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Efficacy of Boron Spraying on Growth and Some External Qualities of Lettuce

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Abstract: A study to evaluate boron, in terms of borax ($B_4O.2Na.10H_2O$) or boric (H_3BO_3) by foliar spraying, on growth and external qualities was conducted on lettuce var. Grand Rapids under field conditions. A Factorial in Completely Randomized Design was arranged with four replications and composed of two factors; two types of boron (borax or boric) with four concentration rates (0, 0.0625, 0.125 or 0.1875%). The results showed that plants-treated with 0.0625% boric had the maximal plant height and bush size. While two types of boron at any concentration had no effect to biomass, chlorophyll content and the leaf colour. Furthermore, plants treated with 0.0625% boric experienced the lowest browning appearance at harvesting stage.

Key words: Efficacy, boron, growth, external qualities, browning appearance, lettuce

INTRODUCTION

Lettuce (*Lactuca sataiva*), belonging to the family Asteraceae, which is a popular vegetable and considered one of the most important all year around crops in Thailand. In 2007, the total area for cultivating lettuce in Thailand was about 2,119.2 ha with an estimated production of 15,499.87 tons/year. Most lettuce is used for fresh consumption as fast food and prepared salads. In addition, lettuce is considered as an important source of potentially healthy bioactive compounds and several mineral nutrients which are valuable to human health (Ahvenainen, 1996; Dupont *et al*., 2000). For example, dietary antioxidants, including phenolics, ascorbic acid, carotenoids, tocopherols and glucosinolates in lettuce are known to have protective effects against various forms of cancer and cardiovascular and cerebrovascular diseases (Lister, 2003; Nicolle *et al*., 2004; Llorach *et al*., 2008; Verlangieri *et al*., 1985). One of the major external losses of quality in lettuce is caused by leaf discolouration and is associated with the enzyme polyphenol oxidase, which leads to browning damage appearing on the leaf surface. This browning appearance could be observed visually on leaf surfaces during the developmental period (Chutichudet *et al*., 2009). This discoloration has long been considered the main production problem of lettuce because it limits consumer acceptance and decreases market value (Lopez-Galvez *et al*., 1996). It has been hypothesized that development of browning disorder in lettuce is a consequence of leaf membrane disintegration (Kays, 1991; Felicetti and Schrader, 2009). Therefore, it is very important to prevent this physiological disorder by seeking a practical method of maintaining membrane integrity (Franck *et al*., 2007). At present, data are scarce

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concerning any practical methods to prevent this browning disorder in lettuce planted under the field conditions. Fageria *et al.* (2002) reported that one of the factors associated with this problem was fertilizer, which provided the nutrients needed by plants to grow properly and yield the quality product (McCraw and Motes, 1972), such as gypsum (Chutichudet *et al.*, 2009) and boron (Marschner, 1995).

Boron is an essential micronutrient for plant growth of several vascular plants (Marschner, 1995) which is presented in soils between 2 and 100 ppm (Villanueva *et al.*, 1998). Generally, less than 5% of boron in soil is available for plants due to the scarcely soluble boron in soil water and the drainage to deep beds (Flores *et al.*, 2006). Rerkasem *et al.* (1989) reported that boron deficiency in agricultural soils has also been found in some areas in Thailand. Naturally boron deficient soils, or those intensively farmed, should be outfed, supplying between 0.5 and 15 boron kg per ha during the plant growth (Flores *et al.*, 2006). The role of boron in plants is still not well understood (Mengel and Kirkby, 2001). It is suggested that the primary effect of boron deficiency appeared to be disruption of the normal functioning of the apical meristems with changes in membrane structure, cell wall synthesis, including metabolisms of auxin and carbohydrate (Parr and Loughman, 1983; Blevins and Lukaszewski, 1998; Brown *et al.*, 2002). Singh *et al.* (2007) reported that pre-harvest foliar application of boron has influenced the occurrence of physiological disorders. For example, in apple trees faced with boron deficiency Peryea (1994) found that these tended to lessen tree size and increase sensitivity toward browning. In another study, Rajbir *et al.* (2007) found that pre-harvest foliar application of boron influenced a significant decrease in the occurrence at harvest of physiological disorders in Chandler strawberries. Xuan *et al.* (2001) mentioned that the application of boron has been shown to reduce browning incidence in Conference pears in some cases. Wojcik *et al.* (2008) also reported that the application of boron to increase yield in many crops by foliar spraying was more efficient than soil fertilization because the absorption rate of applied boron in plants was limited. At present, very little information is available on boron requirements concerning growth characteristics and external qualities in lettuce production. Thus, the aim of this study was to investigate the efficacy of exogenous foliar spraying, boron, on growth and some external qualities, specifically to decrease leaf browning incidence of lettuce grown under field conditions.

