Turk J
Field Crops
2024, 29(1), 9-17
DOI: 10.17557/tjfc.1349344

EFFECTS OF PLANT DENSITY ON MICRONUTRIENT UPTAKE IN SUNFLOWER (*Helianthus annuus* L.) VARIETIES

Gunsu BARISIK KAYIN[1], Hasan KAYIN[2], Abdurrahim Tanju GOKSOY[2]*

[1] *Bursa Uludag University, Vocational School of Gemlik, Department of Horticulture, Bursa, TURKEY*
[2]*Bursa Uludag University, Faculty of Agriculture, Department of Field Crops, Bursa, TURKEY*
**Corresponding Author: gbarisik@uludag.edu.tr*

Received: 24.08.2023

ABSTRACT

The objective of this study was to determine the effects of plant density per unit area on micro nutrients (Iron, Copper, Zinc, Manganese and Boron) uptake of some sunflower genotypes. Three sunflower varieties (Sanay MR, Oliva CL and LG5543 CL) were used as genetic material and three different plant densities: 40800, 57100 and 95200 plants/ha (sowing spacing; 0.35 x 0.70, 0.25 x 0.70 and 0.15 x 0.70 m, respectively). Field experiments were conducted in a split plot design with three replications. According to the results, the micronutrient concentrations as well as the seed and oil yields and partly also oil content increased significantly as the plant density increased. For all analyzed micronutrients (Fe, Cu, Zn, Mn and B), the highest concentration has been obtained with 95200 plant ha-1. Micronutrient elements as well as seed and oil yields differed according to plant density and cultivars. Among the varieties, LG 5543 CL more effected by plant density had the highest micronutrient concentration, seed yield and oil yield. As a result, a high plant density (95,200 plant ha) with the highest micronutrient content and also the highest seed and oil yield could be recommended for Mediterranean environments with a semi-humid climate. However, optimum plant density was found differently according to varieties and years.

Keywords: cultivar, micro nutrients, plant density, sunflower

INTRODUCTION

Sunflower (Helianthus annuus L) has a wide range of adaptation, and is grown as an important oil crop in America, Europe, Asia, Africa and Australia. It was first used by natives in North America as a dyestuff and as an additive to breads. Spanish travelers first cultivated the seeds they collected from North America in the 1850s as ornamental plants. Then it spread by sea from Spain to Italy, Egypt, Afghanistan, China and India. Sunflower, which was brought to Russia in the 18th century, was used here for the first time as an oil plant. With the widespread use of hybrid seeds in sunflower plants, noticeable improvements have been made in high yield, quality and resistance to diseases and pests. In general, its cultivation has become widespread due to its adaptability to all kinds of soil and environmental conditions (Rauf et al., 2017). While the average area of sunflower cultivation in the world was 7.4 million hectares between 1955-59, today this area has tripled and reached 25 million hectares. In the same period, world sunflower production increased approximately 3.9 times and exceeded 20,57 million tons (Hellal et al. 2019; Mansour et al. 2020a, 2020b; FAO, 2023). There has been an increase in cultivation and production areas both in our country and in the world in recent years, since all plant organs can be evaluated and the pulp, stem and table residues remaining after oil is extracted are used as fuel.

Sunflower is an important oil plant after palm, soybean and canola due to its high oil (% 40-47), protein (% 20-27), calcium and vitamin (A, D and E) content. (Skoric et al. 2008; Jabeen and Ahmad, 2011; Iqbal et al. 2014; Li et al. 2017; Diovisalvi et al. 2018; Primo et al. 2018). Approximately 90% of the sunflower seeds produced in the world are processed for oil, and sunflower is the 3rd in the world oilseed production. (MAF, 2020). 12% of the consumable vegetable oil produced in the world is sunflower oil. Besides, linoleic type sunflower oil contains % 60-75 linoleic acid and % 10-30 oleic acid. The ratio of saturated fatty acids (palmitic, stearic, arachidic) is around % 11-12 (Colak et al. 2020).

In order to obtain high yield and quality, optimum growing conditions must be provided in sunflower. If optimum conditions cannot be provided, at the beginning of the main factors limiting growth and development in sunflower, mineral nutrients with a rate of 60% items are coming. Dry matter production in sunflower is high during vegetative and especially generative development period. As a result, the need for nutrients increases from the vegetative development period. Especially in this period, feeding of sunflower plants with microelements enhances the processes of assimilating macro-elements (Domaratskyi, 2021). Micronutrients have significant role on the growth, photosynthesis translocation, seed formation, pollen grain germination, protein and amino acid synthesis, stigma receptivity of oil seed crops. Consequently, micronutrients increase yield and quality in oilseeds (Sher et al. 2021). As a micro nutrient, zinc (Zn) is an essential element for hormone stimulation, chlorophyll formation, protein mechanism, lipid metabolism, carbohydrate synthesis an activity of enzymes. Besides, Zn has a significant role on biomass production by effecting RNA-DNA synthesis and decreasing lipid peroxidation and protein oxidation. (Balafrej et al. 2020; Ozyigit et al. 2021) Boron (B) is needed for growth of burgeons, root tips and leaves. According to previous studies, it has been dedicated that B effects fatty acid concentration and seed protein (Ayaz et al. 2021). Similarly, iron (Fe) plays a very important role in plant growth due to the basic components in physio-biochemical cells (Kim and Guerinot, 2007; Tripathi et al. 2018). It also plays an important role in the biosynthesis of chlorophyll and in the cells of different enzyme functioning (Khobra et al. 2014). In addition, Fe basically retains catalase and peroxidase activities, which are part of the antioxidant defense shield (Kumar et al. 2010). In plants, copper is essential for the capacities of enzymes involved in carbonate assimilation, ATP components, photosynthesis, molybdenum cofactor (Moco) biogenesis, redox reactions (electron transfer chain), lignin biosynthesis, and others (Kumar et al. 2021).

The relationship between plant density and micronutrient uptake is nuanced and can depend on various factors, including the specific nutrient, plant species, soil conditions, and overall management practices. While high plant density can influence micronutrient uptake positively in some situations. High plant density often leads to increased competition for resources such as water, sunlight, and nutrients. This competition can stimulate more efficient nutrient uptake mechanisms in some plants. Higher plant density generally means more roots in a given area. This increased root density can enhance the exploration of the soil for micronutrients, potentially improving nutrient uptake (Bejandi et al. 2012). Besides, the effect of plant density on soil pH can affect micronutrient availability. Changes in pH can increase the solubility and accessibility of some micronutrients in soil, which can affect their uptake by plants. Its well-known that different plant species have varying nutrient requirements and uptake mechanisms. Some plants may respond positively to higher plant density in terms of micronutrient uptake. It has also been observed that these different responses may vary in different varieties of the same plant (Heidari et al. 2008).

