ANSF APPLIED AND NATURAL SCIENCE FOUNDATION

Journal of Applied and Natural Science
14(2), 385 - 395 (2022)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Fixing critical limits of boron in rice soils of Karaikal region, Puducherry union territory, India

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Article Info
https://doi.org/10.31018/jans.v14i2.3415
Received: March 12, 2022
Revised: May 15, 2022
Accepted: May 21, 2022

How to Cite
Kowsalya, A. *et al.* (2022). Fixing critical limits of boron in rice soils of Karaikal region, Puducherry union territory, India. *Journal of Applied and Natural Science*, 14(2), 385 - 395. https://doi.org/10.31018/jans.v14i2.3415

Abstract
Boron is relatively immobile in plants and its deficiency can cause serious yield reduction in rice by retarding panicle formation. Karaiakal region of Puduchuerry union terittory includes different soils with varying fertility status thus supplying boron at optimum level is a must concern to enhance the rice productivity.A pot experiment was conducted to fix critical limits of boron in soils and rice of this Karaikal region. Forty surface soil samples (0-15 cm) were collected from Inceptisol, Entisol and Vertisol soil orders of different locations in Karaikal region. The experiment was conducted with three levels of boron viz., 0, 1 and 2 ppm applied through borax in a factorial completely randomized design with three replications. The available B content of soil was estimated with five extractants. The critical limits of hot water, hot 0.01 M $CaCl_2$, 0.05 M HCl, 1.0 M NH_4OAc, 0.01M $CaCl_2$+ 0.05 M Mannitol extractable B were found to be 0.50, 0.58, 0.46, 0.45 and 0.39 ppm in Inceptisol, 0.48, 0.59, 0.44, 0.39 and 0.48 ppm in Entisol and 0.45, 0.54, 0.45, 0.44 and 0.41ppm in Vertisol and a critical limit of 31.0, 39.0 and 34.0 ppm B in rice plant for Inceptisol(0.5ppm), Entisol(0.48 ppm) and Vertisol(0.45 ppm) as determined by Cate and Nelson's graphical procedure. Among the extractants the hot water extractant showed the highest significant and positive correlation with Bray's percent yield(0.48,0.47and 0.48), plant B content(0.041*, 0.019* and 0.271*) and B uptake(0.012*, 0.646* and 0.293*), respectively in Inceptisol, Entisol and Vertisol. From this study, the indicating knowledge of critical limit of boron will help to avoid yield loss of rice in the study region.

Keywords: Bray percent yield, Boron ,Cate and Nelson's method, Critical limit, Rice

INTRODUCTION

Rice is the staple food for nearly half of the world's population that live in developing countries. The world's total area occupied by rice is one third to the total area planted to cereals. India has 43.78 m ha-1 total rice cultivation areawithaverage productivity of 4.05 t ha^{-1}. In Tamilnadu, rice is cultivated in an area of 1.81 m ha^{-1}1 with the production of 63.08 lakh metric tonnes and average productivity of 2.8 tonnes ha^{-1} (USDA 2020). In the Union Territory of Puducherry, the area under rice cultivation was 16,263 ha during the year 2015-2016, which accounted for63.30 per cent of the total cropped area. Production of rice during 2015-16 was reported as 43,886 Mg as against 52,717 Mg in 2014-2015. The average yield of rice was 2699 kg ha^{-1} in 2016.In Karaikal, rice is grown in an area of 4447 ha with an average yield of 1727 kg ha^{-1} with atotal production of 7682 Mg (Directorate of Economics and Statistics,2016).

The micronutrients in rice areone the most important inputs for abetter yield. The balanced use of micronutrients is essential for sustaining soil fertility and raisingfood grain production. Among micronutrients, boron (B) nutrition got a special importance because of the widespread deficiency of B in crops (Singh et al.,2006; Singh ,2012; Prasad et al., 2014: Sarangi et al., 2016; Yoshinari and Takano,2017). They further observed that, out of 33, 000 soil samples, 45% samples were found to be deficient in B (0.5 mg kg^{-1} hot water-soluble

B as the critical level). Boron deficiency is further affected by coarse texture, low pH, low organic carbon, and leaching under high rainfall (Singh, 2008; Wimmer et al., 2009;Jones et al.,2013 ; Dey et al., 2015;). Based on several field and green house experiments, Singh et al. (2006) and Rattan et al (2009) reported the critical value of B as 0.5 mg kg^{-1}. Crops grown on soils with available nutrient status below the critical limit are likely to be deficient and sensitive crops would show deficiency symptoms and respond well to the addition of that deficient nutrient(Wimmeret al.(2015); Powlson et al. (2011). The hot water-soluble B content of the black soil (Vertisol) was 0.6 and 0.7 mg kg^{-1}, respectively; these results are in accordance with the findings of other researchers,which revealed that the hot water-soluble B consists of a non-specifically adsorbed B fraction and it is very feebly held by divergent soil constituent's particles (Murthy et al., 2012). Consequently, with simple irrigation, this B fraction is released into soil solution and recognized as the most easily available B fraction for plant uptake (Renan and Gupta,1999). There seems to be no report about the status of boron in soils of Karaikalregion of Puducherry Union Territory. Hence, pot experiment was conducted to fix the critical limit of boron in soil and ricevar.ADT-46 plant.