MATERIALS AND METHODS

The research outlined in this report was carried out at the experimental field, Division of Agricultural Technology, Faculty of Technology, Mahasarakham University, in the Northeast of Thailand in the period between May to August, 2008. The seedlings of Grand Rapids lettuce were transplanted at 15 days after planting and grown singly in 2 L pots filled with a sandy loam soil : rice husk : manure ratio 1:1:1 and placed under field conditions. A Factorial in Completely Randomized Design was arranged and composed of two factors: foliar spraying of two types of boron: borax ($B_4O.2Na.10H_2O$) or boric (H_3BO_3) at four concentrations (0, 0.0625, 0.125 or 0.1875%). Each treatment was carried out in four replicates, ten plants per replication. Boron foliar spraying was applied to lettuce plants after planting at 20 and 34 days by using a hand pressure sprayer. Plants untreated with boron served as the control. The different types and concentrations of boron being used as treatments were: 0% boron (T1, control), 0.0625% borax (T2), 0.125% borax (T3), 0.1875% borax (T4), 0.0625% boric (T5), 0.125% boric (T6) and 0.1875% boric (T7). Basal fertilizer of 15:15:15 at the rate of 20 g per 20 L was watered to the plants every seven days. The following determinations were recorded for assessments of (1) plant height (cm), (2) stem diameter (cm), (3) bush size (cm), (4) biomass was determined by the method of AOAC (1980) and expressed in percentage, (5) chlorophyll content by using the SPAD chlorophyll Meter Minolta SPAD 502, China and expressed in SPAD unit, (6) leaf colour was measured with a Hunter Lab Model No. 45/0-L, Serial No. 7092, USA. CIE standard for measuring colour values in terms of L^*(black = -100 and white = +100), a^* (redness) (- = green and + = yellow) and b^* (yellowness) (- = blue and + = yellow) and (7) levels of browning on leaf surfaces were scored by determining visually expressing as percentage. The collected data were statistically analyzed using the SPSS Computer Programme, Version 6 (SPSS, 1999).

RESULTS

The results were collected after putting boron, with different types and concentrations, on lettuce grown under field conditions. The recorded data were composed of:

Plant Height

All recording data about plant height of lettuce showed that plant treated with 0.0625% borax or 0.0625% boric was significantly higher. The maximal plant height of 17.32 and 17.22 cm, respectively at harvest (Table 1).

Stem Diameter

The results from Table 2 showed a significant difference in the size of the stem diameter among treatments from 25 to 53 Days after Planting (DAP). However, the effectiveness of the two types of boron with different concentrations in activating the size of stem diameter of lettuce were diminished when plants were harvested at 60 DAP.

Table 1: Plant height of lettuce after applying different types and concentrations of boron

	Plant height (cm) after planting (days)					
Factors	25	32	39	46	53	60
Boron type						
Control	7.83ab	7.97b	8.58 b	9.72 b	14.38	14.88
Borax	7.01b	8.35b	8.63 b	13.75 a	15.51	16.15
Boric	8.94a	9.88a	9.96 a	14.11 a	15.40	15.98
F-test	**	**	*	**	ns	ns
CV (%)	13.03	12.82	12.46	11.04	10.24	5.54
LSD	0.386	0.4278	0.4267	0.5485	0.5838	0.3873
Boron conc. (%)						
0	7.83	7.97	8.58	9.72c	14.38b	14.88c
0.0625	8.38	9.63	9.41	14.77a	17.10a	17.27a
0.125	8.02	9.23	9.52	14.09ab	14.48b	14.90c
0.1875	7.52	8.5	8.95	12.93b	14.78b	16.04b
F-test	ns	ns	ns	**	**	**
CV (%)	17.46	14.75	14.41	9.81	7.14	2.78
LSD	0.05488	0.5218	0.5235	0.5170	0.4319	0.1745
Type×conc. (%)						
Control 0%	7.83bc	7.97c	8.58bc	9.72d	14.38b	14.88d
Borax 0.0625%	7.04c	8.41bc	8.06c	13.74bc	17.31a	17.32a
Borax 0.125%	6.83c	8.63bc	9.10bc	13.81bc	13.95b	14.69d
Borax 0.1875%	7.15c	8.01c	8.71bc	13.71bc	15.25b	16.45b
Boric 0.0625%	9.72a	10.84a	10.76a	15.81a	16.88a	17.22a
Boric 0.125%	9.21ab	9.83ab	9.94ab	14.38ab	15.00b	15.10cd
Boric 0.1875%	7.89bc	8.99bc	9.20abc	12.16c	14.32b	15.63c
F-test	**	*	*	**	**	**
CV (%)	12.10	12.25	12.02	3.52	7.03	2.36
LSD	0.4812	0.5482	0.5526	0.5680	0.5379	0.1875

