et al.*, (1995)
	2. Chemical Properties	Values	Rating	References
5	Soil pH	8.05	moderately alkaline	Landon (1991)
6	Cation exchange capacity (CEC) (Cmol (+)/kg)	33.2	high	Landon (1991)
7	Available Phosphorous (Olsen) (mg/kg)	18.7	medium	Tekalign *et al.*, (1991)
8	Total nitrogen (%)	0.152	low	Tekalign, (1991)
9	Organic Carbon (%)	1.81	high organic carbon	Hazelton and Murphy, (2007)

4.2. Crop Phenology

4.2.1. Days to 50% anthesis, silking and days to 90% maturity

Neither the main effect of inter-row and intra-row spacing nor their interaction significantly affected number of days to 50% anthesis and days to 90% maturity of maize (Appendix Table 1). Although there was light increase in days to 50% silking, it was statistically not significant. The highest days to 50% silking (78.44) was recorded at inter-row spacing of 85 cm while the lowest days to 50% silking (75.11) was recorded at inter-row spacing of 55 cm (Table 3).

The present result is in line with that of Lakew, *et al.*, (2016) who reported that the effect of inter and intra-row spacing did not significantly affected on tasseling and maturity period of maize. According to Zenebe (2004), the effect of plant population was not significant on days to 50% flowering and days to 90% maturity of sorghum. Similarly, Sikandar et al. (2007) was reported non-significant differences on days to tasseling among maize hybrids, plant densities and their interaction.

Table 3: Main effects of inter and intra-row spacing on days to 50% anthesis, Days to 50% silking and Days to 90% physiological maturity

Treatments	days to 50% anthesis (days)	Days to 50% silking (days)	Days to 90% physiological maturity (days)
Inter-row spacing (cm)			
55	70.11^{a}	75.11^{a}	125.2^{a}
65	70.89^{ab}	76.44^{ab}	125.4^{a}
75	71.44^{ab}	76.89^{ab}	125.8^{a}
85	72.56^{b}	78.44^{b}	126.4^{a}
LSD (0.05)	2.137	2.031	2.506
Intra-row spacing (cm)			
25	70.33^{a}	76.25^{a}	125.2^{a}
30	71.17^{ab}	76.33^{a}	125.8^{a}
35	72.25^{b}	77.58^{a}	126.2^{a}
LSD (0.05)	1.851	1.759	2.171
CV (%)	**3.1**	**2.7**	**2.0**

LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation.
Means in column followed by the same letters are not significantly different at 5% level of significance

4.3. Growth Parameters

4.3.1. Plant height

The main effect of inter-row spacing was highly significant (P<0.01) effect on plant height of maize while intra-row spacing and interactions of inter and intra-row spacing significantly (P<0.05) affected plant height of maize (Appendix Table 2). The narrower inter-row spacing of 55 cm gave significantly taller plants (155.6 cm) than 65, 75 and 85 cm (Table 4). The narrower intra-row spacing of 25 cm gave significantly taller plants (150.5 cm) than 30 and 35 cm (Table 4).

Plant height was consistently decreased as spacing of inter-rows increased from 55 cm to 85 cm. The increase in plant height at narrower inter-row spacing might be due to comparatively low solar interception through crop canopy at narrow spacing (high plant density). Competition for light might be responsible for increase in height due to closer intra-row spacing and this might have resulted in longer internodes. Although it is not significant, plant height was decreased at all inter-row spacing when intra-row spacing increased from 25 cm to 35 cm. This may be due to crowding effect of the plant and higher intra-specific competition for resources. In conformity with the result, Matthews *et al.* (2008) reported that maize planted with plant spacing of 25 cm and row spacing of 50 cm had significantly taller plants than those planted with 30 cm plant spacing and 75 cm row spacing.

