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Responses of sunflower (*Helianthus annuus* L.) to irrigation and nitrogen fertilization rates

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Abstract

This study was conducted to determine the effects of different nitrogen rates (0, 40, 80, 120, 160, 200 and 240 kg ha^{-1} N) on the yield, its components and the quality characters of sunflower (*Helianthus annuus* L.) and to identify the economic optimum N rate for maximum profit under both irrigated and non-irrigated conditions during a 2-year period (2007–2008). As the N rates increased, all of the traits measured significantly increased, except the crude oil content, under both irrigation treatments. Based on the 2-year average, the highest seed yield (2713.6 to 2751.2 kg ha^{-1}) and crude oil yield (1012.7 to 1042.5 kg ha^{-1}) were obtained using 160 kg ha^{-1} N and the higher N rates, with increases of 47.8% and 39.4%, respectively, compared to the control (0 kg ha^{-1} N). Similar trends were also obtained for the other traits, except the crude oil content, which was the highest (39–41%) at 0 kg ha^{-1} N but the lowest (36–38%) under the higher N rates. The highest mean values for the crude protein content and 1000-seed weight were obtained under the highest N rates (200 and 240 kg ha^{-1} N). In 2007, the economic optimum nitrogen rate (EONR) for sunflower was 148.5 kg ha^{-1} N under non-irrigated conditions, as compared with 190.0 kg ha^{-1} N with irrigation. In 2008, the EONRs for sunflower under non-irrigated and irrigated conditions were 145.1 and 176.7 kg ha^{-1} N, respectively. Although the EONR for irrigated conditions was approximately 30–40 kg ha^{-1} N more than that for non-irrigated conditions, the seed yield under the irrigation conditions was approximately 65–79% higher compared with the non-irrigated conditions. As a result, it was determined that the economic optimum N rate for sunflower was 145–150 kg ha^{-1} N under non-irrigated conditions and 177–190 kg ha^{-1} N under irrigated conditions.

Key words: economic optimum nitrogen rate, *Helianthus annuus*, irrigated and non-irrigated conditions, quality, sunflower, yield.

Introduction

Sunflower (*Helianthus annuus* L.) is the most important oilseed crop in Turkey, with a sowing area of approximately 0.6 M ha and a seed production of the 0.9 M tonnes (FAOSTAT, 2010). The largest sunflower production centre of Turkey is the Marmara region (TUIK, 2010), and low yields are mainly due to the scanty precipitation during the summer in this region (Goksoy et al., 2004). Conversely, sunflower plants are rarely irrigated in areas where water resources are adequate; however, in Eastern Anatolia, sunflowers are only grown under irrigated conditions because of insufficient precipitation (Ozer et al., 2004). In addition to significantly responding to irrigation, sunflower clearly responds better to nitrogen fertilization under irrigated conditions compared with non-irrigated conditions. The combined application of irrigation and nitrogen through fertigation is now becoming a common practice in modern agriculture because of its advantages over broadcast nitrogen application (Siddiqui et al., 2009). Some of these advantages are a more timely and more uniform nitrogen application, reduced environmental contamination, faster movement of the applied nitrogen into the rooting zone and reduced crop damage related to mechanical side dressing (Threadgill, 1985). Nevertheless, this fertilization technique is not a common practice in the sunflower production areas of Turkey, even though it has many advantages. Earlier studies indicated that the seed yield and its components are increased in sunflower with increasing rates of nitrogen under irrigated or non-irrigated conditions, and the highest yields were obtained from rates of 80–120 kg ha^{-1} N (Nawaz et al., 2003; Ozer et al., 2004; De Giorgio et al., 2007; Oyinlola et al., 2010).

Quantifying the optimum fertilizer rate accurately is essential to maximize the profitability and minimize the potential negative environmental impact (Chaudhry, Sarwar, 1999). As stated in some previous studies, the economic optimum nitrogen rate (EONR) was closely related to the fertilizer N price/crop value ratio (Belanger et al., 2000; Andraski, Bundy, 2005; Sincik et al., 2008), and the EONR was reported to be 100–110 kg ha^{-1} N to achieve good sunflower production (Ayup et al., 1998; Malik et al., 2004; Peker, Ozer, 2005).

The Southern Marmara region, with a Mediterranean climate, has the most intense sunflower production in Turkey, yet there are no detailed works on N fertilization in sunflower under irrigated and non-irrigated conditions. The aim of the present research was to determine the effects of N fertilizer applications on the yield, its components and the quality traits of sunflower and to identify the EONR for a maximum profit under both irrigated and non-irrigated conditions.

