Turk J Agric For
29 (2005) 275-286

Responses of Irrigated Durum and Bread Wheat Cultivars to Boron Application in a Low Boron Calcareous Soil

Süleyman SOYLU[1], Bayram SADE[1], Ali TOPAL[1], Necdet AKGÜN[1], Sait GEZGİN[2],
Erdoğan Eşref HAKKI[1], Mehmet BABAOĞLU[1] *
[1]Department of Field Crops, Faculty of Agriculture, University of Selçuk, 42031, Kampüs, Konya - TURKEY
[2]Department of Soil Science and Plant Nutrition, Faculty of Agriculture, University of Selçuk, 42031, Kampüs, Konya - TURKEY

Received: 20.07.2004

Abstract: Cereals are sensitive to micronutrient problems. Central Anatolian soils show great variation with respect to both deficiency and toxicity of boron (B). Hence, screening of major wheat cultivars grown in the region with respect to their sensitivity to B is of great importance for the area. Six durum (*Triticum durum* L. cvs. Kızıltan-91, Ç-1252, Selçuklu-97, Kunduru-1149, Yılmaz-98 and Çakmak-79) and 6 bread (*Triticum aestivum* L. cvs., Gün-91, Kınacı-97, Göksu-99, Türkmen, Bezostaja-1 and Sultan-95) wheat cultivars were studied in field experiments for their responses to B application when grown in soils low in extractable B (0.19 mg B kg^{-1}) during the 2000-2001 and 2001-2002 growing seasons. Agronomic characteristics such as grain yield, sterility, number of grains per spike, number of spikes per m^2, thousand kernel weight and flag leaf B concentration were investigated as affected by the application of 3 kg B ha^{-1} as a spray of boric acid (H_3BO_3) to soil. Agronomic characteristics of bread and durum wheat cultivars varied remarkably with the application of B, its deficiency in the soil, and seasonal conditions. B application increased the grain yield by 9.6% on average in durum wheat and by 10.9% in bread wheat. Kızıltan-91 and Yılmaz-98 among durum wheat cultivars, and Gün-91 and Bezostaja-1 among bread wheat cultivars were the most sensitive to B deficiency having the highest grain yields when treated with B. On the other hand, Ç-1252 and Çakmak-79 (durum wheat), Kınacı-97 and Sultan-95 (bread wheat) showed tolerance to B deficiency since their high yield capacities were not affected by B deficiency. This study revealed that B deficiency can depress the yield in cereals to a great extent. Soil B analyses before the cultivation of cereals are, therefore, required to prevent yield losses. In addition, cultivars showing tolerance to B deficiency can be used in breeding programs aiming at the development of B-efficient cultivars.

Key Words: Boron deficiency, bread and durum wheat, interactions, yield attributes

Düşük Bor Oranına Sahip Kireçli Topraklarda Sulu Şartlarda Yetiştirilen Makarnalık ve Ekmeklik Buğdayların Bor Uygulamasına Tepkileri

Özet: Tahıllar mikroelementlerin hem toksitesine hem de noksanlığına hassas bitkilerdir. Orta Anadolu toprakları bor (B)'un noksanlığı ve toksitesi açısından geniş bir varyasyon göstermektedir. Bu nedenle bölgede yaygın olarak yetiştirilen buğday çeşitlerinin B'a karşı hassasiyetlerinin belirlenmesi ekim için uygun çeşit seçiminde gerekli görülmektedir. Altı makarnalık (*Triticum durum* L. cvs. Kızıltan-91, Ç-1252, Selçuklu-97, Kunduru-1149, Yılmaz-98 and Çakmak-79) ve 6 ekmeklik (*Triticum aestivum* L. cvs., Gün-91, Kınacı-97, Göksu-99, Türkmen, Bezostaja-1 and Sultan-95) buğday çeşidinin elverişli B miktarının düşük (0.19 mg B kg^{-1}) olduğu topraklarda 2000-2001 ve 2001-2002 ekim dönemlerinde kurulan tarla denemelerinde B uygulamasına olan tepkileri araştırılmıştır. Toprağa sprey halinde borik asit (H_3BO_3) olarak uygulanan 3 kg ha^{-1} B'un dane verimi, başak sterilitesi, başakta dane sayısı, m^2'de başak sayısı, bin dane ağırlığı ve bayrak yaprağındaki B konsantrasyonuna etkileri incelenmiştir. Agronomik karakterler tüm çeşitlerde bor uygulaması, toprakta B noksanlığı ve iklimsel şartlardan geniş ölçüde etkilenmiştir. Çeşitler B uygulamasına tepkileri yönünden önemli farklılıklar göstermiştir. B uygulaması ortalama olarak makarnalık buğdaylarda %9.6, ekmeklik buğdaylarda ise %10.9 dane verim artışına yol açmıştır. Makarnalık buğdaylardan Kızıltan-91 ve Yılmaz-98, ekmeklik buğdaylardan ise Gün-91 ve Bezostaja-1, B eksikliğine en hassas bitkiler olarak görülmüştür. Bu çeşitlerde B uygulamasıyla yüksek verim elde edilmiştir. Diğer taraftan, Ç-1252 ve Çakmak-79 (makarnalık buğday), Kınacı-97 ve Sultan-95 (ekmeklik buğday) eksiklik şartlarında verim kaybı göstermeyerek bora tolerans göstermiştir. Bu çalışmada, Orta Anadolu koşullarında B eksikliğinin tahıllarda verimi düşürebileceği gösterilmiştir. Dolayısıyla, verim azalmasını önlemek için tahıl üretimi öncesinde toprakta B analizi gereklidir. İlave olarak, bu tür çalışmalar sonucu B eksikliğine toleranslı genotiplerin B-etkin çeşit geliştirme yolunda ıslah programlarında kullanılabilecekleri belirlenmiştir.

