African Journal of Biotechnology Vol. 7 (16), pp. 2854-2861, 18 August, 2008
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB08.402
ISSN 1684–5315 © 2008 Academic Journals

Full Length Research Paper

Effects of application boron on yields, yield component and oil content of sunflower in boron-deficient calcareous soils

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Accepted 21 July, 2008

The study was conducted to investigate the effects of five boron (B) doses; 0, 2.5, 5.0, 7.5 and 10.0 kg B ha^{-1} in B-deficient calcareous soils on yield and some yield components of four sunflower genotypes. Genotypes have shown variations with respect to their responses to B applications. AS-615 and Coban had the highest seed yield (3.75 and 3.23 t ha^{-1}, respectively) at 7.5 kg B ha^{-1}, whereas S-288 and TR-4098 yielded 4.17 and 3.28 t ha^{-1}, respectively, at 0 kg B ha^{-1}. Therefore, S-288 and TR-4098 can be indicator genotypes for B toxicity. The other genotypes appeared to have high sensitivity to B deficiency. For AS-615 and Coban, application at 7.5 kg B ha^{-1} level was found to be sufficient for adequate grain yield, whereas further B levels might have detrimental effects on grain yield.

Key words: Sunflower, boron, seed yield, yield component, oil content.

INTRODUCTION

During the last century, the cultivated sunflower (*Helianthus annus* L.) has emerged as one of the major oil seed crops in the world, ranking second in importance after soybean. According to Food and Agriculture Organization statistics (FAOSTAT, 2006), the world production of sunflower seeds in 2005 was estimated over 31 million tons and the area under its cultivation was 23.4 million hectares.

Sunflower is one of the most sensitive field crops to low B supply, and B deficiency in this crop has been reported from around the world (Blamey et al., 1997). Deficiency symptoms first become evident on the younger leaves which have a bronze colour and become hardened, malformed and necrotic (Blamey et al., 1987; Blamey et al., 1997). The capitulum's is often malformed with poor seed set (Blamey, 1976). The critical concentration for B deficiency (associated with 90% maximum seed yield) in the youngest mature leaf at flowering (Schneiter and Miller, 1981) has been reported as 34 mg kg^{-1} dry wt (Blamey et al., 1979) with 31 - 140 mg kg^{-1} (Bergmann 1992) considered adequate. Increases in seed yield have been reported with the application of B fertilizer when soils consist of low level B (Blamey et al., 1997).

Although the effects of B fertilization on growth and yield of many plants such as chickpea (C*icer arientinum* L.) (Ceyhan et al., 2007), soybean (*Glicine max* Merr. L.) (Ross et al., 2006), cotton (*Gossypium hirsutum* L.) (Roberts et al., 2000) and wheat (*Triticum* spp.) (Soylu et al., 2004) have been investigated; there have been limited studies performed on the response of oil seed sunflower (*Helianthus annuus*) to B fertilization. The objective of this study was to investigate the response of sunflower to B application in a calcareous soil of Central Anatoli, Turkey.

MATERIAL AND METHODS

The field experiments were carried out on a soil that contains 0.19 mg kg^{-1} extractable B using a 0.01 M mannitol + 0.01 M $CaCl_2$ solution before reading in ICP-AES (Varian-Vista Model). The experiments were conducted during 2001 and 2002 growing seasons at

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Table 1. Physicochemical properties of topsoil samples (0 – 30 cm) collected from locations at experimental area (Gezgin et al., 2002).

Property	Mean	Properties	Mean
pH	7.6	Mg (me/100 g)	5.3
$CaCO_3$	20.7	K (me/100 g)	0.6
E.C (μScm^{-1})	94	Na (me/100 g)	0.13
Organic matter (%)	1. 4	P (mg kg^{-1})	8.5
Sand (%)	26.7	B (mg kg^{-1})	0.19
Silt (%)	68.1	Mn (mg kg^{-1})	2.3
Clay (%)	5.2	Zn (mg kg^{-1})	0.3
Ca (me/100 g)	20.2	Fe (mg kg^{-1})	0.4

Table 2. Total monthly rainfall, relative air humidity and mean air temperature during 2001 and 2002 growing seasons and 20 yr average.

