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Forms of boron under different cropping systems in soils of Morigaon district of Assam

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Abstract
Boron is directly or indirectly involved in several physiological and biochemical processes during plant growth. Hundred numbers (100) of surface (0-15 cm) soil samples from different cropping systems were collected with an auger from Morigaon district (between longitude (92° and 95.5°E) latitude, (26.15° and 26.5°N) representing twenty five (25) soil samples from each dominant cropping systems. Soil samples were analyzed to determine the forms of boron under different cropping systems in Inceptisols soils of Morigaon district and its relation to soil properties. The experimental findings revealed that the soils were sandy loam to silty clay loam in texture and strongly acidic to near neutral (4.17 to 6.94) in reaction with organic carbon content ranging from medium to high (0.51 to 1.14 per cent). EC of the soils were very low ranging from 0.01 to 0.06 dS m^{-1}. The CEC of the soils were low and varied from 5.50 to 7.70 [cmol (p^+) kg^{-1}]. The available nitrogen, phosphorus and potassium content of the soil ranged from low to medium (219.52 to 533.12 kg/ha), (21.54 to 57.96 kg/ha) and low to high (104.36 to 419.46 kg/ha). The sequential extraction of boron showed that forms of boron followed the decreasing order as: Res-B > Ox-B > Org-B > SA-B > RS-B and per cent distribution of different forms were also in the same order as: 42.71% > 25.50% > 24.97% > 3.28% > 2.60% of the total. Statistically, RS-B fraction was positively correlated with organic carbon and Org-B of the soil under *rice-rice* and *rice-rapeseed* cropping system. It also showed a positive correlationship with organic carbon, Org-B and Res-B fraction of the soil in *rice-vegetable* and *vegetable-vegetable* cropping system. The SA-B showed a positively relationship with Ox-B fraction of the soil in *rice-rapeseed* cropping system. Ox-B fraction had a positive correlation with Org-B fraction of the soil in *rice-rice* and *rice-rapeseed* and *rice-vegetable* cropping systems. Similarly, Org-B fraction of the soil in all the cropping systems was positively correlated with organic carbon and Ox-B fraction of the soil. Res-B fraction showed positive correlationship with RS-B fraction of the soil in *rice-rapeseed, rice-vegetable* and *vegetable-vegetable* cropping system.
EC: Electrical Conductivity, CEC: Cation Exchange Capacity, RS-B: Readily Soluble Boron, SA-B: Specifically Adsorbed Boron, Ox-B: Oxide Bound Boron, Org-B: Organically Bound Boron, Res-B: Residual Boron

Keywords: Forms, boron under different cropping systems, soils, Morigaon district, Assam

Introduction
Boron is the only non-metallic element in Group 13 of the Mendeleev Periodic Table and shares a chemical resemblance with carbon. The importance of boron as an essential plant nutrient was first established in 1923 by Warrington and now it is reported as the most deficient plant nutrient worldwide (Shorrocks, 1997) [30]. Though plants vary in boron need, there exists a narrow range between toxicity and deficiency and plant can develop symptoms both deficiency and toxicity in the same growing period (Reisenauer *et al*., 1995) [27]. Boron deficiency causes reduction in cell enlargement in growing tissues due to its structural role and responsible for creating male sterility and inducing floral abnormalities (Sharma, 2006) [28]. Boron deficiency is much more common in crops that are grown in soil that have higher amount of free carbonates, low organic matter, and high pH (Rashid *et al*., 2004) [26].
Availability of boron is influenced by their distribution and physico-chemical properties of the soil (Sharma and Chaudhary, 2007) [29]. Several soil factors influence the availability of boron content to the plants. These factors are pH, soil texture, organic matter, clay minerals, microbiological activity, soil drainage, oxidation-reduction conditions, seasonal variation in climatic conditions and interrelations of micronutrients.
Analysis of more than 3 lakhs soil samples carried out under the aegis of All India Coordinated Project on Micro and Secondary Nutrients and Pollutant Elements in Soils and

Plants of the ICAR showed that about 33 per cent soil is deficient in boron. Coarse texture, high pH, calcareousness, declining organic carbon and leaching aggravate micronutrient deficiency. Irrespective of these soil properties, irrigated crops whose productivity is two-three times higher than rainfed crops, suffered more often from micronutrient deficiency. Boron deficiencies that appear to be localized today may expand geographically in the near future posing threat to the production system. As such it is important to estimate and monitor the boron status/deficiencies in various agro ecological regions to forecast potential boron prospect and problems in order to develop models for different soil crop situation (Nayar, 1999) [22].