Anahtar Sözcükler: Bor noksanlığı, ekmeklik ve makarnalık buğday, interaksiyon, verim

* Correspondence to: mbabaogl@selcuk.edu.tr

Introduction

Wheat is the most widely cultivated crop in Turkey. The Central Anatolian region has a total cereal cultivation area of around 6.5 million ha, constituting 40% of the total Turkish cereal acreage (Agricultural Structure and Production, 2001). The soils in Central Anatolia are typical of those in arid and semi-arid regions. They have low organic matter, high free-lime content, high pH, and usually a fine texture. These properties are all well-known factors affecting the availability of micronutrients (Kalaycı et al., 1998). For example, Gezgin et al. (2002) reported significant positive correlations between extractable boron (B) levels of soils and organic matter content ($r = 0.29$, $P < 0.01$), electrical conductivity (EC) ($r = 0.56$, $P < 0.01$), and clay content ($r = 0.23$, $P < 0.01$). In contrast, significant negative correlations were registered between extractable B levels of the soils and lime content ($r = -0.24$, $P< 0.01$), sand content ($r = -0.24$, $P < 0.01$) and Mn content ($r = -0.23$, $P < 0.01$). However, wide spatial variations were observed with respect to both deficiencies and toxicities of B and some other micronutrients (Gezgin et al., 2002). These researchers surveyed B contents of 898 soil samples representing Central Southern Anatolian soils. According to the survey, when the critical soil B level for cereal crops is less than 0.5 mg of B kg^{-1} soil (Keren and Bingham, 1985), 26.6% of soils in the region contain B below this critical value. However, according to Reisenauer et al. (1973) soils that contain less than 1.0 mg of B kg^{-1} may not supply sufficient B to support normal plant growth. According to this criterion, 51.5% of the soils in the region would be low in available B, indicating that the region requires extensive investigations with respect to plant available B levels in soil and plant species that may tolerate B deficiency without reducing yield. Findings for the latter will also guide breeders in selecting high-yielding B-efficient and/or B-tolerant genotypes.

Plant species differ in their capacity to take up B, even when they are grown in the same soil. These differences generally reflect different B requirements for growth. Cereals are considered to be sensitive crops to B (Jamjod and Rerkasem, 1999). Significant genotypic variations were reported among cereals with respect to their sensitivity to B in countries such as China, India, Nepal, Thailand and Turkey (Tandan and Nagvi, 1992; Subedi et al., 1993; Yau et al., 1995; Rerkasem and Jamjod, 1997; Jamjod and Rerkasem, 1999; Topal et al., 2002). A wheat plant can tolerate up to 2 mg of B kg^{-1} in soil with negative effects of B at higher concentrations (Gupta et al., 1985). However, the effect of B deficiency on crop plants can vary based on their sensitivities to B (Dell and Huang, 1997). B deficiency causes grain set failure in bread wheat and barley (Rerkasem and Jamjod, 1997). It lowers the number of grains per spike, grain yield and grain set index in wheat via suppression of the growth of flowering organs without any apparent effect on number of spikes per m^2, number of spikelets per spike, average size of the spike, or component florets per spikelet (Rerkasem et al., 1993; Rerkasem et al., 1997). B deficiency was considered to be the main reason for sterility in susceptible wheat genotypes since B application reduced sterility from 42.6% to 4.5% (Subedi et al., 1997). Since B has important effects on reproductive organs that affect grain yield, the main effects of B deficiency are usually expressed during reproductive development rather than in vegetative plant parts (Rerkasem and Jamjod, 1997; Huang et al., 2000). Jamjod et al. (2004) categorized B-efficient bread wheat genotypes based on their sterility rates in low-B soils. Below a critical B level, B-inefficient genotypes were completely sterile and set no, or just a few, grains, while B-efficient genotypes set grain normally without any decrease in grain yield.

There have been various efforts to screen large numbers of wheat genotypes for their responses to B deficiency (Rerkasem and Jamjod, 1997; Subedi et al., 1997) aiming at finding genotypes for breeding B deficiency tolerant genotypes combined with high yield capacities (Jamjod and Rerkasem, 1999). However, globally, durum wheat is the least screened so far for its B response.

The objective of this study was to investigate the effect of B application on yield and some of the yield attributes of the most commonly cultivated durum wheat and bread wheat cultivars (6 cultivars of each) under irrigated conditions, in a typical Central Anatolian soil low in extractable B and with relatively high lime content.

Materials and Methods

The field experiments were carried out in soil containing 0.19 mg of B kg^{-1} (Table 1) extracted using 0.01 M Mannitol + 0.01 M $CaCl_2$ solution (Cartwright et al., 1983) before reading in ICP-AES (Varian-Vista

Table 1. Selected physical and chemical properties of topsoil samples (0-30 cm depth) collected from the experimental area (mean of soil samples collected before sowing each year).

Properties	Mean	Properties	Mean
pH	7.6	Mg (me 100 g^{-1})	5.3
$CaCO_3$ (%)	20.7	K (me 100 g^{-1})	0.6
E.C (µS cm^{-1})	94	Na (me 100 g^{-1})	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^{-1})	20.2	Fe (mg kg^{-1})	0.4

Model) during the 2000-2001 and 2001-2002 growing seasons at the Research Institute of Rural Affairs, Konya, Turkey. Other soil characteristics are given in Table 1. Extractable B levels of the experimental soils were low according to the critical levels indicated by Reisenauer et al. (1973) and Keren and Bingham (1985) for cereal crops. Six durum wheat (*Triticum durum* L. cvs. Kızıltan-91, Ç-1252, Selçuklu-97, Kunduru-1149, Yılmaz-98 and Çakmak-79) and 6 bread wheat (*Triticum aestivum* L. cvs, Gün-91, Kınacı-97, Göksu-99, Türkmen, Bezostaja-1 and Sultan-95) cultivars were studied. These varieties are the most popular registered varieties currently planted in Central Anatolia.

The experiments were performed in a split plot design in randomized complete blocks with 3 replications. B applications were administered to main plots where the sub-plots contained plant cultivars. Before sowing in both years, B at a rate of 3 kg ha^{-1} was sprayed onto the soil surface using 1.125% H_3BO_3 solution, followed by incorporation to a 0-20 cm depth of soil prior to sowing. These plots were designated 'B+' (boron applied) plots and the control plots were designated 'B-' plots, which were sprayed with water only.