Month	Rainfall (mm)			Relative air humidity (%)			Mean air temperature (°C)		
	2001	2002	20 year	2001	2002	20 year	2001	2002	20 year
April	14.1	70.0	36.5	47.8	67.2	57.6	12.7	9.7	10.3
May	66.0	22.9	39.8	57.2	53.9	56.0	15.0	15.2	15.4
June	0.7	15.3	26.5	36.4	47.5	46.9	22.5	19.8	19.3
July	1.3	27.1	8.1	35.2	39.8	39.3	26.3	24.1	23.3
Total/Mean	82.1	135.3	110.9	44.2	52.1	50.0	19.1	17.2	17.1

the Research Institute of Rural Affairs, Konya, Turkey. The soil characteristics are given in Table 1. Sunflower genotypes were AS-615, S-288, Coban and TR-4098 registered by the Thracian Agricultural Research Institute (TARI), Edirne, Turkey. The genotypes are the most popular varieties registered and currently grown in Turkey.

Experimental design was a randomized complete block in a split-split plot with three replications, using cultivars as main plot, and B treatment as the sub-plots. B treatments were 0 (B_0), 2.5 (B_1), 5.0 (B_2), 7.5 (B_3) and 10.0 kg B ha^{-1} (B_4) applied to sunflower genotypes in the both years. B soil application was sprayed on to the soil surface using 0.86% H_3BO_3 solution, followed by incorporation into soil depth of 10 - 15 cm prior to sowing. Before sowing phosphorus and nitrogen was applied in the form of diammonium phosphate (550 kg ha^{-1}) (18% N; 46% P_2O_5).

After winter wheat for both years, seeds were sown by hand and plots consisted of 5 rows with 3.5 m width and 3 m length on 11 April 2001 and 12 April 2002. Weeds were controlled by hand. In the first year, plots were irrigated five times; while in the second year plots were irrigated four times with sprinkler irrigation system. Three rows in middle of the plots were harvested by hand both years on 22 July. During the two growing seasons, total rainfall was 82.1 mm in 2001 and 135.3 mm in 2002. Seasonal average temperature and average relative humidity were 19.1°C and 44.2% in 2001 and 17.2°C and 52.1% in 2002. Monthly climatic data for a 20 year were shown in Table 2.

Plant height and head diameter were measured on 10 randomly selected plants per plot at maturity (Ekin, 2005). Hull ratio at 100 g samples was determined by following formulas: hulled weight / achene weight (Ekin, 2005). Grain yield was recorded in kg per plot and then it was converted to hectare basis (Ekin, 2005). 1000 seed weight was recorded in g (Ekin, 2005). Oil contents were determined according to Ekin (2005). Oil yields were calculated by multiplying oil contents and grain yields (Ekin, 2005). During flowering stage, the youngest 5 mature leaves of each plot were combined as one sample, and washed with water, and then samples were dried at 70°C for 48 h. After dry weights were measured. Samples were finely ground and 0.5 g plant material was digested with concentrated HNO_3 in a Microwave system (CEM, Mars 5). The extracts were analyzed for B by ICP-AES (Varian-Vista Model) (Nyomora et al., 1997).