In a study on Assam soils reported that 44 and 34 per cent of the alluvial and lateritic soils were deficient in boron, respectively (Borkakati and Takkar, 2000) [2]. On the other hand, importance of boron in crops and cropping systems are increasing, more particularly under intensive agricultural situations in Morigaon district of the state. Considering the above fact and need maiden research investigation was proposed to identify the forms of boron in Inceptisols of Morigaon district of Assam under different cropping systems to determine the forms of boron under different cropping system and its relation to soil properties.

The Morigaon district is situated in the central Brahmaputra valley zone of Assam between longitude (92° and 95.5°E) and latitude (26.15° and 26.5°N). Morigaon district is divided into five blocks *viz.*, Bhurbandha, Mayong, Lahorighat, Kapili, and Mairabari. Total gaon panchayats and Revenue villages are 97 and 790, respectively. Total geographical area of the district is 1550 sq km. Rice is the main crop followed by rapeseed, jute, wheat, vegetable and pulses. Rice is also growing as a monocrop. The soil of the district is alluvial and fertile. According to taxonomic classification soil orders are 3 and 10 great groups. The dominant cropping systems are: 1. *rice – rice,* 2. *rice – rapeseed*, 3. *rice – vegetable* and 4. v*egetable - vegetable.* The climate of the district is sub-tropical humid, characterized by high rainfall. It receives an average annual rainfall of 1291.1 mm of which about 90 per cent falls between April to October and 10 per cent of total annual rainfall is received in between November to March. The maximum temperature goes up to 36 °C in June/July whereas the minimum temperature falls to 8 °C in December/January with an annual average temperature of 22 °C.

Materials and Methods

Representative soil samples from different cropping systems were collected from Inceptisols of Morigaon district. Hundred numbers (100) of surface (0-15 cm) soil samples were collected with an auger from Morigaon district representing twenty five (25) soil samples from each dominant cropping systems as mentioned above. The samples collected were air-dried, ground and passed through a 2 mm sieve and stored in labeled polythene bags for further analysis.

The soil properties and forms of boron contents were determined using the facilities available in the Department of Soil Science, Assam Agricultural University, Jorhat. Standard laboratory procedures adopted during the analysis are presented in Table 1.

Table 1: Methods adopted for physico-chemical analysis

S. No.	Parameters	Methods	References
1.	Soil reaction (1:2.5)	Glass electrode pH meter	Jackson (1973)
2.	Electrical conductivity (1:2.5)	Electrical conductivity meter	Jackson (1973)
3.	Organic carbon	Walkley and Black's method	Jackson (1973)
4.	Cation exchange capacity	Distillation method	Jackson (1973)
5.	Mechanical analysis	International Pipette Method	Piper (1966)
6.	Available nitrogen	Alkaline $KMnO_4$ method	Subbiah and Asija (1956)
7.	Available phosphorus	Extracted with 0.03N NH_4F in 0.025 N HCl (Bray's-I method).	Bray and Kurtz (1945)
8.	Available potassium	Flame photometric method	Jackson (1973)

The modified sequential extraction procedure as described by Hou *et al.* 1996 [11] is presented below:

Step	Fraction	Extractant	Procedures
1	Readily soluble (Solution plus non-specifically adsorbed)	0.01 M $CaCl_2$	0.05 gm soil, 10 ml extract ant; 16 hours shaking.
2	Specifically adsorbed	0.05 M KH_2PO_4	Residue of step 1 shaken for 1 hour with 10 ml extract ant.
3	Oxide bound	0.2 M acidic NH_4-Oxalate	Residue of step 2 shaken for 4 hours with 10 ml extract ant.
4	Organically bound	0.02 M HNO_3; H_2O_2 (30%)	Residue of step 3 heated for 2 hours with 3,5 ml of first two extract ants; reheated with 5 ml of third extract ant shaken and centrifuged
5	Residual	Aqua regia	Residue of step 3 heated with 10 ml aqua regia, diluted and filtered.

