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Critical limit of boron for cauliflower (*Brassica oleracea* var Girija) in soils of Assam

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Abstract
A pot experiment was conducted during 2015-2016 with twenty two number of soils of varying soil characters for selecting the most suitable chemical extractant for determination of available boron and evaluation of critical limits of boron for cauliflower. The soils were extracted with hot water, hot 0.01M calcium chloride, 0, 01M tartaric acid, 1.0M ammonium acetate, 0.5M potassium dihydrogen phosphate and 0.1M salicylic acid. The availability of boron was found to be vary with chemical extractants used. In terms of the efficiency of B extraction, the extractants followed the order in decreasing trend as hot 0.01M calcium chloride(HCC) > hot water (HW) > 0.1M salicylic acid(SA) >0.5M potassium dihydrogen phosphate (PDP) > 0.01 M tartaric acid (TA) >1.0M ammonium acetate(AA). Critical limits of extractable boron as determined by graphical procedure were 0.50, 0.66, 0.45, 0.38, 0.47, 0.50 mg kg^{-1} and by statistical procedure were 0.53, 0.66, 0.47, 0.38 0.47 and 0.50 mg kg^{-1} for hot water, hot 0.01M calcium chloride, 0.01 M tartaric acid, 1.0M ammonium acetate**,** 0.5M potassium dihydrogen phosphate and 0.1M salicylic acid**,** respectively. Both the methods showed very closer values of critical soil boron concentration. Among the extractants, 0.1M salicylic acid recorded the highest correlation with Bray's percent yield, yield at control, B concentration at control and B uptake at control. Therefore, in view of high degree of correlation of soil test values with plant response parameters, 0.1M salicylic acid was found to be the best extractant for assessing the available boron in soils of Assam. The critical level of boron concentration established by graphical and statistical procedures were 24.87 and 25.78 mg kg^{-1}, respectively grown in soils of Assam in cauliflower plant on dry weight basis at 60 days growth period.

Keywords: critical limit, boron, cauliflower, *Brassica oleracea*, Assam

Introduction
A critical limit is the range of concentration of nutrient element at which growth of the plant is restricted in comparison with that of the plant at higher nutrient level. The hypothesis is that the plant with nutrient concentration below the critical limit will respond to addition of fertilizers and very low response observed above the critical limit. The critical limit or level is quite often employed for a wide variety of soils and crops, even though these critical limits may be different not only for soils, crop species but also for different varieties of given crop (Tandon, 1992; Singh and Agarwal, 2007) [9, 8]. The critical level approach, though, used in field crops on large scale, it was rarely advocated in vegetable crops. The response of crop plants to the insufficiency or sufficiency of specific nutrients has helped to generate information on the critical limits of each of the elements. A number of extractants have been developed by soil chemists to assess the relative nutrient status of soils and to serve as the basis for making nutrient recommendations. Soil extractants like hot water, hot calcium chloride, mannitol, tartaric acid, salicylic acid, hydrochloride acid, ammonium acetate, Mehlich 1 and Mehlich 3 were evaluated and a wide range of soil B concentrations reported (Datta, 1996; Redd *et al*., 2008; Niaz *et al*., 2013; Debnath *et al*., 2015) [2, 6, 5, 3]. In a given agro-climatic condition, suitability of different soil extractant needs to be checked in predicting the response of a particular nutrient application (Watham *et al*., 2014) [10].

Materials and Methods
Collection of soil samples
Soil samples from the surface (0-15cm) representing four agro-climatic zones viz., Central Brahmaputra Valley Zone (CBVZ), Lower Brahmaputra Valley Zone (LBVZ), North Bank Plain Zone (NBPZ) and Upper Brahmaputra Valley Zone (UBVZ) were collected covering

fifty locations in each zone. The sites under each zone were selected based on the soil map of Assam (Sen *et al*., 1999) [7].

