FECT OF INTER AND INTRA ROW SPACING ON YIELD COMPONENTS AND YIELD OF MAIZE (*Zea mays* L.) IN KERSA DISTRICT, EAST HARARGHE ZONE, ETHIOPIA

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I hereby certify that I have read and evaluated this thesis, entitled "**Effect of Inter and Intra Row Spacing on Yield Components and Yield of Maize (***Zea mays L.*) **In Kersa District, East Hararghe Zone, Ethiopia**" prepared by Mesfin Tafese Bekele under my guidance. I recommend that it be submitted as fulfilling the thesis requirement.

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DEDICATION

This Msc Thesis is dedicated to my wife Emebet Worku and my whole family and my brother Mikael Mumed Hassen for their selfless sacrifices throughout my educational career.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly matter that is included in the Thesis has been given recognition through citation.

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BIOGRAPHICAL SKETCH

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ACRONYMS AND ABBREVIATIONS

AGBM	Above Ground Bio Mass
CAR	Center of Agricultural Research
CSA	Central Statistical Authority
DZARC	Debre Zeit Agricultural Research Center
EARO	Ethiopian Agricultural Research Organization
EEPA	Ethiopian Export Promotion Agency
FAOSTAT	Food and Agricultural Organization Statistical Data Base
F T C	Farmer Trainning Center
GLM	Generalized Linear Model
HSW	Hundred Seed Weight
IAR	Institute of Agricultural Research
ICAR	International Center of Agricultural Research
ICARDA	International Center of Agricultural Research in Dry Area
ICRSAT	International Crop Research Institute for Semi-Arid Tropics
ILRI	International Livestock Research Institute
LSD	Least Significant Difference
MOANR	Ministry of Agriculture and Natural Resource
MT	Metric Tone
RUTF	Ready-to-Use Therapeutic Food
SNNPR	Southern Nations, Nationalities and Peoples Region
USDA	Units State Development Agriculture

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ABSTRACT

*Maize is an important cereal crop in Ethiopia due to its use as a source of food security. However, its productivity is limited due to the lack of appropriate plant spacing. A field experiment was conducted during the 2023 main cropping seasons in kersa districts of East Harerghe Zone to study the effect inter and intra-row spacing on growth,phonological yield, and yield components of maize. The experiment consisted of three inter-row spacing (55, 65 and 75 cm) and five intra-row plant spacing (20, 25, 30, 35 and 40 cm) and the experiment was laid out in factorial arrangement with Randomized Complete Block Design (RCBD) with three replications. The results showed that the interaction effects of both inter and intra-row spacing had significant effects($P<0.01$) on the number of days to 50% anthesis, days to 90% physiological maturity, leaf area, leaf area index, plant height, number of kernel per ear, thousand kernel weight, aboveground dry biomass, grain yield and harvest index. Further, the main effects of inter and intra-row spacing were highly significant effect ($P<0.01$) on number of ear per plant, ear diameter and ear length. The highest days to 50% anthesis was (79.55), days to 90% physiological maturity (153.3), leaf area (1322.5cm^2), harvest index (4.56) were recorded from 75 cm*40 cm. The highest leaf area index (4.48), plant height (274.5 cm), aboveground dry biomass (25074.55 kg ha^{-1}) was recorded from the interaction effects of 55 cm*20 cm plant spacing. The highest number of kernel per ear (428.5), thousand kernel weight (405.9 g), grain yield (7121 kg ha^{-1}) were recorded from the interaction of 75*25 cm whereas the lowest days to 50% anthesis (74.70), days to 90% physiological maturity (144.7), leaf area (1137.67 cm^2), grain yield (5250.13 kg ha^{-1}), number of kernel per ear (388), thousand kernel weight (336.5 g) and harvest index (2.33) were recorded from the interaction effects of 55 cm*20 cm plant spacing. The interaction 75 cm*40 cm spacing recorded the lowest leaf area index (3.01), plant height (239.8 cm per plant), and aboveground dry biomass (14926.13 kg ha^{-1}). The study found that the optimal plant spacing for maize productivity is 75cm inter row specing with 25 cm intra-row spacing producing the highest grain yield. Therefore, a plant spacing of 75*25 cm was the most appropriate for maize productivity.*

Keywords*: Grain yield, Harvest index, Maize Row spacing Plant density.*

1. INTRODUCTION

Maize (*Zea mays* L) is one of the major cereal crops grown in the humid tropics and Sub-Saharan Africa. It is an essential crop in several parts of the developing world. It occupies the third place after wheat and rice (De Pinto *et al*, 2020). In Ethiopia agriculture, maize is one of the pillars cereal crops ranking first in total production and productivity, and second to *teff* in area coverage (Gizaw, Wasihun, and Desu Assegid.2021). Supplying nutritious, safe, and affordable food to a growing population is one of the far most burning issues currently facing Africa to fulfil food security in the region (Auerbach, Raymond, 2013). In view of its high demand for food grains and high yield per unit area, maize has been among the leading food grains selected to achieve food self-sufficiency in Ethiopia (FAO, 2021)

The grain also has many industrial uses, including transformation into plastic, and fabrics. Some is hydrolysed, and enzymatically treated to produce syrups, particularly high fructose corn syrup. Also some is fermented and distilled to produce grain alcohol (Ceasar and Lamana, 2007). Maize in Ethiopia is used directly for human consumption as food or local drinks. In addition, maize leaves are used for feed to animals and dry stalks are used as fuel and for the construction of fences (Tadesse and Sultan, 2021).

The 2020/2021 Meher season post-harvest crop production survey indicated that at the national level, 16.79% (2,128,948.91 hectares), of the land area was covered by maize and production of grain was about 27.43% or 83, 958, 87.24 tons with an average yield of 3.9 ton ha^{-1}. The first in productivity among the cereal crops in East Hararghe Zone. 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 per hector in the East Hararghe Zone (CSA, 2020).

Even though maize has multiple purposes and high yielding potential, the national average yield (3.9 t, ha^{-1}] in general and the zonal yield (2.57 t, ha^{-1}) are low (CSA, 2020) as compared to developed countries' average yield which is about 6.2 t·ha^{-1} (ATA, 2014). The low productivity of maize is attributed to many factors such as poor agronomic practices like inappropriate seed rate, 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*., 2011). 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 (Kebede, 2019). 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.

Optimum plant density for maximum grain yield per unit area may differ with crop varieties (Tokatlidis *et al.*, 2005). Maize plant population for maximum economic grain yield varies from 30,000 to 90,000 plants ha^{-1} depending on planting date, water availability, soil fertility and maturity. Improved endurance in high stands has allowed maize to intercept and use solar radiation more efficiently, contributing to the remarkable increase in grain yield potential (Abdul Aziz, 2007). However, in Ethiopia, maize spacing recommendation of 44,444 plants per hector (75 cm × 30 cm) has used generally for a long time without taking into account the many morphological differences that exist among maize varieties as well as the presence of soil and climatic differences (EARO, 2004). Plant density and arrangement of plants in a unit area seriously define resource utilization such as light, nutrients, and water. Because of this difference, determination of optimum 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 (Chandra sekaran *et al*., 2010).

Row width plays a great effect on the maize plant population. In this respect designated that increasing distance between rows from 60 to 70 and 80 cm lead to a significant increase in growth character, grain and its components due to better interception and utilization of solar radiation and the increase in photosynthetic processes (Kandil *et al.*, 2017). Furthermore, earlier crop cover provided by smaller row width is instrumental to enhance soil protection, diminishing water runoff and soil erosion (Sangoi *et al*., 1998).

The number of plants per unit area is the most important component of yield because if there are not enough plants cannot be expected high number of ear per unit area and yield (Mandić *et al.*, 2016). Increased plant densities promote utilization of solar radiation by maize canopies. However, efficiency of conversion of intercepted solar radiation into economic maize yield will decrease with high plant density because of mutual shading of plants.

The gap in the study area was that most of the farmers were not used proper spacing when they produce maize. As result improper inter and intra-row spacing or plant density makes final harvested yield very low. The attitude of the farmers in study area on plant density or plant spacing was less under maize production. Some of the farmers said that the national recommendation of inter and intra row spacing is too wide that it does not give higher yield make confusion.

However, the effects of optimum plant spacing at specific districts with agro ecology on yield components and yields of maize are important to study.as, truly explained during personal communication by kebele extension worker said that majority of small holders farmers in study area ware aware of the benefits of adapting optimum spacing of improved technology of maize production to enhance maize productivity. Yet this awareness was mainly limited to some improved technology while the knowledge about optimum plant density and row spacing is not sufficient.