Traditional fertilization practices were followed. Plots were sown on October 26 in the first year, and on October 12 in the second year using a sensitive 8-row experimental plot drill in 8 rows (20 cm apart) in plots 8 m long (1.6 x 8 = 12.8 m^2) at a sowing rate of 500 seeds m^{-2}.

Routine management practices were followed. Plots were sprinkler irrigated 3 times, a) after sowing, b) during tillering, and c) just before spike emergence. Crops were harvested with a plot harvester on 18th July in both years. Harvested area (HA) of a plot was 9.6 m^2 of the internal part after removing the 2 outer rows.

Total amounts of rainfall (September-July) were 191 mm for the first season and 375 mm for the second season. Seasonal average temperatures and average relative air humidities for both seasons were 11.6 °C and 57.1% and 10.2 °C and 66.0%, respectively. Monthly climatic data in comparison with the 60-year averages are shown in Figure 1.

The following measurements were obtained each year:

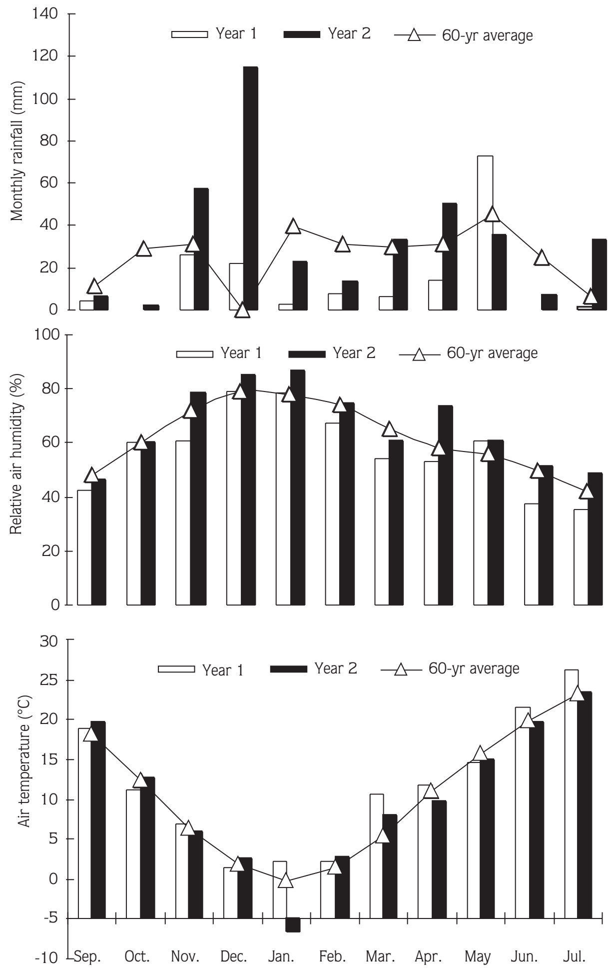

Figure 1. Total monthly rainfall, relative air humidity and mean air temperature during the 2000-2001 and 2001-2002 growing seasons and the 60-year average for the experimental site at Konya, Turkey.

Grain yield: At maturity, plants in each HA were collectively harvested, grains were separated and the data were expressed as kg ha^{-1}.

Sterility: At maturity, 20 spikes per entry were sampled and the number of florets and grains per spike were counted. Number of grains per first and second floret of the 10 central spikelets of each spike were also counted. Sterility was estimated as described by Rerkasem et al. (1991) and Subedi et al. (1997) as sterility (%) = [(20- total number of grains per first + second florets of 10 central spikelets)/20] x 100

Number of grains per spike: Spikes were collected from 20 randomly chosen main stems in each plot at maturity and individual grains were then manually separated and counted.

Number of spikes per m^2: Spike forming plants in a randomly selected area of 1 m^{-2} within the HA were counted.

Thousand kernel weight (TKW): TKW was determined by weighing 100 seeds in 4 replicates from grain yield samples.

B concentration of flag leaf: During the heading stage, 20 flag leaves from main shoots of each plot were combined as 1 sample, washed with deionized water and then oven dried at 70 °C for 48 h for dry weights. Samples were finely ground and 0.5 g of plant material was digested with concentrated HNO_3 in a microwave system. The B in extracts was analyzed using an ICP-AES (Varian-Vista Model) device (Nyomora et al., 1997).

All data were analyzed as a split plot design using a computerized statistical software package (MSTATC).

Results

Grain yield

Durum wheat cultivars showed significantly positive genotypic responses to B application. Averaged across all applications, B application increased grain yield by 9.6% but with large variations (between -10.7% and 37.9%) among the cultivars (Table 2). The highest increases were obtained from Kızıltan-91, Yılmaz-98, Kunduru-1149 and Selçuklu-97, whereas grain yields of Çakmak-79 and Ç-1252 were depressed by B application. Yılmaz-98, Selçuklu-97, Çakmak-79 and Kızıltan-91 were the highest yielding cultivars with respect to their overall genotypic means (4530, 4115, 3930 and 3855 kg ha^{-1}, respectively).

In the second year, higher grain yields were obtained than in the first year. B application reduced the grain yields of Çakmak-79 and Ç-1252 by 24% and 19%, respectively, while the other durum wheat cultivars gave 5%-40% higher grain yields in B applied plots, with the highest increase in Kızıltan-91, followed by Kunduru-1149 and Yılmaz-98 (Table 2).

Among B applied plots, Ç-1252 was the lowest yielding (3275 kg ha^{-1}) cultivar in the average of the years. However, among the control (B-) plots, the highest yield (4155 kg ha^{-1}) was obtained from Çakmak-79, while the lowest yield (3245 kg ha^{-1}) was from Kızıltan-91 (Table 2).

All bread wheat cultivars, except for Kınacı-97, exhibited a positive significant grain yield response (3.5%-32.9%) to B application (Table 3). The highest positive responses were obtained from Bezostaja-1, Gün-91, Göksu-99, and Türkmen cultivars while the lowest positive response was obtained from the Sultan-95 cultivar. Gün-91 (4632 kg ha^{-1}) was the highest yielding and Bezostaja-1 was the lowest yielding (3895 kg ha^{-1}) cultivar (Table 3).