Table 1: Details of bulk soil samples collected for pot experiment

Sr. no	Sample designated as	Location	Latitude	Longutude	Land use
1	S_1	Jamuguri	26 25'398"	92 38'302"	Vegetable
2	S_2	Nam Deuri	26 47'221"	94 03'399"	Vegetable
3	S_3	Upper Deuri	26 48'902"	93 09'205"	Vegetable
4	S_4	Kalbari	26 41'881"	92 22'788"	Vegetable
5	S_5	Hagunpara	26 41'881"	92 22'788"	Vegetable
6	S_6	Danichapori	27 18'383"	27 18'383"	Vegetable
7	S_7	Dichoiporia	27 18'359"	27 18'359"	Vegetable
8	S_8	Kacharipam	26 35'850"	91 11'917"	Vegetable
9	S_9	Kawaimari	26 25'139"	89 53'618"	Vegetable
10	S_{10}	Kumuliagaon	26 40'113"	91 12'619"	Vegetable
11	S_{11}	Kumuliagaon	26 24'841"	89 53'450"	Vegetable
12	S_{12}	Balipara	26 41'887"	92 22'815"	Vegetable
13	S_{13}	Orange	26 12'825"	90 08'007"	Vegetable
14	S_{14}	Kurkani	26 14'107"	90 07'223"	Vegetable
15	S_{15}	Napam	26 13'290"	90 07'618"	Vegetable
16	S_{16}	Parmaiguli	26 25'576"	92 38'351"	Vegetable
17	S_{17}	Thakmora	26 41'843"	92 22'815"	Vegetable
18	S_{18}	Bengnaati	26 25'013"	8953'525"	Vegetable
19	S_{19}	Juria	26 40'113"	91 12'619"	Vegetable
20	S_{20}	Borbari	26 41'841"	92 21'087"	Vegetable
21	S_{21}	Lahorighat	26 48'966"	93 09'143"	Vegetable
22	S_{22}	Moirabari	26 40'428"	91 12'783"	Vegetable

Statistical procedure for critical limit

The steps followed for calculation of critical limit of boron in soil and plant by statistical approach as suggested by Cate and Nelson (1971) [1] was as follows:

1. The initial soil test values of boron were arranged in ascending order.
2. The Bray's per cent yield was written against each soil test boron value.
3. The Correction Factor (C.F.) and Total Corrected Sum of Square (T.C.S.S.) were calculated from Bray's per cent yield by using following formulae:

$$C.F = \frac{(\sum Y)^2}{n} \frac{\sum(Y_1 + Y_2 + Y_3 \ldots\ldots\ldots Y_n)^2}{n}$$

T.S.S. $= \Sigma Yi^2 - C.F.$

$= \Sigma (Y1 + Y2 + Y3 + \ldots\ldots..Yn)^2 - C.F$

Where,

Y= per cent dry matter yield

n = total number of observations

The data were grouped into two groups *i.e*. if the total number of observations are 'n' then data were grouped as (p, n-p), (p + 1, n-P+1) *e.g*. if n = 15 then the data is grouped as (2, 13) (3, 12) …… (13, 2).

4. A table with following columns was prepared.

i) Last value of soil available nutrient.

ii) Plant available B included in population 1st *i.e*

$$= \frac{P_1+P_2+----------+Pn}{n}$$

iii) Combine sum of square of deviation from mean of population 1st *i.e*.

C.S.S.I.

Here total of all values of population 1st was made

$$CSS\ I = \Sigma (P_1^2 + P_2^2 \ldots\ldots + Pn^2) - \frac{\Sigma (P_1 + \ldots\ldots\ldots\ldots Pn)^2}{n}$$

iv) If B_n was the number of observations in population, IInd then mean relative yield in population IInd

$$CSS\ I = \Sigma (P_1^2 + P_2^2 \ldots\ldots + Pn^2) - \frac{\Sigma (P_1 + \ldots\ldots\ldots\ldots Pn)^2}{n}$$

v) Combined sum of squares of deviation from mean of population IInd (CSSII). Here total of all values of population IInd was made *i.e*. $(B_1 + B_2 + \ldots. + B_n)$

$$CSSI = \Sigma (B_1^2 + B_2^2 \ldots\ldots + Bn^2) - \frac{\Sigma (B_1 + \ldots\ldots\ldots\ldots Bn)^2}{n}$$

vi) Postulated critical level (Split between the two population) *i.e.* P.C.L. was calculated as

$$PCL = \frac{\text{Last value in I}^{st}\text{ population + value in II}^{nd}\text{ population}}{2}$$

