Turkish Journal of Agriculture and Forestry

Volume 27 | Number 6 Article 2

1-1-2003

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Recommended Citation

GÜNEŞ, AYDIN; ALPASLAN, MEHMET; İNAL, ALİ; ADAK, M. SAİT; ERASLAN, FİGEN; and ÇİÇEK, NURAY (2003) "Effects of Boron Fertilization on the Yield and Some Yield Components of Bread and Durum Wheat," *Turkish Journal of Agriculture and Forestry*: Vol. 27: No. 6, Article 2. Available at: https://journals.tubitak.gov.tr/agriculture/vol27/iss6/2

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Turk J Agric For
27 (2003) 329-335

Effects of Boron Fertilization on the Yield and Some Yield Components of Bread and Durum Wheat

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Received: 22.07.2003

Abstract: A greenhouse and a 1-year field study were conducted during the cropping season on the effects of B on yield and some yield components of bread (*Triticum aestivum* L, cv. Bezostaja) and durum (*Triticum durum* L. cv. Kiziltan) wheat cultivars in a B-deficient soil (0.68 mg kg^{-1}, NH_4OAc extractable). Boron was applied as H_3BO_3 at 0, 0.5, 1.0, 1.5, 2.0 and 2.5 mg B kg^{-1} in the greenhouse study and 0, 1.0, 2.0, 3.0, 4.0 and 5.0 kg B ha^{-1} in the field study. Shoot dry weights of Bezostaja and Kiziltan significantly increased regardless of the applied B levels in the greenhouse study. In the field study, grain yield increased from 3668 to 5475 kg ha^{-1} at 4.0 kg B ha^{-1} in Bezostaja and 4668 to 5360 kg ha^{-1} at 2.0 kg B ha^{-1} in Kiziltan. At higher levels of B application, the grain yields of the cultivars decreased. Boron concentration in the shoots and grains of both cultivars, and spike number m^{-2}, spike length, number of sterile spikelets per spike, grain yield per spike and harvest index for Bezostaja, and number of fertile spikelets per spike and number of grain per spike for Kiziltan responded to B fertilization in field conditions. The results of this study show that B fertilization should be taken into consideration in fertilizer recommendations after additional research under different soil, genotype, and environmental conditions.

Key Words: Wheat, boron deficiency, boron fertilization, fertility, sterility

Ekmeklik ve Makarnalık Buğdayda Bor Gübrelemesinin Verim ve Verim Parametreleri Üzerine Etkisi

Özet: Bor (B) noksanlığı olan (0.68 mg kg^{-1}, NH_4OAc ile ekstrakte edilebilir) bir toprakta yetiştirilen Ekmeklik (*Triticum aestivum* L, cv. Bezostaja) ve makarnalık (*Triticum durum* L. cv. Kiziltan) buğdayın verim ve bazı verim komponentlerine borlu gübrelemenin etkisini belirlemek için bir sera ve bir yıllık tarla denemesi kurulmuştur. Bor toprağa sera denemesinde H_3BO_3 olarak 0, 0.5, 1.0, 1.5, 2.0 ve 2.5 mg B kg^{-1}, tarla denemesinde ise 0, 1.0, 2.0, 3.0, 4.0 ve 5.0 kg B ha^{-1} seviyelerinde uygulanmıştır. Sera denemesinde uygulanan B düzeylerine bakılmaksızın B uygulamasıyla Bezostaya ve Kızıltan buğdayının gövde kuru ağırlıkları artmıştır. Tarla denemesinde, 4.0 kg ha^{-1} B uygulamasıyla tane verimi bezostayada 3668 den 5475 kg ha^{-1}' a, kızıltanda ise 4668 den 5360 kg ha^{-1}'a yükselmiştir. Bor'un bu düzeyinden sonra buğday çeşitlerinin tane verimi azalmıştır. Her iki çeşitte de gövde ve tanenin B konsantrasyonu borlu gübrelemeye bağlı olarak artmıştır. Buna ilave olarak B' lu gübreleme ile başak sayısı, başak boyu, başakta steril başakcık sayısı, başakta tane verimi ve hasat indeksi bezostaya buğdayında ve başaktaki fertil başakcık sayısı, başaktaki tane sayısı ise kızıltanda artış göstermiştir. Bu çalışmadan elde edilen sonuçlar gübre tavsiyesinde B' lu gübrelemeye yer verilmesinin yararlı olacağını göstermektedir.

