IJCST International Journal of Crop Science and Technology
Volume 2, Issue 2, 2016, Page: 78-86 ISSN: 2458-7540

Investigation of Some Yield and Quality Characteristics of Sunflowers (*Helianthus annuus* L.) Grown in Different Plant Density and Row Orientation

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ABSTRACT

This research was carried out to examine the yield and quality characteristics of sunflowers grown in different plant density and row orientation in the trial fields of Uludag University Mustafakemalpasa Vocational School during 2011 and 2012 years. Two row orientations (East-West= E-W and North-South= N-S) and three plant densities (D1= 2.5, D2= 3.8, D3= 7.7 plant m^{-2}) were studied on variety Sanay of sunflower. The effect of row orientation on seed and oil yields and quality traits was generally minor, but values of seed and oil yield in E-W orientation were approximately 5% greater than N-S orientation in 2011. Increased plant density significantly increased seed yield, oil yield, the rates of sunlight absorbed by crop and plant height, and significantly decreased head diameter, the number of seed per head, seed weight per head and 1000 seed weight. The effect of experimental treatments on fatty acids of sunflower was generally minor; however, the highest palmitic acid content was determined from treatment D2. According to the obtained results, considering the decrease in some yield traits, the E-W row orientation and a 7.7 plant m^{-2} plant density can be recommended for sunflower cultivation.

Keywords: Plant density; Orientation; Seed yield; Oil yield; Fatty acids

INTRODUCTION

Seeds of sunflower (*Helianthus annuus* L.) includes oil in the rates of 36-55 % and protein in the rates of 17.0-18.3 %, also. It is one of the important vegetable oils in terms of nutrition because it is oil contains polyunsaturated fatty acids in high rate (69 %) and saturated fatty acids at low rate (11 %). Sunflower a good rotation plant that are used in many areas in industry and it is remaining oil cake is used in feed rations (Karakas, 2011).

In the world, sunflower productions of over 40 million tons are made in approximately 26 million hectares. Ukraine, Russia, Argentina and China are the pioneer countries in sunflower production (FAOSTAT, 2013).

In Turkey, sunflower production is about 1 million 480 thousand tons annually at the average yield of 2 680 kg ha^{-1} (TUIK, 2014). Sunflower provides approximately 48% of vegetable oil supply of Turkey (Day, 2008). Sunflower containing quality oil highly in the seed may be cultivated in almost every region of our country in dry and wet conditions and it is a crop which ranks first among oil seed crops in terms of cultivation area and oil production (Gurbuz et al., 2003).

Sunflower yield and quality are influenced by many environmental factors as well as genetic characteristics. In addition to irrigation, fertilization, crop protection applications and other cultural practices, microclimate are the most important factors that affect yield and quality. The plant density and row orientation which mostly not considered are very important factors in terms of effective agricultural production (Robinson et al., 2015).

Sunflower is a plant which follows the sun from exit to soil surface of first leaves to the flowering. Head and leaves look to the east direction in the mornings and to the west in the evenings. It gives up tracking the sun a few days before the opening of the fertile flowers and the heads turn their faces to eastward and keep this position until the harvest (Robinson et al., 2015).

Some researchers have declared that formation in E-W or N-S directions of the plant rows do not effect the seed yield, 1000 seed weight and oil rate (Riahinia and Dehdashti, 2008). However, Dhillon et al. (1982) have reported that the rows formed at N-S direction have higher yield potential and must be preferred to E-W direction. Diepenbrock et al. (2001) explained that sunflowers sown in the E-W direction and at 4-8 plant m^{-2} density have given higher seed and oil yield. Barros et al. (2004) showed that while the highest seed yield is obtained at 0.75 m x 0.26 m density, the maximum seed numbers per head and the highest 1000 seed weights were determined at 0.75 m x 0.17 m density.