MATERIALS AND METHODS

A pot experiment with rice variety (ADT - 46) was conducted during 2020 in Karaikal. The 40 surface samples (0-15cm) coming under the order Inceptisol, Entisol and Vertisol were collected from different locations of Karaikal region. The initial soil samples were analysed for both mechanical and chemical compositions following standard methods(*viz.,*Soil pH was measured in suspension of (1:2.5 soil: water) using a glass electrode standardized with pH 4.0,7.0 and 9.2 buffer tablets attached to an Ion analyser, conductivity was measured in the same suspension using a conductivity meter and the cation exchange capacity was determined by Neutral normal ammonium acetate method (Jackson, 1973). The organic carbon content was determined by modified Chromic acid wet digestion titration method (Walkley and Black,1934).CaCO3 % was estimated by Acid neutralization method (Allison and Moodie,1965). The available nitrogen was determined by alkaline permanganate method (Subbiah and Asija, 1956). Available phosphorus (using 0.5 M NaHCO3 of pH 8.5) was quantified by the spectrophotometer method (Olsen et al.,1954). Available potassium (using neutral normal ammonium acetate extract) was determined by Flame photometric method (Standford and English,1949). Soils were analysed for available boron by different extractants (Table 1). There were three B treatments viz. B_0, B_1 and B_2 mg kg^{-1}. Each of the treatments was replicated thrice in a Factorial Completely Randomized Design (FCRD). The total number of earthen pots used in this study was 120. An amount of 10 kg of each soil was weighed and four rice seedlings were planted in each pot. The boron was applied through analytical grade di - sodium tetra borate ($Na_2B_4O_7 10H_2O$) as per treatment schedule (B_o- Control; B_1-0.04 mg/pot; B_2-0.08 mg/pot). The nutrients N, P_2O_5 and K_2O equivalent to @ 150:50:50 kg ha^{-1} were applied as basal dose through urea, single super phosphate and muriate of potash, respectively to each pot. The plants were cut at the stage of 6 weeks, washed with distilledwater and dried in an oven at 65°C for 24 hours. The extractable B content of soil (Wolf, 1971) and B content of plant (Gupta and Stewart,1975) in the digest were determined by Spectrophotometer and B uptake was computedby dry matterproduction(DMP) multiplied with boron content.

The critical limit of B in soil and rice plant was determined by the graphical method proposed by Cate and Nelson's (1965). This procedure plotted a scatter diagram of the Bray's per cent yield on Y–axis versus soil test values on X–axis. For evaluation of different extractants, the co-efficient of correlation between amount of boron extracted by different extractants with Bray's per cent yield, tissue boron concentration and uptake of boron by rice

crop were worked out. Bray's percent yield was calculated by using the formula

$$\text{Bray's per cent yield} = \frac{\text{Yield without Boron X 100}}{\text{Yield at optimum Boron}} \quad \text{Eq.1}$$

Table 1. List of different extractants used for extraction of available soil boron

Name of the extractants	Soil: solution ratio	Shaking time (min)	Reference
Hot water	1:2	5	Berger and Truog (1939)
Hot 0.01 M $CaCl_2$	1:2	5	Aitken et al.(1987)
0.01 M $CaCl_2$ + 0.05 M Mannitol (pH 8.5)	1:2	60	Cartwright et al.(1983)
1.0 M NH_4OAC	1:2	60	Gupta and Stewart(1975)
0.05 M HCl	1:2	60	Cartwright et al.(1983)

RESULTS AND DISCUSSION

Initial soils characteristics

The experiment soils had pH range of 6.16 to 8.79.The soil was alkaline with mean of 8.06, EC ranged from 0.10 to 0.87 dSm^{-1}, non-saline with a mean of 0.43 dSm^{-1}, organic carbon ranged from 3.51 to 14.78 g kg^{-1} with mean of 7.39 g kg^{-1},$CaCO_3$ ranging from 0.53 to 3.53%,soil was non-calcareous with mean of 1.96%, the texture of the soil was sandy clay, sandy clay loam and clay (Table 2).The available N ranged from 198.8 to 588 kg ha^{-1} with mean of 335.86 kg ha^{-1}, P ranged from (7.0 to 64.1 kg ha^{-1}) with mean of 23.18 kg ha^{-1} and K ranged from (104.7 to 413.5 kg ha^{-1}) with mean of 262.89 kg ha^{-1}. The DTPA extractable B varied from (0.34 to 0.78 mg kg^{-1}) with mean of 0.50 mg kg^{-1} (Table 3).

Table 2. Initial characteristics of soils used for the pot experiments

Soil order	Soil (Location)	Textural class	pH	EC (dSm^{-1})	OC (g kg^{-1})	$CaCO_3$ (%)
Inceptisol	Madhur	Clay	8.02	0.40	7.61	1.25
	Madhur	Clay	8.28	0.56	7.46	1.02
	Madhur	Clay	7.58	0.48	7.90	0.98
	Madhur	Clay	8.01	0.44	6.00	1.03
	Madhur	Clay	7.45	0.36	8.05	1.23
	Madhur	Sandy clay loam	6.53	0.18	6.00	0.53
	Madhur	Sandy clay loam	6.16	0.10	5.41	0.76
	Madhur	Sandy clay	7.67	0.25	6.29	0.98
	Madhur	Sandy clay	8.55	0.53	8.34	1.32
	Madhur	Sandy clay	8.33	0.34	7.90	1.27
	Madhur	Sandy clay	8.72	0.42	8.20	1.10
	Madhur	Sandy clay	8.66	0.76	8.05	0.78
	Mupaithangudy	Sandy clay	8.61	0.44	10.39	0.75
	Mupaithangudy	Sandy clay	7.83	0.21	8.34	1.36
	Mupaithangudy	Sandy clay	7.62	0.31	9.37	0.79
	Serumavilangai	Sandy clay loam	8.32	0.39	4.24	0.99
	Serumavilangai	Sandy clay loam	8.86	0.45	4.10	1.52
Entisol	Thiruvengadapuram	Sandy clay	8.34	0.49	10.83	0.78
	Thiruvengadapuram	Clay	8.45	0.87	8.93	2.15
	Kezhaponpethi	Clay	8.06	0.83	9.51	1.36
	Kezhaponpethi	Sandy clay	7.72	0.53	6.59	0.96
	Kezhaponpethi	Sandy clay	7.73	0.38	11.56	3.43
	Thiruvettakudy	Sandy clay loam	8.32	0.39	7.46	1.28
	Thiruvettakudy	Sandy clay loam	8.14	0.44	6.59	1.12
	Thiruvettakudy	Sandy clay loam	8.22	0.52	8.93	1.34
	Thiruvettakudy	Sandy clay loam	7.89	0.40	7.46	0.86
	Thiruvettakudy	Sandy clay loam	8.51	0.53	6.73	1.52
	Thiruvettakudy	Sandy clay loam	8.81	0.57	10.68	2.23
	Thiruvettakudy	Sandy clay loam	8.30	0.40	7.76	1.34
	Thiruvettakudy	Sandy clay loam	8.36	0.48	7.32	1.45
Vertisol	Mathalangudy	Clay	7.28	0.32	14.78	1.46
	Mathalangudy	Clay	7.44	0.28	10.39	1.30
	Mathalangudy	Clay	8.08	0.23	3.51	0.78
	Mathalangudy	Clay	8.44	0.42	4.68	0.83
	Mathalangudy	Clay	8.56	0.51	4.98	1.05
	Mathalangudy	Clay	8.79	0.32	6.15	0.88
	Mathalangudy	Sandy clay loam	8.45	0.78	3.95	3.26
	Mathalangudy	Sandy clay loam	7.78	0.21	3.80	2.58
	Mathalangudy	Sandy clay loam	8.25	0.58	5.12	2.67
	Mathalangudy	Sandy clay loam	7.34	0.14	4.24	3.43
	Range	SCl – SC-C	6.16-8.79	0.10-0.87	3.51 -14.78	0.53 -3.43.
	Mean		8.06	0.43	7.39	1.96

