Indian Journal of Agricultural Sciences **89** (4): 701–7, April 2019/Article
https://doi.org/10.56093/ijas.v89i4.88870

Estimation of suitable extractant and critical level of B in cauliflower (*Brassica oleracea* var. botrytis, cv. Sabour Agrim) for the soils of Indo-Gangetic plain of Bihar, India

JAJATI MANDAL[1], SUNIL KUMAR[2] and RAJEEV PADBHUSHAN[3]

Bihar Agricultural University, Sabour, Bihar 813 210, India

Received: 29 June 2018; Accepted: 20 November 2018

ABSTRACT

This study is a synthesis of information on suitable extractant, critical level of B in soil and plant using cauliflower (*Brassica oleracea* var. botrytis) (Variety: Sabour Agrim) as a test crop grown in Inceptisols, Entisols and Alfisols of Indo-Gangetic plain of Bihar,India. A pot experiment was conducted with soils from 15 locations and five levels of B (0, 0.5, 1.0, 2.0 and 3.0 mg B kg^{-1}) and was replicated thrice. Four extractant methodologies were used for determination of B. The critical level of B in soil and plant was 0.55 and 21.15 mg kg^{-1} respectively. Among the four extractant methodologies, viz. hot-water-soluble (HWS), 0.02M hot-$CaCl_2$ (HCC), 0.5 (M) KH_2PO_4(PDP) and 0.05 (M) HCl used in the present study. HCC proved to be the suitable extractant depending on the soil properties. Assessment of different B application rates revealed that the application of B should be between 0.4 to 3.0 mg kg^{-1} to avoid deficiency and toxicity symptoms and 2.0 mg kg^{-1} of B application emerged as the best treatment.

Key words: Boron, Cauliflower, Critical level, Deficiency, Extractant, Toxicity

Boron (B) is an essential micronutrient (Warrington 1923) that is required by crop plants for their normal growth and development. The range between boron deficiency and toxicity symptoms in plants is typically narrow (Reisenauer *et al*.1973) and crop may face both deficiency and toxicity in a single growing season and it ranges from 0.028 to 0.093 mmol/L for sensitive crops and 0.37 to 1.39 mmol/L for tolerant crops (Goldberg 2002). On the other hand B is unique among the essential elements because it is the only element that is normally present in soil solution as a non-ionized molecule over the pH range optimum for plant growth. Plant roots absorb the boric acid form of B most efficiently. Because of its non-ionic nature, B deficiency is particularly prevalent in light textured soils, soils where water soluble B readily leaches out of soil profile and become unavailable for plants (Mandal and De 1993). The red and lateritic soils with lower amount of organic carbon (C) are acidic in nature and rich in oxides and hydroxides of Fe and Al. These oxides and hydroxides have tremendous capacity to retain B in unavailable forms (Elrashidi and O'Connor 1982). Therefore, management of this element in soils and evaluation of B status in soils for optimum crop nutrition is difficult and to be taken under utmost care. The complexity of B in soil system makes it challenging to develop a soil B extraction method that can determine nutrient status relative to plant needs under wide range of soil conditions for various plant species (Shiffler *et al.* 2005a).

Various extraction techniques have been used by different researchers (Cartwright *et al*. 1983, Goldberg *et al.* 2002, Chaudhari and Shukla 2004, Shiffler *et al.* 2005, Sarkar *et al*. 2008) to assessavailable B status of soils. Hot-water-soluble (HWS) B (Berger and Truog 1944) is the most commonly used method to obtain an index of plant-available B in soils (Cartwright *et al.* 1983). The procedure has its inherent weaknesses for routine use, it is tedious and time-consuming, it produces coloured and opaque extracts, and there are errors associated with boiling process, and so on use of 0.02M hot-$CaCl_2$ (HCC) instead of hot water is advocated for colour-free clean extracts (Parker and Gardner 1981).Potassium dihydrogen phosphate (KH_2PO_4; PDP) is also known to be effective in desorption of B by a ligand exchange mechanism from soil constituents, particularly from inorganic constituents such as oxides and hydrous oxides (Bloesch *et al*.1987) and also represents plant-available B. As an alternative to hot water pressurized hot water (Web *et al.* 2002, Schiffer *et al.* 2005a,b) have also been used. Use of 0.05 M HCl to extract B in rice soils gave promising results as reported by Ponnamperuma *et al*. (1981).

The critical values of B varies with soil, crop and extractant used.Time to time researchers around the globe have reported the critical levels of B in soils and plant

[1,2]Assistant Professor-cum-Junior Scientist (e mail: jajati.bckv@gmail.com), (e mail: drsunilkumar20@gmail.com), [3]MSc., Scientist (e mail: rajpd01@gmail.com), International Rice Research Institute (IRRI), Odisha, India.

tissues for deficiency, sufficiency and toxicity to various crops (Gupta *et al.*1985). As mentioned earlier the narrow range between boron deficiency and toxicity makes it crucial to manage this element in soils and also evaluation of its critical contents in soil and plant for optimum crop nutrition. In this context a modest initiative has been undertaken to determine the suitable extractant and critical level of B in soil and plant using cauliflower as the test crop.