Simple correlation was computed using Pearson's equation to reveal the magnitudes and directions of relationships between selected soil physico-chemical properties and forms of boron. Statistical analysis of the experimental data was done by CoStat Professional, Version 6.311, Copyright© 1998-2005, CoHort Software, CoHort Software, 798 Lighthouse Ave, PMB 320, Monterey, CA 93940, USA.

Findings and Discussion

Results on physico-chemical properties of soils under *rice-rice* cropping systems, the texture of the soils were varied from sandy loam to clayey. Sand, silt and clay fractions of the soils varied from 28.20 to 66.16, 15.00 to 33.00 and 15.84 to 49.40 per cent, respectively. The pH of the soil was strongly acidic to near neutral (4.17 to 6.94) in reaction with a mean value of 4.75. The organic carbon content of the soil ranged from medium to high (0.51 to 0.95 per cent) with a mean value of 0.72 per cent, while CEC of the soil varied from 5.50 to 7.60 [cmol (p^+) kg^{-1}] with an average value of 6.61 [cmol (p^+) kg^{-1}] of the soil. The EC of the soil was very low. It ranged between 0.01 and 0.05 dS m^{-1} with an average value of 0.02 dS m^{-1}. The available nitrogen, phosphorus and potassium content of the soil ranged from low to medium 219.52 to 533.12 kg/ha with a mean value of 381.32 kg/ha; from 21.54 to 57.96 kg/ha with a mean value of 33.54 kg/ha; from 105.36 to 229.95 kg/ha with a mean value of 167.36 kg/ha.

Data showed that the soil of RS-B fraction ranged from 0.45 to 1.89 mg kg^{-1} with a mean value of 1.09 mg kg^{-1}. SA-B fraction of the soil ranged from 1.30 to 2.09 mg kg^{-1} with a mean value of 1.76 mg kg^{-1}. The soil Ox-B fraction varied from 9.50 to 18.90 mg kg^{-1} with a mean value of 13.86 mg kg^{-1}. The Org-B fraction of the soil ranged from 10.05 to 17.20 mg kg^{-1} with a mean value of 13.78 mg kg^{-1} and Res-B of the soil varied from 18.75 to 31.20 mg kg^{-1} with a mean value of 23.53 mg kg^{-1}.

Results on physico-chemical properties of soils under *rice-rapeseed* cropping systems, the results showed that the texture of the soils varied from sandy loam to clay loam. Sand fraction varied from 35.20 to 67.16, silt from 13.00 to 34.28 and clay from 17.84 to 34.12 per cent. The soils were acidic in reaction with pH values ranging from 4.32 to 5.71 with a mean value of 5.01, while the organic carbon content of the soil ranged from medium to high. It ranged from 0.61 to 0.88 per cent with a mean value of 0.70 per cent. The CEC of the soils were found to vary from 5.70 to 7.50 [cmol (p^+) kg^{-1}] with an average value of 6.55 [cmol (p^+) kg^{-1}], while the EC of the soil was found to be very low ranging from 0.01-0.06 dS m^{-1} with an average value of 0.03 dS m^{-1}. The available nitrogen, phosphorus content of the soil ranged from low to medium 282.24 to 533.12 kg/ha with a mean value of 363.76 kg/ha and 21.54 to 53.86 kg/ha with a mean value of 31.54 kg/ha, respectively. The available potassium distributed between low to high from 104.16 to 419.46 kg/ha with a mean value of 170.52 kg/ha.

The RS-B fraction of the soil ranged from 0.83 to 1.98 mg kg^{-1} with a mean value of 1.59 mg kg^{-1}. The fraction of SA-B ranged from 1.50 to 2.24 mg kg^{-1} with a mean value of 1.86 mg kg^{-1} of the soil. The soil of Ox-B fraction varied from 9.50 to 18.90 mg kg^{-1} with a mean value of 14.40 mg kg^{-1}. Org-B fraction ranged from 10.05 to 17.50 mg kg^{-1} with a mean value of 14.37 mg kg^{-1} and Res-B fraction of the soil ranged from 18.75 to 31.20 mg kg^{-1} with a mean value of 23.33 mg kg^{-1}.

