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Response of yield and yield components of tomato (*Solanum lycopersicon* L.) to different inter and intra-row spacing at Merebleke, Northern Ethiopia

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A field experiment was conducted at Aksum Agricultural Research Center Merebleke irrigation testing site for two years, 2014 and 2015 cropping calendar under irrigation condition. The objective of the study was to determine the effect of Inter and intra-row spacing on growth, Yield and fruit characteristics of Melkashola variety of tomato. The trial was laid out in factorial randomized complete block design in three replications. The treatment comprises of twelve treatment combination (20, 30 and 40 cm intra row spacing and 60, 80, 100 and 120 cm inter row spacing). Combined analysis of variance showed that except days to 50% flowering, all traits did not show significant interaction effect. However, main effect of inter and intra row spacing showed significant differences for days to maturity, plant height, number of fruits per plant, fruit weight and marketable fruit yield. The highest number of fruits per plant was found from 40 cm intra row spacing (74) but it is statistically at par with 30 cm intra row spacing (68). Fruit size was significantly affected by intra row spacing; the largest fruit size was recorded from 30 cm intra row spacing (71.1 g) while the smaller size found from 20 cm intra row spacing (67.5 g). However, fruit size didn't show significant difference for different inter row spacing. The highest marketable yield was obtained from 60 cm inter row spacing (654.60qt ha^{-1}) which is statistically not significant with 80 cm inter row spacing (611.7 qt ha^{-1}). Similarly, the narrow intra row spacing that is, 20 cm scored highest marketable yield (651.4 qt ha^{-1}) which is also statistically at par with 30 cm intra row spacing (597.4 qt ha^{-1}). Considering fruit size and marketable yield, 60 cm inter row spacing and 30 cm intra row spacing are appropriate for higher marketable fruit yield and better fruit size in Merebleke wereda.

Key words: Inter and intra-row spacing, tomato, Melkasholla, Mrebleke, marketable yield.

INTRODUCTION

Tomato (*Solanum lycopersicon L.)* belongs to Solanacea family. It is an herbaceous plant, usually sprawling plant of the nightshade family that is typically cultivated for its edible fruit (Ayres, 2008). It originated from elevated

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regions of Peru and Ecuador (Steven and Celso, 2007).

Tomato is a warm season crop that requires very stable temperature ranges with minimums and maximums not being too wide apart. Temperature variation might result in poor fruit quality or reduced yield. The minimum temperature is around 10°C and the maximum being 34°C. Optimum temperatures are around 26 to 29°C (Ayres, 2012). The crop gives good results when grown in well-managed sandy loams and heavy clay loams free of hardpan but best results are obtained in deep, well-drained loams. The soil should be rich in organic matter and plant nutrients, with a pH value of 6 to 7.

Tomato is rich in nutrients such as vitamins, minerals and antioxidants, which are important to well-balanced human diets. Tomato is also an important dietary component because it contains high level of lycopene, an antioxidant that reduces the risks associated with several cancers and neurodegenerative diseases (Srinvasan, 2010).

According FAOSTAT (2016), production of tomato in Ethiopia showed a decreasing trend from 2011 (81,738 tons) to 2013 (55,000 tons) cropping season. Possible reasons for yield reduction are disease and pests (such as infestation of tuta absoluta and late blight), poor agronomic practices, shortage of improved varieties and shortage and poor quality seeds and poor postharvest handling practices.

The central zone of Tigray, especially Merebleke area is one of the potential districts for tomato cultivation. Moreover, the regional government of Tigray has constructed a dam which has a capacity to cultivate more than 3000 hectare. However, farmers in the study area cultivate tomato in a traditional way. That means they do not follow appropriate plant population, improved cultural practices and postharvest management practices. The use of improper plant spacing is among the reasons of low productivity of tomato, and it greatly influences growth, yield, and quality parameters of tomato. A number of authors viz; Awas et al. (2010); Balemi, 2008; Mamnoie and Dolatkhahi, 2013; Ogundare et al., (2015) have conducted trials on the effect of inter and intra row spacing on yield and yield components of tomato for specific agroecology and soil type. However, in Merebleke area no inter and intra row spacing trial was conducted so far for tomato hence, the objective of the experiment was to study the interactive effect of inter- and intra- row spacing, and to determine optimum inter- and intra-row spacing for fruit yield and yield components of Melkashola variety of tomato.

