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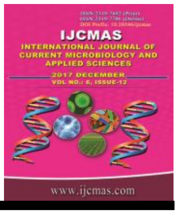

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Depth Wise Distribution of Boron in Some Soils of Red and Laterite Zone of West Bengal, India

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ABSTRACT

Keywords

Red and laterite soil, Readily soluble B, Specifically adsorbed B, Oxide bound B, Organically bound B, Residual B.

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The present dissertation work was undertaken to study the depth wise distribution of boron in some soils of red & laterite zone of West Bengal. Soil samples were collected from five representative locations from three different depths (15cm, 30 cm and 45cm) randomly and analyzed to study the status of B and its different fractions and the relationship between different B fractions and their relationship with soil properties. The available B recoveries from all the selected surface soils were in low to deficient ranges (0.50±0.25 mg kg^{-1} soil) and total B recoveries ranged from 30.90±23.53 mg kg^{-1} soil. The recoveries of different B fractions from the surface soils were observed within ranges of 0.22-0.31 (readily soluble B), 0.45-0.56 (specifically adsorbed B), 0.38-0.88 (oxide bound B), 0.30-0.87 (organically bound B) and 11.32-60.66 (residual B) mg kg^{-1}. All the boron fractions decreased with increasing depth of soil except residual B fraction which increased with soil depth. The recoveries of the hot water extractable B was significantly correlated with the recoveries of total B, residual B, oxide bound B and readily soluble B. Readily soluble B and specifically adsorbed B were significantly and positively correlated with each other. The available B was significantly and positively correlated soil pH, clay, available N, P, K, Fe, Mn and amorphous Fe and Al oxides. It was observed that all the B fractions had significant and positive correlation with clay content, available N and P and amorphous Fe and Al except organic B fractions which was highly correlated with organic matter content of the soil. The results emanating from the study revealed that the soils were low in available B content and only minute fraction of total B is available to plant.

Introduction

The element boron is an important micronutrient indispensible for normal growth and development of plant. This element has a relatively narrow range between its phytotoxic and deficient limit in the soil. Boron is absorbed from the soil by plants as borate, a negatively charged ion (anion). In mineral soils, release of boron is usually quite slow. Much of the available soil boron is held rather tightly by soil organic material. As organic matter decomposition occurs boron is released with a portion being absorbed by plants, leached below the root zone area (especially in high rainfall/acid soil areas) or tied up (unavailable) under alkaline soil conditions.

Boron deficiency is now a widespread phenomenon and affects crop growth both in acid as well as calcarious soil. The extent of B deficiency was about 2% in the year 1980 (Katyal and Vlek, 1985) and now it has increased to 18.3% (Shukla *et al.*, 2014) in India. Boron deficiency is becoming more pronounced in red and lateritic, acidic, coarse textured alluvial soils of India leading to 33% of grid samples to be deficient altogether (68% of soil samples from West Bengal are deficient) (Singh, 2008). Availability of B is generally low in acid soils of high rainfall areas because of leaching of B and adsorption by aluminium (Al) and iron (Fe) oxide minerals (Tsadilas and Kassioti, 2005). Highly leached acid soils of northern Bengal pose serious problem of boron deficiency (Saha and Halder, 1998).

The micronutrient Boron present in soil solution and in minerals, but only B in soil solution can be readily available for plants uptake, although this constitutes less than 3 % of total soil B (Tsadilas *et al.*, 1994).

Boron concentration in soil solution is controlled by the different pools of B in soil fractions and their equilibration with the soil solution (Keren and Bingham, 1985). The partition of the forms of an element has been made using methods originally developed for selective dissolution of trace metals and various techniques have been used for soil B by chemical fractionation schemes. In these procedures, different forms of B present in the soils were generally differentiated into: water soluble, specifically adsorbed, oxide bound, organically bound and residual associated with soil silicates (Hou *et al.*, 1994; Xu *et al.*, 2001; Datta *et al.*, 2002).

