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Adsorption-Desorption Behaviour of Boron in Soils of Assam

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Batch studies were conducted to investigate the adsorption and desorption behaviour of boron in four soils of Assam *viz.* entisol, inceptisol, alfisol and ultisol, which had wide variations in physico-chemical properties. The adsorption isotherms indicated that the adsorption of boron increased with its increasing concentration in the equilibrium solution. The Langmuir adsorption isotherm was curvilinear and it was significant when the curves were resolved into two linear parts. The maximum value of the adsorption maxima (b1) was observed to be 2.657 μg g^{-1} in ultisol and the bonding energy (k) constant was maximum at 2.073 mL μg^{-1} in inceptisol. The Langmuir isotherm best explains the adsorption phenomenon at low concentration of the adsorbent, which was different for different soils. There was significant correlation between b1 and organic carbon (r = 0.916**), clay content (r = 0.739*) and free Al_2O_3 (r = 0.791*) of the soils. A linear relationship was observed between log C and log x/m in all soils and at the whole concentration range from 0.1 to 10 μg B mL^{-1} which indicated that B adsorption data also conform to the Freundlich equation. Soils that had higher affinity for B adsorption (S_4), tended to desorb less amount of B (37.92 %) and that had lower affinity for B adsorption (S_3) showed greater desorption (53.78 %) of adsorbed B. Boron desorption by these soils showed a significant positive correlation with sand content (r = 0.801*) and significant negative correlation with organic carbon (r = –0.709*), CEC (r = –0.834**) and free Al_2O_3 (r = –0.785*) of the soils. The maximum value of desorption maxima (DmB) (56.497 μg g^{-1}) and B mobility (K_dB) (0.061 mL μg^{-1}) was observed in ultisol (S_4).

Keywords: Adsorption, Boron, Soil, Desorption, Freundlich isotherm, Langmuir isotherm.

INTRODUCTION

The distribution of boron between the soil and soil solution is particularly important because of the relatively small range between the levels causing deficiency and toxicity in plants [1]. Therefore, boron is essential for plants growth at low concentration, but becomes phytotoxic when concentration is slightly higher than the optimal range [2]. Soluble boron in the soil mostly exists as undissociated boric acid (H_3BO_3). At relatively low concentrations (< 0.1 M) H_3BO_3 dissociates and hydrates to form $B(OH)_4^-$ which is the ionic species present in soil solution. Moreover, it was reported that boron was adsorbed or fixed more easily than it was removed from the soil by leaching [3].

Adsorption and desorption of boron is an important phenomenon in soils that regulates its supply from soils for plant growth [4]. A potential source of boron in soil solution is that associated with the solid phase in the adsorbed form. The dissolved boron remains in dynamic equilibrium with adsorbed forms and hence cannot be readily removed through leaching. Boron can be physically/chemisorbed as a unionized hydrated borate or chemisorbed by hydroxides. Boron adsorption on soil has been described by various empirical and chemical modeling approaches either by the Langmuir adsorption isotherm [5] or by the Freundlich adsorption isotherm [6]. In many studies, the Langmuir adsorption isotherm equation was able to describe boron adsorption only under conditions of low solution boron concentration [7,8]. Whereas, the Freundlich adsorption isotherm has often been used to describe boron adsorption by soils over a wide range of equilibrium boron concentration [9]. It was reported that boron adsorption could be described by the Langmuir adsorption isotherm over a limited equilibrium boron concentration range and by the Freundlich adsorption isotherm over the entire concentration range studied [10]. In soils of north-west India and the temperate soils of Lesser Himalayas [11,12] respectively, it was observed that adsorption of boron increases with increasing concentration in equilibrium solution. The Langmuir adsorption isotherm was curvilinear and it was significant when curve were resolved into two linear parts. The linear relationship exist in the concentration ranges 0 to 100 mg B L^{-1}, indicating boron adsorption data also conform to the Freundlich equation. However, the Langmuir equation had some limitations as it was based on simple first-order kinetics. But it could give good quantitative information necessary to draw conclusions about the nature of adsorption. An advantage of this isotherm was that it could provide an intensity as well as capacity factor. The climate of Assam is humid sub-tropical. The soils of these regions are acidic and wide variation in physico-chemical characteristics of the soils [13]. In view of the above background an attempt to study adsorption and desorption behaviour of boron in soils of Assam has been considered worthwhile which will help in predicting boron availability to plants.