Data were subjected to analysis of variation (ANOVA) using MSTAT-C. The least significant difference (LSD) test was used to compare the treatment means (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

ANOVA results

There were statistically significant differences within the genotypes for all traits (Tables 3, 4, 5, 6, 7, 8, 9 and 10). Year by genotype interaction has been significant for grain yield, oil yield, oil content, head diameter, 1000 seed weight and hull ratio (Tables 3, 4, 5, 7, 8 and 9). B application had significant effect on the oil yield, oil content, plant height, 1000 seed weight and B concentration of the leaf (Tables 4, 5, 6, 8 and 10). B application by genotype interaction was significant for grain yield, oil yield, plant height, head diameter, 1000 seed weight and B concentration of the leaf (Tables 3, 4, 6, 7, 8 and 10). Significant interactions existed between year by B application for plant height, head diameter and hull ratio (Tables 6, 7 and 9). Statistically significant B application by genotype by year interactions was observed for plant height, head diameter and 1000-seed weight (Tables 6, 7 and 8).

Table 3. Grain yield (t ha^{-1}) of sunflower genotypes when grown in two consecutive years with five levels of B treatments.

Year	Boron application	Genotype				Mean
		AS-615	S-288	Coban	TR-4098	
2001	B_0	2.72	4.33	2.46	3.15	3.17
	B_1	3.18	3.12	2.84	3.10	3.06
	B_2	2.65	3.52	3.04	2.88	3.02
	B_3	3.17	3.40	3.20	2.92	3.17
	B_4	3.30	3.13	2.84	2.85	3.03
	Mean	3.00 bc	3.50 a	2.88 c	2.98 bc	3.09
2002	B_0	2.90	4.01	2.98	3.41	3.32
	B_1	3.71	2.94	3.18	3.20	3.26
	B_2	3.46	3.13	3.20	2.96	3.18
	B_3	4.33	3.29	3.26	2.75	3.41
	B_4	3.36	3.03	3.21	3.08	3.17
	Mean	3.55 a	3.28 ab	3.16 bc	3.08 bc	3.27
Mean	B_0	2.81 cd	4.17 a	2.72 d	3.28 bcd	3.24
	B_1	3.44 bc	3.03 cd	3.01 cd	3.15 bcd	3.16
	B_2	3.05 cd	3.32 bcd	3.10 bcd	2.92 cd	3.10
	B_3	3.75 ab	3.34 bcd	3.23 bcd	2.83 cd	3.29
	B_4	3.33 bcd	3.08 cd	3.03 cd	2.97 cd	3.10
	Mean	3.28 a	3.39 a	3.02 b	3.03 b	
$LSD_{1\%}$[a]: G = 0.211, Y x G = 0.299, B x G = 0.671						

[a]Least significant difference for comparisons between individual means: G; Y x G; B x G indicate genotype main effect (G), interaction of year with genotype (Y x G), interaction of B applied with genotype (B x G).

Table 4. Oil yield (t ha^{-1}) of sunflower genotypes when grown in two consecutive years with five levels of B treatments.

Year	Boron application	Genotype				Mean
		AS-615	S-288	Coban	TR-4098	
2001	B_0	1.15	1.64	0.97	1.43	1.30
	B_1	1.26	1.08	1.08	1.38	1.20
	B_2	1.07	1.25	1.16	1.20	1.17
	B_3	1.31	1.29	1.21	1.20	1.25
	B_4	1.32	1.17	1.19	1.19	1.22
	Mean	1.22 cd	1.28 c	1.12 d	1.28 c	1.23
2002	B_0	1.36	1.57	1.06	1.57	1.39
	B_1	1.61	1.14	1.12	1.45	1.33
	B_2	1.40	1.18	1.06	1.36	1.25
	B_3	1.84	1.29	1.10	1.23	1.37
	B_4	1.40	1.14	1.40	1.40	1.33
	Mean	1.52 a	1.26 c	1.15 d	1.40 b	1.33
Mean	B_0	1.25 efgh	1.61 a	1.02 i	1.50 abc	1.34 a
	B_1	1.43 bcd	1.11 hi	1.10 hi	1.41 bcde	1.26 ab
	B_2	1.24 fgh	1.21 fgh	1.11 hi	1.28 defg	1.21 b
	B_3	1.57 ab	1.29 defg	1.15 ghi	1.22 fgh	1.31 ab
	B_4	1.36 cdef	1.15 ghi	1.30 defg	1.30 defg	1.28 ab
	Mean	1.37 a	1.27 b	1.13 c	1.34 ab	
$LSD_{1\%}$[a]: B = 0.112, G = 0.082, Y x G = 0.115, $LSD_{5\%}$: B x G = 0.168						

[a]Least significant difference for comparisons between individual means: B; G; Y x G; B x G indicate B applied main effect (B), genotype main effect (G), interaction of year with genotype (Y x G), interaction of B applied with genotype (B x G).

