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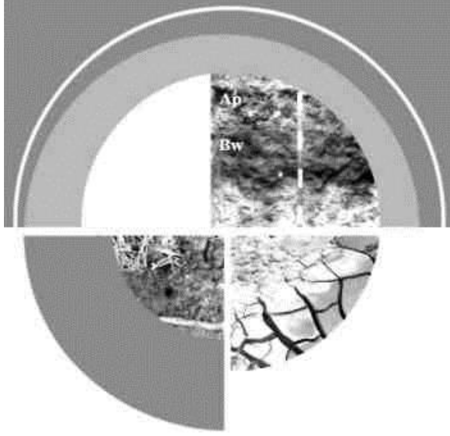

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Effects of boron fertilizer and application methods on yield and chemical composition of rocket (*Eruca Sativa*)

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Abstract

Boron (B) deficiency is widespread in the Anatolia region of Turkey. This could impact production and quality of Roka (*Eruca Sativa*). Greenhouse experiment was conducted to study yield and quality response of Roka to B addition (0, 1, 3 and 9 kg B ha^{-1}) using 4 application methods (seed coating, soil application, seeds were soaked in the B suspension, and foliar fertilizer). B application method affected the plant yield. The optimum economic B rate (OEBR) ranged from 2.0 to 3.2 kg B ha^{-1} resulting in soil B levels of 0.90-1.50 mg kg^{-1}. Independent of application method, B application affected tissue macro-and micro element content and increased tissue P, K, Fe, and Zn content but decreased tissue N, Ca and Mg for each of the cultivars. We conclude a seed coating application method addition was most effective application method to increase the yield and elevate soil B levels to non-deficient levels. Similar studies with different soils and initial soil test B levels are needed to conclude if these B application rates and critical soil test values can be applied across the region.

Key words: Ardisol, boron, fertilizer application method, macro and micro nutrient, optimum economic yield

INTRODUCTION

Vegetable production is getting increase in all around the world. Turkey has favorable ecological conditions for vegetable growth and is one of the most important vegetable producers in the world. Turkey is fourth important producer (26 million tons) country reading of vegetable production in the world (FAO, 2008).

In terms of economic value, nutrition, consumer preference, general adaptability and extent of cultivation, the most commonly grown vegetable crops in Turkey are tomato (*Lycopersicon esculentum* L.), watermelon (*Citrillus lanatus* (Thunb.) Mansf.), cucumber (*Cucumis sativus* L.), pepper (*Capsicum annuum* L.), eggplant (*Solanum melongena* L. *var.*

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esculentum Nees), squashes (*Cucurbita pepo* L., *C. maxima* L. *and C. moschata* L.), onion (*Allium cepa* L.), snap bean (*Phaseolus vulgaris* L.), melon (*Cucumis melo* L.), radish (*Raphanus sativus* L.) and salad vegetables including Roka (*Eruca Sativa*), lettuce (*Lactuca sativa* L. *var. longifolia*) and crisp lettuce (*Lactuca sativa* L. *var. crispa*). Brussels sprout is not commonly grown but there is an increasing interest in its production due to it high nutritional value.

Boron plays an important role in cell-wall synthesis, sugar transport, cell division, differentiation, membrane functioning, root elongation, regulation of plant hormone levels, and generative growth of plants (Marschner, 1995). Boron deficiency symptoms first become evident on the younger leaves which change color and become hardened, malformed and necrotic.

Boron deficiency has been reported in 132 crops in 80 countries (Shorrocks, 1997) and is a major cause of crop yield loss in China, India, Nepal, and Bangladesh (Anantawiroon et al., 1997). In Turkey, B deficiency was identified through individual field trials (Gezgin et al. 2002, Gezgin and Hamurcu, 2006) and in a larger assessment of micronutrient availability (Gezgin et al., 1999). It is estimated that in the central southern and eastern Anatolia regions of Turkey 27 to 34% of the soils are B deficient (Gezgin et al., 2002; Gezgin and Hamurcu, 2006; Angın et al., 2007).