Materials and methods

Two field trials were conducted during 2007 and 2008 at the Applied and Research Centre for Agriculture, Uludag University, Faculty of Agriculture, Department of Field Crops, Bursa, Turkey (40°11′ N, 29°04′ W, 70 m a.s.l.). The soil was a clay (average 58.6% clay content) textural class (Table 1). Soil samples were collected from the 0–0.30 and 0.30–0.60 m profiles and analyzed. The concentrations of extractable phosphorus (P) and exchangeable potassium (K) were determined using the Olsen method, and the ammonium acetate method, respectively. The soil organic matter was determined using Walkley-Black method. Soil test levels of the experimental area in 2007 and 2008 were: pH 7.8 and 7.7, 2.04% and 1.93% organic matter, 36.6 and 29.3 mg kg^{-1} extractable P, 402.4 and 380.0 mg kg^{-1} exchangeable K and 2.52 and 2.57% $CaCO_3$, respectively (Table 1).

Table 1. Soil characteristics of experimental field in 2007 and 2008

Year	Texture	pH-H_2O	P mg kg^{1}	K mg kg^{-1}	$CaCO_3$ %	Organic matter %
2007	clay	7.8	36.6	402.4	2.52	2.04
2008	clay	7.7	29.3	380.0	2.57	1.93

The experimental site is located in the Southern Marmara region, Turkey, with an average annual rainfall of 700 mm, average annual relative humidity of 69.0% and a mean monthly temperature of 14.6ºC. Climatic data were obtained from the nearest weather station in Bursa (Table 2). The total rainfall from March to August was 165, 208 and 256 mm in 2007, 2008 and long term (1929–2001), respectively, values that correspond to 37% of the annual precipitation and are insufficient for sunflower production.

The experimental plots were arranged in a split-plot design with three replications in both years. The irrigation treatments, non-irrigated and irrigated, were the main plots, and seven different nitrogen levels, 0, 40, 80, 120, 160, 200, and 240 kg ha^{-1} N, were the subplot treatments. The subplot size was 14.0 m^2 (2.8 × 5.0 m) and consisted of four planting rows, with the middle two rows designated as harvest rows.

The hybrid cultivar ‘Muson’ obtained from the “May Seed Company” (Turkey) was used as the planting material. The crop previously grown in the experimental area in both years was corn (*Zea mays* L.). The experimental area was cultivated by ploughing at a depth of 25–30 cm in the autumn and by disc-harrowing at 8–10 cm depth in the spring. Sunflower seeds were hand planted on 13 April 2007 and 17 April 2008 at 0.70 m between-row spacing and 0.30 m within-row spacing. Prior to planting, triple super phosphate and potassium sulphate were incorporated into the disc-harrowed soil at 80 kg ha^{-1} P_2O_5 and 50 kg ha^{-1} K_2O. Half the nitrogen rate was applied before planting, and the remaining N was top-dressed before the second hoeing or first irrigation. The N fertilizers were banded urea, approximately 5 cm below and to the side of the seed row. After planting, Linuron was sprayed at a rate of 0.20 cm^3 m^{-2} for weed control.

Table 2. Mean air temperature, relative humidity and total monthly precipitation in 2007–2008 and long-term (LT) (1929–2001) at Bursa

Month	Air temperature °C			Relative humidity %			Precipitation mm		
	2007	2008	LT	2007	2008	LT	2007	2008	LT
January	5.8	3.0	5.3	72.6	73.4	74.1	86.7	56.9	88.8
February	7.1	5.3	6.2	67.8	74.1	73.4	73.4	46.1	77.5
March	10.1	12.0	8.3	67.4	70.5	70.2	45.2	118.5	69.8
April	13.4	15.3	13.0	72.1	65.3	70.3	26.5	38.4	62.9
May	19.9	18.1	17.6	62.0	64.2	69.5	31.8	22.1	50.0
June	24.4	23.7	22.1	57.1	59.0	62.9	46.6	28.8	30.4
July	26.1	25.0	24.5	52.2	55.3	58.1	13.6	0.2	24.0
August	26.5	26.3	24.1	53.8	56.1	60.5	1.0	0.0	18.9
September	20.9	20.3	20.1	59.8	62.2	66.4	3.2	132.2	40.1
October	16.9	15.8	15.6	71.4	78.0	72.8	39.4	36.8	60.4
November	14.1	12.1	11.2	74.2	79.1	75.6	48.2	65.2	76.3
December	9.2	7.6	7.6	70.5	77.4	74.2	68.6	93.9	99.9
Average / Total	16.2	15.4	14.6	60.1	67.9	69.0	484.2	639	699

During the growing season, all of the plots were cultivated once with a harrow (3 weeks after planting) and twice (5 and 8 weeks after planting) using a tractor-mounted cultivator. The plots were harvested by hand on 6 September 2007 and 8 September 2008 when the seeds contained approximately 15% moisture content.