B application x cultivar, and year x B application x cultivar interactions were significant in both durum and bread wheat varieties. In bread wheat, year x cultivar interaction was also significant for grain yield (Tables 2 and 3).

Considering significant ($P < 0.05$) B application x cultivar interaction, Yılmaz-98, Kızıltan-91 and Selçuklu-97 were the highest yielding durum wheat cultivars in B applied plots whereas the yields of Ç-1252 and Çakmak-79 were lower (Table 2). Significant ($P < 0.05$) year x B application x cultivar interaction (Table 2) showed that Yılmaz-98, Kızıltan-91, Selçuklu-97 and Kunduru-1149 were the durum wheat cultivars that yielded best in the second year when B was applied, whereas B application reduced the grain yields of Çakmak-79 and Ç-1252 in the second year. On the other hand, Çakmak-79, Yılmaz-98 and Selçuklu-97 were the highest yielding cultivars for the second year in control plots, with Kızıltan-91 and Kunduru-1149 placed in the third group after Ç-1252. Cultivars exhibited more homogeneous responses to B application in the first year although they had much lower yield levels than in the second year. In the first year,

Table 2. Yield and yield components of durum wheat cultivars as affected by B application.

Cultivars[a]	2000-2001		2001-2002		Mean		Overall genotypic means	[b]Mean variation (%)
	B-	B+	B-	B+	B-	B+		
	Grain yield (kg ha^{-1})							
Yılmaz-98	2530 h	3880 fg	5580 abc	6140 a	4055 bcd	5010 a	4532 a	23.5
Kızıltan-91	2070 h	2770 h	4420 def	6180 a	3245 e	4475 ab	3860 ab	37.9
Selçuklu-97	2410 h	2770 h	5510 abc	5770 ab	3960 b-e	4270 abc	4115 ab	7.8
Kunduru-1149	2180 h	2370 h	4540 c-f	5390a-d	3360 de	3880 bcd	3620 b	15.5
Çakmak-79	2370 h	2880 gh	5940 ab	4540 c-f	4155 bc	3710 cde	3932 ab	-10.7
Ç-1252	2290 h	2450 h	5050 b-e	4100 ef	3670 cde	3275 e	3472 b	-10.8
Mean	2310	2850	5170	5350	3740	4100	3920	9.6
$LSD_{1\%}$ C = 705.5; $LSD_{5\%}$ B x C = 745.7, Y x B x C = 1055								
	Sterility (%)							
Yılmaz-98	3.2 c	1.7 c	2.5 c	1.7 c	2.8	1.7	2.3	-41.0
Kızıltan-91	9.8 ab	5.2 bc	2.0 c	0.5 c	5.9	2.8	4.4	-51.7
Selçuklu-97	2.9 c	5.5 bc	2.2 c	1.7 c	2.5	3.6	2.8	42.1
Kunduru-1149	12.4 a	3.0 c	0.8 c	3.8 c	6.6	3.4	5.0	-48.6
Çakmak-79	5.7 bc	3.0 c	2.2 c	3.0 c	4.0	3.0	3.5	-24.4
Ç-1252	2.5 c	1.7 c	0.8 c	1.3 c	1.7	1.5	1.6	-9.6
Mean	6.1	3.3	1.8	2.0	3.9	2.7	3.3	-31.9
$LSD_{5\%}$ Y x B x C = 5.29								
	Number of spikes per m^2							
Yılmaz-98	361	419	435	487	398 b-f	453 ab	426 ab	13.8
Kızıltan-91	361	416	398	480	380 c-f	448 ab	414 ab	17.9
Selçuklu-97	413	384	452	448	433 abc	416 a-d	424 ab	-3.9
Kunduru-1149	344	308	372	367	358 def	338 f	348 c	-5.8
Çakmak-79	381	425	571	430	476 a	427 abc	452 a	-10.1
Ç-1252	396	308	421	390	408 b-e	349 ef	379 bc	-14.5
Mean	376	377	442	434	409	405	407	-0.9
$LSD_{1\%}$ C = 63.3; $LSD_{5\%}$ B x C = 66.9								
	TKW (g)							
Yılmaz-98	43.8	46.9	52.3	52.7	48.1 bc	49.8 ab	48.9 a	3.7
Kızıltan-91	41.0	42.4	48.2	52.5	44.6 fgh	47.5 b-e	46.0 b	6.4
Selçuklu-97	36.0	42.3	49.3	48.7	42.7 h	45.5 c-g	44.1 b	6.6
Kunduru-1149	45.6	48.3	50.0	54.5	47.8bcd	51.4 a	49.6 a	7.5
Çakmak-79	40.0	39.9	49.5	46.5	44.8 e-h	43.2 gh	44.0 b	-3.4
Ç-1252	41.0	40.2	53.0	50.3	47.0 c-f	45.2 d-h	46.1 b	-3.7
Mean	41.2	43.3	50.4	50.9	45.8	47.1	46.4	2.8
$LSD_{1\%}$ C = 2.62; $LSD_{5\%}$ B x C = 2.77								

B-= Control, B+= Boron application.

LSD = Least significant difference for comparisons between individual means; C; B x C; Y x C; Y x B x C indicates cultivar (C) main effect, interaction of B application (B) with cultivars, interaction of year (Y) with cultivar and the interaction of year with B application and cultivar.

[a] Cultivars are sorted in decreasing order of significance where appropriate.

[b] Relative performance of cultivars calculated as %: (mean B+ value/mean B- value)-1 x 100 (Kalaycı et al., 1998).

Data for number of grains per spike were excluded from the table due to insignificant variations/responses of cultivars to applications.

Table 3. Yield and yield components of bread wheat cultivars as affected by B application.

