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Uptake of Boron by Kiwifruit Plants Under Various Levels of Shading and Salinity

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ABSTRACT

Two experiments were conducted. In the first one, kiwifruit plants were grown in sand/perlite mixtures and irrigated with modified Hoagland's nutrient solutions containing two boron (B) concentrations (0.025 and 0.2 mM) combined with four levels of salinity (0.75, 2, 4, and 6 $dS\,m^{-1}$). Certain growth parameters and B concentration of the various plant parts were investigated. The highest level of salinity imposed was toxic for kiwifruit plants. Significant correlations (significance 0.000***) were found between B and salinity levels of the nutrient solutions and shoot height, mean shoot fresh weight, number of new leaves, mean leaf fresh weight, B concentration of upper leaves, basal leaves, 2-year old shoots and roots of kiwifruit

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plants. By increasing salinity level, the B concentration of leaves decreased when B concentration in solution was 0.2 mM. In another experiment, the nutrient solutions contained three B concentrations (0.025, 0.15, and 0.3 mM) and the plants were subjected to shading (100, 70, and 30% of full sunshine). Regression analysis indicated that significant correlations were found between B and shading (independent variables) and shoot height, mean shoot fresh weight, number of new leaves, B concentration of various plant organs (significance 0.000***) and mean leaf fresh weight (significance 0.018*).

Key Words: Boron absorption; Boron toxicity; Osmotic stress; Transpiration rate.

INTRODUCTION

A nutrient survey in kiwifruit orchards of northern Greece revealed the existence of boron (B) toxicity, which resulted in a dramatic reduction of fruit yield. Boron absorption by plant roots is affected by various soil and climatic factors. Important soil factors influencing B absorption include the initial B content of the soil, the pH of the soil, the type of exchangeable ions present in the soil solution, the amounts and types of minerals in the soil, the content of soil organic matter and the water to soil ratio. Among the climatic factors, air humidity and wind velocity are very important since they control transpiration. The transpiration rate seems to be the most important factor governing B absorption.[1] Low light intensity and high levels of salinity are known to reduce transpiration in barley[2] and eucalyptus,[3] respectively.

Therefore, the objective of the present research was to investigate the effects of salinity and overhead shading on B uptake and growth of kiwifruit plants.

MATERIALS AND METHODS

First Experiment

Two years-old kiwifruit [*Actinidia deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson var. deliciosa cv. Hayward] plants uniform in macroscopic characteristics were planted in plastic containers containing 3 L of a sand-perlite medium (1:1). The experimental plants were maintained in a growth room at $22 \pm 1°C$, 16 h light and 8 h dark period and photosynthetic photon flux density 550 μmol m^{-2} s^{-1}. The plants were irrigated daily with 0.3 L of modified Hoagland's nutrient solutions.[4] Macronutrients were supplied at half strength of the previous solution and micronutrients except B, at full strength. Boron was supplied at two concentrations (0.025 and 0.2 mM) and salinity at four levels (Ec: 0.75, 2, 4, and 6 dS m^{-1}). Different salinity levels were provided by the preparation of a stock solution of NaCl (4 M). Progressively, a few mL of the stock solution were added in the nutrient solutions until the desirable level of salinity was achieved. The measurements of conductivity were conducted by a conductivity-meter (cyberscan con 410). In each treatment, 8 plants (replicates) were included. When a period of 8 weeks was elapsed, B toxicity symptoms were clearly visible in certain treatments. Afterwards, the plants were harvested and certain growth parameters were measured such as shoot height, number of leaves and mean fresh weight of shoots and leaves. The samples for chemical analysis were separated into upper leaves, basal leaves, one-year-old shoots, two-year-old shoots, and roots. The samples were initially washed once with tap water and afterwards twice with distilled water. Boron was determined by the azomethine-H method.[5]

Regression analysis was performed in order to describe the effect of continuous variables (B, salinity). Precisely, analysis of variance was performed in order to ascertain the existence of significant correlations between the independent variables (B, salinity) and the dependent variables (growth parameters, B concentration of various plant organs). Furthermore, linear regression equations and *R*-values were calculated for each treatment.