For the irrigated plots, the three growth periods of sunflower suggested by Doorenbos and Kassam (1979), heading, flowering and seed filling and sensitive to water stress, were considered. Therefore, irrigation was applied throughout heading (20 June 2007 and 23 June 2008), flowering (12 July 2007 and 14 July 2008), and seed filling (31 July 2007 and 02 August 2008) in both experimental years. In addition, germination irrigation was applied once after planting (14 April 2007 and 18 April 2008) in the two seasons. In the irrigated plots of the second replication of the various treatments, the soil water content was monitored prior to irrigation at the three growth stages (heading, flowering, and seed filling) using the gravimetric method (Black, 1965); these values were converted to volumetric water contents using bulk density. According to the soil water contents measured, the plots were irrigated from a deficit moisture content of the 0–90 cm soil layer to field capacity (FC) at each growth stage. More water than the estimated (FC-available water content) was not applied to the 90 cm soil profile to reach the FC because it was assumed that deep percolation would be very low due to the clayey soil characteristics; thus, a water table-rising problem would not occur. A water meter was used to measure the amount of irrigation water. Emergence water was applied by a sprinkler system, and a furrow system was used for the other irrigations (heading, flowering and milking).

All of the data were subjected to an analysis of variance for each variable using *SAS* software version *3.1* (SAS System, 1992). Interactions of the main effects, year, irrigation treatment and N rate, were determined at the 0.05 and 0.01 probability levels. The *F*-protected least significant difference (LSD) was calculated at the 0.05 probability level, according to Steel and Torrie (1980). The sunflower seed yield-N rate relationships were determined using regression analysis (SAS System, 1992).

The economic optimum nitrogen rates (EONRs) were calculated using the quadratic model. The EONR was calculated by setting the derivative of the N response curve equal to the ratio between the cost of fertilizer and the price of sunflower. The prices of sunflower seed per kilogram in 2007 and 2008 were 0.523 and 0.622 $ US, respectively, and the prices of N fertilizer per kilogram in the same years were 0.654 and 0.935 $ US, respectively.

The quadratic model is as follows:

$Y = a + bN + cN^2$.

And the EONR is calculated by the following equation (Belanger et al., 2000):

$EONR = (CP - b) / 2c$, where a, b, and c are the intercept and linear and quadratic parameters, respectively, and CP is the ratio of the cost of N fertilizer to the price of sunflower. In this study, CP was calculated as 1.25 in 2007 and 1.50 in 2008. In addition, the yield at EONR (YEONR) was calculated using quadratic regression functions for each irrigation treatment and individual year.

Results and discussion

The analysis of variance indicated that the years significantly affected all of the traits measured. According to both the data combined over two years and the individual years, the irrigation treatments (IT) and nitrogen rates significantly affected all of the observed traits. The irrigation treatment × nitrogen rate interactions were significant at a 1% level of probability for the seed yield and crude oil yield in each individual year and the combined years and for the head diameter in 2007 and the combined years. In addition, the Y × IT × N interaction was highly significant for the seed yield (Tables 3 and 4).

Table 3. Results of variance analysis and mean effects of irrigation treatment (IT) and nitrogen (N) rate on plant height, head diameter and seed yield of sunflower in 2007, 2008 and combined years