Boron management is challenging as the optimum B application range is narrow (Gupta, 1993), and optimum B application rates can differ from one soil to another (Gupta, 1993; Marschner, 1995). Crop response to B application has been documented for wheat (*Triticum durum* Desf.) (Soylu et al., 2004), sunflower (*Helianthus annuus* L.) (Asad et al., 2002; Oyinlola, 2007), and chickpea (*Cicer arietinum* L.) (Ceyhan et al., 2007). However, little is known about the B requirements of Roka.

The objectives of this study were (1) to evaluate the yield response of Roka to boron fertilizer, (2) to determine the effects of B addition on the mineral composition of Roka, and (3) to determine optimum soil test B levels for Roka under greenhose conditions.

MATERIAL AND METHODS

Initial Soil Sampling and Characterization

Soil was sampled from the Ap horizon (0-20 cm) of an Aridisol (Soil Survey Staff, 1992) with parent materials mostly consisting of volcanic, marn and lacustrin residual and transported material in Erzurum province (39° 55' N, 41º 61' E), Turkey. Soil was air-dried indoors until it could be crumbled to pass through 4 mm for the pot experiment and crushed to 2 mm for chemical and physical analyses. Particle size analysis was performed by the pipette method after pre-treatment with 35% H_2O_2 and 1.0 *M* HCl to remove organic matter and carbonates according to Gee and Bauder (1986). Bulk density was determined with the graduated cylinder method (Blake and Hartge, 1986) and cation exchange capacity (CEC) was determined using sodium acetate (buffered at pH 8.2) and ammonium acetate (buffered at pH 7.0) according to Sumner and Miller (1996). The Kjeldahl method (Bremner, 1996) was used to determine organic N while plant-available P was determined by using the sodium bicarbonate method of Olsen et al. (1954). Electrical conductivity (EC) was measured in saturation extracts according to Rhoades (1996). Soil pH was determined in 1:2 extracts, and calcium carbonate concentrations were determined according to McLean (1982). Soil organic matter was determined using the Smith-Weldon method according to Nelson and Sommers (1982). Ammonium acetate buffered at pH 7 was used to determine exchangeable cations (Thomas, 1982). Micro elements in the soils were determined by Diethylene Triamine

Pentaacetic Acid (DTPA) extraction methods (Lindsay and Norvell, 1978). Samples were analyzed for extractable B using the azomethine-H extraction of Wolf (1974) and a UV/VIS (Aqumat) spectrophotometer (Thermo Electron Spectroscopy LTD, Cambridge, UK). These soil characterization data are presented in Table 1.

Table 1. Chemical and physical properties of the soil sample used in the study, prior to experiment for boron response trials at roka (mean ± SD, n = 5).

Soil Properties	Units	Value
Sand	%	25.3±2.10
Silt	%	33.4±1.90
Clay	%	41.3±2.00
CEC	$cmol_{(+)}$ kg^{-1}	25.8±2.40
Organic C	g kg^{-1}	1.7±0.40
pH	1:2.5 w/v	7.4±0.80
$CaCO_3$	g kg^{-1}	0.9±2.00
Total N	g kg^{-1}	0.9±0.20
Olsen-P	mg kg^{-1}	7.2±1.30
EC	dS m^{-1}	1.8±0.30
Exc. K	$cmol_{(+)}$ kg^{-1}	2.2±0.20
Exc. Ca	$cmol_{(+)}$ kg^{-1}	13.3±2.30
Exc. Mg	$cmol_{(+)}$ kg^{-1}	2.8±0.60
Exc. Na	$cmol_{(+)}$ kg^{-1}	0.30±0.30
Extr. Fe	mg kg^{-1}	0.95±0.30
Extr. Mn	mg kg^{-1}	2.1±0.10
Extr.Zn.	mg kg^{-1}	0.74±0.10
Extr.Cu	mg kg^{-1}	1.05±0.10
Extr. B	mg kg^{-1}	0.11±0.03