Results on physico-chemical properties of soils under *rice-vegetable* cropping system, the results were showed that the texture of the soil varied from sandy loam to silty clay loam. Sand, silt and clay fraction varied from 19.16 to 66.88, 10.48 to 54.00 and 17.84 to 44.60 per cent, respectively. The soils were found to be strongly acidic to medium acidic in reaction with pH values ranging from 4.28 to 5.94 with a mean value of 4.90. Organic carbon content of the soil varied from low to high with values ranging from 0.49 to 1.05 per cent with a mean value of 0.71 per cent. The CEC of the soil was found to range from 5.70 to 7.60 [cmol (p^+) kg^{-1}] with an average value of 6.59 [cmol (p^+) kg^{-1}], while the EC of the soil was found to be very low which ranged from 0.01 to 0.06 dS m^{-1} with an average value of 0.03 dS m^{-1}. The available nitrogen, phosphorus and potassium content of the soil varied from low to medium 219.52 to 533.12 kg/ha with a mean value of 365.00 kg/ha; low to medium from 21.54 to 57.96 kg/ha with a mean value of 32.91 kg/ha; low to high from 107.11 to 462.47 kg/ha with a mean value of 173.90 kg/ha.

Data showed that the RS-B fraction of the soil ranged from 0.65 to 2.09 mg kg^{-1} with a mean value of 1.59 mg kg^{-1}. SA-B fraction of the soil ranged from 1.50 to 2.24 mg kg^{-1} with a mean value of 1.87 mg kg^{-1}. The Ox-B of the soil ranged from 9.50 to 18.90 mg kg^{-1} with a mean value of 14.59 mg $kg^{-1}$of the soil. Organically bound boron content of the soil ranged from 32.00 to 52.00 mg kg^{-1} with a mean value of 39.40 mg kg^{-1} and residual boron content of the soil ranged from 10.05 to 17.50 mg kg^{-1} with a mean value of 14.47 mg kg^{-1}.

Results on physico-chemical properties of soils under *vegetable-vegetable* cropping system are presented in Table 4.7. The results showed that the texture of the soil varied from sandy loam to clay soil. Sand, silt and clay fraction varied from 19.16 to 63.56, 15.00 to 52.00 and 16.00 to 50.00 per cent, respectively. The soils were found to be strongly acidic to medium acidic in reaction with pH values ranging from 4.40 to 6.95 with a mean value of 5.09. Organic carbon content of the soil varied from medium to high with values ranging from 0.58 to 1.14 per cent with a mean value of 0.77 per cent. The CEC of the soil was found to range from 5.70 to 7.70 [cmol (p^+) kg^{-1}] with an average value of 6.60 [cmol (p^+) kg^{-1}], while the EC of the soil was found to be very low which ranged from 0.01 to 0.06 dS m^{-1} with an average value of 0.03 dS m^{-1}. The available nitrogen, phosphorus and potassium content of the soil varied from medium to high 282.24 to 533.12 kg/ha with a mean value of 387.60 kg/ha; medium to high from 23.33 to 57.96 kg/ha with a mean value of 37.06 kg/ha and low to high 117.46 to 425.37 kg/ha.

Data revealed that RS-B fraction of the soil ranged from 0.66 to 1.98 mg kg^{-1} with a mean value of 1.59 mg kg^{-1}. The soil of SA-B fraction ranged from 1.50 to 2.24 mg kg^{-1} with a mean value of 10.00 mg kg^{-1}. Ox-B fraction ranged from 9.50 to 18.90 mg kg^{-1} with a mean value of 14.94 mg $kg^{-1}$of the soil. The Org-B fraction of the soil ranged from 10.05 to 17.50 mg kg^{-1} with a mean value of 14.83 mg kg^{-1} and Res-B fraction ranged from 18.75 to 39.20 mg kg^{-1} with a mean value of 24.57 mg kg^{-1} in the soil.