Anahtar Sözcükler: Buğday, bor noksanlığı, bor gübrelemesi, fertilite, sterilite

Introduction

Boron deficiency in crops is more widespread than the deficiency of any other micronutrient in the world (Gupta, 1993). According to Eyuboglu et al. (2002) more than 50% of the soils (in 830 soil samples) of Central Anatolia, which is the major wheat producing area of Turkey, contain lower plant available B than the critical value of 0.5 mg hot water extractable-B kg^{-1}. Adequate B nutrition is critical not only for high yields but also for high quality crops (Brown and Shelp, 1997). B deficiency causes many anatomical, physiological and biochemical changes in plants (Blevins and Lukaszewski, 1998). B has many physiological functions in plants such as sugar transport, cell wall synthesis, reproduction, pollen tube growth, pollen germination, lignification, carbohydrate metabolism, RNA metabolism, respiration, indole acetic acid metabolism (IAA), phenol metabolism, membrane integrity, ascorbate metabolism and oxygen activation (Blevins and Lukaszewski, 1998; Parr and Louhgman, 1983; Cakmak and Römheld, 1997).

The availability of B to plants decreases with increasing soil pH, particularly in calcareous soils and in soils with a high clay content, presumably as a result of the formation of $B(OH)_4^-$ and increase in anion adsorption. Availability also decreases sharply under drought conditions probably because of both a decrease in B mobility by mass flow to the roots and the polymerization of boric acid (Marchner, 1995). The growing conditions of wheat, a widely cultivated crop in Turkey, favor all the possibilities of B deficiency in wheat as mentioned above because of drought (rainfed) conditions, and high pH, lime and clay content of the soils.

The sterility problem in wheat as a consequence of B deficiency has been reported in different parts of the world (Subedi et al., 1997a, 1997b). B deficiency causes the poor development of anthers and pollen, and the failure of pollen germination in wheat has been identified as male sterility, resulting in grain set failure (Rerkasem et al., 1997; Rerkasem and Jamjod, 1997), with losses of grain yield and quality. As a result of the general immobility of B in plants that is characteristic of most species, plants require a constant supply of B during all phases of plant growth. Even a short period of limitation in B availability can depress plant growth. If B deficiency occurs during critical reproductive stages, significant yield losses can be expected (Brown and Shelp, 1997).

The objective of this study was to investigate the responses of yield, sterility, fertility and other agronomic components of bread (*Triticum aestivum* L, cv. Bezostaja) and durum (*Triticum durum* L. cv. Kiziltan) wheat cultivars to B fertilization in greenhouse and rainfed field conditions.

Materials and Methods

Greenhouse Experiment

A pot experiment was carried out in plastic pots holding 2.0 kg of air-dried soil collected from the same site of the field experiment. Some of the characteristics of the soil were as follows: texture clay loam, $CaCO_3$ 27.67%, pH (1:2.5 water) 7.62, EC 0.64 dS m^{-1}, organic matter 1.81%, total N 0.21%. Extractable and total S concentrations were 12.78 mg kg^{-1} and 96.05 mg kg^{-1}, respectively. The concentrations of NH_4OAc-extractable K, Ca, Na and B were (mg kg^{-1}), 225, 7400, 80 and 0.68, respectively. The B level of the soil was insufficient (Güneş et al., 2002). Plant available ($NaHCO_3$-extractable) P was 11.20 mg kg^{-1}. Bread (*Triticum aestivum*, cv. Bezostaja) and durum (*Triticum durum*, cv. Kiziltan) wheat cultivars were used in the experiment.

B was added to soil in the form of H_3BO_3 at rates of 0, 0.5, 1.0, 1.5, 2.0 and 2.5 mg B kg^{-1} soil. A basal treatment of 200 mg N kg^{-1} soil as NH_4NO_3 with 100 mg P kg^{-1} and 125 mg K kg^{-1} soil as KH_2PO_4 was applied to all the pots. All nutrients applied were mixed thoroughly with the soil before seed sowing. Twenty seeds from each wheat cultivar were sown at a depth of 2.5 cm in each pot and thinned to 15 after emergence. The water content of the soil was maintained at 75% of the field capacity. After 50 days of growth in the greenhouse, shoots were harvested, their dry weights were determined and they were subsequently ground for B analysis.