The number of plants per unit area is one of the factors that have the greatest effect on unit area yield. The number of plants per unit area is provided by the distances intra-rows and between rows applied in planting. Since the distance between rows is adjusted in accordance with the working width of the hoeing machines so that cultural operations can be carried out easily, this width is generally applied in the range of 60-70 cm. For this reason, different plant Density are obtained by keeping the spacing between rows constant and changing the distance intra-rows. Optimum plant density may vary according to the climate and soil conditions of the region, as well as according to the variety used. Undoubtedly, plant density per unit area also affects the nutrient and micronutrient uptake of plants. In many studies, researchers stated that planting frequency has important effects on yield and quality factors in sunflower (Emam and Awad, 2017; Fakirah at all. 2017; Ozkan, 2019; Gul and Ada, 2019; Alpman and Sinan, 2020).

Based on the above information, this study aimed to determine the effect of different plant density on micronutrient uptake of oil sunflower varieties for Mediterranean environments with a semi-humid climate.

MATERIALS AND METHODS

Experiment design

This field research was conducted at Bursa Uludag University Faculty of Agriculture Application and Research Centre during spring seasons in both 2017 and 2018. Field experiments were conducted in a split-plot design with three replications in both years. Varieties were main plots and plant density subplot. Main plots were set as 25,2 m x 6 m and subplots as 2,8 m x 6 m and 4 rows were planted for each plot All statistics of the research were obtained from plants in the middle two rows. Plants in the outermost rows were considered as edge effects and were not taken into consideration. Three sunflower varieties (Sanay MR, Oliva CL and LG5543 CL) were used as genetically material and three different plant density: 40800, 57100 and 95200 plants ha^{-1} (sowing spacing; 0.35 x 0.70 m, 0.25 x 0.70 m and 0.15 x 0.70 m, respectively).

Soil and climate characteristics of the trial sites

Soil physical and chemical characteristics are shown in Table 1. As can be seen from the table, the farm soil in the BUU Faculty of Agriculture Agricultural Research and Application Center, where the experiments were carried out, contains some heavy-textured material rich in lime and clay (Katkat et al. 1985). There is no salinity problem. It contains Na^+ 0.26 me/100g, K^+ 0.92 me/100g, Mg^{++} 10.20 me/100g, Ca^{++} 30.42 me/100g (Aksoy et al. 2001). Rich in potassium and phosphorus, poor in organic matter.

In the first year (2017), a total precipitation of 255.4 mm was recorded during the sunflower vegetation period (March-August). In 2018, a total of 282.4 mm precipitation occurred. More precipitation occurred in the second year of the experiment compared to the first year. When looking at the average temperature for many years, it is obvious that there is no serious temperature difference between the trial years. Climatic data for the growing season are given in Table 2. When the precipitation totals for many years are examined, it is seen that almost the same amount of precipitation was received as in 2018, the second trial year.

Cultural practices

Sowing was done in the first half of April in both years. Hand hoeing was done twice for weed control and soil ventilation. Experiments were carried out in dry conditions.

Harvest was done in September in both years. In order to prevent nutrient deficiencies in the plants and to ensure the optimum development of the plants 84 kg ha^{-1} N (15-15-15), 50 kg ha^{-1} P and 50 kg ha^{-1} K was applied on the plant rows in the all experimental area. Then, when the plants were at the 6-8 leaf stage, 25 kg of nitrogen was used.

Table 1. Soil properties of experimental area

Properties	Quantities	Properties (mg kg $^{-1}$)	Quantities
Texture	Clay	Sodium (Na)	134
pH	7,86	Potassium (K)	224
EC (mS cm^{-1})	0,32	Magnesium (Mg)	346,8
Lime (% $CaCO_3$)	2,25	Calcium (Ca)	8367
Organic matter (%)	1,74	Iron (Fe)	8,67
Total nitrogen (N) (%)	0,12	Copper (Cu)	1,39
Available phosphorus (P) (mg kg^{-1})	17,65	Zinc (Zn)	1,69
		Manganese (Mn)	21,37
		Boron (B)	1,19

Table 2. Climatic data for the growing season

	Avg. Temperature (°C)			Avg. Humidity (%)			Monthly Precipitation (mm)		
Months	**2017**	**2018**	**Long Term Avg.**	**2017**	**2018**	**Long Term Avg.**	**2017**	**2018**	**Long Term Avg.**
March	10,8	13,7	8,6	71,7	71,4	67,7	24,2	66,0	66,1
April	13,2	16,2	13,0	67,8	68,5	66,1	38,2	14,6	66,0
May	18,3	20,4	17,4	75,0	75,3	62,0	80,2	92,6	43,4
June	23,0	23,6	22,5	70,0	70,0	57,8	75,2	59,4	36,5
July	25,7	25,9	24,8	55,3	62,1	56,2	15,0	15,8	17,7
August	25,8	26,4	24,5	66,0	63,5	57,3	5,0	2,0	13,8
September	23,2	22,3	20,2	61,0	68,7	63,8	17,6	32,0	40,8
Total	**140**	**148,5**	**131**	**466,8**	**479,5**	**430,9**	**255,4**	**282,4**	**284,3**
Average	**20**	**21,2**	**18,7**	**66,6**	**68,5**	**61,6**	**36,4**	**40,3**	**40,6**

Plant analysis

Representative grains were collected on day 130, washed by tap and distilled water than dried at 70 °C until they reach a constant weight. Grain samples were grounded and acid digested in 3 mL of %65 nitric acid (HNO_3) and d 3 mL of 35% hydrogen peroxide (H_2O_2) in microwave system (Berghof MWS 2, Germany) (Celik et al. 2017). Fe, Cu, Zn, Mn and B concentrations of grains were determined with ICP-OES (Inductively coupled plasma optical emission spectrometry) (PerkinElmer Optima 2100 DV) (Hansen et al. 2013). Dry weights and Fe, Cu, Zn, Mn and B concentrations were multiplied for calculation of grain micro element contents.