Dry matter production, B content and uptake

Rice plants significantly(p=0.05) responded to boron application in all the soils (Table 4). DMP improved drastically to B applied in soils which were low in B content(0.4 ppm) compared to high B content(0.85ppm) soils. The dry matter production was highest (48.9 g/pot) with application of 2 mg kg^{-1} of boron and was significantly higher over other levels of boron. The plant boron content and uptake were significantly influenced in all soils where B was applied at the rate 2 mg kg^{-1}. The plant B content in boron2 mg kg^{-1}treated pot ranged from 25.5 – 45.5 ppm with mean value 40.4 ppm and while 1mg kg^{-1}ranged from 21.5 – 45.5ppm with mean value of 34.9ppm and in control pot B con-

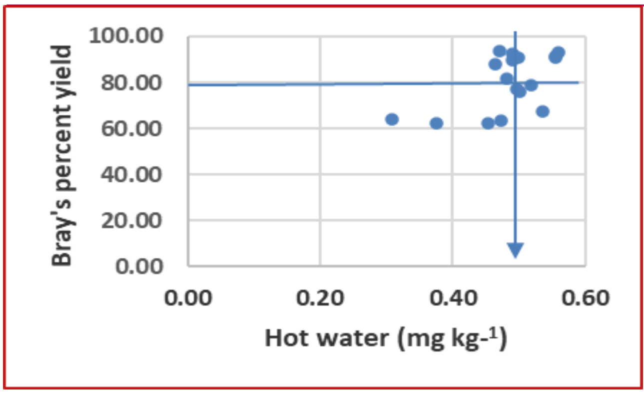
Table 3. Available nutrient status of soils used for pot experiments

Soil order	Soil (Location)	Available N (Kg ha^{-1})	Available P (Kg ha^{-1})	Available K (Kg ha^{-1})	Available B (mg kg^{-1})
Inceptisol	Madhur	305.2	25.8	344.6	0.73
	Madhur	322.0	20.2	345.5	0.85
	Madhur	378.0	14.2	288.9	0.71
	Madhur	523.6	16.7	342.4	0.47
	Madhur	380.8	11.3	322.4	0.40
	Madhur	327.6	25.9	104.7	0.61
	Madhur	240.8	17.2	178.0	0.45
	Madhur	288.4	17.4	181.2	0.78
	Madhur	330.4	21.2	257.3	0.43
	Madhur	266.0	44.2	210.2	0.65
	Madhur	344.4	48.8	216.2	0.72
	Madhur	386.4	17.8	255.6	0.48
	Mupaithangudy	291.2	25.8	251.1	0.85
	Mupaithangudy	341.6	20.8	365.1	0.69
	Mupaithangudy	347.2	20.9	188.3	0.81
	Serumavilangai	277.2	9.2	184.6	0.53
	Serumavilangai	257.6	9.8	185.6	0.68
Entisol	Thiruvengadapuram	302.4	26.6	220.5	0.47
	Thiruvengadapuram	319.2	12.6	275.2	0.41
	Kezhaponpethi	288.4	17.5	180.2	0.73
	Kezhaponpethi	260.4	17.6	310.2	0.56
	Kezhaponpethi	338.8	19.9	431.5	0.78
	Thiruvettakudy	330.4	35.1	301.9	0.83
	Thiruvettakudy	414.4	24.3	234.8	0.46
	Thiruvettakudy	299.6	17.1	331.8	0.65
	Thiruvettakudy	445.2	12.6	296.0	0.73
	Thiruvettakudy	260.4	9.2	253.1	0.81
	Thiruvettakudy	277.2	12.6	331.4	0.68
	Thiruvettakudy	294.0	7	349.0	0.41
	Thiruvettakudy	291.2	7.2	314.1	0.75
Vertisol	Mathalangudy	364.0	27.1	360.1	0.48
	Mathalangudy	459.2	30.6	111.4	0.64
	Mathalangudy	271.6	25.7	220.5	0.73
	Mathalangudy	585.2	64.1	355.0	0.50
	Mathalangudy	327.6	53.9	272.1	0.73
	Mathalangudy	198.8	20.6	281.7	0.46
	Mathalangudy	238.0	18.5	202.8	0.86
	Mathalangudy	355.6	28.6	211.0	0.72
	Mathalangudy	588.0	54.6	276.0	0.74
	Mathalangudy	316.4	16.9	173.5	0.77
	Range	198.8 – 588	7.0 – 64.1	104.7 -431.5	0.34- 0.78
	Mean	335.86	23.18	262.89	0.50