MATERIALS AND METHODS

Description of the experimental site

The experiment was conducted at Aksum Agricultural Research center, Mereblekhe irrigation experimental station. Merebleke is located 1101 km from Addis Ababa and 77 km to the north of Axum city, at14°409'38"N" latitude and 38°735'45"E longitude, and has an altitude of 1395 m.a.s.l, The annual rainfall ranged from 400 to 700 mm and the average temperature of the area varied from 23 to 30°C. The soil type of the experimental site is sandy loam (Merebleke BoARD, 2014).

Experimental design and treatments arrangements

The experiment was laid out in 4 x 3 factorial arrangements. Factor one: inter-row spacing with four levels (60, 80,100 and 120 cm) and factor two: intra-row spacing with three levels (20, 30 and 40 cm) were used in randomized complete block design (RCBD) with three replications. Melkasholla variety of tomato was used as experimental unit. The variety was released nationally by Melkassa agricultural research center in 1988, and recommended by Axum agricultural Research Center for the study area. It has semi determinate growth habit. The size of each experimental plot was 3x4.8m=14.4m^2. Each plot contained different number of seedlings depending on the inter and intra-row spacing capacity in order to obtain specified number of plants per plot.

Experimental procedures

Seeds of melkashola tomato variety were sown in 15 cm row spacing on well prepared seed bed of 1m x 5 m nursery area. The seed was covered with light soil and mulching grasses with the aim to protect seeds from washing away during watering. Beds were watered with watering can followed by surface irrigation. Proper management (weeding, watering) practices were followed to produce healthy and vigorous seedlings. Land preparation was practiced in advance for better seedling establishment and to expose the soil to solar treatments that could be useful to reduce diseases and insect pest incidence. Healthy and uniform seedlings with 3 to 4 leaf number were transplanted at the age of 35 days after sowing. The seedlings were irrigated after transplanting. Inorganic fertilizers, Di Ammonium phosphate (DAP) and urea were applied to each plot at the rate of 92 kg ha^{-1} P_2O_5 and 69 kg ha^{-1} N, respectively according to the recommendation of the crop (Lemma, 2002). The whole amount of phosphorus fertilizer was applied at transplanting, whereas half rate of nitrogen was applied during transplanting, and the remaining was applied during the flowering stage of the plant.

Data collected

Data were collected from randomly selected and tagged plants from the central row excluding the border rows. The parameters that were considered were: days to 50% flowering, days to maturity, plant height (cm), fruit Length (cm) and diameter (cm), number of branch per plant ,number of cluster per plant, number of fruit per plant, average fruit weight(g), marketable yield (qt ha^{-1}), unmarketable yield (qt ha^{-1}) and total yield (qt ha^{-1}).

Data analysis

Combined Analysis of Variance (ANOVA) was made using SAS version 9.2 (SAS Institute, 2008) after testing the ANOVA assumptions. Means that showed significant difference were compared using Duncan multiple range test (DMRT).

RESULTS AND DISCUSSION

Combined mean square of ANOVA for inter and intra row spacing of tomato showed that there were no

Table 1. Combined ANOVA of inter and intra row spacing of tomato evaluated for two years in Merebleke Wereda, central zone of Tigray.