Plant Analysis

Plant samples were oven-dried at 68°C for 48 h and ground to pass 1mm sieve. Flag leaf of each treatment were analyzed for N, P, Ca, Mg, Fe, Mn, Zn, Cu, and B content to assess the relationship between plant mineral content and soil B content and application rate. The Kjeldahl method and a Vapodest 10 Rapid Kjeldahl Distillation Unit (Gerhardt, Konigswinter, Germany) were used to determine total N (Bremner, 1996). Macro- (P, S, K, Ca and Mg) and micro-elements (Fe, Mn, Zn Cu, and B) were determined after wet digestion of dried and ground sub-samples using a HNO_3-H_2O_2 acid mixture (2:3 v/v) with three step (first step; 145ºC, 75%RF, 5 min; second step; 180ºC, 90%RF, 10 min and third step; 100ºC, 40%RF, 10 min) in microwave (Bergof Speedwave Microwave Digestion Equipment MWS-2) (Mertens, 2005a). Tissue P, K, S, Ca, Mg, Fe, Mn, Zn, Cu and B were determined Inductively Couple Plasma spectrophotometer (Perkin-Elmer, Optima 2100 DV, ICP/OES, Shelton, CT 06484-4794, USA) (Mertens, 2005b).

Pot Experiment

The experiments were conducted using a randomized complete block design with four B application rates (0, 1, 3, and 9 kg ha^{-1} as $Na_2B_4O_7$. 10 H_2O) four application method ; seed contacted with dry B fertilizer (SDC), seed soaked in the B solution waited 2h (SSS), soil application (SA), and foliar fertilizer application (FA) and three replications. Initial soil B levels amounted to 0.10-0.11 mg kg^{-1}, reflecting a B deficiency. NH_4NO_3 (33 %N) and TSF (48% P_2O_5) were used as fertilizers in the study. Soil tests did not indicate a need for additional K so no K fertilizer was applied. Soil was mixed with the equivalent of 250 kg ha^{-1} N and 150 kg ha^{-1} P_2O_5 placed in 60 pots (25 cm diameter and 18 cm depth) sterilized with 20% sodium hypochlorite solution (3 kg soil pot^{-1}). Roka seed was sown at a rate of 1 kg seeds/ 1000 m^2 in 0.5 cm depth. Plants were grown into a greenhouse under a natural day-night cycle, 25-16°C and 55% relative humidity during the experimental period. The water content of the soil was maintained at 70% of field capacity (375 g kg^{-1}) throughout the 60 d experiments by daily additions of dionized water, and plants were harvested 60 d after planting and washed with dionized water to remove soil particles.

Statistical Analysis

Data gathered at each treatment were subjected to analysis of variance (ANOVA) and significant means were compared using the Duncan multiple range test, performed using SPSS 13.0 [28]. Mean differences were considered significant when $P \leq 0.05$.

RESULTS AND DISCUSSION

Yield and Yield Parameters

Different boron fertilizer application method and doses affected the total fresh weight (TFW), roka (Figure 1). The highest TFW (2224 g pot^{-1} was obtained from SDC application method with optimum B ranges (OBRs) that ranged from 6.5 kg B ha^{-1}. Without B addition, the average TFW was determined 1560 g pot^{-1}. Compared to without B fertilizer, these increases ratio for SDC, SSS, Sa, and FA were 42%, 12%, 31%, and 33%, at applied at the 6 kg ha^{-1} respectively, (Figure 1).

