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Effect of directly-applied and residual boron on nutrition in French bean-cabbage cropping sequence under Alfisol

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ABSTRACT

Effects of directly-applied-to-the-soil and residual boron (B) in soil were assessed in French bean (*Phaseolus vulgaris* L.) - cabbage (*Brassica oleracea var. capitata* L.) cropping sequence and cycle under Alfisol, with either low or adequate hot-water-soluble boron (HWS-B) content. The experiments focussed on effects of various levels of applied B on leaf tissue B and crop yield, HWS-B content in the year of B application, and in subsequent years. Response of the crops to applied B reflected initial soil B levels. Application of the highest level of B (8kg ha^{-1}) reduced crop yield at Site-I throughout the four years of experimentation. Applied B up to 2kg ha^{-1}enhanced French bean yields at Site I, while at Site II, at all the levels of applied B, yields were reduced in the first two crops; during the third and fourth crop, yields in plots receiving 1kg B ha^{-1} were higher than those in plots that did not receive supplemental B. In both French bean and cabbage, high B concentrations caused toxicity symptoms manifested as browning of leaf margin. These symptoms appeared in both French bean and cabbage under all the plots receiving B e" 4kg ha^{-1}. Monitoring HWS-B content at harvest in each crop during the experiment indicated that applied B diminished rapidly in these soils. However, at Site II, residual HWS-B was above the critical level throughout the period of experimentation. A single application of higher amounts of B fertilizer led to B toxicity and caused yield suppression in these vegetables. French bean, being a sensitive crop, should be grown preferably on residual B rather than subjecting it to direct application of B in any vegetable cropping system under red soils.

Key words: Alfisols, cabbage, French bean, HWS-B, B toxicity, tissue B, residual B, yield, cropping sequence

INTRODUCTION

Boron deficiency is widespread in Alfisols of southern India, and, is a major constraint in vegetable production (Satisha and Ganeshamurthy, 2012). Response of vegetables to boron application in southern India has been reported by several workers (Edward Raja, 2007; Kotur, 1993; Sharma and Brar, 2008). In general, vegetables of Brassicaceae and Leguminaceae families are more sensitive to B deficiency than are other crops, and respond to added B (Gupta 1983; Gupta and Cutcliffe, 1975; 1978). Information on B requirement in cabbage and French bean has been summarized by Gupta (1979) and Edward Raja (2007). However, information on B requirement or tolerance by cabbage and French bean, specifically in Alfisols, is limited. Moreover, these two crops are not only sensitive to B deficiency, but also to excess B (Bradford, 1966; Gupta, 1983). Farmers in southern India generally grow French bean and cabbage under rotation and apply B frequently. Therefore, it is desirable to obtain information on effects of residual B on succeeding crops that may be sensitive to high levels of B in soil. The objectives of this study were to determine the effects of various levels of B applied in the first crop, in a rotation cycle, on plant tissue B concentrations, and, yield of French bean and cabbage in the year of application and in years following B application.

MATERIAL AND METHODS

Field experiments were conducted at two locations in the research farm of Indian Institute of Horticultural Research, Bengaluru, during 2009-2012 in Randomized Block Design comprising five levels of B, and four replicates. French bean was grown in *kharif* (monsoon season, June-September), followed by cabbage in *rabi* (post monsoon season, October-February) each year, for four years. Soil characteristics of the two experimental sites are presented in Table 1. The initial hot-water-soluble B (HWS-B) content

Table 1. Soil physic-chemical properties at experimental sites

Soil characteristics	Site I	Site II
Soil classification	Typic Haplustert	Typic Haplustert
Soil texture	Loamy sand	SiltyClayloam
Bulk density	1.46g cm^3	1.42g cm^3
pH	5.6	6.7
EC	0.27dS m^{-1}	0.31dS m^{-1}
Organic C	5.24g kg^{-1}	5.03g kg^{-1}
Mineralizable N	242kg ha^{-1}	212kg ha^{-1}
Bray's P	27.3kg ha^{-1}	21.5kg ha^{-1}
Exchangeable K	149kg ha^{-1}	164kg ha^{-1}
Exchangeable Ca	1240kg ha^{-1}	1370kg ha^{-1}
Exchangeable Mg	278kg ha^{-1}	321kg ha^{-1}
Extractable S	11.36mg kg^{-1}	13.48mg kg^{-1}
DTPA Zn	0.620mg kg^{-1}	0.590mg kg^{-1}
DTPA Cu	0.371mg kg^{-1}	0.422mg kg^{-1}
DTPA Mn	4.32mg kg^{-1}	5.710mg kg^{-1}
DTPA Fe	56.4mg kg^{-1}	62.14mg kg^{-1}
HWS-B	0.27mg kg^{-1}	0.61mg kg^{-1}