Source of variation	Df	Mean square								
		Days to 50% flowering	Days to maturity	Plant height (cm)	No. of fruits plant $^{-1}$	Fruit diameter (cm)	Fruit length (cm)	Marketable fruit yield (qt ha^{-1})	Unmarketable yield (qt ha^{-1})	Total yield (qt ha^{-1})
Block	2	0.54	4.86	106.72	47.2	0.26	1.547^{ns}	9352	364.2	10378
Intra row (1)	2	3.17*	15.29*	112.08**	971.6**	0.001^{ns}	0.349^{ns}	68479**	904.4**	81728**
Inter row (2)	3	15.94**	73.68**	121.92**	2010.8**	0.0761^{ns}	0.347^{ns}	62936**	1293.7**	76015**
Year (3)	1	445.01**	21.13*	501.39**	305.9^{ns}	0.0383^{ns}	42.013**	311^{ns}	1580.5**	490^{ns}
1* 2	6	2.20*	4.63^{ns}	6.41^{ns}	132.5^{ns}	0.0382^{ns}	0.331^{ns}	9363^{ns}	321.3^{ns}	11263^{ns}
2*3	2	7.06**	30.54**	56.71^{ns}	668.0*	0.0046^{ns}	0.019^{ns}	29104^{ns}	297.0^{ns}	33506^{ns}
1*3	3	0.68^{ns}	0.83^{ns}	33.81^{ns}	296.7^{ns}	0.2141^{ns}	0.209^{ns}	3788^{ns}	124.7^{ns}	5116^{ns}
1*2*3	6	0.28^{ns}	3.13^{ns}	24.46^{ns}	44.6^{ns}	0.072^{ns}	0.075^{ns}	3650^{ns}	91.0^{ns}	3811^{ns}
Residual	46	0.95	4.397	24.69	135.1	0.1022	0.2968	11763	165.2	12570
Total	71	-	-	-	-	-	-	-	-	-

Df= degree of freedom, *= significant, **= highly significant, ns= non-significant.

significant interaction effects ($p<0.05$) for most of the traits except days to 50% flowering. On the contrary, combined main effect of inter and intra row spacing was significant ($p<0.05$) for most of the traits except fruit diameter and fruit length. In line with this, Getahun and Biki (2015) found non significant difference for fruit length and width for five intra row spacing (20, 30, 40, 50 and 60 cm) tested in Fogera wereda, Ethiopia. The effect of year was significant for some of the responses such as days to 50% flowering, days to maturity, plant height, fruit length and unmarketable yield indicating that performance of the experiment varied across season for the aforementioned traits. It could be due to high infestation of blight disease in 2013 as compared with 2014, and this resulted in poor performance of the crop (Table 1).

Interaction effect of inter and intra row spacing on days to 50% flowering

Combined interaction effect of inter and intra-row spacing showed significant ($p<0.05$) difference on days to 50% flowering. A combination of 30cm intra row and 120 cm inter row space took the earliest (48 days) while 30 cm intra raw and 60 cm inter row space took the longest (52 days) time to reach days to 50% flowering. Generally, as the inter-row spacing increases from 60 to 120 cm, and intra-row spacing increases from 20 to 40 cm, days to 50% flowering showed an increasing trend (Table 2). Similarly, Getahun and Bikis (2015) found that as intra row spacing increased from 20 to 60 cm the number of days required to reach 50% flowering increased from 42 to 47 days.

Main effect of intra row spacing on different responses of tomato

The combined main effect of intra row spacing had significant difference ($p<0.05$) for days to maturity, plant height, fruit number per plant and single fruit weight. 40 cm intra row spacing took the highest number of days (92 days) to mature. Generally, as the intra row spacing increased from 20 to 40 cm it showed an increasing trend in days required to maturity. The tallest (59.9 cm) plant length was recorded from 20 cm intra row spacing while the shortest (55.8 cm) was obtained from 40 cm intra row spacing. This was because as plants get narrow spacing they compete to get sunlight and forced to increase their length. Similarly, Balemi (2008) found that highest plant length was found from narrow spacing (80*30 cm) inter and intra row spacing as compared to wider spacing (100* 30 cm).

The highest number of fruits per plant (74) was found from 40 cm intra row spacing, but it was statistically at par with 30 cm spacing (68). This is because as the plants get optimum space the number of fruits increase in comparison with the narrow intra row spacing, that is, 20cm. Fruit size is significantly affected by intra row spacing. The largest fruit size (71.2 g) was found from intra row space of 30 cm which is statistically not significantly different from 40 cm (66.3 g) while the least size was scored from intra row spacing of 20 cm (64.7 g).

