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Growth and Productivity of Maize (Zea mays L.) as Influenced by Inter- and Intra-Row Spacing in Kombolcha, Eastern Ethiopia

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Abstract
Effect of intra- and inter-row spacing on growth, yield components and grain yield of maize was investigated at Kombolcha, Eastern Ethiopia in 2014. The Objective of the experiment was to investigate the influence of intra- and inter-row spacing on growth, yield components and grain yield of maize in Kombolcha, East Hararghe zone. The experiment was arranged in a factorial combination of the three intra-rows (20, 25 and 30 cm) spacing and five inter-row spacing (45, 55, 65, 75 and 85 cm) spacing which were laid out in RCBD with three replication using maize (Zea mays L.) BH 660 variety. The results obtained had shown that there was highly significant (P< 0.01) main effect of inter-row spacing on leaf area, leaf area index, number of ears per plant, above ground dry biomass yield per hectare, number of kernels per ear, 1000 kernels weight and harvest index. Thousand kernels weight and number of kernels per ear highly significantly increased with decreased inter-row spacing while above ground dry biomass yield decreased with decreased inter-row spacing. Highly significant difference due to the main effects of intra-row spacing was observed on all the above parameters except harvest index. Thousand kernels weight and number of kernels per ear highly significantly increased with decreased intra-row spacing. There was highly significant interaction effect of inter-row by intra-row spacing on stand count percent, above ground dry biomass yield per plant, grain yield per plant, and grain yield per hectare. In general, significantly higher grain yield and above ground dry biomass yield were obtained due to intermediate and closer spacing. It may therefore be concluded that spacing combinations of 65 x 25 cm responded favorably in attaining higher grain yield of maize in the area.
Keywords: 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 (177,379,567 ha) and first in total production (872,066,770 MT) and productivity (4.9 t ha^{-1}) (FAOSTAT, 2013). Maize is recognized worldwide as a strategic food and feed crop that provides an enormous amount of protein and energy for humans and livestock. Its advantages in the ethanol industry also keep maize in high demand. Although much of the worlds maize production is utilized for animal feed, human consumption in many developing and developed countries is steadily increasing (Rosegrant *et al.,* 2010).

In Ethiopia, maize grows under a wide range of environmental conditions between 500 to 2400 meters above sea level. Maize is Ethiopia's leading cereal in terms of production, with 6.16 million tons produced in by 9 million farmers across 2.01 million hectares of land in 2012/2013 *Meher* season (CSA, 2013). In the proposed study area of Kombolcha District, maize is the leading cereal with cultivated area of (5,370 ha), output (1,485.39 t) and productivity (2.8 t ha^{-1}). Being a major cereal grown in the area, maize is the staple diet and important source of income for many farmers. In addition, maize stalks are used for firewood, fodder and construction purposes (BoA of Kombolcha District, 2013).

As compared to other cereals, maize can attain the highest potential yield per unit area. World average yield for maize is about 4.5 t ha^{-1} and that of developed countries is 6.2 t ha^{-1}. The average yield in developing countries is 2.5 t ha^{-1}. In Ethiopia the national average yield is about 3.01 t ha^{-1} (CSA, 2013). While significant gains have been made in maize production over the past decade, there remains large potential to increase productivity.

The great majority of smallholder farmers in Ethiopia are aware of the benefits of adopting input technologies to enhance their maize productivity. However, this awareness is mainly about some improved varieties, Urea and DAP, while knowledge about micro-nutrients and recommended agronomic packages like optimum plant density are almost not sufficient. Similarly, there is much room for improvement in getting farmers to adopt and implement the recommended package of agronomic management methods including proper tillage and land preparation, row planting, maintaining the right planting depth, plant population, time and frequency of weeding, and proper time of harvesting (ATA, 2013).

Zaffaroni and Schneiter (1991) noted three production variables that a producer can manipulate to influence the production of a given crop are plant population, row arrangement and hybrid variety selection. 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).

Though, most of appropriate agronomic practices and requirements of maize have been studied and determined, there is limited information on plant population and row arrangement according to different situations like height and maturity period of variety, soil fertility status etc. Hence, realizing the importance of developing appropriate cultural practices such as plant spacing for optimum production of maize in Kombolcha, this study was envisaged.

Most of the farmers in Kombolcha have been using their own spacing and agronomic practices rather than the recommended spacing (75 cm x 30 cm). Most of them use from 50 to 60 cm inter row spacing and 20 to 30 cm intra row spacing even for tall and late maturing varieties (personal observation). This variation in spacing needs to be compared with the recommended spacing of 75x30 cm with that of farmers practice. Therefore the research was conducted to investigate the influence of intra- and inter-row spacing on growth, yield components and grain yield of maize.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted during the main cropping season of 2013 from May to October in Kombolcha District, Kombolcha ATVET College demonstration farm, eastern Hararghe Oromia Region. It is located 542 km from Addis Ababa and 17 km from Harar city. The site is found at an altitude of 2010 masl, with the minimum and maximum average annual temperature of 16 ^{0}C and 25 ^{0}C, respectively; the average annual rainfall is 800 mm. (BoA of Kombolcha District, 2008).