So most of the farmers in study area had been using their own row spacing and agronomic practice then using proper inter and intra row spacing which resulted in low productivity of maize Thus, a need to specific recommendation of inter and intra- row spacing in order to achieve maximum and higher yields (ha^{-1}) for consumption and market during rain fed season production Therefore, to fully utilize the optimal intra-row and inter-row spacing for high-yielding of maize to greater output are needed.

- Therefore, the study was undertaken with the objectives of; to evaluate the effect of intra and inter row spacing on yield components and yield of maize in Kersa District, Eastern Ethiopia.

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. 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 diversity of native forms is found in this region (Bonavia D, Grobman A .2014) .

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 16^{th} or early 17^{th} century through Portuguese contacts (McCann, 2005). From the time when it's coming, the crop has expanded to most agro-ecologies of the country. Because of its long-term cultivation 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 m.a.s.l, including moisture stress semi-arid lowlands, sub-humid areas of low altitude, mid-altitude and high altitude agro- ecologies of Ethiopia (MosisaWorku *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).

The centre of origin of maize is the Mesoamerican region, probably in the Mexican highlands, from where it spread rapidly. Archaeological records and phylogenetic analysis suggest that domestication began at least 6,000 years ago. Maize spread around the world after European discovery of the Americas in the 15th century, particularly in temperate zones (Office of the Gene Technology Regulato, 2008).Some authors consider maize to have started from a wild grass, called teosinte, which is quite different from the maize of today, while others suggest the formation of a hybrid of two wild grasses a perennial subspecies of teosinte (*Zeadiploperennis*) and a species of Tripsacum. By systematically collecting and cultivating plants best suited for human consumption, Native Americans transformed maize over a couple 1000 years to a plant with larger cobs and more rows of kernels, making it a better source of food. This provided enough food for the bulk of their diet for an entire year, allowing people to live in one location for an extended period of time (Ranum and Pe, 2014).

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. 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. The major maize producing regions are southern, western and south-western Ethiopia and the highlands of Hararghe in eastern parts of the country (Abduruman and Husen, 2021). The environments found in the tropical and sub-tropical locations are extremely diverseWith highly variable effects on flowering in maize (Jean *et al*., 2009) Reported that anthesis rather than silkin was more stable and reliable among the flowering trait because of more prominen environmental stress effects on silking (Oluwaranti *et al*, 2008).

Temperature is one of the most important factors that determine plant growth, development, and yield. Perfect summary of plant temperature response in plants is a prerequisite to successful crop systems modelling and application of such models to crop management (Xinyou*et al*., 1995). Thermal models involving a framework of three cardinal temperatures used to study crop development with particular reference to maize. The cardinal temperatures were the base (Tb), the optimum (To) and the top limit (Tc). Maize is a warm weather crop and not grown in areas where the mean daily temperature is less than 19°C or where the mean of the summer months is less than 23°C (*Agegnehu et al., 2013*). The report of the research conducted on crop heat revealed that Crop Heat Unit (CHU) closely foreseen days to silking than other flowering behaviours (Wiekai and Hunt, 1999).

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 produces entirely in the staminate inflorescence and eggs, entirely in the pistillate inflorescence. Maize is wind pollinated and both self and cross-pollination are usually possible. Shed pollen usually remains viable for 10 to 30 minutes, but can remain viable for longer durations under favourable conditions (Oluwaranti *et al*., 2008). 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 clump 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 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 continual 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 above ground organs of the plant (Takacs *et al*., 2012). Maize leaves are began one at a time, with successive leaves being initiated from opposite side of the shoot apical meristem, resulting in an alternating phyllotaxy. 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. 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 neighboring 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 277,638,380.98quintals) 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.

2.4. Constraints to Maize Production

Maize is still considered a low yielding crop in the West and Central Africa sub-regions compared with what obtains in the USA where a yield of 10 tonnes per hectare is achievable, though a modest increase in average yield from the long standing less than 1.0 tonne per hectare to about 1.3 tonnes per hectare has occurred (Fakorede *et al*., 2003). It production is generally confronted with a number of biotic and abiotic stresses that are responsible for the low yields in farmers' fields. Some of these production-limiting factors include low soil nutrient supply, Striges parasitism and poor management practices, notably low plant density, late planting and late first weeding. Abiotic stresses that undermine agricultural production and particularly maize production severally include the potentially adverse effects of drought, salinity, flooding, metal toxicity, nutrient deficiency, and high and low temperatures.

Others which are often sporadic and localized in their occurrence are shade, ultra-violent exposure, photo inhibition, air pollution, wind, hail, and gaseous deficiency (Shafiq-ur-Rehman *et al*., 2005).

Abiotic stresses result in a chain of morphological, physiological, biochemical and molecular changes with dramatic negative impacts on growth and productivity of crop plants (Wang *et al*., 2001a). Drought and salinity are common in a few regions, posing a major catastrophe of salinization of over 50% of agricultural lands by 2050 (Wang *et al*., 2003). An array of diseases plagues maize growing areas in sub-Saharan Africa. These include downy mildew, rust, leaf blight, stalk and ear rots, leaf spot, and maize streak virus. Insect pests, including stem and ear borers, armyworms, cutworms, grain moths, beetles, weevils, grain borers, rootworms, and white grubs are also a great threat to the survival of maize in Africa. In the Nigerian savannah, for example, weed-related yield losses ranging from 65 to 92% have been recorded (IITA, 2009).

The parasitic weed, known as witch weed (*Striga*) is a major pest in Sub-Saharan Africa and causes an estimated cereal grain loss of up to US$7 billion. This adversely affects the lives of about 300 million people (IITA, 2009). The limited use of nitrogenous fertilizers and declining soil fertility are major maize production constraints in Sub-Saharan Africa. The effects of prolonged droughts, such as those that have struck Eastern and Southern Africa in recent years, have been disastrous (Bolanos and Edmeades, 1996). Maize in the developing world is almost exclusively grown by small scale farmers under rain fed conditions with minimal input and management (Fakorede *et al*., 2003).

In Ethiopia Soil fertility and biotic constraints account for more of the yield gap than farm management practices. Low soil fertility is the primary constraint to maize productivity in Sub-sahan Africa, accounting for an estimated 122 kg ha^{-1} loss or seven present of the total smallholder yield gap (Gibbon *et al*. 2007). Additional soil fertility and biotic constraints such as, *Turcicum*leaf blight, weeds, grain weevils, grain borers, maize stem borer, stock borer and grey leaf spot are responsible for an estimated 272 kg ha^{-1} loss, accounting for 15% of the yield gap. Management constraints, including late planting, row spacing and weeding, account for an additional three present of the gap, resulting in an estimated loss of 54 kg ha^{-1} hectare.

2.5. Effects of Plant Density on Maize Growth Parameter

In a dense population most plants remain barren; ear and ear size remains smaller, crop be- comes susceptible to lodging, disease and pest, while plant population at sub-optimum level resulted in lower yield per unit area (Sharifi, 2016). Increasing the ridge spacing significantly recorded No. of days to 50% tasseling and silking, plant and ear heights were in some direction (*Kandil et al., 2017*). Sharifi, (2016) reported that the maximum biological yield was found at higher planting density. Planting on the 80 cm ridge was associated with a significant increase in ear length No. of kernels/row, 1000 kernel weight and grain yield (Kandil *et al*., 2017). Due to plant population density has a significant impact on growth and yield of crops, including maize, a popular C_4 cereal crop. Therefore, understanding how plants regulate their growth in response to plant population densities has problems, such as determination of optimal sowing density. Increased plant populations could lead to increased yields under optimal climatic and management conditions due to the greater number of smaller cobs per unit area (Muhidin Biya, 2019). The number and length of the internodes determine the height of the stalk. In this way, plant height can vary from 0.3 m to 7.0 m, depending on the variety and growing conditions (Gynes-Hegyi *et al*., 2002). Usually, early maturing varieties are shorter and late maturing ones are taller.

Plants that grow within a dense canopy under high plant density receive a different quality of light, enriched with far red (FR) and impoverished in red (R) radiation. This high FR/R ratio triggers many morphological changes in plant architecture, stimulating stem elongation, favouring apical dominance and decrease in stem diameter (Rajcanand Swanton, 2001). In addition, Troyer and Rosenbrook (1991) reported that stalk breakage and Ear drop page increase because crowded maize plants have smaller diameter stems and shanks due to mutual shading. Such changes make maize stalks more susceptible to breakage before kernels reach physiological maturity. Stalk lodging represents one of the most serious constraints to the use of high plant densities in maize (Argenta *et al*., 2001). Thus, many high-yielding hybrids are often rejected during development because of stalk lodging.

Result of different study indicated that sown maize plants in width rows (75 cm) produced the highest number of ear/plant, number of rows/ear and number grains/row and ear length, ear diameter, grains weight/ear, shelling percentage and 1000 grain weight. maize has multiple purposes and high yielding potential, the national average yield (3.67 ton per hector) in general and the zone yield (2.57 ton per hectare) are low as compared to developed countries' average yield which is about 6.2 ton per hector The low productivity of maize is attributed to many factors (Kebede, 2019).