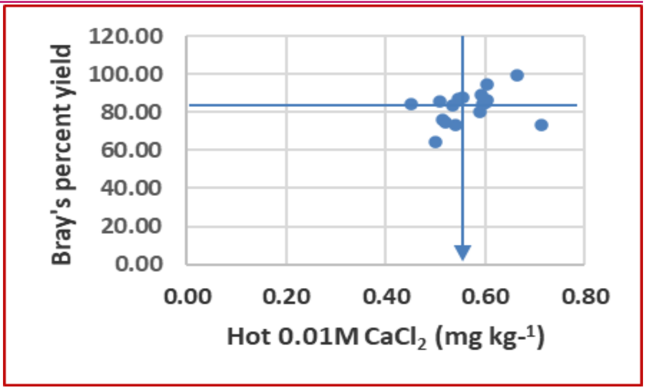
Table 4.Effect of added B on DMP, B content and uptake by rice and Bray's per cent yield (Mean value of three replications)

	Soil (Location)	Dry matter ~~weight~~ production (g/pot)			Bray's per cent yield	Boron content (ppm)			Boron uptake (mg/pot)		
	Boron Levels	B_0	B_1	B_2		B_0	B_1	B_2	B_0	B_1	B_2
Inceptisol	Madhur	31.8	34.2	39.8	85.9	17.2	21.5	25.5	0.5	0.7	1.0
	Madhur	38.3	48.9	54.8	73.9	18.6	29.3	32.6	0.7	1.4	1.8
	Madhur	38.7	42.1	48.3	85.6	20.9	26.6	31.8	0.8	1.1	1.5
	Madhur	30.6	37.5	39.6	79.4	24.5	28.6	32.9	0.7	1.1	1.3
	Madhur	34.0	38.9	42.9	83.2	20.9	26.5	35.8	0.7	1.0	1.5
	Madhur	34.3	38.4	44.2	83.0	27.4	31.4	36.8	0.9	1.2	1.6
	Madhur	45.3	52.8	63.3	78.0	25.3	32.6	38.6	1.1	1.7	2.4
	Madhur	43.6	54.4	72.8	68.5	28.9	32.8	39.9	1.3	1.8	2.9
	Madhur	33.3	35.8	63.2	67.3	31.6	35.6	43.7	1.1	1.3	2.8
	Madhur	33.6	42.6	56.9	67.6	29.7	38.9	44.8	1.0	1.7	2.5
	Madhur	45.1	54.9	61.2	77.6	31.6	34.8	37.6	1.4	1.9	2.3
	Madhur	25.4	31.9	50.9	61.4	32.5	35.1	44.8	0.8	1.1	2.3
	Mupaithangudy	36.9	44.5	49.9	78.1	35.6	38.4	42.9	1.3	1.7	2.1
	Mupaithangudy	48.7	52.1	61.8	85.5	38.6	41.2	52.5	1.9	2.1	3.2
	Mupaithangudy	39.2	42.2	52.8	82.5	28.4	32.5	43.5	1.1	1.4	2.3
	Serumavilangai	39.0	45.6	49.9	81.7	25.7	32.0	41.6	1.0	1.5	2.1
	Serumavilangai	42.7	49.8	50.2	85.5	28.4	33.8	43.7	1.2	1.7	2.2
Entisol	Thiruvengadapuram	35.0	35.2	39.3	94.0	21.8	35.6	40.2	0.8	1.3	1.6
	Thiruvengadapuram	30.2	36.9	37.9	80.7	18.0	32.3	38.5	0.5	1.2	1.5
	Kezhaponpethi	33.7	41.9	46.2	76.4	20.9	35.9	41.3	0.7	1.5	1.9
	Kezhaponpethi	33.9	43.4	46.2	75.6	27.4	38.4	42.3	0.9	1.7	2.0
	Kezhaponpethi	45.8	59.2	60.5	76.4	28.2	39.1	45.6	1.3	2.3	2.8
	Thiruvettakudy	27.1	30.6	50.0	67.3	32.6	38.3	44.5	0.9	1.2	2.2
	Thiruvettakudy	28.9	49.5	56.7	54.5	31.6	35.3	38.3	0.9	1.7	2.2
	Thiruvettakudy	28.7	36.1	38.9	76.4	32.9	41.2	43.7	0.9	1.5	1.7
	Thiruvettakudy	27.5	32.1	38.7	77.8	28.9	37.4	40.8	0.8	1.2	1.6
	Thiruvettakudy	34.1	54.6	64.4	57.3	35.6	41.9	43.0	1.2	2.3	2.8
	Thiruvettakudy	38.0	42.7	47.8	84.0	35.8	45.5	49.2	1.4	1.9	2.3
	Thiruvettakudy	32.5	36.2	43.9	81.1	33.7	40.9	44.4	1.1	1.5	2.0
	Thiruvettakudy	28.5	31.7	45.8	73.6	37.2	42.6	47.0	1.1	1.4	2.2
Vertisol	Mathalangudy	32.2	37.5	42.6	80.4	23.3	29.0	31.5	0.8	1.1	1.3
	Mathalangudy	31.5	36.1	39.8	83.0	28.6	32.2	35.3	0.9	1.2	1.4
	Mathalangudy	27.6	35.4	40.7	72.5	31.7	38.9	41.6	0.9	1.4	1.7
	Mathalangudy	33.6	41.8	43.9	78.4	29.5	40.5	43.7	1.0	1.7	1.9
	Mathalangudy	33.5	38.6	41.1	84.0	26.9	31.7	37.8	0.9	1.2	1.6
	Mathalangudy	34.3	37.7	39.7	88.6	28.4	32.0	38.3	1.0	1.2	1.5
	Mathalangudy	34.8	38.0	40.2	89.1	31.5	34.4	41.7	1.1	1.3	1.7
	Mathalangudy	37.5	42.7	49.3	81.6	30.8	32.6	37.7	1.2	1.4	1.9
	Mathalangudy	41.1	49.2	53.3	80.1	26.6	32.9	38.8	1.1	1.6	2.1
	Mathalangudy	36.3	42.0	44.7	83.7	32.4	35.7	41.1	1.2	1.5	1.8
	Range	25.4- 48.7	30.6-59.2	37.9-72.8	54.5 -94.0	17.2- 38.6	21.5- 45.5	25.5-52.5	0.5-1.9	0.7-2.3	1.0-3.2
	Mean	36.2	41.9	48.9	78.0	28.6	34.9	40.4	1.0	1.6	2.0

