Plant Archives Vol. 25, Supplement 2, 2025 pp.2221-2229 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-2.282

STATUS AND BEHAVIOR OF BORON IN COASTAL ALLUVIAL SOILS UNDER PADDY CULTIVATION OF UDUPI DISTRICT, KARNATAKA, INDIA

Manoj N.[1], Meghana V.C.[2], Jayaprakash S.M.[1*], Madhusudana[3] and Dhananjaya, B.C.[1]
[1]Department of Soil Science, College of Agriculture, Keladi Shivappa, Nayaka,
University of Agriculture and Horticulture Science, Shivamogga, Karnataka, India
[2]Department of Soil Science and Agriculture Chemistry, G.K.V.K., Bangalore, Karnataka, India
[3]Department of Biochemistry, College of Agriculture, Keladi Shivappa, Nayaka,
University of Agriculture and Horticulture Science, Shivamogga, Karnataka, India
*Corresponding author
(Date of Receiving : 04-04-2025; Date of Acceptance : 12-06-2025)

ABSTRACT

A study was conducted in the Department of Soil Science, College of Agriculture, Shivamogga, KSNUAHS, Shivamogga, Karnataka in order to know the status and behaviour of boron in soils under paddy cover of Udupi district, Karnataka. One forty surface (0-15 cm depth) soil samples were collected and analysed for texture, chemical and available B status. pH, EC and OC of these soils varied from 3.92 to 6.15, 0.06 to 0.89 dSm^{-1} at 25 ^{0}C and 1.12 to 23.44 g kg^{-1}, respectively. Available B in soils varied from 0.04 to 1.06 mg kg^{-1} and it was noticed that 92.14 per cent of the soils were found to be deficient in available B status (< 0.5 hot water extractable B). Further, 16 soils were selected based on texture, pH, and OC and used for B fractionation. Readily soluble boron (Rs-B), specifically bound boron (Sp-B), oxide bound boron (Ox-B), organically bound boron (Org-B) and residual boron (Res-B), fractions varied from 0.39 to0.84, 0.72 to 1.64, 2.74 to 5.98,4.70 to 7.40 and 86.23 to 90.35, mg kg^{-1} respectively. The contribution of different B fractions to the total B (98.02 to 146.70 mg kg^{-1}) followed the order of RES > Org-B > Ox-B > Sp-B > Rs-B. Further, adsorption behaviour of B was studied by selecting 5 soils based on texture and quantity of B adsorption increased with increase in B concentration of equilibrium solution. Adsorption behaviour of boron in soils well fitted to Freundlich adsorption isotherm indicating the heterogeneity of adsorption surface and the quantity of B adsorption increased with clay content of soils.
***Keywords* :** Available boron, Boron fractions, Boron adsorption, Soil.

Introduction

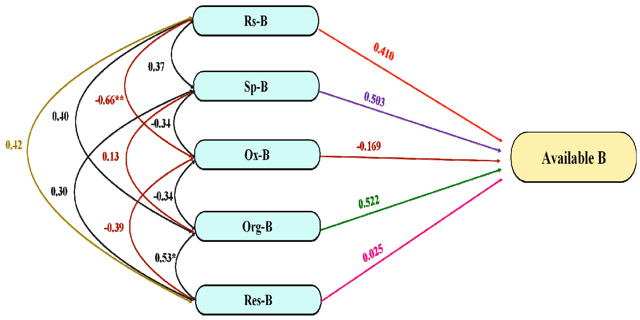
Boron is one of the essential nutrients elements of higher plants and also classified as micronutrient element based on the quantity of its requirement by higher plants. Plants absorb boron from soils in the form of H_3BO_3 and mainly contributed from tourmaline, fluorine boro-silicate minerals, OM, irrigation water and also boron containing fertilizers. Modern agriculture involving high yielding varieties (HYV), continuous use of high analysis chemical fertilizers without any organic manure and leaching loss of B may be responsible for deficiency of boron in soils. Singh (2009) reported that nearly 30 percent soils in Karnataka were found deficient in boron.

Uptake of boron by plants is a function of its availability in soils. Available status of boron in soils is known to be influenced by soil properties like texture, pH, EC, OC, sesquioxides and calcium carbonate contents of soils (Prasanth, 2018). Boron occurs in different forms such as readily soluble boron (Rs-B), specifically bound boron (Sp-B), oxide bound boron (Ox-B), organically bound boron (Org-B) and residual boron (Res-B) forms in soils. The magnitude of their distribution and also their contribution to available boron pool may be influenced by soil properties such as pH, organic carbon, Fe and Al oxides and calcium carbonate contents in soils (Vena Sharma *et al*., 2010). Similarly, adsorption and desorption behavior of boron in soils also influencing its availability, loss through leaching and ultimately affecting the plant growth.