2.6. Maize and It's Spacing

2.6.1. Principles and facts of plant spacing

The spatial distribution of plants in a crop community is an important determinant of yield. For sole cropping; the different aspects of plant density and spatial arrangement are well understood. 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. 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-raw spacing (Reddy, 2000). 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 inter-plant competition increases. Obviously, both factors can be adjusted to provide optimal plant spacing and typically plant density increases as row spacing decreases (Adetola, 2004). 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). 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 (Reddy, 2000).

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 produced enough leaf area to maximum light interception during vegetative growth. Secondly, medium spacing between plants affects between competitions. Hence, it will be very important to adjust the spatial distribution of the recommended population in order to have maximum yield (Reddy, 2000). The optimum density of plant population for any given situation results in mature plants that are sufficiently crowded to efficiently use resources such as water, nutrients, and sunlight, and production from the entire field is optimized.

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 (Ali *et al.*, 2010). 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 plateau level the yield declines (Singh and Singh, 2002).

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 numbers of plants stand per hectare and 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 grown under a set of particular environmental and management conditions and declines when plant density is increased above optimum level (Gozubenli *et al*., 2004).

2.6.2. 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 (Balasubramaninan 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. 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 (Singh and Singh, 2002).

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. 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 (Adetola, 2004). Generally, the most appropriate spacing is one, which enables the plants to make the best use of the conditions at their disposal. 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 (Murphy *et al.*, 1996).

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. 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). Wider spacing encourages growth of weed and thus, more labour 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).

2.7. Factors Affecting Optimum Population Density

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

2.7.1. Cultivar maturity and length of the growing season

Generally speaking; early hybrids require higher plant densities for maximum yield than late hybrids (Tollenaar, 1992). This occurs because early hybrids are normally smaller, produce less leaves, have lower leaf area per plant and present fewer self-shading problems than late cultivars.

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

2.7.2. Time of planting

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

Early planted maize also silks earlier in the growing season, when the atmospheric evaporative demand is usually smaller (Matzenauer *et al*., 1998), decreasing the probability of moisture stress, which can be another reason for early planted maize higher tolerance to increased plant population. Ethiopia has two crop growing seasons; Belg (from Februayy to April) and *Meher* (from June to

September), where rain fed agriculture is the dominant practice. In most parts of the country, the Bilge rain begins around February and ends in April, whereas the *Maher* rain stretches from June to September. After many years of high variability and low level of cereals production, the country starts recording a better performance since 2002/03. However, there is high variability of production, which could be attributable to different factors like irregularity of weather condition, change in areas harvested, use of inputs, technology and policies (FAO/WFP 2008). Maize growing period in Ethiopia is not uniform throughout the country (Regional Agricultural Trade Expansion Support Program, 2003).

Generally, it is planted during the Bilge season which stretches from February to end of Aril, in semi-arid parts of the country. In the Eastern and South eastern parts of Ethiopia, maize planting period starts in March and ends late April. Harvesting in these regions is from early November to late December. In the North western and A South western parts, maize planting starts in early May and ends June. Harvesting for this period is from late December-middle of January.

2.7.3. Water availability

Water availability is probably the most important uncontrollable factor affecting optimum plant density for maize grain yield under rain fed production systems (Loomis & Connors, 1992). Precipitation, soil water and plant population interact, particularly during the rapid growth period of the crop (from 30cm height to silking). The final effect on yield of these three interacting factors is determined by the level of soil water available to plants at the beginning of rapid growth period, by the amount and distribution of precipitation during this period and by the amount of water transpired by the canopy (Matzenauer *et al*,. 1998). Increasing plant density increases leaf area index and consequently water consumption (TetioKagho& Gardner, 1988a). Therefore, the use of high plant populations under limited water supply may increase plant water stress and dramatically reduce grain yield, especially if a water shortage coincides with the period of 2-3 weeks bracketing silking (Westgate, 1994).

Even though the increase in water use as plant density is raised is not proportional to the stand increase, small deficits during critical stages, especially at flowering, can drastically reduce kernel set and grain yield. Shallow soil profiles, high atmospheric temperatures and irregular precipitation distribution favour drought stress.

3. MATERIALS AND METHODS

3.1. Description of Experimental Site

The trial was conducted in Kersa District. Gola Wachu kebele Eastern Hararghe Zone , Oromia Regional State Ethiopia during the 2023 main cropping season. The District is 51 km far from Harar City in the West direction. Situated at latitude between 9° 24’ and 9° 14.6’ East North and longitude between 41° 37’ and 41° 8.75’ East, in mid-highland and the altitude ranges from 1550 - 2500 meters above sea level (Figure 1). Climatically, the district is classified into Degas (20%), Woina dega (74%) and kola (6%) agro climatic zones. As in the most of the Horn of Africa, two rainy seasons characterize the Kersa District climate. The first named Belg, which is the shortest one and takes place between March and April, while the second and the most important is Meher between June and September. The rainfall distribution during the year is then bi-modal, with a dry-spell period during the months of May which, depending on its duration, may affect crop growth. The soil type is sand with clay loam texture. The average rainfall (803 mm). The temperature of the area is, ranging from 18 to 26°C (KNRAO, 2018). Major cereal crops grown in the study area are maize, sorghum, wheat. Commonly maize is the staple crop cultivated by farmers, in the locality of the site.

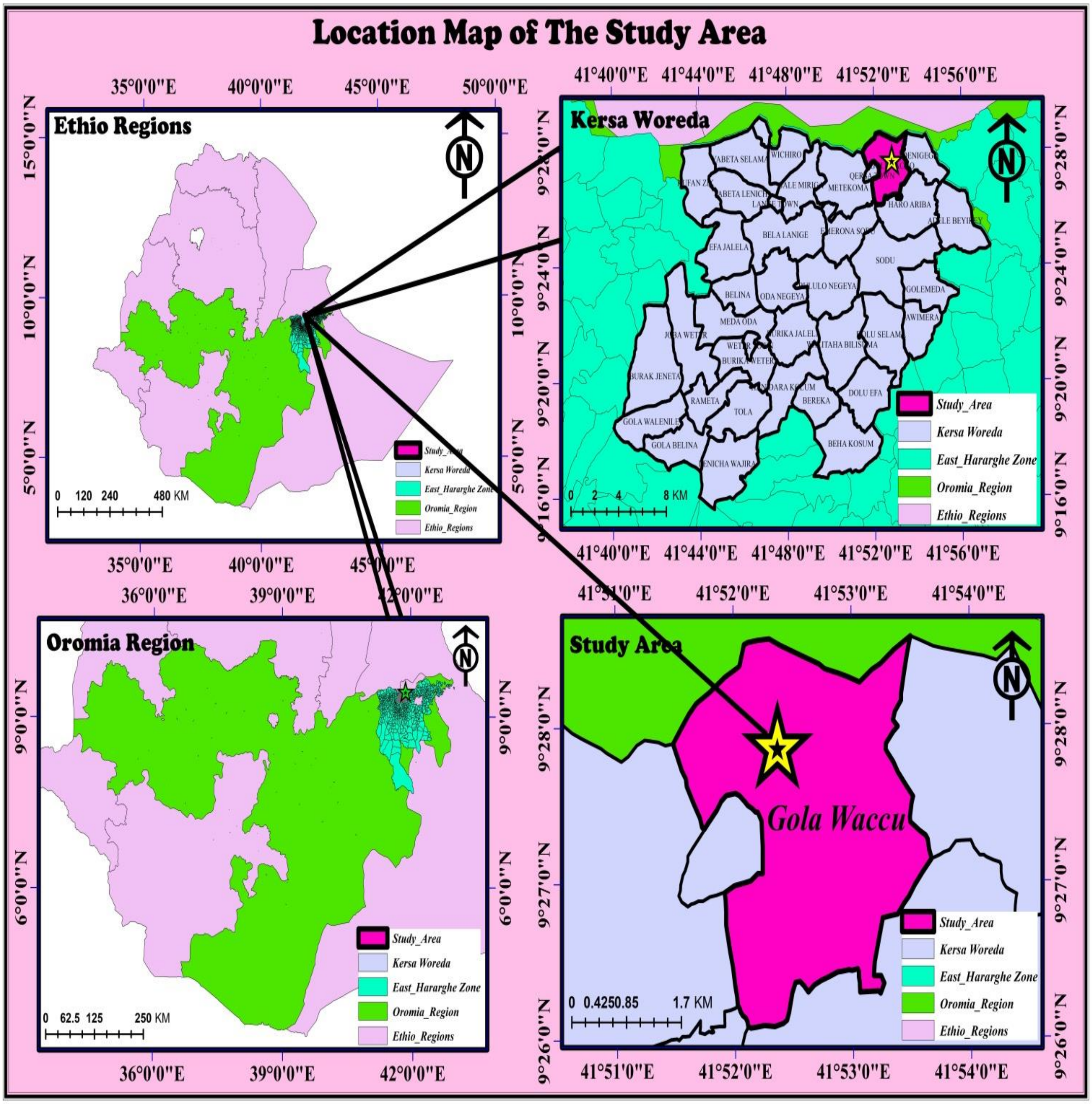

Figure 1. Map of Study Area

Metrological Data of The Study Area

Table 1: Temperature Data of The Study Area

Month	***Temperature (°c)***		
	Min	**Max**	**Avg**
January	16.9	15.3	16.1
February	17.6	15.8	16.7
March	18.8	16.9	17.85
April	19.7	17.9	18.8
May	20.3	18.4	19.35
June	20.1	18.1	19.1
July	18.7	16.8	17.75
August	18.1	16.4	17.25
September	18.8	17.1	17.95
October	18.5	16.6	17.55
November	17.6	15.9	16.75
December	17.2	15.6	16.4