In West Bengal, The red and laterite soils occur in the districts of Birbhum, Bankura, Purulia, Jhargram, Burdwan and West mednapur. The soils are generally acidic (pH 5.0 to 6.5), high in Iron and aluminium oxide, poor in calcium, organic matter, available phosphate and bases. Very little information is available about the different B fractions in these soil and available informations were confined to surface soils only. Roots of many crops (such as pulses and oilseeds) may go beyond the surface layer to derive part of their nutrient requirements from the subsurface layers. Therefore, the information about the depth wise distribution of available B content in the soils is desirable. Keeping this in view our present investigation was carried out to study the depth wise distribution of B in red and laterite soils of west Bengal, their inter relationship and relationship of different B fractions with soil properties.

Materials and Methods

Soil samples were collected from 5 representative locations (Kusmasuli, Telkata, Jhargram, Barakadra, Ruisanda) of red and laterite zone of West Bengal, India, at three different depths: surface (0–0.15m), midsurface (0.15–0.30m), and subsurface (0.30–0.45m) layers (at least 5 samples from each location). These soils were air-dried, thoroughly mixed and ground to pass through a 2-mm sieve. Several important physico-chemical properties of these soil samples were determined by following the standard methods detailed hereafter.

Fractionation of different Boron pools in soil

Readily soluble boron

Five grams of soil in duplicate were weighed into 50 ml polyethylene centrifuge tubes to which 10 ml of 0.01 M $CaCl_2$ were added and shaken for 16 hours (Hou *et al.*, 1994). After centrifuging at 10,000 rpm for 30 min the supernatant solution was filtered through Whatman no 42 filter paper. Boron was determined in clear extracts using Azomethine-H (Wolf, 1971).

Specifically adsorbed B

The residue from the above step was then extracted with 10 ml of 0.05 M KH_2PO_4 by shaking for 1 hour (Hou *et al.*, 1994). After centrifugation, B was measured in the clear supernatant as described in the previous step because KH_2PO_4 was also found not to interfere with the estimation of B with Azomethine-H (Wolf, 1971).

Oxide bound B

The residue from the previous step was extracted with 20 ml of 0.175 M NH_4-oxalate, pH 3.25 by shaking for 4 hours (Hou *et al.*, 1994). Most of these extracts had a yellow to slight reddish colour. The yellow colour was mainly due to Fe and the reddish colour was due to slight dissolution of organic matter. The colours were eliminated by treating the extracts with NaOH and $HClO_4$ (Datta *et al.*, 2002). After that B in the clear extracts was determined by the carmine method (Hatcher and Wilcox, 1950).

Organically bound B

The residue from the NH_4-oxalate extraction was treated with 20 ml of 0.5 M NaOH by shaking for 24 hours followed by filtration through Whatman no. 42. The extracts of all samples except sand soils, were dark in colour due to the dissolution of organic matter. Therefore, 14 ml of aliquot was taken in a Teflon beaker to destroy the organic matter and the same procedure was followed as described in case of oxide bound fraction. Final volume was made up to 7 ml. After centrifuging the samples at 10,000 rpm for 15 minutes, B in the supernatant was determined with carmine reagent (Hatcher and Wilcox, 1950).

Residual B fraction

The residue from the previous step was dried and ground. 1 g subsample was taken into a 50 ml Teflon beaker and few drops of concentrated H_2SO_4, 5 ml of HF (40%), and 0.5 ml of $HClO_4$ (60%) were added (Lim and Jackson, 1982). The beaker was placed on a hot plate at 135 ± 5^0C and the volume reduced to about 3 ml. Then, 5 ml of concentrated H_2SO_4 and 5 ml of HF (40%) were added and heating continued. Further HF was added in increments of 2-5 ml until complete digestion of the soil. After digestion, 3 to 5 ml of $HClO_4$ (60%) was added depending upon the intensity of colour in the extract to get a clear extract. Finally, the volume was reduced to 3 to 4 ml by heating to drive off HF and $HClO_4$ completely. The content was transferred to a polyethylene centrifuge tube and the volume was made up to 25 ml. After centrifuging at 10,000 rpm B in the clear supernatant was determined with carmine reagent (Hatcher and Wilcox, 1950).