Letter(s) within columns indicate Least Significant Differences (LSD) at **p = 0.01, *p = 0.05, NS: Non significant

Table 2: Stem diameter of lettuce after applying different types and concentrations of boron

	Stem diameter (cm) after planting (days)					
Factors	25	32	39	46	53	60
Boron type						
Control	0.31	0.31 b	0.33	0.36	0.38	0.47
Borax	0.33	0.33 a	0.34	0.35	0.41	0.46
Boric	0.33	0.34 a	0.35	0.36	0.40	0.46
F-test	ns	*	ns	ns	ns	ns
CV (%)	0.01	0.02	0.03	0.02	7.83	3.74
LSD	0.0081	0.0079	0.0039	0.0057	0.0143	0.0153
Boron conc. (%)						
0	0.31b	0.31	0.33b	0.36ab	0.38b	0.47
0.0625	0.33ab	0.33	0.34b	0.34b	0.36b	0.46
0.125	0.34a	0.35	0.35a	0.36ab	0.42a	0.45
0.1875	0.32b	0.34	0.35a	0.37a	0.44a	0.46
F-test	*	ns	**	*	**	ns
CV (%)	0.01	0.02	0.01	0.03	0.03	3.74
LSD	0.0076	0.0084	0.0035	0.0051	0.0086	0.0165
Type×conc. (%)						
Control 0%	0.31c	0.31	0.33b	0.36ab	0.38c	0.47
Borax 0.0625%	0.32bc	0.32	0.33b	0.33c	0.36c	0.46
Borax 0.125%	0.35a	0.35	0.35a	0.36ab	0.42b	0.45
Borax 0.1875%	0.33abc	0.34	0.36a	0.37a	0.46a	0.46
Boric 0.0625%	0.34ab	0.35	0.35a	0.35b	0.37c	0.46
Boric 0.125%	0.34ab	0.35	0.35a	0.36ab	0.42b	0.46
Boric 0.1875%	0.31c	0.33	0.35a	0.36ab	0.43ab	0.47
F-test	*	ns	**	*	**	ns
CV (%)	0.02	0.03	0.03	0.03	0.01	3.74
LSD	0.0091	0.0105	0.0030	0.0059	0.0105	0.0222

Letter(s) within columns indicate Least Significant Differences (LSD) at **p = 0.01, *p = 0.05, NS: Non significant

Bush Size

The significant differences in the size of lettuce's bush between the two types of boron with different concentrations are shown in Table 3. At harvest, the maximal bush size of lettuce plants would be activated by applying 0.0625 and 0.1875% boric.

Biomass

The percentage of biomass gradually increased during plant development. Almost all recorded data in this parameter showed a similar amount of biomass in both boron treatments and control samples (Table 4).

Chlorophyll Content

Forty two days after planting, lettuce tended to increase its chlorophyll content. The highest chlorophyll levels were obtained at 49 DAP. Afterwards, chlorophyll contents gradually decreased and showed no significant difference (Table 5).

Colour Values

The results from Table 6-8 showed the changes in leaf colour of lettuce measured in terms of L*, a* and b*. The results showed that no significant difference in any of the measured colours was observed through 42 to 63 DAP.