Source: WorldClim Data 2024

Table 2: Rainfall Data of The Study Area

Month	***Rainfall (mm)***		
	Min	**Max**	**Avg**
January	19	18	19
February	26	25	26
March	60	59	60
April	99	91	95
May	105	95	100
June	59	56	58
July	126	115	121
August	173	154	164
September	98	92	95
October	46	44	45
November	19	15	17
December	6	6	6
Total	**836**	**770**	**803**

Source: WorldClim Data 2024

3.2. Description of Experimental Materials

The maize variety BH661 was used in the study area. It is released in 2011 from Bako research canter. The productivity on research and on farm is 95-120 and 65-85 quintal per hectare, respectively. The variety requires the amount of rainfall that ranges from 1000 to 1500 mm annually and potential to grow in altitude range from (1600 to 2200 m.a.s.l.

3.3. Treatments and Experimental Design

The treatments consisted of three inter-rows spacing (75, 65 and 55 cm) and five intra-rows spacing (40, 35, 30, 25 and 20 cm). The gross plot size was 4 *3 m = (12m^2) accommodating 5, 6 and 7 rows for 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 1m wide space and each plot was separated by 0.50 cm 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 20 cm, 25 cm, 30cm, 35 cm, and 40 cm, was 1.4 m 1.6 m 1.8m 2m and 2.2m respectively and the width for inter-row spacing of 75.65, and 55 cm was 3 m 2.75 and 2.6 m respectively .The central rows left aside for data recording was 3, 4 and 5, rows for 75, 65, and 55 cm inter- respectively.

Table 3: Details of Treatment Combination, descriptions of plant densities, net plot. gross plot and population plants h[1]

Eastern harerghe zone kersa district during, 2023 main cropping season .

Treatments	***Inter and intra-row spacing (cm)***	***No of Plant per Row***	***No rows***	***Plant Density (m^2)***	***Dimension of Gross Plot (WxL)***	***Net Area (No of Rows x L x W) (m^2)***	***Plant Population h^{-1}***
T1	55x20cm	15	7	105	3.6m^2	2.54m^2	90900
T2	55x25cm	12	7	84	4.16m^2	2.92m^2	72720
T3	55x30cm	10	7	70	4.68m^2	3.27m^2	60600
T4	55x35cm	9	7	63	5.2m^2	3,64m^2	51943
T5	55x40cm	8	7	56	5.72m^2	4.0m^2	45450
T6	65x20cm	15	6	90	3.85m^2	2.31m^2	76900
T7	65x25cm	12	6	72	4.4m^2	2.64m^2	61520
T8	65x30cm	10	6	60	4.84m^2	2.97m^2	51267
T9	65x35cm	9	6	54	5,5m^2	3.3m^2	43943
T10	65x40cm	8	6	48	6.6m^2	3.6m^2	38450
T11	75x20cm	15	5	75	4.2m^2	2.1m^2	66650
T12	75x25cm	12	5	60	4.8m^2	2.4m^2	53320
T13	75x30cm	10	5	50	5.4m^2	2.7m^2	44444
T14	75x35cm	9	5	45	6m^2	3.0m^2	38086
T15	75x40cm	8	5	40	6.6m^2	3.3m^2	33325

3.4. Experimental Procedures and Management

Prior to sowing, the land was well prepared by repeated plugging 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 P_2O_5 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, were applied to all treatments as per recommended.

3.5 Soil analysis

3.5.1. 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 cat ion 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 (Tegegn, Fikeremariam, Tamiru Dejen, Brehanu Woldu, Getnet Belay, and Adem Kedir. P(2020). Available phosphorus was determined by the Olsen's method using a spectrophotometer (Olsen et al., 1954). Cat ion exchange capacity (CEC) was determined after saturating the soil with 1N ammonium acetate (NH4OAc) and displacing it with 1N NaOAc (Chapman, 1965).

3.6. Data Collection

3.6.1. Phonological parameters

Days to 50% an thesis (DA): was recorded from the number of days from planting to the start of shedding of pollen by 50% of the maize plants in a net plot reached the respective phonological stage.

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

Days to 90% Physiological Maturity: number of days when 90% of the plant in the plot formed black layer.

3.6.2. Growth parameters

Leaf area: All available leaves of five plants per net plot were collected at 50% milk stage and leaf length and width were measured and leaf area was calculated 0.733 x leaf length x maximum leaf width (Francis *et al*., 1969; Pearce *et al*., 1975).

Leaf area index (LAI): It was calculated as the ratio of total leaf area per five plants (cm^2) per area of land occupied by the plants (Diwaker and Oswalt, 1992).

Plant height (cm): it was measured at ground level to terminal stem using measuring stick at the point where the tassel starts branching from five randomly selected plants.

3.7. Yield and Yield Component

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

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

Ear length (cm): It was the measure from the point at the ear attached to the stem of the ear from ten randomly taken ears in the central net plot at the crop harvested

Number of rows per cobs: It was recorded from the average of the ten randomly taken ears per plot. It was collected by manually counting the normal rows and averaged was taken.

Thousand Seed weight (g): thousand seeds were counted from a bulk of shelled grains from a net plot and weighted using sensitive balance adjusted to 12.5% moisture level.

Above ground dry biomass (AGDB) (kg ha^{-1}) 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.

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

Harvest index It was calculated as the ratio of grain yield to aboveground dry biomass per net plot and multiplied by 100.

3 .8 Data Analysis

Data collected were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD according to General Linear Model (GLM) of GenStat 16thEdition (GenStat, 2013). Interpretations were made following the procedure described by Gomez and Gomez (1984). The differences between treatment means was compared using Least Significant Difference (LSD) test at a 5% level of significance when the ANOVA showed the presence of significant difference.

4. RESULTS AND DISCUSSION

4.1. Soil Physico-chemical Properties of the Experimental Site

The results revealed that the percentages of sand, silt, and clay were 63.5%, 14.5%, and 20.5%, respectively (Table 1). With a pH of 7.4, the soil is almost neutral and has a sandy clay loam texture. Given that maize thrive in well-drained soil with a sandy loam texture and a pH range of 5.5 to 7.3, the soil's texture and pH are ideal for maize cultivation accordance with Bouyoucos (1962)'s classification. Tekalign (1991) categorized soil's total nitrogen availability into five groups: < 0.1% very low, 0.1-0.2% low, 0.2-0.5% moderate, 0.5–1 high, and >1% very high. The analysis indicated that 0.06% of the total nitrogen was present (Table 1). This suggests that maize plants highly exhausted nutrient for high standing and good yields. Therefore, experimental site require the application of nitrogen fertilizers at planting time.

The soil's cat ion exchange capacity, which is the amount of negative charge per unit weight of soil or the number of cat ions that a certain sample of soil might carry in an exchangeable size, was found to be 23.42 cmol (+) kg-1, or (meq /100 g soil) (Table 1). Landon (1991) categorized CEC as follows: < 6, 6–12, 12–25, 25–40, > 40 cmol (+)/kg, corresponding to very low, low, moderate, high, and very high. As a result, the research site's CEC was moderate.

Tekalign (1991) classified amount soils Phosphorus: as low, medium, high, or extremely high depending on the <10, 11-31, 32-56, and >56 ppm. The analysis also revealed that the research site's available P level was medium, at 11.2 ppm. The results of the research area soil indicated that the overall quantity of available soil S level was low (5.10 ppm) (Ethio SIS, 2014). Murphy (2007) categorized the percentages of soil organic carbon as very low, low, medium, high, and very high, respectively, for values of less than 0.60, 0.60–1.0, 1.0–1.80, 1.80–3.0, and > 3. As a result according to this evaluation, the research area's organic carbon content was (0.71), suggesting low percentages of soil organic carbon as well as low levels of total N and available soil S. In general, the soil in this area shows a need for soil amendment and a supply of nutrient sources.