Statistical analysis

The data obtained from the experiments were statistically analyzed according to the split plot design in randomized blocks with 3 replications. The effects of the varieties, plant Density and variety x plant density interaction were evaluated at the 0.05 and 0.01 probability levels using the F-test. The F-protected least significant difference (LSD) was calculated at the 0.05 probability level according to Steel and Torrie (1960). Variance analyses (ANOVA) for all data were analyzed by JMP 9.0.2. software to determine the significance of treatments and their interactions. In addition, Person's correlation coefficient values were calculated using the MINITAB (version 19) software to determine the degree of pairwise relationships between seed yield, yield components, and macro and micro nutrients uptake in hybrid sunflower varieties. On the other hand, the relationship between seed yield (dependent variable) and independent variables such as some yield components and some macro and micro nutrients was evaluated by multiple stepwise regression analysis.

RESULTS AND DISCUSSION

The effect of different sunflower cultivars with different plant density rates on some micro-nutrients concentrations are shown in Table 3. According to table, micronutrient (Fe, Cu, Zn, Mn, B) uptake of cultivars were significantly increased by increasing plant density in the two experimental years. In addition, the highest values were obtained with 95200 plant ha^{-1} and the lowest values were obtained with 40800 plant ha^{-1} plant density in both years. Same results have been described in many previous studies. Jaswinder et al. (2019) dedicated that high plant density increases the nutrient uptake. The same researchers reported that, increasing nutrient uptake might be due to better established root system, translocation of nutrients from soil, transport of nutrients to seed which led to better yield.

Table 3. Effects of plant density and variety on micro elements of sunflower in 2017 and 2018

	Plant density (plant ha^{-1})					
	95200		57100		40800	
	2017	2018	2017	2018	2017	2018
Cultivars	**Fe (mg kg^{-1})**					
Sanay MR	25,09 a	23,71 a	21,58 c	20,83 bc	20,16 d	18,78 de
Oliva CL	21,71 c	19,92 cd	25,08 a	23,34 a	21,93 bc	20,46 bc
LG 5543 CL	25,45 a	23,99 a	23,11 b	21,65 b	18,91 d	17,54 e
Mean	**24,09 A**	**22,54 A**	**23,26 B**	**21,94 A**	**20,33 C**	**18,93 B**
	Cu (mg kg^{-1})					
Sanay MR	2559,28 a	2485,74 a	1914,31 bc	1858,77 bc	1692,92 de	1643,65 de
Oliva CL	1911,28 bc	1855,68 bc	2566,35 a	2491,56 a	1813,74 cd	1761,19 cd
LG 5543 CL	2597,46 a	2522,17 a	1979,99 b	1922,35 b	1556,92 e	1511,93 e
Mean	**2356,01 A**	**2287,86 A**	**2153,55 B**	**2090,89 B**	**1687,86 C**	**1638,92 C**
	Zn (mg kg^{-1})					
Sanay MR	623,02 a	604,70 a	399,11 b	388,10 b	298,34 d	287,75 d
Oliva CL	328,70 cd	319,38 cd	603,22 a	586,36 a	220,59 e	214,17 e
LG 5543 CL	584,65 a	568,16 a	366,46 bc	355,79 bc	195,80 e	190,30 e
Mean	**512,13 A**	**497,41 A**	**456,26 B**	**443,42 B**	**238,24 C**	**230,74 C**
	Mn (mg kg^{-1})					
Sanay MR	61,04 ab	59,08 ab	38,19 c	37,09 c	27,37 e	26,84 e
Oliva CL	31,40 de	30,49 de	61,94 a	60,14 a	21,18 f	20,43 f
LG 5543 CL	57,40 b	55,42 b	35,04 cd	33,97 cd	18,00 f	17,48 f
Mean	**49,95 A**	**48,33 A**	**45,05 B**	**43,73 B**	**22,08 C**	**21,58 C**
	B (mg kg^{-1})					
Sanay MR	3,69 a	3,58 ab	2,11 b	2,04 c	1,39 d	1,34 e
Oliva CL	1,77 c	1,72 d	3,79 a	3,71 a	1,16 de	1,13 ef
LG 5543 CL	3,54 a	3,44 b	1,98 bc	1,93 cd	0,92 e	0,90 f
Mean	**3,00 A**	**2,91 A**	**2,63 B**	**2,56 B**	**1,15 C**	**1,12 C**

Fe and Cu concentrations of sunflower varieties were observed between 17,54 mg kg^{-1} - 25,45 mg kg^{-1} and 1511,93 - 2597,46 mg kg^{-1} respectively depending on plant density. The highest Fe and Cu concentrations were found in LG 5543 CL which was cultivated as 95200 plant ha^{-1} for both experiment years. In addition, the lowest values were obtained with LG 5543 CL and 4800 plant ha^{-1} plant density.

As can be seen from Table 2, the Zn concentration decreases as the plant density decreases, the highest Zn concentration was obtained at 95200 plant ha^{-1}. Between the cultivars, while the highest Zn concentration was observed as 623,02 mg kg^{-1} in Sanay MR and as 584,7 mg kg^{-1} in LG 5543 CL which planted as 5200 plant ha^{-1}, the lowest concentration was observed in as 190,30 mg kg^{-1} with LG 5543 CL which planted as 4800 plant ha^{-1} (Table 3).

Mn and B concentrations of sunflower varieties were observed between 17,48 mg kg^{-1} – 61,94 mg kg^{-1} and 0,90 – 3,79 mg kg^{-1} respectively depending on plant density. Unlike the aforementioned elements; the highest Mn and B concentrations were obtained as 61,94 and 3,79 mg kg^{-1} respectively in Oliva CL with 57100 plant ha^{-1} but, the lowest values were obtained as 17,48 and 0,90 mg kg^{-1} respectively in LG 5543 CL with 40800 plant ha^{-1} plant density (Table 3). As a result, 95200 plant ha^{-1} was the optimal plant density for Fe, Cu, Zn uptake while, 57100 plant ha^{-1} was the optimal for B and Mn uptake of sunflower.