Table 5. Oil content (%) of sunflower genotypes when grown in two consecutive years with five levels of B treatments.

Year	Boron application	Genotype				Mean
		AS-615	S-288	Coban	TR-4098	
2001	B_0	42.3	38.0	39.5	45.2	41.3
	B_1	39.8	34.6	38.0	44.4	39.2
	B_2	40.4	35.3	38.2	41.6	38.9
	B_3	41.3	37.8	37.6	41.1	39.5
	B_4	40.0	37.1	34.3	41.8	38.3
	Mean	40.8 c	36.6 e	37.5 de	42.8 b	39.4
2002	B_0	46.5	39.4	35.9	46.2	42.0
	B_1	44.0	38.7	35.3	45.5	40.9
	B_2	40.6	37.8	33.2	46.2	39.4
	B_3	42.4	39.3	33.6	44.9	40.0
	B_4	41.5	37.5	33.3	45.4	39.5
	Mean	43.0 b	38.5 d	34.3 f	45.6 a	40.4
Mean	B_0	44.4	38.7	37.7	45.7	41.6 a
	B_1	41.9	36.7	36.7	45.0	40.1 ab
	B_2	40.5	36.6	35.7	43.9	39.2 b
	B_3	41.9	38.6	35.6	43.0	39.8 b
	B_4	40.8	37.3	33.8	43.6	38.9 b
	Mean	41.9 b	37.6 c	35.9 d	44.2 a	
$LSD_{1\%}$[a]: B = 1.595, G = 1.168, Y x G = 1.652						

[a]Least significant difference for comparisons between individual means: B; G; Y x G indicate B applied main effect (B), genotype main effect (G), interaction of year with genotype (Y x G).

Table 6. Plant height (cm) of sunflower genotypes when grown in two consecutive years with five levels of B treatments.

Year	Boron application	Genotype				Mean
		AS-615	S-288	Coban	TR-4098	
2001	B_0	85.8 pq	107.8 j-n	110.5 h-l	111.5 h-l	103.9 bc
	B_1	88.2 opq	112.1 h-l	117.7 g-k	118.7 g-j	109.2 b
	B_2	85.6 pq	105.5 k-n	96.9 nop	110.3 h-m	99.6 cd
	B_3	83.1 q	90.2 opq	105.7 k-n	109.3 i-n	97.1 d
	B_4	113.7 h-k	83.5 q	97.5 m-p	99.8 l-o	98.6 cd
	Mean	91.3	99.8	105.7	109.9	101.7
2002	B_0	127.3 c-g	130.4 a-g	132.1 a-f	135.3 a-e	131.3 a
	B_1	128.5 b-g	133.3 a-f	129.7 a-g	136.2 a-d	132.0 a
	B_2	121.1 f-i	134.9 a-e	140.1 abc	138.7 a-d	133.7 a
	B_3	122.6 e-h	133.6 a-f	136.3 a-d	141.2 ab	133.4 a
	B_4	127.1 d-g	137.7 a-d	139.6 a-d	141.5 a	136.5 a
	Mean	125.4	134.0	135.6	138.6	133.4
Mean	B_0	106.6 d	119.1 abc	121.3 a	123.4 a	117.6 ab
	B_1	108.4 d	122.7 a	123.7 a	127.5 a	120.6 a
	B_2	103.4 d	120.2 ab	118.5 abc	124.5 a	116.6 b
	B_3	102.8 d	111.9 bcd	121.0 ab	125.3 a	115.3 b
	B_4	120.4 ab	110.6 cd	118.5 abc	120.7 ab	117.6 ab
	Mean	108.3 c	116.9 b	120.6 ab	124.3 a	
$LSD_{5\%}$[a]: B = 3.442, $LSD_{1\%}$: G = 5.072, Y x B = 6.468, Y x G = 9.148, B x G = 18.44, Y x B x =12.94						