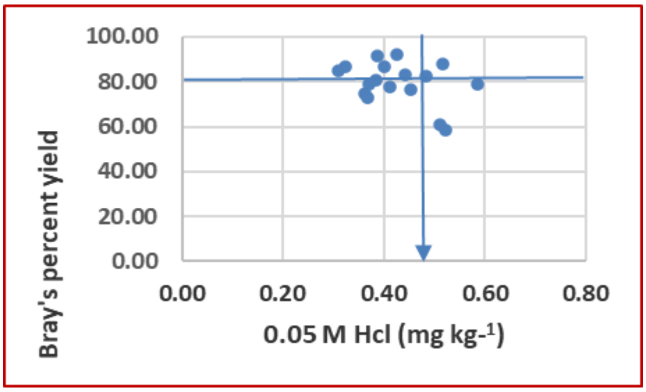
[Bo- 0 ppm ; B1- 1ppm; B2- 2 ppm (B_o- Control; B_1-0.04 mg/pot; B_2-0.08 mg/pot)]



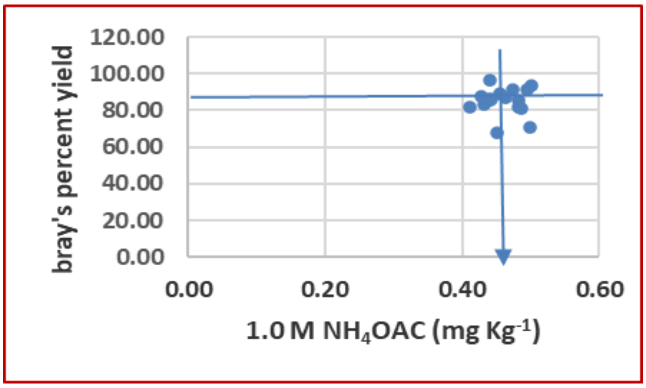
(a) Hot water



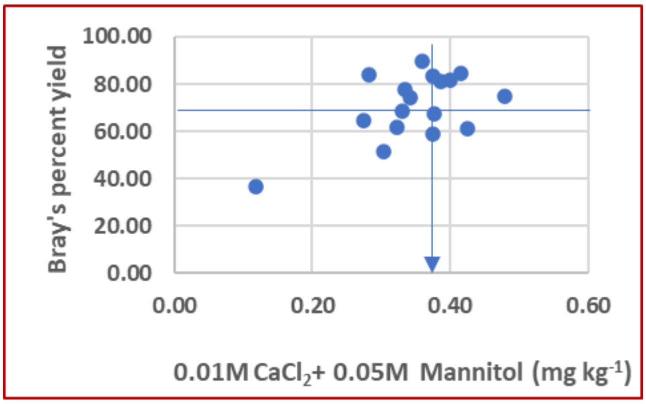
(b) Hot 0.01 M $CaCl_2$



(c) 0.05 M HCl



(d) 1.0 M NH_4OAC



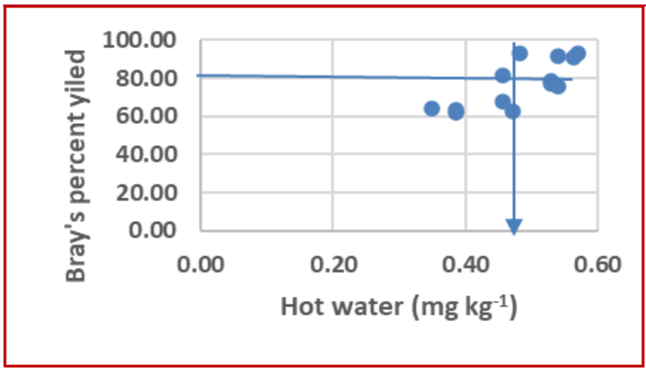
(e) 0.01 M $CaCl_2$ + 0.05 M Mannitol

Fig. 1. *Critical limit of B in Inceptisol among various extractants*

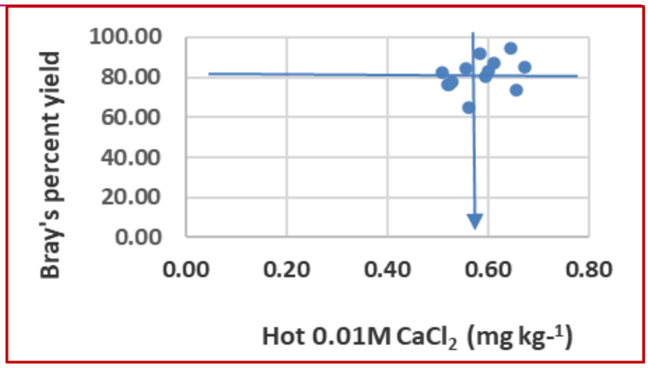
tent ranged from 17.2-38.6ppm with mean value of 28.5ppm. The B uptake in B 2 mg kg^{-1} treated pots ranged from 1.0 - 3.2 mg/pot) with mean value of 2.0 mg/pot, while 1 mg kg^{-1} treated pots ranged from (0.7 – 2.3 mg/pot) with mean value of 1.5 mg/pot, in control pot, B uptake ranged from (0.5–1.9 mg/pot) with mean value of 1.0 mg/pot. The Bray's per cent yield ranged from (54.5 – 94.0) with mean value of 78 %.Boron deficiency is the second most important micronutrient constraint in soils inIndia after that of zinc (Zn)(Rehman et al.,2018). Hence, there was response to application of boron as noticed in the present study.Theapplication of B resulting in increased DMP might be due to its favourable effect onthe cell-dividing metabolic pathways as reported by Hatwar et al., (2003).Positive influence of boron on DMP and boron uptake by rice silty clay,clay and calcareous soil was reported by Khan et al.(2006); Rehman et al.,2016; Ramesh and Rani (2017); Laik et al.(2021), respectively.