at the two locations prior to initiating experiments ranged from 0.27 to 0.61mg kg^{-1} soil, and initial soil pH was within the range of 5.6-6.7. Boron was applied at 0, 1.0, 2.0, 4.0 and 8.0 kg boric acid (containing 17.4% B) to the soil by mixing it with 50:50:25 N:P_2O_5:K_2O for French bean, and 150:125:100kg N:P_2O_5:K_2O for cabbage. Full dose of boron was applied only in the first year, and just NPK fertilizer was applied in subsequent years. Fertilizers were broadcasted for incorporation into the soil prior to planting. The experiment plots were 8.0m x 20.0m in size. French bean was sown at 40cm row-to-row, and plant-to-plant spacing of 5cm. Cabbage was grown at 45cm x 30cm. The first crop of French bean was planted in July 2009, while cabbage was planted on the same plot in September 2009, after harvesting French bean. Standard cultural practices recommended by IIHR for French bean and cabbage were followed (Prabhakar *et al*, 2010). The crop was irrigated with tube-well water which contained only traces of B. Mean annual precipitation in the experimental area during 2009-2012 was 974.5mm. Both French bean and cabbage were harvested at the maturity stage (for vegetable purpose). Data on the central rows alone in each plot were used for yield calculation. Vegetable quality parameters like pod colour, disorders and marketable yield were recorded. During the growth season, both the crops were thoroughly examined for visible symptoms of B deficiency and B toxicity. French bean crop was harvested in the second half of September, while, cabbage was harvested in the second half of December each year. Leaf tissue samples comprised recently-matured leaves from 20 plants per plot, taken at pre-bloom stage. In cabbage, leaf tissue samples were collected just prior to head-formation. The entire leaf blade of the most-recently matured leaf was detached at the point of intersection of lamina and petiole. Leaf tissue samples in both the crops were collected randomly from each plot. All the samples were brought to the laboratory, washed thoroughly in B-free water, dried, ground, ashed and extracted with 2N HCl. The diluted extract was analyzed for B content by azomethine-H colorimetric method using Systronics spectrophotometer. Soil samples (0-15cm depth) were taken, at the end of each crop cycle after harvest, from all the plots (eight cores per plot) and were analyzed for HWS-B as per Gupta (1979). Analysis of Variance was conducted for each site too.

RESULTS AND DISCUSSION

The experimental soils contained 0.27mg kg^{-1} of HWB at Site I and 0.67mg kg^{-1} at Site II (Table 1). Applied B significantly affected yield in both French bean and cabbage throughout the four years of experimentation. The yield (averaged over four crops) for French bean was 11.67t ha^{-1} at Site I, and 9.35t ha^{-1} at Site II; while, for cabbage, this was 37.0 and 40.06t ha^{-1}, respectively. Applied B enhanced the yield (Table 2) of French bean at Site I up to 2kg ha^{-1}, while at Site II, applied B at all the levels showed diminished yield in the first two crops; during the third and fourth crop, yield in plots receiving 1kg B ha^{-1} was higher than in plots not receiving any B. At both the sites, application of highest levels of B (8kg B ha^{-1}) reduced the yield in all the four years of experimentation. On the other hand, applied B significantly increased the yield in cabbage up to 4kg B ha-1 at Site I, and 1kg B ha^{-1} at Site II in the first crop (*i.e.*, Year I). Subsequently, the response improved in second and third crops. In the fourth crop, yield levels were significantly higher: up to 8.0kg B ha^{-1} at Site I, and up to 4kg B ha^{-1} at Site II (Table 2).

Applied B enhanced B levels in French bean tissue from 19.2 to 154.0mg kg^{-1} in the first crop (Year I) at Site I, and from 36.2 to 174.0mg kg^{-1} at Site II (Table 3). In cabbage, tissue B concentration in the first crop increased from 11.6 to 79.8mg kg^{-1} at Site I, and from 15.6 to 111.6mg kg^{-1} at Site II. Toxicity of B manifested as browning of leaf margin in both French bean and cabbage at high concentrations of tissue B. At both 4 and 8kg B ha^{-1}, toxicity symptoms were visible in the first two crops (Years I and II), but disappeared in the third crop. Symptoms were more severe at Site II than at Site I. It has been reported that B concentration of >60mg kg^{-1} in French bean leads to appearance of toxicity symptoms, and yield reduction occurs at tissue concentrations of >109mg kg^{-1} (Gupta and Cutcliffe, 1984).