Scientists have investigated the effect of plant density or row direction on yield and quality but studies examining together effects of the plant density and row direction are very limited. In addition, there is no consensus on the effects of especially row direction for sunflower cultivation according to the literature. Likewise, it is believed that the differences of soil and climatic conditions, varieties, cultural applications such as irrigation and fertilization may lead to these circumstances.

This research was carried out in two years period at the semi-moist climate conditions to find out the effect of plant density and row direction on sunflower seed yield and quality.

MATERIALS AND METHODS

Field trials were conducted in the trial plots of Mustafakemalpaşa Vocational School (40º02′ N latitude and 28º23′ E longitude) during 2011 and 2012 years. Trial field is plain and altitude is 25 m. According to results of analysis made on soil samples taken from 0-30 cm depth of the research area, soil is clayey-loam textured. For the trial field soil, total nitrogen rate 0.20%, available phosphorus 81 kg ha^{-1}, exchangeable potassium 1395 kg ha^{-1}, organic matter rate 1.9 %, pH 7.8 and electrical conductivity (EC) as 0.48 dS m^{-1} were determined (Anonymous, 2011). These results reveal that soil is moderately limy, salt-free, medium in organic matter, rich in potassium and slightly alkaline.

The monthly total rainfall, average temperatures and relative humidity data taken from the meteorological station which is approximately 1 km away from the trial field were given in Table 1. The averages of monthly air temperature at the trial years are similar to data of long-years period. Whereas, total amount of precipitation during the growing period in 2011 has been more higher according to 2012 and long-years average. Particularly, the total rainfall in June of 2011 (130.8 mm) has realized very high quantities according to 2012 and averages of long-years (Anonymous, 2012).

Hybrid sunflower 'Sanay' variety as plant material in the trial was used. Sowings of sunflower seeds were made by hand on 02 April 2011 and 05 April 2012. The plot size is 13.0 m^2 (2.6 m x 5.0 m).

Previous crop in the trial field has been soybean in both years. Field was tillage in 25 cm depth with mouldboard plough in the fall and there are no other process made until spring. Before sowing, the soil has embossed with a stringed rake, subsequently it has been prepared to sowing using the disc harrow. In the soil preparation stage, 200 kg ha^{-1} 20-20-0 as bottom fertilizer and 150 kg ha^{-1} urea (46-0-0%) fertilizers in the second irrigation were applied.

Table 1- Monthly total rainfall, average temperature and relative humidity values

Climate parameters	April	May	June	July	August	September
Total precipitation (mm)						
2011 year	63.0	26.6	130.8	25.4	4.0	51.6
2012 year	67.6	25.2	11.6	5.2	24.6	43.0
Long-year average (1996-2009)	60.3	28.3	27.9	16.6	13.1	53.2
Average temperature (ºC)						
2011 year	13.9	19.2	22.7	25.3	27.7	22.1
2012 year	10.9	16.6	21.8	25.8	23.5	21.8
Long-year average (1996-2009)	13.2	18.1	22.7	25.2	25.2	20.6
Relative humidity (%)						
2011 year	77.4	72.6	59.3	60.3	59.8	68.9
2012 year	78.3	76.6	63.2	56.4	61.3	68.0
Long-year average (1996-2009)	66.7	63.4	58.8	57.8	60.4	66.0

The first two irrigation is sprinkler, third and final irrigation was realized as ponding in the buns and moisture of soil was brought to field capacity level in each irrigation. Weed control is done with the hand hoe. Harvest processes were carried out in the dates of 05 September 2011 and 07 September 2012.

That trial subjects were examined as three replications in split plot trial design: row directions (N-S= North–South and E-W= East-West) and plant densities (D1= 2.5, D2= 3.8 and D3= 7.7 plant m^{-2}). Row spacing at every three plant densities was applied as 0.65 m. Intra-row spacings for P1, P2 and P3 subjects were taken as respectively 0.6, 0.4 and 0.2 m. Row direction as the main plots and plant density as the sub-plots were used.