The result also agreed with the observation of Goldsworthy and Taylor (1990) who reported increase in sorghum height with increase in plant density. Similarly, Ketema (1983) and Miko and Manga (2008) reported that sorghum height was significantly affected by inter-row spacing and 50 cm inter-row spacing was observed to give significantly higher plant height than 75 cm.

4.3.2. Leaf area

The main effect of inter-row spacing was highly significant (P<0.01) effect on leaf area and intra-row spacing was showed significant (P<0.05) effect on leaf area while the interaction effect was not significant (Appendix Table 2). The highest leaf area (7287 cm^2) was recorded at inter-row spacing of 85 cm while the lowest (5990 cm^2) was at 55 cm (Table 4). In general leaf area

was decreasing with decreasing inter-row spacing (from 85 cm to 55 cm). Similarly, the highest leaf area of (6806 cm^2) was obtained from the widest intra-row spacing of 35 cm while the lowest (6348 cm^2) was recorded under the narrowest intra-row spacing of 25 cm (Table 4).
The higher leaf area in the wider inter-row spacing and intra-row spacing might be due to more availability of growth factors and better penetration of light, consequently increased number of leaves produced and the size of individual leaves in plants at wider row spacing. This result was in agreement with Lakew *et al.* (2016) who reported the highest leaf area per plant of 7338.4 cm^2 was obtained from the widest intra-row spacing of 30 cm while the lowest (6732.3 cm^2) was recorded under the narrowest intra-row spacing of 20 cm. Moreover, Sangoi *et al.* (2001) showed that higher leaf area of maize (7258 cm^2) was attained at row spacing of 75 cm than at 50 cm (6118 cm^2).

4.3.3. Leaf area index

The main effects of inter and intra-row spacing on leaf area index was highly significant ($P<0.01$) while the interaction effect was not significant (Appendix Table 2).

The narrowest inter-row spacing of 55 cm resulted in highest leaf area index (3.68), while the lowest leaf area index of (2.9) was recorded under wider inter- row spacing (85 cm) (Table 4). The highest leaf area index of 3.68 was recorded under the narrowest intra-row spacing (25 cm), while the lowest leaf area index of (2.82) was observed from the widest intra-row spacing of 35 cm (Table 4).

This could be due to high number of plants per unit area in narrow spacing than under wider spacing. This result was in agreement with Lakew *et al.* (2016) who reported the narrowest inter-row spacing of 45 cm resulted in highest leaf area index (5.33), while the lowest leaf area index of (3.33) was recorded under wider inter- row spacing (85 cm). Similarly, Yousaf *et al.* (2007) reported that a difference in LAI between maize row spacing was significant and the highest value of 5.33, 5.83 and 6.19 were recorded at 75 cm, 60 cm and 45 cm row spacing, respectively.

Table 4: Main effects of inter and intra-row spacing on plant height, leaf area and leaf area index

Treatments	Plant height (cm)	leaf area (cm^2)	Leaf area index
Inter-row spacing (cm)			
55	155.6^{b}	5990^{a}	3.687^{c}
65	148.6^{a}	6354^{b}	3.308^{b}
75	147.2^{a}	6728^{c}	3.031^{a}
85	144.3^{a}	7287^{d}	2.903^{a}
LSD (0.05)	5.543	331.9	0.1320
Intra-row spacing (cm)			
25	150.5^{a}	6348^{a}	3.685^{c}
30	148.6^{a}	6616^{b}	3.189^{b}
35	147.6^{a}	6806^{b}	2.822^{a}
LSD (0.05)	4.80	287.4	0.1144
CV (%)	**3.8**	**5.2**	**4.2**

LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation.
Means in column followed by the same letters are not significantly different at 5% level of significance

4.4. Yield and Yield Components of Maize

4.4.1. Plant stand count percent

The analysis of variance showed that there were highly significant ($P<0.01$) variation on stand count percent due to inter and intra-row spacing as well as their interactions (Appendix Table 3). At all intra-row spacing, stand count percent increased as inter-row spacing increased. The highest stand count of 97.87% and the lowest stand count of 91.27% were recorded at combination of inter row and intra-row spacing of 85 cm x 35 cm and 55 cm x 25 cm respectively (Table 5).