Second Experiment

In a second experiment conducted at the same time with the first one, two-year-old kiwifruit plants were planted in plastic containers containing 3 L of sand-perlite medium (1:1) and grown outdoors. Thus, midday photosynthetic photon flux density was not constant as in the first experiment but varied from 1480–1890 μmol m^{-2} s^{-1} as was found by repeatable measurements by a photometer. The shading treatments imposed were (a) unshaded control (100% sunshine), (b) 70% sunshine, and (c) 30% sunshine. Light intensity was modified by using commercially available black woven polypropylene. The plants were irrigated daily with 0.3 L of modified Hoagland's nutrient solution as described at the first experiment. Boron was supplied at three concentrations (0.025, 0.15, and

0.3 mM). Therefore, 9 treatments were included in the experiment, each one with 8 plants (replicates). When 8 weeks from the initiation of the experiment were elapsed, shoot height, number of leaves, and mean shoot and leaf fresh weight were measured. The samples for chemical analysis were separated into leaves, one-year-old shoots, two-year-old shoots (separated into bark and wood), and roots. Boron determination and statistical analysis were conducted as described in the first experiment.

RESULTS AND DISCUSSION

First Experiment

Kiwifruit plants produced the longest shoots, more leaves and the greatest fresh weight of shoots and leaves when treated with 0.025 mM B combined with the two lowest levels of salinity (Table 1). Kiwifruit is a very sensitive plant to excess B, demanding irrigation water containing less than 0.048 mM B.[6] When the B concentration of irrigation water exceeds that value, characteristic foliar symptoms of B toxicity appear.[7] At higher than 0.048 mM B concentrations of irrigation water, the restriction of growth could be ascribed to a decrease of photosynthetic rate and of water use efficiency as was shown in a previous experiment.[8] Kiwifruit plants exposed to the highest level of salinity became progressively wilted and suffered from leaf burn. The growth of plants may be reduced under

Table 1. Effect of B concentration (mM) and salinity ($dS\,m^{-1}$) treatments on certain growth parameters of kiwifruit plants.

B (mM)	Electrical conductivity ($dS\,m^{-1}$)	Shoot height (cm)	Mean shoot fresh weight (g)	Number of new leaves	Mean leaf fresh weight (g)
	0.75	101 ± 4.2[a]	17.62 ± 0.3	12 ± 1.0	2.84 ± 0.2
	2	96 ± 1.7	17.91 ± 0.6	12 ± 1.2	2.80 ± 0.3
0.025	4	72 ± 3.9	13.13 ± 0.5	6 ± 0.4	2.75 ± 0.2
	6	58 ± 2.6	11.42 ± 0.4	5 ± 0.5	2.24 ± 0.2
	0.75	70 ± 1.4	12.22 ± 0.4	7 ± 0.6	2.48 ± 0.2
	2	72 ± 3.7	12.26 ± 0.3	7 ± 0.7	2.51 ± 0.2
0.2	4	19 ± 1.7	7.30 ± 0.2	3 ± 0.4	2.22 ± 0.3
	6	9 ± 1.1	8.41 ± 0.1	3 ± 0.3	1.79 ± 0.2

[a]Values are the means of eight replications ±SE.

Table 2. Effect of B concentration (mM) and salinity ($dS\,m^{-1}$) treatments on B concentration of leaves, shoots, and roots of kiwifruit plants.