2.2. Description of Experimental Material

Improved maize variety BH-660 was used for the experiment. It is a late maturing maize variety released in 1993, performing well in agro-ecological range of 1600-2200 m.a.s.l with rainfall range of 1000-1500 mm. It can give 9.0-12.0 t ha^{-1} and 6-8 t ha^{-1} grain yields under on-station and on-farm experiments, respectively. It is moderately tolerant to disease and lodging with plant height of 255-290 cm (Mosisa et al., 2001). Diammonium phosphate (DAP) and Urea fertilizers were used as a source of phosphorus and nitrogen

2.3. Treatments and Experimental Designs

The treatments were five inter-rows spacing (45, 55, 65, 75 and 85 cm) and three intra-rows spacing (20, 25 and 30 cm). The gross plot size was 4.55 m x 3 m (13.65 m^2) accommodating 10, 8, 7, 6, and 5 rows for 45, 55, 65, 75, and 85 cm inter-rows, respectively. The experiment was laid out in randomized complete block design (RCBD) in factorial with three replications. The blocks were separated by 1.5 m wide space and each plot was separated by 1 m space. As the inter and intra-row spacing varied the net plot area also varied (Table 2). Therefore, the corresponding length of net plot for intra-row spacing of 30 cm, 25 cm and 20 cm was 1.8 m, 2 m and 1.8 m, respectively and the width for inter-row spacing of 85, 75, 65, 55 and 45 cm was 2.55 m, 3 m, 2.6 m, 2.75 m, and 2.6 respectively. The central rows left aside for data recording was 3, 4, 4, 5 and 6 rows for 85, 75, 65, 55, and 45 cm inter-row spacing, respectively.

2.4. Management of the Experiment

Prior to sowing, the land was finely prepared using oxen plough. Maize seeds were planted as per proposed inter row spacing. Initially two seeds per hill were planted and latter thinned to one plant at 3 to 4 leaf stage. At time of planting, all plots were received a basal application of 100 kg DAP (18 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}). In addition all plots were top dressed with 34.5 kg N ha^{-1} at knee stage and 34.5 kg N ha^{-1} at tasseling stage in the form of urea (46 kg N). All other agronomic practices like hoeing, weeding, etc were the same for all treatments.

2.5. Crop Data Collection

Samples were taken randomly from the central two rows. Data on crop phenology (days to 50% tasseling, days to 50% silking and days to physiological maturity) were recorded at their respective stages. Leaf area at 50% tasseling, leaf area index (LAI), plant height, stand count percent, number of ears per plant, above ground dry biomass yield per plant, above ground dry biomass yield per hectare, number of kernels per ear, thousand kernels weight, grain yield per plant, grain yield per hectare and harvest index were collected

2.6. Statistical Data Analysis

The measured variables were analyzed using Statistical Soft ware (SAS, 2004) as per the model described for randomized complete block design. Effects were considered significant if P values are < 0.05. Significant differences among treatment means were compared using LSD at 5% level of significance (Gomez and Gomez, 1984).

3. Results and Discussion

3.1. Crop Phenology

The main effect of inter and intra-row spacing as well as the interaction of inter-row spacing and intra-row spacing did not affect significantly days to 90% maturity, number of days to 50% tasseling and silking of maize (Appendix Table 1). The present result is in line with that of Gozubenli (2004) who reported that the effect of inter and intra-row spacing did not significantly affect on tasseling and maturity period of maize. Similarly, Park *et al.,* (1989) reported that plant density did not affect days to tasseling and maturity. According to Zenebe (2004), the effect of plant population was not significant on days to 50% flowering and days to 90% maturity of sorghum.

3.2. Growth Parameters

3.2.1. Plant height

Neither main effect of intra-row spacing nor the interactions of inter and intra-row spacing significantly affected plant height of maize (Appendix Table 2). However, it was significantly ($P < 0.05$) affected by the main effects of inter-row spacing. The narrower inter-row spacing of 55 cm gave significantly taller plants (279.1 cm) than wider inter-row spacing of 75 cm and 85 cm. There is significant difference in plant height between 65 cm and 85 cm inter-row spacing also (Table 3).

Table 3. 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)			
45	271.00^{bc}	5931^{c}	5.33^{a}
55	279.17^{a}	6904^{b}	5.14^{a}
65	275.92^{ab}	7608^{a}	4.81^{ab}
75	273.04^{bc}	7616^{a}	4.25^{b}
85	268.83^{C}	7621^{a}	3.33^{c}
Significance	*	**	**
LSD (0.05)	5.982	515	0.580
Intra-row spacing (cm)			
20	273.42	6732^{b}	5.24^{a}
25	274.17	7337^{a}	4.66^{b}
30	273.17	7338^{a}	3.81^{c}
Significance	NS	**	**
LSD (0.05)	NS	551	0.518
CV (%)	2.7	7.4	7.5

** and ** =significant at 5% and 1% significance levels, respectively;* NS= Non-Significant.
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

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 except at 45 cm when intra-row spacing increased from 25 cm to 30 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.

3.2.2. Leaf area and leaf area index

The main effects of both intra and inter-row spacing on leaf area as well as leaf area index were highly significant ($P < 0.01$) while the interaction effect was not significant (Appendix Table 2). The highest leaf area per plant (7621 cm^2) was recorded at inter-row spacing of 85 cm while the lowest (5931 cm^2) was at 45 cm (Table 3). In general leaf area per plant was increased with decreasing inter-row spacing (from 85 cm to 45 cm). Similarly, 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 (Table 3).