MATERIALS AND METHODS

Soil sampling and analysis

The soils used for the pot experiment were collected from the surface (0-15 cm) from 15 different locations of the Indo-Gangetic plain of Bihar, India. Taxonomically the soils belong to Inceptisols, Entisols and Alfisols order. They were analyzed for pH (1:2.5 soil-to-water ratio), clay content (International pipette method), organic carbon (C) (Walkley and Black 1934) and acidic ammonium oxalate extractable Fe, Al and manganese (Mn) oxides (McKeague and Day 1966) (Table 1). Four extraction methodologies were followed to determine the available B as depicted in (Table 2). B content in the extract was estimated spectrophotometrically by Azomethine-H procedure (Wolf 1971).

Pot experiment

The experiment was carried out during the month of September to November of 2014-15 and 2015-16. Plastic pots were filled with 10 kg of soil and moistened to field capacity with deionized water. Healthy disease free 15 days old seedlings of cauliflower (*Brassica oleracea* var. botrytis, cv. Sabour Agrim) were planted in each pot. The soils were treated with 0, 0.5, 1.0, 2.0 and 3.0 mg B kg^{-1} using reagent grade sodium borate ($Na_2B_4O_7$).10(H_2O). The soils were treated with recommended doses of nitrogen, phosphorus and potassium (NPK) (at the rate of 180, 40 and 80 kg ha^{-1}) in the form of reagent grade urea, monopotassium phosphate (KH_2PO_4) and potassium chloride (KCl), respectively, to avoid B contamination. Full amounts of P and K were applied at pre-sowing basal while N was applied in three equal splits - basal, 20 and 35 days after planting of seedlings. Irrigation was given, as and when required, using deionized water to maintain the field capacity.The experiment was conducted in completely randomized block design with three replications using a total 225 (15×5×3) pots. The curd was harvested after full maturity.

Leaf analysis

The leaf samples were washed first in running tap water

Table 2 Extraction methodologies used

Fraction	Extractant	Soil (g): Extractant (ml)	Condition	Reference
Hot $CaCl_2$ (HCC)	0.02 (M) $CaCl_2$	1:2	Reflux 10 min on hot plate	Parker and Gardner (1981)
HCl	0.01(N) HCl	1:2	Shaking for 5 minutes	Ponnamperuma *et al.* (1981)
KH_2PO_4 (PDP)	0.5 (M) KH_2PO_4	1:2	Shaking for 1 hour	Bloech *et al.* (1987)
Hot H_2O (HWS)	Hot H_2O	1:2	Reflux 10 min on hot plate	Berger and Troug (1939)

Table 1 Salient chemical properties of selected soils for greenhouse study

Site	Taxonomic classification	pH	OC (%)	Sand (%)	Silt (%)	Clay (%)	Am-Fe (g kg^{-1})	Am-Al (g kg^{-1})	Mn-oxides (g kg^{-1})
Belsar	VerticHaplustepts	7.4	0.62	6.6	40.4	53.0	3.76	7.16	0.81
Ekchari	VerticEndoaqualfs	6.4	0.40	13.0	49.1	37.9	4.62	7.88	0.94
Ghoga	Typic Haplustepts	6.4	0.66	16.6	61.9	21.5	4.51	7.67	0.78
Bhawanipur	Aquic Ustifluvents	6.3	0.58	31.2	47.9	20.9	2.89	6.11	0.68
Belgachhi	Typic Ustifluvents	7.1	0.36	56.0	20.5	23.5	2.56	5.32	0.62
Gaupur	Typic Ustifluvents	7.0	0.42	14.1	51.3	34.6	3.02	6.27	0.57
Tarapur	Typic Haplustepts	6.0	0.48	26.6	52.9	20.5	4.12	7.56	0.76
Dumri	Aquic Udipsamments	7.9	0.34	65.4	18.3	16.3	2.71	6.88	0.61
Mathiya	Aquic Eutrudepts	7.1	0.32	36.6	45.3	18.1	4.38	7.13	0.71
Domdhan	Typic Haplustepts	6.0	0.71	62.6	17.9	19.5	4.72	7.82	0.73
Jaypur	Typic Ustorthents	5.3	0.56	50.0	21.9	28.1	2.43	5.47	0.66
Karda	Typic Rhodustalfs	5.9	0.51	61.4	24.5	14.1	4.89	8.23	1.06
Bakhada	Typic Psammaquents	7.1	0.46	26.9	55.2	17.9	2.77	5.07	0.56
Bananiya	Aquic Ustipsamments	6.4	0.11	95.1	2.7	2.2	3.11	5.12	0.67
Bikramganj	Fluventic Haplustepts	5.8	0.35	63.6	9.2	27.2	4.61	7.48	0.82
Range		5.3-7.9	0.11-0.66	6.6-95.1	2.7-61.9	2.2-53.0	2.43-4.89	5.07-8.23	0.56-1.06

followed by dilute HCl solution and finally with deionized water. The leaf materials were dried first in air and then in an oven at 70 °C. Samples were then ground with the help of a stainless steel mechanical grinder. Representative samples were dry ashed at 550 °C in a muffle furnace and then after cooling extracted with 0.36 N H_2SO_4 following the method as determined by Gains and Mitchell (1979) with only slight modification of time allowed for colour development, which was one and half an hour in lieu of just one hour used by the former. Extractable B was determined colorimetrically by the azomethine-H method (Parker and Gardner 1981).