B (mM)	Electrical conductivity ($dS\,m^{-1}$)	B ($\mu g\,g^{-1}$ d.w.) Upper leaves	Basal leaves	1-year-old shoots	2-year-old shoots	Roots
0.025	0.75	57 ± 2.8[a]	79 ± 2.1	18 ± 1.1	14 ± 1.2	30 ± 1.4
	2	55 ± 2.3	77 ± 2.3	16 ± 0.9	14 ± 1.1	28 ± 1.7
	4	49 ± 2.1	74 ± 1.7	16 ± 1.0	13 ± 1.3	29 ± 1.4
	6	47 ± 1.6	71 ± 2.6	15 ± 1.2	10 ± 1.1	24 ± 1.2
0.2	0.75	144 ± 3.7	196 ± 3.9	18 ± 1.4	20 ± 1.9	43 ± 1.8
	2	140 ± 3.6	190 ± 2.7	18 ± 1.2	19 ± 1.2	41 ± 2.4
	4	75 ± 1.7	96 ± 1.8	14 ± 1.2	15 ± 1.2	30 ± 1.7
	6	78 ± 1.5	92 ± 2.5	14 ± 0.9	11 ± 1.1	32 ± 1.4

[a]Values are the means of eight replications $\pm$SE.

salt stress. This could be ascribed to osmotic stress and to ion toxicity.[9] This is well documented in studies with pecan[10] and wheat.[11] By increasing salinity level, the B concentration of leaves decreased when B concentration in solution was 0.2 mM (Table 2). Regression analysis indicated that significant correlations (significance 0.000***) exist between B and salinity levels of the nutrient solutions and growth parameters (shoot height, mean shoot fresh weight, number of new leaves and mean leaf fresh weight) (Table 2). The highest R value (0.945) was calculated for the following equation: shoot height $= 121.65 - 222.14(\text{B}) - 10.8(\text{salinity})$.

Significant correlations (significance 0.000***) were calculated between B and salinity levels of the nutrient solutions and B concentration of upper leaves, basal leaves, 2-year old shoots and roots (Table 3). Salinity has a strong influence on reducing leaf B concentration of various *Prunus* rootstocks[12] and of eucalyptus (*Eucalyptus camaldulensis*),[3] respectively, due to a decrease of transpiration rate of plants. Kiwifruit has large requirements of chloride.[13] Leaf concentrations of 2–6 $mg\,g^{-1}$ d.w. are required for healthy growth. Chloride toxicity is not usually observed in kiwifruit until leaf concentrations exceed 25 $mg\,g^{-1}$ d.w. On the contrary, kiwifruit plants are extremely sensitive to comparatively low concentrations of sodium in their root zone. From a practical point of view, the use of potassium chloride fertilizer, when applied at adequate quantities based on soil and leaf analyses may reduce B uptake by kiwifruit plants, irrigated with high B water.

Table 3. Linear regression analysis of the data of the first experiment.

Regression	Mean square	*F*	Significance	Equation	*R*
$(B^a,C^b)^c$ Shoot height[d]	13492.2	120.67	0.000***	$y = 121.65 - 222.14(B) - 10.8(C)$	0.945
$(B,C)^c$ Mean shoot fresh weight[d]	188.3	99.95	0.000***	$y = 19.49 - 28.96(B) - 1.16(C)$	0.935
$(B,C)^c$ Number of new leaves[d]	150.6	45.18	0.000***	$y = 13.23 - 22.14(B) - 1.19(C)$	0.870
$(B,C)^c$ Mean leaf fresh weight[d]	1.5	10.78	0.000***	$y = 3.08 - 2.18(B) - 0.12(C)$	0.653
$(B,C)^c$ Boron in upper leaves[d]	17771.1	56.3	0.000***	$y = 70.68 + 328.2(B) - 8.47(C)$	0.892
$(B,C)^c$ Boron in basal leaves[d]	28218.8	39.5	0.000***	$y = 104.48 + 390(B) - 12.27(C)$	0.855
$(B,C)^c$ Boron in 1-year old shoots[d]	28.8	5.8	0.008**	$y = 18.35 - 1.07(B) - 0.67(C)$	0.534
$(B,C)^c$ Boron in 2-year old shoots[d]	153.5	22.6	0.000***	$y = 16.23 + 20.4(B) - 1.27(C)$	0.781
$(B,C)^c$ Boron in roots[d]	454.7	25.8	0.000***	$y = 31.54 + 48.93(B) - 1.59(C)$	0.801

[a]B (Boron); [b]C (Conductivity); [c]Independent variables; [d]Dependent variables.
NS, *,**,***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively.