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 was in agreement with Ahmad *et al.* (2006) who reported maximum leaf area of maize under wider row spacing (75 cm) and (65 cm) than in narrower (55 cm) spacing. 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).

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) (Table 3). Leaf area index decreased with increase in intra and inter-row spacing. The highest leaf area index of 5.24 was recorded under the narrowest intra-row spacing (20 cm), while the lowest leaf area index of 3.81 was observed from the widest intra-row spacing of 30 cm (Table 3). This could be due to high number of plants per unit area than under higher leaf area. This result was in agreement with Ahmad *et al.* (2006) who reported higher leaf area index of maize (6.45) under narrower row spacing (55 cm) unlike at wider row spacing (75cm and 65 cm). 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. Similarly, Sangoi *et al*. (2001) reported higher leaf area index (4.6) at 50 cm than at 75 cm (3.64).

3.3. Yield and Yield Components of Maize

3.3.1. Plant stands count percent

The analysis of variance showed that there occurred highly significant (P<0.01) variation on stand count percent due to intra and inter-row spacing as well as their interactions (Appendix Table 2). At all intra-row spacing, stand count percent increased as inter-row spacing increased. The 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 %) (Table 4).

Table 4. Interaction effects of inter and intra-row spacing on stand count percent

	Intra-row spacing (cm)		
Inter-row spacing (cm)	20	25	30
45	91^{f}	93^{e}	93^{e}
55	93^{e}	94^{de}	94^{de}
65	93^{e}	95^{cd}	98^{a}
75	95^{cd}	97^{ab}	98^{a}
85	96^{bc}	98^{a}	98^{a}
Significance	**		
LSD (0.05)	1.141		
CV (%)	0.8		

**= Significant at 1% significance levels
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.

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) where as 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 Sangoi *et al.* (2001) who reported that wider inter and intra-row spacing of 75 cm x 26.6 cm had greater plant stand count percent of maize as compared to the initial count than that of narrow inter and intra spacing of 50 cm x 17.7 cm. Similarly, Eskandarnejada *et al*. (2013) reported that higher plant stand count percent was achieved due to the wider spacing combinations of 75 cm x 30 cm than narrower spacing of 55 cm x 20 cm.

3.3.2. Number of ear per plant

Analysis of variance indicated that both main effects of inter and intra-row spacing had highly significant (p<0.01) effect on number of ears per plant (Appendix Table 3). However, there was no significant interaction effect. Significantly lower number of ears per plant was found in narrow spacing (45 and 55 cm) than wider spacing. Number of ears per plant was statistically the same for 65 cm and 75 cm, 75 cm and 85 cm inter-row spacing (Table 5). The wider intra- row spacing of 25 cm and 30 cm also resulted in significantly higher number of ears per plant than the narrower intra-row spacing (20 cm).

The decrease on number of ears per plant with increase in plant inter-row spacing could be due to increased intra specific competition which eventually caused reduction in number of ears per plant. In contrast, the increase in the number of ears per plant with decreased inter-row spacing might be due to higher net assimilation rate and partitioning and reduction of competition in wider spacing. In agreement with this result, Ahmad et al. (2006) recorded that the highest number of ears per plant in maize crop sown in 75 cm spaced rows than crops grown at 55 cm and 45 cm. Eskandarnejada et al. (2013) also reported that plant spacing of 30 cm produced higher number of ears per plant than 20 cm plant spacing. 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.

3.3.3. Number of kernels per ear

Main effect of intra-row spacing showed significant (P < 0.05) effect while inter-row spacing showed a 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 (543.6) was recorded at 85 cm inter-row spacing and the lowest number of kernel (465.1) was recorded at 45 cm inter-row spacing (Table 5). Increasing inter-row spacing from 45 cm to 85 cm showed linear and consistent kernels increment though there was no significant difference between 75, 65, and 55 cm inter-row spacing. The highest number of kernels per ear (517.5) was recorded at 30 cm intra-row spacing and the lowest number of kernels (480.6) was recorded at 20 cm intra-row spacing. 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). According to Zamir *et al*. (2011), the highest 1000 kernels weight (253 g) was produced at 30 cm intra-row spacing followed by 25 cm intra-row spacing (249 g) and the lowest number of ears per plant (223 g) was produced at intra-row spacing of 15 cm. Plant spacing of 30 cm produced more number of kernels per ear (416.30) than that of 20 cm plant spacing (410.20) (Mahmood *et al*., 2001). Similar results have also been reported by Gambin *et al*., (2006), Malaviarachchi *et al.* (2007) and Arif *et al.* (2012) who reported that number of kernels per ear decreased with increase in plant density of maize.