EXPERIMENTAL

Soils: The study was carried out in four surface (0-15 cm) soil samples, belonged to the four major orders of Assam *viz.* entisol, inceptisol, alfisol and ultisol (Table-1). The physical and chemical parameters *i.e.* pH and organic carbon [14], texture [15], CEC [16], free oxides of Fe [17] and Al [18] of the soils were determined by following standard procedures.

TABLE-1
DETAILS OF THE SOIL SAMPLES

Sample No.	Location	Taxonomic order	Latitude	Longitude
S_1	Majuli	Entisol	26°50"N	94°03"E
S_2	Baghchung	Inceptisol	26°43"N	94°13"E
S_3	Titabar	Alfisol	26°25"N	94°10" E
S_4	Shilonijaan	Ultisol	26°19"N	93°50"E

Boron adsorption study: The adsorption of boron in the soils of Assam was studied by conducting batch experiment in the laboratory. 10 g of soil sample from each soil in duplicates were placed in 18 pre-weighted polyethylene centrifuge tubes of 100 mL capacity. To it 20 mL of 0.01 M $CaCl_2$ solution containing varying amounts of boron (0.1, 0.15, 0.25, 0.5, 1.0, 1.5, 2, 5, 10 μg mL^{-1}) were added. Tubes were then stopper with rubber corks and suspension of soil solutions were equilibrated for 24 h at constant room temperature at 23 ± 1 °C with intermittent shakings. The suspension were centrifuged at 8000 rpm for 5 min and filtered with Whatman No 42 filter paper. The filtrate was analyzed for boron concentration spectrophotometrically using Azomethine-H method [19]). The amount of boron adsorbed by the soils was calculated as the difference between added boron and boron present in equilibrium solution.

The data of boron adsorption were fitted to the following adsorption isotherm equations:

$$\text{Langmuir equation: } C/x/m = 1/Kb + C/b$$

$$\text{Freundlich equation: } \log x/m = 1/n \log C + \log K$$

where, C is equilibrium concentration (μg B mL^{-1}), x/m is the amount of boron adsorbed by soil (μg B g^{-1} soil), k is a constant related to the bonding energy of adsorption as obtained by diving the slope (1/b) by the intercept (1/Kb) and b is the adsorption maxima (μg B g^{-1}), which is reciprocal of the slope (1/b) of the regression line. 1/n is the slope of the regression line and K and n are empirical constants.

Boron desorption study: After completion of the adsorption experiments soil suspensions were used for conducting desorption experiments. Boron was desorbed from the soil suspensions by equilibrating them with 20 mL boron – free 0.01 M $CaCl_2$ solution. The soil solution suspensions were equilibrated at constant room temperature at 23 ± 1 °C for 24 h with intermittent agitation. The suspensions were then centrifuged at 8000 rpm for 5 min and the supernatant were filtered with Whatman No. 42 filter paper. This procedure was repeated for three more times resulting in a total of four extractions for each adsorption sample. The sum of each equilibrium concentration of boron in four extractions was taken as total boron desorbed. The boron desorbed was estimated spectrophotometrically using Azomethine-H method.

The data on the amount of boron desorbed from the amount of adsorbed boron in each addition of boron by 0.01 M $CaCl_2$ extractant were evaluated by using a Langmuir type equation [20].

$$De/x/m = 1/K_d\, Dm + De/Dm$$

where, x/m is boron adsorbed (μg B g^{-1}), De is boron desorbed (μg B g^{-1}), Dm is the desorption maxima (μg B g^{-1}) and K_d is a constant related to mobility of boron (mL B $μg^{-1}$).