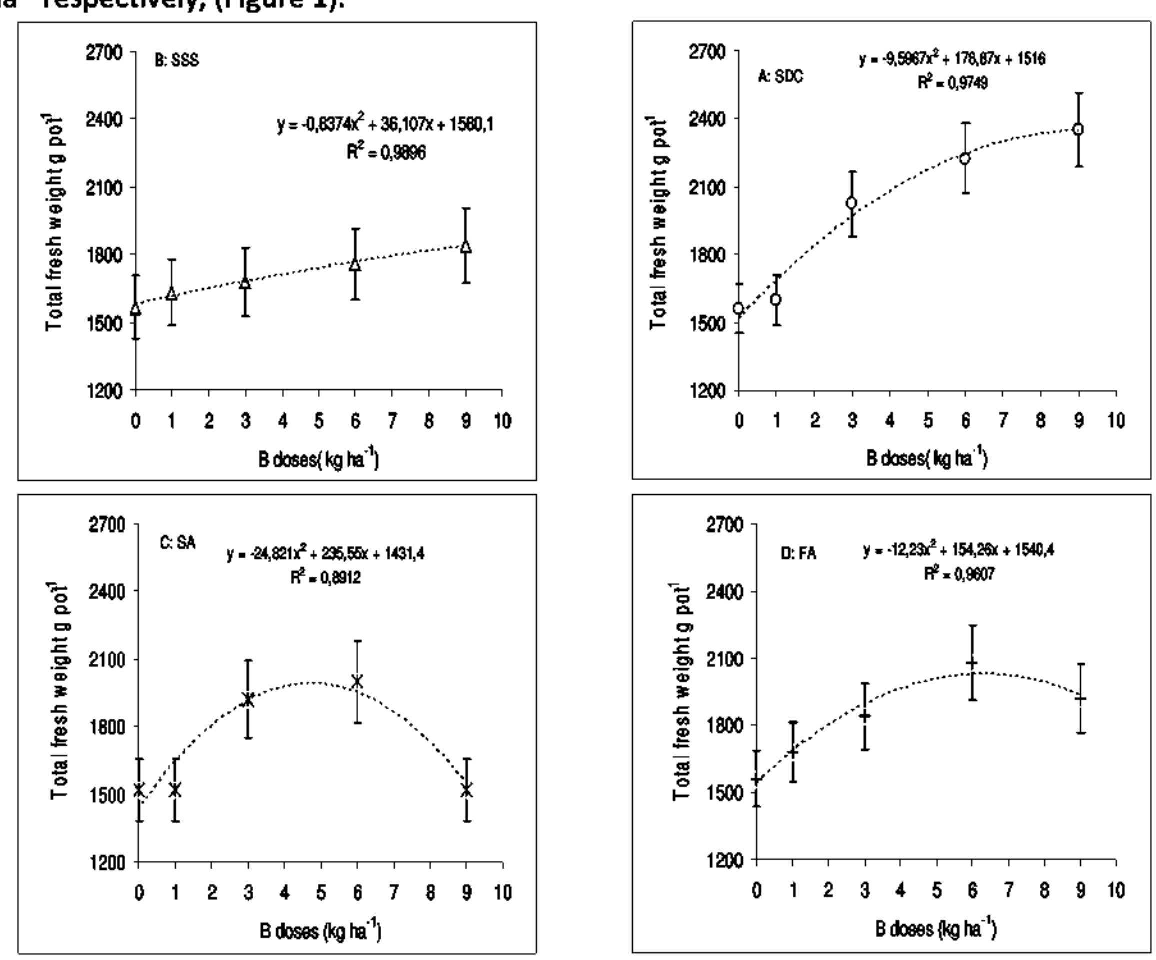

Figure 1. Roka total fresh weight as affected by boron (B) applications methods; A: seed contacted with dry B fertilizer (SDC) and B: seed were soaked in the B solution waited 2h (SSS) C: soil application (SA), and D: foliar fertilizer application (FA) at different ratio to a B-deficient calcareous Aridisol.

The optimum B rates (OBRs) for TFW in our study were higher than 1.20 kg B ha^{-1} rates obtained Ross et al. (2006), 1.3 kg B ha^{-1} Oplinger et al. (1993), 0.5 kg B ha^{-1} , Santos et al. (2004), 1.5 kg B ha^{-1} Moniruzzaman (2007), 2.3, 2.6, 2.4 kg B ha^{-1} Dursun et al. 2010 for soybean (*Glycine max* Merr. L), cotton (*Gossipium hirsutum*), alfalfa (*Medicago sativa* cv. Crioula), bentgrass (*Agrostis palustris* Huds.), tomatoes (*Lycopersicon esculentum* L.), pepper (*Capsicum annum* L.) and cucumber (*Cucumis sativus* L.) but lower than the 8.0 kg B ha^{-1} obtained by Oyinlola (2007). This result can be attributed initial soil B level (0.09 mg kg-1) soil type (Alfisol) and sunflower particularly sensitive to B deficiency and is used as an indicator crop for assessing available B in soils (Milkovic et al. 1996, Tisdale et al. 1985).