Table 5. 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 ears per plant	Number of kernels per ear	1000 kernels weight (g)
Inter-row spacing (cm)			
45	1.09^{d}	465.1^{c}	336.2^{c}
55	1.11^{cd}	478.8^{bc}	351.7^{bc}
65	1.15^{a}	497.9^{b}	359^{b}
75	1.14^{ab}	508.3^{b}	367.5^{ab}
85	1.12^{bc}	543.6^{a}	382.7^{a}
Significance	**	**	**
LSD (0.05)	0.019	31.03	15.89
Intra-row spacing (cm)			
20	1.11^{b}	480.6^{b}	340.8^{b}
25	1.13^{a}	498.2^{ab}	363.6^{a}
30	1.13^{a}	517.5^{a}	373.8^{a}
Significance	**	*	**
LSD (0.05)	0.014	24.03	12.31
CV (%)	2	7.6	5.4

* and **= significant at 5% and 1% significance levels, respectively;
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

3.3.4. Thousand kernels weight

Main effect of inter and intra-row spacing were highly significant (P < 0.01) on thousand kernel weight. However, the interaction was not significant (Appendix Table 3). With increase inter-row spacing, thousand kernels weight increased where the highest thousand kernels weight (382.7 g) was recorded at the widest inter-row spacing of 85 cm whereas, the lowest (336.2 g) was recorded at the narrowest inter-row spacing of 45 cm. With respect to intra-row spacing, the kernel weights increased with increase in intra-row spacing where the lowest thousand kernel weight (340.8 g) was recorded at 20 cm intra-row spacing and the highest weight (373.8 g) was at 30 cm intra-row spacing (Table 5). .

With increased inter and intra-row spacing, thousand kernel weight decreased. This decrease might be because of assimilates partitioning between higher numbers of kernels used in connection with the decreased inter plant competition that lead to increased plant capacity, for utilizing the environmental inputs in building great amount of metabolites to be used in developing new tissues and increasing its yield components. In addition, wider spaced plants, that improved the supply of assimilates to be stored in the kernel hence, the weight of thousand kernel increased. 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.

3.3.5. Grain yield per plant

The main effects of inter and intra- row spacing as well as their interaction were highly significant ($P < 0.01$) on grain yield per plant (Appendix Table 3). The highest mean grain yield per plant (188.5 g) was obtained at 30 cm x 85 cm, but was not statistically different from 25 cm x 85 cm, 30 cm x 75 cm and 25 cm x 65 cm spacing (Table 6). Moreover, the lowest grain yield per plant (112.5 g) was recorded at the narrow spacing combination of 20 cm x 45 cm. In general, at all intra-row spacing, grain yield per plant increased with increase in inter-row spacing. Increase in grain yield per plant at wider spacing is not surprising because lower plant density exerts lesser interplant competition for space as well as growth factors.

Furthermore, greater yield per plant (Table 6) in present investigation at wider spacing resulted from higher 1000 kernel weight and higher number of kernels per ear (Table 5) at wider spacing combinations. The result of this study was in agreement with Ahmad *et al.* (2006) who reported that increasing plant population reduced yield of individual plants but increased yield per unit area of maize. Similarly, Gozubenli *et al.* (2004) reported that grain yield per plant increased with the increase of inter and intra-row spacing. This result was also in line with Eskandarnejada *et al*. (2013) who obtained decreased grain yield per plant under narrower inter and intra- row spacing on maize.

Table 6. Interaction effects of inter- and intra-row spacing on grain yield per plant (g)

	Intra-row spacing (cm)		
Inter-row spacing (cm)	20	25	30
45	112.5^{f}	119.0^{f}	132.75^{e}
55	144.5^{d}	162.2^{c}	150.8^{d}
65	147.8^{d}	178.8^{ab}	170.3^{bc}
75	165.8^{c}	167.2^{c}	179.5^{ab}
85	167.0^{c}	180.5^{ab}	188.5^{a}
Significance	**		
LSD (0.05)	11.30		
CV (%)	5.0		

** = significant at 1% significance levels.

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

3.3.6. Grain yield per hectare

Both inter and intra-row spacing as well as their interactions showed highly significant ($P < 0.01$) effect on grain yield per hectare (Appendix Table 3). For 20 and 25 cm intra-row spacing grain yield was increased when inter-row spacing increased from 45 cm to 55 cm and then decreased after 55 cm. Highest grain yields ha^{-1} of 10.902 t ha^{-1}, 10.692 t ha^{-1} and 10.062 t ha^{-1} were obtained from the spacing combinations of 55 cm x 25 cm, 65 cm x 25 cm and 55 cm x 20 cm, respectively (Table 7). However, the lowest grain yields ha^{-1} of 5.483 t ha^{-1} and 5.603 t ha^{-1} were obtained from spacing combinations of 85 cm x 30 cm, and 85 cm x 25 cm, respectively. 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.

Table 7. Interaction effects of inter- and intra-row spacing on grain yield (t ha^{-1})

	Intra-row spacing (cm)		
Inter-row spacing (cm)	20	25	30
45	8.51^{cde}	8.69^{bcd}	8.50^{cde}
55	10.06^{ab}	10.90^{a}	7.10^{fghi}
65	9.15^{bc}	10.69^{a}	6.82^{ghij}
75	8.30^{cfgh}	7.44^{defg}	6.70^{ghi}
85	7.09^{fgh}	5.60^{hi}	5.48^{i}
Significance	**		
LSD (P 0.05)	1.517		
CV (%)	13.2		

** = Significant at 1% significance levels.

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

In agreement with this result, Maqsood *et al*. (2002) reported that there was higher grain yield of maize (6.6 t ha^{-1}) at narrower spacing of 60 cm x 15 cm against the lower grain yield (3.28 t ha^{-1}) at wider spacing of 60 cm x 30 cm. Similarly, narrow spacing combinations had significant effect on maize grain yield and the highest grain yield was obtained from 15 cm x 60 cm than 20 cm x 60 cm spacing (Ulger, 2001). Moreover, Mahmood *et al.* (2001) reported that narrower spacing of 60 cm x 20 cm produced lower grain yield of maize (4.30 t ha^{-1}) while spacing of 60 cm x 30 cm produced 5.1 t ha^{-1}.