The effect of different sunflower cultivars with different plant density rates on some quality properties and yield of sunflower are shown in Table 4. As can be seen from the table, quality parameters as seed yield, oil content and oil rate are significantly increased by increasing plant density in the two experimental years. On the contrary, head diameter of sunflowers was significantly decreased with plant density. Maximum head diameter was observed between 15,59 and 23,86 cm according to plant density. For both experiment years the maximum head diameter was measured with 40800 plant ha^{-1} plant density in Sanay MR cultivar. In addition, the minimum head diameter observed in Oliva CL cultivar with 95200 plant ha^{-1} plant density in both experiment years. Allam and Galal, (1996); Salehi and Bohrani, (2000); Al-Thabet, (2006) dedicated that decreasing in plant density was led to an increase in head diameter which results are similar with our study. Several studies have reported that with increasing plant density decreases head diameter but increasing plant density enhances the seed yield (Johnson et al. 2010; Jahangir et al. 2006; Panhwar et al. 2017). Modanlo et al. (2021) reported that, with increasing plant density yield and oil yield have effected positively but, head diameter, plant height, 100-grain yield and grain yield per plant were decreased with increasing plant density.

Table 4. Effects of plant density and variety on some quality properties and yield of sunflower in 2017 and 2018

	Plant density (plant ha^{-1})					
	95200		57100		40800	
	2017	2018	2017	2018	2017	2018
Cultivars	**Head diameter (cm)**					
Sanay MR	19,54 bcd	18,05 bcde	17,13 cd	16,28 de	23,86 a	23,10 a
Oliva CL	16,53 d	15,59 e	19,86 bc	19,87 bc	21,10 ab	21,10 ab
LG 5543 CL	18,13 bcd	17,23 cde	19,93 bc	18,95 bcd	20,76 ab	20,77 ab
Mean	**18,07 B**	**16,95 B**	**18,97 B**	**18,36 B**	**21,91 A**	**21,65 A**
	Seed Yield (kg ha^{-1})					
Sanay MR	328,96 f	298,36 g	356,42 e	331,42 ef	343,63 e	313,25 fg
Oliva CL	405,65 b	386,50 b	386,64 c	365,86 bc	370,33 d	357,48 cd
LG 5543 CL	481,03 a	450,83 a	369,74 d	339,68 de	346,03 e	323,60 ef
Mean	**405,21 A**	**378,56 A**	**370,93 B**	**345,65 B**	**353,33 C**	**331,44 C**
	Oil content (%)					
Sanay MR	43,76 c	44,40 d	45,45 b	46,50 b	42,49 d	43,26 e
Oliva CL	44,21 c	45,24 c	45,55 b	46,28 b	43,40 cd	44,61 cd
LG 5543 CL	45,59 b	46,42 b	47,40 a	48,55 a	43,86 c	44,66 cd
Mean	**44,52 B**	**45,35 B**	**46,13 A**	**47,11 A**	**43,25 C**	**44,18 C**
	Oil Yield (kg ha^{-1})					
Sanay MR	143,92 e	132,43 g	161,96 c	154,13 de	146,02 e	135,53 fg
Oliva CL	179,37 b	174,90 b	176,13 b	169,35 bc	160,72 c	159,43 cd
LG 5543 CL	219,33 a	209,31 a	175,26 b	164,92 bcd	151,76 d	144,51 ef
Mean	**180,87 A**	**172,21 A**	**171,11 B**	**162,80 B**	**152,83 C**	**146,49 C**

Yield and oil yield of sunflower cultivars have effected positively with increasing plant density. Yield was observed between 313,25 and 481,03 kg ha^{-1} according to plant density and oil yield was observed between 135,53 - 219,33 kg ha^{-1}.

Maximum seed yield and oil yield were obtained with 95200 plant ha^{-1} plant density in LG 5543 CL cultivar but, minimum values were observed in Sanay MR cultivar with 40800 plant ha^{-1} plant density for both experimental years. Unlike these parameters, maximum oil content of sunflower was obtained with 57100 plant ha^{-1} plant density. It was measured between % 42,49 and % 47,40. LG 5543 CL cultivar which provided the highest grain and oil yield in 95 200 plant ha^{-1} Density, also achieved the highest Fe, Cu, Zn and B uptake at the same plant density. These results revealed that high uptake of micronutrients in the plant provides high seed and oil yield. Therefore, many studies were found that fertilization with these micronutrients increases the yield and quality of sunflower (Khurana and Chatterjee, 2001; Gawande et al. 2022; Baraich et al. 2016; Pattanayak et al. 2017; El-Din Mekki, 2015). Similar to yield parameters, maximum and minimum oil content values were found in LG 5543 CL and Sanay MR cultivars respectively. Findings on oil content in previous studies have shown different results at varying plant densities (Modanlo et al. 2021; Partal, 2022). This is thought to be because seed from higher plant density may have a thinner pericarp with a slightly higher oil content. In addition, the percentage of oil of sunflower seeds depends on the ratio of the percentage of shell and oil content in the kernel (Rao and Reddy, 1985; Sabo and Pepo, 2007; Namvar et al. 2012). As the distance between the rows increased, in other words, as the plant density decreased, low seed yields is obtained in these plots due to the low plant numbers per unit area. The best seed yields per hectare is measured in narrow row sowing distances (Alpman and Sinan 2020). Our results are supported by findings of some previous studies which indicating that increase plant density significantly increase seed yield (Beg et al. 2003, Robinson 1976, Barros et al. 2004; Sabo and Pepo, 2007; Weiss, 2000; Wade and Foreman, 1988). On the contrary some researchers dedicated that the seed yield was not affected by increasing plant densities explaining that the optimum plant density for seeds yield depends on the cultivar and environment (Majid and Schneiter, 1987; Pala, 1992; Barros et al., 2004).

The results showed that as the plant density increased, the uptake of micronutrients such as Fe, Cu, Zn increased, as well as the seed and oil yield and oil content. Increasing plant density provided an increase in seed and oil yield and partially also oil content by increasing the micronutrient uptake in the plant. Khurana and Chatterjee (2001) reported that zinc fertilization had a positive effect on sunflower and increased seed yield of sunflower and seed oil by application of zinc. Because of Zn having important role in carbohydrate and nitrogen metabolism, fruit and root development. In addition, Zn is essential in amino acid and RNA - DNA synthesis, by involving in in bio-synthesis of plant hormones, Indole Acetic Acid (IAA) and variety of enzymes. Gawande et al. (2022) dedicated that when Zn and Fe concentrations increases in sunflower, number of filled seed is also increased thus the yield of sunflower is enhanced. The same researchers also indicated that this increase in dry matter and yield in sunflower is due to higher photosynthetic rate of plants, which depends upon number of functional leaves, plant height, and dry matter accumulation in plants. In many studies, researchers have explained this increase in yield is because zinc and iron have a very important role especially in protein and auxin metabolism and that they are essential for many enzyme activations (Rao et al. 2020; Farzanian et al. 2010).