Field Experiment

A field experiment was carried out in the 2000-2001 cropping season in Ankara, Turkey under rainfed conditions in the Research and Experiment Station of the Faculty of Agriculture, Ankara University. The total precipitation during the vegetation period was 278.5 mm. Long-term precipitation, mean temperature and mean humidity were 400 mm, 9.7 °C and 73.2% respectively. The field experiment was conducted with the same wheat cultivars used in the greenhouse experiments. Sowing was done at the start of October 2000 in 6 m^2 (1.2 x 5 m) plots by an experimental drill. The seeding rate was 140 g of seed per plot. The basal fertilizer application at the sowing was 150 kg of diammonium phosphate (18% N, 46% P_2O_5) ha^{-1}. B was applied at the tillering stage in March 2001 as H_3BO_3 at rates of 0, 1.0, 2.0, 3.0, 4.0 and 5.0 kg B ha^{-1} in liquid form. N as ammonium nitrate (33% N) was side dressed at 100 kg N ha^{-1} in March 2001 to all plots.

Plant shoot samples from all the plots were taken at the beginning of the heading stage for the determination of B concentrations. At maturity, just before harvest, plants were sampled again for yield component measurements (spike number m^{-2}, spike length, thousand kernel weight, number of fertile and sterile spikelets per spike, number of grain per spike, grain yield per spike and harvest index) by hand harvesting 0.25 m^2 sub-plots (Adak, 1994). Then the remaining plants were harvested in July 2001 by experimental machine harvester. After recording grain yield, sub-samples of grains were ground for B determination.

Measurement of B Concentrations

Shoot samples from greenhouse and field experiments were washed thoroughly in deionized water, and dried in a thermoventilated oven at 65 °C until reaching a constant mass. Then shoot and grain samples were subsequently ground for the determination of B concentration. For the measurement of B, sub-samples were analyzed by dry ashing and the azomethine-H procedure (Wolf, 1972).

Statistical Analysis

The greenhouse experiment was designed completely randomized, and the field experiment was in a randomized complete block design with 4 replications. To determine the effects of B application, analysis of variance (ANOVA) and correlation coefficients were used to analyze the experimental data via the Minitab statistical program. The Least Significant Difference (LSD) test was used to separate means when the F-test indicated statistical significance at $P < 0.05$ level.

Results

Effects of B under Greenhouse Conditions

B application significantly increased the shoot dry weight of the wheat cultivars ($P < 0.01$, Table 1). Dry weights obtained from the applied B levels did not greatly differ in both cultivars. The application of B clearly increased the B concentration of both cultivars ($P < 0.01$, Table 1). There were positive correlations between shoot dry weight and B concentration in both cultivars, giving the correlation coefficients of $r = 0.503^*$ for Bezostaja and $r = 0.550^{**}$ for Kiziltan.

Effects of B in Field Conditions

The responses of yield, B concentrations in the shoots and grains of Bezostaja and Kiziltan wheat cultivars to B fertilization grown in the field conditions are given in Table 2. The grain yield results of the field experiment were confirmed by the dry weight results of the greenhouse experiment in which growth and grain yield at the applied B gave better results than the control.

Grain yield increased significantly ($P < 0.01$) by almost 50%, from 3668 to 5475 kg ha^{-1} in Bezostaja at 4.0 kg B ha^{-1}, and, after this level, grain yield decreased

Table 1. Effect of B fertilization on the shoot dry weight (DW), and B concentrations in Bezostaja (*bread*) and Kiziltan (*durum*) wheat cultivars grown under greenhouse conditions.

Boron levels mg kg^{-1}	Bezostaja		Kiziltan	
	Dry weight, g pot^{-1} ± SE	Boron, mg kg^{-1} ± SE	Dry weight, g pot^{-1} ± SE	Boron, mg kg^{-1} ± SE
0	4.71 ± 0.07	14.34 ± 1.26	3.22 ± 0.07	12.12 ± 0.37
0.5	5.50 ± 0.15	22.67 ± 3.10	3.53 ± 0.07	16.41 ± 0.74
1.0	5.68 ± 0.10	26.99 ± 4.69	3.67 ± 0.06	15.84 ± 1.55
1.5	5.60 ± 0.10	42.38 ± 1.95	3.53 ± 0.10	22.66 ± 2.88
2.0	5.26 ± 0.10	28.26 ± 2.51	3.53 ± 0.07	26.33 ± 1.06
2.5	5.67 ± 0.12	38.70 ± 2.22	3.83 ± 0.03	29.68 ± 2.22
LSD $P < 0.05$	0.36	7.28	0.17	5.45
F test	9.71**	18.23**	8.44**	14.16**

F test significance level: ** $P < 0.01$

Table 2. Effect of increasing levels of B application on the yield and B concentrations (±SE) of shoots and grains of Bezostaja and Kiziltan wheat cultivars in field conditions.