Udupi district comes under coastal agro-climatic zone of Karnataka (Zone 10) that receives high annual rainfall (3000 to 4500 mm). Soils under paddy cover are found to be lateritic and coastal alluvial soils which belong to the order Ultisols. The productivity of rice in this district (2.64 t ha^{-1}) is lower than the productivity of rice in the state (3.28 t ha^{-1}) which might be attributed to the deficiencies of nutrients in soils due to acidic condition and high rainfall as one of the factors. Hence, an investigation was carried out in the Department of soil Science, College of Agriculture, Shivamogga, Karnataka during the period of 2023-24 to understand the available boron status, distribution boron forms and adsorption behaviour of boronin soils under paddy cover of Udupi district of Karnataka, India

Material and Methods

One hundred forty (140) surface soil samples (0-15 cm depth) were collected from soils under paddy cultivation of seven taluks coming under Udupi district of Karnataka (Fig 1). After processing, soils were analysed for texture, pH, EC, OC and calcium carbonate equivalent(CCE) using standard methods such as International pipette method (Piper, 1966), potentiometric method, conductometric method, Walkley- Black's methods(1934) and acid - base titration methods, respectively as described by Jackson (1973). Available boron was extracted from soils using hot water and boron concentration in hot water extract was determined by Azomethine-H colorimetric method (Wolf, 1974). For boron fractionation, 16 soils (Table 3) were selected based on the texture, pH and organic carbon status and were analysed for distribution of boron forms such as readily soluble (Rs-B), specifically bound boron (Sp-B), oxide bound boron (Ox-B), organically bound boron (Org-B) and residual boron (Res-B)as per the procedure described by Datta *et al*, (2002) and total B content of soils was calculated by adding all the above boron fractions. Then correlation coefficients were recorded between soil properties and available B and also between B fractions and available B through statistical analysis (Sundararaj *et a*l., 1972). Further, a path coefficient analysis was carried out between B fractions and available B in soils (Li, 1956) to understand the contribution of boron fractions to the available B pool in soils under paddy cover of Udupi district, Karnataka.



Residual = 0.2654

Fig. 1: Path analysis diagram between available boron and boron fractions in soils under paddy cover of Udupi district, Karnataka. Rs-B: Readily soluble boron, Sp-B: Specifically bound boron, Ox-B: Oxide bound boron, Org-B: Organically bound boronand Res-B: Residual boron

Similarly, for boron adsorption study, 25 ml of 0.01 M $CaCl_2$ containing different concentrations of boron (1.0, 2.0, 3.0, 5.0, 7.0, 10.0, 15.0 and 20.0 ppm) were prepared and added to 2.5 g soils taken in polythene centrifuge tubes. The samples were intermittently shaken for 24 hours to attain equilibrium condition. Then the samples were centrifuged and filtered. The B concentration in the clear filtrate was determined by the Azomethine-H colorimetric method (Wolf, 1974), using a spectrophotometer. The adsorbed quantity of boron was obtained from difference between initial boron concentration and that remained in equilibrium solution. Finally, the data of B adsorption was fitted to both Freundlich and Langmuir adsorption equations as given below and regression analysis was carried out to find the best fitting model.

- **Freundlich adsorption isotherm**

  $\mathbf{x/m = kC^{1/n}}$ **or** $\mathbf{\log x/m = \log k + 1/n \log C}$

  Where: x/m = Quantity of B adsorbed per unit mass of soil, C = B concentration in equilibrium solution and n and k = Constants

- **Langmuir adsorption model**

  $\mathbf{C/x/m = 1/kb + C/b}$

  Where: C = concentration of B in equilibrium solution (ppm), x/m = Quantity of B adsorbed per unit mass of soil, b = Adsorption maxima (mg g^{-1}) and k = Bonding energy constant for zinc (ppm^{-1})

Results and Discussion

Results presented in Table 1 indicated that soils under paddy cover of Udupi district, Karnataka were found acidic in reaction and their pH varied from 3.92 to 6.15 with a mean of 4.80 ± 0.40. Acidic nature of these soils may be attributed to the intense weathering and leaching of bases due heavy rainfall and the accumulation of iron and aluminium oxides in soils.

Similar findings were reported by Dolui and Sarkar (2001) and Jayaprakash *et al.* (2022). Similarly, the electrical conductivity of these soils ranged from 0.06 to0.89 dSm^{-1} at 25°C with a mean of 0.55 ± 0.18 dS m^{-1} at 25℃ which indicated that soluble salts concentration was with in the normal range (<1 dSm^{-1} at 25 °C) and also low soluble salts concentration in these soils may be due to the intensive weathering and leaching of salts due to high rainfall coupled with the coarse textured nature of the soils. These results are in accordance with the findings of Patil *et al.* (2017) and Jayaprakash *et al.* (2022).

Table 1: Chemical properties and available boron status in soils under paddy cover of different taluks in Udupi district of Karnataka, India

Taluk		pH	EC (dSm^{-1} at 25 °C)	OC (g kg^{1})	B(mg kg^{-1})	soils Sufficient in B (%)	Soils Deficient in B (%)
Udupi	Range	4.51-6.15	0.09-0.77	1.95-20.93	0.04 – 0.67	10	90
	Mean	4.95±0.39	051±0.22	13.87±5.23	0.36 ± 0.14		
Bramhavara	Range	3.98- 4.91	0.06- 0.71	2.51-16.74	0.12 – 0.68	5	95
	Mean	4.40 ± 0.25	0.51 ± 0.16	9.08 ± 4.31	0.28 ± 0.14		
Kapu	Range	4.53- 6.08	0.21- 0.84	2.51-15.90	0.10 – 0.70	5	95
	Mean	5.04 ± 0.49	0.56 ± 0.17	5.73 ± 2.35	0.10 ± 0.70		
Kundapura	Range	4.01- 5.73	0.09- 0.86	3.35-23.44	0.12 - 0.84	10	90
	Mean	4.77 ± 0.64	0.62 ± 0.23	13.22±5.31	0.37 ± 0.17		
Bynduru	Range	4.30- 5.44	0.19- 0.72	2.23-20.65	0.10 – 0.81	15	85
	Mean	4.87± 0.32	0.48 ± 0.16	12.36±5.38	0.38 ± 0.17		
Hebri	Range	3.92- 5.77	0.44- 0.69	2.51-18.69	0.12 – 1.06	10	90
	Mean	4.78 ± 0.41	0.55 ± 0.07	7.59 ± 4.29	0.35 ± 0.22		
Karkala	Range	4.31- 5.63	0.23- 0.89	1.12-23.16	0.12 – 0.92	5	95
	Mean	4.78 ± 0.36	0.62 ± 0.15	7.29 ± 5.25	0.36 ± 0.17		
Udupi district	**Range**	**3.92- 6.15**	**0.06- 0.89**	**1.12-23.44**	**0.04 – 1.06**	**7.86**	**92.14**
	Mean	**4.80 ± 0.47**	**0.55 ± 0.18**	**9.90 ± 5.49**	**0.34** ± 0.16		

