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Proceeding Paper

Evaluating the Synergistic Effects of Foliar Boron and Magnesium Application for Mitigating Drought in Wheat †

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Abstract: The grain yield of wheat is primarily limited by drought. To increase the level of productivity under these conditions, a pot experiment was carried out to investigate the effect of foliar fertilizer with boron and magnesium under drought at either tillering or anthesis stages on some physiological parameters and yield components of two varieties of durum wheat. Foliar application with combined boron and magnesium significantly improved the transpiration rate, relative water content, and total chlorophyll content. Foliar application with combined boron and magnesium significantly increased the grain weight of wheat varieties at tillering and anthesis drought by 25% and 36%, respectively. Our findings showed the significance of foliar application at anthesis drought rather than at tillering for improvement of grain yield.

Keywords: macronutrient; relative water content; tillering drought; yield component

1. Introduction

Wheat (*Triticum durum*) is among the most crucial field crops grown under rainfed conditions in Jordan and considered essential for food security at the national and global level [1]. Drought is a major abiotic stress and the most unpredictable constraint, with adverse effects on crop production. Drought has a negative impact on plants by disturbing many plant activities, including the carbon assimilation rate, decreased turgor, and changes in leaf gas exchange, thus causing a reduction in yield [2]. Reduced chlorophyll due to water stress causes chlorosis, which leads to a reduction in photosynthesis [3]. In addition, drought also reduces leaf relative water content (RWC) and stomatal conductance, which ultimately leads to reduced growth and biomass production [4]. Drought stress most commonly occurs after anthesis in wheat [5].

The foliar application of different nutrients to different crops at different growth stages can increase the tolerance mechanism in crops and therefore enhance crop yield [6]. Boron (B) is required by plants in microquantities and has stimulated responses of resistance against drought stress [7]. The nutritional supply of B resulted in improved stomatal conductance and carbon assimilation [8]. Boron application improves the growth, grain production, and water-use efficiency of wheat [9]. In addition, magnesium (Mg) is a macronutrient required for chlorophyll synthesis and thus essential for the photosynthesis process in plants. Also, Mg enhanced drought tolerance and played a vital role in all the biochemical and physiological processes of plants through different pathways [10].

Several studies have shown that foliar applications of boron and magnesium can increase crop yields. However, limited or no information is available regarding the effect of the combined foliar application of boron and magnesium on the growth and yield of durum wheat under water stress. Therefore, this study was designed to evaluate the effect of B and Mg application alone and in combination on improving some of the physiological

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traits and yield components of two varieties of durum wheat grown under tillering or drought stress during the anthesis stage.

2. Materials and Methods

2.1. Plant Materials

Two durum wheat (*Triticum durum* L.) varieties (Hourani and Maru 1) were used in this experiment. Maru1 is an improved variety released and registered in 2019–2020, while Hourani is an old variety (released in 1976) and known as a drought-tolerant variety.

2.2. Soil Preparation and Seed Sowing

A pot experiment was conducted in a glasshouse at the Maru Agricultural Research Station (MARS), Jordan. Seventy-two pots (27 cm diameter × 27 cm height) were used for this experiment, and each pot was filled with 4 kg of clay soil mixed with peat (1:1) (*v*/*v*). Plants were thinned to two seedlings per pot at the two-leaf stage one week after emergence.

2.3. Growth Conditions and Treatments

The temperature in the greenhouse was controlled at 25/15 °C (day/night). Pots were supplied with NPK fertilizer on a weekly basis from the beginning of tillering. Foliar spraying was applied twice during the experiment: once during the tillering drought and another during the anthesis drought, and compared with those sprayed in well-watered conditions. Fertilizer treatments (boron, magnesium, and boron + magnesium) were sprayed one day before the beginning of the drought either at the tillering or anthesis growth stages, while the controls were sprayed with distilled water. Boron was sprayed in the form of boric acid (H_3BO_3) at a concentration of 0.3 g/L (% B in boric acid = 17.48%), whereas magnesium was sprayed in the form of magnesium sulfate ($MgSO_4{\cdot}7H_2O$) at a concentration of 5 g/L (% Mg in magnesium sulfate = 9.86%). Drought was imposed by withholding watering for 7 days at tillering (GS 22; D1) or anthesis (GS 65; D2) according to the Zadoks scale [11] on separate sets of plants and compared with well-watered (WW) plants, which were regularly watered to field capacity.