Results and Discussion

Physico-chemical properties of the collected soil

The soils have been characterized by determining important physico-chemical properties and the observations have been recorded in table 1. The soils are mildly acidic (pH- 5.83±0.14) and medium to low in organic carbon (5.24±1.86 g kg^{-1} surface soil) content. The clay content, which in surface soil varies from 185.4±157.74, highest in Ruisanda soil and lowest in Jhargram soil. The available N (209.32±32.05mg kg^{-1}), available P (25.36±5.86mg kg^{-1}) and available K (131.62±49.52mg kg^{-1}) are low in the collected soils. As for the micronutrients, DTPA extractable Zn and Cu are low to deficient (1.11±0.171 and 1.06±0.16 respectively) and Available (DTPA) Fe and

Mn in the red and laterite soil are exorbitantly high (50.99±10.38 and 47.72±11.29 mg kg^{-1}, respectively).

These soils were further analyzed to determine the depth wise profile of important physico-chemical characteristics (Table 1). The pH of the selected soils has been found to increase with increasing depth of sampling (up to 45 cm). This is because the upper horizons receive maximum leaching by rainfall, and by dissolved carbonic acid and organic acids which remove metal cations (e.g., Ca^{2+}, $K^{+,}$ Mg^{2+}) and replace them with H^+ ions. Lower horizons are not so strongly leached and, in fact, in dryer areas may accumulate calcium and other materials removed from the upper soil (Brady and weil, 2008). Other soil parameters showed gradual decline with increasing depth of sampling as also substantiated by Jobbagy and Jackson (2001) who found topsoil concentrations of all nutrients were higher than in the lower soil profiles where the elements were scarcer.

B fractions and their relation with soil properties

The recoveries of different fractions of B from soils, their extent, proportions to account for the total B pool and availability to standing crop largely depends upon the soil properties. Total B recoveries however, is not considered as a reliable index to understand the B supplying capacity of the respective soils. The plant available pools are often dictated by different B pools and soil physico-chemical properties. The B recoveries from selected soils of these zones have been recorded in table 2.

Hot water soluble B (HWSB)

The average HWSB recoveries from the selected surface soils ranged from 0.14-0.71 mg kg^{-1} (0.50±0.25) in (Table 1) which accounted for 1.61 % of total B recoveries. This findings can be well substantiated by Raza *et al.*, (2002) reporting an average of 1% of the total soil B as HWSB, which is considered most available for plant uptake.

The available B (HWSB) recoveries were found to decrease (Table 2) with increasing depth of sampling to 15-30 and 30-45 cm (0.43±0.20 to 0.35±0.17 mgkg^{-1}). This is due to leaching which was more pronounced in relatively light textured red and lateritic soils.

Similar trends of depth wise profile B recoveries have been reported by Arora and chahal (2005), Chaudhary and Shukla (2003).

The recoveries of the HWSB (plant available B) was observed to be significantly correlated with the recoveries of total B, residual B and oxide bound B (Table 3). Ho and Houng (1991) found an important correlation between hot water extractable B and total soil B together with fixation of supplemental B.

Datta *et al.*, (2002) has identified that 75% variability in the hot $CaCl_2$ extractable B (Hcc-B) could be attributed to RsB, SpB, OxB, and OrgB. Similar relationships have also been observed by Anitha *et al.*, (2013) who reported that the available boron content has significant and positive correlations with readily soluble, specifically adsorbed and oxide bound boron.

The hot water soluble B (HSWB) is significantly and positively correlated with soil pH, clay content, available N, P, K (Table 4). Sarkar *et al.*, (2008) also found significant and positive correlation with soil pH. As the soil is highly weathered soil, rich in iron and aluminium oxide, large portion of B is bound with these oxides. Thus we got a significant positive correlation of HWSB with available Fe, Mn and amorphous Fe and Al (Table 4). A positive correlation (r=0.584*) was also found with oxide bound B and HWSB.