Level of Browning

Overall browning in lettuce, which marked the visible level of discolouration during plant development, is presented in Table 9. The results show that at harvest, plants-treated with 0.125% borax, 0.1875% borax and 0.0625% boric, had similar or lesser extent of browning

Table 3: Size of lettuce's bush after applying different types and concentrations of boron

Factors	Bush size (cm) after planting (days) 25	32	39	46	53	60
Boron type						
Control	5.95	5.20b	6.30	8.44b	11.15a	11.30ab
Borax	5.73	5.52ab	6.54	8.97ab	9.95b	10.12b
Boric	7.03	6.05a	6.96	9.55a	11.18a	11.90a
F-test	ns	*	ns	*	**	**
CV (%)	22.37	11.02	11.29	7.83	3.84	11.88
LSD	0.5269	0.2338	0.2813	0.2666	0.3509	0.4895
Boron conc. (%)						
0	5.95ab	5.20b	6.30	8.44	11.15	11.30
0.0625	6.92a	6.24a	6.97	9.63	10.93	11.14
0.125	7.18a	5.63ab	6.71	9.25	1.017	10.39
0.1875	5.04b	5.48b	6.57	8.90	10.60	11.50
F-test	*	*	ns	ns	ns	ns
CV (%)	20.01	10.69	11.67	7.93	10.29	13.94
LSD	0.4998	0.2409	0.3085	0.2868	0.4331	0.6093
Type×conc. (%)						
Control 0%	5.95cd	5.20b	6.30	8.44	11.15ab	11.30bc
Borax 0.0625%	5.59cd	5.78b	6.63	9.43	10.33abc	10.61bc
Borax 0.125%	6.60bc	5.47b	6.54	8.87	9.86bc	9.93bc
Borax 0.1875%	5.00d	5.30b	6.47	8.62	9.68c	9.83c
Boric 0.0625%	8.26a	6.70a	7.31	9.84	11.54a	11.68ab
Boric 0.125%	7.76ab	5.79b	6.89	9.63	10.48abc	10.86bc
Boric 0.1875%	5.08d	5.65b	6.68	9.18	11.52a	13.18a
F-test	**	*	ns	ns	*	*
CV (%)	15.97	3.96	11.93	7.74	3.77	10.93
LSD	0.5048	0.2838	0.3987	0.3540	0.4669	0.6041

Letter(s) within columns indicate Least Significant Differences (LSD) at **p = 0.01, *p = 0.05, NS: Non significant

Table 4: Biomass of lettuce after applying different types and concentrations of boron

Factors	Biomass (%) after planting (days) 25	32	39	46	53	60
Boron type						
Control	5.39	5.51a	5.98b	6.16	6.39	6.84
Borax	5.38	5.39b	6.04ab	6.28	6.47	6.95
Boric	5.30	5.33b	6.18a	6.22	6.44	6.93
F-test	ns	**	*	ns	ns	ns
CV (%)	2.13	1.44	2.65	1.52	2.64	1.58
LSD	0.0432	0.0286	0.0600	0.0345	0.0634	0.0413
Boron conc. (%)						
0	5.39	5.51a	5.98	6.16	6.39	6.84
0.0625	5.34	5.38b	6.06	6.27	6.45	6.90
0.125	5.37	5.35b	6.16	6.22	6.43	6.98
0.1875	5.31	5.34b	6.10	6.26	6.48	6.94
F-test	ns	*	ns	ns	ns	ns
CV (%)	2.29	1.56	2.85	1.52	2.69	1.58
LSD	0.0481	0.0324	0.0689	0.0376	0.0684	0.0432
Type×conc. (%)						
Contro l0%	5.39	5.51a	5.98	6.16	6.39	6.84
Borax 0.0625%	5.35	5.37b	6.09	6.27	6.34	6.88
Borax 0.125%	5.43	5.40ab	6.07	6.27	6.47	7.00
Borax 0.1875%	5.36	5.39b	5.96	6.30	6.60	6.97
Boric 0.0625%	5.33	5.39b	6.04	6.28	6.57	6.93
Boric 0.125%	5.31	5.30b	6.24	6.17	6.39	6.96
Boric 0.1875%	5.27	5.29b	6.25	6.22	6.36	6.92
F-test	ns	*	ns	ns	ns	ns
CV (%)	2.29	1.44	2.49	1.52	2.35	1.65
LSD	0.0610	0.0377	0.0766	0.0469	0.0757	0.0567

Letter(s) within columns indicate Least Significant Differences (LSD) at **p = 0.01, *p = 0.05, NS: Non significant

Table 5: Chlorophyll content of lettuce after applying different types and concentrations of boron