Total number of soil samples analysed = 140
Critical limit of hot water extractable B: 0.5 mg kg^{-1}

Organic carbon status of these soils varied from 1.12 to 23.44 g kg^{-1} with an average of 9.90 ± 5.49 g kg^{-1}. Out of 140 soil samples analysed, 21.43 per cent of the soils recorded low organic carbon status(< 5g kg^{-1}) which might be due to coarse textured nature and lower amounts of organic matter addition to the soils (Dudal, 1965). The remaining 17.86 and 60.71 per cent of the soils were recorded medium and high (> 7.5 g kg^{-1}) in organic carbon status, respectively (Table 1). High organic carbon status of these soils may be attributed to addition of organic matter and reduced rate of decomposition caused by poor aeration due to submerged condition and low microbial activity. This was supported by a significant positive correlation recorded between OC and soil pH (Table 2). Similar findings were also reported by Anil Kumar *et al.* (2012), Kantharaj *et al.* (2022) and Jayaprakash *et al.* (2022).

Available boron status in soils

The available boron status in soils under paddy cover of Udupi district, ranged from 0.04 to 1.06 mg kg^{-1} with a mean of 0.34 ± 0.16 mg kg^{-1} (Table 1). The variation in available boron status of these soils may be due to variation in soil properties such as soil pH, organic matter and texture of these soils. This may be supported by a negative correlation observed between available boron and sand content (r = - 0.485), a significant positive correlation was recorded between available boron and soil pH (r = 0.756**), organic carbon (r = 0.812*) and clay content (r = 0.527*) of these soils (Table 2). Further, considering 0.5 mg kg^{-1} as a critical limit of hot water extractable boron (available boron), it was found that 92.14 per cent of soils were deficient in available boron status and only 7.86 per cent soils were recorded as sufficient in respect of available boron (Table 1). Leaching loss of boron from soils due to acidic condition and high rain fall in addition to coarse textured nature of these soils may be responsible for boron deficiency in soils (Anitha *et al*., 2015). Coarse textured soils generally had low available B status compared to fine-textured soils as reported by Takkar *et al.* (1989), Raza *et al.* (2002) and Malhi *et al.* (2003). Similar findings were also reported by Srinivasan *et al.* (2013), Kavitha and Sujatha (2015), Malhotra *et al.* (2017), Chandrakala *et al.* (2018) and Lingappa *et al.* (2024).

Table 2: Correlation coefficients (r) recorded between soil physical, chemical properties and available B in soils under paddy cover of Udupi district in Karnataka, India

Parameters	pH	OC	Sand	Silt	Clay	CCE	Available Zn
pH	1.000						
OC	0.599*	1.000					
Sand	-0.356	-0.324	1.000				
Silt	-0.114	0.005	-0.376	1.000			
Clay	0.445	0.337	-0.818**	-0.225	1.000		
CCE	0.939**	0.677**	-0.389	-0.088	0.464	1.000	
Available B	0.756**	0.812**	-0.485	-0.028	0.527*	0.853**	1.000

** Significant at 1% *Significant at 5%

Forms and distribution of boron in soils

Similarly, results presented in Table 4 indicate the forms and distribution boron soils. It was noticed that readily soluble boron (Rs-B) ranged from 0.48 to 1.09 mg kg-1 and constituted 0.39 to 0.84 per cent of total boron in soils. Specifically adsorbed boron (Sp-B) varied between 0.80 and 1.97 mg kg-1 (0.72 to 1.64 % of total B), while oxide-bound boron (Ox-B) was in the range of 3.94 to 6.56 mg kg-1 (2.74 to 5.98 % of total B). Similarly, organically bound boron (Org-B) ranged from 5.33 to 8.85 mg kg^{-1}, accounting for 4.70 to 7.40 per cent of total B. Among all the fractions, residual boron (Res-B) form was found to be the most dominant fraction, ranging from 85.96 to 132.54 mg kg^{-1} contributing 86.23 to 90.35 per cent of total boron content in soils. An order of their distribution or their contribution to the total B status (98.02 – 146.92 mg kg^{-1}) in soils was found as Res-B > Org-B > Ox-B > Sp-B > Rs-B. Further, it was observed that magnitude of their distribution in soils very much influenced by texture and chemical properties like pH, OC, Fe and Al oxides, calcium carbonate content of the soils.