Cultivars[a]	2000-2001 B-	2000-2001 B+	2001-2002 B-	2001-2002 B+	Mean B-	Mean B+	Overall genotypic means	[b]Mean variation (%)
	Grain yield (kg ha^{-1})							
Gün-91	2810 ij	3820 gh	5770 bcd	6130 ab	4290 bc	4975 a	4632 a	16.0
Türkmen	3100 i	3530 ghi	5540 b-f	5940 abc	4320 bc	4735 ab	4527 ab	9.6
Göksu-99	2980 ij	4060 g	5280 def	5370 c-f	4130 bc	4715 ab	4422 ab	14.2
Kınacı-97	3100 i	3300 hi	5580 b-e	4900 f	4340 bc	4100 c	4220 bc	-5.5
Sultan-95	3120 i	3160 i	5040 ef	5290 def	4080 c	4225 bc	4152 bc	3.5
Bezostaja-1	1790 k	2400 jk	4900 f	6490 a	3345 d	4445 abc	3895 c	32.9
Mean	2820	3380	5350	5680	4085	4530	4300	10.9
$LSD_{1\%}$ C = 432.7, B x C = 612.1, Y x C = 612.1; LSD5% Y x B x C = 646.9								
	Number of grains per spike							
Gün-91	31.8	43.4	37.3	40.5	34.6 c	41.9 a	38.2 ab	21.3
Türkmen	31.8	32.7	35.9	33.7	33.8 c	33.2 c	33.5 c	-1.9
Göksu-99	42.8	38.2	38.9	42.8	40.9 ab	40.5 ab	40.7 a	-0.8
Kınacı-97	34.0	33.8	37.6	39.1	35.8 c	36.4 bc	36.1 bc	1.7
Sultan-95	42.1	39.9	39.5	33.4	40.8 ab	36.7 bc	38.7 ab	-10.1
Bezostaja-1	31.4	33.3	36.8	33.4	34.1 c	33.4 c	33.7 c	-2.1
Mean	35.7	36.9	37.7	37.2	36.7	37.0	36.8	0.8
$LSD_{1\%}$ C = 4.36; $LSD_{5\%}$ B x C = 4.60								
	Number of spikes per m^2							
Gün-91	452	389	493	493	472	441	457 ab	-6.6
Türkmen	442	362	597	588	519	475	497 a	-8.5
Göksu-99	414	452	603	527	509	490	499 a	-3.8
Kınacı-97	433	411	490	487	462	449	455 ab	-2.8
Sultan-95	488	402	532	523	510	462	486 a	-9.3
Bezostaja-1	338	335	435	477	386	406	396 b	5.0
Mean	428	392	525	516	476	454	465	-4.7
$LSD_{1\%}$ C = 69.19								
TKW (g)								
Gün-91	29.1 mn	32.7 klm	41.1 bc	43.0 ab	35.1	37.8	36.5 b	7.8
Türkmen	33.8 i-k	34.7 h-l	40.7 bcd	39.9 b-e	37.2	37.3	37.3 ab	0.2
Göksu-99	25.7 no	31.4 lm	38.5 c-g	38.2 c-h	32.1	34.8	33.5 c	8.5
Kınacı-97	33.2 jkl	35.0 g-l	38.8 c-f	37.4 d-l	36.0	36.2	36.1 b	0.6
Sultan-95	27.6 no	25.4 o	33.0 jkl	33.4 jkl	30.3	29.4	29.9 d	-2.9
Bezostaja-1	36.3 f-k	36.5 e-j	39.9 b-e	45.9 a	38.1	41.2	39.7 a	8.2
Mean	30.9	32.6	38.7	39.6	34.8	36.1	35.5	3.8
$LSD_{1\%}$ C = 2.42, Y x C = 3.42; $LSD_{5\%}$ Y x B x C = 3.62								

B-= Control, B+= Boron application.

LSD = Least significant difference for comparisons between individual means; C; B x C; Y x C; Y x B x C indicates cultivar (C) main effect, interaction of B application (B) with cultivars, interaction of year (Y) with cultivar and the interaction of year with B application and cultivar

[a] Cultivars are sorted in decreasing order of significance where appropriate.

[b] Relative performance of cultivars calculated as %: (mean B+ value/mean B- value)-1 x 100 (Kalaycı et al., 1998).

Data for sterility rates were excluded from the table due to insignificant variations/responses of cultivars to applications.

Yılmaz-98 was the only cultivar with clear variation in B applied plots whereas no variation was observed among cultivars in the control plots.

B application x cultivar ($P < 0.01$), year x cultivar ($P < 0.01$) and B application x year x cultivar ($P < 0.05$) (Table 3) interactions had significant effects on the grain yields of bread wheat cultivars. Gün-91, Türkmen, Göksu-99 and Bezostaja-1 gave the highest yields in B applied plots, followed by Sultan-95 and Kınacı-97 (Table 3), whereas all cultivars except for Sultan-95 and Bezostaja-1 (in decreasing order) provided similar yields in the control plots. Considering significant ($P < 0.01$) year x cultivar interactions, Gün-91, Türkmen and Bezostaja-1 were ranked in the first statistical group in the second year, followed by other cultivars with various degrees of variations in the same year. As revealed by significant ($P < 0.05$) year x B application x cultivar interactions (Table 3) Bezostaja-1, Gün-91 and Türkmen exhibited higher grain yields in the second year when B was applied, whereas the grain yield of Kınacı-97 was reduced by B application in the same year, although this cultivar was, together with Gün-91 and Türkmen, one of the best yielding cultivars in the control (B-) plots.

Similar to the case of durum wheat, B application generally increased yields of bread wheat cultivars in the first year where Gün-91, Türkmen and Göksu-99 were the leading cultivars in grain yield. Interestingly Bezostaja-1 was the lowest yielding cultivar in both B applied (B+) and control (B-) plots in the first year (Table 3). For the first year, Sultan-95 showed no response to B application.

Sterility

As the average of overall genotypic means, sterility rates ranged between 1.6% and 5.0% in durum wheat (Table 2).

The year x B application x cultivar interaction was significant ($P < 0.05$) for sterility in durum wheat. The highest sterility rates among control plants were exhibited by Kunduru-149 (12.4%) and Kızıltan-91 (9.8%) in the first year, whereas Ç-1252 (2.5%), Selçuklu-97 (2.9%) and Yılmaz-98 (3.2%) gave the lowest sterility rates. When B was applied, cultivars generally produced lower rates of sterility in the first year. In the second year, which provided better growing conditions, all cultivars showed low and comparable rates of sterility when B was applied. Although not significant, mean % variations in sterility as affected by B application ranged between 42.1% (Selçuklu-97) and –51.7% (Kızıltan-91).