[a]Least significant difference for comparisons between individual means: B; G; Y x G; B x G; Y x B x G indicate B applied main effect (B), genotype main effect (G), interaction of year with genotype (Y x G), interaction of B applied with genotype (B x G), interaction of year with B applied and genotype (Y x B x G).

Table 7. Head diameter (cm) of sunflower genotypes when grown in two consecutive years with five levels of B treatments.

Year	Boron application	Genotype				Mean
		AS-615	S-288	Coban	TR-4098	
2001	B_0	12.8 j-m	16.2 bcd	15.7 c-f	15.9 b-e	15.2 abc
	B_1	14.1 f-k	16.7 abc	18.3 a	15.3 c-h	16.1 bc
	B_2	15.3 c-h	16.3 bcd	16.2 bcd	15.9 b-e	15.9 a
	B_3	15.7 c-f	13.9 g-l	17.6 ab	14.7 d-i	15.5 ab
	B_4	15.9 b-e	12.4 klm	15.6 c-g	13.8 h-m	14.4 c
	Mean	14.8 b	15.1 b	16.7 a	15.1 b	15.4
2002	B_0	13.9 g-l	12.5 klm	13.1 i-m	13.0 i-m	13.1 d
	B_1	13.3 i-m	12.3 lm	12.6 j-m	12.7 j-m	12.7 d
	B_2	13.3 i-m	12.1 m	13.3 i-m	12.9 j-m	12.9 d
	B_3	13.3 i-m	12.6 j-m	12.3 lm	12.8 j-m	12.8 d
	B_4	14.3 e-j	12.5 klm	12.9 j-m	14.0f-l	13.4 d
	Mean	13.6 c	12.4 d	12.8 cd	13.1 cd	12.9
Mean	B_0	13.3 de	14.3 a-d	14.4 a-d	14.4 a-d	14.2
	B_1	13.7 cde	14.5 a-d	15.5 a	14.0 bcd	14.4
	B_2	14.3 a-d	14.2 bcd	14.8 abc	14.4 a-d	14.4
	B_3	14.5 a-d	13.3 de	14.9 abc	13.7 cde	14.2
	B_4	15.1 ab	12.5 e	14.2 bcd	13.9 bcd	13.9
	Mean	14.2 ab	13.7 b	14.8 a	14.1 ab	
$LSD_{1\%}$[a]: G = 0.7365, Y x B = 0.896, Y x G = 1.042, B x G = 1.267, Y x B x G = 1.791						

[a] Least significant difference for comparisons between individual means: G; Y x G; B x G; Y x B x G indicate genotype main effect (G), interaction of year with genotype (Y x G), interaction of B applied with genotype (B x G), interaction of year with B applied and genotype (Y x B x G).

Table 8. 1000 seed weight (g) of sunflower genotypes when grown in two consecutive years with five levels of B treatments.