2.4. Physiological Measurements and RWC

The transpiration rate (μg cm^{-2} s^{-1}) was measured with a portable steady state porometer (LICOR model LI-1600), while the total chlorophyll content (TCC) was determined non-destructively using a portable chlorophyll meter, the SPAD 502 Chlorophyll Meter (Spectrum Technologies Inc., Plainfield, IL, USA), on the same leaf as RWC prior to excision at the beginning and one week after plant stresses at either tillering or anthesis stages. The relative water content (RWC) was determined according to the methodology outlined by the authors of [12].

2.5. Growth and Yield Components

At the full maturity stage, the number of tillers and heads was counted. The aboveground plant parts were harvested and separated into vegetative and head parts. The grains were separated from the heads by threshing, and grain weight was determined for each pot. The total dry weight of the shoots was determined after drying in an oven at 80 °C for two days. The one thousand-grain weight was determined from the weight of 200 seeds per sample. The harvest index (HI) was calculated by dividing grain weight by total (grain plus shoot) weight.

2.6. Statistical Analysis

This experiment was performed in a factorial, completely randomized design. There were three replicates for each treatment. The data were analyzed by factorial ANOVA using Statistix 8.1. When there were significant interactions, the one-way ANOVA was used, and the means were separated by least significant differences (LSDs).

3. Results

The transpiration rates were significantly ($p < 0.05$) higher in var. Maru 1 than those in var. Hourani at tillering. Moreover, the controls had significantly lower transpiration rates and RWCs than foliar fertilizer treatments (Table 1). At anthesis, the measured physiological parameters revealed a significant reduction in controls when compared with other foliar fertilizer treatments. However, the B + Mg treatment had a significantly higher RWC than either the B or Mg treatments (Table 1).

Table 1. Mean values of transpiration rate (μg cm^{-2} s^{-1}), total chlorophyll content by SPAD, and relative water content (RWC%) for two durum wheat varieties and four foliar fertilizer treatments under the beginning of tillering and anthesis droughts (Day 0) and end of tillering and anthesis droughts (Day 7). According to the least significant difference (LSD) test, different letters within the same columns indicate significant differences ($p < 0.05$). B: boron; Mg: magnesium; and B + Mg: combined boron and magnesium.

Variety	Drought	Transpiration Rate		SPAD		RWC	
		Tillering	Anthesis	Tillering	Anthesis	Tillering	Anthesis
Hourani	Day 0	4.92	10.84	52.06	53.39	91.93	92.28
	Day 7	2.82	2.88	46.47	43.11	71.49	50.65
Variety mean		3.87 B	6.8 A	49.26 A	48.25 A	81.71 A	71.47 A
Maru 1	Day 0	4.78	10.59	52.16	53.53	92.34	92.09
	Day 7	3.83	2.82	46.11	44.34	72.05	54.21
Variety mean		4.30 A	6.70 A	49.13 A	48.93 A	82.19 A	73.15 A
Foliar treatment							
B	Day 0	4.82	10.78	50.95	54.33	92.18	92.55
	Day 7	3.39	2.92	48.10	43.45	79.39	52.48
Treatment mean		4.11 A	6.85 A	49.53 A	48.89 A	85.78 A	72.52 B
Mg	Day 0	4.86	10.87	52.85	54.03	92.79	90.97
	Day 7	3.73	3.25	45.32	44.42	72.89	55.50
Treatment mean		4.29 A	7.06 A	49.08 A	49.23 A	82.84 A	73.23 B
B + Mg	Day 0	4.79	11.01	53.07	53.28	91.84	92.53
	Day 7	3.99	3.85	47.52	46.83	73.26	62.03
Treatment mean		4.39 A	7.43 A	50.29 A	50.06 A	82.55 A	77.28 A
Control	Day 0	4.94	10.21	51.57	52.18	91.74	92.69
	Day 7	2.18	1.38	44.22	40.20	61.52	39.72
Treatment mean		3.56 B	5.79 B	47.89 A	46.19 B	76.63 B	66.21 C
LSD (0.05)							
Variety		0.33	0.53	2.06	1.11	2.85	2.60
Foliar treatment		0.47	0.76	2.92	1.57	4.03	3.68