In general, plant stand percent decreased as plant population increased and that might be due to crowding effect. There is a possibility that at narrower inter and intra-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 the weaker plants might have died by the time the crop approached maturity. 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 Lakew, *et al.* (2016) reported highest stand count (98 %) as compared with the initial stand was recorded from 65 cm x 30 cm, 85 cm x 25 cm, and 85 cm x 30 cm spacing combinations whereas 45 cm x 20 cm resulted in lowest stand count (91 %). 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 5: The interaction effects of inter and intra-row spacing on stand count percent

Inter-row spacing (cm)	Intra-row spacing (cm)		
	25	30	35
55	91.27^{a}	92.80^{bc}	92.64^{b}
65	93.52^{c}	93.18^{bc}	94.64^{d}
75	94.44^{d}	95.02^{d}	95.83^{e}
85	96.66^{f}	96.33^{ef}	97.87^{g}
LSD (0.05)		0.7947	
CV (%)		**0.5**	

LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation.
Means in column and row followed by the same letters are not significantly different at 5% level of significant.

4.4.2. Ear length (cm)

Both inter and intra-row spacing showed highly significant (P<0.01) effect on ear length and interactions of inter and intra-row spacing showed significant (P<0.05) effect on ear length (Appendix Table 3).

The highest ear length (27.20) was recorded at spacing combination of 85 cm x 35 cm while lowest ear length (20.87) was recorded at spacing combination of 55 cm x 25 cm (Table 6).

The longer ear at lower plant population (increased inter and intra-row spacing) might be due to the fact that at lower population level there are available space and less competition for resources in low plant population density. The current result was in agreement with Muhidin, (2019) the main effect of inter and intra row showed that ear height was responsive to the change in planting density.

Table 6: The interaction effects of inter and intra-row spacing on ear length

Inter-row spacing (cm)	Intra-row spacing (cm)		
	25	30	35
55	20.87[a]	21.60[ab]	22.00[abc]
65	22.80[cd]	22.10[bc]	23.60[de]
75	23.27[d]	23.60[de]	23.80[de]
85	24.40[e]	26.13[f]	27.20[g]
LSD (0.05)		1.151	
CV (%)		**2.9**	

LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation
Means in column and row followed by the same letters are not significantly different at 5% level of significant.

4.4.3. Number of ear per plant

Analysis of variance indicated that main effects of inter-row spacing had highly significant ($P<0.01$) effect on number of ears per plant while intra-row spacing had significantly ($P<0.05$) effect on number of ears per plant (Appendix Table 3). However, there was no significant interaction effect. Significantly lower number (1.12) of ears per plant was found in narrow inter-row spacing of 55 cm than wider (1.32) inter-row spacing 85 cm.

Significantly lowest number of ears per plant (1.21) was recorded at the narrowest intra-row spacing of 25 cm while significantly highest number of ears per plant (1.3) was recorded at the widest intra-row spacing of 35 cm (Table 7).

The result indicated that a number of ears per plant showed an increasing trend as inter-row spacing increased from 55 to 85 cm. This could be due to the fact that at closer spacing or high plant densities, there may be intense intraspecific competition among plants for growth resources like nutrients, soil moisture, light, and carbon dioxide, thus, the supply of growth resources to growing ear is reduced in turn to reduce the number of ears per plant.

This result was in agreement with Belay, (2019) reported that the maximum number of ears per plant (1.95) were produced from variety BH-QPY-545 at a wider inter-row spacing (75 cm), while the lowest number of ears per plant (1.35) were produced from variety BH-661 at a closer inter-row spacing (65 cm). Similarly, Zamir *et al.* (2011) reported that the highest number of ears per plant (1.42) was produced at 30 cm intra-row spacing followed by 25 cm intra-row spacing and the lowest number of ears per plant (1.21) was produced at intra-row spacing of 15 cm.