Year	Boron application	Genotype				Mean
		AS-615	S-288	Coban	TR-4098	
2001	B_0	43.3 fg	60.0 a	48.4 b-f	46.6 c-g	49.6
	B_1	46.4 c-g	45.0 d-g	60.3 a	48.0 b-g	49.9
	B_2	43.4 fg	50.4 b-e	45.6 d-g	47.4 b-g	46.7
	B_3	41.8 g	44.1 efg	53.2 b	44.9 efg	46.0
	B_4	52.1 bc	44.8 efg	51.4 bcd	44.9 efg	48.3
	Mean	45.4 c	48.9 ab	51.8 a	46.4 bc	48.1
2002	B_0	47.2 b-g	48.2 b-g	49.0 b-f	52.3 bc	49.2
	B_1	44.8 efg	43.7 fg	53.1 b	49.6 b-f	47.8
	B_2	47.3 b-g	46.6 c-g	45.6 d-g	48.6 b-f	47.0
	B_3	46.8 b-g	43.4 fg	48.7 b-f	48.2 b-g	46.8
	B_4	49.1 b-f	45.3 d-g	47.3 b-g	46.9 b-g	47.2
	Mean	47.0 bc	45.5 c	48.7 b	49.1 ab	47.5
Mean	B_0	45.3 def	54.1 ab	48.7 cde	49.5 cd	49.4 a
	B_1	45.6 def	44.4 ef	56.7 a	48.8 cde	48.9 ab
	B_2	45.4 def	48.5 cde	45.6 def	48.0 cdef	46.9 bc
	B_3	44.3 ef	43.8 f	51.0 bc	46.5 cdef	46.4 c
	B_4	50.6 bc	45.1 def	49.4 cd	45.9 def	47.7 abc
	Mean	46.2 b	47.2 b	50.3 a	47.7 ab	
$LSD_{5\%}$[a]: Y x G = 2.939, $LSD_{1\%}$: B = 2.280, G = 2.914, B x G = 4.560, Y x B x G = 6.449						

[a] Least significant difference for comparisons between individual means: B; G; Y x G; B x G; Y x B x G indicate B applied main effect (B), genotype main effect (G), interaction of year with genotype (Y x G), interaction of B applied with genotype (B x G), interaction of year with B applied and genotype (Y x B x G).

Table 9. Hull ratio (%) of sunflower genotypes when grown in two consecutive years with five levels of B treatments.

Year	Boron application	Genotype				Mean
		AS-615	S-288	Coban	TR-4098	
2001	B_0	29.8	31.0	30.0	28.7	29.9 bc
	B_1	31.7	31.2	32.3	28.6	31.0 abc
	B_2	29.8	32.3	30.8	27.1	30.0 bc
	B_3	27.6	30.4	29.8	26.4	28.6 c
	B_4	26.6	31.6	29.6	27.0	28.7 c
	Mean	29.1 de	31.3 bc	30.5 cd	27.6 e	29.6
2002	B_0	31.7	36.2	31.3	30.4	32.4 ab
	B_1	35.5	28.9	32.1	31.6	32.0 ab
	B_2	29.7	33.6	30.7	27.8	30.4 bc
	B_3	35.2	35.0	28.7	34.0	33.2 a
	B_4	33.5	34.5	30.7	30.2	32.2 ab
	Mean	33.1 ab	33.6 a	30.7 c	30.8 cd	32.1
Mean	B_0	30.7	33.6	30.7	29.5	31.1
	B_1	33.6	30.1	32.2	30.1	31.5
	B_2	29.8	32.9	30.7	27.4	30.2
	B_3	31.4	32.7	29.3	30.2	30.9
	B_4	30.0	33.0	30.2	28.6	30.4
	Mean	31.1 ab	32.5 a	30.6 bc	29.2 c	
$LSD_{5\%}$[a]: Y x G = 1.913, $LSD_{1\%}$: G = 1.896, Y x B = 2.736						

[a]Least significant difference for comparisons between individual means: G; Y x B; Y x B indicate, genotype main effect (G), interaction of year with B applied (Y x B), interaction of year with genotype (Y x G).

Grain yield

Mean grain yield was found as 3.09 and 3.27 t/ha in 2001 and 2002, respectively. In general, grain yield decreased by the B treatments (except for B_3) compared with the control. Lower grain yield of sunflower with B application could possibly have been due to Fe or Zn deficiency (Table 3) at higher concentrations of B. In both the first and second years, application of 7.5 kg B ha^{-1} increased grain yield, despite of greater in the second year. The increase in grain yield of sunflower by application of low to medium amounts of B indicated that plants require B application (Blamey et al., 1997). Increased seed yield due to B application was reported by Sumathi et al. (2005). But, Renukadevi et al. (2002) observed significant increases in sunflower yield as well as B accumulation with B application. The highest responses (16% increased seed yield) were recorded with soil application of 2.0 kg B ha^{-1}.