The results of the research showed that micronutrient uptakes, seed and oil yield, and partly also oil contents in sunflower vary according to plant density and cultivars. Our findings revealed that the plant density to be applied in planting and the variety to be preferred are important in order for the plants to obtain higher micronutrient uptakes and to reach higher yield and quality.

Since the uptake of micronutrients such as Fe, Cu and Zn increases as the plant density increases, these micronutrients must be sufficiently present in the soil in areas where high plant Density are applied. For high yield and quality in sunflower, these micronutrients, which are deficient in the soil, should be applied in the form of fertilizer. Thus, Milev (2015) proved that sunflower reacted to multicomponent mineral fertilizers with increased yield and its quality. Baraich et al. (2016) showed that foliar fertilization (8 Zn + 0.75 B + 0.30 Fe kg ha^{-1}) significantly improved the sunflower yield and its components. Pattanayak et al. (2017) showed that sunflower positively responded to combined NPK, zinc and boron fertilization. Kandhro et al. (2021) proved the beneficial interaction of Zn fertilization and plant irrigation on sunflower yielding. In addition, they indicated the need to select an appropriate variety for the habitat conditions. Li et al. (2018) demonstrated that foliar zinc fertilization had a positive effect on the yielding of sunflower, even when the content of this element in the soil was sufficient. Mekki (2015) believed that boron was important in fertilizing sunflower seeds. In a greenhouse experiment, he showed that the deficiency of this micronutrient in the soil reduced both the size and quality of the crop. Al-Amery et al. (2011) proved that boron fertilization reduced the number of empty achenes, which resulted in a significant increase in yield.

In the study, positive and significant relationships were found between seed and oil yields and the uptake of some micronutrients. Pearson correlation coefficients describing pairwise relationships between yield components and some micronutrients of the tested hybrid sunflower cultivars are shown in **Table 5.** Positive and significant correlation were observed between SY and Fe ($r = 0.447$, $p \leq 0.01$), Cu ($r = 0.416$, $p \leq 0.01$), Zn ($r = 0.292$,$p \leq 0.05$), Mn ($r = 0.297$, $p \leq 0.05$), B ($r = 0.326$, $p \leq 0.05$), Mg ($r = 0.326$, $p \leq 0.05$) and HD ($r = - 0.347$, $p \leq 0.01$). Also, the pairwise relationships between oil yield and the same micronutrient elements gave similar results. Similarly, significant and positive correlations were observed between OC and Fe ($r = 0.283$, $p \leq 0.05$), Cu ($r = 0.267$, $p \leq 0.05$), Zn ($r = 0.277$, $p \leq 0.05$), Mn ($r = 0.284$, $p \leq 0.05$), B ($r = 0.94$, $p \leq 0.05$), Mg ($r = 0.288$, $p \leq 0.05$) and HD ($r = - 0.423$, $p \leq 0.01$). In contrast, the correlations between grain yield, oil yield and oil ratio and micronutrients were not statistically significant. Micronutrients, both present in the plant and applied externally to the plant, have an increasing effect on yield and quality. Anuprita et al., (2005) detected that application of micronutrients increase the uptake of all the plant nutrients and enhance the mechanism against disease and pest thus consequently improve yield and plant growth. Iron (Fe) is also one of the important nutrient involved in the formation of chlorophyll and light reaction of electron transport chain and thus can enhance the growth and yield of crop (Kakar et al., 2000; Tariq and Mott, 2006). The use of boron has increased the vegetative and reproductive growth of the sunflower (Asad *et al.*,2003). Boron is involved in cell wall synthesis, maintenance, sugar translocation and membrane integrity and its requirement is higher for seed production than vegetative production (Dordas and Brown, 2001). Alipatra et all (2018) reported that sunflower seed yield showed highest significant positive correlation with TNU (total N uptake, r = 0.670**), closely followed by TBU (Total B uptake, r = 0.669**), TSU (Total S uptake, r = 0.662**), TPU (Total P uptake, r = 0.618**) and TKU (Total K uptake, r = 0.561**).

Table 5. Correlation coefficients between seed yield and macro and micronutrients uptake in hybrid sunflower genotypes (based on mean values of two years)

Traits	Fe	Cu	Zn	Mn	B	HD	SY	OC	OY
Fe	1,0000	0,9240**	0,8516**	0,8531**	0,8596**	-0,2584	0,4466**	0,2827*	0,447**
Cu		1,0000	0,9609**	0,9645**	0,9733**	-0,286*	0,4161**	0,2673*	0,416**
Zn			1,0000	0,9979**	0,9942**	-0,294*	0,2916*	0,2774*	0,292*
Mn				1,0000	0,9976**	-0,290*	0,2974*	0,2836*	0,297*
B					1,0000	0,3265*	0,2881*	0,2941*	0,326*
HD						1,0000	-0,347**	-0,423**	-0,35**
SY							1,0000	0,2289	1,00**
OC								1,0000	0,2289
OY									1,0000

Notes:Fe = Iron, Cu = Copper, Zn = Zinc, Mn = Manganese, B = Boron, HD = Head diameter, SY = Seed yield, OC = Oil content, OY = Oil yield.

A multiple regression model was used to evaluate the relationships between seed yield (dependent variable) and macro and micro nutrients and some yield components (independent variables). According to multiple regression analysis, the appropriate regression model was determined as follows:

Seed yield = 189.7 + 1.527 total Cu uptake** - 0.429 total Zn uptake** - 4.767 Head diameter*

The stepwise regression equation showed that an independent variable like total Cu uptake had positive significant relationships but negative significant total Zn uptake and head diameter with seed yield (dependent variable). In a similar study, Alipatra et al. (2018) found that independent variables like total N uptake, plant height, available N, weight of filled seeds/capitulum and seed index (100-seed weight) had positive significant relationship with seed yield (dependent variable). The results of this study and previous studies have revealed that there is a positive and significant relationship between grain and oil yields and some macronutrients, micronutrients and some yield components in sunflower, but there may be changes in macro and micronutrient elements that may affect grain yield depending on the conditions in which the research is conducted.