This revealed that competition effect for nutrient, space, and air is minimal at wider space and this

Table 2. Combined interaction effect of inter and intra-row spacing on days to flowering, fruit diameter (cm) and fruit length (cm) .

Intra * inter row spacing (cm)	Days to 50% flowering			Fruit diameter (cm)			Fruit length (cm)		
	2013	2014	Combined	2013	2014	Combined	2013	2014	Combined
20*60	47.3	51.0^{ef}	49.2^{def}	4.0	4.5	4.3	8.1	6.8	7.5
20*80	48.0	51.7^{def}	49.8^{cde}	4.3	4.5	4.4	8.5	6.8	7.7
20*100	47.3	52.0^{cde}	49.7^{cde}	4.5	4.3	4.4	8.5	6.8	7.7
20*120	48.7	52.3^{cde}	50.5^{abc}	4.5	4.2	4.3	8.4	7.0	7.7
30*60	46.0	50.3^{f}	48.2^{f}	4.2	4.4	4.3	8.9	7.2	8.0
30*80	46.3	51.7^{def}	49.0^{ef}	4.3	4.5	4.4	8.7	6.9	7.8
30*100	48.0	53.3^{abc}	50.7^{abc}	4.3	4.4	4.4	8.7	7.1	7.9
30*120	49.3	54.0^{ab}	51.7^{a}	4.4	4.1	4.3	8.2	7.1	7.7
40*60	46.3	52.7^{bcd}	49.5^{cde}	4.5	4.4	4.5	8.3	6.9	7.6
40*80	47.7	53.0^{abcd}	50.3^{bcd}	4.3	4.5	4.4	8.2	6.8	7.5
40*100	47.3	54.0^{ab}	50.7^{abc}	4.3	4.5	4.4	9.3	7.3	8.3
40*120	48.3	54.3^{a}	51.3^{ab}	4.2	4.0	4.1	8.5	7.1	7.8
CV (%)	2.1	1.6	1.9	5.2	9.1	7.4	7.2	6.7	7.0
SEM (±)	0.56	0.49	1.13	0.13	0.23	0.13	0.35	0.27	0.22
Level of sig.	ns	*	*	ns	ns	Ns	ns	ns	Ns

CV= coefficient of variation, SEM= standard error of the mean, *= significant, **= highly significant, Ns= non-significant. Means followed by the same letter within the same column are not significantly different at 5% level of significance.

favored the plant to increase fruit size. This is in agreement with the finding of Mamnoie and Dolatkhahi (2013) who found significant different for fruit number per plant and single fruit weight (g) for four intra row spacing (30, 40, 50 and 60 cm) for two tomato varieties evaluated in Iran. They reported that highest number of fruits per plant and larger fruit size were found from 60 cm intra row spacing.

Main effect of inter row spacing on different traits of tomato

Combined main effect of inter row spacing had significant difference for days to maturity, plant height and fruit number per plant while it showed non-significant different for single fruit weight. 120 cm inter row spacing took the highest number of (93.2) days to maturity whereas the smallest number of days for maturity (88.6) was recorded from 60 cm inter row space. Similar to intra row spacing effect, the influence of inter row spacing on maturity showed an increasing trend when the spacing increased from 60 to 120 cm. the highest number of fruits (81) was scored from the wider inter row spacing, 120 cm and the least (55) was recorded from 60 cm spacing (Table 3).

Combined main effect of intra row spacing on fruit yield of tomato

Combined main effect of intra row spacing was significant for marketable, unmarketable and total fruit yield per hectare. The highest marketable fruit yield (619.4 qt ha^{-1}) was recorded from 20 cm intra row spacing, which is statistically not different with 30 cm intra row spacing (597.4 qt ha^{-1}). The least marketable yield was found from 40 cm intra row spacing (Table 4). This might be because the narrow intra row spacing had higher plant population as compared to wider spacing. On the contrary, fruit size was significantly smaller in 20 cm intra row as compared to 30 and 40 cm intra row spacings. This is in agreement with the finding of Mammoie and Dolatkhahi (2013) who found that as intra row spacing increased from 30 to 60 cm fruit size increased from 126.5 to 166.5 gram. Generally, relatively higher yield with larger fruit size was obtained from 30 cm intra row spacing in the study area.