Table 4: Soil physical and chemical properties of the experimental site before planting

Properties	Result	Rating	References
1. Physical properties (%)			-
Sand (%)	63.5	-	-
Silt (%)	14.5	-	-
Clay (%)	20.5	-	-
Textural class	Sandy clay loam		Bouyoucos (1962)
2.Chemical Properties			
pH (1: 2.5 H2O)	7.9	Neutral	(Tekalign, 1991)
/Organic carbon (%)	0.71	low	(Murphy, 2007)
CEC (Cmol (+)kg-1)	23.43	Medium	(Landon, 1991)
Total N (%)	0.06	Very low	(Tekalign, 1991)
Available Phosphorus[olsen][mg/kg]	11.2	Medium	(Tekalign 1991)
Available Sulfur[ppm]	5.11	Very low	(EthioSIS, 2014)
3. Exchangeable Bases			
Ca (cmol (+)/kg soil	6.11	Medium	(FAO, 2006)
Mg (cmol (+)/kg soil)	3.33	High	(FAO, 2006)
K (cmol (+)/kg soil)	1.08	High	(FAO, 2006)

4.2. Phonological Parameters

4.2.1. Days to 50 % An thesis

Analysis of variance revealed that the interaction effects of inter and intra-row spacing on days to 50% anthesis was significantly affect ($P<0.05$) whereas, the main effects of inter and intra row spacing also significant effects on days to 50% anthesis (AppendixTable 1). The delayed days to anthesis (79.55 days) was recorded from the interaction effects of (75 *40 cm).whereas, the shortest days of 50% anthesis (74.70) days were recorded from the interaction effect (55*20 cm) Days to 50% anthesis decreased by about 4.80 days in the 55*20 cm inter and intra row spacing as compared with 75*40 cm. This could be due to higher competition of plants for resource in the closer spacing that lead the plants to stress and ultimately the plants anthesis early instead of prolonged vegetative growth. In agreement, with these results, Abdulatif, (2002) also indicated that maize required longer mean flowering days with a lower population density of (30,952 plants ha^{-1}), followed by the mean (34,111 plants ha^{-1}) maize plant density Comparable to this effect, Hamid and Nasab. (2001) showed that increases in plant densities and the duration of the vegetative and reproductive period are significantly decrease comparatively shorter periods than those that were planted with lower density. The result of the present investigation has consistency with previous findings reported by Tahir (2021) who concluded that closer spacing had shortened days to maturity as compared to wider spacing. In line with this result Nure and Jara (2021) reported that closer spacing has shortest days to anthesis than wider spacing plants.

4.2.2. Days to 50% silking

Analysis of result showed that the interaction effects of inter and intra-row spacing were highly significant effect ($p<0.001$) on days to 50% silking whereas the main effects were significantly affect ($p<0.05$) 0n days to 50% silking. (AppendixTable 1).

The delayed days to 50% silking (83.87 days were recorded from the interaction of 75 *40 cm inter and intra-row spacing, whereas the lowest days to 50% silking (78.33) days were recorded from the interaction effects of 55*20. The delayed silk formation in the low plant density due to less competition for growth factors, more vegetative growth, which ultimately delayed the days until silk formation., Similarly, with increasing plant density from 57,000 plant ha^{-1} to 99,000 plant ha^{-1}, the number of days until 50% silk formation was decrease in four days and the longest days until silking (78.38) was obtained 99,000 plant ha^{-1} (Mahmood *et al* , 2001).The highest days up to 50% silking were recorded with increasing row spacing, with the highest days up to silking (84.07 days) being recorded at 85 cm row spacing, while the narrowest row spacing of 55 cm was recorded at the earliest in days up to silking (78. 80) days (Nure and Jara, 2021)

4.2.3. Days to 90% physiological maturity

The analysis of results indicated that the interaction effect of inter and intra row spacing had highly significantly influenced days to 90% maturity ($p<0.001$) whereas, the main effects inter and intra-row spacing had significantly ($P<0.05$) on days to 90% physiological maturity (Appendix Table 1). Maximum days to physiological maturity (153.33 days) were recorded from the interaction of 75*40 cm inter and intra row spacing. Whereas, the shortest days to physiological maturity (144.7 days) was recorded from the interaction effects of 55*20 cm. (Table 5) This may be due to plants in the high population density matured the earliest, while plants at the lower population density matured lately because of high competition for light, soil moisture and nutrients , in higher population density and days to anthesis, days to silking and physiological maturity of plants were earlier in higher plant population density than lower plant population density. The result of the present investigation has consistency with previous findings reported by Tahir (2021) who concluded that closer spacing had shortened days to maturity as compared to wider spacing.

Table 5: Interaction effect of intra and inter row spacing on Phenological Parameter of maize Eastern Harerghe Zone Kersa District during 2023 main cropping Season

Treatment		**Phonological Parameter**		
Inter row spacing (cm)	Intra-row	DA	DS	PM
55	20	74.70[d]	78.33[d]	144.7[d]
	25	76.01[c]	79.43[c]	145.7[c]
	30	76,54[c]	80.55[b]	147[bc]
	35	76.99[c]	81.23[b]	148.4[b]
	40	76.67[c]	81.21[b]	148.2[b]
65	20	76.5[c]	79.5[c]	145.6[c]
	25	77.82[b]	79.87[c]	144.8[d]
	30	77.34[b]	80.98[b]	147.5[bc]
	35	77.95[b]	81.76[b]	149.9[b]
	40	77.92[b]	82.33[ab]	148.56[b]
75	20	75.53[d]	80.5[b]	145.5[c]
	25	76.67[c]	81.33[b]	146.7[c]
	30	77,98[b]	81.67[b]	150.12[ab]
	35	78.93[a]	83.22[a]	152.5[ab]
	40	79.55[a]	83,87[a]	153.33[a]
LSD (5%)		0.779	0.679	0.608
CV		10.1	5.7	7.2

Means sharing the same letter within a column are not significantly different according to L.S.D at 5% least significance of difference at 5%; CV= Coefficient of variation; PM= physiological maturity, DS= Days to silking. DA= Days to anthesis.

4.3. Growth Parameter

4.3.1. Leaf area

The interaction effects of both intra and inter-row spacing on leaf area were significant effect on ($P<0.05$) on leaf area and also the main effect of intra and inter-row spacing ware significant effect ($P< 0.05$) leaf area[Appendex Table 2]. The highest leaf area per plant (1398.48 cm^2) was recorded at inter-row and intra row spacing of 75*40 cm, while the lowest (1147.67 cm^2) was at 55*20 cm inter and intra row spacing (Table 6). In general leaf area per plant was increased with increasing inter and intra-row spacing (from 55*20 cm to 75*40 cm). The higher leaf area per plant 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 agreed with Lakew *et al*. (2016), who reported the highest leaf area per plant of 7338.4 cm^2, was obtained from the widest inters row spacing of 30 cm, while the lowest (6732.3 cm^2) was measured at the narrowest inters row spacing of 20 cm maize. In addition, Sangoi (1998) showed that with a inter row spacing of 75 cm a larger leaf area of maize (7258 cm^2) was achieved than with inter row spacing 50 cm (6118 cm^2). This result in agreement with Nure and Jara (2021) showed that higher leaf area of maize (8392 cm^2) was attained at row spacing of 75 cm than at 50 cm row spacing (7557 cm^2).

4.3.2. Leaf area index (LAI)

The analysis of the variance revealed that LAI was highly significantly affected by interaction effect ($P<0.01$) of intra and inter row spacing were as the main effects both inter and intra row spacing had significantly effects ($p< 0.05$) on leaf area index (Appendix Table 2). Numerically treatments having maize planted at 55 *20 cm spacing produced higher LAI (4.48). But its effect was statistically significant from the treatment combination of 55*25, 75*20, 65*20 and 65*25 cm. The lowest LAI (3.01) was obtained from interaction effects of (75*40 cm) (Table 6) which is statistically par with 65*40 cm. The highest leaf are index recorded at closer spacing could be due to high number of plants per unit area that produce more number of leaves creates mutual shedding in closest spacing ,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 as ,the minimum leaf area index occurred at the widest spacing . Similarly, Abuzar, (2012) 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}. According to Saberali (2007) in high maize density leaf area index was increased as compared to low maize density throughout crop growth season. In contrast to leaf area index, the closest row spacing of 55 cm resulted in a maximum leaf area index (4.617), while the lowest leaf area index (3.680) was recorded below the widest row spacing of 85 cm (Nure and Jara, 2021).Amona (2014)also showed that the highest leaf area index (4.19) was obtained at the narrowest plant spacing (55 cm × 25 cm) and the lowest leaf area index (2.67) at the widest plant spacing (75 cm × 30 cm) of maize.