The main means of foliar fertilizer treatments for the growth and yield of the two wheat varieties are presented in Table 2. The number of heads (HN) and tillers (TN) per plant for var. Maru 1 was significantly higher than those for var. Hourani. Variety Maru 1 showed significantly higher grain number (GN), grain weight (GW), and 1000-grain weight (TGW) per plant ($p < 0.01$) than var. Hourani. The controls had significantly reduced GW, GN, and TGW per plant by 18%, 16%, and 6%, respectively, when compared with those sprayed by the B + Mg treatment. The dry matter weight (DMW) per plant was similarly affected by treatments as the GW and GN. The overall mean harvest index (HI) of var. Maru 1 was significantly higher than that of var. Hourani.

Table 2. The main effect of wheat varieties and foliar fertilizer treatments on growth and yield components. B: boron; Mg: magnesium; B + Mg: combined boron and magnesium; TN: number of tillers per plant; HN: number of heads per plant; GN: number of grains per plant; TGW: 1000-grain weight; GW: grain weight per plant; DMW: shoot dry weight per plant excluding grain; HI: harvest index; and LSD: least significant difference at $p < 0.05$. Figures labeled with the same letter in each column are not significantly different.

Main Effect	TN	HN	GN	TGW (g)	GW (g)	DMW (g)	HI
Variety							
Hourani	9.0 b	8.5 b	310.1 b	37.3 b	12.1 b	19.1 b	0.37 b
Maru 1	9.8 a	9.3 a	452.8 a	42.6 a	20.1 a	22.3 a	0.46 a
Foliar treatment							
B	9.5 a	9.1 a	396.4 a	40.3 b	16.8 a	21.3 a	0.42 a
Mg	9.5 a	9.0 a	383.1 a	42.0 a	16.8 a	21.4 a	0.42 a
B + Mg	9.3 a	9.0 a	405.2 a	40.0 b	16.9 a	21.9 a	0.42 a
Control	9.0 a	8.5 a	340.9 b	37.4 c	13.8 b	18.1 b	0.40 a
LSD (0.05)							
Variety	0.34	0.33	20.84	1.10	0.73	1.29	0.019
Foliar treatment	0.49	0.47	29.48	1.56	1.04	1.82	0.027

There was a significant ($p < 0.05$) foliar fertilizer × drought interaction effect for the GW per plant (Figure 1). The combined foliar fertilizer (B + Mg) treatment did not improve the GW under well-watered (WW) conditions when compared to the controls. However, the B + Mg treatment had significantly increased the GW per plant by 33% and 57% at tillering drought (D1) and anthesis drought (D2), respectively, when compared to the controls.