The organic carbon was significantly positive correlated with CEC (r=0.464*), RS-B (r=0.692**) and Org-B (r=0.751**) fraction of the soil. RS-B (r=0.510**) and Ox-B (r=0.450*) fractions were showed a positive correlation with Org-B fraction of the soil.

The organic carbon was significantly positive correlated with CEC (r=0.470*), RS-B (r=0.424*) and Org-B (r=0.574**) fraction of the soil. RS-B fraction was found to be positive correlation with Res-B (r=0.504*) fraction of the soil. Similarly, SA-B fraction had a positive correlation with Ox-B (r=0.400*) and Ox-B showed positively correlated with Org-B (r=0.416*) fraction of the soil.

The organic carbon was significantly positive correlated with RS-B (r=0.545**) and Org-B (r=0.707**) fraction of the soil. RS-B fraction was found to be positive correlation with Org-B (r=0.408*), Res-B (r=0.603**) fraction of the soil. Similarly, Ox-B fraction showed a positively correlated with Org-B (r=0.430*) fraction of the soil.

Soil pH found to be positive correlation with organic carbon (r=0.640**), Org-B (r=0.398*) and Res-B (r=0.556**) fraction of the soil. The organic carbon was significantly positively correlated with CEC (r=0.473*), RS-B (r=0.519**), Org-B (r=0.781**) and Res-B (r=0.465*) fraction of the soil. CEC of the soil was found to be positive correlated with Res-B (r=0.467*) fraction of the soil. Similarly, RS-B fraction was found to be positive correlation with Org-B (r=0.604**) and Res-B (r=0.418*) fraction of the soil.

Discussion

Data revealed that soils of Morigaon district were sandy loam to silty clay loam in texture, strongly acidic to near neutral in reaction and organic carbon content ranged from medium to high. The EC content of the soils were low. The available nitrogen and phosphorus content of the soils ranged from low to medium, but potassium content of the soils ranged from low to high.

Most of the soils of the study area were sandy loam and silty clay loam in texture. Coarse textured (sandy) soils often adsorbed less available boron than fine textured soils, thus boron deficiency frequently arises in areas located in sandy soils (Fleming, 1980). In a soil higher percentage of sand indicates lower percentage of silt and clay content and vice-versa. Thus, increase in sand content reduces the reactive surface area of a soil. So, a negative correlationship was observed between available boron and sand content. The finding of the present investigation was in conformity with the findings of Wilson *et al.* (1951) [34] and Oyinlola *et al.* (2010) [25], who reported that higher sand content facilitated leaching of boron from the surface soil. Thus, negative relationship between available boron and sand content could be justified. Finding of the present investigation was in conformity with the findings of Chabbra *et al.* (1996) [4] and Nazif *et al*. (2006) [23].

Correlation co-efficient analysis were also conducted among different soil properties with nutrient and boron fraction of soil irrespective of cropping system considering all the soil samples. The correlation co-efficient values of all the soils of the district analyzed revealed that soil pH was found to be positive correlation with organic carbon (r=0.235*), RS-B (r=0.247*) and Org-B (r=0.217*) fraction of the soil. Organic carbon showed positive correlationship with organic carbon (r=0.198*), RS-B (r=0.465**), Org-B (r=0.694**) and Res-B (r=0.338**) fraction of the soil. Clay content of the soil was found to be positive correlation with RS-B (r=0.208*) fraction of the soil. Similarly, RS-B fraction was positively correlated with Org-B (r=0.476**), Res-B (r=0.346**) fraction of the soil. The SA-B fraction showed a positive relationship with Ox-B (r=0.203*) and Ox-B fraction was found to be positively correlated with Res-B (r=0.384**) fraction of the soil.

Data on amount of boron extracted by sequential extraction procedure were in the decreasing order as: Res–B > Ox–B > Org–B > SA–B > RS–B and per cent distribution of different forms were also in the same order as: 42.71% > 25.50% > 24.97% > 3.28% > 2.60% of the total. The sequence of different forms were reported to be the same order by several workers (Jin *et al.,* 1987; Hou *et al.,* 1994 and Xu *et al.,* 2001) [15, 12, 35].