Values of plant height, head diameter, number of seed per head, seed weight per head were determined using randomly selected 10 plants from the second and third rows of the plots. 1000 seed weight and oil contents were measured using the seeds of all plants harvested from plots. Seed yields were calculated by proportioning to hectare of plot yields. Fatty acid contents (oleic, linoleic, palmitic and stearic acid) has been fixed on the mixed seeds of both trial years, using gas chromatography instruments of a special oil factory, as also reported of Oz et al (2009). The radiation (sunlight) values absorbed by plants are determined by subtracting the values of radiation reaching the soil and reflected from the plant surface from gross radiation from the sun (Emami-Bistghani et al 2012).

Radiation absorbed by plants = Gross radiation come from the sun – (Radiation reaching the soil + Radiation reflected from the plant surface)

Measurements have been performed on V_9 and R_2 growth stage of the plant and theirs averages were used (Rivelli et al., 2000). To this end, a radiation meter (LI-COR LI-191 S, Lincoln, NE) set has been used.

All the data obtained from trial were subjected to analyses of variance for each trait using SPSS Statistical Pragramme (IBM® SPSS® Statistics, Version 20, Copyright 1989, 2011 SPSS Inc.). Differences between the means were evaluated at 0.05 probability level using Duncan's multiple range test.

RESULTS AND DISCUSSION

Seed Yield, Oil Ratio, Oil Yield and the Ratio of Sunlight Absorbed by Plants

Values of seed yield, oil ratio, oil yield and ratio of sunlight absorbed by the plant as associated with plant row direction and plant density were given in Table 2. In terms of seed yield, in year 2011, while according to the N-S direction from the E-W direction has been obtained higher yield; in the year 2012, effect of row direction was found insignificantly.

Table 2- Seed yield, oil ratio and oil yield of sunflower crop and the ratio of sunlight absorbed by crop in relation to plant row directions and plant density

Subject of trial	Seed yield (kg ha^{-1})		Oil ratio (%)		Oil yield (kg ha^{-1})		Ratio of sunlight absorbed by crop	
	2011	2012	2011	2012	2011	2012	2011	2012
Effect of row direction								
North-South	3716 b	4060	41.2	41.2	1533 b	1676	90.8	91.6
East-West	3918 a	3962	40.8	42.1	1602 a	1664	90.3	90.9
Effect of plant density								
2.5 plant m^{-2}	3385 c	3706 c	41.3	42.3	1399 c	1566 b	89.4 b	90.0 c
3.8 plant m^{-2}	3860 b	4076 b	41.1	42.1	1589 b	1717 a	90.8 a	91.4 b
7.7 plant m^{-2}	4207 a	4250 a	40.7	40.6	1714 a	1728 a	91.6 a	92.4 a
RD x PD Interaction								
N-S 2.5 plant m^{-2}	3313	3897 c	41.3	41.3	1370	1609	89.5	90.2
E-W 2.5 plant m^{-2}	3457	3517 d	41.3	43.3	1428	1522	89.3	89.8
N-S 3.8 plant m^{-2}	3713	4117 b	41.3	41.6	1535	1715	91.0	91.7
E-W 3.8 plant m^{-2}	4007	4037 bc	41.0	42.6	1644	1719	90.6	91.1
N-S 7.7 plant m^{-2}	4123	4167 ab	41.1	40.9	1694	1704	92.0	92.9
E-W 7.7 plant m^{-2}	4291	4333 a	40.3	40.4	1734	1752	91.2	92.0
Significance								
Row direction (RD)	***	ns	ns	ns	*	ns	ns	ns
Plant density (PD)	***	***	ns	ns	***	**	*	*
RD × PD	ns	*	ns	ns	ns	ns	ns	ns

*, ** and ***: Means shown by the different letters within a column are statistically different at 0.05, 0.01 and 0.001, respectively; ns: non significant

While the highest seed yield was obtained from the 7.7 m^{-2} plant density, the lowest yield has given the 2.5 m^{-2} plant density (Table 2). In year 2012, found statistically different of the row direction × plant density interaction effects, reveals that can change of effects of the direction and density. In terms of both row direction, the highest and lowest seed yields were measured in the 7.7 plants m^{-2} and 2.5 plants m^{-2} densities, respectively, but effect of row direction × plant density interaction in years 2011 is not found statistically significant.