4.4.4. Number of kernels per ear

Main effects of inter and intra-row spacing showed highly significant ($P<0.01$) effect on number of kernels per ear. However, their interaction effect was not significant (Appendix Table 3). The highest number of kernels per ear (540.4) was recorded at 85 cm inter-row spacing and the lowest number of kernel (486) was recorded at 55 cm inter-row spacing (Table 7).

Increasing inter-row spacing from 55 cm to 85 cm showed linear and consistent kernels increment. The highest number of kernels per ear (533.2) was recorded at 35 cm intra-row spacing and the lowest number of kernels (496.6) was recorded at 25 cm intra-row spacing. In both inter-and intra-row spacing, kernel number increased as spacing increased. This variation might be due to the fact that widely spaced plants encountered less intra plant competition than closely spaced plants and thus exhibited better growth that contributed to more number of kernels per ear.

In agreement with this result, Eskandarnejada *et al.* (2013) reported that inter-row spacing of 30 cm produced more number of kernels per ear than that 20 cm plant spacing. Moreover, Mukhtar *et al.* (2012) reported that wider spacing (17.50 cm) produced higher number of kernels per ear (717.00) while narrower spacing (10 cm) gave lower number of grains (540.30).

4.4.5. Thousand kernels weight

Main effect of inter and intra-row spacing were significant ($P<0.05$) on thousand kernel weight. However, the interaction was not significant (Appendix Table 4). With increase inter-row spacing, thousand kernels weight increased where the highest thousand kernels weight (348.6g) was recorded at the widest inter-row spacing of 85 cm whereas, the lowest (335.6g) was recorded at the narrowest inter-row spacing of 55 cm.

With respect to intra-row spacing, the kernel weights increased with increase in intra-row spacing where the lowest thousand kernel weight (336.5g) was recorded at 25 cm intra-row spacing and the highest weight (347g) was at 35 cm intra-row spacing (Table 7).

The higher thousand kernels weight at the wider inter-row spacing might also be due to availability of more resources (light, nutrient, water) for comparatively less number of plants, which they utilized efficiently to produce bigger kernels.

The present result was in line with that of Mahmood *et al.* (2001) who reported that plant spacing of 30 cm produced significantly higher 1000 kernels weight than 10 cm plant spacing. The result was in agreement with Ogunlela *et al.* (2005), Arif *et al.* (2010) and Mukhtar *et al.* (2012) who reported that 1000 kernels weight decreased with increase in plant density.

Table 7: Main effects of inter and intra-row spacing on number of ears per plant, number of kernels per ear, and thousand kernel weight

Treatments	Number of ear per plant	Number of kernels per ear	Thousand kernels weight
Inter-row spacing (cm)			
55	1.12[a]	486[a]	335.6[a]
65	1.25[b]	506.1[b]	338.6[ab]
75	1.30[b]	526.1[c]	346.5[bc]
85	1.32[b]	540.4[d]	348.6[c]
LSD (0.05)	0.0766	15.60	9.52
Intra-row spacing (cm)			
25	1.21[a]	496.6[a]	336.5[a]
30	1.23[a]	514.2[b]	343.4[ab]
35	1.30[b]	533.2[c]	347[b]
LSD (0.05)	0.0663	13.51	8.25
CV (%)	**6.3**	**3.1**	**2.8**

LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation;
Means in column followed by the same letters are not significantly different at 5% level of significance

4.4.6. Grain yield (kg/ha)

Both inter and intra-row spacing showed highly significant (P<0.01) effect on grain yield per hectare while interactions of inter and intra-row spacing showed significant (P<0.05) effect on grain yield per hectare (Appendix Table 4). The highest (5594 kg^{-1}) grain yield weight was obtained from the spacing combinations of 55 cm x 25 cm with plant density of 72,727 plants/ha while the lowest (3367 kg^{-1}) grain yield weight were obtained from spacing combinations of 85 cm x 35 cm with plant density of 33,612 plants/ha (Table 8). This indicates that the narrowest spacing (55 x 25 cm) gave the highest grain yield than the widest spacing (5594 kg ha^{-1} vs 3367kg ha^{-1}).