Statistical analysis

Correlation was performed to evaluate the relationships among the various parameters. Statistical analysis was done by Microsoft Excel (Microsoft Corporation, USA) and SPSS window version 16.0 (SPSS Inc., Chicago, USA).

Determination of critical concentration of boron

The critical levels of B for deficiency, adequacy and toxicity were determined from the relationships between curd yield and plant B concentration or extractable soil B. Deficient level of B was calculated using both the graphical procedure as proposed by Cate and Nelson (1965) using curd yield and relative curd yield, Bray's per cent yield (BPY), concentration and relative concentration of B, uptake and relative uptake of B etc. as the variables. The BPY was calculated using the formulae:

$$\text{BPY} = \frac{\text{Yield without nutrient}}{\text{Yield with optimum nutrient}} \times 100$$

Soil test values (X-axis) were plotted against BPY (Y-axis). A pair of perpendicular lines were drawn, one line 5 cm from and parallel to Y-axis and other line 10 cm from and parallel to X-axis. The four resulting sectors on the overlay were marked "-" for the bottom right and upper left and "+" for bottom left and upper right. The overlay was moved horizontally and vertically on the graph until the number of points showing in two "+" quadrants was the maximum. The point where the vertical line crosses the X-axis was taken as the critical soil test level. In a similar way, the plant concentration was placed in X-axis and BPY in Y-axis to get the critical levels of B in plant tissues.Only the highest value of relative yield for each soil was chosen to determine deficient B levels in soil and in plant. Adequate level of B was worked out at 90% of the curd yield and toxic level was calculated at 10% reduction in curd yield after attaining maximum yield (Fageria *et al.* 2003).

RESULTS AND DISCUSSION

Extractable boron content in the experimental soils

The experimental soils varied widely in terms of physical and chemical properties (Table 1). The pH and organic carbon ranged from 5.3 to 7.9 and from 0.11 to 0.66 % respectively. The sand silt and clay percentages ranged between 6.6 to 95.1, 2.7 to 61.9 and 2.2 to 53.0 respectively. The ranges of amorphous Fe, Al and Mn-Oxides were 2.43-4.89, 5.07-8.23 and 0.56 to 1.06 g kg^{-1} respectively.The amount of B extracted by PDP, HWS, HCl, HCC varied from 0.28 to 0.97, 0.33 to1.14, 0.21 to 0.70 and 0.26 to 0.81 mg kg^{-1} respectively (Table 3). Thus the efficiency of the tested extractants was in the order: HWS > PDP > HCC > HCl. Gupta *et al.* (1985) observed that boiling the soil in hot water and HCC extracted comparatively more B than other extractants as they extract not only inorganic soluble B, but from other pools like the organic and adsorbed inorganic pools. The higher amount of PDP might be due to an effective desorption of B from inorganic constituents such as the oxides and hydroxides of Fe and Al etc by the phosphate as the extractant since phosphate is known to desorb B easily from the adsorbing surfaces because of its higher bonding energy constant than that of borate (Bloesch *et al.*1987). The extraction of B with HCl is originally designed for acid soils, is equally effective in diagnosing B deficiency in alkaline and calcareous soils. The HCl method is simple, economical and also effective (Ponnamperuma *et al.* 1981).

Relationship with the soil properties

Results (Table 4) indicated the amount of B extracted by each of the four extractants showed significant positive correlation with pH of the soils. The amount of B extracted by all the extractants except PDP were found to be correlated positively with organic carbon, amorphous Fe-oxides and Mn-oxides content of the soil did not show significant relationship with the amount of B extracted by any of the extractants used in the study. A negative correlation with sand fractions was recorded with respect to all the extraction methodologies, whereas it was found to be positive with respect to the clay fractions except extraction with HCl.