Second Experiment

Within each B treatment, shoot elongation, mean shoot fresh weight, number of new leaves, and mean leaf fresh weight of unshaded plants were significantly greater than those of heavily shaded ones (Table 4). The results are in agreement with other reports for apple trees.[14] Plants grown in the shade have smaller photosynthetic rates, than those grown in full sun.[15] This leads to a reduced plant growth and productivity. In plants subjected to medium shading, a decrease of B concentration of leaves and 1-year-old shoots was measured, in comparison to the control for the two lowest B treatments (Table 5). The reduced light intensity around the canopy of kiwifruit plants decreases transpiration rate and, therefore, B uptake as was reported by Hu and Brown.[1] The increase of B concentration from 0.025 to 0.3 mM in the nutrient solution resulted in an increase of B concentration of leaves, shoots, and roots (Table 5). Regression analysis indicated that significant correlations exist between B and shading (independent variables) and shoot height, mean shoot fresh weight, number of new leaves (significance 0.000***), and mean leaf fresh weight (significance 0.018*) (Table 6). Furthermore, the highest *R* value (0.917) was calculated for the following equation: shoot height $= 65.63 - 59.2(B) + 0.47(\text{shading})$.

Regression analysis indicated the existence of significant correlations between B and shading (independent variables) and B concentration of the various plant organs (significance 0.000***) (Table 6).

Table 4. Effect of B concentration (mM) and shade levels on certain growth parameters of kiwifruit plants.

B (mM)	Shade (% full sun)	Shoot height (cm)	Mean shoot fresh weight (g)	Number of new leaves	Mean leaf fresh weight (g)
	100	112 ± 4.9[a]	9.42 ± 1.6	17 ± 1.7	2.84 ± 0.4
0.025	70	105 ± 4.1	9.30 ± 1.2	16 ± 2.6	2.79 ± 0.3
	30	74 ± 3.8	8.23 ± 1.4	14 ± 1.8	2.35 ± 0.2
	100	101 ± 4.0	8.65 ± 1.1	15 ± 0.9	2.56 ± 0.3
0.15	70	95 ± 2.7	8.42 ± 1.2	13 ± 2.1	2.50 ± 0.2
	30	71 ± 3.1	8.02 ± 1.3	12 ± 1.1	2.39 ± 0.2
	100	92 ± 2.9	8.17 ± 1.1	13 ± 1.2	2.44 ± 0.3
0.30	70	86 ± 2.5	7.97 ± 0.9	11 ± 1.5	2.35 ± 0.2
	30	60 ± 1.9	7.61 ± 0.9	9 ± 0.8	2.21 ± 0.2

[a]Values are the means of eight replications ±SE.

Table 5. Effect of B concentration (mM) and shade levels on B concentration of leaves, shoots, and roots of kiwifruit plants.

(B μg g^{-1} d.w.)						
B (mM)	Shade (% full sun)	Leaves	1-year-old shoots	2-year-old shoots (bark)	2-year-old shoots (wood)	Roots
0.025	100	76 ± 3.6[a]	18 ± 1.2	38 ± 1.9	5 ± 0.6	35 ± 2.46
	70	65 ± 3.2	12 ± 0.9	39 ± 1.6	4 ± 0.5	35 ± 1.65
	30	57 ± 3.0	12 ± 1.0	37 ± 2.0	4 ± 0.5	28 ± 2.04
0.15	100	162 ± 5.3	22 ± 1.4	59 ± 2.8	6 ± 0.4	45 ± 2.45
	70	119 ± 4.1	15 ± 0.9	55 ± 2.2	5 ± 0.5	38 ± 2.27
	30	122 ± 4.3	14 ± 0.6	48 ± 2.1	7 ± 0.6	32 ± 1.84
0.30	100	232 ± 4.9	28 ± 2.5	68 ± 3.1	9 ± 1.0	73 ± 2.87
	70	225 ± 5.1	24 ± 2.2	64 ± 2.9	10 ± 0.9	67 ± 2.25
	30	229 ± 4.8	23 ± 2.3	63 ± 3.3	8 ± 0.8	70 ± 2.29