Bread wheat varieties showed no significant responses to applications with respect to sterility rates, and hence the data were excluded from Table 3.

Number of grains per spike

There were insignificant differences in numbers of grains per spike between durum wheat cultivars with respect to average of years and B application (data not shown). However, for this character, bread wheat cultivars varied significantly in terms of the mean of years and overall genotypic means (Table 3). In addition, a significant B application x cultivar interaction was found only in bread wheat cultivars. For instance, the number of grains per spike in Gün-91, for the mean of years, increased from 34.6 to 41.9 in B applied plots. This situation was the opposite in Sultan-95 in which the number of grains per spike was reduced, from 40.8 to 36.7, when B had been applied (Table 3). In terms of overall genotypic means, the number of grains per spike varied between 40.7 (Göksu-99) and 33.5 (Türkmen) (Table 3).

Number of spikes per m^2

B application significantly increased the number of spikes per m^2 in Kızıltan-91 (17.9%) and Yılmaz-98 (13.8%), but its effect was negative in Çakmak-79 and Ç-1252 (-10.1% and -14.5%, respectively) (Table 2). The B application x cultivar interaction was significant in this character in durum wheat. In terms of overall genotypic means, the highest number of spikes per m^2 (452) was obtained from Çakmak-79 followed by Yılmaz-98 (426), Selçuklu-97 (424) and Kızıltan-91 (414), while the lowest and statistically different mean value (348) was from Kunduru-1149 (Table 2). Genotypic variations in the number of spikes per m^2 as affected by B application were between 5% and –9.3% as the average of years (Table 3) for the bread wheat cultivars.

Thousand Kernel Weight (TKW)

TKW showed significant variations (-3.7% for Ç-1252 to 7.5% for Kunduru-1149) between the durum wheat cultivars as affected by B application. Kunduru-1149 and Yılmaz-98 had the highest TKWs in terms of average of B applications and average of cultivars (Table 2).

B application x cultivar interaction had a significant effect on TKWs of durum wheat cultivars, whereas B application and interactions of year x cultivar, and year x B application x cultivar significantly effected on TKWs of bread wheat cultivars (Tables 2 and 3).

Generally, bread wheat cultivars responded well to B application, except for Sultan-95 which exhibited lower (-2.9%) TKWs when treated with B. The highest mean increase (8.5%) in TKW was obtained from Göksu-99 as a result of B application. Bezostaja-1 (39.7 g) and Türkmen (37.3 g) had the highest average TKWs of cultivars that was determined to be statistically significant. Mean TKW (29.9 g) of Sultan-95 was the lowest (Table 3).

Considering significant year x cultivar x B interactions, Bezostaja-1 and Gün-91 gave the highest TKWs in the second year, followed by Kınacı-97, Türkmen and Bezostaja-1 in the first year. The lowest values were from Sultan-95 in both years.

The significant ($P < 0.05$) year x B application x cultivar interaction revealed that Bezostaja-1 and Gün-91 had the highest TKWs in the second year when B had been applied. Again, Bezostaja-1 was the cultivar with the highest TKW in the first year in B applied plots. On the other hand, Gün-91, Bezostaja-1 and Türkmen had high TKWs in the second year in the control plots.

Boron Concentration of the Flag Leaf

B application significantly ($P < 0.01$) increased flag leaf B concentrations in all wheat cultivars (Table 4). In addition, significant B application x cultivar, year x cultivar and year x B application x cultivar interactions were registered in both durum and bread wheat in flag leaf B (Table 4).

Flag leaf B concentrations in durum wheat cultivars varied between 12.2 mg kg^{-1} dry matter (Selçuklu-97) and 16.7 mg kg^{-1} dry matter (Kunduru-1149). Genotypic overall means showed that Kunduru-1149 and Kızıltan-91 contained the highest flag leaf B concentrations among durum wheat cultivars. However, Çakmak-79 had the highest rate of increase in flag leaf B accumulation as a result of B application (Table 4). Considering the B application x cultivar interaction, the highest flag leaf B was found in Kızıltan-91, Çakmak-79 and Kunduru-1149 as the mean of the years, whereas Kızıltan-91 and Çakmak-79 had the highest B concentrations in flag leaves in the first year, as shown by the year x B application x cultivar interaction.

Bread wheat cultivars also showed significant variations with respect to their flag leaf B concentrations as affected by B application. Sultan-95 and Bezostaja-1 contained the highest flag leaf B (14.6 and 15.4 mg kg^{-1}), while Göksu-99 and Kınacı-97 contained the lowest B concentration in their flag leaves (11.9 and 12.2 mg kg^{-1}, respectively).

The year x B application interaction showed that the flag leaf B concentrations were higher in all cultivars in the first year, but all cultivars in the control plots contained similar flag leaf B.

Considering the significant B x cultivar interaction, Kınacı-97, Göksu-99 and Türkmen contained the lowest B contents in their flag leaves in the control plots, whereas the highest flag leaf B concentrations were found in Sultan-95, Bezostaja-1 and Türkmen in B applied plots. The significant year x B application x cultivar interaction showed that the highest flag leaf B was in Sultan-95 in the first year. On the other hand, the significant year x B x cultivar interaction revealed that Kınacı-97 and Göksu-99 (first year) and Türkmen (second year) contained the lowest flag leaf B in the control plots while the highest flag leaf B was found in Sultan-95 and Türkmen in the first year in B applied plots.

Cultivars varied in their flag leaf B concentrations (Table 4). Considering the mean of years and all cultivars, the regression equation for durum wheat flag leaf B concentrations was: $y = 53.23 x^2 - 1665.2 x + 16,691$, where x was flag leaf B concentration (mg kg^{-1}) and y was the grain yield (kg ha^{-1}). For bread wheat, $y = -90 x^2 + 2419.8 x - 11,593$ can indicate the flag leaf B concentration as the mean of years and cultivars. In durum wheat cultivars, flag leaf B concentration was related more to the grain yield ($R^2 = 0.41$) than in the bread wheat cultivars with a weaker relation ($R^2 = 0.15$).