The desorption parameters such as desorption maxima (D_m) and constant related to mobility of the solid phase (K_d) were worked out from the linear plots of De *vs.* De/x/m according to the Langmuir desorption relationship.

RESULTS AND DISCUSSION

Soil properties: The soils of Assam varied in pedogenic development from entisol to ultisol had texture ranged from sandy loam to sandy clay loam, pH ranged from 4.95 to 7.12, organic carbon content from 0.92 to 1.10 %, clay content ranged from 12.50 to 25.60 %, CEC from 6.50 to 9.50 c mol (p+) kg^{-1} and free Fe and Al oxides content from 0.13 to 1.12 and 0.36 to 0.71 %, respectively (Table-2).

Adsorption of boron by soils: The data revealed that there was a variation in equilibrium boron concentration of different soils at the same level of added boron (Table-3). In all the soils, the equilibrium boron concentration increased with the addition of increasing amounts of boron to the soils. This could be interpreted as the intensity of boron supply was increasing in these soils with increasing amount of boron added within the range 0.1 to 10 μg B mL^{-1}. Similarly the capacity of boron

TABLE-2
PHYSICO-CHEMICAL PROPERTIES OF THE SOILS

Sample No.	pH	Organic carbon (%)	Mechanical analysis (%)			Textural class	CEC [c mol (p+) kg^{-1}]	Free Fe_2O_3 (%)	Free Al_2O_3 (%)	Free Fe_2O_3 + Al_2O_3 (%)
			Sand	Silt	Clay					
S_1	7.12	0.98	60.00	22.00	17.60	Sandy loam	9.10	0.75	0.52	1.27
S_2	5.20	1.05	55.00	28.00	17.00	Sandy loam	7.45	0.90	0.41	1.31
S_3	5.82	0.92	54.50	33.00	12.50	Loam	6.50	0.13	0.36	0.49
S_4	4.95	1.10	52.00	22.30	25.60	Sandy clay loam	9.50	1.12	0.71	1.83

CEC = Cation exchange capacity

TABLE-3
EQUILIBRIUM SOLUTION CONCENTRATION OF BORON (C, mg mL^{-1}) IN SOILS OF ASSAM

Sample No.	Added boron (µg g^{-1})									Range	Mean
	0.1	0.15	0.25	0.5	1.0	1.5	2.0	5.0	10		
S_1	0.046	0.070	0.119	0.255	0.520	0.785	1.06	2.73	5.70	0.046-5.70	1.25
S_2	0.035	0.054	0.095	0.210	0.430	0.660	0.90	2.35	5.30	0.035 -5.30	1.11
S_3	0.039	0.059	0.105	0.230	0.498	0.765	1.03	2.75	5.90	0.039-5.90	1.26
S_4	0.028	0.043	0.074	0.165	0.340	0.530	0.72	2.00	4.50	0.028-4.50	0.93

supply was also increasing in the soils with increase addition of boron (Table-4). However, there were wide variations in adsorption of boron at the same level of addition of boron in the soils. The differences in adsorption of boron were due to variations in physico-chemical properties of the soils. The highest adsorption of boron was observed in ultisol, S_4 (2.69 µg g^{-1}) because of the presence of more clay, organic carbon and free oxides of Fe and Al content, as compared to the other soils. Alfisol (S_3) had the lowest adsorption capacity of boron (2.03 µg g^{-1}), as it contained less amount of clay, organic carbon and free oxides of Fe and Al.

The per cent of adsorbed boron decreased as the concentration of added boron increased (Table-5). The characteristics steep slope of adsorption isotherms at lower equilibrium solution concentrations of added boron also indicated the higher per cent of boron adsorption. The decreasing slope of the isotherms at higher equilibrium solution concentrations of added boron indicated the lower per cent of boron adsorption (Fig. 1). The amount of boron adsorbed (x/m) progressively increased while the per cent adsorption decreased with increasing boron concentration in the solution. The phenomena may be due to the fact that increase in added boron in the soils might result in saturation of their adsorption sites and thereby decreased their adsorption capacity [4,21,22].