Relationship between yield and tissue B contents

Boron concentrations in plant leaves tissue were increased with increase B application doses all of the application method. The average tissue B content in the control treatments was 3.34 mg kg^{-1} for roka, and this value was reached the 29.8 mg B kg^{-1} at 9 kg ha^{-1} for SDC application method. This increased to 36.6 and 40.6 and 35.1 mg B kg^{-1} for SSS, SA and FA methods, respectively. B concentrations in plant leaves tissue were correlated to yield but, beyond the OBR for TFW of plant, tissue B continued to increase without significant increases in yield (Figure 2).

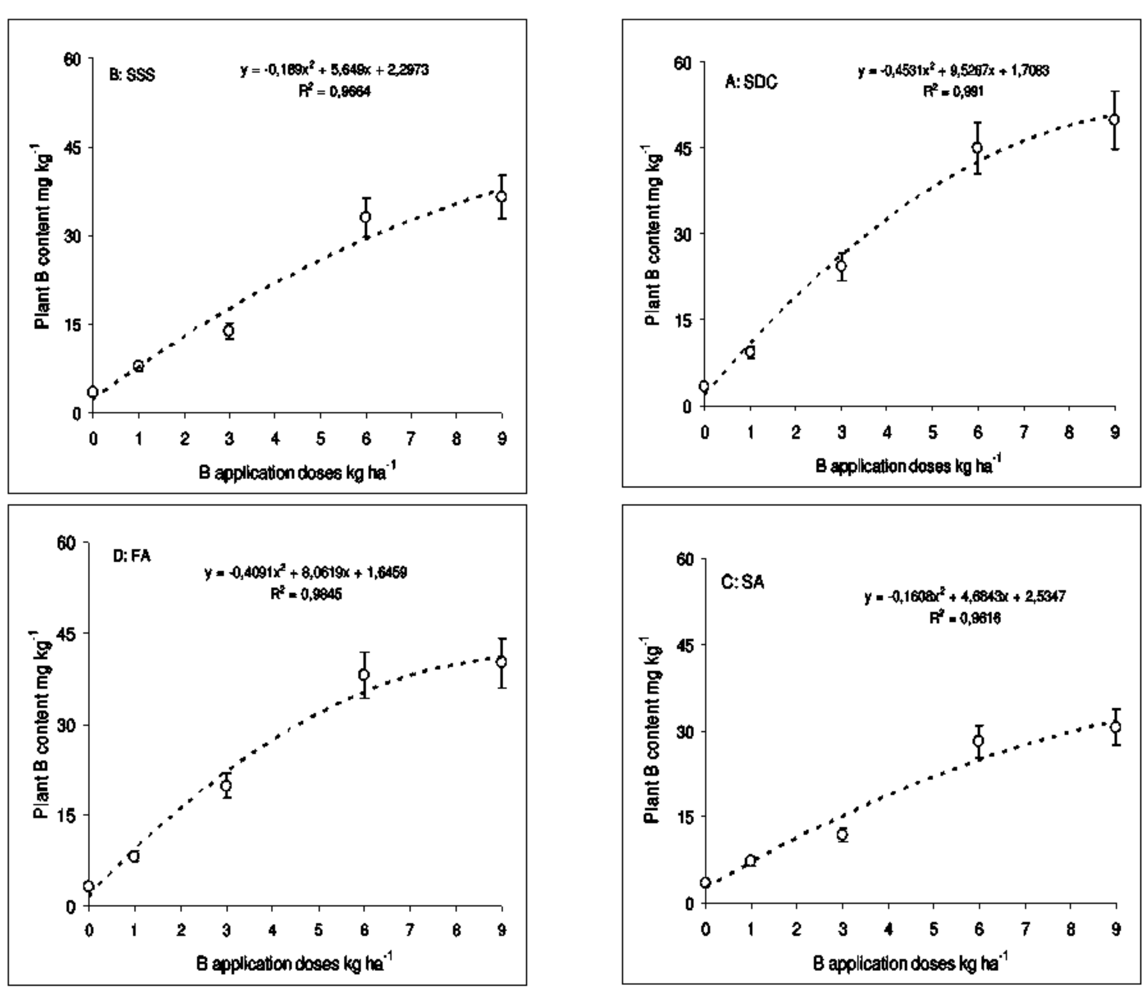

Figure 2. Effects of boron application methods (A:SDC, B: SSS, C:SA, and D:FA) on plant B concentration of roka grown on a calcareous Aridisol