CONCLUSION

In sunflower, which is an important oil plant, the effects of plant density per unit area and cultivar differences on the micronutrient uptake, yield and quality of the plant were investigated. The results revealed that micronutrient uptakes, seed and oil yield, and partly also oil contents in sunflower vary according to plant density and cultivars. Increasing plant density provided an increase in seed and oil yield and partially also oil content by increasing uptake of micronutrient such as Fe, Cu, Zn in the plant. In study, maximum seed yield and oil yield were obtained with 95200 plant ha^{-1} plant density in LG 5543 CL cultivar but, minimum values were observed in Sanay MR cultivar with 40800 plant ha^{-1} plant density for both experimental years. The conclusion that can be obtained from this study is to suggest a high plant density (95200 plant ha) and a suitable cultivar in order to achieve high micronutrient uptake in sunflower and hence high seed and oil yield and partly high oil content in Mediterranean environments with a sub-humid climate. The study has evaluated the most commonly used planting densities in the literature. In future research, higher and lower plant densities should be considered to further support and enrich the literature. The results of our study have demonstrated a positive impact on yield and micronutrient uptake at higher densities. However, how yield and nutrient element uptake will be affected when density is further increased should be determined in future studies.

LITERATURE CITED

Ahmad, S. H. E. R., A. Sattar, I. J. A. Z. Muhammad, A. Nawaz, T. A. Yasir, M. Hussain, and M. Yaseen. 2021. Combined foliage application of zinc and boron improves achene yield, oil quality and net returns in sunflower hybrids under an arid climate. Turkish J. Field Crop. 26(1) :18-24.

Aksoy, E., M.S. Dirim, Z. Tumsavas and G. Ozsoy, 2001. Formation of Uludag University campus soils, important physical and chemical properties and classification. U.U. Research Fund Project No: 98/32, Bursa. 118s.

Al-Amery, M.M., J.H. Hamza and M.P. Fuller. 2011. Effect of boron foliar application on reproductive growth of sunflower (*Helianthus annuus* L.). Int. J. Agron. 230712:1–5.

Alipatra, A., H. Banerjee and D. Mazumdar. 2018. Correlation and Path coefficient analysis of quantitative and qualitative traits in hybrid sunflower (*Helianthus annuus* L.). Int.J.Curr.Microbiol.App.Sci. 7(10): 568-578.

Allam, A.Y. and A.H. Galal. 1996. Effect of nitrogen fertilization and plant density on yield and quality of sunflower. Assiut. J. Agric. Sci. 27 (2):169 -177.

Alpman, K. and N. S. Sinan, 2020. The effect of plant frequency on yield and yield components of sunflower (*Helianthus annuus* L.) Varieties in different maturization group in dry conditions in Cukurova. CUNAS. 39-5.

Al-Thabet, S.S., 2006. Effect of plant spacing and nitrogen levels on growth and yield of sunflower (*Helianthus Annus* L.) J. Agric. Sci. 19:1-11.

Anuprita, H., S.R. Jadhav, R.D. Dalal and P. Rajeshwari. 2005. Effect of micronutrients on growth and flower production of Gerbera under poly house conditions, Adv. PI. Sci. 18(11): 755-758.

Asad, A., F.P.C. Blamey and D.G. Edwards. 2003. Effects of Boron foliar applications on vegetative and reproductive growth of sunflower. Ann. Bot. 92(4): 656-570.

Ayaz, A., S. Saqib, H. Huang, W. Zaman, S. Lü, and H. Zhao. 2021. Genome-wide comparative analysis of long-chain acyl-CoA synthetases (LACSs) gene family: A focus on identification, evolution and expression profiling related to lipid synthesis. Plant Physiol. Biochem. 161: 1-11.

Balafrej, H., D. Bogusz, Z. E. A. Triqui, A. Guedira, N. Bendaou, A. Smouni and M. Fahr. 2020. Zinc hyper accumulation in plants: A review. Plants. 9(5):562.

Baraich, A.A.K. A.W. Gandahi, S. Tunio and Q. Chachar. 2016. Influence of micronutrients and their method of application on yield and yield components of sunflower. Pak. J. Bot. 48, 1925–1932.

Barros, J.F.C., M.D. Carvalho and G. Basch. 2004. Response of sunflower (*Helianthus annuus* L.) to sowing date and plant density under Mediterranean conditions. Europ. J. Agron. 21: 347- 356.

Bejandi, T. K., R. S. Sharifii, M. Sedghi and A. Namvar. 2012. Effects of plant density, Rhizobium inoculation and microelements on nodulation, chlorophyll content and yield of chickpea (Cicer arietinum L.). Ann. Biol. Res. 3(2), 951-958.

Beg, A., M. Pala and S.S. Poudad. 2003. Sunflower Production as Influenced by Plant Density and Row Spacing on Dry Land. Proceeding of International Dry Land Conference held at Tehran Iran. September 2003.

Celik, H., M. A. Turan, B. B. Asik and A. V. Katkat. 2017. Evaluation of analytical methods for boron determination in maize shoots. Commun. Soil Sci. Plant Anal. 48 (21):2573–81. doi: 10.1080/00103624.2017.1416135.

Colak, C., S. Hasancebi and Y. Kaya, 2020. Determination of high oleic acid property in sunflower by using molecular markers. J. of AARI, 30(1):57-68.

Diovisalvi, N., N.R. Calvo, N. Izquierdo, H. Echeverria, G.A. Divito and F. Garcia. 2018. Effects of genotype and nitrogen availability on grain yield and quality in sunflower. Agron. J. 110: 1532-1543.

Domaratskyi, Y. 2021. Leaf Area Formation and Photosynthetic Activity of Sunflower Plants Depending on Fertilizers and Growth Regulators. J. Ecol. Eng. 22(6).

Dordas, C., and P.H. Brown. 2001. Permeability and the mechanism of transport of boric acid cross the plasma membrane of Xenopus laevis oocytes. J. Biol. Trace Element Res., 81: 127-139.

Emam, S.M. and A.A.M. Awad. 2017. Impact of plant density and humic acid application on yield, yield components and nutrient uptakes of sunflower (*Helianthus annuus* L.) grown in a newly reclaimed soil. J.Soil Sci. and Agric. Eng., Mansoura Univ. 8(11): 635- 642.