This might be due to the fact that high population ensured early canopy coverage and maximizes light interception greater crop growth rate and crop biomass resulting increased yield in maize. In agreement with this result, Maqsood *et al.* (2002) reported that there was higher grain yield of maize (6.6 tons ha^{-1}) at narrower spacing of 60 cm x 15 cm against the lower grain yield (3.28 tons ha^{-1}) at wider spacing of 60 cm x 30 cm. Similarly, Yousaf *et al.* (2007) reported that the highest grain yield produced at narrow spacing of 45 cm x 25 cm (88,888 plants ha^{-1}) and the lowest grain yield was recorded for 75 cm x 30 cm spacing (44,4,44 plants ha^{-1}). The recommended spacing for maize (75 x 30 cm) gave 4617 kg ha^{-1} , which is significantly lower by 977 kg ha^{-1}than the finding (55 x 25 cm).

Table 8: Interaction effects of inter and intra-row spacing on grain yield (kg/ha)

Inter-row spacing (cm)	Intra-row spacing (cm)		
	25	30	35
55	5594^{e}	4824^{d}	4712^{d}
65	4855^{d}	4675^{d}	3848^{c}
75	4875^{d}	4617^{d}	3555^{ab}
85	4636^{d}	3753^{bc}	3367^{a}
LSD (0.05)		435.9	
CV (%)		**5.8**	

LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation
Means in column and row followed by the same letters are not significantly different at 5% level of Significant

4.4.7. Above ground dry biomass yield (kg/ha)

The main effect of inter and intra-row spacing had highly significant ($P<0.01$) effect on above ground dry biomass yield but the interaction was not significant (Appendix Table 4). The highest above ground dry biomass yield (14,704 kg^{-1}) was recorded at narrowest inter-row spacing of 55 cm and the lowest dry biomass yield (9763 kg^{-1}) was recorded at widest of inter-row spacing of

85 cm. The highest above ground dry biomass yield (14,055kg^{-1}) was recorded at narrowest intra-row spacing of 25 cm and the lowest dry biomass yield (10,198 kg^{-1}) was recorded at widest of intra-row spacing of 35 cm (Table 9).

Increasing inter-row spacing from 55 cm to 85 cm decreased above ground dry biomass yield and showed consistent decrement. This might be due to higher plant population recorded at narrow inter and intra-row spacing and hence greater dry matter production. In agreement with this result Mahmood *et al.* (2001) showed that total biomass yields of maize were significantly higher in the narrow intra-row spacing (20 cm) than in wider intra-row spacing (30 cm) due to more number of taller plants per unit area and better interception of solar radiation.

4.4.8. Harvest index (%)

The analysis of variance showed that there was highly significant ($P<0.01$) variation on harvest index due to the main effect of inter-row spacing while the effects of intra-row spacing as well as interaction of inter and intra-row spacing were not significant (Appendix Table 4). The highest harvest index (40.48) was recorded at inter-row spacing of 85 cm whereas the lowest harvest index (34.5) was obtained from 55 cm inter-row spacing (Table 9).

Plant density also affect harvest index. At the widest inter-row spacing less intra-specific competition led to greater proportional increase in grain yield than total above-ground dry matter accumulation, incidentally resulting in a higher harvest index. Maize harvest index typically decreases at above-optimum plant densities as intra-specific competition reduces biomass partitioning to the ear (Pagano and Maddonni, 2007). Similarly, Yousaf *et al.* (2007) reported that harvest index initially increased with increasing plant and row spacing but declined when plant density increased further.