The Readily Soluble B (Rs_B) and the specifically adsorbed B (Sp_B)

Readily soluble B includes dissolved plus B adsorbed nonspecifically on edges of clays and other variable charge surfaces. This fraction varied from 0.22 to 0.31 mgkg^{-1} (0.27±0.04) in surface soil and contribute 0.87% of total B (Table 2). The recovery of specifically adsorbed B varied from 0.45 to 0.56 mgkg^{-1} (0.49±0.08) in top layer, which share almost 1.58 % of total B (Table 2). Both the fractions significantly and positively correlated (r=0.693**) with each other means there is a dynamic equilibrium between these two fractions. Kusum Kumari *et al.,* (2017) also found significant positive relation (r=0.980**) between readily soluble B and specifically adsorbed B. Both readily soluble B and specifically adsorbed B have significant and positive correlation with available N(r=0.584* and 0.652**), P (r=0.672** and 696**) and amorphous Fe (r=0.618* and 0.726**), Al (r=0.561* and 0.719**). We found significant positive correlation between specifically adsorbed B and clay content (r=0.580*). The clay content, which affected on B sorption process, could have a dominating effect on specifically adsorbed B fraction, as also observed by Xu *et al.,* (2001). Although, Hou *et al.,* (1994) and Datta *et al.,* (2002) failed to establish any significant correlations of specifically adsorbed B with clay or with NH_4-oxalate extractable Al and Fe. This fraction probably originates from the weakly binding sites of both organic and inorganic constituents and none of these constituents contributed exclusively towards this B fraction (Hou *et al.,* 1994).

Both the fractions decreased with increasing depth of soil (Table 2 and Figure 1). This decrease may be due to decreasing organic carbon content, clay content and Fe content with depth (Table 1). Sarkar *et al.,* (2008) also observed similar type findings.

Important physico-chemical properties of these soil samples

Soil Parameters	Methodologies	References
pH	Soil-water suspension (1:2.5)	Jackson, 1973
EC	Soil-water suspension (1:2.5)	Jackson, 1973
Clay content	Hydrometer method	Bouyoucos, 1962
Organic Carbon	Wet digestion method	Walkley and Black, 1934
Amorphous Fe, Al and Mn oxides	0.2 M acidified ammonium oxalate	McKeague and Day, 1966
Available N	Hot alkaline permanganate	Subbiah and Asija, 1956
Available P	0.5 M $NaHCO_3$	Olsen *et al.,* 1954
Available P	0.03 N NH_4F + 0.025 N HCL (pH 3.5)	Bray and Kurtz, 1945
Available K	Neutral Normal ammonium acetate extraction	Brown & Warncke, 1988
Available Zn^{2+}, Mn^{2+}, Cu^{2+}, Fe^{2+}	DTPA extractant	Lindsay& Norvel, 1978
Available B (mg kg^{-1})	Hot water extraction	Berger and Truog, 1939
Total boron (mg kg^{-1})	Aqua Regia + HF dissolution	Zarcinas and Cartwright, 1987