In the second year of trial, it was obtained higher seed yield according to the first year. As about subject, while some researchers have reported that row direction do not affect seed yield (Shafiullah et al, 2001), if some researchers have claimed that more advantageous of row formation in the E-W direction (Dhillon et al., 1982 and Temizel et al., 2011). These finding are parallel to the findings obtained from our research. Riahinia and Dehdashti (2008) stated that seed yield decreases together with decline the number of plants in the unit area.

With increasing number of plants per unit area, leaf area index also increases and thus more sunlight is absorbed by plants (Andrade et al., 2002). Also, by covering earlier surface of soil the plants grown in narrow row spacing ensures to increase of the

absorbed light quantity (Heitholt et al., 1992). The findings obtained from this study support the other research findings. Due to the increase in plant density was determined an increase in the rates of light absorbed by the plant (Table 2).

While Diepenbrock et al. (2001) were announced the 4-8 m^{-2} density as the best option, Ibrahim (2012) has recommended 7.5-9.0 plant m^{-2} density. These values are consistent with our research findings. Sunflower oil rates were unaffected from plant row direction and different plant intensity and, oil rates have ranged between 40.3-42.6 % (Table 2). In parallel to findings obtained from this study, it was determined that the plant density is not affect oil content of sunflower in previously conducted similar studies (Al-Thabet, 2006). However, Ibrahim (2012) stated that if the number of plants per unit area decreases, oil rates increased. Similar to the results of seed yield, plant density has affected oil yield statistically significant (Table 2). While the highest oil yield in the first year of the experiment was obtained from 7.7 plants m^{-2} density, in the second year, the highest values were measured in the 3.8 and 7.7 plants m^{-2} densities.

Dissimilarity between the years in terms of plant density has been significant and, in 2012 relatively more high oil yield was determined. In 2011, the effect on the oil yield of the row direction has been found significant at 0.05 probability level and in the E-W orientation has been detected the highest oil yield. However, it were not found significant the row direction effect in year 2012 and the row direction × plant density interaction effects in both trial year. In a similar study, according to Diepenbrock et al. (2001) oil yields of sunflower sown to rows created the in N-S direction are found higher from oil yield of sunflower sown in E-W direction. Findings of Ibrahim (2012) reported to show increase of oil yield along with increase of plant density are overlap with the trial findings.

Yield Components

While effects on plant height of the plant density and direction × density interaction in year 2011 has been significantly, examined all features has been statistically significant in year 2012 (Table 3).

In general, plants in the row formed in E-W direction have been longer from plants grown in N-S direction. When analyzed in terms of plant density, plant height was increased with increase of the number of plant per unit area. In the second trial year the average of plant height has been realized higher compared to average of the first trial year. As the reason for this, show changes between years of sunshine duration realized in the sunflower growing season may be said. According to row direction × plant density interaction calculated as significant, the highest plant heights were measured in 7.7 plant m^{-2} density grown in the plots formed in the E-W and N-S directions. The lowest values were determined in the 3.4 m^{-2} density of row created on the both E-W and N-S directions (Table 3). In parallel to the findings obtained from this study, Shafiullah et al. (2001) have determined that the more advantageous of E-W direction in terms of plant height. With the increase in number of plants per unit area, plant height increases, also (Asghar et al., 2007). In this study, effect of the plant row direction on head diameter found as statistically insignificant. However, the head diameters were decreased depending on the increase of plant density (Table 3). In terms of row direction × plant density interaction, the highest values has been measured in 2.5 plant m^{-2} density created in N-S direction and, but the effect of this interaction was determined statistically insignificant.