Last value in Ist population + value in IInd population

$$R^2 = \frac{TCSS - (CSS\ I + CSS\ II)}{TCSS}$$

The concentration having highest R^2 is considered as the critical concentration of investigated nutrient in question. The data obtained were statistically analyzed according to the procedure given by Panse and Sukhatme (1957).

Pot experiment

Twenty two bulk soil samples of varying soil characteristics were collected from the different zone of Assam for conducting pot experiment during 2015-16 for determination of critical limits of boron for cauliflower in soils. Soils were

air dried, grind and passed through a 2 mm sieve. The processed soil samples were analyzed for important physio-chemical properties before start of the experiment. The experiment was conducted in a plastic pots filled with 5 kg air-dried soil. Three level of B (B) viz., B_0 (no B), $B_{1.0}$ (1.0 kg B ha^{-1}) and $B_{2.0}$ (2.0 kg B ha^{-1}) were applied through AR grade Borax ($Na_2B_4O_7.7H_2O$). Treatments were replicated thrice for each soil. A basal dose of 80:60:60 kg NPK ha^{-1} was applied in the form of urea, single super phosphate and murate of potash, respectively in each pot. The soils in the pots were then moistened to field capacity with deionized water and planted with one healthy seedling of hybrid cauliflower (var. Girija) plant in each pot and irrigation was given with deionized water as and when required. The cauliflower plants were harvested after 60 days of growth, washed with distilled water and dried in an oven at 65 ºC. Dry matter yield of oven dried samples was recorded.

Evaluation of suitable extractants for boron

The surface soil samples used for pot experiment were analyzed for available boron by using six extractants. The following six extraction procedures are given below

Table 2

Sl. no.	Extractants	Soil: extractant ratio	Shaking time (min)	References
1	Hot water	1:2	5 min reflux	Berger and Truog (1939)
2	Hot 0.01M $CaCl_2$	1:2	10	Aitken *et al*. (1987)
3	0.01M $CaCl_2$	1:2	60	Aitken *et al*. (1987)
4	1.0 M NH_4OAC (pH4.8)	1:2	60	Gupta and Stewart (1975)
5	0.5 M KH_2PO_4	1:2	60	Chao and Sanzolone (1989)
6	0.1M Salicylic acid	1:2	60	Datta *et al*. (1998) [2]

Statistical analysis

The raw data observed from pot experiments were put for statistical analysis using two Factorial Complete Randomized Design (CRD), respectively to draw the valid differences among the treatments. The significance of treatment on dry matter yield, concentration and uptake of boron by cauliflower plant was tested by adopting the procedure for factorial randomized block design for pot experiment as recommended by Federer (1967) [4].

Pot culture experiment

Initial physico-chemical properties of bulk soil samples

The data pertaining to the physico-chemical properties of initial bulk soil samples are presented in Table 3. The soils were acidic in nature and pH ranged from 5.00 to 6.32 with an average mean value of 5.68. The soil organic carbon and cation exchange capacity varied from 0.30 to 0.91% and 5.00 to 8.40 [cmol (p^+) kg^{-1}] with an average of 0.61(%) and 6.62 [cmol (p^+) kg^{-1}], respectively. The sand, silt, and clay fractions varied from 16.20-67.00, 16.00-48.20 and 12.00-36.00 %, respectively.