Evaluation of boron adsorption data using Langmuir adsorption isotherm: The results indicated that the data for boron adsorption for all the soils studied conform to the Langmuir adsorption isotherm within the concentration range of 0.1 to 10 µg B mL^{-1} (Fig. 2). In all the soils, a plot of C *vs.* C/x/m for Langmuir adsorption isotherm was curvilinear and it was significant and excellent when the curves were resolved into two linear parts (part I and part II) (Figs. 3 and 4). The data were fitted to the Langmuir equation and its constants for

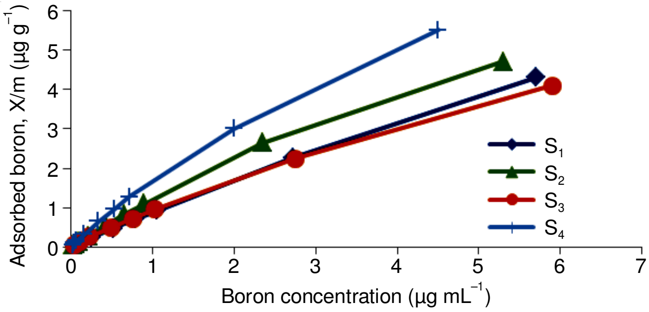

Fig. 1. Boron adsorption isotherms in soils of Assam

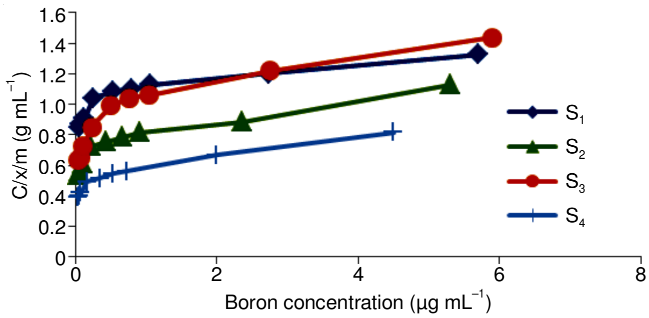

Fig. 2. Langmuir adsorption isotherms for boron in soils of Assam

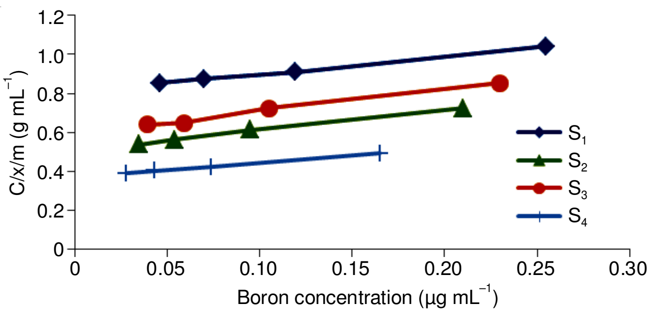

Fig. 3. Langmuir adsorption isotherms (part I) for boron in soils of Assam

TABLE-4
AMOUNT OF BORON ADSORBED (x/m, µg g^{-1}) IN SOILS OF ASSAM

Sample No.	Added boron (µg g^{-1})									Range	Mean
	0.1	0.15	0.25	0.5	1.0	1.5	2.0	5.0	10		
S_1	0.108	0.160	0.262	0.490	0.960	1.43	1.88	4.54	8.60	0.108-8.60	2.05
S_2	0.130	0.192	0.310	0.580	1.14	1.68	2.20	5.30	9.40	0.130-9.40	2.33
S_3	0.122	0.182	0.290	0.540	1.00	1.47	1.94	4.50	8.20	0.122-8.20	2.03
S_4	0.144	0.214	0.352	0.670	1.32	1.94	2.56	6.00	11.0	0.144-11.00	2.69