Evaluation of different extractants

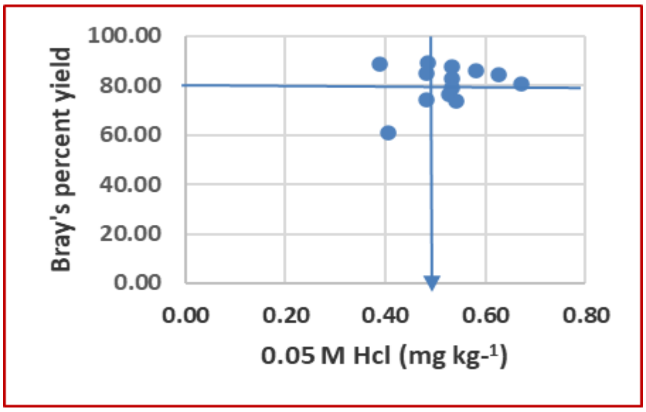
The boron extracted by different extractants differed significantly among the soils (Table 5). The B extracted by hot water (0.35-0.58, 0.35–0.63 and 0.34–0.58 ppm) with mean value of (0.48, 0.47 and 0.48ppm), Hot 0.01 M $CaCl_2$ (0.44 – 0.71, 0.45 – 0.62 and 0.44 – 0.63ppm) with mean value of (0.53, 0.52 and 0.55ppm), 0.05 HCl (0.41 – 0.59, 0.36 – 0.60 and 0.40 – 0.35 ppm) with