Table 3: Physical and chemical properties of selected soils under paddy cover of seven taluks in Udupi district, Karnataka and used for fractionation of boron in soils

Taluk	Sample No.	pH	EC (dSm^{1}at 25°C)	OC (g kg^{-1})	CCE (%)	Avail. B (mg kg^{-1})	Sand			Silt Clay Texture
							%			
Udupi	1	6.15	0.64	17.58	0.68	0.48	72.45	5.34	22.21	Sandy clay loam
	2	5.50	0.77	18.69	0.42	0.45	76.16	11.95	11.89	Sandy loam
Bramhavara	3	4.25	0.83	13.67	0.18	0.38	82.02	7.10	10.88	Loamy sand
	4	4.81	0.50	8.09	0.20	0.28	82.21	3.12	14.67	Sandy loam
Kapu	5	4.85	0.80	6.14	0.21	0.19	84.95	3.81	11.24	Loamy sand
	6	4.72	0.06	8.93	0.19	0.23	87.00	3.51	9.49	Sandy
Kundapura	7	4.12	0.71	3.35	0.10	0.12	89.10	3.10	7.80	Sandy
	8	5.25	0.81	16.74	0.41	0.40	81.21	4.51	14.28	Sandy loam
Bynduru	9	4.62	0.42	17.58	0.17	0.26	82.38	3.02	14.60	Sandy loam
	10	4.54	0.63	6.70	0.15	0.20	78.85	6.05	15.10	Sandy loam
Hebri	11	4.43	0.63	6.70	0.11	0.18	74.57	14.79	10.64	Sandy loam
	12	3.92	0.44	6.14	0.09	0.12	79.25	11.27	9.48	Loamy sand
	13	5.02	0.62	9.49	0.39	0.46	72.35	4.84	22.81	Sandy clay loam
Karkala	14	4.57	0.86	6.97	0.14	0.23	67.66	4.69	27.65	Sandy clay loam
	15	4.93	0.61	23.16	0.36	0.48	70.10	7.10	22.80	Sandy clay loam
	16	4.69	0.55	6.42	0.18	0.26	76.51	9.83	13.66	Sandy loam

CCE: Calcium carbonate equivalent

Table 4: Forms and distribution of boron in soils (mg kg^{-1}) under paddy cover of Udupi district, Karnataka, India

Sample number	Rs-B	Sp-B	OX-B	Org-B	Res-B	Total B
1	1.02 **(0.75)**	1.37**(1.00)**	3.94**(2.89)**	8.79**(6.44)**	121.30**(88.92)**	136.42
2	1.09 **(0.84)**	1.77**(1.36)**	4.69**(3.60)**	7.57**(5.81)**	115.28**(88.40)**	130.40
3	0.53 **(0.44)**	1.97**(1.64)**	5.69**(4.73)**	5.65**(4.70)**	106.46**(88.50)**	120.30
4	0.48 **(0.39)**	0.96**(0.79)**	6.54**(5.37)**	7.31**(6.00)**	106.48**(87.44)**	121.77
5	0.56 **(0.41)**	0.98**(0.72)**	5.84**(4.29)**	6.98**(5.13)**	121.76**(89.45)**	136.12
6	0.82 **(0.76)**	0.86**(0.80)**	4.98**(4.64)**	7.01**(6.53)**	93.75**(87.27)**	107.42
7	0.55 **(0.56)**	0.80**(0.82)**	5.38**(5.49)**	5.33**(5.44)**	85.96**(87.70)**	98.02
8	0.72 **(0.56)**	1.36**(1.06)**	5.84**(4.54)**	7.12**(5.53)**	113.73**(88.32)**	128.77
9	0.56 **(0.40)**	1.13**(0.80)**	4.79**(3.41)**	7.90**(5.62)**	126.29**(89.78)**	140.67
10	0.53 **(0.51)**	1.55**(1.48)**	4.59**(4.38)**	7.75**(7.40)**	90.30**(86.23)**	104.72
11	0.71 **(0.54)**	1.12**(0.85)**	4.58**(3.46)**	7.02**(5.30)**	118.95**(89.85)**	132.38
12	0.55 (0.50)	0.96**(0.87)**	6.56**(5.98)**	6.79**(6.18)**	94.93**(86.47)**	109.79
13	0.50 **(0.42)**	0.94**(0.79)**	6.12**(5.15)**	8.40**(7.07)**	102.83**(86.56)**	118.79
14	0.84 **(0.57)**	1.36**(0.93)**	4.02**(2.74)**	7.94**(5.41)**	132.54**(90.35)**	146.70
15	0.77 **(0.54)**	1.54**(1.08)**	5.36**(3.77)**	8.85**(6.22)**	125.73**(88.39)**	142.25
16	0.63 **(0.50)**	1.15**(0.90)**	5.52**(4.34)**	7.40**(5.82)**	112.54**(88.45)**	127.24
Range	0.48 – 1.09 **(0.39 – 0.84)**	0.80 – 1.97 **(0.72 – 1.64)**	3.94 – 6.56 **(2.74 – 5.98)**	5.33 – 8.85 **(4.70 – 7.40)**	85.96 – 132.54 **(86.23 – 90.35)**	98.02 – 146.70
Mean	0.68 ± 0.19	1.24 ±0.35	5.28±0.84	7.36 ± 1.00	110.55 ± 14.49	125.11 ± 14.92

Rs-B: Readily soluble boron Sp-B: Specifically bound boron Ox-B: Oxide bound boron
Org-B: Organically bound boron Res-B: Residual boron