TABLE-5
ADSORPTION (% AdsB) OF ADDED BORON IN SOILS OF ASSAM

Sample No.	Added boron (µg g^{-1})									Range	Mean
	0.1	0.15	0.25	0.5	1.0	1.5	2.0	5.0	10		
S_1	54.0	53.33	52.40	49.0	48.0	47.67	47.0	45.40	43.0	43.0-54.0	48.87
S_2	65.0	64.0	62.0	58.0	57.0	56.0	55.0	53.0	47.0	47.0-65.0	57.44
S_3	61.0	60.67	58.0	54.0	50.2	49.0	48.5	45.0	41.0	41.0-61.0	51.93
S_4	72.0	71.33	70.4	67.0	66.0	64.67	64.0	60.0	55.0	55.0-72.0	65.60

TABLE-6
REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION FOR LANGMUIR MODELS OF BORON ADSORPTION IN SOILS OF ASSAM

Sample No.	Part I		Part II	
	Regression equations	R^2	Regression equations	R^2
S_1	C/x/m = 0.4042 + 0.4512 C	0.996**	C/x/m = 0.5293 + 0.0313 C	0.991**
S_2	C/x/m = 0.2531 + 0.5248 C	0.996**	C/x/m = 0.3664 + 0.0367 C	0.990**
S_3	C/x/m = 0.2962 + 0.5703 C	0.990**	C/x/m = 0.4874 + 0.0403 C	0.989**
S_4	C/x/m = 0.1838 + 0.3763 C	0.998**	C/x/m = 0.2536 + 0.0354 C	0.989**

**Significant at 1 % level

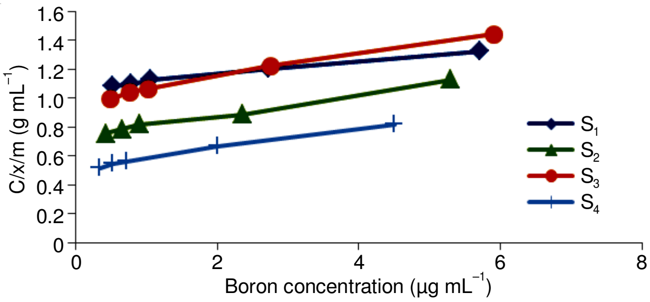

Fig. 4. Langmuir adsorption isotherms (part II) for boron in soils of Assam

boron adsorption by soils were calculated from slopes and intercepts of the curves. The values of adsorption maxima and bonding energy constant have been designated as b1 and k1 for the lower part (part I) and b2 and k2 for the upper part (part II) of the isotherms.

There was good fit of adsorption data in part I of the isotherms, indicating that the Langmuir isotherm best explained the adsorption phenomenon at low concentrations of the adsorbent (Fig. 3). However, it was varied among the soils. The marked variation in the slopes and intercepts of the two parts of the isotherm suggested two types of reaction of boron adsorption in the soils. The lower part (Part I) of the isotherms might have resulted from monolayer adsorption of boron and the upper part (Part II) might have resulted from multilayer adsorption and/or precipitation reactions as well as due to heterogeneity of sites at higher boron concentration. Therefore, the assumption of monolayer reaction and homogeneity of adsorption sites in the Langmuir equation was not valid for the soils studied. The coefficients of determination (R^2) were also higher for part I as compared to the part II of the isotherms (Table-6).

The difference in slopes and intercepts of the two parts of the adsorption isotherms gave significantly different values of Langmuir constants. The adsorption maxima (b) were higher for part II (upper part) whereas the bonding energy constant (k) was higher for part I (lower part) of the isotherms (Table-7). Therefore, the retention of applied boron to soils was stronger when applied in lower amounts and the strength of retention of boron was decreased with increasing concentrations of boron in equilibrium solution. This might be due to the precipitation reaction at higher concentrations [23].