As similar with the results of the study, some researchers have reported decreases of head diameter due to the increase in plant density (Asghar et al., 2007; Ibrahim, 2012). Seed number per head which is a major yield component was influenced statistically significant from the plant row direction and plant density (Table 3).

Table 3- Yield components of sunflower crop in relation to plant row directions and plant density

Subject of trial	Plant height (cm)		Head diameter (cm)		Seed number per plant		Seed weight per plant (g)		1000 seed weight (g)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Effect of row direction										
North-South	198.1	199.0 b	25.2	26.0	1109	982 b	75.9	73.6 b	66.9	75.0 b
East-West	199.8	206.4 a	23.6	24.4	1120	1031 a	76.5	80.8 a	67.4	77.8 a
Effect of plant density										
2.5 plant m^{-2}	179.2 c	185.3 c	29.8 a	32.6 a	1318	1285 a	99.2 a	110.2 a	78.3 a	89.0 a
3.8 plant m^{-2}	196.5 b	201.1 b	25.0 b	24.0 b	1083	1018 b	75.2 b	76.7 b	69.5 b	76.5 b
7.7 plant m^{-2}	221.3 a	221.6 a	18.3 c	19.0 c	941	718 c	54.3 c	45.0 c	53.7 c	63.6 c
RD x PD Interaction										
N-S 2.5 plant m^{-2}	174.0 c	178.0 c	31.7	34.0	1301	1265	100.7 a	104.0	80.7	86.0
E-W 2.5 plant m^{-2}	184.3 b	192.7 b	28.0	31.3	1336	1305	97.7 a	116.3	75.8	92.0
N-S 3.8 plant m^{-2}	199.7 b	198.0 b	26.0	25.0	1071	966	72.3 c	75.0	67.5	77.0
E-W 3.8 plant m^{-2}	193.3 b	204.3 b	24.0	23.0	1095	1069	78.0 b	78.3	71.5	76.0
N-S 7.7 plant m^{-2}	220.7 a	221.0 a	18.0	19.0	954	716	54.7 d	42.0	52.6	62.0
E-W 7.7 plant m^{-2}	222.0 a	222.3 a	18.7	19.0	928	720	54.0 d	48.0	54.8	65.3
Significance										
Row direction (RD)	ns	*	ns	ns	ns	*	ns	**	ns	*
Plant density (PD)	***	***	***	***	***	***	***	***	***	***
RD × PD	*	*	ns	ns	ns	ns	*	ns	ns	ns

*, ** and ***: Means shown by the different letters within a column are statistically different at 0.05, 0.01 and 0.001, respectively; ns: non significant

The number of seed obtained from the plants cultivated on the rows formed in E-W direction has been more than the number of seeds determined for N-S direction. Increase of the number of plants per unit area has reduced the number of seed per head. While the highest value was taken from of 2.5 plants m^{-2} density, this was followed by 3.8 plants m^{-2} density.

In addition, in the previously conducted similar studies, it is stated that with increase of the number of plants per unit area, decreases of the seed number per head (Salehi and Bahrani, 2000; Al-Thabet, 2006). Effect of row direction on the seed yield per head was found as statistically significant in year 2012 and, the rows created in E-W direction according to N-S direction has given higher values. The seed weight values in head increased with decreasing plant density (Table 3). According to row direction × plant density interaction measured as significantly, N-S × 2.5 and E-W x 2.5 plants m^{-2} subjects were given higher values. Findings of Salehi and Bahrani (2000) revealing decreases of seed yield per plant along with increasing of the plant density in unit area supports results of our trial. As parallel to these findings the seed weight per head, in year 2012, the impact on 1000 seed weight of row direction was found statistically significant and more higher values from plants grown in E-W direction were obtained. By the number of plants located in unit area, in between values of 1000 seed weight were formed significant differences and the highest values was obtained from 2.5 plants m^{-2} density and, 3.8 plants m^{-2} density has followed it.