Table 9: The Main effects of inter and intra-row spacing on above ground dry biomass yield (kg/ha) and harvest index (%)

Treatments	Above ground dry biomass yield	Harvest index
Inter-row spacing (cm)		
55	14704[c]	34.48[a]
65	12537[b]	36.19[a]
75	11685[b]	37.80[ab]
85	9763[c]	40.50[b]
LSD (0.05)	1297.8	3.918
Intra-row spacing (cm)		
25	14055[c]	35.98[a]
30	12264[b]	37.31[a]
35	10198[a]	38.47[a]
LSD (0.05)	1124.0	3.393
CV (%)	**10.9**	**10.8**

LSD= Least Significant Difference at 5% level; CV= Coefficient of Variation
Means in column and row followed by the same letters are not significantly different at 5% level of Significant

5. SUMMARY AND CONCLUSION

In crop production, plant population, row arrangement, variety selection, soil fertility and crop management practices are major variables that can be manipulated by producer to influence the production of a given crop. Among agronomic practices, plant spacing deserves special attention. Therefore, this experiment was conducted in 2019 cropping season in Chinaksen, East Hararghe Zone, Oromia Regional State, eastern Ethiopia with the objective to investigate the effects of inter-and intra-row spacing on yield components and grain yield of maize in the study area.

In this spacing experiment, maize variety Melkassa-II was used. The experiment was arranged in a factorial combination of the four inter-rows (55, 65, 75 and 85 cm) and three intra-rows (25, 30 and 35 cm) which were laid out in a randomized complete block design (RCBD). Data on phenological, growth, yield and yield components were collected.

The results obtained had shown that maize crop phenological parameters were not significantly affected by either main effects or their interactions. The main effect of inter-row spacing showed highly significant ($P<0.01$) effect whereas, intra-row spacing and interactions of inter and intra-row spacing showed significant ($P<0.05$) effect on plant height. Higher plant height (155.6 cm and 150.5 cm) was observed at 55 cm and 25 cm inter and intra-row spacing, respectively while the shortest of plant height (144.3 cm and 147.6 cm) was observed at 85 cm and 35 cm inter and intra-row spacing, respectively. The main effects of both intra and inter-row spacing on leaf area as well as leaf area index were highly significant. The highest leaf area (7287 cm^2 and 6806 cm^2) were recorded at inter and intra-row spacing of 85 cm and 35 cm, respectively while the lowest (5990 and 6348) were at 55 cm and 25 cm inter and intra-row spacing, respectively. The narrowest inter- and intra-row spacing of 55 cm and 25 cm gave the highest leaf area index (3.687 and 3.685) respectively.

Inter and intra-row spacing had highly significant effect on number of kernels per ear and above ground dry biomass yield ha^{-1}. The highest number of kernels per ear (540.4) was observed for 85 inter-row spacing. Similarly the widest intra-row spacing of 35 cm gave the highest number of kernels per ear (533.2). The narrowest inter-row spacing of 55 cm produced significantly higher biomass yield (14,704 kg^{-1}) than all the other inter-row spacing. There was highly significant variation on number of ears per plant and harvest index due to the main effect of inter-row spacing. The highest number of ears per plant (1.32) and harvest index (40.48) were recorded at the widest inter-row spacing of 85 cm. Main effect of inter and intra-row spacing were significant on thousand kernel weight. The highest thousand kernels weight (348.6g) was recorded at the widest inter-row spacing of 85 cm. Similarly the highest thousand kernels weight (347g) was recorded at 35 cm intra-row spacing. There was highly significant interaction effect of inter and intra-row spacing on plant stand count percent, ear length and grain yield per hectare. The highest plant height stand count percentage (97.87%), ear length (27.2 cm) and grain yield (5594kg^{-1}) was recorded from 85 x 35 cm, 85 x 35 cm and 55 cm x 25 cm inter and intra-row spacing combinations respectively. Higher grains yields were obtained from the spacing combinations of 55 cm x 25 cm, 65 x 25 cm and 75 cm x 25 cm.