4.3.3. Plant height

The analysis of the results revealed that the interaction effects of inter and intra row spacing significantly affected ($P<0.05$) on plant height of maize and the main effects of both inter and intra row spacing had significantly effects ($p<0.0500$) on plant height. (Appendix Table 2). Numerically among the treatments, the highest plant height (264.55 cm) was recorded from the interaction effects of (55*20 cm). The shortest plant height (239.3 cm) was recorded from the interaction effects of (75*40 cm) . Highest plant height in closer inter and intra row spacing there might be due to the presence of higher competition for sun light, crowding effect of the plant and other resources that decrease in the stem diameter and number of green leaves. Higher plant height at narrow spacing could also be explained that when the plants are sown closely, their stems are shaded from light resulting in accumulation of auxin (a growth hormone) that stimulates cell division and elongation of internodes, thereby increase in height. Consistent with the result, Mathews *et al*. (2008) reported that maize planted with a plant spacing of 25 cm and a row spacing of 50 cm had significantly taller plants than those planted with a plant spacing of 30 cm and a row spacing of 75 cm.

While, in widely spaced plants, auxin destruction by light occurs resulting in plants being shorter in height (Mureithi *et al*., 2012). This result agreed with the findings of Hunduma and Tamirat (2022); Zeleke *et al*., (2018); Imran *et al*., (2015); Adeniyan (2014).

The results explained that the number of plants increased in a given area, the competition among the plants for nutrients uptake and sunlight interception also increased (Nure and Jara 2021). These finding is in agreement with Tahir (2021) who revealed that plant height decreased with increasing inter and intra row plant spacing density.

Table 6: Interaction effects of inter and intra-row spacing on growth parameters

Eastern Harerge Zone Kersa District during 2023 main cropping season

Treatment	**Growth Parameter**			
Inter row spacing (cm)	Intra-row	LA	LAI	PH (cm)
55	20	1147.6[d]	4.48[a]	264.55[a]
	25	1256.9[abc]	4.01[ab]	258.66[ab]
	30	1250.1[abc]	3.82[b]	251.22[b]
	35	1255.9[abc]	3.45[b]	243.77[c]
	40	1258.7[abc]	3.22[c]	243.69[c]
65	20	1147.67[d]	4.14[ab]	258.16[ab]
	25	1246.93[abc]	4.02[ab]	256.91[b]
	30	1250.13[abc]	3..84[b]	254.08[b]
	35	1256.93[abc]	3.25[c]	252.08[b]
	40	1311.14[ab]	3.1[c]	249.31[bc]
75	20	1201.60[c]	4.01[ab]	253.16[b]
	25	1291.67[b]	3.9[b]	251.91[b]
	30	1297.13[ab]	3.7[b]	244.08[c]
	35	1298.48[a]	3.33[c]	242.08[c]
	40	1398.5[a]	3.01[c]	239.8[d]
LSD (5%)		76.0	0.779	1.96
CV		3.65	10.1	7.2

Means sharing the same letter with in a column are not significantly different according to LS.D at 5% least significance of difference at 5%; CV= coefficient of variation LA=leaf area LAI =leaf area index PH= plant height

4.4. Yield and Yield Components

4.4.1. Number of ear per plant

The analysis of result showed that the interaction effect of inter and intra row spacing were significant effects ($P<0.001$) on the number of ear per plants (Appendix Table 3).Also the main effects of inter and intra row spacing were significant ($p<0.05$) on the numbers of ear per plant The highest number of ear per plants (1.88) was recorded from the 75x40 cm inter and intera row spacing. Whereas; the lowest number of ear per plants (1.39) was recorded from the 55x20 cm intra and inter-row spacing. This might be due to inter plant competition of ear per plants was increase at narrow plant spacing. Due to in efficiently use of growth factors like light, nutrients. Similarly, with result Abuzer *et al*. (2011) reported that increasing plant density by reducing plant spacing significantly reduced the number of ears per plant due to the decreased supply of nitrogen, photosynthesis and water to the growing ears. Similarly, Dalley *et al*. (2006), and. Shafi *et al.*, (2012) reported that wider-spaced maize plants obtained more soil moisture and nutrients that led to having a high number of ears per plant than narrow spacing. Zamir *et al*., (2011) also reported that with decreasing of plant spacing from 30 cm to 15 cm, the number of ears per plant was significantly reduced from 1.42 to 1.21 possibly due to more competition for light, aeration and nutrients and consequent

On the other hand the main effects of intra-row spacing significant (P<0.05) effect on number of ear per plants. The highest number of ear per plants (1.87)was recorded from the 35 cm whereas, the lowest number of ear per plants (1.51)were recorded from the 20 cm intra row spacing. This might be due wider intra-row spacing had maximum ear per plant because of availability of more resources and competition is less when we compared with narrow row spacing for nutrients, sunlight and soil moisture These finding are in agreement with Hashemi-Dezfouli and Herbert (1992) who reported a significantly higher number of ear per plant at lower plant density as compared to higher plant density.

4.4.2. Ear diameter

The analysis of the result revealed that interaction effects of intra and inter row spacing had highly significant effect (P<0.001) on ear diameter and were as the main effects inter and intra row spacing had significantly effects (p<0.05) on ear diameter (Appendix Table 3) Statistically mean thickest value of ear diameter (4.99) were recorded from 75x40 cm inter and intra row spacing; while the thinnest ear diameter (4.33d) was recorded from 55x20 cm intra and inter-row spacing (Table 7). Wider inter and intra row spacing had maximum ear diameter because of availability of more resources and competition is less when we compared with narrow row spacing for nutrients, sun light and soil moisture and high net assimilation rate and favourable assimilate portioning from the source to the sink resulting enhanced healty,thick cobs and high seed production These finding was in contrary with Arif *et al*. (2010) and Zamir *et al*. (2010) who reported that inter and intra row spacing interaction did not show significant difference on ear diameter.

On the other hand the main effects of intra-row spacing was significant effect($p< 0.05$) on ear diameter. The highest ear diameter (4.98)was recorded from the 35 cm intra row spacing. which is not statistically significant effects 40 cm (4.96) whereas; the lowest ear diameters (4.03)were recorded from the 20 cm intra row spacing. This might be due wider intra row spacing had maximum ear diameter because of availability of more resources and competition is less when we compared with narrow row spacing for nutrients, sunlight and soil moisture. These finding was in contrary with Arif *et al*. (2010) and Zamir *et al*. (2010) who reported that inter and intra row spacing interaction did not show significant difference on ear diameter.

4.4.3. Ear length (cm)

The interaction effects of inters and intra-row spacing were indicated that significant effect ($P< 0.001$) on ear length of maize. Also the main effects of inter and intra-row spacing were significant effect ($p<0.05$) on ear length of maize (appendix table 3). The result revealed that highest ear length (19.99cm) was recorded from 75x40 cm interaction effect of inter and intra row spacing and lower plant densities whereas the shorter ear length (16.7 cm) was recorded from higher plant densities 55x20 cm interaction effect . Higher plant populations can also reduce the amount of light that reaches individual plants and insufficient light can impair photosynthesis and subsequently affect ear size and overall yield.

As the relationship between plant density and light availability is crucial for understanding ear development in maize (Brad *et al*., 2020). This result agreed with results of Mandic *et al.,* (2016); Adeniyan (2014) and Shafi *et al.,* (2012) who reported that ear length decreased with increasing plant population.In the case of row spacing, Zamir *et al*. (2011) reported that the cob length decreased when the plant population increased significantly. The results agreed with the findings of Gobeze *et al*. (2012), who found that an increase in plant density from 5 to 15 plants (m^{-2}) reduced the ear length of maize from 17.0 to 12.23 cm. Similarly, the result agreed with the results of Donatus *et al*. (2014), who found that increasing the plant population from 57,142 to 100,000 plants ha^{-1} reduced the ear length of maize from 18.39 to 15.64 cm. Concerning to intra-row spacing, the maximum ear length (18.7 cm) was recorded at a spacing of 30 cm, Conversely, the minimum ear length of (17.5 cm) was recorded from at an intra-row spacing of 20 cm. This might be due to an increase in cell elongation and more vegetative growth attributed to crop requirements of the wider intra-row than narrow intra-row spacing. This result agreed with the finding of Orebo *et al.*, (2021), who reported that ear length increased with decreasing plant population.