Table 2. Effect of applied boron on French bean and cabbage yield (t ha^{-1})

Applied B(kg ha^{-1})	2009		2010		2011		2012	
	French bean	Cabbage	French bean	Cabbage	French bean	Cabbage	French bean	Cabbage
Site I (HWS-B* 0.61mg kg^{-1})								
0	9.4	34.1	10.2	36.3	9.8	35.6	10.6	32.5
1	14.3	37.7	14.0	39.1	13.7	37.4	12.4	34.1
2	14.1	40.3	14.5	42.3	14.8	41.0	15.1	39.4
4	9.9	35.2	10.6	37.2	12.2	39.4	14.0	39.0
8	6.0	33.6	7.6	32.8	9.7	34.2	11.4	33.8
LSD (0.05)	2.1	2.2	1.8	2.7	1.5	2.1	1.1	2.3
Site II (HWS-B* 0.61mg kg^{-1})								
0	10.6	41.6	11.9	43.7	9.0	40.8	9.90	41.6
1	10.7	44.9	11.4	46.2	9.6	44.6	10.7	44.7
2	9.1	39.8	9.6	41.9	8.9	43.9	9.9	43.7
4	8.0	36.2	9.1	38.2	8.9	39.2	8.7	41.2
8	7.1	30.1	8.3	29.4	7.3	31.4	8.4	38.3
LSD (0.05)	1.0	1.9	1.2	2.3	NS	2.0	1.2	1.8

*Hot-water-soluble boron
LSD = Least significant difference

They also reported that 16mg kg^{-1} of B in the case of cabbage and 26mg kg^{-1} of B in the case of French bean caused deficiency symptoms in the plant. In our study, deficiency symptoms were noticed in both French bean and cabbage in Control plots alone, at Site I. HWB content in soil after harvest in each crop is presented in Table 4. Availability of applied B diminished rapidly at both the experimental sites.

Little is known about B availability and response of vegetable crops to B in Asian soils, including India. However, B is a nutrient deficient in Indian soils, particularly in light-textured, low organic-matter containing soils, and, in heavy-rainfall areas (Singh *et al*, 2009). In the Indian soils, HWS-B level below 0.5mg kg^{-1} is considered as critical for most crops (Katyal and Rattan, 2003; Rao *et al*, 2008). Soil at Site I in our experiment had 0.27mg kg^{-1} HWS-B and, Site II had 0.61mg kg^{-1} HWS-B. Therefore, soil at Site I is seen to be deficient in available B, while, soil at Site II had sufficient available B. Hence, crops grown at Site I were expected to respond better to applied B those grown at Site II. However, application of this nutrient of boron fertilizer at higher levels may lead to accumulation of this nutrient in soils at levels toxic to plants. Robertson *et al* (1975) concluded that 1.5mg kg^{-1} B in soil at harvest was toxic.

In the present study, applied B at 2kg B ha^{-1} prior to planting significantly increased pod yield in French bean at Site I; while, even as low as 1kg B ha^{-1}, did not increase pod yield at Site II. Yield in cabbage as a follow-up crop (after application of 2kg B ha^{-1}) significantly increased at Site I, as also at 1kg B ha^{-1} at Site II. In the subsequent crops, the level of response to residual B gradually improved at Site I, and, after the third cropping year, both French bean and cabbage responded significantly well to 4kg ha^{-1} B applied at the onset of the experiment. At Site II, French bean yield at all the levels of applied B remained suppressed (following B application), even in the fourth crop in French bean-cabbage rotation cycle. Cabbage yield, however, remained significantly higher than in Control at 1kg B ha^{-1} throughout the four years; but, at 2kg B ha^{-1}, the favourable response could be observed only third year onwards. At higher applied B levels, yield remained lower than in Control. This confirms earlier reports that French bean is highly sensitive to excess B, compared to cabbage (Bradford 1966; Gupta and Cutcliffe, 1984). Bradford (1966) and Gupta and Cutcliffe (1984) speculated that B perhaps got fixed in the soil, or leached out quickly from the root zone. Gupta and Cutcliffe (1984) also stated that beans were not as sensitive to B toxicity as that reported by Robertson *et al* (1975). It was observed that bean yield was suppressed at high levels of B application (> 8kg ha^{-1}) in these light-textured soils. However, such yield-suppression was not observed in the subsequent crops. However, yield suppression at much lower levels of applied B can be attributed to a reduced leaching-loss, as, the crop was irrigated with drip system, and, soil B fixation here is not as high (as, it can reduce availability of applied B to very low levels).