Table.1 Depth wise physio-chemical properties of the collected soils

	Kusmasuli			**Teltaka**			**Jhargram**			**Barakadra**			**Ruisanda**		
	15cm	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**
pH	5.72	5.89	5.98	5.91	6.11	6.22	5.66	5.78	5.81	5.83	5.89	6.12	6.01	6.21	6.34
EC (dSm^{-1})	0.072	0.063	0.083	0.032	0.02	0.014	0.063	0.034	0.042	0.031	0.066	0.056	0.037	0.05	0.023
Clay (g kg-1)	162	156	150	188	172	136	62	45	30	66	76	78	449	423	406
Org. C (g kg-1)	8.52	7.32	6.52	4.81	4.52	3.62	4.32	3.52	3.2	3.92	3.53	3	4.63	4.21	3.75
Av. N (kg ha-1)	184.8	169.5	155.2	215.6	200.1	185.6	184.2	175.2	160.2	200.1	189.1	170.4	261.8	251.2	231
Av_P (kg ha-1)	28.4	25.75	18.93	26.25	24.31	20.48	15.66	11.53	12.34	25.35	22.14	20.13	31.12	30.1	25.13
Av. K (kg ha-1)	113.9	118.5	98.6	218.8	195.6	173.1	106.8	95.48	103.8	121.2	130.1	115.2	97.35	125.7	113.6
Am-Fe (g kg-1)	9.6	7.12	6	10.2	8.22	8	8.03	6.12	7.5	9.16	7.23	7	11.02	12.03	9.21
Am-Al (g kg-1)	3.26	3	3.45	4.08	4.12	3	2.84	2.01	1.7	3.6	2.14	1.98	4.36	3.11	4.12
Av. Zn (mg kg-1)	0.4	0.45	0.56	1.1	0.96	0.93	1.25	1.24	1.19	1.3	1.12	1.1	0.98	0.9	0.84
Av. Mn (mg kg-1)	32.2	40.23	30.12	53.11	50.23	48.33	40.1	35.26	42.31	53.11	50.23	48.33	60.1	55.33	55
Av. Cu (mg kg-1)	0.88	0.98	0.86	1.03	0.96	0.86	1.3	1.28	1.11	0.95	0.92	0.88	1.12	1.07	1.1
Av. Fe (mg kg-1)	40.25	30.23	28.23	53.23	50.32	45.23	41.23	43.21	35.22	55.26	50.23	40.32	65.02	60.23	55.23
HWB (mg kg-1)	0.34	0.32	0.25	0.71	0.60	0.53	0.14	0.13	0.10	0.64	0.55	0.46	0.67	0.54	0.42

	Mean±S.D		
	15cm	**30cm**	**45cm**
pH	5.83±0.14	5.98±0.18	6.094±0.21
EC dSm-1	0.047±0.019	0.047±0.019	0.044±0.027
Clay (g kg-1)	185.4±157.74	174.4±148.81	160±145.62
Org. C (g kg-1)	5.24±1.86	4.62±1.57	4.018±1.43
Av. N (kg ha-1)	209.32±32.05	197.03±32.56	180.51±30.53
Av_P (kg ha-1)	25.36±5.86	22.77±6.92	19.40±4.60
Av. K (kg ha-1)	131.62±49.52	133.104±37.45	120.88±30.01
Am-Fe (g kg-1)	9.60±1.22	8.144±2.296	7.54±1.19
Am-Al (g kg-1)	3.63±0.61	2.88±0.85	2.85±1.009
Av. Zn (mg kg-1)	1.11±0.171	1.014±0.16	1.008±0.138
Av. Mn (mg kg-1)	47.72±11.29	46.26±8.23	44.82±9.36
Av. Cu (mg kg-1)	1.06±0.16	1.042±0.144	0.96±0.131
Av. Fe (mg kg-1)	50.99±10.38	46.84±11.09	40.87±10.21
HWB (mg kg-1)	0.50±0.25	0.428±0.198	0.35±0.17

Table.2 Depth wise distribution of B in red and lateritic soils

	Kusmasuli			Teltaka			Jhargram			Barakadra			Ruisanda		
	15cm	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**	**15cm**	**30cm**	**45cm**
Rs_B	0.25	0.24	0.20	0.30	0.22	0.24	0.22	0.21	0.15	0.29	0.25	0.16	0.31	0.26	0.18
Sp_B	0.46	0.44	0.39	0.59	0.46	0.25	0.40	0.35	0.28	0.45	0.28	0.30	0.56	0.54	0.38
Ox_B	0.38	0.35	0.29	0.52	0.48	0.41	0.43	0.35	0.42	0.5	0.56	0.54	0.88	0.74	0.77
Org_B	0.87	0.85	0.8	0.4	0.45	0.39	0.44	0.38	0.34	0.3	0.25	0.18	0.65	0.6	0.51
Res_B	11.32	12.23	14.23	42.32	42.34	44.23	14.23	15.13	16	9.36	11.12	12.01	60.66	62.2	65.62
Unac_B	0.4	1.08	2.48	1.62	4.26	5.08	1.67	0.79	0.72	2.25	1.6	2.05	2.43	1.87	0.55
Tot_B	13.56	15.2	18.5	45.5	48.21	50.97	17.2	17.22	18.1	12.85	13.99	15.45	65.37	66.21	68.32