Table 7: Interaction effects of inter and intra row spacing on number of ear per plant, ear diameter and ear length (cm) Eastern Hararghe Zone Kersa district 2023 main cropping season

Treatment		**Yield and yield components**		
Inter row spacing (cm)	Intra-row(cm)	No of Ear/plant	Ear Diameter(d)	Ear Length (cm)
55	20	1.33[f]	4.33[d]	16.7
	25	1.37[f]	4.37[d]	16.8[c]
	30	1.42[f]	4.52[cd]	17.3[c]
	35	1.57[f]	4.55[cd]	17.6[c]
	40	1.61[cd]	4.58[cd]	18.1[bc]
65	20	1.63[cd]	4.66[c]	18.0[bc]
	25	1.65[cd]	4.68[c]	18.44[b]
	30	1.68[c]	4.75[b]	18.73[b]
	35	1.70[c]	4.79[b]	18.92[b]
	40	1.72[c]	4.82[ab]	19.54[ab]
75	20	1.74[c]	4.83[ab]	19.65[ab]
	25	1.86[b]	4.89[ab]	19.87[ab]
	30	1.86[b]	4.96[a]	19 .95[a]
	35	1.87[b]	4.98[a]	19.97[a]
	40	1.88[a]	4.99[a]	19.99[a]
LSD (5%)		0.415	0.086	2.11
CV		12.6	2.3	3.21

Means sharing the same letter with in a column are not significantly different according to LS.D at 5% least significance of difference at 5%; CV= coefficient of variation NEPP = a number of ear per plant ED =ear die meter EL =ear length

4.4.4. Number of kernel per ear

The interaction effect of inter and intra row spacing were highly significantly ($p<0.01$) influenced number of kernel per ear whereas, the main effects both inter and intra row spacing had significantly($p<0.05$) effects on numbers of kernel per ear (Appendix Table 3). Maximum number of kernel per ear (428.5) was recorded from spacing combination of 75*25 cm. But its effect was not statistically significant from the treatment combination of 75*35 cm, and 75*40 cm. while minimum number of kernel per ear (388.2) was recorded from 55*20 cm (Table 8). The highest number of kernel per ear recorded at wider spacing could be due to high utilization of growth factors plants per unit area that creates high photosynthetic in wider spacing that leads to higher number of kernel per ear. The lowest number of grains per ear at high plant density might be due to high competition for the resources such as light, moisture and fertilizer or due to less availability of nutrients to grain formation. This result agreed with the findings of Mandic *et al.*, (2016); Dawadi and Sah (2012) and Abuzar *et al* (2011) who reported that number of grains per ear decreased with increasing planting density. This result was also in agreement with Tahir (2021) who concluded that grain number per cob was highest at wider plant spacing compared with lower plant spacing.

Larger distances between the rows in the number of kernels per ear; which leads to less competition between the plants for the growth resource, which is manifested in a high number of kernels per ear. Consistent with this finding, Eskandarneja *et al* (2013) reported that a row spacing of 30 cm produced more grains per ear than this 20 cm plant spacing. Abuzar *et al*. (2011) observed that an increase in plant density decreased the number of kernel per ear.

4.4.5. Thousand Kernels weight

Grain weight is an important component of the yield that is very helpful in estimating the grain yield. The analysis of the results revealed that both the main factors and their interaction showed significant affect ($P<0.05$) on thousand kernel weight (Appendix Table 4). The highest thousand kernel weight (407.8g) was recorded from treatment combination of (75*30 cm) But its effect was not statistically significant from the treatment combination of 75*35 (Table 8). However, the lowest thousand kernel weight (336.5 g) was recorded from the interaction effects of 55*20 cm plant spacing. The decrease in weight of 1000 seeds could be attributed to the decrease in assimilate division among seeds as a result of increased competition between plants in utilizing environmental inputs in building a large amount of metabolites for use in developing new tissues, thereby reducing weight. in case of wider spacing plants that improved the supply and portioning of assimilates from source to sink to be stored in the grains and it might be the reason for producing higher seed weight .The result agreed with Daud Abdi and Tahir.(2020)who reported that the weight of 1000 grains decreased with increasing plant density.

From this study it has been observed that decreased plant densities from 55*20 to 75*30 cm spacing increased thousand kernel weights significantly. This implies that maize plants planted at

75*30 cm inter and intra-row spacing developed wider canopy due to enough inter and intra row spacing, low inter plant competition to resources like light and nutrients. As the plant increase in their canopy they have the chance to intercept light, high net assimilation rate that increase thousand kernel weight. This result agreed with the finding of Nure and Jara (2021), who reported that an increase plant spacing to optimum significantly increased the thousand grain weight of the maize. This finding is in agreement with (Arif, *et al*., 2010), who reported that corresponding reduction of TSW with increasing plant density was due to unfavourable growing conditions such as less aeration, light penetration and mineral nutrient availability at a high plant density.

4.4.6. Above ground dry biomass yield (kg ha^{-1})

Statistical analysis of the result revealed that both interaction and main effects of inter and intra row spacing had highly significantly affected ($p<0.001$) on above ground biomass yield (Appendix Table 4). Maximum above ground biomass yield (25074.55 kg ha^{-1}) from 55*20 cm and lowest above ground biomass (14926.4 kg ha^{-1}) were recorded from (75*40 cm) (Table 8).

The mean above ground biomass yield increased with increasing in plant density. This could be due to a higher plant population recorded with close spacing between and within rows and thus higher dry matter production. Consistent with this finding, Mahmood *et al*. (2001) showed that the total biomass yields of maize in the narrow row spacing (20 cm) were significantly higher than in the wider row spacing (30 cm) due to the higher number of taller plants per unit area and the better interception of solar radiation, and plant height also directly contributed to bio mass yield increment.

This result in line with Imran *et al.,* (2015), who reported that higher above ground dry biomass yields were obtained from higher planting density. These results were in agreement with Bullock *et al*. (1998) who reported that narrow row spacing made more efficient use of available light and shaded the surface soil more completely during the early part of the growing season while the soil is still moist and therefore, narrow row spacing are more effective in producing biomass.

Table 8: Interaction effects of inter- and intra-row spacing on number of kernel per ear, thousand kernels weight and above ground biomass Eastern Harerghe Zone, kersa district in 2023 main cropping season

Treatment		**Growth Parameter**		
Inter row spacing **(cm)**	**Intra-**	**NKPE**	**TKW**	**AGDBM**
55	20	388.2^{d}	336.5^{e}	25074.55^{a}
	25	392.93^{c}	372.2^{c}	21262.6^{b}
	30	398.13^{c}	390.3^{bc}	20341.2^{b}
	35	407.9^{b}	386.5^{c}	20143.7^{b}
	40	409.4^{b}	371.4^{c}	19734bc
65	20	393.5^{c}	366.5^{d}	21263.16^{b}
	25	416.3^{a}	380.4^{c}	20156.91^{b}
	30	411.1^{b}	401.9^{ab}	19035.08^{bc}
	35	419.3^{ab}	398.3^{b}	18132^{c}
	40	412^{b}	391.2^{b}	17967^{c}
75	20	417.8^{b}	390.7^{b}	17125.6^{cd}
	25	428.5^{a}	396.7^{b}	17126^{cd}
	30	423.6^{a}	**407.7^{a}**	15867.5^{d}
	35	425.8^{a}	405.9^{ab}	15245.1^{d}
	40	424.5^{a}	395.9^{b}	14926.4^{e}
LSD (5%)		1.85	0.779	252.5
CV		3.65	10.1	5.2

Means sharing the same letter within a column are not significantly different according to L.S.D at 5% least significance of difference at 5%; CV= coefficient of variation; NKPE= Number of kernel per ear, Intra row spacing= IRS, TKW= thousand kernel weight AGDBM=Above ground dry biomass yield.