Fakirah, A.B., M.A.H. Al-Thobhani and M.M. Al-Aqil. 2017. Effect of plant density and bio–fertilizer on some morphological traits, seed yield and yield components of sunflower (Helianthus annus L.). UU J. of Faculty of Agr. 31(2):139-155.

FAO. 2020. Food and Agriculture Organization of the United Nations. FAOSTAT. url: http://www.fao.org/faostat/en/#data (Accessed December 12, 2022).

Farzanian, M., M. Yarnia, A. Javanshir and A. R. Tarinejhad. 2010. Effects of microelement application methods on seed yield components in Alestar sunflower hybrid. J Food Agric Environ. 8(3-4): 305-308.

Gawande, R. S., P. N. Karanjikar, P. S. Waghmare, A. P. Kokate and D. S. Sawant. 2022. Effect of soil and foliar application of zinc sulphate and ferrous sulphate on growth and yield of sunflower (*Helianthus annus* L.). Pharma Innov. 11(1):1349-1352.

Gul, A. and R. Ada. 2019. Determination of effects of different intra-row spacing on yield and quality in sunflower (*Helianthus annuus* L.) Journal of Bahri Dagdas Crop Research, 8 (2): 289-298, 20.

Hansen, T. H., T. C. de Bang, K. H. Laursen, P. Pedas, S. Husted and J. K. Schjørring. 2013. Multielement plant tissue analysis using ICP spectrometry. In plant mineral nutrients methods and protocols, ed. F. J. M. Maathuis, 121–41. Totowa, NJ: Humana Press.

Heidari, F., S. Zehtab Salmasi, A. Javanshir, H. Aliari and M. R. Dadpoor. 2008. The effects of application microelements and plant density on yield and essential oil of peppermint (Mentha piperita L.). IJMAPR. 24(1), 1-9.

Hellal, F., H. Mansour, M. Abdel-Hady, S. El-Sayed and C. Abdelly. 2019. Assessment water productivity of barley varieties under water stress by AquaCrop model. AIMS Agric. Food, 4(3): 501-517.

Iqbal, M.A., A. Iqbal, N. Akbar, R.N. Abbas, H.Z. Khan and Q. Maqsood. 2014. Response of canola to foliar application of moringa (*Moringa oleifera* L.) and brassica (*Brassica napus* L.) water extracts. Int. J. Agric. Crop Sci. 7(14): 1431-1433

Jabeen, N. and R. Ahmad. 2011. Effect of foliar-applied boron and manganese on growth and biochemical activities in sunflower under saline conditions. Pak. J. Bot. 43(2): 1271-1282

Jahangir, A. A., R. K. Mondal, K. Nada, S. Afoze and M. A. Hakim. 2006. Response of nitrogen and phosphorus fertilizer and plant spacing on growth and yield contributing character of sunflower. BJSIR. 41(1):33-40.

Jaswinder, K., K. Himani, S. Pankaj and J. Neeraj. 2019. Effect of plant densities and integrated nutrient management on productivity, nutrient uptake and quality of sweet corn (*Zea mays* L. Saccharata). IOSR-JAVS, 38-42.

Johnson, B. L., M. E. Zarnstorff and J. F. Miller. 2010. Effect of row spacing and plant density on oil seed sunflower. In Proceedings of 21st Sunflower Research Workshop Dgs (pp. 183-192).

Kakar, K. M., M. Tariq, M.R. Tareen and W. Ullah. 2000. Shoot growth curve analysis of wheat receiving different levels of boron and Iron. Pak. J. Agron. 1(1): 47-48.

Kandhro, M.N., Z.A. Abbasi, A.A. Soomro, N. Leghari, M.I. Keerio, A.N. Shah, G.M. Jamro., N. Mangrio and S.P. Tunio. 2021. Evaluation of Irrigation Frequencies and Seed Priming with Plant Nutrients on Growth and Yield of Sunflower (*Helianthus annuus* L.) Genotypes. Pak. J. Agric. Res., 34(1).

Katkat, V., F. Ayla and I. Guzel. 1985. Soil survey and efficiency status of Uludag University faculty of agriculture application and research farm land. J. of Agricultural Faculty of Uludag University 3: 71-78.

Khurana, N., and C. Chatterjee. 2001. Influence of variable zinc on yield, oil content, and physiology of sunflower. Commun. Soil Sci. Plant Anal. 32(19-20), 3023-3030.

Khobra, R., S. Ahuja and B. Singh. 2014. Chlorophyll biosynthesis as the basis of iron use efciency under iron defciency and its relationship with the phytosiderophore synthesis and release in wheat. Indian J. Plant Physiol. 19:330–337

Kim, S.A. and M.L. Guerinot. 2007. Mining iron: iron uptake and transport in plants. FEBS Lett 581:2273–2280

Kobraee, S., K. Shamsi and B. Rasekhi. 2011. Effect of micronutrients application on yield and yield components of soybean. Ann. Biol. Res. 2(2):476-482.

Kumar, P., R.K. Tewari and P.N. Sharma. 2010. Sodium nitroprusside-mediated alleviation of iron deficiency and modulation of antioxidant responses in maize plants. AoB Plants 2010:1–11

Kumar, V., S. Pandita, G. Sidhu, A. Sharma, K. Khanna, P. Kaur, A. S. Bali and R. Setia. 2021. Copper bioavail-ability, uptake, toxicity and tolerance in plants: A comprehensive review. Chemosphere 262:127810.

Li, C., P. Wang, J. Wu, F. P. C. Blamey, N. W. Menzies and P. M. Kopittke. 2018. Absorption of foliar applied Zn is decreased in Zn deficient sunflower (*Helianthus annuus*) due to changes in leaf properties. Plant Soil. 433:309–322.

Li, W.P., H.B. Shi, K. Zhu, Q. Zheng and Z. Xu. 2017. The quality of sunflower seed oil changes in response to nitrogen fertilizer. Agron. J. 109: 2499-2507.

MAF, 2020. Sunflower in the World. Product Desks (Sunflower Bulletin). Ministry of Agriculture and Forestry. General Directorate of Crop Production. Department of Agriculture Basins. Ankara (Accessed December 07, 2022).