	Mean±S.D			**% contribution to total (mean value)**		
	15cm	30cm	45cm	15cm	30cm	45cm
Rs_B	0.27±0.04	0.24±0.02	0.19±0.04	0.87	0.74	0.55
Sp_B	0.49±0.08	0.41±0.10	0.32±0.06	1.58	1.27	0.93
Ox_B	0.54±0.20	0.50±0.16	0.49±0.18	1.74	1.55	1.42
Org_B	0.53±0.23	0.51±0.23	0.44±0.23	1.71	1.58	1.28
Res_B	27.58±22.84	28.60±22.76	30.42±23.66	89.25	88.90	88.76
Unac_B	1.48±0.77	1.91±1.38	2.41±1.87	4.79	5.93	7.03
Tot_B	30.90±23.53	32.17±23.76	34.27±23.99			

Table.3 Relationship between different B pools in selected soil

Correlations							
	HWSB	Rs_B	Sp_B	Ox_B	Org_B	Res_B	Tot_B
HWSB	1						
Rs_B	0.655*	1					
Sp_B	0.486	0.693**	1				
Ox_B	0.584*	0.312	0.392	1			
Org_B	-0.123	0.208	0.448	-0.116	1		
Res_B	0.563*	0.258	0.425	0.761**	.098	1	
Tot_B	0.580*	0.265	0.415	0.746**	.095	0.998**	1

* Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

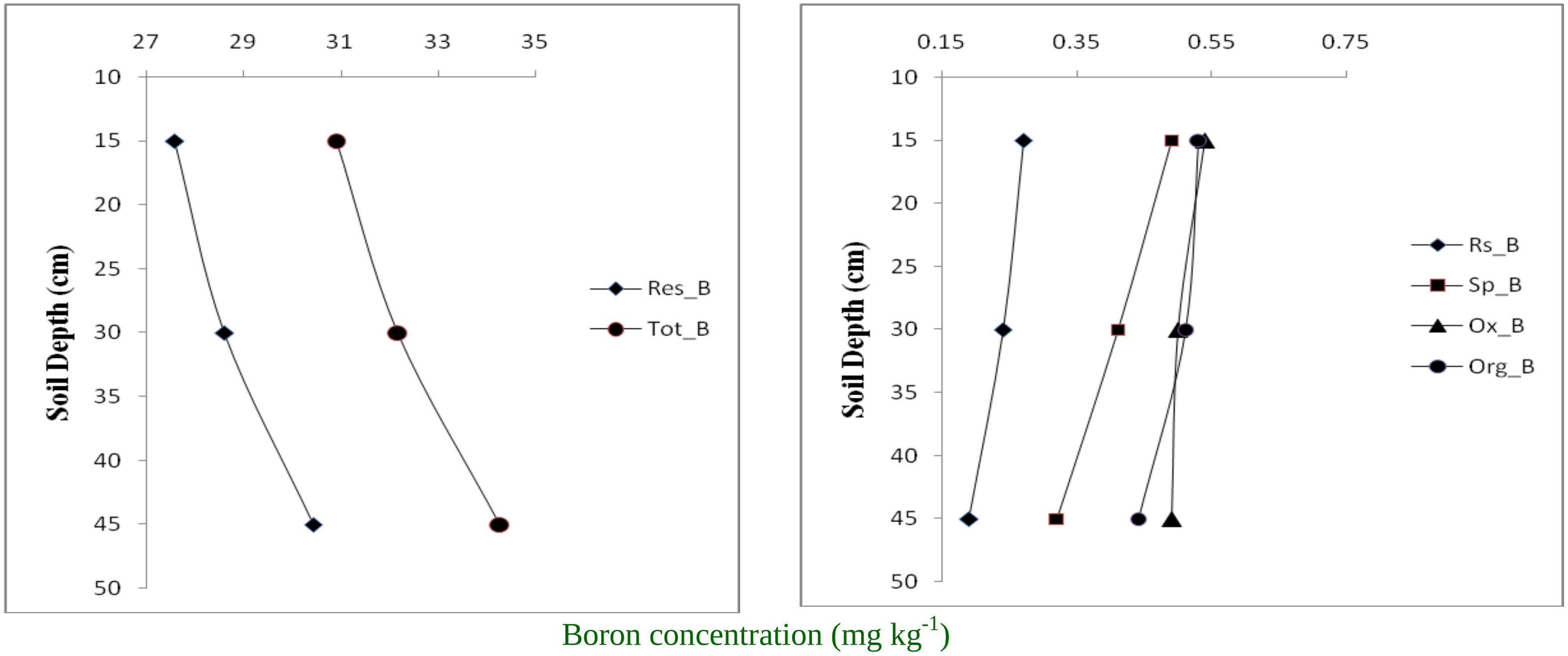
Table.4 Relationship between B fractions and soil properties