Maize crop grown at 60 x 15 cm spacing produced significantly higher grain yield (3.53 t ha^{-1} than that of 60 x 35 cm (3.15 t ha^{-1}) (Randhawa *et al*., 2007). Eskandarnejada *et al*. (2013) also reported that higher grain yield of maize (15.25 t ha^{-1}) was obtained at narrower (55 cm x 20 cm) spacing than at wider (75 cm x 30 cm) spacing which is 11.43 t ha^{-1}. Mukhtar *et al*. (2012) showed that higher grain yield of maize (8.370 t ha^{-1}) was obtained with 12.50 x 70 cm spacing while lower (6.646 t ha^{-1}) at 17.50 cm x 70 cm spacing. According to their result at higher plant density, overall grain yield of maize increased due to increasing number of ears per hectare. Similarly, Farnham (2001) reported that maize grain yield increased from 10.1 to 11.2 t ha^{-1} as plant density increased from 59,000 to 89,000 plant ha^{-1}. According to Shrestha (2013), grain yield (5.11 t ha^{-1}) obtained under plant density of 66666 plants/ha (60 × 25 cm spacing) was significantly higher than that of 55555 plants/ha (60 × 30 cm spacing) but that was at par with yield of 83333 plants/ha (60 × 20 cm spacing). A similar trend in yield across planting density has been observed by Malaviarachchi *et al*. (2007) who reported that grain yield increased with increasing maize plant density. 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}). Similar results have been reported by, Fulton (1990), Naraqanaswamy *et al*. (1994), Baron *et al*. (2001) and Arif *et al*. (2010) on maize spacing trial.

3.3.7. Above ground dry biomass yield per plant

The main effect of inter and intra-row spacing as well as their interaction had highly significant ($P < 0.01$) effect on above ground dry biomass yield per plant (Appendix Table 3). The highest above ground dry biomass yield per plant (360.0 g) was recorded at 30 cm x 85 cm but the lowest dry biomass yield per plant was recorded at 20 cm x 45 cm (Table 8). Generally for all intra-row spacing above ground dry biomass yield per plant increased when inter-row spacing increased from 45 cm to 85 cm except at 65x25 cm.

The highest above ground dry biomass yields per plant at the widest inter and intra-row spacing might be due to high stem diameter and high leaf area because there is more availability of growth factors and better penetration of light at wider row spacing. In agreement with this study, Gozubenli *et al.* (2004) reported that above ground dry biomass yield per plant increased with the increase of inter and intra-row spacing. Similarly, Miko and Manga (2008) reported that above ground dry biomass per plant was significantly increased with decreased plant density of maize.

Table 8. Interaction effects of inter and intra-row spacing on above ground dry biomass yield per plant (g)

	Intra-row spacing (cm)		
Inter-row spacing (cm)	20	25	30
45	260.0^{j}	290.0^{i}	318.8^{f}
55	292.8^{d}	344.5^{cd}	331.0^{e}
65	300.8^{h}	351.0^{abc}	341.0^{d}
75	308.0^{g}	345.2^{cd}	358.0^{ab}
85	321.8^{ef}	349.2^{bcd}	360.0^{a}
Significance	**		
LSD (0.05)	9.486		
CV (%)	2.0		

** = Significant at 1% probability levels.
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

3.3.8. Above ground dry biomass yield per hectare

Above ground dry biomass yield was highly significantly ($P<0.01$) affected by main effect of inter and intra-row spacing but the interaction was not significant (Appendix Table 3). The narrowest inter-row spacing of 45 cm produced significantly the highest above ground dry biomass yield per ha (27.87 t ha^{-1}) than all the other inter-row spacing. The spacing of 85 cm produced the lowest above ground dry biomass yield (15.82 t ha^{-1}) (Table 10). Increasing inter-row spacing from 45 cm to 85 cm decreased above ground dry biomass yield and showed consistent decrement though there was no significant difference among 65, 75 and 85 cm inter-row spacing. In agreement with this result, Miko and Manga (2008) showed that higher sorghum above ground dry biomass yield was obtained at narrow inter row spacing**.** When the intra-row spacing become narrower from 30 cm to 20 cm, the biomass yield per ha increased significantly while intra-row spacing of 20 cm and 25 cm were at par with each other. 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. According to Yousaf *et al.* (2007), maize planted at 45 cm row spacing produced 14% and 34 % higher total above ground dry biomass than that of 60 and 75 cm row spaced sown crop, respectively. Plant spacing of 15 cm produced 42% and 22% higher above ground dry biomass than that recorded for 30 cm and 22.5 cm plant spacing, respectively. Similarly, Gobeze *et al*. (2012) reported that the highest biomass was recorded at row spacing of 25 cm with plant density of 10 plants m^2 and followed by the same row spacing with plant density of 12.5 plants m^2 while the lowest biomass was observed at row spacing of 90 cm with plant density of 5 plants m^2.

3.3.9. Harvest index

The analysis of variance showed that there was highly ($P<0.01$) significant variation on harvest index due to the main effect of inter-row spacing while the effects of intra-row spacing as well as inter and intra-row interaction were not significant (Appendix Table 3). The highest harvest index (0.49) was recorded at 65 cm whereas the lowest harvest index (0.31) was obtained from 45 cm (Table 10).