In addition, flag leaf B concentration had a strong relation to higher sterility rates in durum wheat cultivars, indicating that cultivars containing higher flag leaf B (x) also had higher sterility (y) rates in their spikes ($y = 0.1775x^2 - 4.5346 x + 31.384$; $R^2 = 0.81$).

Discussion

Large variations with respect to B response were observed among the durum and bread wheat cultivars that are predominantly grown in Central Anatolia.

Table 4. Flag leaf B concentration of durum (top) and bread wheat (bottom) cultivars as affected by B application.

Cultivars[a]	Flag leaf B concentration (mg kg^{-1})							
	2000-2001		2001-2002		Mean		Overall genotypic means	[b]Mean variation (%)
	B-	B+	B-	B+	B-	B+		
Yılmaz-98	9.6j	14.9d-f	10.5h-j	15.5de	10.1e	15.2bc	12.6bc	50.8
Kızıltan-91	13.7d-h	24.9 a	9.99j	15.3 d-f	11.8de	20.1 a	15.9a	69.9
Selçuklu-97	10.0j	14.4d-f	10.2ij	14.4d-f	10.1e	14.4bc	12.2c	42.6
Kunduru-1149	12.0f-j	19.2bc	14.1d-g	21.6ab	13.0cd	20.4a	16.7a	56.2
Çakmak-79	10.4h-j	23.4a	9.5j	13.5d-i	9.9e	18.4a	14.2b	85.2
Çeşit-1252	12.3e-j	16.6cd	10.9g-j	14.4d-f	11.6de	15.5b	13.6bc	33.2
Mean	11.4	18.9	10.9	15.8	11.1	17.3	14.2	56.1
$LSD_{1\%}$ C = 1.65; B x C = 2.34; Y x C = 2.34; Y x B x C = 3.31								
	Flag leaf B concentration (mg kg^{-1})							
Gün-91	9.7j-m	15.7d-f	12.1g-j	16.7c-e	10.8e	16.2bc	13.5bc	49.0
Türkmen	10.9h-l	19.9ab	7.9m	13.0gh	9.4ef	16.5a-c	12.9cd	75.2
Göksu-99	8.9k-m	17.3cd	9.1k-m	12.3g-j	9.0f	14.8c	11.9d	64.1
Kınacı-97	7.9m	18.1b-d	8.8lm	13.9fg	8.4f	16.0c	12.2d	90.3
Sultan-95	11.5g-k	22.5a	10.2i-m	14.1e-g	10.9e	18.3a	14.6ab	68.0
Bezostaja-1	12.5g-l	17.7b-d	13.1gh	18.4bc	12.9d	18.0ab	15.4a	41.2
Mean	10.2 c	18.5 a	10.2 c	14.7 b	10.2	16.6	13.4	62.6
$LSD_{1\%}$ C = 1.32; B x C = 1.86; Y x B = 0.90; Y x C = 1.86; Y x B x C = 2.64								

B-= Control, B+= Boron application.

LSD = Least significant difference for comparisons between individual means; C; B x C; Y x C; Y x B x C indicates cultivar (C) main effect, interaction of B application (B) with cultivars, interaction of year (Y) with cultivar and the interaction of year with B treatment and cultivar

[a] Cultivars are sorted in decreasing order of significance where appropriate.

[b] Relative performance of cultivars calculated as %: (mean B+ value/mean B- value)-1 x 100 (Kalaycı et al., 1998).

Grain yields of all cultivars were lower in both the control and B applied plots in the first year than in the second year. This may be attributed to the poorer climatic conditions in the first year (Figure 1). Responses of cereals to B deficiency and/or its application have been reported to vary based on environmental conditions (Shorrocks, 1997). Çetin et al. (1999) reported that unsuitable weather conditions such as low rainfall, low relative air humidity and high temperature occurring during spike emergence, grain setting and maturity stages (between March and June, Figure 1) were able to depress the yield and yield attributes, even when plants were grown under irrigated conditions.

It seems that adverse climatic conditions in the first year induced more stress in plants, resulting in the greater variation than in the second year, which provided better climatic conditions for plant growth. In addition, possible interactions of various factors might have resulted in the increased and different genotypic variations in B sensitivity as reported by Rerkasem and Jamjod (1997). Furthermore, when soil moisture is at adequate levels, the solubility of B and its availability to plants will increase, as might have happened in the second year. Again, early inhibition of root growth, as a result of low soil B levels, compared to shoot growth, increases the shoot:root ratio, which further may enhance the susceptibility of plants to environmental stresses such as marginally deficient supplies of other nutrients and water deficit in soil (Dell and Huang, 1997), which in turn negatively affect grain yield. However, there is a great diversity of effects of low B on reproductive growth among species, and within the same species between sites and seasons (Dell and Huang, 1997).

B application was reported to increase plant endurance against various stress conditions such as high light intensity, drought and cold (Cakmak et al., 1995; Marshner, 1995; Cakmak and Römheld, 1997). Higher grain yield increases particularly recorded in the first year, which imposed more environmental stress conditions on plants could be due to the effect of B application.

Among durum wheat cultivars Kızıltan-91 and Yılmaz-98 emerged as the most B sensitive cultivars that gave the highest positive grain yield responses when treated with B. Moreover, Yılmaz-98 was the second high-yielding cultivar when not treated with B, indicating that this cultivar can be successfully grown in low B soils, but that if fertilized with B, it can be the most efficient durum wheat cultivar under such conditions.

Çakmak-79 and Ç-1252 exhibited negative responses to B application, and emerged as B-sensitive cultivars. The sensitivity of Çakmak-79 to B application was also reported by Yau et al. (1995). Therefore, Çakmak-79 can be an indicator cultivar in entries testing B sensitivity (toxicity) of durum wheat genotypes. In addition, this study confirmed that Çakmak-79 was tolerant of low soil B but was still high-yielding. Consequently, Çakmak-79 and Ç-1252 may be proposed for the B-deficient soils of Central Anatolia, unless Yılmaz-98 and Kızıltan-91 are the preferred cultivar and B fertilization is considered.