In the first crop of French bean, applied B enhanced B levels in tissues of the bean from 19.2mg kg^{-1} in plots receiving no external B, to 154.0mg kg^{-1} in plots receiving 8kg B ha^{-1}at Site I, and, 39.2-174.0mg kg^{-1}, respectively, at Site II (Table 3). In cabbage, tissue B concentration in the first crop (Year I) increased from 11.6mg kg^{-1} in plots receiving no external B, to 79.8mg kg^{-1} in plots receiving 8kg B ha^{-1}. This was 15.6-111.6 mg kg^{-1} at Sites I & II, respectively, in both French bean and cabbage, with high concentrations of B in plant tissue. Toxicity of B manifested as browning of leaf margin. The symptom appeared in both French bean and cabbage in all the plots receiving B at the rate of e" 4kg ha^{-1}. Typical symptoms included chlorosis and dwarfing of plants in French bean, and, chlorosis and bunched appearance in plants of cabbage. Chlorosis worsened with progress of time and resulted in a burnt appearance, with the leaf margin curling up. This was also evident in suppressed crop yield. It has been reported that B concentrations greater than 60mg kg^{-1} cause toxicity symptoms in bean, and that yield reduction occurs at tissue concentrations greater than 109mg kg^{-1} (Gupta and Cutcliffe, 1984). Robertson *et al* (1975) estimated B threshold level for bean plants as 100mg kg^{-1}. MacKay *et al* (1962) and Gupta (1983) also observed B toxicity in beans when B concentration exceeded 160 and 125mg kg^{-1}, in the respective papers. In the present study, toxicity symptoms appeared when tissue concentration of B exceeded 48.7mg kg^{-1} in French bean and 51.3mg kg^{-1} in cabbage. Reduction in leaf area and appearance of stunted growth of plant (following toxicity) and a reduced photosynthesis, may be the reason for yield reduction observed in this study. In our experiment, although cabbage was grown after the French bean crop (without any direct application of B), higher levels of applied B (>4kg B ha^{-1}) showed toxicity symptoms and resultant reduced yield. Cabbage was less sensitive to excess B, compared to other crops. Gupta and Cutcliffe (1984) did not record toxicity symptoms in cabbage even at tissue concentrations as high as 132mg kg^{-1} in calcareous soils. But, this level is reported as toxic for a number of other crops, as summarized by Gupta (1979). In sand culture studies on response to B in cabbage, the top portion of 55-day-old plants contained 12mg kg^{-1} B (Agarwala *et al*, 1977). In the present study, B levels were considerably higher than this value and, hence, both deficiency-symptoms and yield-suppression occurred at high levels of applied B. Results of our study indicates that B application rate of 8.0kg ha^{-1} to a previous crop is detrimental to the subsequent (follow-up) crop in a rotation cycle. Application of 2-4kg B ha^{-1} to sensitive crops can be practiced without B toxicity, in French bean grown in subsequent years. Cabbage was found to be more tolerant than French bean to B toxicity, as, yield-suppression occurred only at higher levels of applied B.

Information on residual B in soils, particularly in horticultural cropping systems, is lacking. Data based on HWS-B content at harvest in each crop indicate that availability of applied B diminished rapidly in these soils (Table 4); But the residual levels were, still, high enough to influence a subsequent crop in the cropping system. Post-harvest soil analysis at conclusion of the first French bean crop showed that HWS-B rose to 1.36mg kg^{-1} from 0.27mg kg^{-1}, and rose to 2.16mg kg^{-1} from 0.61mg kg^{-1} in plots receiving 8kg B ha^{-1} at Site I and Site II, respectively. Even at Site I, applied B @ 2kg ha^{-1} left behind residual B above a critical level in the soil, after the first crop of French bean

Table 3. Effect of applied boron on boron concentration (mg kg^{-1}) in leaf tissue of French bean-cabbage cropping sequence