	Chlorophyll content (SPAD Unit) after planting (days)			
Factors	42	49	56	63
Boron type				
Control	16.4100	18.1300a	17.7600a	17.1300
Borax	16.8500	16.0800b	15.1400b	14.4300
Boric	17.0100	15.5000b	14.9200b	17.3600
F-test	ns	**	*	ns
CV (%)	13.5700	7.9600	10.0700	18.0200
LSD	0.8525	0.4782	0.5787	1.0793
Boron conc. (%)				
0	16.4100	18.1300a	17.7600a	17.1300
0.0625	16.8600	15.1000b	15.4600b	14.7600
0.125	18.1900	16.0500b	14.7400b	16.0500
0.1875	15.7400	16.2200b	14.8800b	16.8800
F-test	ns	**	*	ns
CV (%)	12.5200	7.7300	10.1100	19.7900
LSD	0.8342	0.4928	0.6160	1.2569
Type×conc. (%)				
Control 0%	16.4100	18.1300a	17.7600	17.1300
Borax 0.0625%	16.8400	15.7600bc	15.7000	14.1900
Borax 0.125%	17.7400	16.1600bc	14.7000	13.5500
Borax 0.1875%	15.9800	16.3000ab	15.0100	15.5600
Boric 0.0625%	16.8800	14.4400c	15.2100	15.3300
Boric 0.125%	18.6500	15.9400bc	14.7900	18.5500
Boric 0.1875%	15.5100	16.1400bc	14.7500	18.2000
F-test	ns	*	ns	ns
CV (%)	13.2500	7.8500	10.7500	18.0200
LSD	1.1170	0.6328	0.8285	1.4481

Letter(s) within columns indicate Least Significant Differences (LSD) at **p = 0.01, *p = 0.05, NS: Non significant

Table 6: Colour values in term of L* after applying different types and concentrations of boron

	L* values after planting (days)			
Factors	42	49	56	63
Boron type				
Control	50.8200a	54.1000	55.8000	48.1700
Borax	46.1000b	54.2500	53.0800	45.0100
Boric	50.2400a	55.5800	50.8800	45.4100
F-test	**	ns	ns	ns
CV (%)	5.9200	3.4600	7.4700	13.8600
LSD	1.2519	0.7062	1.4612	2.3568
Boron conc. (%)				
0	50.8200	54.1000	55.8000	48.1700
0.0625	49.0700	55.4600	52.9500	45.5900
0.125	47.1500	54.4200	53.0100	47.5700
0.1875	48.2900	54.8600	49.9900	42.5000
F-test	ns	ns	ns	ns
CV (%)	3.0900	3.6500	7.4300	13.4000
LSD	1.5524	0.7901	1.5428	2.4169
Type×conc. (%)				
Control 0%	50.8200	54.1000	55.8000	48.1700
Borax 0.0625%	46.5300	55.0700	52.8000	46.8700
Borax 0.125%	46.1400	53.9500	54.1600	46.8600
Borax 0.1875%	45.6200	53.7400	52.2800	41.3000
Boric 0.0625%	51.6000	55.8600	53.0900	44.3100
Boric 0.125%	48.1600	54.8000	51.8600	48.2300
Boric 0.1875%	50.9700	55.9900	47.7100	43.7000
F-test	ns	ns	ns	ns
CV (%)	7.1600	3.6200	7.3500	14.1000
LSD	1.7374	0.9926	1.9304	3.2160

Letter(s) within columns indicate Least Significant Differences (LSD) at **p = 0.01, NS: Non significant

Table 7: Colour values in term of a* after applying different types and concentrations of boron