Treatment	Plant height cm			Head diameter cm			Seed yield kg ha^{-1}		
	2007	2008	Combined years	2007	2008	Combined years	2007	2008	Combined years
Irrigation treatment									
No-irrigated	125 b[x]	136 b	131 b	10.7 b	12.5 b	11.6 b	1662 b	1948 b	1805 b
Irrigated	137 a	147 a	142 a	20.0 a	22.0 a	21.0 a	2740 a	3490 a	3115 a
N rate kg ha^{-1}									
0	122 e	130 d	126 d	13.2 d	14.9 d	14.0 e	1582 e	2109 e	1845 e
40	128 d	139 c	134 c	14.3 c	16.2 c	15.2 d	1890 d	2464 d	2177 d
80	131 c	141 bc	136 b	14.9 c	17.1 bc	15.9 c	2139 c	2707 c	2423 c
120	132 bc	143 ab	138 b	15.8 b	17.8 ab	16.8 b	2349 b	2837 b	2593 b
160	134 ab	147 a	140 a	16.3 ab	18.6 a	17.4 a	2472 a	2962 a	2717 a
200	135 a	146 a	140 a	16.6 a	18.4 a	17.5 a	2509 a	2993 a	2751 a
240	135 a	146 a	141 a	16.6 a	18.4 a	17.5 a	2467 a	2959 a	2713 a
Mean (year)	131 B	142 A	–	15.4 B	17.3 A	–	2201 B	2719 A	–
F values									
Year (Y)	–	–	**	–	–	**	–	–	**
Blocks (years) (B)	ns	ns	ns	*	ns	*	ns	ns	ns
IT	**	**	**	**	**	**	**	**	**
Y × IT	–	–	ns	–	–	ns	–	–	**
N	**	**	**	**	**	**	**	**	**
IT × N	ns	ns	ns	*	ns	**	**	**	**
Y × N	–	–	ns	–	–	ns	–	–	ns
Y × IT × N	–	–	ns	–	–	ns	–	–	**

Notes. [x] – means in the same location followed by the same letter were not significantly different at 0.05 level using LSD test.
*, ** – *F*-test significant at $P > 0.05$, and $P > 0.01$, respectively, ns – not significant.

All of the components had significantly higher means under irrigated conditions than the non-irrigated conditions. In addition, the highest seed yield and crude oil yield were obtained using irrigation, at 2740.4 and 1059.8 kg ha^{-1} in 2007 and 3490.0 and 1295.4 kg ha^{-1} in 2008, respectively. When compared as a percentage, the sunflower plants grown under irrigated conditions in 2007 and 2008 produced 64.7% and 79.2% more seed yield (kg ha^{-1}), respectively, in comparison with the non-irrigated conditions for the same years. In addition, the irrigated conditions in 2007 and 2008 produced higher mean values for the plant height (8.9% and 8.3%), head diameter (86.9% and 76.0%), crude protein content (9.1% and 10.9%) 1000-seed weight (5.5% and 5.1%) and crude oil yield (56.9% and 72.2%), respectively, whereas the non-irrigated conditions produced 3.8–4.9% higher crude oil content (Tables 3 and 4). In a study conducted at this location from 1999 to 2001, Goksoy et al. (2004) reported that the highest seed yield (4056 kg ha^{-1}) was obtained under an HFM treatment (irrigation at heading, flowering and seed filling periods, no water stress), with a 85.4% increase compared with the control (non-irrigated). Similar results were reported by Unger (1982) and Gholinezhad et al. (2009).

Table 4. Results of variance analysis and mean effects of irrigation treatment (IT) and nitrogen (N) rate on crude oil content, crude protein content, 1000-seed weight and crude oil yield of sunflower in 2007, 2008 and combined years

Treatment	Crude oil content %			Crude protein content %			1000-seed weight			Crude oil yield kg ha^{-1}		
	2007	2008	Combined years	2007	2008	Combined years	2007	2008	Combined years	2007	2008	Combined years
Irrigation treatment												
NI	40.7 a^{x}	38.6 a	39.7 a	18.6 b	19.2 b	18.9 b	61.6 b	66.5 b	64.1 b	675 b	751 b	713 b
I	38.8 b	37.2 b	38.0 b	20.3 a	21.3 a	20.8 a	65.0 a	69.9 a	67.5 a	1059 a	1295 a	1177 a
N rate kg ha^{-1}												
0	41.4 a	39.3 a	40.4 a	17.4 f	18.2 e	17.7 e	57.5 e	63.3 d	60.4 f	653 e	825 e	739 e
40	40.4 ab	38.5 b	39.4 b	18.1 e	18.9 d	18.5 d	60.8 d	66.6 c	63.7 e	758 d	942 d	850 d
80	40.1 b	38.2 bc	39.1 bc	18.7 d	19.3 d	19.0 d	63.2 cd	67.2 c	65.2 de	852 c	1028 c	940 c
120	39.6 bc	38.7 cd	38.7 cd	19.8 c	20.6 c	20.2 c	63.6 c	68.5 bc	66.0 cd	924 b	1066 bc	995 b
160	39.4 bc	37.6 cd	38.5 cd	20.4 b	21.2 b	20.8 b	64.4 bc	69.8 ab	67.1 bc	966 ab	1107 a	1036 a
200	39.1 bc	37.4 de	38.2 de	20.8 ab	21.6 ab	21.2 ab	65.9 ab	71.6 ab	68.7 ab	973 a	1111 a	1042 a
240	38.4 c	36.8 e	37.6 e	21.1 a	21.9 a	21.5 a	67.8 a	70.6 ab	69.2 a	943 ab	1082 ab	1012 ab
Mean (year)	39.7 A	37.9 B	–	19.5 B	20.2 A	–	63.3 B	68.2 A	–	867 B	1023.4 A	–
F values												
Y	–	–	**	–	–	**	–	–	**	–	–	**
B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
IT	**	**	**	**	**	**	**	**	**	**	**	**
Y × IT	–	–	ns	–	–	ns	–	–	ns	–	–	**
N	**	**	**	**	**	**	**	**	**	**	**	**
IT × N	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	*	**
Y × N	–	–	ns	–	–	ns	–	–	ns	–	–	ns
Y × IT × N	–	–	ns	–	–	ns	–	–	ns	–	–	*