Both extreme wider and narrower inter-row spacing caused lower harvest index. This could be due to the higher proportion of increment in above ground dry biomass yield as population increased than proportion of increment in grain yield. At all intra-row spacing as inter-row spacing increased from 45 cm to 65 cm, HI increased consistently. As inter-row spacing increased from 65 cm to 85 cm, HI decreased. Hence, higher harvest index was obtained from intermediate inter-row spacing. In agreement with this result Eskandarnejada *et al*. (2013) showed that intermediate inter-row spacing gave significantly higher harvest index of maize than both lower and higher inter-row spacing. 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. Main effects of inter and intra-row spacing on dry biomass yield and harvest index

Treatments	Above ground dry biomass yield (ton/ha)	Harvest index
Inter-row spacing (cm)		
45	27.87^a	0.31^c
55	24.94^b	0.39^b
65	17.73^c	0.49^a
75	16.43^c	0.46^a
85	15.82^c	0.39^b
Significance	**	**
LSD (0.05)	2.723	0.05
Intra-row spacing (cm)		
20	22.43^a	0.41
25	21.44^a	0.42
30	17.81^b	0.40
Significance	**	NS
LSD (0.05)	2.109	NS
CV (%)	16.1	14.9

** and NS = Significant at 1% significance levels and Non-Significant respectively; LSD (0.05) = Least Significant Difference at 5% level; CV= Coefficient of Variation; NS= Non-Significant. Means in column followed by the same letters are not significantly different at 5% level of significance

4. Summary and Conclusion

In crop production, major production variables that a producer can manipulate to influence the production of a given crop are plant population, row arrangement, variety selection, soil fertility and crop management activities. 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. Though, most of appropriate agronomic practices and requirements of maize have been studied and determined, there is limited information on plant population and row arrangement according to different situations like height and maturity period of variety, soil fertility status etc.

Although there is a national recommendation on spacing of maize from research centers, most of farmers in East Hararghe zone especially in Kombolcha District do not use the recommended spacing. Most of farmers in the stud area use their own spacing and agronomic practices rather than the recommended spacing. Most of them use from 50 to 60 cm inter row spacing and 20 to 30 cm intra row spacing even for tall and late maturing varieties of maize to harvest more biomass. Because, maize dry biomass (stover) is an important and valuable source of animal feed and fuel for the area. Moreover, individual farmers in this area have small plot of land due to high population density and fragmented land holding system in the area. Even farmers claim that they can get comparable grain yield by using narrow spacing combination than wider spacing combinations.

Hence, realizing this situation, investigating and developing appropriate cultural practices such as plant spacing for optimum production of maize in District is important. Therefore, the present experiment was conducted in 2013 cropping season in Kombolcha, Eastern Hararghe, Oromia Regional State, with the objective to investigate the influence of intra- and inter-row spacing on growth, yield components and grain yield of maize. In this spacing experiment, maize variety BH 660 was used. The experiment was arranged in a factorial combination of the three intra-rows (20, 25 and 30 cm) spacing and five inter-row spacing (45, 55, 65, 75 and 85 cm) which were laid out in an 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. Neither main effect of intra-row spacing nor the interactions of inter and intra-row spacing significantly affected plant height of maize. However, it was significantly affected by the main effects of inter-row spacing. Higher mean height was observed at 55 cm inter-row spacing than 85 cm. 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 were recorded at inter and intra-row spacing of 85 cm and 30 cm, respectively while the lowest were at 45 cm and 20 cm inter and intra-row spacing, respectively. The narrowest inter- and intra-row spacing of 45 cm and 20 cm gave the highest leaf area index.

Inter and intra-row spacing had highly significant effect on above ground dry biomass yield ha^{-1}, number of ears per plant, number of kernels per ear and 1000 kernels weight. The highest number of kernels per ear and thousand kernel weight were observed for 85 inter-row spacing. Similarly the widest intra-row spacing of 30 cm gave the highest number of kernels per ear and 100 kernels weight. The narrowest inter-row spacing of 45 cm produced significantly higher biomass yield than all the other inter-row spacing. There occurred highly significant variation on HI due to the main effect of inter-row spacing. The highest number of ears per plant and harvest index were recorded at the intermediate inter-row spacing of 65 cm.

There was highly significant interaction effect of inter and intra-row spacing on grain yield per plant, above ground dry biomass yield per plant and grain yield per hectare. The highest above ground dry biomass yield per plant and grain yield per plant were recorded at 30 cm x 85 cm. For all intra-row spacing grain yield increased when inter-row spacing increased from 45 cm to 55 cm then yield decrease. Higher grains yields were obtained from the spacing combinations of 55 cm x 25 cm, 65 x 25 cm and 55 cm x 20 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. Results of this experiment indicated that spacing combination of 65 cm x 25 cm was superior than 55 cm x 25 cm and 55 cm x 20 cm concerned to yield components: numbers of ears per plant, number of kernels per ear, 1000 kernels weight and harvest index, 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 more dry 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 and may be used by farmers of the area. However, this tentative generalization, based on one season at one location, and using one variety required confirmation with further studies to give a valid recommendation. So, further study on different varieties on different seasons and at different locations are required for further investigation and to give complete recommendation.