	pH	EC	Clay	Org. C	Av. N	Av. P	Av. K	Am-Fe	Am-Al	Av. Zn	Av. Mn	Av. Cu	Av. Fe
HWSB	0.502*	-0.416	0.504*	-0.094	0.669**	0.767**	0.630*	0.614*	0.622*	0.030	0.777**	-0.403	0.721**
Rs_B	-0.134	-0.123	0.345	0.255	0.584*	0.672**	0.326	0.618*	0.561*	-0.010	0.409	-0.050	0.586*
Sp_B	-0.042	-0.027	0.580*	0.400	0.652**	0.696**	0.247	0.726**	0.719**	-0.179	0.316	0.175	0.486
Ox_B	0.530*	-0.333	0.809**	-0.353	0.903**	0.591*	-0.029	0.726**	0.427	0.190	0.852**	0.196	0.853**
Org_B	-0.076	0.438	0.414	0.893**	0.073	0.425	-0.228	0.178	0.406	-0.879**	-0.397	-0.121	-0.253
Res_B	0.739**	-0.574*	0.875**	-0.214	0.839**	0.520*	0.310	0.691**	0.618*	-0.036	0.690**	0.159	0.709**
Tot_B	0.752**	-0.583*	0.865**	-0.215	0.829**	0.522*	0.330	0.680**	0.626*	-0.039	0.691**	0.130	0.703**

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Fig.1 Depth wise distribution of different B fractions



The oxide bound B (Ox_B)

The oxide bound B fraction included tightly bound B at mineral surfaces as well as B that has isomorphously replaced Al or Fe within the octahedral sheet of the minerals (Hou 1994). The recoveries of the oxide bound B (Ox_B) from the selected surface soils were ranged from 0.38 to 0.88 mg kg^{-1} (Table 2). This fraction has significant positive correlation with Hot water soluble B and residual B fraction (Table 3). So this fraction has a contribution to plant available form of B. Kusum Kumari *et al.,* (2017) also observed significant and positive correlation among these fractions. The oxide bound B also significantly and positively correlated with pH, clay, available N, P, Mn, Fe and amorphous Fe and Al oxides.