	a* values after planting (days)			
Factors	42	49	56	63
Boron type				
Control	-9.96	-11.10	-9.46	-8.34
Borax	-9.95	-10.37	-9.99	-8.44
Boric	-9.94	-9.67	-9.65	-8.77
F-test	ns	ns	ns	ns
CV (%)	6.10	13.37	10.19	11.68
LSD	0.2259	0.5068	0.3713	0.3728
Boron conc. (%)				
0	-9.96	-11.10	-9.46	-8.34
0.0625	-9.50	-9.97	-10.29	-8.75
0.125	-10.22	-9.84	-9.74	-8.48
0.1875	-10.12	-10.25	-9.43	-8.58
F-test	ns	ns	ns	ns
CV (%)	5.32	13.96	9.90	12.01
LSD	0.2097	0.5615	0.3825	0.4067
Type×conc. (%)				
Control 0%	-9.96	-11.10	-9.46	-8.34
Borax 0.0625%	-9.83	-10.20	-10.71	-8.39
Borax 0.125%	-10.10	-10.34	-9.58	-8.79
Borax 0.1875%	-9.94	-10.56	-9.69	-8.14
Boric 0.0625%	-9.18	-9.73	-9.88	-9.11
Boric 0.125%	-10.35	-9.34	-9.90	-8.18
Boric 0.1875%	-10.30	-9.94	-9.18	-9.03
F-test	ns	ns	ns	ns
CV (%)	5.16	14.43	10.09	11.96
LSD	0.2564	0.7338	0.4926	0.5120

NS: Non significant

Table 8: Colour values in term of b* after applying different types and concentrations of boron

	b* values after planting (days)			
Factors	42	49	56	63
Boron type				
Control	31.36	32.81	30.35	29.60
Borax	29.55	31.53	30.69	28.06
Boric	30.29	29.40	30.77	27.81
F-test	ns	ns	ns	ns
CV (%)	5.17	15.08	10.01	3.13
LSD	0.6926	1.7311	1.1445	0.9589
Boron conc. (%)				
0	31.36	32.81	30.35	29.60
0.0625	28.96	30.30	31.03	28.39
0.125	30.56	29.77	30.71	28.25
0.1875	30.23	31.34	30.45	27.17
F-test	ns	ns	ns	ns
CV (%)	5.99	15.63	10.19	3.13
LSD	0.7135	1.9032	1.2354	1.0165
Type×conc. (%)				
Control 0%	31.36	32.81	30.35	29.60
Borax 0.0625%	28.92	31.20	32.28	28.44
Borax 0.125%	30.53	30.78	28.96	28.94
Borax 0.1875%	29.20	32.62	30.84	26.80
Boric 0.0625%	29.00	29.39	29.78	28.34
Boric 0.125%	30.59	28.76	32.46	27.56
Boric 0.1875%	31.27	30.06	30.06	27.54
F-test	ns	ns	ns	ns
CV (%)	5.04	16.29	3.97	3.60
LSD	0.9100	2.5086	1.5285	1.3531

NS: Non significant

Table 9: Level of browning of lettuce after applying different types and concentrations of boron

Factors	Level of browning (%) after planting (days) 42	49	56	63
Borontype				
Control	13.6500	25.1500	31.1500	30.1500a
Borax	14.9800	15.2300	24.8200	26.9800b
Boric	7.4000	21.8200	23.9800	28.9800ab
F-test	ns	ns	ns	*
CV (%)	15.1200	5.3600	3.4900	7.7900
LSD	4.5221	3.8927	3.3035	0.8210
Boron conc. (%)				
0	13.6500ab	25.1500a	31.1500a	30.1500
0.0625	22.2800a	25.6500a	27.0300a	28.1500
0.125	3.9000b	22.7800a	17.9000b	27.7800
0.1875	7.4000b	7.1500b	28.2800a	28.0300
F-test	**	**	*	ns
CV (%)	8.8500	9.2500	3.0700	3.6800
LSD	4.0367	3.0211	3.0780	0.9708
Type×conc. (%)				
Control 0%	13.6500abc	25.1500a	31.1500	30.1500a
Borax 0.0625%	24.6500a	25.1500a	28.4000	29.4000a
Borax 0.125%	6.6500bc	19.4000ab	19.9000	26.1500b
Borax 0.1875%	13.6500abc	12.1500b	26.1500	25.4000b
Boric 0.0625%	19.9000ab	26.1500a	25.6500	26.9000b
Boric 0.125%	1.1500c	26.1500a	15.9000	29.4000a
Boric 0.1875%	1.1500c	13.1500b	30.4000	30.6500a
F-test	*	*	ns	**
CV (%)	16.3100	13.3600	3.1900	5.7700
LSD	4.9818	3.5098	4.0415	0.8165

Letter(s) within columns indicate Least Significant Differences (LSD) at **p = 0.01, *p = 0.05, NS: Non significant

appearance on leaf surfaces. These indicated that borax at high concentrations of 0.125 and 0.1875% had the potential to decrease the browning incidence on leaf surface at low concentration of 0.0625% boric. While, the concentrations of boric above 0.0625% showed promotion of severe damage.