Table 3: Initial physico-chemical properties of bulk soil samples

Soil no	pH	Organic Carbon (%)	CEC cmol (p^+) kg^{-1}	Sand (%)	Silt (%)	Clay (%)	Textural class
S_1	5.10	0.71	8.10	30.00	42.00	28.00	Cl
S_2	6.32	0.81	8.30	41.00	30.50	28.50	Cl
S_3	5.71	0.62	7.00	42.30	31.70	26.00	L
S_4	5.30	0.42	7.50	42.00	38.00	20.00	Sl
S_5	5.33	0.52	5.50	57.00	30.00	13.00	Sl
S_6	5.85	0.91	8.40	40.00	24.00	36.00	Cl
S_7	5.91	0.36	5.50	53.00	35.00	12.00	L
S_8	6.27	0.54	5.00	64.00	22.00	14.00	Sl
S_9	5.20	0.90	7.90	47.20	33.80	19.00	Sl
S_{10}	5.69	0.72	5.50	48.00	25.00	27.00	Scl
S_{11}	6.32	0.42	5.80	58.20	29.80	12.00	Sl
S_{12}	5.55	0.45	5.60	60.20	21.00	18.80	Sl
S_{13}	5.62	0.75	7.60	16.20	48.20	35.60	sicl
S_{14}	5.71	0.62	7.40	28.00	47.00	25.00	L
S_{15}	5.59	0.66	5.00	56.00	24.00	20.00	Sl
S_{16}	5.27	0.44	6.90	52.30	34.20	13.50	Sl
S_{17}	6.28	0.67	5.90	45.00	32.00	23.00	L
S_{18}	5.82	0.72	7.00	28.00	46.00	26.00	Cl
S_{19}	6.23	0.71	6.20	40.90	34.20	24.90	L
S_{20}	5.22	0.56	7.50	32.00	33.00	35.00	Cl
S_{21}	5.00	0.30	6.20	67.00	16.00	17.00	Sl
S_{22}	6.21	0.62	5.80	53.00	26.00	21.00	Sl
Range	5.00-6.32	0.30-0.91	5.00-8.4	16.20-67	16.00-48.2	12.00-36	-
Mean	5.68	0.61	6.62	45.51	31.97	22.51	-

Available boron content extracted by different extractants

The results on available boron extracted by different extractants have been presented in (Table 8). Available B content of the soils as extracted by HW, HCC, TA, AA, PDP and SA were found in the range of 0.22 - 0.89, 0.32 - 0.96, 0.17 - 0.73, 0.13 - 0.67, 0.27 - 0.76 and 0.25 - 0.90 mg kg^{-1} with a mean value of 0.55, 0.62, 0.46, 0.37, 0.49 and 0.52 mg kg^{-1},respectively. The highest amount of B was extracted with HCC while the lowest amount was recorded with AA.

Table 4: Amount of boron (mg kg^{-1}) extracted by different extractants

Soil no	Hot water (HW)	Hot 0.01M Calcium chloride (HCC)	0.01M Tartaric acid (TA)	1.0M Ammonium acetate (AA)	0.5M Potassium dihydrogen phosphate (PDP)	0.1M Salicylic acid (SA)
S_1	0.67	0.66	0.53	0.50	0.42	0.45
S_2	0.80	0.96	0.44	0.44	0.56	0.62
S_3	0.74	0.80	0.67	0.33	0.40	0.40
S_4	0.38	0.60	0.17	0.24	0.32	0.38
S_5	0.52	0.57	0.56	0.67	0.42	0.48
S_6	0.89	0.88	0.40	0.64	0.68	0.90
S_7	0.30	0.44	0.33	0.22	0.40	0.37
S_8	0.22	0.32	0.27	0.17	0.36	0.27
S_9	0.85	0.78	0.45	0.52	0.60	0.75
S_{10}	0.40	0.43	0.27	0.31	0.55	0.42
S_{11}	0.45	0.55	0.70	0.24	0.42	0.50
S_{12}	0.50	0.62	0.55	0.34	0.47	0.40
S_{13}	0.83	0.68	0.55	0.36	0.75	0.66
S_{14}	0.59	0.85	0.73	0.60	0.52	0.70
S_{15}	0.24	0.52	0.35	0.20	0.27	0.46
S_{16}	0.26	0.32	0.36	0.24	0.41	0.25
S_{17}	0.51	0.68	0.57	0.41	0.38	0.75
S_{18}	0.78	0.95	0.45	0.54	0.70	0.78
S_{19}	0.76	0.48	0.65	0.38	0.76	0.68
S_{20}	0.53	0.78	0.47	0.42	0.54	0.56
S_{21}	0.36	0.35	0.29	0.13	0.35	0.29
S_{22}	0.46	0.45	0.30	0.17	0.45	0.32
Range	0.22-0.89	0.32-0.96	0.17-0.73	0.13-0.67	0.27-0.76	0.25-0.96
Mean	0.55	0.62	0.46	0.37	0.49	0.52