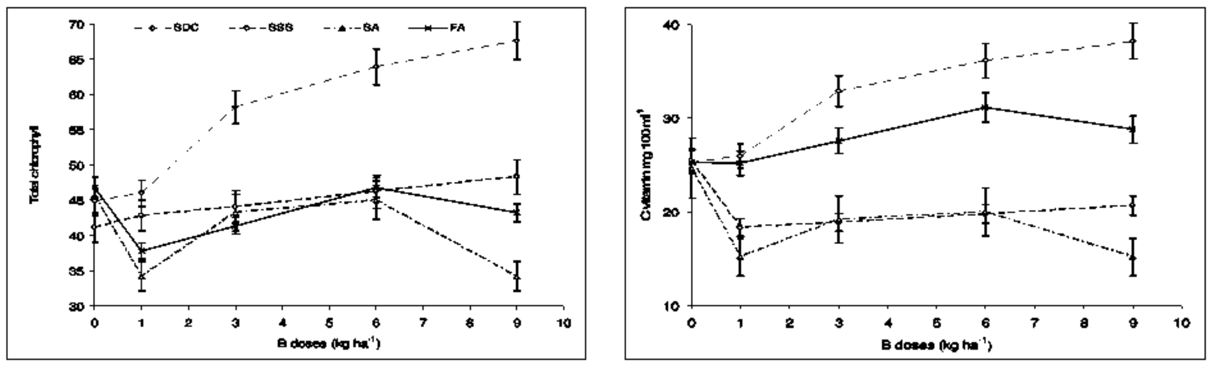

Figure 3. Effects of boron application methods (A:SDC, B: SSS, C:SA, and D:FA) on plant total chlorophyll and C vitamin concentration roka grown on a calcareous Aridisol

Compiling results from the greenhouse and field experiments published during 10 years, Guertal (2004), Santos et al. (2004), Ross et al. (2006) suggested that 10 mg kg^{-1}, 66 mg kg^{-1}, 44.1 mg kg^{-1} in plant tissue as critical level for boron in bentgrass (*Agrostis palustris* Huds.), alfalfa (*Medicago sativa* cv. Crioula) and soybean (Glycine max (Merr.) L), whereas Goldberg et al. (2003) reported a range of 142 to 3000 mg kg^{-1} in different plant parts of melons (*Cucumis sativus* L.).

Total chlorophyll, Vitamin C and Mineral Contents of Plant

Total chlorophyll, vitamin C, P, K, Mg, Fe, Zn, Mn, and Cu of plant leaves increased with increasing boron application doses all of the B application method but, decreased leaf tissue Ca (Table 2). The concentrations of plant nutrients measured were generally within accepted critical levels. Mills and Jones (1996) suggested critical values for optimum roka growing as 1.7-3.0% for N, 0.2-0.5% for P, 2.0-4.0% for K, 1.0- 2.5.0% for Ca, 0.25-0.75 for Mg, 0.30-0.75% for S, 60-300 mg kg^{-1} for Fe, 25-200 mg kg^{-1} for Zn, 16-200 mg kg^{-1} for Mn, and 5-15 mg kg^{-1} for Cu .