Kızıltan-91 and Yılmaz-98 (durum wheat), and Bezostaja-1, Gün-91 and Göksu-99 (bread wheat) were the most sensitive cultivars to B deficiency. In contrast, Ç-1252 and Çakmak-79 (durum wheat), Kınacı-97 and Sultan-95 (bread wheat) appeared to be tolerant of B deficiency, since their high yielding capacities were not affected by the deficiency of B. Such genotypes were considered B-efficient genotypes by various researchers (Nable, 1991; Rerkasem and Jamjod, 1997).

Our study showed that the adverse effects of B deficiency on sterility rates were particularly profound among durum wheat cultivars. The negatively significant ($r = -0.570$, $P < 0.01$, durum wheat; $r = -0.754$, $P < 0.01$, bread wheat) relationship between sterility and grain yield in wheat cultivars untreated with B may be an indication of the effect of B deficiency on sterility.

Based on the categorization described by Jamjod et al. (2004), bread wheat cultivars in this study were all B-efficient since there was no significant change in sterility rates in either the control or B applied plots. However, Kunduru-1149 and Kızıltan-91 appeared to be B-inefficient among the durum wheat cultivars, having higher sterility rates in the control plots, especially in the first year because of the unsuitable climatic conditions recorded. In other words, Ç-1252, Selçuklu and Yılmaz-98 were B-efficient durum wheat cultivars due to their lower sterility rates.

The cultivar x B application interaction with respect to the number of spikes per m^2 was significant in durum wheat cultivars. This was evident in Kızıltan-91 and Yılmaz-98, in which B application increased the number of spikes per m^2, indicating their sensitivities to B deficiency in a similar way to that for grain yield. Subedi et al. (1997) reported that the number of spikes per m^2 was not influenced by B application on B-deficient soils in bread wheat, whereas this character was increased by additional B application in durum wheat (Topal et al., 2002). These findings were also in agreement with ours.

In bread wheat, grain yield increases by B application were due to various factors. For instance, higher yield may be attributed to the higher number of spikes per m^2 in Yılmaz-98 and Kızıltan-91 in durum wheat, and to the higher number of grains per spike in Gün-91.

Zada and Afzal (1997) reported that application of B increased TKWs of bread wheat genotypes, whereas Subedi et al. (1997) reported reductions in TKWs of various bread wheat genotypes following B application. Göksu-99, Bezostaja-1 and Gün-91 showed the highest responses to B application for TKWs indicating that these bread wheat cultivars are sensitive to B deficiency. In contrast, cultivars that were tolerant of B deficiency with low or negative responses to grain yield, showed low or negative TKW responses to B application. This indicates that B application can affect TKW positively or negatively depending on the soil B content as well as genotypic differences.

B deficiency symptoms were not observed in control (B-) plants that contained more than 7 mg of B kg^{-1}, which was reported as a critical level for wheat flag leaf (Rerkasem and Loneragan, 1994). However, the significant B application x cultivar interaction was registered for flag leaf B concentrations in all cultivars. The best genotypic responses to B applications were from Kızıltan-91 and Çakmak-79 in durum wheat, and from Kınacı-97 and Türkmen in bread wheat.

Increase in flag leaf B also resulted in an increase (7.8%-37.9% in durum wheat; 3.5%-32.9% in bread wheat) in grain yields of all cultivars, except for Ç-1252 and Çakmak-79 (durum wheat) and Kınacı-97 (bread wheat). A negative response was recorded in the latter cultivars as these gave lower grain yield in addition their higher flag leaf B concentration. The results showed that B concentrations in flag leaves could help in predicting the grain yield of the wheat cultivars studied. However, such data should also be supported by whole plant B analyses.

Conclusion

1. This study revealed that remarkable responses to B deficiency and/or B application were exhibited by the most popular Turkish durum and bread wheat cultivars. The results of this study could be beneficial to cereal breeders, particularly those who are interested in improving their germplasms with high B efficiency.
2. Çakmak-79 and Ç-1252 can be successfully grown without B fertilization due to their tolerance of B deficiency. From this point of view, both cultivars can be considered B-efficient according to the categorization of Jamjod et al. (2004), having high agronomic value. In addition, both cultivars may serve as suitable parental materials for the development of B-efficient genotypes. Cultivars showing sensitivity to B deficiency (e.g., Yılmaz-98, Kızıltan-91 and Kunduru-1149) can be fertilized for adequate crop yield, but fertilization should be based on soil analyses.
3. Among the bread wheat cultivars, Kınacı-97 and Sultan-95 were the most tolerant of B deficiency. However, as a cultivar sensitive to B deficiency, Gün-91 gave grain yields comparable to those obtained from cultivars tolerant of B deficiency, but grown without B application, indicating that this cultivar can also be recommended for cultivation in such B-deficient soils.
4. It was clear that Kızıltan-91 (durum wheat) and Bezostaja-1 (bread wheat) should not be grown in B-deficient soils due to their sensitivity to B deficiency. In both durum and bread wheat cultivars, there was an apparent relation between sensitivity to B deficiency and grain yield increase when treated with B. Grain yield increase in B responsive cultivars resulted from differential contributions of various yield components. In other words, contribution of yield attributes to grain yield in wheat cultivars was genotype specific.
5. Flag leaf B concentration that relates positively to sterility in most cultivars should be taken into account when selecting suitable genotypes for sterility, particularly in high B soils.
6. Yau et al. (1995) suggested that germplasms collected from Algeria, Iraq, Libya, Syria, and the Anatolian Plateau in Turkey should be screened first for B tolerance in durum wheat. The results of our study confirm that Anatolian durum wheat cultivars have large variations with respect to their B responses. Cultivars showing of B tolerance here probably inherited their germplasms from their native Anatolian progenitors during their improvement.

Acknowledgment

The financial support from the Turkish State Planning Organization (DPT) (Project No: 1999 K120560) is gratefully acknowledged.

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