Graphical method

The critical limits of extractable boron as determined by graphical procedure were 0.50, 0.66, 0.45, 0.38, 0.47, 0.50 mg kg^{-1} for HW, hot 0.01 M $CaCl_2$, 0.01M TA, 1.0M AA, 0.5M PDP, 1.0M SA. respectively and values are shown diagramaticaly in fig (1 and 2)

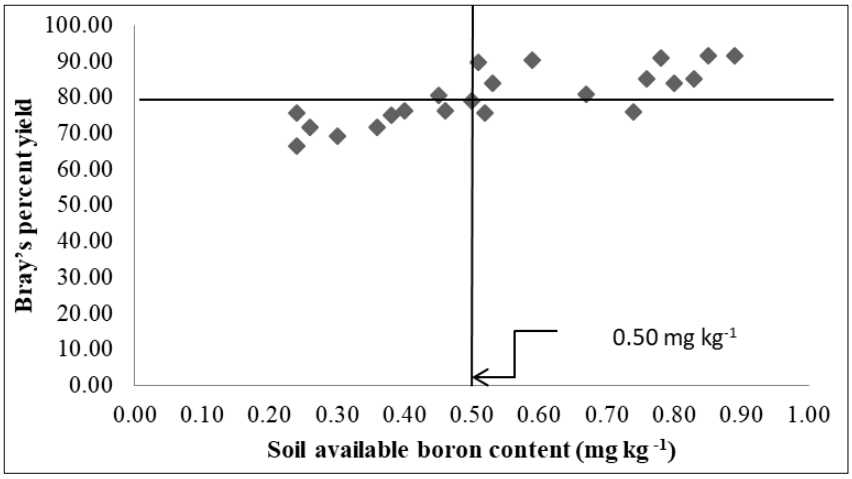

Fig 1: Scatter diagram of Hot water soluble B vs. Bray's percent yield of cauliflower

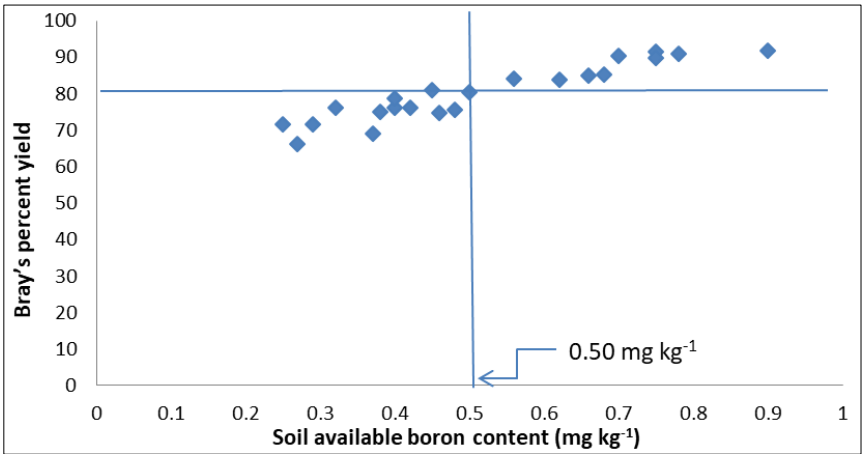

Fig 2: Scatter diagram of 0.1M Salicylic acid vs Bray's percent yield of cauliflower