DISCUSSION

The efficacy of preharvest spraying of boron on the growth and some external qualities of Grand Rapids lettuce was studied. The results revealed that boron application could activate lettuce growth. This corresponds with the results of Dong *et al*. (2009), who reported that pre-harvest application of boron could significantly influence an increase in the number and size of plant cells. Shkol'nik and Kopmane (1970) also cited the functions of boron have been associated with several plant physiologies, such as, water relations, sugar translocation, cation and anion absorption and the metabolism of N, P, carbohydrates and fats. These results are consistent with Wojcik *et al.* (2008), who also reported that plant growth was incremental after applying boron. It may also be that boron activated the high amount of assimilates transported into leaf tissues and led to an increase in cell expansion (Marschner, 1995; Dell and Huang, 1997). These results showed that boron applications can stimulate crop growth.

The best growth parameters, in terms of plant height and bush size, were affected by boron fertilization in the form of boric at 0.0625%. This implied that the main factors acting on the boron plant uptake included properties of the micronutrient components (Flores *et al*., 2006). This could be explained by considering the components of borax ($B_4O.2Na.10H_2O$) compared with boric (H_3BO_3). The difference between the two may have caused an osmotic imbalance, or a high level of a particular ion toxicity of soda (Na_2O) ion in the structure of borax molecule (François and Maas, 1999). Lettuce, in particular, might be sensitive to elevated levels of Na_2O (Dontsova *et al*., 2005). In plant species, Oertli and Richardson (1970) found that the distribution of boron in shoots primarily followed transpiration streams and boron in the form of boric was relatively high in membrane permeability (Takano *et al*., 2008). Furthermore, the solutions of boric acid [$B(OH)_3$] mainly exist as an uncharged boron substance and have no interaction with other biomolecules (Woods, 1996). This relatively high value of 0.0625% is the basis of the widely believed theory that there is passive diffusion of boric acid across the lipid bilayer, the major component of plant membrane. The passive diffusion causes better transport of boric through the channel-mediated membrane into the leaf cells (Takano *et al*., 2008). Taking into account that as a result of better plant uptake of boric acid, crops would be able to increase plant growth. Westmark *et al.* (1996) found that boronic acids facilitated sugar transport through artificial lipid bilayer membranes, consequently leading to an improvement in the vigor and yield of Jonagold apple trees. In contrast to the results of Adhikary *et al.* (2004), who found that the plant height of cauliflower was observed increasing with increasing levels of borax application. Furthermore, some unknown plant factors might have profound influences on plant ability to absorb and utilize different boron form (Fageria *et al*., 2002).

However, boron application at higher concentrations had a detrimental effect on lettuce growth. This is inconsistent with the results of Shannon and Grieve (1998) who found that specific ion sensitivities may be responsible for critically limiting crop growth especially sensitivities to boron that may be found in toxic or growth-limiting concentrations at higher concentrations. The application of more than 0.0625% of borax and boric resulted in no further benefit, but tended to decrease plant height. The results of this study are in line with the report of Oyinlola (2007) who observed that reduced height could be due to toxic effect as a result of excess boron. Contrarily, the results of this study are inconsistent with the results of Marschner (1995) who found that crop yield was affected positively and negatively by boron, depending upon the doses used. Similarly, Oyinlola (2007) reported that the plant height of sunflowers increased up to 8 kg boron ha^{-1} after which there was a decline in the plant height with further increases in boron rates. These height concentrations may be attributed to toxic conditions of the upper level that began to set in thereby exerting adverse effect on plant metabolic activities which consequently negatively affected plant height (Oyinlola, 2007). Thus, the range of proper application of boron is rather narrow and its harmful effects can be induced by excessive application (Gupta *et al*., 1985). Excess boron application led to physical injury and is toxic to plants (Takano *et al*., 2008). Thus, the recommended application rates of boron for promoting Grand Rapid lettuce's growth is 0.0625% boric.

For the results on biomass content, it was found that biomass percentages of lettuce were quite similar and relatively unaffected by boron treatments. These correspond to the results of Chutuchidet *et al.* (2009) who also cited that gypsum application had no effect to biomass content of lettuce. This was presumably due to these applied fertilizer improving only the fresh weight, not including dry weight (Prado *et al*., 2005).