Applied B (kg ha^{-1})	2009		2010		2011		2012	
	French bean	Cabbage	French bean	Cabbage	French bean	Cabbage	French bean	Cabbage
Site I (HWS-B* 0.61mg kg^{-1})								
0	19.2	11.6	19.6	10.9	19.0	10.0	19.0	10.0
1	31.5	23.7	29.5	19.3	22.7	16.4	22.7	16.4
2	48.7	38.4	41.2	30.1	30.2	22.6	30.2	22.6
4	70.3	51.3	60.4	44.8	47.5	35.5	49.7	31.5
8	154.0	79.8	107.5	64.7	65.0	56.7	65.0	56.7
LSD (0.05)	14.1	8.9	9.4	7.8	8.8	6.9	9.6	8.1
Site II (HWS-B* 0.61mg kg^{-1})								
0	39.2	15.6	36.9	14.5	35.1	14.1	34.8	13.6
1	58.6	39.6	51.6	37.4	49.3	30.6	42.3	24.1
2	71.4	68.4	64.3	56.7	52.5	41.1	51.5	36.1
4	97.3	89.1	86.9	80.1	79.4	64.5	64.0	61.5
8	174	111.6	158.5	82.6	138.5	81.3	111.5	79.8
LSD (0.05)	11.5	8.3	5.7	6.3	5.9	7.1	6.0	7.8

*Hot-water-soluble boron
LSD = Least significant difference

Table 4. Effect of applied boron on hot-water-soluble B (mg kg^{-1}) content in soil at the end of crop cycle

Applied B(kg ha^{-1})	2009		2010		2011		2012	
	French bean	Cabbage	French bean	Cabbage	French bean	Cabbage	French bean	Cabbage
Site I (HWS-B* 0.27mg kg^{-1})								
0	0.27	0.23	0.25	0.22	0.21	0.19	0.22	0.21
1	0.41	0.36	0.38	0.32	0.35	0.30	0.32	0.28
2	0.76	0.71	0.76	0.67	0.70	0.49	0.55	0.37
4	1.06	0.98	1.01	0.91	0.94	0.82	0.86	0.74
8	1.36	1.17	1.20	1.01	1.06	0.94	0.97	0.83
LSD (0.05)	0.17	0.09	0.11	0.08	0.14	0.16	0.08	0.09
Site II (HWS-B* 0.61mg kg^{-1})								
0	0.61	0.55	0.61	0.54	0.59	0.48	0.55	0.41
1	0.89	0.81	0.82	0.70	0.73	0.68	0.70	0.64
2	1.19	1.06	1.10	0.95	0.99	0.83	0.85	0.71
4	1.59	1.44	1.51	1.32	1.38	1.19	1.25	0.98
8	2.16	1.85	1.94	1.77	1.80	1.59	1.63	1.44
LSD (0.05)	0.11	0.19	0.08	0.13	0.06	0.12	0.10	0.09

*Hot-water-soluble boron
LSD = Least significant difference

was harvested. At the end of eight crops in French bean-cabbage rotation cycles, these levels diminished to 0.83 and 1.44mg kg^{-1}, respectively. These levels were above the critical HWS-B levels in soil. Hence, both French bean and cabbage yield in these plots remained suppressed throughout the four-year cropping cycle. Residual levels of applied B in plots receiving 2kg B ha^{-1} at Site I fell below the critical level only after six crops. In all other plots receiving higher levels of B, residual HWS-B levels were higher than the critical level of 0.5mg kg^{-1}. However, residual HWS-B level was above the critical level in all the plots at Site II throughout the period of (four years) experimentation. These observations suggest that a single application of high level of B fertilizer to these soils can lead to residual B toxicity, thereby, causing yield suppression in vegetables. Moreover, B sensitive French bean crop should be grown preferably on residual B than on directly applied B in any vegetable cropping system in red soils.

The four-year experiment on assessing direct and residual effects of applied boron (B) showed that application of highest levels of B in the study (8kg ha^{-1}) reduced crop yield in eight crops, spread over four years. Applied B enhanced the yield of French bean under low available B soil up to 2kg ha^{-1}, while, high available B soil (at all the levels of applied B) reduced yield during the first two crops; during the third and fourth crop, the yield improved. In both French bean and cabbage, high B in plant tissue resulted in toxicity. HWS-B content at harvest in each crop indicated that availability of applied B diminished rapidly in these soils. A single application of high level of B-containing fertilizer to these soils leads to accumulation of B in toxic proportions, and causes yield suppression in vegetables. French bean, being a low accumulator of B and being a more sensitive crop, should be grown preferably on residual B rather than subjecting it to direct application of B-containing fertilizer to soil in any vegetable cropping system in red soils.

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