Table 3 Boron content in the experimental soil after extraction with different methodologies

Site	PDP	HWS	HCl	HCC
Belsar	0.97	1.14	0.62	0.81
Ekchari	0.79	0.91	0.61	0.73
Ghoga	0.63	0.82	0.57	0.52
Bhawanipur	0.52	0.79	0.50	0.65
Belgachhi	0.56	0.66	0.61	0.51
Gaupur	0.63	0.80	0.68	0.67
Tarapur	0.44	0.57	0.38	0.55
Dumri	0.60	0.74	0.70	0.65
Mathiya	0.53	0.68	0.42	0.67
Domdhan	0.68	0.82	0.63	0.72
Jaypur	0.37	0.51	0.31	0.43
Karda	0.29	0.54	0.22	0.26
Bakhada	0.64	0.86	0.54	0.61
Bananiya	0.28	0.33	0.21	0.35
Bikramganj	0.39	0.52	0.40	0.47

Table 4 Pearson's correlation matrix between extractable soil boron and physicochemical characteristics of soils

	PDP	HWS	HCl	HCC
pH	0.549*	0.551*	0.628*	0.522*
OC	0.417	0.552*	0.599*	0.611*
Sand	-0.689**	-0.761**	-0.493	-0.617*
Silt	0.470	0.582*	0.353	0.453
Clay	0.735**	0.710**	0.498	0.607*
Am-Fe	0.060	0.078	-0.148	0.001
Am-Al	0.193	0.232	0.078	0.152
Mn-oxides	-0.056	0.000	-0.349	-0.243

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

Soluble B content in soils was highly significantly correlated with solution pH (Bergerand Truog 1945, Elrashidi and O'Connor 1982).Boron uptake by plants at identical water soluble B content was greater at lower soil solution pH (Goldberg *et al*. 2002). Hence a positive correlation was observed with pH and B extracted with different extractants. A positive correlation between organic carbon and extractable B was observed by (Mandal *et al*. 2016 and Sarkar *et al*. 2008). Adsorbed B and B adsorption maxima were highly significantly correlated with organic carbon content (Elrashidi and O'Connor 1982, Evans 1987). The positive correlation of extractable B with clay content of the soil was not uncommon (Elrashidi and O'Connor 1982). Fleming (1980) observed that coarse textured soils often contain less available B than fine textured soils and thus it is not usual to observe B deficiency in plants growing in sandy soils. Extraction of B bound by oxides of Fe and Mn is not known because these oxides at higher pH combined B through ligand exchange mechanisms, making it difficult to extract (Mandal and De 1993). Hence no significant correlation was observed between the amorphous Fe, Al and Mn-oxides except with PDP having higher correlation in comparison to other extractants but it was not significant. This may be due to phosphate containing extractants (PDP), which acts as pH buffer, may help B to get released to the soil solution (Sarkar *et al*. 2008).

Suitability of extractant

Correlation coefficient (r) values between available B content in soils as extracted by the four extractants and BPY, dry matter yield (DMY), B concentration, relative B concentration, B uptake and relative B uptake at the harvesting stage of cauliflower (Table 5). There is marked differences in the nature and degree of relationships between the soil extractable B content by the four extractants and the yield, concentration and uptake parameters of the crop under study. Among the four extractants used in the present study HCC was found to have the highest correlations with almost all the crop parameters. Similarly greater suitability of HCC for assessing the B status in B deficient soils of India for B nutrition of crops was also observed by many researchers (Batabyal *et al*. 2015, Chaudhary and Shukla 2004). Some other studies (Chaudhary and Shukla 2004, Shiffler *et al.* 2005a) also showed higher correlation values between available soil B content extracted by several extractants using different crops. Based on the correlation studies the extractants could be arranged in the following order as to their suitability for assessing B status in the soils of the investigated regionHCC>HWS>HCl>PDP. It was also observed that the amount of B extracted by all the four extractants was found to be significantly and positively correlated with each other (Table 6). This indicated that the extractants could extract B from more or less similar pools in the soils. The magnitude of efficiency of the extractants, however, might vary depending upon the soil properties.

Table 5 Correlation coefficients (r) between BPY, concentration and uptake of B and extractable B content of soil

Extractant	BPY	DMY	B conc.	Relative B conc.	B uptake	Relative B uptake
HCC	0.706**	0.723**	0.646**	0.745**	0.721**	0.691**
PDP	0.448	0.337	0.287	0.397	0.422	0.411
HCl	0.610	0.235	0.180	0.088	0.274	0.110
HWS	0.623*	0.606*	0.287	0.350	0.370	0.420

*, ** Significant at $P \leq 0.05$ and $P \leq 0.01$ respectively.

Critical limit of boron

Critical limit of any element both for soil as well as plants is usually determined by raising plants over a wide concentration range that is from deficiency to sufficiency limits of the element in the soils. The soils used in the present experiment for determining critical limit belong to the Indo-Gangetic plain of Bihar. The present experiment was conducted with soils containing available B ranging from 0.26 to 0.81 mg kg^{-1} (HCC extractable).