Average of years, the highest yield (3.39 t ha^{-1}) was obtained from S-288, whereas the highest yield was obtained AS-615, TR-4098 and Coban with 3.28, 3.03 and 3.02 t ha^{-1}, respectively. The highest seed yield (4.17 t ha^{-1}) was obtained from S-288 genotype at the B_0 rate. The lowest yield (2.72 t ha^{-1}) was obtained from Coban at the B_0 rate. All genotypes had higher grain yield in 2002 than 2001. The highest grain mean yield (3.55 t ha^{-1}) in 2002 was obtained from AS-615. The lowest (2.88 t ha^{-1}) is from Coban in 2001 (Table 7). Grain size was established around anthesis and was partially a response to the supply of assimilates (Andrade, 1995). Yields of S-288 and TR-4098 was reduced by B treatments resulting in smaller seed size and head diameter. In general, seed size and head diameter at B treatments was smaller than B_0 (Table 6). Our results confirmed the findings by Marschner (1997) who determined that B had a very narrow range between deficiency and toxicity, thus it was a difficult nutrient to manage in sunflower production.

S-288 and TR-4098 were considered B efficient genotypes by some researchers (Soylu et al., 2000; Ceyhan et al., 2007). Consequently, S-288 and TR-4098 can be proposed for the B deficiency soils.

Oil yield

As average of two years, the highest oil yield (1.37 t ha^{-1}) was obtained from AS-615. On the other hand, Coban had the lowest oil yield (1.13 t ha^{-1}) (Table 4). AS-615 (1.52 t ha^{-1}) had the highest oil yield in 2002. Generally, increasing B levels decreased oil yield in S-288 and TR-4098 genotypes. Thus, S-288 and TR-4098 can be considered as a tolerant genotype to B deficiency. AS-615 and TR-4098 are sensitive to B deficiency. B application increased the oil yield for AS-615 and TR-4098 genotypes, indicating their sensitivities to B deficiency in

Table 10. B concentration of the leaf (mg kg^{-1}) of sunflower genotypes when grown in two consecutive years with five levels of B treatments.

Year	Boron application	Genotype				Mean
		AS-615	S-288	Coban	TR-4098	
2001	B_0	71.87	68.43	70.10	66.54	69.23
	B_1	75.32	71.04	77.87	69.62	73.46
	B_2	83.54	77.34	81.78	72.36	78.75
	B_3	92.72	78.80	82.50	75.93	82.49
	B_4	94.17	85.56	89.57	80.12	87.36
	Mean	83.52	76.24	80.36	72.91	78.29
2002	B_0	72.70	67.55	70.31	65.96	69.13
	B_1	75.92	71.64	79.97	69.72	74.31
	B_2	82.51	78.82	81.60	71.77	78.68
	B_3	89.22	80.67	83.36	78.41	82.92
	B_4	92.95	84.61	90.12	82.06	87.44
	Mean	82.66	76.66	81.07	73.58	78.49
Mean	B_0	72.29 i	67.99 jk	70.20 ij	66.25 k	69.18 e
	B_1	75.62 h	71.34 i	78.92 e-g	69.67 ij	73.89 d
	B_2	83.03 cd	78.08 f-h	81.69 de	72.06 i	78.71 c
	B_3	90.97 ab	79.74 e-g	82.93 cd	77.17 gh	82.70 b
	B_4	93.56 a	85.09 c	89.85 b	81.09 d-f	87.40 a
	Mean	83.09 a	76.45 c	80.72 b	73.25 d	
$LSD_{1\%}$[a]: B = 1.571, G = 1.562, B x G = 3.142						

[a]Least significant difference for comparisons between individual means: B; G; B x G indicate B applied main effect (B), genotype main effect (G), interaction of B applied with genotype (B x G).

a similar way to that for seed yield. Similarly, Sumathi et al. (2005) reported that B application in B deficient soils increased oil yields of sunflower cultivars.