The fraction RS–B extracted by 0.01 M $CaCl_2$ ranged from 0.45 to 1.98 mg kg^{-1} with a mean value of 1.46 (2.60 per cent) mg kg^{-1} in all the cropping systems. Spouncer *et al.* (1992) [31] reported amount of boron extracted by 0.01 M $CaCl_2$ was twice the available form of boron with in a pH range of 4.2 to 7.8. Under *rice-rice, rice-rapeseed*, *rice-vegetable* and *vegetable-vegetable* cropping systems, the mean RS-B values were 1.09 (2.03 per cent), 1.59 (2.86 per cent), 1.59 (2.75 per cent), 1.59 (2.78 per cent) mg kg^{-1}, respectively, which were almost double the available boron content of the soil. Keren and Bingham (1985) [16, 17] reported that RS-B represented only a small percentage 0.66 to 1.21 mg/ha of total soil boron. They further reported that RS-B was more readily available for plant uptake which was adsorbed by soil components. Datta *et al.* (1994) [5] reported that RS–B fraction ranged from 0.14 to 2.09 mg kg^{-1} with a mean value of 0.69 mg kg^{-1} of the acid sedentary soils of Chotanagpur region. Similar findings were also reported by Moafpouryan *et al*. (2004) [21]. Diana *et al.* (2006) [6] reported that RS–B fraction ranged from 0.91 to 1.79 mg kg^{-1} in soil of Lazio region in Italy. The RS-B fraction of Inceptisols of Morigaon constituted 2.60 per cent of the total soil boron (combination of all fractions as reported by Hou *et al.*, 1996) [11] in all the cropping systems. Working on soils of New Zealand Khan (2012) [18] found that the RS-B fraction constituted between 0.05 per cent to 4 per cent of the total soil boron. In *rice-rice* and *rice-rapeseed* cropping systems, RS-B showed a positive correlationship between organic carbon and Res-B content of the soil. In *rice-vegetable* and *vegetable-vegetable* cropping systems, RS-B was found to be correlated with organic carbon, Org-B and Res-B (Keren and Bingham, 1985) [16, 17], where organic carbon status was relatively higher. Organic matter plays an important role in controlling boron availability in soil. Higher organic carbon might have influenced RS-B content of the soil as well as Org-B of the soils in the above two cropping systems.

The value of SA–B fraction extracted by 0.05 M KH_2PO_4 varied from 1.30 to 2.24 mg kg^{-1} with a mean value of 1.84 (3.28 per cent) mg kg^{-1} under all the cropping systems. In *rice-rice*, *rice-rapeseed*, *rice-vegetable* and *vegetable-vegetable* cropping systems, SA-B of the soils fraction ranged from 1.30 to 2.10 (3.29 per cent), 1.50 to 2.24 (3.33 per cent), 1.50 to 2.24 (3.22 per cent) and 1.50 to 2.24 (3.29 per cent) mg kg^{-1}, respectively. Gupta, *et al.* (1968) [9] reported that SA-B fraction constituted 4 to 8 per cent of total soil boron. However, Goldberg *et al.* (1993) [8] also reported that SA-B fraction ranged from 0.44 to 0.51 mg kg^{-1}. A positive correlationship between SA-B and Ox-B fraction was observed in *rice-rapeseed* cropping system which might be due to the fact that changes in Ox-B fraction of the soils might have influenced the SA-B fraction. The present result was in the conformity with the findings of Hou *et al.* (2008) [12].

The fraction of Ox-B extracted by acid NH_4-oxalate ranged from 9.50 to 18.90 mg kg^{-1} with a mean value of 14.45 (25.50 per cent) mg kg^{-1} in the soil of Morigaon. Goldberg and Glaubig (1985) conducted an experiment on California soil and observed that Ox-B fraction varied from 9.61 to 10.86 mg/kg with a mean value of 10.24 mg kg^{-1}. The Ox-B fraction under *rice-rice*, *rice-rapeseed*, *rice-vegetable* and *vegetable-vegetable* cropping systems were 13.31 (25.07 per cent), 13.86 (25.32 per cent), 14.59 (25.77 per cent), 14.27 (25.87 per cent) mg kg^{-1}, respectively, which was in conformity with the findings of Diana *et al.* (2006) [6]. Gupta *et al.* (1968) [9] and Keren *et al.* (1985) [16, 17] also reported that Ox-B fraction was 16 and 57 per cent of total soil boron, respectively. In *rice-rice* and *rice-rapeseed* and *rice-vegetable* cropping systems, Ox-B fractions were positively correlated with Org-B fraction of the soil.