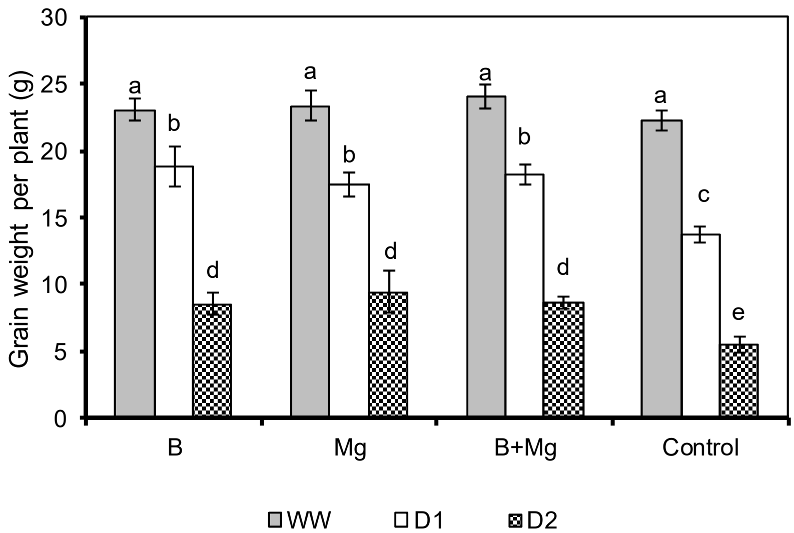

Figure 1. Foliar fertilizer x drought interaction effect on grain weight per plant. Columns with the same letter are not significantly different at $p < 0.05$ using the LSD test. Error bars show standard errors; $n = 3$.

4. Discussion

In this study, foliar application was effective in improving the transpiration rate of wheat under drought. Similar findings were obtained by the authors of [9]. The response of micronutrient application to various abiotic stresses depends on the crop, growth stage, and concentration of the nutrient solution [13]. The key mechanisms affecting the ability of micronutrients and macronutrients to alleviate the effects of drought stress include enhancing water uptake and transport, regulating stomatal behavior, and transpirational water loss [14]. Our results showed that wheat transpiration at anthesis drought was lower by approximately 14% than at tillering drought. This may be due to the higher water uptake of larger root biomass during the anthesis stage. Similarly, the authors of [15] found that transpiration rates during the anthesis were higher than during the vegetative phase. Therefore, the soil water supply is more rapidly exhausted during anthesis drought.

Foliar application with combined boron and magnesium increased total chlorophyll content by SPAD at anthesis drought. These results are consistent with other studies [16,17] that indicated that Mg has a main role in chlorophyll formation and the activation of enzymes, and it may increase plant resistance to water stress. Similarly, foliar application by B increased total chlorophyll content at the late growth stages of winter wheat [9]. Thus, these findings indicated the prominence of foliar application with combined boron and magnesium to reduce the harmful effects of drought stress that often occur during anthesis.

In the current study, foliar fertilizer significantly increased the RWC of wheat under drought conditions. Similar results were obtained by [18,19], who found that the foliar application of macronutrients and micronutrients improved the RWC for some crops. The higher RWC under combined boron and magnesium might be due to higher chlorophyll formation during the drought, whereas the increase in RWC by application of foliar boron might be due to leaf membrane stability and higher resistance against abiotic stresses [7,20].

Our results also indicated significant differences between both wheat varieties in terms of yield and yield components due to a difference in the genetic makeup of the variety. It is well documented that wheat varieties grown under drought conditions demonstrate a natural genetic difference in traits related to drought tolerance [21]. Our study demonstrated that the foliar application increased the grain yield of durum wheat under different drought conditions, which may be due to the crucial role of such fertilizers in the enhancement of photosynthesis, transpiration rate, pollen viability, the number of grains per spike, and higher concentrations of these nutrients in the grain. Similar results were obtained by [9,22]. Our findings were also in agreement with the results of [9], who found that the grain yield of winter wheat was not improved by foliar applications in the absence of drought. Furthermore, the foliar application of B and Mg was more effective at anthesis drought for improving the grain yield. These results were similar to the findings of [23], who found that the foliar application of potassium was the most effective at the anthesis stage. However, ref. [22] found that the booting stage was the best time for boron application increase grain production.

In conclusion, drought stress at either the tillering or anthesis growth stage inhibits the physiological growth and yield parameters of durum wheat varieties. Yield reduction was greater during anthesis drought than during tillering. Therefore, exogenous application of B and Mg to wheat under drought alleviated the negative effects of the water deficit. Results of this pot experiment revealed that foliar application of B and Mg enhanced leaf transpiration rate and relative water contents, which, in turn, improved the crop yield of wheat. However, the foliar application of B and Mg in combination performed similar to that of a single nutrient. The results from this study show the significance of foliar application at the anthesis stage for improving wheat yield under drought conditions. Further studies are required to examine the effect of foliar application and drought on wheat yield and growth under field conditions.

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