References

Ahmad, R., A. Tanveer, M.M. Maqbool and Z. Ata, 2006. Growth and yield of maize (*Zea mays* L.) as affected by row spacing and weed competition durations. *Journal of Plant Science,* 38(4): 27-36.

Arif, M., I. Amin, M. T. Jan, I. Munir, K. Nawab, N. U. Khan and K. B. Marwat, 2010. Effect of plant population and nitrogen levels and methods of application on ear characters and yield of maize. *Journal of Agriculture and Biology*, 42(3): 1959-1967.

ATA (Agricultural Transformation Agency), 2013. Maize Sector Development Strategy (Working Document 2013-2017), Addis Ababa, Ethiopia.

Baron, V. S., H. G. Najda and F. C. Stevenson, (2001). Influence of population density, row spacing and hybrid on forage corn yield and nutritive value in a cool-season environment. *Journal of Plant Science***,** 86: 1131–1138.

BoA (Kombolcha District Bureau of Agriculture), 2008. Unpublished metrological data, Kombolcha District, East Harerghe, Ethiopia.

BoA (Kombolcha District Bureau of Agriculture), 2013. The 2013 (2005/06) Meher Pre Harvest Crop Assessment, Unpublished data, Kombolcha District, East Hararghe, Ethiopia.

CSA (Central Statistics Agency), 2013. Agricultural Sample Survey 2012/2013. Volume I. Report on area and production of major crops (private peasant holdings, Meher season). *Statistical Bulletin* 532, Addis Ababa, Ethiopia.

Eskandarnejada, S., S. Khorasani, S. Bakhtiaric, A. R. Heidarian, 2013. Effect of row spacing and plant density on yield and yield components of sweet corn (*Zea mays* L.). *Journal of Crop Science*, l3(1): 81-88.

FAOSTAT (Food and Agriculture Organization of the United Nations), 2013. Online database, FAO, Rome.

Farnham, D.E., 2001. Effects of row spacing, plant density and variety on maize grain yield. *Journal of Agronomy*, 93: 1049-1053.

Gambin B.L., L. Borras and M.E. Otegui. 2006. Source-sink relations and kernel weight differences in maize temperate hybrids. *Journal of Crop Science*, 95: 316-326.

Gobeze Yada Loha, G. C. Michael and L.V.R. Daniel, 2012. Effect of row spacing and plant density on yield and yield component of maize (*Zea mays* L.) under Irrigation. *Journal of Agricultural Science and Technology*, 2 (12):263-271.

Goldsworthy, P. R. and Taylor, R. S. (1990). The effect of plant spacing on grain yield of tall and short sorghum in Nigeria. *Journal of Agricultural Science*, 50 (8):566-568.

Gomez, K.A. and A.A. Gomez, 1984. *Statistical Procedures for Agricultural Research*, John Wiley and Sons Inc., New York.

Gozubenli, H., O. Sener, O. Konuskan and M. Kilinc, 2004. The effect of intra-row spacing on the grain yield and some agronomic characteristics of maize (*Zea mays* L.) hybrids. *Asian Journal of Plant Science*, 3(4):429-432.

Ketema, Belete, 1983. Effect of row spacing, plant population and nitrogen level on grain sorghum production under required tillage systems, MSc. Thesis. Oklahoma State University.

Mahmood, M.T., M. Maqsood, T. H. Awan and R. Sarwa, 2001. Effect of different levels of nitrogen and intra-row plant spacing on yield and yield components of maize. *Journal of agricultural science,* 38(2):35-38.

Malaviarachchi, M.A., K.M. Karunarathne and S.N. Jayawardane, 2007. Influence of plant density on yield of hybrid maize (*Zea mays* L.) under supplementary irrigation. *Journal of Agricultural Science,* 3 (2): 58-66.

Maqsood, M., M. S. Ibin Zamir, M. A. Safi and M. Yousat, 2002. Effect of plant spacing on yield and yield components of maize. *International Journal of Agriculture and Biology*, (3)25: 15.

Matthews, E., I.I. Ibeawuchi, I. I., O. Miriam, P. Chinyere and V.N. Onyia, 2008. Plant spacing, dry matter accumulation and yield of local and improved maize cultivars. *Journal of American Science*, 4(1):145-163.

Matthews, P.W., E.L. Armstrong, C.J. Lisle, I.D. Menz, P.L. Shephard and B.C. Armstrong, 2001. The effect of faba bean plant population on yield, seed quality and plant architecture under irrigation in southern NSW. *Australia Crop Agronomy Journal,* 2(20): 30-40.

Miko, S. and A. A. Manga, 2008. Effect of intra–spacing and nitrogen rates on growth and yield of sorghum (*Sorghum bicolor* L.) Var. ICSV 400. *Journal of Agronomy,* 4 (2): 66-73.

Mosisa Worku, Jemale Abdurehman, Leta Tulu, Haji Tuna, Legesse Wolde, Kassa Yihun, Wonde Abera, Aschalew Guta, Sewagegne Tarikue, Teshale asefa, Tamirat Birhanu, Yosef Beyene and Habtamu Zeleke, 2001. Development of improved maize germ plasm for the mid and low altitude sub humid agro ecologies of Ethiopia. In: Enhancing the Contribution of Maize to Food Security in Ethiopia: Proceedings of the second national maize workshop of Ethiopia: CIMMYT (International Maize and Wheat Improvement Center) and EARO (Ethiopian Agricultural Research Organization). Pp:27-30.