TABLE-7
LANGMUIR ADSORPTION PARAMETERS FOR BORON IN SOILS OF ASSAM

Sample No.	Part I		Part II	
	Adsorption maxima (b1) (µg g^{-1})	Bonding energy (k1) (mL µg^{-1})	Adsorption maxima (b2) (µg g^{-1})	Bonding energy (k2) (mL µg^{-1})
S_1	2.216	1.116	31.949	0.059
S_2	1.905	2.073	27.248	0.100
S_3	1.753	1.925	24.814	0.083
S_4	2.657	2.047	28.249	0.139

The results also indicated that fine textured soils recorded the highest adsorption maxima (b1) for boron (Table-7). The highest value of adsorption maxima was found in ultisol (S_4) for part I of the isotherms because of the higher per cent of organic carbon, free Al_2O_3, clay content and CEC of the soil [24]. These results were also substantiated by the existence of highly significant positive correlation between adsorption maxima (b1) with organic carbon (r = 0.916**), clay content (r = 0.739*) and free Al_2O_3 (r = 0.791*) of the soils (Table-8) [25].

TABLE-8
SIMPLE CORRELATION COEFFICIENT RELATING LANGMUIR ADSORPTION PARAMETERS FOR BORON ADSORPTION TO SOIL PROPERTIES

Soil properties	Part I		Part II	
	Adsorption maxima (b1) (µg g^{-1})	Bonding energy (k1) (mL µg^{-1})	Adsorption maxima (b2) (µg g^{-1})	Bonding energy (k2) (mL µg^{-1})
pH	-0.141	-0.357	0.594	-0.841**
Organic carbon	0.916**	-0.572	-0.151	0.739*
Sand	-0.401	0.506	-0.245	-0.127
Silt	-0.190	-0.281	0.227	-0.403
Clay	0.739*	-0.231	-0.078	0.741*
Cation exchange capacity	0.685	-0.743*	0.556	0.002
Free Fe_2O_3	0.546	-0.149	-0.262	0.646
Free Al_2O_3	0.791*	-0.415	-0.097	0.572
Free Fe_2O_3 + Al_2O_3	0.684	-0.255	-0.231	0.684

*Significant at 5 % level, **Significant at 1 % level

The relative bonding energy (k) of boron adsorption was varied from soil to soil. The k1 was higher than the respective k2 for all the soils (Table-7). This indicated that there were stronger retentions of boron in part I of the isotherms, *i.e.* at lower concentrations than at higher concentrations (part II). The low values of k2 were possibly because of multilayer adsorption and/or precipitation of boron at higher boron concentrations, whereas high values of k1 had resulted from the monolayer adsorption of boron at low concentrations of the equilibrium solution [26]. The bonding energy constant (k1) had a significant negative correlation (r = –0.738* for part I) with the adsorption maxima values. This indicated that boron was less strongly bound in the soils which had higher adsorption capacity. Therefore, the soils with higher bonding energy constant expected to have lesser supply capacity of boron for plant growth.

Evaluation of boron adsorption data using Freundlich adsorption isotherm: The Freundlich model could also successfully describe boron adsorption in soils of Assam over the entire range of initial boron concentrations (Fig. 5). In all soils the plot of boron adsorbed against equilibrium boron concentration on a log-log scale gave a linear relationship at the concentration range from 0.1 to 10 µg mL^{-1}. The Freundlich model assumes multilayer adsorptions and heterogeneity of the sites compared to the monolayer adsorption and homogeneity of sites in the Langmuir adsorption model. At higher concentration of added boron, a multilayer adsorption and/or precipitation reaction appeared to have occurred, which resulted in a better fit of the data with the Freundlich model than the Langmuir model. This results were in agreement with some scientist who also observed compatibility of the Freundlich model for assessing boron adsorption in soils [27-29]. The coefficients of determination (R^2) along with regression equations of the Freundlich adsorption isotherms for different soils are were highly significant statistically at 1 % level of probability (Table-9).