1000 seed weight (76.3 g) measured in the second year of experiment has been statistically significantly higher than value

determined for the first year (67.1 g).
In similar studies, Shafiullah et al (2001) announced that sowing direction does not affect the 1000 seed weight. Whereas, according to Suzer (2010), 1000 seed weight has decreased in contrast to the increase in the number of plants per unit area and, this finding supports our research results.

Table 4- The rates of some sunflower oil acids in relation to plant row directions and plant density

Subject of trial	Fatty Acids (%)			
	Oleic acid	Linoleic acid	Palmitic acid	Stearic acid
Effect of row direction				
North-South	51.2	38.4	5.5 a	3.0
East-West	50.8	38.1	5.3 b	3.0
Effect of plant density				
2.5 plant m^{-2}	51.4	38.5	5.2 c	3.0
3.8 plant m^{-2}	50.9	38.0	5.6 a	3.1
7.7 plant m^{-2}	51.0	38.3	5.4 b	2.9
RD x PD Interaction				
N-S 2.5 plant m^{-2}	50.2 b	39.9 a	5.3 b	3.0
E-W 2.5 plant m^{-2}	52.6 a	37.2 c	5.2 b	3.0
N-S 3.8 plant m^{-2}	51.5 ab	37.8 bc	5.5 a	3.0
E-W 3.8 plant m^{-2}	50.1 b	38.3 bc	5.6 a	3.1
N-S 7.7 plant m^{-2}	52.1 a	37.7 bc	5.2 b	2.9
E-W 7.7 plant m^{-2}	49.9 b	39.0 ab	5.6 a	2.9
Significance				
Row direction (RD)	ns	ns	*	ns
Plant density (PD)	ns	ns	**	ns
RD × PD	**	**	*	ns

*, ** and ***: Means shown by the different letters within a column are statistically different at 0.05, 0.01 and 0.001, respectively; ns: non significant

Fatty Acids

Linoleic acid having two double bond and oleic acid having a double bond from unsaturated fatty acids; stearic acid contents from saturated fatty acids were not affected from the sowing direction and plant density. Palmitic acid rate from other saturated fatty acids has been found higher in the N-S direction than in E-W direction (Table 4). While palmitic acid content set for 3.8 plants m^{-2} density has taken maximum value, 7.7 plants m^{-2} density has followed this value. Oleic acid, linoleic acid and palmitic acid contents were found different and significant in terms of row direction × plant density interaction effect. The highest oleic acid contents have been obtained from N-S × 7.7 plant m^{-2} and E-W x 2.5 plant m^{-2} densities. While the highest linoleic acid contents were taken from N-S × 2.5 plants m^{-2} and E-W × 7.7 plants m^{-2} plots, relatively more higher palmitic acid contents were determined in 3.8 and 7.7 plants m^{-2} densities for E-W direction with 3.8 plant m^{-2} density for N-S direction.
Bukhsh et al. (2011) reported that with the increasing of plant numbers in the unit area, oleic acid and linoleic acid rates were unchanged, palmitic acid rates were decreased and stearic acid rates were increased.

CONCLUSION

Results of this trial carried out as the two years in a semi-humid climate in northwestern of Turkey can be summarized as follows. While the effect of row direction on yield and quality components of sunflower was found less, effect of plant

density has been more different and significant. The results obtained from trial revealed that particularly seed and oil yields by increasing the number of plant in unit area can be significantly increased. Indeed, the increase in plant density can provide to significant benefits in sunflower cultivation. Because, significant increases in sunlight absorbed by plants takes place and at the same time taller plants are obtained. Thus, more efficient use of agricultural inputs may be provided. However, in increased plant density conditions, it was determined that in values of head diameter, number of seed per head, seed weight per head and 1000 seed weight may be reductions. Except palmitic acid, effect on other fatty acids of plant density was found insignificant.

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