Boron levels kg ha^{-1}	Bezostaja			Kiziltan		
	Yield kg ha^{-1}	Shoot Boron mg kg^{-1}	Grain Boron mg kg^{-1}	Yield kg ha^{-1}	Shoot Boron mg kg^{-1}	Grain Boron mg kg^{-1}
0	3668 ± 210	17.26 ± 0.48	17.13 ± 0.83	4668 ± 198	20.53 ± 0.47	16.42 ± 1.11
1	4441 ± 122	26.87 ± 2.66	20.57 ± 1.31	4962 ± 385	22.67 ± 0.50	20.34 ± 0.28
2	4394 ± 74	28.55 ± 0.69	23.51 ± 1.31	5360 ± 232	23.68 ± 0.50	23.51 ± 1.11
3	4292 ± 231	29.67 ± 0.51	25.75 ± 2.65	5282 ± 183	28.92 ± 1.75	23.16 ± 0.81
4	5475 ± 163	29.91 ± 0.72	26.26 ± 0.69	5080 ± 117	32.38 ± 1.25	25.92 ± 3.36
5	3515 ± 165	33.10 ± 1.86	27.44 ± 2.87	4858 ± 315	33.77 ± 1.70	25.52 ± 3.45
LSD P < 0.05	542	4.49	5.39	-	3.17	6.57
F test	14.96**	13.33**	4.82**	1.58^{ns}	27.01**	2.69*

F test significance levels: * P < 0.05, ** P < 0.01, ns: non significant

strongly to 3515 kg ha^{-1} at the highest level of applied B. Grain yield also increased up to 2.0 kg B ha^{-1} from 4668 to 5360 kg ha^{-1} (14.8% increase) and decreased with higher B levels in Kiziltan. This increase, however, was statistically insignificant.

Concentrations of B in the shoots and grains of both cultivars increased significantly with increasing levels of applied B (Table 2). Significant positive correlations were observed between grain B concentrations and shoot B concentrations in Bezostaja and Kiziltan (r = 0.765**; r = 0.579**, respectively)

The response of yield components, namely thousand kernel weight (TKW), spike number m^{-2}, spike length, number of fertile and sterile spikelets per spike, number of grains per spike, grain yield per spike and harvest index to B fertilization, is presented in Table 3.

B treatment did not significantly affect TKW in either cultivar. TKW was positively correlated with grain yield, grain yield per spike, and the number of grains per spike (r = 0.425*, r = 0.444* and r = 0.377*, respectively) in Bezostaja.

Spike number significantly increased from 318 m^{-2} to 481 m^{-2} in Bezostaja at 3.0 kg B ha^{-1} and decreased to 332 at 5.0 kg B ha^{-1} (P < 0.01). Spike number also increased from 310 m^{-2} to 365 m^{-2} in Kiziltan. However, this effect of the B treatments was not significant. Spike length was increased by B fertilization in Bezostaja compared to the control treatment (P < 0.05); however, the differences between B treatments were insignificant (Table 3). Spike length was positively correlated with the shoot and grain B (r = 0.754** and r = 0.572**, respectively) in Bezostaja. B treatments had no effect on spike length in Kiziltan (Table 3).

In general, B fertilization slightly increased the number of fertile spikelets per spike in both cultivars, but the increases were significant in Kiziltan only. The number of sterile spikelets per spike significantly decreased from 1.10 to 0.10 in Bezostaja due to B treatments (P < 0.01). Sterile spikelet number per spike also decreased from 1.05 to 0.75 with increasing levels of applied B in Kiziltan, but this decrease was not significant. The number of fertile spikelets per spike was positively correlated (r = 0.393*) with shoot B concentration while the number of sterile spikelets per spike was negatively correlated with shoot and grain B concentration (r = -0.758** and r = -0.484**, respectively) in Bezostaja. Similar correlation coefficients between the number of fertile spikelets per spike and shoot and grain B concentration were also observed in Kiziltan, but these correlations were not statistically significant.