Oil content

Mean oil content was 39.4 and 40.4% during 2001 and 2002, respectively. Based on mean of years and B applications, the average oil contents of genotypes ranged from 35.9 in Coban to 44.2% inTR-4098. The maximum oil content (41.6%) was obtained from B_0 level. Compared to the control, generally, oil content decreased with B levels in genotypes (Table 5). After pollination and seed set, the protein is formed and thereafter oil synthesis starts (Miralles et al., 1997). Thus, high levels of B particularly after anthesis or during grain filling may reduce seed oil content.

Plant height

The maximum plant height was observed in TR-4098 with 124.3 cm, while the minimum plant height was found in AS-615 with 108.3 cm. Genotypes showed significantly ($P < 0.05$) responses to B treatment. Compared to the control, B_1 level increased plant height (3%) in genotypes, but generally, plant height decreased at other B applications (Table 6). Ceyhan et al. (2007) also found significant effects of B application for plant height in chickpea.

Head diameter

As average of years, the largest head diameter (14.8 cm) was obtained from Coban, followed by AS-615, TR-4098 and S-288 with 14.2, 14.1 and 13.7 cm, respectively (Table 7). Increasing B level decreased diameter of head. A major effect of B nutrition was reported to be on seed set (Blamey, 1976). B applications significantly increased seed set rates AS-615 and Coban genotypes (Table 7). An increase on seed set was parallel to the rates of application of B or the contents in the leaves of the sunflower. This contributed to the improvement of pollen development and growth from an application of B (Dell and Huang, 1997). The capitulum's was often mal-formed with poor seed set (Blamey, 1976), causing reductions in seed yield (Table 3).

1000 seed weight

The mean over two years, 1000-seed weight of the Coban (50.3 g) had higher seed weight than the other cultivars. The maximum 1000 seed weight (49.4 g) was

obtained at B_0 treatment and this was significantly higher than in the other B applications. B levels gradual decreased 1000 seed weight (Table 8). Subedi et al. (1997) reported reductions in thousand seed weight of some bread wheat genotypes following B application. These results were in agreement with ours.

Hull ratio

Hull ratio was 29.6 and 32.1% during 2001 and 2002, respectively. Based on mean of years and B applications, the average hull ratios of genotypes ranged from 29.2 in Coban to 32.5% in S-288. The highest hull ratio (33.6%) was obtained from S-2888. Compared to the control, generally, oil content decreased with B_1 levels in genotypes (Table 9).

B concentration of the leaf

Average of the years and B applications, the highest B concentration of the leaf was obtained from (83.09 mg kg^{-1}) AS-615, whereas the other genotypes (Coban, S-288 and TR-4098) gave 80.72, 76.45 and 73.25 cm, respectively. The most evident effects of B treatment on the B concentration of the leaf were shown by AS-615, Coban, S-288 and TR-4098 with increases by 29, 23, 25 and 22% at B_4, respectively (Table 10), compared to control plots.

Conclusions

The response of sunflower to B application was not significant for seed yield in this study. AS-615 and Coban responded positively to B fertilization in field experiments while the lowest positive response was obtained from the S-288 and TR-4098 cultivars. S-288 and TR-4098 can be grown successfully without B fertilization due to its tolerance to B deficient. The other genotypes were found to be sensitive to B deficiency and these cultivars must be fertilized with B for adequate yield.

ACKNOWLEDGEMENTS

The financial supports of the Turkish State Planning Organization (DPT) (Project No: 1999K120560) and the Selcuk University Scientific Research Projects (BAP) are gratefully acknowledged.

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