The low values of Rs-B may be due to fixation of boron in unavailable forms by Fe and Al oxides due to acidic nature of these soils as supported by a significant positive correlation observed between soil pH and Rs-B (r = 0.672**) and also its leaching loss from soils under high rainfall. Specifically bound boron (Sp-B) probably originated from the weakly binding sites of both organic and inorganic constituents especially their specific adsorption sites which itself explains the low and high values of Sp-B in soils. Further, high Ox-B in soils could be due to binding of boron to Al and Fe oxidesas well as layer silicate clay minerals as evidenced by a negative correlation recorded between Ox-B and soil pH (r = - 0.355) which might be due to decrease in activity of sesquioxides with increase in soil pH (Dey *et al.,* 2015). The variation in Org-B in soils may be attributed to variation in organic carbon content in soils as evidenced by a significant and positive correlation recorded between Org-B and organic carbon state of these soils (r = 0.505*). This relationship explains very clearly the role of organic matter in the retention of boron and also a significant positive correlation was recorded between this fraction and available B (r = 0.561*) indicates that boron associated with organic matter is the principal boron pool for plant growth. Among the fractions of B, residual B was found to be dominant because most of the boron is presumably found within the crystalline structures of minerals and organic matter as evidenced by a positive and significant correlation observed between residual boron fraction and OC (r = 0.500*) and also with clay content of soils(r = 0.556*) as per the correlation coefficients given in Table 5. Similarly, Res-B had a significant and positive correlation with total boron (r = 0.957*). Further, total boron content in soils ranged from 98.02 to 146.70 mg kg^{-1} with a mean of 125.11 ± 14.92 mg kg^{-1}. However, from the fractionation study it was found that the contribution of different boron fractions to the total B followed the order of Res-B > Org-B > Ox-B > Sp-B > Rs-B. Similar findings were also reported by Datta *et al.* (2002), Jones (2003), Chaudhary and Shukla (2004), Diana (2006), Dey *et al.* (2015), Kumari *et al.* (2017), Patra *et al.* (2018), Prashanth (2018). Similarly, in order to know the effect of different boron fractions to the available boron pool in soils, a path coefficient analysis was applied and the results are presented in Table 6 and Fig.1. The results revealed that Rs-B, Sp-B and Org-B showed positive direct effects on available boron in soils. But, Ox-B and residual boron (Res-B) fractions showed a negative direct effect on available boron. Even though the direct effects of these fractions are negative, they contributed to the available boron pool through specifically adsorbed boron. Sp-B had a direct positive effect and significant positivecorrelation (r = 0.543*) with available B (Table 5) which indicates that its contribution to available boron thorough Rs-B as these fractions are in dynamic equilibrium with each other as evidenced by positive correlation between them (r = 0.370). Even Org-B had significant positive correlation (r = 0.561*) and direct effect on available boron and also it was significantly and positively correlated with organic carbon (r = 0.505*) indicating that soil organic matter is an important parameter contributing towards availability of B in soils. Mathur and Sudan (2011) and Kumari *et al.* (2017) reported similar findings. Therefore, the path analysis clearly indicated that Rs-B, Sp-B and Org-B are the major contributors to available boron pool due to the existence of dynamic equilibrium between them. Similar findings were reported by Santhosh (2013) in soilsof different agro ecological zones of Kerala.

Table 5: Correlation coefficients(r) recorded between physical, chemical, available B and B fractions in soils under paddy cover of Udupi district, Karnataka, India

	pH	OC	Clay	CCE	Avail. B	Rs-B	Sp-B	Ox-B	Org-B	Res-B	Total B
pH	1.00										
OC	0.599*	1.000									
Clay	0.445	0.337	1.000								
CCE	0.939**	0.231	0.464	1.000							
Avail. B	0.756**	0.812**	0.527*	0.853**	1.000						
Rs-B	0.672**	0.506*	0.273	-0.204	0.458	1.000					
Sp-B	0.252	0.583*	0.212	0.307	0.543*	0.370	1.000				
Ox-B	-0.355	-0.213	0.346	-0.231	-0.100	-0.659**	-0.335	1.000			
Org-B	0.638**	0.505*	0.786**	0.113	0.561*	0.395	0.126	-0.341	1.000		
Res-B	0.422	0.500*	0.556*	0.321	0.380	0.415	0.300	0.385	0.534*	1.000	
Total B	0.443	0.485	0.569*	0.325	0.405	0.330	0.246	0.237	0.562*	0.957**	1.000

*Significant at 5%, **Significant at 1%, Rs-B: Readily soluble boron, Sp-B: Specifically bound boron, Ox-B: Oxide bound boron, Org-B: Organically bound boron and Res-B: Residual boron

Table 6: Path coefficient analysis between available boron and boron fractions in soils

	Rs-B	Sp-B	Ox-B	Org-B	Res-B	r- values between available b and B fractions
Rs-B	**0.410**	0.186	-0.334	0.207	-0.010	0.458
Sp-B	0.152	**0.503**	-0.170	0.066	-0.008	0.543*
Ox-B	-0.270	0.507	**-0.169**	-0.178	0.010	-0.100
Org-B	0.162	0.064	-0.173	**0.522**	-0.013	0.561*
Res-B	0.170	0.151	-0.195	0.279	**-0.025**	0.380

Figures in **bold** indicate the direct effect, Residual = 0.2654, Rs-B: Readily soluble boron Sp-B: Specifically bound boron, Ox-B: Oxide bound boron, Org-B: Organically bound boron and Res-B: Residual boron

Table 7: Physical and chemical properties of selected soils under paddy cover of Udupi district, Karnataka used for boron adsorption study