According to Lemma (2002), fruits with cracks, damaged by insect, disease, birds, small size fruits and sun burn are considered as unmarketable. Hence, the highest (65.86 qt ha^{-1}) unmarketable yield was found from 20 cm intra

Table 3. Combined main effect of inter and intra row spacing on yield and yield component of tomato evaluated for two years.

Inter row spacing (cm)	Days to maturity			Plant Height (cm)			Fruit no. per plant			Single fruit weight (g)		
	2013	2014	Combined	2013	2014	Combined	2013	2014	Combined	2013	2014	Combined
60	88.2^{b}	88.9^{c}	88.6^{c}	59.3	49.9^{b}	54.6^{b}	62^{b}	48^{c}	55^{c}	64.8	67.6	66.2
80	89.6^{b}	91.2^{b}	90.4^{b}	60.4	56.0^{a}	58.2^{a}	67^{ab}	65^{b}	66^{b}	64.8	71.2	68.0
100	91.4^{a}	92.6^{ab}	92.0^{a}	62.5	58.7^{a}	60.6^{a}	72^{ab}	68^{b}	70^{b}	69.6	71.3	70.5
120	92.8^{a}	93.7^{a}	93.2^{a}	61.2	57.6^{a}	59.4^{a}	78^{a}	83^{a}	81^{a}	65.3	64.3	64.8
SEM (±)	0.46	0.39	0.494	1.55	1.18	1.17	3.6	3.7	2.7	2.63	3.18	2.196
Level of sig	**	**	**	ns	**	**	*	**	**	ns	ns	ns
Intra row spacing (cm)												
20	91.3^{a}	89.8^{a}	90.5^{b}	63.6^{a}	56.1^{a}	59.9^{a}	69^{ab}	54^{b}	66^{b}	62.1^{b}	67.2	64.7^{b}
30	89.3^{b}	92.0^{b}	90.7^{b}	59.9^{ab}	58.1^{a}	59.0^{a}	65^{b}	71a	68^{ab}	71.3^{a}	71.1	71.2^{a}
40	90.9^{a}	93.0^{b}	92.0^{a}	59.0^{b}	52.5^{b}	55.8^{b}	76^{a}	72a	74^{a}	65.0^{ab}	67.5	66.3^{ab}
CV (%)	1.5	2.5	2.3	7.64	7.4	8.5	15.6	16.8	17.1	11.9	13.9	13.8
SEM (±)	0.40	0.67	0.428	1.34	1.68	1.01	3.1	3.2	2.4	2.28	2.76	1.902
Level of sig	**	**	*	*	**	**	*	**	**	*	ns	*

CV= coefficient of variation, SEM= standard error of the mean, *= significant, **= highly significant, Ns= non-significant. Means followed by the same letter within the same column are not significantly different at 5% level of significance.

Table 4. Combined main effect of inter and intra row spacing on yield of tomato.