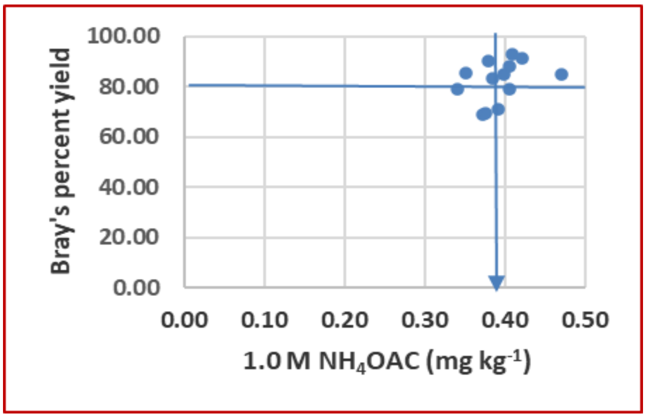
(a) Hot water



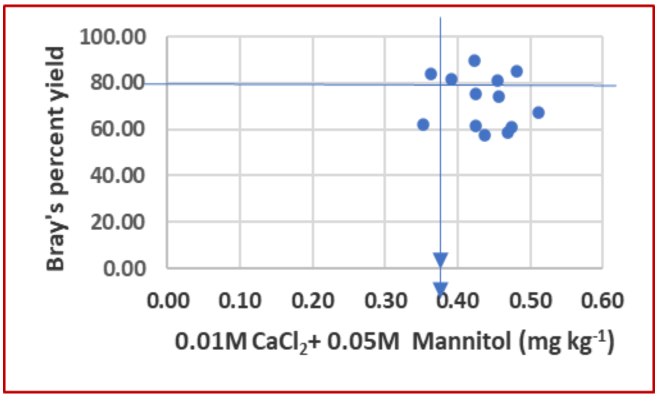
(b) Hot 0.01 M $CaCl_2$



(c) 0.05 M HCl



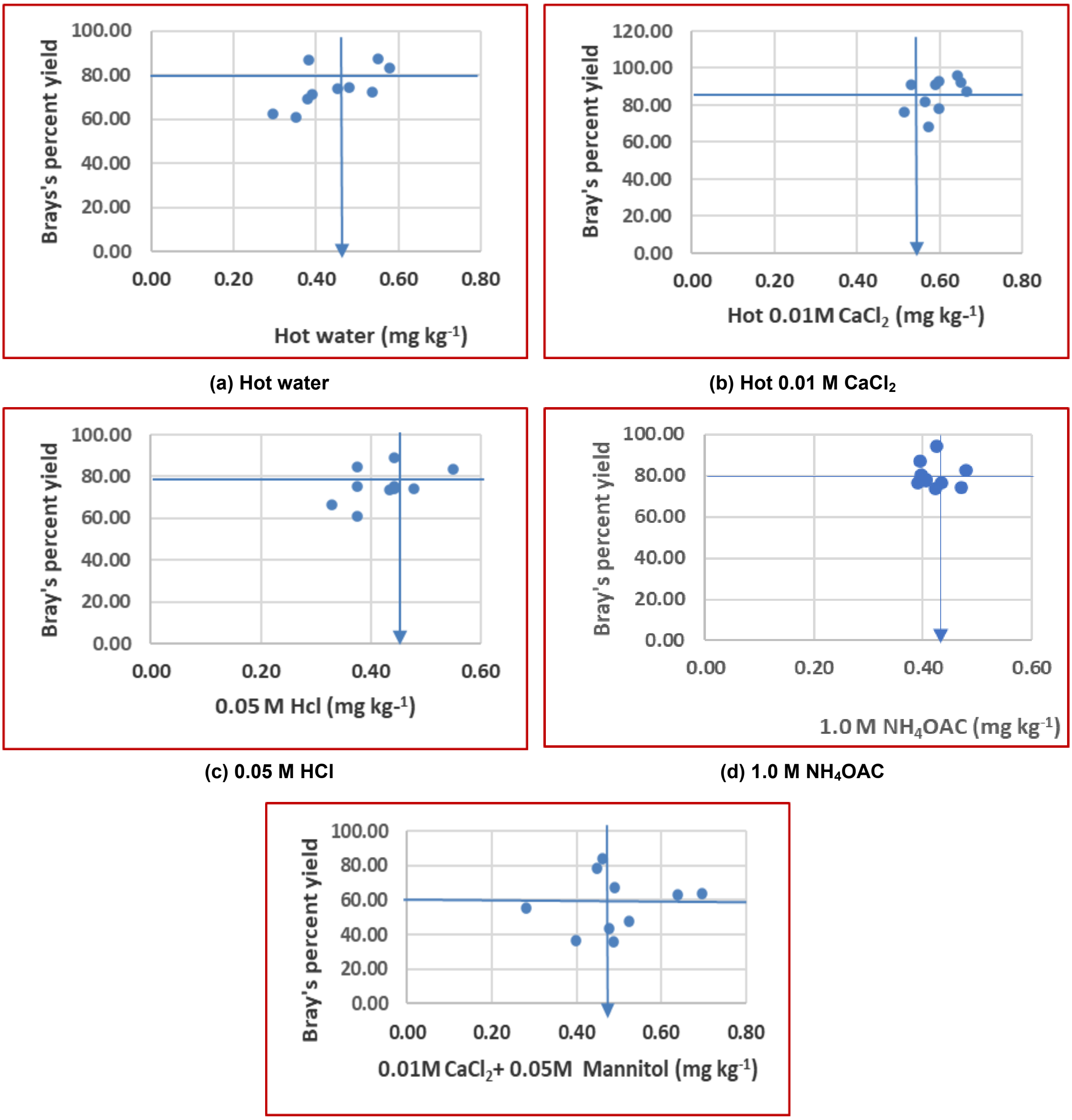
(d) 1.0 M NH_4OAC



(e) 0.01 M $CaCl_2$ + 0.05 M Mannitol

Fig. 2. *Critical limit of B in Entisol among various extractants*

mean value of (0.50, 0.49 and 0.48 ppm), 1.0 M NH_4OAC (0.41 – 0.49, 0.41 – 0.48 and 0.41 – 0.48ppm) with mean value of (0.45, 0.45 and 0.47ppm) and 0.01M $CaCl_2$ + 0.05M Mannitol (0.37 – 0.48, 0.21 – 0.51 and 0.19 – 0.53ppm) with mean value of (0.42, 0.37 and 0.37ppm) in Inceptisol, Entisol and Vertisol, respectively. Based on the amount of B extracted by different extractants, the relative efficiency was of the following order Hot 0.01 M $CaCl_2$> 0.05M HCl > Hot water > 1.0 M NH_4OAc>0.01M $CaCl_2$+ 0.05M Mannitol (pH 8.5) in Inceptisol, Entisol and Vertisol. The amount of B extracted by different extractants were correlated with Bray's per cent yield, plant tissue and boron uptake by rice crop (Table 5). Among the extractants,hot water correlated the highest with Bray's per cent yield (r = 0.629**, 0.762** and 0.587**) which gave positive and significant relationship as compared to other extractants in Inceptisol, Entisol and Vertisol and also hot water recorded significant positive correlation with B content (0.041*, 0.019* and 0.271*) and uptake (0.012*, 0.646* and 0.293*), respectively in Inceptisol, Entisol and Vertisol. Hence hot water was considered as the best B extractant for influencing available B in soils. The hot-water-soluble boron (HWS-B) extraction procedure was used as a benchmark to see any relative variation in available B in comparison with alternate extractants(0.0 M HCL, 0.018M $CaCl_2$, 1M NH_4OAc, 0.25 M sorbitol-DTPA,0.05 M Mannitol prepared in



(a) Hot water

(b) Hot 0.01 M $CaCl_2$

(c) 0.05 M HCl

(d) 1.0 M NH_4OAC

(e) 0.01 M $CaCl_2$ + 0.05 M Mannitol

Fig. 3. *Critical limit of B in Vertisol among various extractants*

0.01M $CaCl_2$, 0.005 M AB-DTPA)(Niaz et al., 2011;Sofi Khurshid et al., 2017).

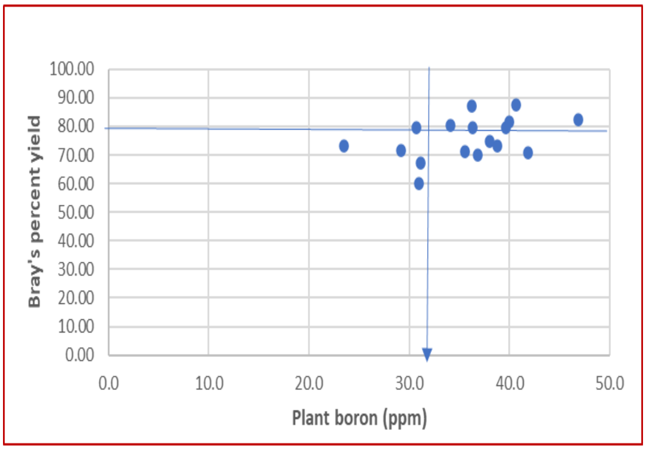
Critical limits of boron

The critical limits for soil boron extracted by hot water, Hot 0.01 M $CaCl_2$, 0.05M HCl, 1.0 M NH_4OAc and 0.01M $CaCl_2$+ 0.05M Mannitol (pH 8.5) solution in Inceptisol, Entisol and Vertisol worked out to be 0.50, 0.58, 0.46, 0.45 and 0.39 ppm Inceptisol (Fig.1 a-e), 0.48, 0.59, 0.44, 0.39 and 0.38 ppm(Entisol (Fig.2 a-e) and 0.45, 0.54, 0.45, 0.44 and 0.41ppm Vertisol (Fig.3 a-e),. The critical limits of B were fixed following the procedure of graphical method (Cate and Nelson,1965). From the correlation coefficient between B extractants and Bray's per cent yield, the critical limits of 0.50, 0.48 and 0.45 ppm obtained with hot water is the critical limits of B for rice soils of Karaikal region. The present result was in agreement with earlier workers (Marupaka et al.,2022; Samreen et al.,2022))and they reported that HWSBoron method was given better results than the other extractants tried. A critical limit of 31.0, 39.0 and 34.0 ppm in rice plants for Inceptisol,