The mean value of Org–B fractions of the soils extracted by 0.02 M HNO_3 were 13.78 (24.96 per cent), 14.37 (24.97 per cent), 14.59 (25.07 per cent), 14.47 (24.89 per cent) mg kg^{-1} in *rice-rice*, *rice-rapeseed*, *rice-vegetable* and *vegetable-vegetable* cropping systems. In all the cropping systems, Org–B fractions of the soils ranged from 10.05 to 17.50 with a mean value of 14.36 (24.97 per cent) mg kg^{-1}**,** respectively. In the pioneering work on chemical fractionation of sol boron, Hou *et al.* (1994) [12] reported that Org-B fraction ranged from 5.44 to 6.98 mg kg^{-1} in Canadian soils. From the correlation study it was further found that Org–B fraction had a positive relationship with organic carbon and pH of soil. The results were in conformity with the findings of Diana (2006) [6]. Org-B fraction of the soil in all the cropping systems was positively correlated with organic carbon content of the soil. It is a well-established fact that organic carbon content of the soil largely control in organic fractions of all the nutrients. Hence the positive relationship between Ox-B and Org-B could be justified. Hou *et al.* (2008) [12] found that a positive relationship between Org-B and organic carbon content of the soil.

The Res–B fraction extracted by HF ranged from 18.75 to 31.20 mg kg^{-1} with a mean value of 23.90 (42.71 per cent) mg kg^{-1}. Under *rice-rice*, *rice-rapeseed*, *rice-vegetable* and *vegetable-vegetable* cropping systems, the mean values of Res-B were 23.53 (44.01 per cent), 23.33 (42.01 per cent), 24.16 (41.86 per cent), 24.57 (42.99 per cent) mg kg^{-1}, respectively. Xue *et al*. (2001) [35] reported that Res-B fraction ranged from 7.00 to 39.90 mg kg^{-1}. Olykan *et al.* (2008) [24] observed that 24 to 44 per cent of residual boron was held in the top 0-20 cm soil depth at the Balmoral forest in Canterbury, New Zealand. In *rice-rapeseed*, *rice-vegetable* and *vegetable-vegetable* cropping systems, Res-B showed positively correlated with RS-B content of the soil in all the cropping systems.

In addition to individual correlationship study under different cropping systems total correlation coefficient analysis was also conducted taking all the soil samples (100) as a whole. Data revealed that RS-B fraction showed positive correlationship with pH, organic carbon, clay, Org-B and Res-B fraction of the soil. Hou *et al.* (2008) [12] also observed that RS-B had a positively correlation with pH. The SA-B fraction showed a positively relationship with Ox-B fraction of the soil due to the fact that changes in Ox-B fraction of the soils might have influenced the SA-B fraction of the soil. The findings were in the conformity with the results of Evans and Sparks (1983). The Ox-B had a positive correlation with Org-B fraction of the soil and in turn Org-B fraction of the soil was positively correlated with pH, organic carbon, RS-B and Ox-B fraction. Org–B fraction had a positive relationship with organic carbon and pH of soil which was in conformity with the findings of Diana (2006) [6]. Res-B fraction showed positive correlationship with organic carbon of the soil. On the other hand, RS-B also showed a positive relationship with organic carbon. So, a positive relation between Res-B and RS-B could be justified.