Mekki, B. E. D. 2015. Effect of boron foliar application on yield and quality of some sunflower (*Helianthus annuus* L.) cultivars. J. Agri. Sci. Technol. 5:5-309.

Majid, H.R., and A.A. Schneiter. 1987. Yield and Quality of Semi-dwarf and Standard Height Mantioba Agriculture 1983. Field Crop Recommendations for Manitoba, Manitoba Agriculture, Publications Distribution, Winnipeg, Man. 88 pp.

Mansour, H. A., M. S. Gaballah, and O. A. Nofal. 2020a. Evaluating the water productivity by Aquacrop model of wheat under irrigation systems and algae. Open Agric. 5(1): 262-270.

Mansour, H. A., S. El Sayed Mohamed and D. A. Lightfoot. 2020b. Molecular studies for drought tolerance in some Egyptian wheat genotypes under different irrigation systems. Open Agric. 5(1): 280-290

Mehmood, A., J. Ahmed, S. Rukh, K. Shahzad, M. Rafique, M. Imran and G. Chung. 2021. Response to foliar micronutrients application: oil content, fatty acid profiling, growth and yield attributes in sunflower hybrids. https://doi.org/10.21203/rs.3.rs-394987/v1

Milev, G. 2015. Effect of foliar fertilization on sunflower (*Helianhtus annuus* L.). Agric. Sci. Technol. 7:324–327.

Modanlo, H., M., Baghi and A. Ghanbari Malidarreh. 2021. Sunflower (*Helianthus annuus* L.) grain yield affected by fertilizer and plant density. Cent. Asian. J. Plant Sci. Innov, 1(2):102-108.

Namvar, A., T. Khandan and M. Shojaei. 2012. Effects of bio and chemical nitrogen fertilizer on grain and oil yield of sunflower (*Helianthus annuus* L.) under different rates of plant density. Ann. Biol. Res. 3: 1125-1131.

Ozyigit, I. I., H. Can and I. Dogan, 2021. Phytoremediation using genetically engineered plants to remove metals: a review. Environ. Chem. Lett. 19(1): 669-698.

Ozkan, F. 2019. The Effects of Different Sowing Date and Intra-Row Spacing On Oil Rate, Yield and Yield Components of

Sunflower (Helianthus annuus L.). (Master's thesis, Kırşehir Ahi Evran University Science and Engineering Institute Field Crops Department)

Pala, M. 1992. Oilseeds. Annual Report, Farm Resource Management Programme. ICARDA

Panhwar, H. A., G. M. Laghari, A. A. Kaleri, M. K. S. A. A. Panhwar, J. K. Soothar, M. M. R. A. Abro, and J. K. Soothar. 2017. Effects of seed rates on the growth and yield of different sunflower varieties. PAB, 6(4):1189-1197.

Partal, E. 2022. Sunflower Yield and Quality Under The Influence Of Sowing Date, Plant density And The Hybrid. Rom. Agric. Res. 39:463-470.

Pattanayak, S., A.K. Behera, P. Das, M.R. Nayak, S.N. Jena and S. Behera. 2017. Performance of summer sunflower (*Helianthus annuus* L.) hybrids under different nutrient management practices in coastal Odisha. J. Appl. Nat. Sci., 9:435–440.

Primo, D. C., R. S. Menezes, F. F. Oliveira, J. C. B. Dubeux Junior and E. V. Sampaio, 2018. Timing and placement of cattle manure and/or gliricidia affects cotton and sunflower nutrient accumulation and biomass productivity. An. Acad. Bras. Ciênc 90:415-424.

Rao N.K., E, Rajath and K. Kumara, 2020. Yield, quality parameters and economics of sunflower (*Helianthus annuus* L.) as influenced by micronutrient mixture foliar application. IJCMAS. 9(1):1999- 2005.

Rao, Y.T. and S.C. Reddy. 1985. Effect of Phosphorus Levels at Different Plant Densities on the Yield Attributes of Sunflower (*Helianthus annus*, L.) J. Farming syst. 1: 44–47.

Rauf, S., N. Jamil, S. Ali Tariq, M. Khan, M. Kausar and Y. Kaya, 2017. Progress in modification of sunflower oil to expand its industrial value. J. Sci. Food Agric. 97 (7): 1997-2006.

Robinson, E. L. 1976. Yield and height of cotton as affected by weed density and nitrogen level. Weed Science, 24(1), 40-42.

Sabo, A. and P. Pepo. 2007. Effect of Plant Density on Yield and Oil Content of Different Sunflower Genotypes. Alps-Adria Sci. Obervellach, Austria 239: 1121-1129.

Salehi, F. and M.J. Bohrani. 2000. Sunflower Summer Planting Yield as Affected by Plant density and Nitrogen Application Rates. Iran agric. Res. 18:63-72.

Sher, A., A. Sattar, M. Ijaz, A. Nawaz, T.A. Yasir, M. Hussain and M. Yaseen. 2021. Combined foliage application of zinc and boron improves achene yield, oil quality and net returns in sunflower hybrids under an arid climate. Turk. J. Field Crops. 26(1): 18-24

Skoric, D., S. Jocic, Z. Sakac and N. Lecic. 2008. Genetic possibilities for altering sunflower oil quality to obtain novel oils. Can. J. Phy. Pharmacol, 86: 215-221.

Steel, R. G. and J. H. Torrie. 1960. Principles and procedures of statistics: a biometrical approach. New York, NY, USA: McGraw-Hill.

Tariq, M. and C.J.B. Mott. 2006. Effect of applied Boron on the accumulation of cations and their ratios to boron in radish. Soil and Environ., 25 (1): 40-47.

Tripathi, D.K., S. Singh, S. Gaur, S. Singh, V. Yadav, S. Liu, V.P. Singh, S. Sharma, P, Srivastava and S.M. Prasad. 2018. Acquisition and homeostasis of iron in higher plants and their probable role in abiotic stress tolerance. Front Environ Sci 5:86

TUIK. 2020. Turkish Statistical Institute, Herbal Production Statistics. https://data.tuik.gov.tr/Bulten/Index?p=Crop-Production-Statistics-2022-45504anddil=2 (Accessed December 07, 2022)

Wade, J. and W. Foreman. 1988. Density- Maturity Interactions for Grain Yield in Sunflower. Aust. J. Exp. Agric. 28:623-627.

Weiss, E.A. 2000. Oil seed crops Blackwell Sci. led. London. 364 pp.