Inter row spacing (cm)	Marketable fruit yield (qt ha^{-1})			Un marketable yield (qt ha^{-1})			Total yield (qt ha^{-1})		
	2013	2014	Combined	2013	2014	Combined	2013	2014	Combined
60	654.6^{a}	607.4^{ab}	631^{a}	69.1^{a}	71.2^{a}	70.18^{a}	723.7^{a}	678.7^{a}	698.2^{a}
80	611.7^{a}	616.2^{a}	613.9^{a}	52.7^{b}	66.8^{ab}	59.72^{b}	664.3^{a}	683.0^{a}	673.6^{ab}
100	563.9^{ab}	575.2^{ab}	569.6^{ab}	45.7^{b}	54.7^{b}	50.23^{c}	609.6^{ab}	630.0^{ab}	619.8^{bc}
120	491.2^{b}	505.9^{b}	498.5^{b}	49.2^{b}	61.5^{ab}	55.36^{bc}	540.4^{b}	567.3^{b}	553.9^{c}
SEM (±)	37.36	28.93	22.14	3.64	3.87	3.03	38.45	30.5	26.43
Level of sig	**	**	**	**	**	**	*	**	**
Intra row spacing (cm)									
20	651.4^{a}	587.4^{ab}	619.4^{a}	65.2^{a}	66.5	65.86^{a}	716.6^{a}	653.9^{a}	685.3^{a}
30	561.3^{ab}	633.6^{a}	597.4^{a}	49.9^{b}	62.9	56.42^{b}	611.2^{b}	696.5^{ab}	653.9^{a}
40	528.3^{b}	507.5^{b}	517.9^{b}	47.4^{b}	61.3	54.34^{b}	575.7^{b}	568.8^{b}	572.2^{b}
CV	19.3	17.4	18.8	20.2	21.1	21.8	18.2	16.5	17.6
SEM (±)	32.3	28.93	25.56	3.15	3.87	2.62	33.2	30.48	22.89
Level of sig	**	**	**	**	ns	**	*	**	**

CV= coefficient of variation, SEM= standard error of the mean, *= significant, **= highly significant, Ns= non-significant. Means followed by the same letter within the same column are not significantly different at 5% level of significance.

row spacing and the least from 40 cm spacing (54.34 qt ha^{-1}). This is because narrow intra row spacing had high population density and resulted in competition for nutrient, space and sunshine, which in turn resulted in small sized, deformed and unmarketable fruits.

Combined main effect of inter row spacing on fruit yield of tomato

Similar to the effect of intra row spacing, inter row spacing also had highly significant difference on marketable, un-marketable and total fruit yield per hectare of tomato. 60 cm inter row spacing had the highest marketable yield (631 qt ha^{-1}), and the least yield was obtained from 120 cm spacing (498.5 qt ha^{-1}). This may be due to high population in the narrow inter row spacing, and fruit size was not significantly different among the four inter row spacing which resulted in high marketable yield.

In line with this, Harnet et al. *(*2015) found the least marketable yield of tomato from 120*40 cm inter and intra row spacing while the highest marketable yield was found from interaction effect of 50*20 cm inter and intra row spacing at southern Tigray, Ethiopia. Similarly, Balemi (2008) reported that highest total fruit yield (78.6 kg $plot^{-1}$) was found from 80*30 cm inter and intra row spacing whereas the least yield (67.6 kg $plot^{-1}$) was obtained from 100*30 cm inter and intra row spacing for the study conducted at Ambo University, Ethiopia.

On the contrary, highest unmarketable yield (70.18 qt ha^{-1}) was found from 60 cm inter row spacing while 120 cm scored the least (55.36 qt ha^{-1}). This might be associated as inter row spacing increase from 60 to 120 cm fruit size showing an increasing trend, even though it is not statistically and it might result in higher unmarketable yield.

Conclusion

Tomato is among the most important vegetable crops in low land central zone of Tigray, especially Merebleke wereda. Farmers get lower yield mainly due to the use of in-appropriate agronomic practices Plant spacing greatly influenced growth, yield, and quality parameters of tomato. Considering this problem, an experiment was conducted for two years aiming to investigate the effect of inter-row and intra-row spacing on yield and yield component of tomato.

Combined mean results of the two year study showed that the highest marketable yield was recorded from 60 cm inter row spacing (654.60qt ha^{-1}) but it is statistically at par with 80 cm inter row spacing (611.7 qt ha^{-1}). Similarly, narrow intra row spacing that is, 20 cm scored highest marketable yield (651.4 qt ha^{-1}) but significantly smaller fruit size (67.5 g) as compared to 30 cm intra row spacing (71.1 g). On the other hand, inter row spacing didn't show significant difference in fruit size. Therefore, it is recommended that 60 cm inter row spacing and 30 cm intra row spacing are appropriate for higher marketable fruit yield and fruit size in central zone of Tigray, Merebleke wereda.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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