Statistical method

The data on available soil boron corresponding to corrected sum of squares for the population, postulated critical level and predictability value (R^2) are computed as per statistical model as described by Cate and Nelson (1971) [1] and value for Hot water soluble boron is given in (Table 5). Results revealed that R^2 values ranged between 0.111 and 0.714. The highest R^2 value recorded was 0.714. On the basis of highest predictability (R^2) value, two populations can be easily partitioned which correspond to the postulated critical lewel i.e. 0.53 mg kg^{-1}. *Critical limit as* evaluated by statistical procedure were 0.53, 0.66, 0.47, 0.38,0.47 and 0.50 mg kg^{-1} for HW,HCC,TA,AA,PDP and SA, respectively. It is evident from the Table that critical limits worked out by both the procedures were closely related.

Table 5: Soil available boron, Bray's per cent yield and predictability values (R^2)

Sr. no	Soil boron in population-I Hot Water(HW)	Bray's % yield	Mean Bray's % yield in population -I	Corrected sum of squares of deviation from mean of population CSS-I	Mean Bray's % yield in population -II	Corrected sum of squares of deviation from mean of population CSS-II	R^2 TSS - (CSSI-CSSII) TSS
1	0.22	66.32			80.23	1238.89	**0**
2	0.24	69.19	67.75	4.10	80.89	1036.20	0.160
3	0.26	71.57	69.02	13.79	81.48	892.24	0.269
4	0.3	71.58	69.66	18.68	82.00	788.81	0.348
5	0.36	74.80	70.69	39.77	82.58	674.13	0.424
6	0.38	75.12	71.43	56.12	83.04	609.97	0.462
7	0.4	75.51	72.01	70.42	83.53	543.36	0.505
8	0.45	76.03	72.51	84.53	84.07	474.73	0.549
9	0.46	76.15	72.92	89.07	84.64	405.47	0.601
10	0.5	76.23	73.25	106.13	85.30	327.74	0.650
11	0.51	78.83	73.76	134.41	86.05	238.67	0.699
12	0.52	80.42	74.31	175.09	86.71	181.72	0.712
13	0.53	80.95	74.82	215.74	87.34	138.18	0.714
14	0.59	83.92	75.47	292.64	88.05	92.80	0.689
15	0.67	84.03	76.04	360.93	88.56	73.64	0.649
16	0.74	84.95	76.60	435.36	89.21	50.11	0.608
17	0.76	85.24	77.11	505.67	89.92	28.94	0.568
18	0.78	89.70	77.81	655.52	90.86	2.65	0.469
19	0.8	90.39	78.47	805.63	90.39	3.25	0.347
20	0.83	91.02	79.10	955.29	91.40	0.23	0.229
21	0.85	91.50	79.69	1101.81	91.59	0.01	0.111
22	0.89	91.67	80.23	1235.01			
						SS	142856.79
						TSS	1238.89
						CF	141617.89

Conclusion

Status of available boron (HWS-B) content of the soil was found low to high category. Boron was found deficient in all four zones of Assam. Considering 0.50 mg kg^{-1} as critical limit for hot water, 32.50 per cent of soils of Assam were deficient in HWS-B and thus need boron fertilization for maximizing the production of vegetable crops. Among the extractants, 0.1M salicylic acid was found to be best extractant for assessing the available boron in soils of Assam for cauliflower. The critical level of boron concentration in soil and plant (cauliflower of 60 days growth) was found to be 0.50 and 24.87 mg kg^{-1} with 0.1M salicylic acid and cauliflower plant, respectively. These values may be used to predict the response of cauliflower to applied boron.

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