4.4.7. Grain yield (kg ha^{-1})

Grain yield is the end result of many complex morphological and physiological processes occurring during the growth and development of the crop. The interaction effects of inter and intra-row spacing were significant effect (P<0.05) on grain yield while as, the main effect of inter and intra-row spacing were also significant effect (p<0.05} on grain yield (Appendix Table 4). The highest grain yields (7021.0 kg ha^{-1}) recorded from the treatment combination of 75*25 cm which is not statistical significant difference from the treatment combination of the (75*30 cm) On the other hand, the lowest mean yield of (5250.13 kg ha^{-1}) were recorded from the interaction effects (55*20 cm) The higher grain yield at optimum planting densities might be due to the availability of more nutrients which led to more growth and higher assimilates translocation to grains. This result disagreed with the findings of Chalchissa, Chala, and Bahiru Addisu Mideksa Chala. (2023) who reported that grain yield of maize increased with increasing plant density of 53,300 plants ha^{-1} to 99,900 plants ha^{-1}. This might be due to in the wider inter and intra row spacing resulted in higher utilization of growth factors results higher grain yield ha^{-1}. 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. Maize harvest index typically decreases when the plant densities are above optimal, as the intra specific competition reduces the distribution of the biomass on the ears (Pagano *et al*., 2007). These finding was contrast with Farnham (2001) who reported that maize grain yield increased as plant density increased from 59,000 to 89,000 plant ha^{-1} and contrary with Abuzar *et al*. (2011) who observed the minimum grain yield at the highest population. Similarly to above result maize is more sensitive to variations in plant density than other members of the grass family mainly due to lack of tillering, just opposite of other members of the grass family, cannot compensate for low leaf area and very few numbers of reproductive units by branching (Gardner *et al*., 1985). Sarlangue *et al*. (2007) reported the maize grain yield was significantly influenced by the planting densities

Table 9: Interaction effects of Inter- and Intra-row spacing on grain yield (kg ha^{-1}) of maize Eastern Harerghe Zone Kersa district during 2023 main cropping season

Treatment	**Inter-row spacing (cm)**		
Intra-row spacing (cm)	55	65	75
20	5250.13^{c}	5315.13^{c}	6811.3^{bc}
25	5621.0^{b}	5721.0^{b}	7021.0^{a}
30	5756.93^{a}	6056.9^{a}	6956.9^{b}
35	5733.2^{ab}	5965.9^{b}	6811.5^{bc}
40	5550.55^{c}	5515.13^{c}	6713.7^{c}
LSD	257		
CV	3.77		

Means of the same letters indicated that no significance difference LSD =Least significance difference at 5% significance level CV= Coefficient of variation

4.4. 8. Harvest index (HI)

The harvest index indicates the physiological efficiency and ability of a culture to convert total dry matter into an economic yield. The interaction of inter and intra row spacing had a highly significant effect ($P<0.001$)) on harvest index. However the main effects of inter and intra row spacing significant effect ($P<0.05$) on the harvest index (Appendix Table 4). The highest harvest index (39.46) was recorded from the treatment combination of 75*25 cm while the lowest harvest index (31.02%) was recorded from the treatment combination of (55*20 cm) which is statistically par with the treatment combination of [55’25] (Table 7). The increment in harvest index at lower plant density might be attributed to greater photo assimilate production and its ultimate partitioning into grain yield. The higher HI in the decreased plant population doe to maximum nutrient uptake and transform of the plant while, lower harvest index in the increased plant population density might be due to minimum nutrient uptake and transform when we compared with decreased plant population density. The obtained results were in agreement with the findings of Valadabadi and Aliabadi Farahani (2010) who claimed that with increasing the plant population, the harvest index was decreased. This result also agreed with the findings of Nure and Jara (2021) who reported that optimum plant population significantly increases harvest index of maize.

Table 10: Interaction effects of inter-and intra-row spacing on Harvest index (HI %)

Eastern Harerghe Zone Kersa District During 2023 Main Cropping Season.

Treatment	Inter-row spacing (cm)		
Intra-row spacing (cm)	**55**	**65**	**75**
20	31.02^{d}	33.02^{c}	36.62^{c}
25	31.32^{c}	33.40^{c}	39.46^{a}
30	31.45^{c}	33.55^{c}	$38.75^{a b}$
35	31.68^{c}	35.86^{b}	38.02^{ab}
40	32.66c	36.02^{a}	37.57^{c}
LSD	4.62^{***}		
CV	4.85		

Means of the same letters indicated that no significance difference LSD =Least significance difference at 5% significance level CV= Coefficient of variation

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 2023 cropping season in Kersa District, 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 BH-661 was used. The experiment was arranged in a factorial combination of the three inter-rows (55, 65, and 75 cm) and five intra-rows (20. 25, 30, 35 and 40 cm) which were laid out in a randomized complete block design (RCBD). Data on phonological, growth, yield and yield components were collected.

The results of inter and intra-row spacing showed that the interaction effects of both inter and intra-row spacing had highly significant effects (P<0.01) days of 50% silking, ear diameter. thousand kernel weight, aboveground dry biomass, harvest index. Whereas, the main effects of inter and intra-row spacing were highly significant effect (P<0.01) on number of ear per plant, ,above ground dray biomass. The highest days to 50% anthesis (79.55), days to 50% silking (83.8), days to 90% physiological maturity (153.3), leaf area (1398.48cm^2), were recorded from 75*40 cm. whereas the lowest days to 50% anthesis (74.70), days to 50% silking (78.33), days to 90% physiological maturity (144.7), leaf area (1147.67), grain yield (5250.13 kg ha^{-1}), number of kernel per ear (388), thousand kernel weight (336.5 g) and harvest index (2.33) were recorded from the interaction effects of 55*20 cm plant spacing.

The highest leaf area index (4.48), Plant height (274.5 cm), aboveground dry biomass (25074.55 kg ha^{-1}) was recorded from the interaction effects of (55*20 cm) plant spacing whereas, the highest number of kernel per ear (428.5g)grain yield (7021 kg ha^{-1}) and harvest index [39.46%] were recorded from the interaction effects of (75*25 cm). The lowest leaf area index (3.01), Plant height (239.8 cm), aboveground dry biomass (14926.13 kg ha^{-1}) were recorded from the interaction (75*40 cm) plant spacing.

The main effects of inters and intra-row spacing highly significant effect (P<0.01) on ear diameter of plants, above ground dray biomass. The highest number of ear per plant (1.78), highest ear length (18.7 cm), and highest ear diameter (4.98 cm), were recorded from 75 cm inter-row spacing, whereas, the lowest number of ear per plant (1.38), ear length (17.5 cm), ear diameter (4.33), were recorded from 55 cm inter-row spacing. Concerning with intra row spacing the highest number of ear per plants (1.72), ear length (18.3 cm) ear diameter (4.78) from 40 cm . Whereas, the lowest number of ear per plant (1.51), ear diameter (4.03), ear length (17.5) were recorded from 20 cm intra-row spacing.

In general, the result of this study had shown production of maize at relatively optimum inter and intra spacing combinations can increase both grain yield of maize and above ground dry biomass yield in unit area of land. Even if the national recommendation of inter and intra row spacing were (75x30)cm. The spacing combination of 75 cm x 25 cm was better concerned to grain yield and above ground dry biomass yield at study districts This enables the farmers of study 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 75 cm x 25 cm spacing combination were superior especially concerned to grain 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. APPENDICES

Appendix Table 1: Mean squares of intra row, inter row, and intra * inter row interaction for phenological parameter of maize

	Days to 50% anthesis	Days to 50% silking	Days to 90% PM
Inter-row	75.44*	79.33*	149.44*
Intra-row	76.8*	79.67*	150.76*
inter*intra row	76.11*	82.55**	152.55**
Error	39.5	41.3	120 .08
Grand mean	76.12	82.58	150.45

Appendix Table 2: Mean squares of intra row, inter row, and intra * inter row interaction for Growth parameter of maize

	Leaf area	Leaf area index	Plant height (cm)
Inter-row	1256.45*	4.22*	256.56*
Intra-row	1244.55*	3.87*	266.87*
inter*intra row	1267.65*	4.011*	258.321*
Error	24.784	0.678	0.9956
Grand mean	1252.345	4.132	259.975

Appendix Table 3: Mean squares of intra row, inter row, and intra*inter row interaction for parameter of No ear per plant, No of kernel per ear, Ear length, Ear diameter

	No ear per plant	No of kernel per ear	Ear length	Ear diameter
Inter-row	1.6*	385.432*	16.9*	4.7*
Intra-row	1.5*	387.098*	18.33*	5.23*
inter*intra row	1.7*	402.312**	17.5*	4.75**
Error	0.148	0.865	0.55	0,432
Grand mean	1.664	401.66	17.432	4.675

Appendix Table 4: Mean squares of intra row, inter row, and intra*inter row interaction for parameter of Above ground Dry BM, Grain yields, Harvest Index and TKW

	Above ground Dry BM	Grain yields	Harvest Index	TKW
Inter-row	12546.009**	6755.765*	40.12*	354.89*
Intra-row	15705.670**	7009.654*	38.70*	321.976*
Inter*Intra row	13799.00**	6654.897*	37.66**	366.454*
Error	7.987	34.987	1.23	12.89

Grand mean	14778.098	6432.643	3.7654	355.7

Appendix Picture 1: Land Preparation

Appendix Picture 2: Layout Preparation

Appendix Picture 3: Sowing of maize plants

Appendix Picture 4: Days to anthesis

Appendix Picture 5: Data Collection at an days to 50% anthesis

Appendix Picture 6: Data Collection at days to 90% Physiological Maturity

Appendix Picture 7: Treatment identification by code

Appendix Picture 8: Data Collection at Physiological Maturity

Appendix Picture 9: Data Collection of yield and yield components

Appendix Picture 10 Data Collection of above ground dry biomass yield.