Critical limit of B in soil for B nutrition of cauliflower was determined using the data obtained from only one extractant (HCC) that was proved to be most suitable in the experiment. The BPY, concentration and curd yield were used in estimating critical value of available B in soils following the graphical methods of Cate and Nelson (1965). Results in Fig 1 showed that the critical values of B in soils as extracted by HCC for B nutrition in soil considering BPY, concentration in plant and soil and curd yield varied from 0.53 to 0.58 mg kg^{-1}. Therefore the average of 0.53 and 0.58 mg kg^{-1}, 0.55 mg kg^{-1} might be considered as the

Table 6 Analysis of variance showing the effect of soil, B rate and (Soil × B rate) interaction

Sources of variance		Fresh biomass yield (g $plant^{-1}$)		Tissue B concentration (mg kg^{-1})	
	df	Plant	Curd	Plant	Curd
Soil	14	**	**	**	**
B rate	4	NS	*	**	**
Soil × B rate	56	NS	NS	NS	NS

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

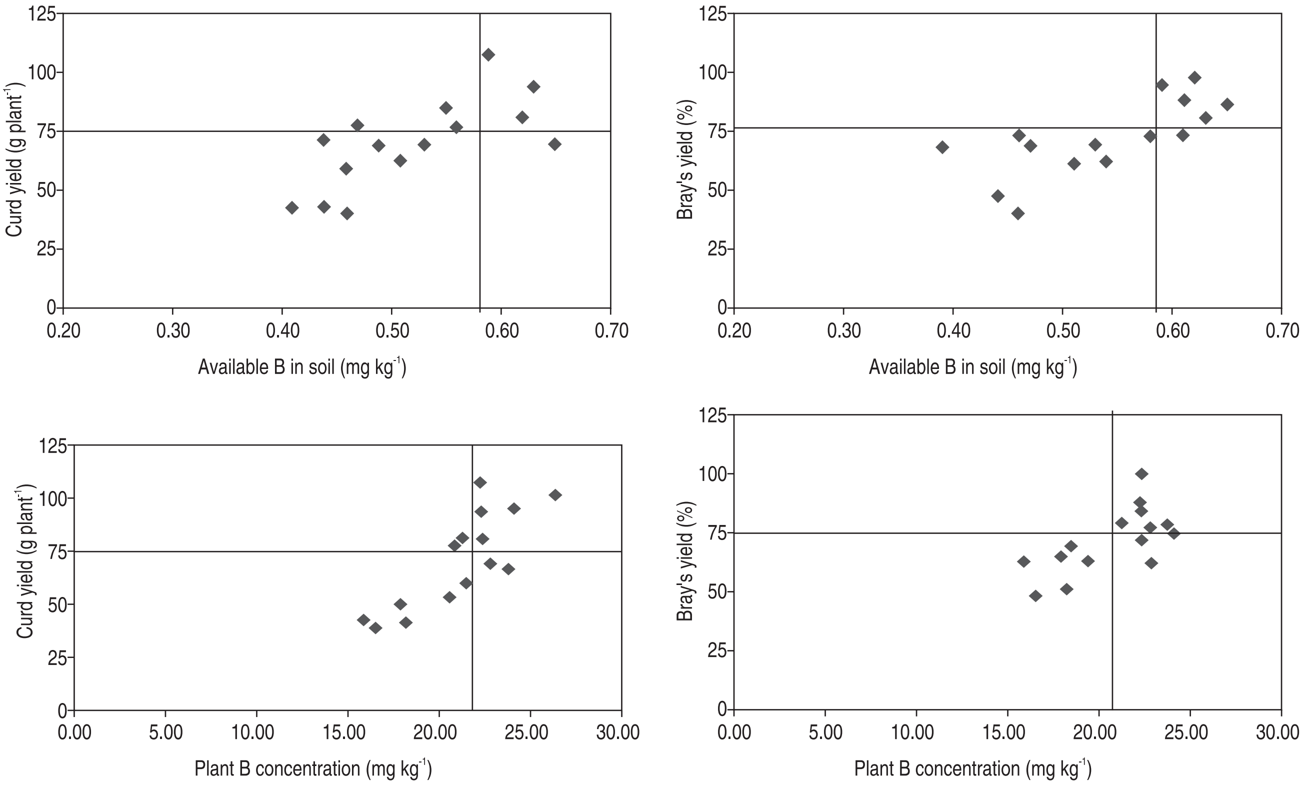

Fig 1 Critical limit (vertical lines intercepting X axis indicating the values) obtained by graphical method using BPY, concentration (plant and soil) and curd yield of cauliflower.

critical soil B by HCC.

The critical value of B in cauliflower curd at the harvesting stage was also determined. This was done using the data of BPY, concentration in curd and curd yield following the above method of Cate and Nelson. Results (Fig 1) showed that the critical level by graphical method varied from 21.0 to 21.3 mg kg^{-1}. Therefore the average of both the values being 21.15 mg kg^{-1} may be considered as the critical plant B concentration. Batabyal *et al*. (2015) reported that the critical level at harvest for the cauliflower to be 17 mg kg^{-1}, however it was reported for Inceptisols of West Bengal.