Although there were no significant differences among the B treatments, the number of grains per spike increased with B fertilization in Bezostaja. While the

Table 3. Effect of increasing levels of B application on some yield components (±SE) of Bezostaja and Kiziltan wheat cultivars in field conditions.

Boron levels kg ha^{-1}	Thousand kernel weight g	Spike number m^{-2}	Spike length cm	No. of fertile spikelets per spike	No. of sterile spikelets per spike	No. of grains per spike	Grain yield yield per g spike-1	Harvest İndex %
				Bezostaja				
0	35.50 ± 1.33	318 ± 27.9	9.30 ± 0.25	17.00 ± 0.69	1.10 ± 0.06	34.85 ± 0.46	1.31 ± 0.05	21.17 ± 1.19
1	36.65 ± 1.64	412 ± 18.8	10.05 ± 0.21	18.70 ± 0.95	0.35 ± 0.05	41.50 ± 3.21	1.65 ± 0.12	29.24 ± 1.01
2	35.60 ± 0.98	452 ± 37.9	10.00 ± 0.17	19.85 ± 0.55	0.55 ± 0.10	41.25 ± 1.48	1.58 ± 0.04	25.44 ± 1.51
3	36.60 ± 1.60	481 ± 36.8	10.25 ± 0.10	18.75 ± 0.41	0.35 ± 0.15	42.60 ± 2.22	1.53 ± 0.04	36.28 ± 8.19
4	40.25 ± 2.39	447 ± 11.0	10.10 ± 0.33	18.30 ± 0.48	0.30 ± 0.10	41.45 ± 2.36	1.74 ± 0.06	30.25 ± 2.81
5	38.50 ± 0.74	332 ± 30.5	10.85 ± 0.36	18.75 ± 0.42	0.10 ± 0.06	42.30 ± 0.62	1.71 ± 0.03	24.96 ± 0.68
LSD P < 0.05	-	68.04	0.80	-	0.27	-	0.22	9.83
F test	1.31^{ns}	8.90**	3.49*	2.26^{ns}	14.77**	1.90^{ns}	4.65**	2.76*
				Kiziltan				
0	45.40 ± 2.26	310 ± 22.0	7.13 ± 0.10	17.70 ± 0.52	1.05 ± 0.17	36.35 ± 0.61	1.76 ± 0.22	28.98 ± 3.72
1	45.70 ± 0.94	349 ± 49.9	7.58 ± 0.50	19.00 ± 0.29	0.70 ± 0.24	45.15 ± 1.89	2.01 ± 0.08	43.93 ± 5.93
2	44.10 ± 1.59	288 ± 27.5	7.70 ± 0.39	19.60 ± 0.32	0.80 ± 0.12	48.20 ± 2.59	2.35 ± 0.10	41.69 ± 2.53
3	44.17 ± 1.68	350 ± 29.1	6.98 ± 0.19	18.20 ± 0.91	0.80 ± 0.08	44.95 ± 1.68	1.99 ± 0.21	36.11 ± 1.28
4	46.18 ± 0.78	349 ± 33.7	7.30 ± 0.20	20.10 ± 0.49	0.90 ± 0.06	46.40 ± 1.31	2.07 ± 0.22	44.03 ± 5.60
5	48.15 ± 0.89	365 ± 63.9	7.23 ± 0.31	18.53 ± 0.52	0.75 ± 0.05	45.85 ± 1.09	2.24 ± 0.04	43.66 ± 5.61
LSD P < 0.05	-	-	-	1.60	-	4.24	-	-
F test	0.91^{ns}	0.55^{ns}	0.75^{ns}	2.84*	0.85^{ns}	8.69**	2.07^{ns}	1.74^{ns}

F test significance levels: * P < 0.05, ** P < 0.01, ns: non-significant

increase in number of grains per spike in Kiziltan was significant, it was not significant in Bezostaja. When the average of all the B treatments was compared to the control, the number of grains per spike increased from 34.85 to 41.82 in Bezostaja and from 36.35 to 46.11 in Kiziltan (Table 3). The number of grains per spike was closely correlated with the number of fertile spikelets per spike in Bezostaja (r = 0.628**) and Kiziltan (r = 0.426**). While the number of grains per spike was negatively correlated with the number of sterile spikelets per spike (r = -0.633**) in Bezostaja and (r = -0.485**) in Kiziltan, the number of grains per spike was positively correlated with shoot and grain B in Bezostaja (r = 0.540** and r = 0.338*) and in Kiziltan (r = 0.426* and r = 0.483*, respectively).