Soils No.	pH	OC (g kg^{-1})	CCE (%)	Sand	Silt	Clay	Texture class
				%			
1	4.12	3.35	0.10	89.10	3.10	7.80	Sandy
2	4.25	13.67	0.18	82.02	7.10	10.88	Loamy sand
3	4.43	6.70	0.11	74.57	14.79	10.64	Sandy loam
4	4.62	17.58	0.17	82.38	3.02	14.60	Sandy loam
5	4.93	23.16	0.36	70.10	7.10	22.80	Sandy clay loam

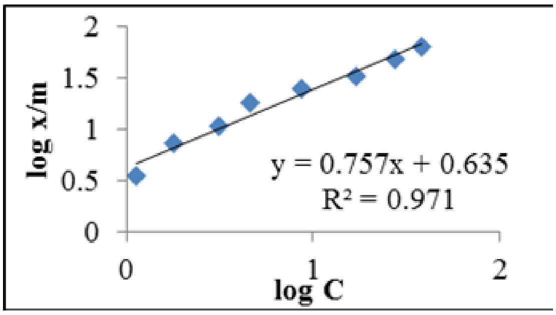
CCE= Calcium carbonate equivalent

Table 8: Freundlich adsorption characteristics of boron in selected soils under paddy cover of Udupi district, Karnataka

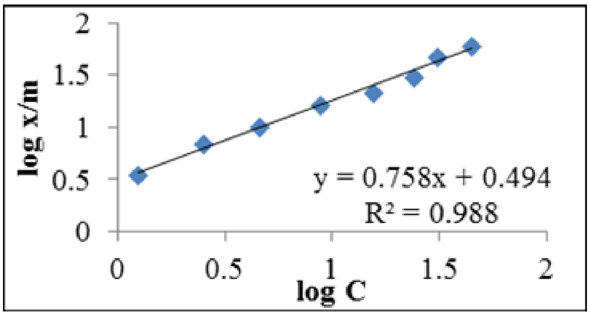
Texture	Concentration range used (µg ml^{-1})	Quantity adsorbed µg g^{-1}	Equilibrium solution concentration (µg ml^{-1})	n	k
Loamy sand	1-20	8.88 – 161.79	1.12 – 38.21	1.32	4.32
Sandy	1-20	8.76 – 154.80	1.24 – 45.20	1.32	3.12
Sandy loam	1-20	8.94 – 178.46	1.06 – 21.54	1.08	3.78
Sandy loam	1-20	8.96 – 174.86	1.04 – 25.14	1.13	4.14
Sandy clay loam	1-20	9.29 – 181.50	0.71 – 18.50	1.10	5.18

Boron adsorption in soils

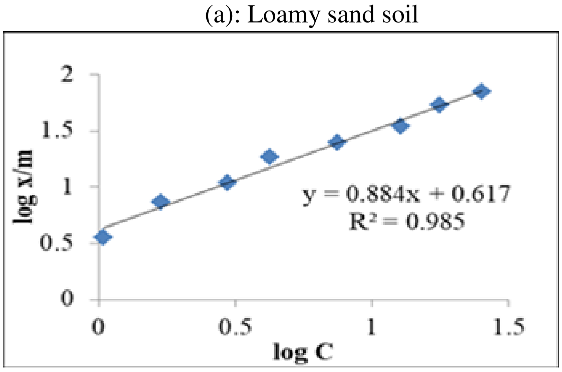
Quantity of boron adsorption increased from 8.76 to 181.50 µg g^{-1} of soil with increase in concentration of boron in equilibrium solution from 1.0 to 20.0 µg ml^{-1} [Table 8 and Fig. 2(a) to 2(e)]. Adsorption data clearly showed that all the soils had an affinity for boron adsorption. To understand the relationship between the amount of boron adsorbed and the boron concentration in equilibrium concentration, Freundlich and Langmuir adsorption isotherms were used. Accordingly, adsorption data fitted well to Freundlich adsorption isotherm model which indicated that quantity of boron adsorption increased with increase in concentration of boron in the equilibrium solution, yet the percentage of adsorbed boron decreased in all soils. This may be because of an increase in the ratio of adsorbate to adsorbent. Adsorption of B was found to be highest in sandy clay loam soil (9.29 to 181.50 µg g^{-1}) and least in sandy soil (8.76 to 154.80 µg g^{-1}) which may be attributed to variation in clay and organic matter content of soils. Mineral composition of soil, texture, and soil pH influenced the parameters of isotherm therms (Goldberg, 1993). Similarly,Bloesch *et al.* (1987) also noted that adsorption of boron increases with increasing concentration of boron in solution. Among the soil types studied, quantity of boron adsorbed per unit mass of soil followed the order of sandy clay loam > sandy loam > loamy sand > sandy soil. This clearly suggests that the quantity of boron adsorption increases with increase in clay content of soils. Freundlich adsorption equation indicated that boron had an affinity for clays and their proportion in the equilibrium solution varied with soil pH, clay and organic matter content (Keren and Gast, 1981; Keren and Mezuman, 1981). Further, as the rupture of clay minerals creates positively charged sites which facilitates the anion adsorption, the adsorption of B as $B(OH)_4^-$ anion at broken bond edges is common. Rhoades *et al.* (1970) and Sims and Bingham (1968) reported that adsorption of boron on amorphous hydroxide minerals, as well as on magnesium hydroxides and sesquioxides of soils.