Response to different levels of B

The response of different levels of B on the fresh yield of plant and curd, B concentration in leaf and curd is depicted in (Table 6). Analysis of variance revealed that fresh yield of cauliflower plant varied significantly by soils of different locations however it was non-significant with respect to B rates as well as (Soil × B rate) interaction. The curd yield was found to be significant with respect to soils of different locations as well as B rates but interaction effects were non-significant. The application of B has increased the fresh biomass yield to the tune of 4%, 8%, 12% and 2% with respect to control, whereas the curd yield increased by 17%, 21%, 31% and 13% against 0.5,1.0, 2.0 and 3.0 mg kg^{-1} B application rates respectively (Fig 3). The results revealed that application of B have increased the fresh yield and curd yield up to 2.0 mg kg^{-1}. A reduction in both fresh

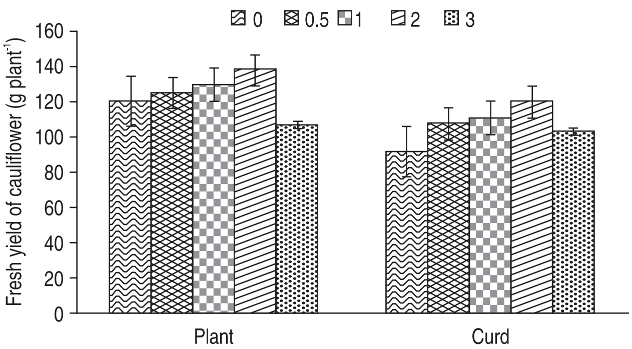

Fig 2 Average fresh yield of Cauliflower plant and curd for the 15 soils with 0, 0.5.1.0, 2.0, 3.0 mg kg^{-1} B doses. The result presented is the average of 15 soils with Standard Error.

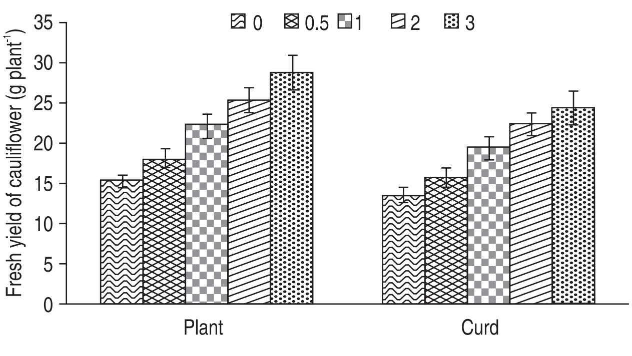

Fig 3 Average B concentration for 15 soils with 0, 0.5, 1.0, 2.0, 3.0 mg kg^{-1} B doses. The result presented is the average of 15 soils with Standard Error.

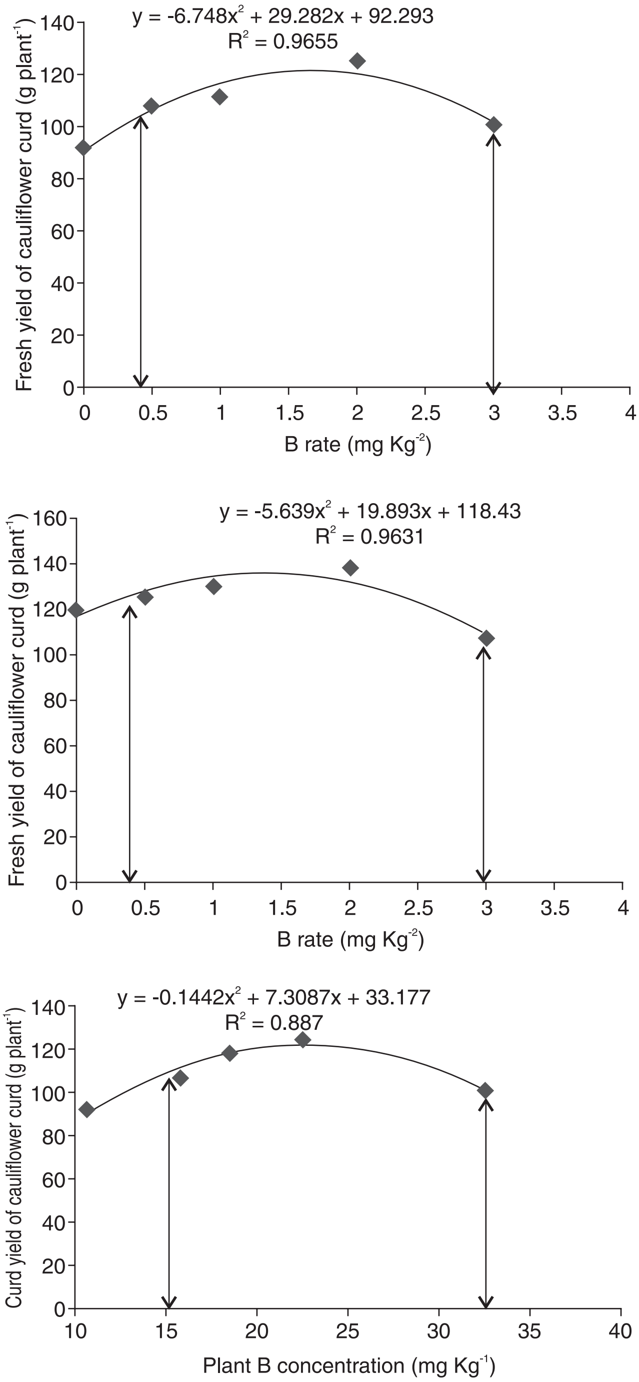

Fig 4 Relationship between fresh plant yield, curd yield with plant B concentration and B rates. The results presented here is the average of 15 soils.

and curd yield was recorded at 3 mg kg^{-1} B rate. The reason for lower response with application of 0.5 mg B kg^{-1} of soil may be either due to deficiency or hidden hunger in cauliflower and with 4.0 mg B kg^{-1} of soil may be due to toxicity of this element to the crop. Similar findings about response of cauliflower to B application in soils of India were reported by Batabyal *et al*. (2015) and Sarkar *et al*. (2012).