Notes. NI – non-irrigated, I – irrigated, Y – year, B – blocks (year). ^{x} – means in the same location followed by the same letter were not significantly different at 0.05 level using LSD test. *, ** – F-test significant at $P > 0.05$, and $P > 0.01$, respectively, ns – not significant.

As the N rates increased, all of the traits significantly increased, except the crude oil content, in both years. The highest seed yield, crude oil yield, plant height, and head diameter were obtained at the 160–240 kg ha^{-1} N rates. When the N rates increased from 0 to 240 kg ha^{-1} N, the seed yield ranged from 1582 to 2468 kg ha^{-1} in 2007 and from 2109 to 2959 kg ha^{-1} in 2008, whereas the crude oil yield also varied from 653 to 943 kg ha^{-1} and from 825 to 1082 kg ha^{-1}, respectively. The 160 kg ha^{-1} N and higher N rates in 2007 and 2008 produced approximately 57.0% and 41.0% more seed yield, respectively, than the control (0 kg ha^{-1} N), and the crude oil yield values were 47.0% and 33.0%, respectively. Our findings are in agreement with those of Kasem and El-Mesilby (1992), Ozer et al. (2004), De Giorgio et al. (2007) and Oyinlola et al. (2010) who reported that the seed yield and other yield components increased with higher N rates. In some other studies conducted under irrigated conditions in Pakistan, the optimal fertilizer requirements for sunflower crops were reported to be 80-50-50 kg ha^{-1} NPK (Nawaz et al., 2003). In addition, Ozer et al. (2004) suggested that, under irrigated conditions, an N rate of 120 kg ha^{-1} was adequate for sunflower production in Eastern Anatolia, Turkey. Ruffo et al. (2003) reported that an N supply of 231 kg ha^{-1} N was required to maximize the sunflower yield in Argentina. Our findings for the crude oil yield are in accordance with the results obtained by several researchers (Steer et al., 1986; Ozer et al., 2004) who found that oil yields in irrigated sunflower increased as the N rates increased.

Similar trends were also obtained for the other characters, with the exception of the crude oil content, which was the highest (39–41%) at 0 kg ha^{-1} N but the lowest (36–38%) at higher N rates. The highest mean values for the crude protein content and 1000-seed weight, important quality components, were found at the highest N rates (200 and 240 kg ha^{-1} N). The crude protein content increased up to 20–21% at the highest N rates, whereas it was 17–18% under the control treatment (0 kg ha^{-1} N). Our results are in agreement with those of Kassem and El-Mesilby (1992), Ayup et al. (1998), and Ozer et al. (2004) who stated that the protein content increased with increasing N rates, whereas the oil content decreased significantly. In contrast, our findings do not correspond with those of Steer et al. (1986), and Oyinlola et al. (2010) who reported that the oil content of sunflower seeds were increased by nitrogen fertilizers. Our results for the 1000-seed weight support the previous work of Kamel et al. (1980) and Ozer et al. (2004) who reported that the 1000-seed weight increased with increasing N rates.