Regardless of increases in B levels, grain yield per spike increased in both cultivars by B addition. While the increase in grain yield per spike was not statistically significant in Kiziltan, there was a positive correlation between grain yield per spike and the number of grains per spike in Bezostaja and Kiziltan (r = 0.784** and r = 0.543**, respectively). Grain yield per spike was also positively correlated with shoot and grain B (r = 0.665** and r = 0.412*, respectively) in Bezostaja and (r = 0.337 and r = 0.481*, respectively) in Kiziltan. The grain yield per spike was also positively correlated with the number of fertile spikelets per spike in Besostaja (r = 0.568**) and in Kiziltan (r= 0.400*). In Bezostaja, grain yield per spike was negatively correlated with the number of sterile spikelets per spike (r = -0.715**, respectively).

B treatments had a strong positive effect on the harvest index in Bezostaja. The harvest index was highest in Bezostaja at 3.0 kg B ha^{-1}, which increased 71.37% relative to the control (Table 3). The harvest index also increased at all B levels compared to the control. However, these increases in the harvest index were not significant in Kiziltan. The harvest index was negatively correlated with the number of sterile spikelets per spike in both cultivars (r = -0.412* in Bezostaja, and r = -0.524** in Kiziltan), and there was a close correlation (r = 0.496* in Bezostaja, and r = 0.609** in Kiziltan) between the harvest index and the number of grains per spike.

Discussion

As reported by Sillanpaa (1982), low B soils are common throughout the world and B deficiency in wheat has been reported in many countries, i.e. Thailand (Pant et al., 1998), Nepal (Subedi et al., 1997a, 1997b), India (Singh and Sinha, 1976), and Turkey (Eyüboglu et al., 2002). In the present study, Bezostaja and Kiziltan responded positively to B fertilization in both the greenhouse and field experiments. B application increased the shoot and grain B concentrations of both cultivars grown in a soil containing 0.68 mg B kg^{-1}, leading to significant increases in yield compared to control treatments. As reported by Subedi et al. (1997b), the role of B in pollen development, germination and pollen tube growth and consequently reproductive development is particularly important. B plays a vital role in pollination, fruit and seed set, and the viability of pollen grains is inhibited by B deficiency. In this study, B treatments decreased the number of sterile spikelets per spike but increased fertile spikelets per spike in both cultivars, but the increases in the number of fertile spikelets per spike in Bezostaja and the number of sterile spikelets per spike in Kiziltan were not statistically significant. However, shoot and grain B concentrations were positively correlated with the number of fertile spikelets per spike and negatively with the number of sterile spikelets per spike in Bezostaja. As indicated by the correlation coefficients, increases in the number of fertile spikelets per spike and decreases in the number of sterile spikelets per spike were closely correlated with increases in the number of grains per spike and grain yield per spike. Positive effects of B on the growth, yield and yield components of wheat were also reported earlier by other researchers (Subedi et al., 1997a, 1997b; Rerkasem and Jamjod, 1997).

Conclusion

Wheat is the most important winter cereal in Turkey and is cultivated on 60% of the total agricultural lands with alkaline pH, and higher percentages of lime and clay in soils under rainfed conditions. All environmental and soil factors are suitable for potential B deficiency in wheat grown in Turkey. B deficiency in the vegetative growth stage is not easy to detect, and undetected deficiency of micronutrients, such as B, would probably severely restrict food production in many parts of the world. Therefore, it is essential to diagnose and correct B deficiency in these areas. In this study, the experiments clearly demonstrated that the application of B was effective in improving wheat performance.

Based on the latest results in B research conducted in different parts of the world as reported by Subedi et al. (1997a, 1999) and our results, B is an important micronutrient, and its deficiency is widespread. Because crops suffer from this problem, it is becoming a limiting factor for increasing crop production. While the application of B fertilizer is not common practice for the production of wheat in Turkey, the results of this study suggest that fertilization with B should be taken into consideration after additional research under different soil, genotype and environmental conditions.

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