From Table 7 it was observed that tissue B concentrations were observed to be significant with respect to soils of different locations and also B rates and interaction effects were found to be non-significant. The B concentration in plant and curd showed an increasing trend as observed in Fig 4. Average of all the 15 soils recorded an increase in B concentration in plant to the tune of 18%, 45%, 66% and 88% against 0.5, 1.0, 2.0 and 3.0 mg kg^{-1} B application rates respectively with respect to control. Similar trend was observed for B concentration in curd and it increased by 16%, 44%, 65% and 81% against 0.5, 1.0, 2.0 and 3.0 mg kg^{-1} B application rates respectively with respect to control.

The relationship between fresh yield with B rate, curd yield with B rate and curd yield with B concentration showed polynomial effect (Fig 4). This polynomial effect may possibly be due to the reduction in the curd yield as well as the fresh yield due to increase B tissue concentration due to higher B application rates causing toxicity of the element. The critical concentration of cauliflower curd as determined from Fig 1 was 21.15 mg kg^{-1} for deficiency. Adequate and toxic concentrations of B in cauliflower, variety Sabour Agrim at harvest ranged between 15.5 mg kg^{-1} to 33.5 mg kg^{-1}. These findings are in accordance with the observations recorded by Batabyal *et al*. (2015) mentioning the narrow range between the B deficiency and toxicity in cauliflower tissue. Similar interpretation was also drawn by other researchers (Goldberg 1997, Mandal *et al*. 2016). The variation in the range of adequate and toxic concentration in comparison to the findings of other researchers might be due to dissimilar variety of the same crop having altered physiological demand for nutrient, varying rooting pattern and also may be due to different soil type.

From Fig 5 it is observed that plant B concentration at harvest showed linear relationship with the B application rates, therefore with the increase in B application rate there is an increase in the B concentration but both the fresh plant and curd yield were affected at higher doses. This can be visualized from Fig 4, again justifying the narrow range between adequate and toxic concentrations. The polynomial relationship between fresh plant and curd yield with B application rates provides the information that application of B below 0.4 mg kg^{-1} cannot meet the crop demand for B and application of B above 3.0 mg kg^{-1} will cause toxic effect to the crop. To achieve economical yield for cauliflower from Inceptisols, Entisols and Alfisols of Indo-Gangetic plain of Bihar the application rate of B

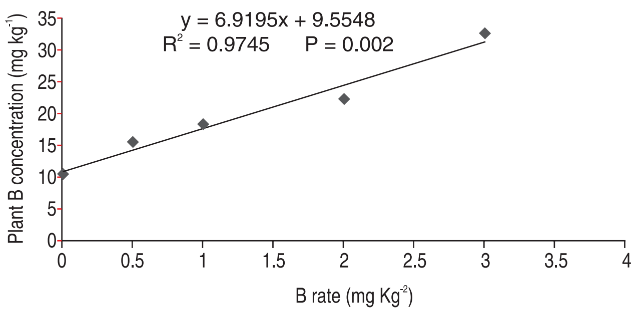

Fig 5 Relationship between B concentrations with B rates. The results presented here is the average of 15 soils.

should range between 0.4 to 3.0 mg kg^{-1} which corresponds to 0.9 kg ha^{-1} to 6.8 kg ha^{-1}.

Conclusion

Among the four extractants used in the present study HCC was found to be suitable extractant for the Alfisols, Inceptisols and Entisols of Indo-Gangetic plains of Bihar. Based on the suitability the extractants can be arranged in the following order HCC>HWS>HCl>PDP. It was also found that the extractants were efficient in extracting B more or less from similar pools of the soil. The critical level of B in soil (HCC extractable) was found to be 0.55 mg kg^{-1}, whereas the critical level for B concentration in cauliflower at harvest was found to be 21.15 mg kg^{-1}. B application rates have significant effect on the economic yield of cauliflower. The best response was observed against B application rate of 2.0 mg kg^{-1}. From the study it can be concluded that the B application at the rate of 0.9 kg ha^{-1} to 6.8 kg ha^{-1} will provide optimum nutrition and curd yield for cauliflower in the Alfisols, Inceptisols and Entisols of Indo-Gangetic plains of Bihar.

ACKNOWLEDGEMENT

The authors acknowledge Hon'ble Vice Chancellor, Bihar Agricultural University, Sabour for providing funds and Director Research, Bihar Agricultural University, Sabour for providing infrastructural facilities.