The plant height, an important agronomical character, was 135 cm (2007) and 147 cm (2008) for the N rates between 160 and 240 kg ha^{-1} N, whereas it was 122–130 cm under the control treatment (0 kg ha^{-1} N). The highest head diameter was obtained at 120 kg ha^{-1} N and the higher N rates (16.3–18.6 cm), followed by the 80 and 40 kg ha^{-1} N rates, with 16 and 14 cm, respectively. The higher N rates produced 23–25% larger head diameters than the control treatment. Previous studies indicated that application of nitrogen up to 150

Table 5. Irrigation treatment × N rate interaction for seed yield and crude oil yield of sunflower in 2007, 2008 and combined years

Irrigation treatment	N rate kg ha^{-1}							Mean
	0	40	80	120	160	200	240	
				Seed yield kg ha^{-1}				
				2007				
Non-irrigated	1275 i^{x}	1525 h	1682 g	1741 fg	1775 e-g	1829 ef	1810 ef	1662 B
Irrigated	1889 e	2255 d	2597 c	2957 b	3170 a	3188 a	3125 a	2740 A
Mean	1582 E	1890 D	2139 C	2349 B	2472 A	2509 A	2467 A	
				2008				
Non-irrigated	1502	1726	1980	2053	2143	2129	2102	1948 B
Irrigated	2716	3201	3434	3622	3782	3857	3817	3490 A
Mean	2109 E	2464 D	2707 C	2837 B	2962 A	2993 A	2959 A	
				Combined years				
Non-irrigated	1388 i	1625 h	1831 g	1897 fg	1959 f	1979 f	1956 f	1805 B
Irrigated	2302 e	2728 d	3015 c	3289 b	3476 a	3522 a	3471 a	3115 A
Mean	1845 E	2177 D	2423 C	2593 B	2717 A	2751 A	2713 A	
				Crude oil yield kg ha^{-1}				
				2007				
Non-irrigated	534 h	632 g	691 fg	709 ef	716 ef	734 ef	708 ef	675 B
Irrigated	772 e	885 d	1014 c	1140 b	1216 a	1212 a	1178 ab	1059 A
Mean	653 E	758 D	852 C	924 B	966 AB	973 A	943 AB	
				2008				
Non-irrigated	599 h	675 g	769 f	794 f	822 f	811 f	786 f	751 B
Irrigated	1051 e	1210 d	1287 c	1338 bc	1391 ab	1411 a	1377 ab	1177 A
Mean	825 E	942 D	1028 C	1066 BC	1107 A	1111 A	1082 AB	
				Combined years				
Non-irrigated	566 h	654 g	730	751 f	769 f	772 f	747 f	713 B
Irrigated	911 e	1047 d	1151	1239 b	1303 a	1312 a	1278 ab	1177 A
Mean	739 E	850 D	940 C	995 AB	1036 A	1042 A	1012 AB	

Note. ^{x} – means in the same location followed by the same letter were not significantly different at 0.05 level using LSD test.

kg ha^{-1} N increased the plant height when compared with the control treatment (Kassem, El-Mesilby, 1992; Ayup et al., 1998). Ozer et al. (2004) reported that the head diameter was 20.7 and 20.6 cm for N rates of 120 and 160 kg ha^{-1} N, respectively, whereas it was 18.5 cm under the control treatment. Our results for the plant height and head diameter are in close agreement with those of Robinson et al. (1979), Ayup et al. (1998), Sadiq et al. (2000), Malik et al. (2004), and Ozer et al. (2004).

A significant irrigation treatment × N rate interaction for the seed yield and crude oil yield in both years indicated that, according to the irrigation treatment, certain N rates affected the seed yield and crude oil yield differently. There were significant differences between the 120 kg ha^{-1} N rate and higher N rates in terms of the seed yield and crude oil yield under irrigated conditions, whereas differences between the same N rates for the seed yield and crude oil yield were not statistically significant under the non-irrigated conditions in both experimental years (Table 5).

The seed yield-N rate relationships were obtained by plotting the observed seed yield on the Y-axis and the N rate on the X-axis for each irrigation treatment over the individual experimental years and the mean of both years (Fig.). Both linear and quadratic responses to N were significant ($p < 0.01$) for seed yield. A significant irrigation treatment × N rate interaction for the seed yield indicates that the seed yield responded differently to the various N rates under each irrigation treatment. Changes in the seed yield-N rate relationship under the irrigation treatments in the individual years and over the combined years are illustrated in Figure. In 2007, the N rates increasing up to