For leaf colour and chlorophyll content, the results showed that both parameters were not influenced by boron fertilization. These results were inconsistent with those reported by Wojcik *et al.* (2008) who found that leaves of apple trees supplied with boron had higher chlorophyll and net photosynthetic rate than those of the control trees. Sharma and Ramchandra (1990) also showed increased leaf chlorophyll concentration in boron supplement mustard (*Brassica alba*) plants. These are probably due to plant species react in different ways to boron application.

The results on degree of leaf browning showed an increasing trend with a plant's development time. Generally, the presence of browning appearance on leaf surface at harvest increased the risk of quality decrease. Plants treated with 0.125 and 0.1875% borax and 0.0625% boric had reduced browning damage by showing the least level of leaf browning. This may be due to the fact that these substances are related to the preservation of membrane integrity. Basically, enzymatic browning can be defined as an initial enzymatic oxidation of phenolic compounds into slightly coloured o-quinones, catalysed by polyphenol oxidase (PPO). Although, PPOs are localised in plastids, their phenolic substrates are mainly located in the vacuole so that enzymatic browning only occurs when this sub-cellular compartmentalization is lost (Cantos *et al*., 2002). O'Neill *et al.* (2004) reported that boron has been shown to be essential to the structure and function of plant cell walls, where it cross-links pectic polysaccharides through borate-diol bonding of two rhamnogalacturonan II (RG-II) molecules (Kobayashi *et al*., 1996; Ishii and Matsunaga, 1996; O'Neill *et al*., 1996). This could possibly be due to a role for boron in maintaining the stability of membrane integrity and as an important stabilizer of cell wall structure. The boron delayed the loss of cellular compartments and led to slow down of browning formation (de Castro *et al*., 2008). In addition, the concentration of certain minerals, such as boron, which has been shown to have an influence on membrane integrity and maintain several cellular functions (Cakmak and Römheld, 2004). These results were in agreement with O'Neill and York (2003) who cited that boron was an important stabilizer of cell wall structure and led to maintain the membrane stability and cell wall strength (Parr and Loughman, 1983; O'Neill and York, 2003). Furthermore, Camacho-Cristóbal *et al.* (2002) reported that boron was one of the nutrients responsible for the changes in concentration and metabolism of phenolic compounds in vascular plants, since it was well known that boron deficiency caused an accumulation of phenolics (Blevins and Lukaszewski, 1998; Cakmak and Römheld, 2004) and led to an increase in polyphenoloxidase (PPO) activity which caused an increase in the enzymatic browning (Pfeffer *et al*., 1998). While Dong *et al.* (2009) cited that pre-harvest foliar application of boron had significant effect on the cross-linked polymer network of tissue segment membrane, which is useful for improving the structure of the segment membrane, reducing transcript levels and the activities of some enzymes and maintaining the integrity of the cell wall membrane level as well as strengthening the cell tissue structure. Furthermore, PPO, normally bound to membranes or walls, becomes active when released under boron-inadequate or over abundant conditions. These alter plant metabolism and increase the level of browning (Ruiz *et al*., 1999). Unfortunately, the underlying biochemistry of enzymatic browning associated with boron has not yet been fully elaborated. Thus, pre-harvest boron sprays associated with the extent of leaf browning in lettuce remains unknown. Further experiments will be necessary in order to investigate the exact mechanism of boron on reducing the browning disorder of lettuce. These results provide important data on the response of lettuce plants to boron application, on promoting plant growth and decreased browning occurrence during plant growth. It is emphasized that boron, in the form of boric at 0.0625%, can be a good application for improving lettuce production.

In conclusion, the effect of foliar spraying of boron on growth and control of browning appearance on Grand Rapids lettuce was studied. Treatment of 0.0625% boric effected to increase the highest plant height and bush size, but both of the boron substances at any concentration had no effect to stem diameter, biomass, chlorophyll content and leaf colour. Furthermore, the least extent of browning incidence of plants treated with 0.125 or 0.1875% borax and 0.0625% boric were observed. These research findings confirm that foliar spraying boron in the form of boric application at 0.0625% is an effective method to promote plant growth and reduce the leaf damage from browning. The effect of boron on controlling browning occurrence of lettuce warrants further investigation. It thus seems that use of boron in term of boric at 0.0625% by foliar spraying is an interesting practicable method for improving the plant growth and decreasing leaf browning incidence in lettuce production.

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