Datta *et al.,* (2002) observed that pH and NH_4-oxalate extractable Fe are the main contributors of oxide bound B explaining 42% variability of this fraction. As NH_4-oxalate can solubilize non-crystalline and some crystalline oxy-hydroxides of Fe and Al from soils, the relationship of oxide bound B and NH_4- oxalate extractable Fe is logical as an adsorption of B both as $B(H)_3^0$ and $B(0H)_4^-$ species takes place on Fe_2O_3 via ligand exchange (Su and Suarez, 1995). Our findings are also in good agreement with observations of Colak *et al.,* (2013) who reported that B occluded in Mn oxides and occluded in amorphous Fe-Al oxyhydroxides were correlated with soil properties such as: organic matter content, pH, free aluminum and iron oxyhydroxides, amorphous aluminum and iron oxy-hydroxides. This fraction was also decreased with depth soil (Table 2 and Figure 1) mainly due to the decrease in clay content and amorphous Fe and Al oxide content of the soils at lower depths, as evidenced by significant positive correlations between the extractable B with those soil properties.

The organically bound B (Org_B)

The recoveries of organically bound B from selected soils ranged from 0.30 to 0.87 mg kg^{-1} (Table 2). This fraction under the present study were observed to be significantly and positively correlated with organic C content (0.893**). Such observations are complimented by similar findings of Datta *et al.,* (2002) who observed that organically bound B was positively correlated with organic carbon content.

The significant relationship observed between organically bound B fraction and OM content indicated that organic matter played an important role in B adsorption and release in soils (Ranjbar and Jalali, 2013). This fraction solely depended on the organic carbon content of the soil (Kartikeyan and Sukla, 2011). The close association of soil organic matter with organically bound B may be attributed to the release of B when organic matter decomposition occurs in soil (Jin *et al.,* 1987).

As organic carbon content decreased with soil depth this fraction also decreased with increasing soil depth (Figure 1).

The residual B (Res_B)

Boron held within primary (tourmaline) and secondary (colemanite) minerals is described as residual B (Res_B). Residual B is generally associated with silicates (Jin *et al.,* 1987). Residual B accounts for the major portion of total soil B. The recoveries of residual B from selected surface soils under the present investigation were observed to be 11.32 to 60.66 mg kg^{-1} (Table 1). The greatest significant correlation was observed between residual B and total B (r = 0.99**) followed by relationship between residual B and oxide bound B (r = 0.76**) (Table 3). The greatest correlation between residual B and total B might be due to among all the extracted fractions as it contributed to the tune of 89.25 % to total B fraction (Table 2). This residual B significantly and positively correlated with pH, clay, available N, P, amorphous Fe, Al oxides and available Fe, Mn (Table 4). Similar findings have also been reported by Datta *et al.*, (2002) who observed that residual B was significantly and positively correlated with clay, Al, Fe, and Al + Fe which confirms that the residual B is the structural constituent of clay and sesquioxides. The residual B also includes B occluded in crystalline Al and Fe oxyhydroxides (Xu *et al.*, 2001). The residual B has been observed to increase with depth from 15 cm to 45 cm which actually accounted for the increase in total B recoveries with increasing depth of sampling (Figure 1). The structural B (clay lattice and alumino-silicates bound residual B) were higher at depth of the soil profile where the soils are less disturbed and beyond plough reach.

The proportionate recoveries of different fractions of B with respect to total boron recoveries have been presented in Table 2. We found that the contents of B fractions followed the order Residual B >> Oxide bound B ≅ Organically bound B > specifically adsorbed B > Readily soluble B. Our finding matches with the observation of Diana and Beni (2006) who said that the contents of B fractions followed the order Res-B >> Ox-B > Om-B > Sol-B > Spa-B ≅ Nsa-B.

The present investigation has made a modest attempt to characterize boron in some soils randomly selected from these agriculturally most important regions of the state. We have sorted to the B fractionation scheme developed by Hou *et al.*, (1994) and later modified by Datta *et al.*, (2002) for colorimetric determination instead of costly ICP-OES studies. The B fractions recovered from different soils, their interrelationship and relationship with soil properties have been worked out throughout the present initiative. A thorough investigation regarding B status, availability and soil factors controlling such availability have been explored. The database generated through the present investigation may help extending our understanding of the B behavior and B availability in a wide range of cultivable lands in the state and to ignore artifacts relating to B availability/or deficiencies.

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