[a]Values are the means of eight replications ±SE

Shading of kiwifruit plants is quite common in agricultural practice since light penetration within kiwifruit orchards is usually diminished by the tall hedges used as windbreaks, the prolific vegetative growth which results in self-shading and by horizontal netting used as hail or wind shelter. Therefore, growers may take advantage of the following practices for the partial control of B absorption by kiwifruit plants in areas where B toxicity is an agricultural problem.

CONCLUSIONS

Kiwifruit plants produced the longest shoots, the greatest number of leaves and the highest weight of shoots and leaves with 0.025 mM B combined with the two lowest levels of salinity. The highest level of salinity imposed was toxic for kiwifruit plants. Significant correlations (significance 0.000***) were found between B and salinity levels of the nutrient solutions and shoot height, mean shoot fresh weight, number of new leaves, mean leaf fresh weight, B concentration of upper leaves, basal leaves, 2-year old shoots and roots of kiwifruit plants. By increasing salinity level, the B concentration of leaves decreased when B concentration in solution was 0.2 mM. From a practical point of view, the use of potassium chloride fertilizer, when applied at adequate quantities based

Table 6. Linear regression analysis of the data of the second experiment.

Regression	Mean square	*F*	Significance	Equation	*R*
$(B^a,S^b)^c$ Shoot height^d	4108.98	87.73	0.000***	$y = 65.63 - 59.52(B) + 0.47(S)$	0.917
$(B,S)^c$ Mean shoot fresh weight^d	5.22	14.44	0.000***	$y = 8.27 - 3.83(B) + 0.01(S)$	0.683
$(B,S)^c$ Number of new leaves^d	92.81	10.02	0.000***	$y = 12.9 - 16.6(B) + 0.045(S)$	0.615
$(B,S)^c$ Mean leaf fresh weight^d	0.58	4.52	0.018*	$y = 2.38 - 1.19(B) + 0.004(S)$	0.464
$(B,S)^c$ Boron in leaves^d	81454.28	468.26	0.000***	$y = 30.68 + 594.3(B) + 0.27(S)$	0.983
$(B,S)^c$ Boron in 1-year old shoots^d	470.89	36.73	0.000***	$y = 6.51 + 39.85(B) + 0.08(S)$	0.831
$(B,S)^c$ Boron in 2-year old shoots (bark)^d	2299.77	85.59	0.000***	$y = 31.52 + 98.64(B) + 0.07(S)$	0.916
$(B,S)^c$ Boron in 2-year old shoots (wood)^d	71.29	26.09	0.000***	$y = 3.46 + 17.69(B) + 0.0023(S)$	0.783
$(B,S)^c$ Boron in roots^d	4505.88	83.72	0.000***	$y = 17.82 + 137.95(B) + 0.11(S)$	0.914

[a]B (Boron); [b]S (Shading); [c]Independent variables; [d]Dependent variables.
NS, *,**,***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively.

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on soil and leaf analyses may reduce B uptake by kiwifruit plants, irrigated with high B water.

In plants subjected to medium shading, a decrease of B concentration of leaves and 1-year-old shoots was measured, in comparison to the control for the two lowest B treatments. Significant correlations were found between B and shading (independent variables) and shoot height, mean shoot fresh weight, number of new leaves, B concentration of various plant organs (significance 0.000***) and mean leaf fresh weight (significance 0.018*). Since B toxicity is difficult to deal with, a partial shading of vines may control B absorption by kiwifruit plants in areas where B toxicity is still an agricultural problem.

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