Mukhtar, T., M. Arif, S. Hussain, M. Atif and K. Hussain, 2012. Yield and yield components of maize hybrids as influenced by plant spacing. *Journal of Agricultural research,* 50(1):63-67

Naraqanaswamy, M.R., V. Veerabadran, C. Jayanthi and C. Chinnuswamy, 1994. Plant density and nutrient management for rain-fed maize. *Mardras Agricultural Journal,* 81:248-51.

Ogunlela, V. B., G. M. Amoruwa and O. O. Olongunde. 2005. Growth, yield components and micronutrient nutrition of field maize grown as affected by nitrogen fertilization and plant density. *Journal of Agronomy,* 17: 385-1314.

Randhawa, M., A. Mahmood and A. J. khan, 2007. Effect of plant spacing on quality and yield of maize crop. *Journal of Agriculture and biology,* 29(2):370-371.

Rosegrant, M.W., S. Msangi, C. Ringler, T.B. Sulser, T. Zhu, S.A. Cline, 2010. International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): *Model Description*. International Food Policy Research Institute: Washington, D.C.

Sangoi, L., M. Ender, A. Guidolin, M.L. de Almeida and P. C. Heberle, 2001. Influence of row spacing reduction on maize grain yield and yield components. *Agronomy Journal*, 36(6) 861-869,

SAS (Statistical Analysis) Institute, 2004. SAS user guides version 9.1.SAS Inc. Cary. North Crolina, USA.

Shrestha, J., 2013**.** Effect of nitrogen and plant population on grain yield of winter maize. *Journal of Agricultural*

Science, 2:17-22.
Singh N.P., and R.A. Singh, 2002. *Scientific crop production,* X press Graphics, Delhi-28, 1st ed., India.
Singh, B.B., O.L. Chamblis, and B. Sharma, 1997. Advance in Cowpea Research. Co publication of International Institute of Tropical Agriculture and Japan International Research Center for Agricultural Science, Ibadan Nigeria.
Singh, J. 1987. *Field manual of maize breeding procedures*, FAO, Rome.
Ulger, A.C., 2001. The effect of different rows and intra-row spacing on grain yield and some agronomic characteristics of maize. *Journal of Agriculture,* 13:95-104.
Yousaf, N., A. Raouf, M.S., S. Kamel S. Amer. 2007. Investigating the influence of varying row spacing and planting density on growth characteristics, agronomic and yield traits, quality of grain and nutrient up-take patterns of diverse maize (*Zea mays* L.) hybrids. *Journal of Agriculture and Biology*, 8:120-123.
Zaffaroni E. and A.A Schneiter, 1991. Sunflower production as influenced by plant type, plant population, and row arrangement. *Journal of Agronomy*, 83: 113-118.
Zamir M.S.I., A.H.. Ahmad, H.M.R. Javeed, T. Latif, 2011. Growth and Yield Behavior of Maize Hybrids (*Zea mays* L.) towards different plant spacing. *Journal of Agriculture and Biology,* 2(46):16-24.
Zenebe Tsegaw, 2004. Effect of plant population and variety on yield and yield related traits of sorghum (*Sorghum bicolar* (L.) *moench*) Under Dire Dawa Condition. MSc Thesis, Haramaya University, Haramaya, Ethiopia.

Appendices

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

Source of variation	df	Mean squares		
		Days to 50% tassling	Days to 50% silking	Days to 90% maturity
Block	3	6.644	11.306	12.283
Inter-row space	4	1.067	0.108	0.558
Intra-row space	2	2.467	0.817	1.317
RS X PS	8	0.779	0.921	0.671
Error	42	3.442	3.544	3.474
CV (%)		2.1	1.9	1.2

RS= inter-row spacing, PS= intra-row spacing

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

Source of variation	df	Mean squares		
		Plant Height (cm)	Leaf area (cm^2)	Leaf area index
Block	3	134.80	499405	0.1406
Inter-row space	4	198.44*	5803264**	7.8069**
Intra-row space	2	5.42	4836384**	10.3323**
RS X PS	8	66.49	3497431	0.2106
Error	42	58.19	265261	0.1161
CV (%)		2.7	7.4	7.5

** and ** significant at 5% and 1% probability levels, respectively; RS= inter-row spacing*

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

Source of variation	df	Mean squares								
		Stand count percent	No of ears per plant	Dry biomass yield (g/plant)	Dry biomass yield (tons/ha)	No of kernels per ear	1000 kernels weight (g)	Grain yield (g/plant)	Grain yield (tons/ha)	Harvest index (HI)
Block	3	6.639	0.0002	61.16	15.19	868	1000.9	16.84	1.663	0.0019
Inter-row space	4	51.75**	0.0049**	4886.02**	360.14**	10910**	3620.1**	6053.11**	21,70**	0.0501**
Intra-row space	2	34.02**	0.0027**	11276.52**	118.46**	6813*	5709.6**	1630.55**	20.01**	0.0013
RS X PS	8	2.6**	0.0007	345.39**	19.59	1542	305.6	211.88**	3.812**	0.0055
Error	42	0.639	0.0005	44.19	10.92	1418	372.1	62.73	1.131	0.0037
CV (%)		0.8	2	2.0	16.1	7.6	5.4	5.00	13.2	14.9

** and ** significant at 5% and 1% probability levels, respectively; RS= inter-row space, PS= intra-row spacing*