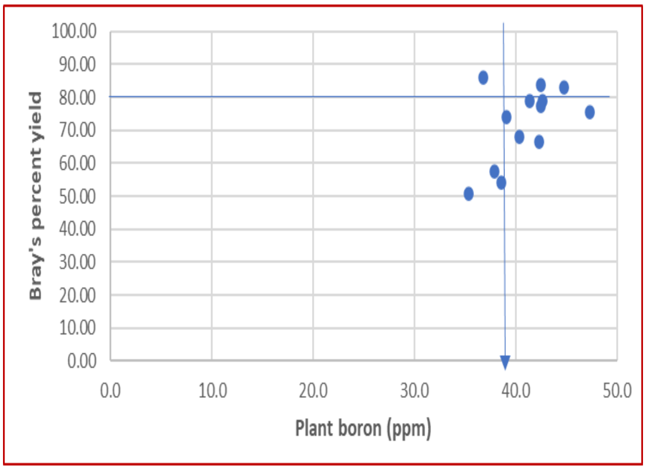
Table 5. Boron extracted and its relationship with Bray's per cent yield, plant boron and uptake (Mean value of three replications)

Extractant	Boron extracted(ppm)						Critical limits in soils						Correlation (r) with soil Boron at vegetative stage					
	Inceptisol		Entisol		Vertisol		Inceptisol		Entisol		Vertisol		Inceptisol		Entisol		Vertisol	
	Range	Mean	Range	Mean	Range	Mean	(ppm)	BPY	(ppm)	BPY	(ppm)	BPY	Boron Conc.	Boron uptake	Boron Conc.	Boron uptake	Boron Conc.	Boron uptake
Hot 0.01 M $CaCl_2$	0.44-0.71	0.53	0.45-0.62	0.52	0.44-0.63	0.55	0.60	0.208*	0.58	0.340*	0.57	0.457*	0.167*	0.082*	0.139*	0.175*	0.05*	0.059*
Hot water	0.35-0.58	0.48	0.35-0.63	0.47	0.34-0.58	0.48	0.49	0.629**	0.48	0.762**	0.45	0.587**	0.041*	0.012*	0.019*	0.646*	0.271*	0.293*
0.05M HCl	0.41-0.59	0.50	0.36-0.60	0.49	0.40-0.35	0.48	0.46	0.534**	0.44	0.585**	0.45	0.482*	0.543**	0.535**	0.478*	0.081*	0.226*	0.236*
1.0 M NH_4OAC	0.41-0.49	0.45	0.41-0.48	0.45	0.41-0.48	0.47	0.45	0.258*	0.39	0.372*	0.44	0.555**	0.522**	0.296*	0.084*	0.023*	0.270*	0.208*
0.01M$CaCl_2$+ 0.05M Mannitol(pH 8.5)	0.37-0.48	0.42	0.21-0.51	0.37	0.19-0.53	0.37	0.39	0.582**	0.38	0.167*	0.41	0.160*	0.200*	0.299*	0.199*	0.279*	0.178*	0.240*

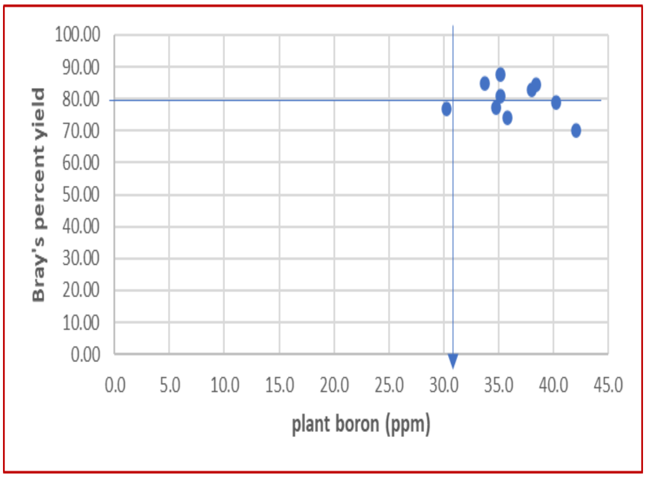
[Bo- 0 ppm ; B1- 1ppm; B2- 2 ppm (Bo- Control; B_1-0.04 mg/pot; B_2-0.08 mg/pot)]



Inceptisol



(b) Entisol



(c) Vertisol

Fig. 4. *Critical limit of rice plant B*

Entisol and Vertisol were determined (Fig.4). Based on the critical limit the percent boron deficient soils in Karaikal region was67.5% and sufficient soil was32.5%.With respect to soil orders, B deficient soil were 30.5, 37.5 and 20.9 % and B sufficient soil were 25.4, 31.4 and 24.2% in Inceptisol, Entisol and Vertisol respectively (Table 6).

Table 6. Response of rice to boron application in deficient and non-deficient soil (Mean value of three replications)

Boron status	Number of soils	Average DMP g pot^{-1}			% Response
		B_0	B_1	B_2	
Inceptisol					
Deficient < 0.59 mg kg^{-1}	11	35.46	44.92	53.89	39.3
Sufficient > 0.59 mg kg^{-1}	6	34.60	40.40	51.63	33.0
Entisol					
Deficient < 0.59 mg kg^{-1}	8	32.91	41.12	49.04	37.0
Sufficient > 0.59 mg kg^{-1}	5	32.10	40.24	44.81	32.5
Vertisol					
Deficient < 0.59 mg kg^{-1}	7	34.59	40.28	44.14	22.0
Sufficient > 0.59 mg kg^{-1}	3	33.37	38.99	42.08	21.5

[Bo- 0 ppm ; B1- 1ppm; B2- 2 ppm (B_o- Control; B_1-0.04 mg/pot; B_2-0.08 mg/pot)]

Conclusion

The study concluded that hot water was the better extractant for assessing the available boron status for Karaikal region soils. It is expected that rice crop will respond to B application when the soil contained less than 0.50 (Inceptisol), 0.48 (Entisol) and 0.45(Vertisol) and rice plant with B concentration 31.0, 39.0 and 34.9 ppm. Based on the critical limit, the percent boron deficient soils in Karaikal region was67.5% and sufficient soil was 32.5%. From the study, farmers of Karaikal region can optimize the boron application to rice soils.

ACKNOWLEDGEMENTS

The authors acknowledge the Department of Soil Science and Agricultural Chemistry, Faculty of Agriculture, Annamalai University, Annamalai Nagar for providing research facilities cum support for the conduct of the experiment.

Conflict of interest

The authors declare that they have no conflict of interest.

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