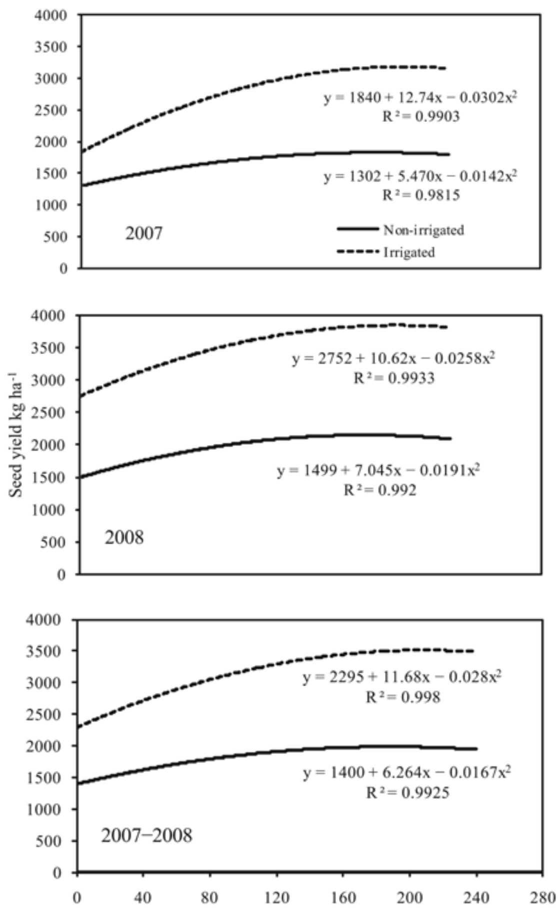

Figure. Relationships between N rates and seed yield at non-irrigated and irrigated conditions in 2007, 2008 and combined years

160 kg ha^{-1} N significantly increased the seed yield under both non-irrigated and irrigated conditions, although the seed yield at 160 kg ha^{-1} N and higher N rates under non-irrigated conditions was similar to the yield obtained at 0 kg ha^{-1} N under irrigated conditions. In 2008, the response of the seed yield to the N rate was not different than that in 2007 (Table 5).

The EONR and YEONR determined from the quadratic regression models are summarized in Table 6. In 2007, the EONR for sunflower was 148.5 kg ha^{-1} N under the non-irrigated conditions compared with 190.0 kg ha^{-1} N under irrigated conditions. The increase in the EONR under the irrigated conditions compared with the non-irrigated conditions was 41.5 kg ha^{-1} N. The seed yield at the EONR under both the non-irrigated and irrigated conditions was not different than those for the maximum N rate (240 kg ha^{-1} N) in this study. But, the YEONR for the sunflower grown under irrigated conditions was 76% higher than that for the sunflower grown under non-irrigated conditions (Table 6).

Table 6. Regression models for the relationship between N rates and seed yield economic optimum nitrogen rate (EONR) and yield at EONR (YEONR) for sunflower at non-irrigated and irrigated conditions in 2007 and 2008

Year	Treatment	Regression equations	R^2	EONR kg ha^{-1}	YEONR kg ha^{-1}
2007	Non-irrigated	$y = 1302 + 5.470x - 0.01421x^2$	98.1**	148.5	1801
	Irrigated	$y = 1840 + 12.74x - 0.03024x^2$	99.0**	189.9	3169
2008	Non-irrigated	$y = 1498 + 7.105x - 0.01931x^2$	99.2**	145.1	2123
	Irrigated	$y = 2752 + 10.62x - 0.02581x^2$	99.3**	176.7	3823

In 2008, the EONRs for sunflower grown under non-irrigated and irrigated conditions were 145.1 and 176.7 kg ha^{-1} N, respectively. The EONR for the irrigated plants was 31.6 kg ha^{-1} N, which was higher than for the non-irrigated conditions. The sunflower YEONRs under the non-irrigated and irrigated conditions were similar to the seed yield of maximum N rates (160–240 kg ha^{-1} N). However, YEONR for the irrigated plants was 80% higher than for the non-irrigated plants. The total rainfall during the growth period of sunflower in 2008 was 26% higher than during the same period in 2007. However, the total precipitation during the summer months (June, July and August) in 2007 was 32.2 mm higher than during the same period in 2008. In particular, no precipitation was recorded during July and August in 2008. The fertilizer N losses in 2007 were likely to be a little higher than those in 2008 due to the higher rainfall during the summer months in 2007. Thus, the sunflower seed yields for both the non-irrigated and irrigated conditions may have responded greater to the fertilizer rate in 2007 compared with 2008. In a previous study, Malik et al. (2004) found that, although the highest seed yield (1231.5 kg ha^{-1} N) was achieved when the crop was fertilized with 130-90-90 kg ha^{-1} NPK, the highest net benefit was obtained when N, P, and K fertilizers were applied at 110-70-0 kg ha^{-1}, respectively. In addition, Ayup et al. (1998) recorded that nitrogen applications of 100 and 150 kg ha^{-1} gave statistically similar achene yields and, thus, the application of nitrogen more than 100 kg ha^{-1} was not economical. In an earlier study, the EONR was found to be approximately 110 kg ha^{-1} for sunflower plants grown under irrigated conditions in the Eastern Anatolia region of Turkey (Peker, Ozer, 2005). However, in another study conducted under irrigated conditions in the Central Anatolia region of Turkey, EONRs for sunflower were estimated to be 170 kg ha^{-1} N for seed production and 175 kg ha^{-1} N for oil production (Avci et al., 1996).