In general, the result of this study had shown production of maize at relatively narrow spacing combinations and/or intermediate spacing combination can increase both grain yield and above ground dry biomass yield of maize per unit area of land, and enable production of additional dry biomass without significant reduction of maize grain yield. However, spacing combination of 55 cm x 25 cm was better than 65 cm x 25 cm concerned to grain yield and above ground dry biomass yield. This enables to farmers of the area to produce drier biomass (stover) yield per unit area as it is an important source of fuel and animal feed.

Therefore, from this finding, it can be concluded that maize sowing at 55 cm x 25 cm spacing combination is superior especially concerned to grain and biomass yield. However, this tentative generalization is based on one season at one location and using one variety. So, further study on different varieties on different seasons and at different locations are required for further investigation and to give complete recommendation.

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7. APPENDICS

Appendix Table 1: Mean square values of ANOVA for phonological parameters of maize as influenced by Inter and intra-row spacing

		Mean squares		
Source of variation	Degree of freedom	Days to 50% anthesis (days)	Days to 50% silking (days)	Days to 90% physiological maturity (days)
Replication	2	33.083	54.194	85.361
Inter-row spacing	3	9.509ns	17.000*	2.556ns
Intra-row Spacing	2	11.083ns	6.694ns	3.111ns
Inter x Intra	6	0.120ns	1.250ns	1.333ns
Error	22	4.780	4.316	6.573
CV (%)		**3.1**	**2.7**	**2.0**

Where, * = significant; ns= non-significant

Appendix Table 2: Mean square values of ANOVA for growth parameters of maize as influenced by Inter and intra-row spacing

		Mean squares		
Source of variation	Degree of freedom	Plant height(cm)	Leaf area (cm^2)	Leaf area index (%)
Replication	2	78.78	430481	0.10167
Inter-row spacing	3	204.85**	2762101**	1.08486**
Intra-row Spacing	2	25.72*	635357*	2.25310**
Inter x Intra	6	25.75*	43810 ns	0.02268 ns
Error	22	32.14	115248	0.01824
CV (%)		**3.8**	**5.2**	**4.2**

Where, ** = highly significant; * = significant; ns= non-significant

Appendix Table 3: Mean square values of ANOVA for yield components and yield of maize as influenced by Inter and intra-row spacing

		Mean squares			
Source of variation	Degree of freedom	Plant stands count (%)	Ear length (cm)	No. of ear per plant	No. of kernels per ear
Replication	2	1.8373	2.8253	0.025833	454.2
Inter-row spacing	3	36.0102**	30.8832**	0.072222**	5070.2**
Intra-row Spacing	2	5.1612**	5.2719**	0.023333*	4028.3**
Inter x Intra	6	0.7074**	1.2060*	0.003333 ns	418.3 ns
Error	22	0.2202	0.4622	0.006136	5600.1
CV (%)		**0.5**	**2.9**	**6.3**	**3.1**

Where, ** = highly significant; * = significant; ns = non-significant

Appendix Table 4: Mean square values of ANOVA for yield components and yield of maize as influenced by Inter and intra-row spacing

		Mean squares			
Source of variation	Degree of freedom	Thousand kernel weight	Grain yield (kg ha^{-1})	Dry biomass yield (kg ha^{-1})	Harvest index (%)
Replication	2	1767.75	203637	441952	38.78
Inter-row spacing	3	342.71*	1932542**	37765300**	58.96*
Intra-row Spacing	2	340.6*	3767618**	44712163**	18.35ns
Inter x Intra	6	11.84 ns	176571*	1866354 NS	14.91ns
Error	22	94.88	66257	1762305	16.06
CV (%)		**2.8**	**5.8**	**10.9**	**10.2**

Where, ** = highly significant; * = significant; ns = non-significant