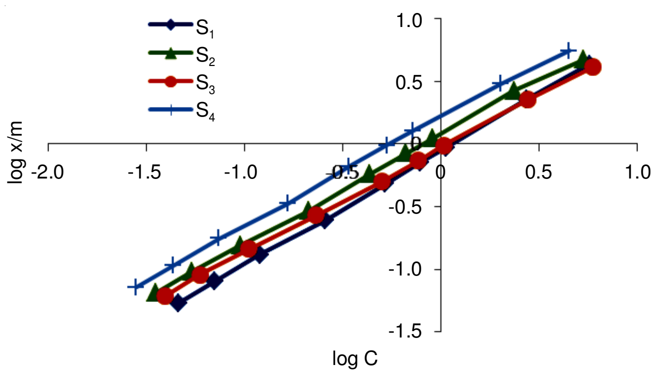

Fig. 5. Freundlich adsorption isotherms for boron in soils of Assam

TABLE-9
REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION FOR FREUNDLICH MODELS OF BORON ADSORPTION IN SOILS OF ASSAM

Sample No.	Regression equations	R^2
S_1	log x/m = 0.2494 + 0.9098 log C	0.999**
S_2	log x/m = 0.3737 + 0.8645 log C	0.999**
S_3	log x/m = 0.2721 + 0.8356 log C	0.999**
S_4	log x/m = 0.5109 + 0.8605 log C	0.999**

**Significant at 1 % level

The value of Freundlich's K signifies the amount of boron adsorbed in µg g^{-1} soil when the concentration of boron in equilibrium solution is 1 µg mL^{-1}. In other words the constant K is an index of relative affinity of boron adsorption in soils [30,31]. The results indicated that the values of K ranged from 1.775 to 3.242 in soils of Assam with the maximum in ultisol (S_4) and minimum in entisol (S_1) (Table-10). The highly significant positive correlation between the Freundlich's K and the organic carbon (r = 0.752*) and clay content (0.819*) of the soils (Table-11) lead to the conclusion that the magnitude of variation of K values might be due to differences in organic carbon and clay content of the soils. The value of Freundlich's 1/n was also positively and significantly correlated with CEC (r = 0.866**) of the soils.

TABLE-10
FREUNDLICH ADSORPTION PARAMETERS FOR BORON IN SOILS OF ASSAM

Sample No.	Freundlich constant	
	K	1/n
S_1	1.775	0.909
S_2	2.364	0.865
S_3	1.871	0.836
S_4	3.242	0.861

TABLE-11
SIMPLE CORRELATION COEFFICIENT RELATING FREUNDLICH ADSORPTION PARAMETERS FOR BORON ADSORPTION TO SOIL PROPERTIES

Soil properties	K	1/n
pH	-0.774*	0.524
Organic carbon	0.752*	0.528
Sand	-0.243	-0.372
Silt	-0.370	0.097
Clay	0.819*	0.284
Cation exchange capacity	0.182	0.866**
Free Fe_2O_3	0.631	0.224
Free Al_2O_3	0.589	0.411
Free $Fe_2O_3 + Al_2O_3$	0.678	0.310

*Significant at 5 % level, **Significant at 1 % level

Evaluation of boron desorption data using Langmuir desorption isotherm: The boron desorption data in these soils conform to a Langmuir model in range of added boron concentration (0.1 to 10 µg g^{-1}) used in the adsorption study (Fig. 6). A plot between desorbed boron (DeB) *vs.* boron desorbed/boron adsorbed (DeB/x/m) in all soils gave Langmuir desorption isotherms. The coefficient of determination (R^2) along with the regression equations are presented in Table-12.

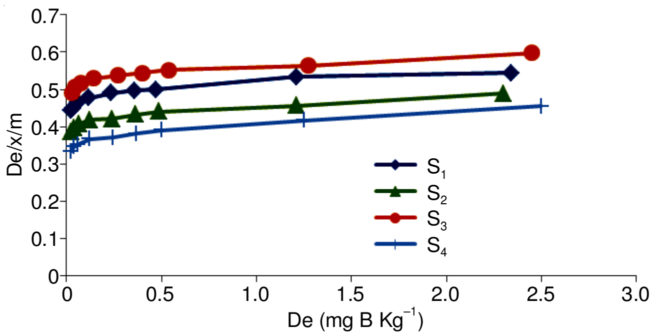

Fig. 6. Langmuir desorption isotherms for boron in soils of Assam

TABLE-12
REGRESSION EQUATION AND COEFFICIENT OF DETERMINATION FOR LANGMUIR MODELS OF BORON DESORPTION IN SOILS OF ASSAM

Sample No.	Regression equations	R^2
S_1	De/x/m = 0.4680 + 0.0195 x	0.773*
S_2	De/x/m = 0.4058 + 0.0197 x	0.863**
S_3	De/x/m = 0.5950 + 0.0224 x	0.904**
S_4	De/x/m = 0.2890 + 0.0177 x	0.750*