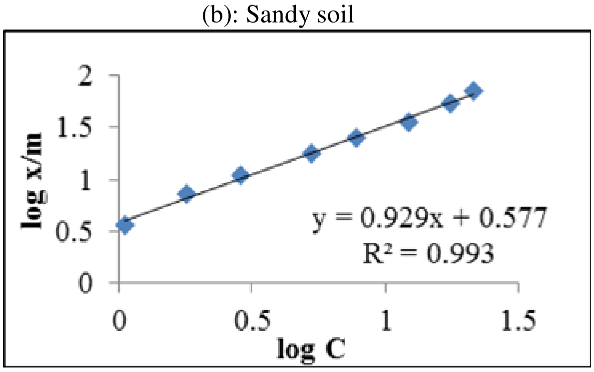
(a): Loamy sand soil



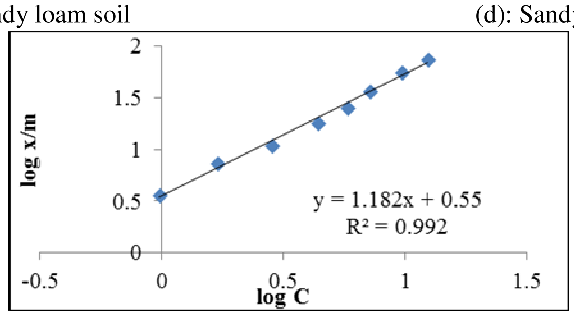
(b): Sandy soil



(c) : Sandy loam soil



(d): Sandy loam soil



(e) : Sandy clay loam soil

Fig.2: (a & b): Freundlich adsorption isotherm for boron in loamy sand and sandy soils, (c & d): Freundlich adsorption isotherm for boron in sandy loam soils and (e): Freundlich adsorption isotherm for boron in sandy clay loam soil

Finally, it was concluded that soils under paddy cover of Udupi district, Karnataka were found acidic and 60.71 per cent soils were recorded high in organic carbon status. Available B in soils varied from 0.04 to 1.06 mg kg^{-1} and it was noticed that 92.14 per cent of the soils were found to be deficient in available B status (< 0.5 hot water extractable B). The distribution of boron fractions in soils or their contribution to the total boron (98.02 to 146.70 mg kg^{-1}) followed the order of Res-B > Org-B > Ox-B > Sp-B > Rs-B. Further, Adsorption behaviour of boron in soils well fitted to the Freundlich adsorption isotherm indicating the heterogeneity of adsorption surface and the quantity of B adsorption increased with clay content of soils.

References

Anil Kumar, K.S., Nair, K.M., Krishnan, P., Naidu, L.G.K. and Dipak Sarkar. (2012). Deficiencies Of Exchangeable Calcium and Magnesium: An Emerging Threat in Soils of Tropical Coffee Plantations of Karnataka, India. *In; Compendium of Abstracts, 8th Psilph,* Uas, Bangalore: 25-26.

Anitha, M.S., Anil Kumar, K.S. and Prashantha, G.M. (2015). Distribution of Plant Available Boron in Major Soil Types and Their Correlation with Other Properties of The Soil. *Ecol. Environ. Cons.,* **21**: 148.

Bloesch, P.M., Bell, L.C. and Hughes, J.D. (1987). Adsorption and Desorption of Boron by Goethite. *Australian J. Soil Res.,* (**25**), 377-390.

Chandrakala M, Ramesh M, Sujatha K, Rajendra Hegde, Singh, S.K. (2018). Soil Fertility Evaluation Under Different Land Use System in Tropical Humid Region of Kerala, India. *Int. J. Plant Soil Sci.,* **24**(4), 1-13.

Chaudhary, D. R. and Shukla, L. M. (2004). Boron Forms and Their Relationships with Characteristics of Arid Soils of Western Rajasthan. *J. Indian Soc. Soil Sci.,* **52**(2), 197–199.

Datta, S. P., Rattan, R. K., Kandregula Suribabu and Datta, S.C. (2002). Fractionation And Colorimetric Determination of Boron in Soils. *J. Plant Nutr.,* (**165**), 179-184.

Dey, A., Dwivedi, B. S., Datta, S. P., Meena, M. C. and Agarwal, B. K. (2015). Soil Boron Status: Impact of Lime and Fertilizers in An Indian Long-Term Field Experiment on A *Typic Paleustalf.* Acta Agriculturae Scandinavica, *Section B - Soil Plant Sci.,* (**65**), 54-62.

Diana, G. (2006). Boron In the Soil, From Deficit to Toxicity. *Informatore Agrario.,* **(62),** 54-58.

Dolui, A. K. and Sarkar, R. (2001). Influence of Nature of Acidity on Lime Requirement of Two *Inceptisol* and An *Alfisol*. *J. Indian Soc. Soil Sci.,* (**49),** 195-198

Dudal, R. (1965). Dark Clay Soils of Tropical and Sub-Tropical Regions. Fao, *Agric. Development Paper No.* (**83**), Rome.

Goldberg, S. (1993). Chemistry and Mineralogy of Boron in Soils. *In Boron* and Its Role in Crop Production. Ed. U C Gupta. Pp 3-44. Crc Press, Boca Raton, Usa.

Jackson, M. L. (1973). *Soil Chemical Analysis.* Prentice Hall of India, Pvt. Ltd., New Delhi.

Jayaprakash, S.M., Faijalahmadmulla, T.G. And Naveen, N.E. (2022). Characterization of Soils of Micronutrients Under Arecanut Based Cropping Systems in The Coastal Region of Udupi District. *J. Pharm. Innov.,* **11**(12), 4234-4239.