As a result, although the 160 kg ha^{-1} N and higher N rates resulted in higher yields compared to the other N rates, these rates are not economical due to the higher cost of the fertilizer. Therefore, in our study, it was found that the most suitable and economical N levels for sunflower were the 145–150 kg ha^{-1} N for non-irrigated conditions and 177–190 kg ha^{-1} N for irrigated conditions.

Conclusion

Sunflower is a crop that is highly responsive to nitrogen fertilizer. Our findings revealed that the seed yield and crude oil yield increased significantly when N rates increased; similar trends were also obtained for the other characters, except the crude oil content. It was found that the 160 kg ha^{-1} N and higher N rates produced approximately 41.0% to 57.0% more seed yield and 33.0% to 47.0% more crude oil yield in comparison to the control (0 kg ha^{-1} N).

As a result, the economic optimum nitrogen rate (EONR) for sunflower was 145–150 kg ha^{-1} N under non-irrigated conditions and 177–190 kg ha^{-1} N under irrigated conditions in the Southern Marmara region of Turkey.

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Tikrosios saulėgrąžos (*Helianthus annuus* L.) atsakas į lietinimą ir tręšimą azotu

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Santrauka

Dvejus metus (2007–2008) vykdyto eksperimento metu įvertinta azoto įvairių normų (0, 40, 80, 120, 160, 200 ir 240 kg ha^{-1}) įtaka saulėgrąžų sėklų derliui bei jo sudėtinėms dalims ir nustatyta ekonomiškai optimali azoto norma, užtikrinanti maksimalų pelną lietinimo ir nelietinimo sąlygomis. Didinant azoto normą visų tirtų saulėgrąžų sėklų derliaus savybių vertės esmingai didėjo, išskyrus žalio aliejaus kiekį. Remiantis dvejų metų vidutiniais duomenimis, didžiausias sėklų derlius (2713–2751 kg ha^{-1}) ir žalio aliejaus išeiga (1012–1042 kg ha^{-1}) gauti tręšiant 160 kg ha^{-1} ir didesniu kiekiu azoto – padidėjimas buvo atitinkamai 47,8 ir 39,4 %, lyginant su kontroliniu variantu. Panašios tendencijos pastebėtos ir kitų sėklų derliaus savybių, išskyrus žalio aliejaus kiekį, kuris didžiausias (39–41 %) buvo esant 0 kg ha^{-1} N, mažiausias (36–38 %) – tręšiant didesniu kiekiu azoto. Didžiausios vidutinės žalio aliejaus kiekio vertės ir 1000 sėklų masė gauti tręšiant didžiausiu kiekiu (200 ir 240 kg ha^{-1}) azoto. Saulėgrąžoms ekonomiškai optimalus kiekis azoto 2007 m. nelietinant buvo 148,5 kg ha^{-1}, lietinant – 190,0 kg ha^{-1}, 2008 m. nelietinant ir lietinant – atitinkamai 145,1 ir 176,7 kg ha^{-1}. Ekonomiškai optimalus kiekis azoto lietinant buvo 30–40 kg ha^{-1} didesnis nei nelietinant, tačiau sėklų derlius lietinimo sąlygomis buvo 65–79 % didesnis, lyginant su nelietinimo sąlygomis. Taigi buvo nustatyta, kad saulėgrąžoms ekonomiškai optimalus kiekis azoto buvo 145–150 kg ha^{-1} nelietinant ir 177–190 kg ha^{-1} lietinant.

Reikšminiai žodžiai: derlius, *Helianthus annuus*, lietinimo ir nelietinimo sąlygos, kokybė, ekonomiškai optimalus kiekis azoto.