*Significant at 5 % level, **Significant at 1 % level

The desorption parameters computed from the Langmuir desorption isotherms clearly indicated the differential behaviour of each soil in supplying boron to the plants (Table-13). Desorption maxima of boron (DmB), indicated the maximum desorption capacity of the soils and the higher the DmB value, the less potential were the soils for releasing boron to meet the requirements of crops. The ultisol (S_4) was found to have the maximum DmB (56.497 μg g^{-1}) which might be due to higher clay, organic carbon and free oxides of Fe and Al content of the soil.

TABLE-13
LANGMUIR DESORPTION PARAMETERS FOR BORON IN SOILS OF ASSAM

Sample No.	Desorption maxima (μg g^{-1}) (DmB)	Mobility of boron (mL μg^{-1}) (K_dB)
S_1	51.282	0.042
S_2	50.761	0.049
S_3	44.643	0.037
S_4	56.497	0.061

The smaller the K_d value of boron (K_dB) value, the lesser was the desorption of soil boron, thereby suggesting a need for boron fertilization [20]. Alfisol (S_3) had the minimum K_dB value (0.037 mL μg^{-1}) and hence in this group of soils of Assam there is a need for boron fertilization. The mobility constant (K_dB) had an inverse relationship with bonding energy of boron adsorption and indicated that the mobility of adsorbed boron in heavy textured soils occurred at a lower rate.

The desorption of boron was found to be maximum in alfisol (S_3), *i.e.* from this soil the adsorbed boron could be released to soil solution very easily. The greater desorption of boron might be attributed to higher sand content and lower CEC of the soil. Also the desorption maxima (DmB) of the soils showed a significant positive correlation with sand content (r = 0.801*) and significant negative correlation with organic carbon (r = – 0.709*), CEC (r = – 0.834**) and free Al_2O_3 (r = –0.785*) of the soils (Table-14).

TABLE-14
SIMPLE CORRELATION COEFFICIENT RELATING LANGMUIR DESORPTION PARAMETERS FOR BORON TO SOIL PROPERTIES

Soil properties	Desorption maxima (μg g^{-1}) (DmB)	Mobility of boron (mL μg^{-1}) (K_dB)
pH	-0.009	-0.380
Organic carbon	-0.709*	0.832*
Sand	0.801*	-0.578
Silt	0.213	-0.161
Clay	-0.594	0.862**
Cation exchange capacity	-0.834**	0.642
Free Fe_2O_3	-0.197	0.505
Free Al_2O_3	-0.785*	0.842**
Free Fe_2O_3 + Al_2O_3	-0.419	0.670

*Significant at 5 % level, **Significant at 1 % level

Conclusion

Conclusion can be drawn from the above discussion that addition of increasing amount of boron increases both equilibrium boron concentration and adsorption of boron indicating increased intensity and capacity factor of boron supply of the soils of Assam, respectively. Boron adsorption data were satisfactorily described by the Langmuir adsorption isotherm at low concentrations of boron addition and by the Freundlich adsorption isotherm over the entire concentration range studied. Soil properties such as pH, organic carbon, clay, cation exchange capacity and free Al_2O_3 had a dominant role in adsorption and desorption of boron. The soil belong to ultisol were rich in these soil properties and adsorbed higher amount of boron leading to depletion of boron in soil solution. This indicated that there will be greater need for boron fertilizations in these soils of Assam. It is evident from the present investigation that the soils of Assam had varying capacity in respect of both adsorption of boron and the energy of adsorption as indicated by variation in adsorption maxima, Freundlich's K and bonding energy constant of the soils. These two factors affect the ability of the soils to release and maintain the supply of boron in the soil solution for crop nutrition.

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