Jones, J. B. (2003). Plant Mineral Nutrition. In: *Agronomic Hand Book: Management Of Crops, Soils and Their Fertility, Pages 325, Crc Pres, Boca Raton, Fl, U.S.A.*

Kantharaj, T. (2022). Evaluation of Fertility Status of Soils Under Traditional Paddy Land Cover in Udupi District of Coastal Karnataka. *J. Pharm. Innov.,* **11**(12), 167-173

Keren, R. and Gast, R. G. (1981). Effects of Wetting and Drying and Of Exchangeable Cations on Boron Adsorption and Release by Montmorillonite. *Soil Sci. Soc. American J.,* (**45**), 478-482.

Keren, R. and Mezuman, U., 1981, Boron Adsorption by Clay Minerals Using a Phenomenological Equation. *Clay Miner.,* (**29),** 198-204.

Kumari, K., Singh, A., Nazir, G., Kumar, P. and Shukla, A. K. (2017). Adsorption And Desorption of Boron in Cultivated Soils of Himachal Pradesh. *Int. J. Chem. Stud.,* **5**(6), 1712-1716.

Kavitha, C. and Sujatha, M. P. (2015). Evaluation Of Soil Fertility Status in Various Agro-Ecosystems of Thrissur District, Kerala, India. *Int. J. Agric. Crop Sci.,* 328-338.

Li, C. C. (1956). Population Genetics. *Biometrics,* **12**: 190.

Lingappa, M., Kumar, B.N., Ramesha, T.J. and Rashmi, R. (2024). Characteristics Of West Coast Lateritic Soils of Southern India. *Int. J. Res. Agron.,* **7**(3), 659-664.

Mathur, R. and Sudan, P. (2011). Relationship and Distribution of Various Forms of Boron with Different Physicochemical Properties of Soil in Bikaner District. *J. Chem. Pharma. Res.,* (**3**), 290-294.

Malhi, S. S., Raza, M., Schoenau, J. J., Mermut, A. R., Kutcher, R., Johnston, A. M. and Gill, K. S. (2003). Feasibility of B Fertilization for Yield, Seed Quality, And B Uptake of Canola In North Eastern Saskatchewan. *Canadian J. Soil Sci.,* (**83),** 99-108.

Malhotra, S. K., Maheswarappa, H. P., Selvamani, V., Chowdappa,P. (2017). Diagnosis and Management of Soil Fertility Constraints in Coconut (*Cocos Nucifera*): A Review. *Indian J. Agril. Sci.,* **87**(6), 711-726.

Prashanth, K.M. (2018). Dynamics of Boron in Soils Under Paddy Land Cover of Bhadra Command, Karnataka. *Ph. D. Thesis,* Uni. Agric. Hortic. Sci., Shivamogga, India.

Patra, A., Sinha, A. K., Rakesh, S., Biswas, S. and Mukhopadhyay, P. (2018). Different Fractions of Boron in Soils of *Alfisol* and *Entisol* of West Bengal. *J. Pharmacogn. Phytochem.,* **7**(1), 510-513.

Patil, S. I. D. H. A. R. A. M., Kumar, K. A. and Srinivasamurthy, C. A. (2017). Soil Fertility Status and Nutrient Index for Primary Nutrients in Western Ghats and Coastal Karnataka Under Different Agro-Ecological Systems. *Asian J. Soil Sci.*, **12**(2), 314-319.

Piper, C. S. (1966). *Soil And Plant Analysis*. Hans Publishers. Bombay.

Rhoades, J. D., Ingvalson, R. D. and Hatcher, J. T. (1970). Adsorption of Boron by Ferromagnesium Minerals and Magnesium Hydroxide. *Soil Sci. Soc. Am. Proc.,* (**34**), 938-944

Raza, M., Mermut, A. R., Schoenau, J. J. and Malhi, S. S. (2002). Boron Fractionation in Some Saskatchewan Soils. *Canadian J. Soil Sci.,* (**82),** 173-179.

Sundararaj, Nagaraju, S., Venkataramu, M. N. and Jaganath, M. K. (1972). Design and Analysis of Field Experiment. *Univ..Agric. Sci.,* Bangalore. Pp. 183.

Srinivasan, R., Natarajan, A. And Kumar, K. A. (2013). Characterization Of Major Cashew-Growing Soils of Dakshina Kannada. *Agropedology,* **23**(2), 59-64.

Santhosh, C. (2013). Chemistry and Transformation of Boron in Soils of Kerala. *Ph.*

D. Thesis, Department Of Soil Science & Agricultural Chemistry, College Of Horticulture, Vellanikkara.

Singh, M. V. (2009). Micronutrient Nutritional Problems in Soils of India and Improvement for Human and Animal Health. *Indian J. Fert.,* **5**(4), 19-26.

Takkar, P.N., Chibba, I.M. and Mehta, S.K. (1989). Twenty Years of Coordinated Research on Micronutrient in Soils and Plants. *Bull.* 314. *Indian Institute of Soil Science*, Bhopal, India.

Veena Sharma, Asimkumar Mondal, Bhat, A. K. and Pardeep Wali. (2010). Boron Adsorption Characteristics in Temperature Orchard Soils of Jammu. *Agropedology,* **20**(1), 67-73.

Wolf, B. (1974). Improvements In the Azomethine-H Method For The Determination Of Boron. *Commun. Soil Sci. Plant Anal.*, **5**(1), 39-44.