An increase in tissue P, K, Fe, Mn, Zn, and Cu upon B application was also reported for chickpea (*Cicer arientinum* L.) P content (Sing and Sing 1990), lentil (*Lens culinaris* Medikus) K content (Sing and Sing 1983), sugar beet (*Beta vulgaris* L.) Zn content (Hamurcu and Gezgin, 2001), rice (*Oryza sativa* L.) Fe content (Santra 1989), cowpea (*Vigna unguiculata*) Mn content (Singh 1988), cotton (*Gossypium herbaceum*) Cu content (El-Gharabbly and Bussler, 1986), Brussels sprouts (*Brassica oleracea* L. Gemnifera) N, P, K content (Turan et al. 2009a), lucerne (*Medicago sativa* L.) N, P, K, and Fe (Turan et al. 2009b) and tomatoes (*Lycopersicon esculentum* L.), pepper (*Capsicum annum* L.), cucumber (*Cucumis sativus* L.) P, K, Fe, Mn, Zn and Cu content Dursun et al. (2010).

CONCLUSION

Both B application doses and application method affected the TFW of roka. The highest TFW was obtained from SDC application method. Independent of application methods, B application increased total chlorophyll, vitamin C, P, K, Mg, Fe, Zn, Mn, and Cu , but decreased leaf tissue Ca content. We conclude beyond the OBR for TFW of plant, tissue B continued to increase without significant increases in yield. This study was conducted on calcareous soils. Similar studies with different soils and initial soil test B levels are needed to conclude if these critical soil and tissue values can be applied across the region under field condition.

Table 2. Macro and micro element contents of roka leaves grown in Aridisol with different B application method at various rates in greenhouse condition (mean ± SD, n=3), mg kg^{-1}.

B doses, kg ha^{-1}	N	P	K	Ca	Mg	S	Fe	Zn	Mn	Cu
					SDC					
0	2.75	0.27 b	1,52c	0,51a	0,25b	0,19b	33,85c	47,73c	27,17c	6,64b
1	3.08	0,34ba	2,27b	0,52a	0,29a	0,24ab	49,32b	65,12b	46,47ab	9,83a
3	3.20	0.40a	3,65a	0,49a	0,31a	0,25a	79,29a	81,73a	42,97b	9,83a
6	3.14	0.41a	3,65a	0,46ab	0,32a	0,26a	81,96a	81,73a	50,84a	9,28a
9	3.06	0,42a	3,46a	0,34b	0,33a	0,27a	92,58a	77,40a	53,47a	10,35a
					SSS					
0	2,31	0,27b	1,91c	0,43a	0,21b	0,16b	28,51d	40,22c	22,72c	5,59b
1	2,59	0,28b	1,91c	0,43a	0,24ab	0,20a	41,53c	54,83b	38,85ab	8,27a
3	2,69	0,34a	3,07a	0,42a	0,26a	0,21a	66,79b	68,86a	35,93b	8,27a
6	2,65	0,35a	3,07a	0,38a	0,29a	0,22a	69,02b	68,86a	42,53a	7,83a
9	2,59	0,35a	2,91ab	0,29b	0,29a	0,22a	77,98a	65,19a	44,73a	8,72a
					SA					
0	2,52	0,25b	2,08b	0,47a	0,23b	0,16b	31,06d	43,81c	24,76d	6,09b
1	2,83	0,31ab	2,08b	0,47a	0,26ab	0,20a	45,25c	59,76b	42,36ab	9,01a
3	2,93	0,37a	3,35a	0,46a	0,28a	0,21a	72,78b	75,04a	39,14c	9,01a
6	2,89	0,38a	3,35a	0,42a	0,30a	0,22a	75,21b	75,04a	46,35b	8,53a
9	2,82	0,39a	3,17a	0,31b	0,30a	0,22a	84,98a	71,04a	48,74a	9,51a
					FA					
0	2,29	0,27	1,98b	0,48a	0,20b	0,18	30,36b	33,26c	18,80c	4,62b
1	2,14	0,23	2,03b	0,36a	0,20b	0,16	34,34b	45,36b	32,13ab	6,85a
3	2,23	0,28	2,54a	0,35a	0,21b	0,18	55,22a	56,94a	29,72b	6,78a
6	2,19	0,29	2,54a	0,31ab	0,27a	0,18	57,07a	56,94a	35,18a	6,47a
9	2,13	0,30	2,41a	0,23b	0,33a	0,18	64,48a	53,91a	36,98a	7,20a

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