REFERENCES

Batabyal K, Sarkar D and Mandal B. 2015. Critical levels of boron in soil for cauliflower (*Brassica oleracea* var. botrytis). *Journal of Plant Nutrition* **38**(12): 1822–35.

Berger K C and Truog E. 1944. Boron tests and determination for soils and plants. *Soil Science* **57:** 25–6.

Bloesch P M, Bell L C and Hughes J D. 1987. Adsorption and desorption of boron by goethite. *Australian Journal of Soil Research* **25**: 377–90.

Cartwright B, Tiller K G, Zarcinas B A and Spouncer L R. 1983. The chemical assessment of the boron status of soils. *Australian Journal of Soil Research* **21**: 321–32.

Cate R B and Nelson L S. 1965. A rapid method for correlation of soil test analysis with crop response data. International Soil Testing Series Technical Bulletin No. 1, Agricultural Experimental Station, North Carolina State University Raleigh, NC.

Chaudhari D R and Shukla L M. 2004. Evaluation of extractants for predicting availability of boron to mustard in arid soils of India. *Communications in Soil Science and Plant Analysis* **35**: 267–83.

Elrashidi M A and O'Connor G A. 1982. Boron sorption and desorption in soils. *Soil Science Society of America Journal* **46**: 27–31.

Fageria N K, Barbosa Filho M P and Stone L F. 2003. Adequate and toxic levels of micronutrients in soil and plants for annual crops. Paper presented at the XXIX Brazilian Soil Science Congress,13–18 July 2003, Ribeir˜ao Preto, S˜ao Paulo, Brazil.

Fleming G A. 1980. Essential micronutrients: Boron and molybdenum. (In) *Applied Soil Trace Elements*, p.155–176. Davies B E (Ed). John Wiley and Sons, New York.

Goldberg S. 1997. Reaction of Boron with soils. *Plant and Soil* **193**: 35–48.

Goldberg S, Shouse P J, Lesch S M, Grieve C M, Poss C M, Forster H S and Suarez D L. 2002. Soil boron extractions as indicators of boron content of field-grown crops. *Soil Science* **167**: 720–8.

Gupta U C, Jame Y W, Campbell C A, Leyshon A J and Nicholaichuk W. 1985. Boron toxicity and deficiency: A review. *Canadian Journal of Soil Science* **65**: 381–409.

Mandal B and De D K. 1993. Depth wise distribution of extractable boron in some acidic Inceptisols of India. *Soil Science* **155**: 256–62.

Mandal J, Padbhushan R, Kumar S, Vimal B K, Das A, Bhowmick R and Kumar A. 2016. Evaluation of different extractants and profile distribution of boron in guava orchard in an Inceptisol of Bihar. *International Journal of Bio-resource and Stress Management* **7(3)**: 398–405.

McKeague J A and Day J H. 1966. Dithionite- and oxalate-extractable Fe and Al as aids in differentiating various classes of soils. *Canadian Journal of Soil Science* **46**: 13–22.

Parker D R and Gardner E H. 1981. The determination of hot water soluble boron in some acid Oregon soils using a modified azomethine-H procedure. *Communications in Soil Science and Plant Analysis* **12**: 1311–22.

Ponnamperuma F N, Cayton M T and Lantin R S. 1981. Dilute hydrochloric acids as an extractant for available zinc, copper and boron in rice soils. *Plant and Soil* **61**: 297–310.

Reisenauer H M, Walsh L M and Hoeft R G. 1973. Testing soils for sulphur, boron, molybdenum, and chlorine. (*In*) *Soil Testing and Plant Analysis*, Walsh L M and Beaton J D (Eds). 173–200. SSSA, Madison, Wisc.

Sarkar D, Mandal B and Mazumdar D. 2008. Plant availability of boron in acid soils as assessed by different extractants. *Journal of Plant Nutrition and Soil Science* **171**: 249–454.

Sarkar D, Batabyal K, Das R, Datta A, Hazra G C, Mandal B and Saha J K. 2012. *Boron in Soils and Crops of West Bengal*. Kalyani, India: Bidhan Chandra Krishi Viswavidyalaya.

Shiffler A K, Jolley V D, Christopherson J E and Webb B L. 2005. Pressurized hot water and DTPA-sorbitol as viable alternatives for soil boron extraction, II: Correlation of soil extraction to responses of boron-fertilized alfalfa. *Communications in Soil Science and Plant Analysis* **36**: 2189–207.

Walkley A and Black I A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29–38.

Warrington K. 1923. The effect of boric acid and borax on the broad bean and certain other plants. *Annals of Botany* **37**: 629–72

Webb B L, Hanks D H and Jolley V D. 2002. A pressurized hot water extraction method for boron. *Communications in Soil Science and Plant Analysis* **33**: 31–9

Wolf B. 1971. The determination of boron in soil extracts, plant materials, composts, manures, water and nutrient solutions. *Communications in Soil Science and Plant Analysis* **2**: 363–74.