A perusal of “r” values revealed that RS-B was positively correlated with pH of the soil but no correlation was observed while individual cropping system was considered. That might be due to the fact that individual cropping systems were that pH of individual cropping systems were within a narrow range and reflected no variability. When all the soils of the cropping systems was taken into considered, pH variation become pertinent and so a relationship was observed. Working on acid soils (pH < 7) of America, Berger and Troug (1945) [1] observed a positive correlation with pH. Similarly, Sharma and Chaudhary (2007) [29] also reported that a direct relationship of available boron with pH. SA-B was found to be positive correlation with Ox-B, but among the cropping systems only in *rice-rapeseed*, SA-B fraction was found to be positive correlated with Ox-B fraction. Org-B was positively correlated with RS-B, Ox-B and organic carbon, but no such relationship was observed in *rice-rice* and *rice-rapeseed* systems. Res-B content revealed a positive relationship with organic carbon while no relationship was *rice-rice* and rice vegetable cropping systems.

Table 2: Simple correlation between physico-chemical properties and forms of boron in soils under different cropping systems

	pH	**OC**	**CEC**	**SAND**	**SILT**	**CLAY**	**RS-B**	**SA-B**	**Ox-B**	**Org-B**	**Res-B**
pH	-	0.235*	0.092	0.152	-0.125	-0.109	0.247*	0.052	0.017	0.217*	0.181
OC		-	0.198*	0.093	-0.125	0.005	0.465**	-0.026	0.189	0.694**	0.338**
CEC			-	-0.022	-0.014	0.061	0.101	0.002	0.026	0.111	0.169
SAND				-	-0.842*	-0.681*	-0.083	-0.166	-0.203	-0.035	0.156
SILT					-	0.180	-0.038	0.190	0.134	-0.058	-0.139
CLAY						-	0.208*	0.045	0.194	0.150	-0.094
RS							-	0.126	0.154	0.476**	0.346**
SA								-	0.203**	0.145	-0.040
OB									-	0.385**	0.149
Org-B										-	0.169
Res-B											-

* Significant at 5% level

** Significant at 1% level

Summary and Conclusion

An investigation on the “Forms of boron under different cropping systems in soils of Morigaon district of Assam” representing Inceptisols of the district was carried out at Assam Agricultural University, Jorhat during 2011-2013. Four dominant cropping systems of Morigaon district were selected and studied for determine the forms of boron in soils of Morigaon district and its relation to soil properties under different cropping systems. Simple correlation was carried out between soil physico-chemical properties and forms of boron. The results of the study are summarized below:

- The soil texture varied from sandy loam to silty clay loam in texture and soils were strongly acidic to near neutral (4.17 to 6.94) in reaction with organic carbon content ranged from medium to high (0.51 to 1.14 per cent). The soils were low in CEC with magnitude ranged from 5.50 to 7.70 [cmol (p^+) kg^{-1}] and EC ranged from 0.01to 0.06 dS m^{-1} which were very low indicating non saline nature of the soils.
- The available nitrogen and phosphorus content of the soil ranged from low to medium (219.52 to 533.12 kg/ha), (21.54 to 57.96 kg/ha) and available potassium status were low to high (104.36 to 419.46 kg/ha).
- Different forms of boron extracted followed the order of: Res–B > Ox–B > Org–B > SA–B > RS–B.
- The percentage distribution of different forms of boron in Inceptisols of Morigaon district were also in the same order as: 42.71% > 25.50% > 24.97% > 3.28% > 2.60% of the total.
- RS-B fraction was positively correlated with organic carbon and Org-B of the soil under *rice-rice* and *rice-rapeseed* cropping system. It also showed a positive correlationship with organic carbon, Org-B and Res-B fraction of the soil in *rice-vegetable* and *vegetable-vegetable* cropping system.

- The SA-B fraction showed a positive relationship with Ox-B fraction of the soil in *rice-rapeseed* cropping system.
- The Ox-B fraction had a positive correlation with Org-B fraction of the soil in *rice-rice* and *rice-rapeseed* and *rice-vegetable* cropping systems.
- Org-B fraction of the soil in all the cropping systems was positively correlated with organic carbon, Ox-B and Org-B fraction of the soil.
- Res-B fraction showed positive correlationship with RS-B fraction of the soil in *rice-rapeseed, rice-vegetable* and *vegetable-vegetable* cropping systems.
- Intercorrelation study of soil parameters and forms of boron in Inceptisols of the district differed in some cases when interrelationship of individual cropping systems were compared.

References

1. Berger KC, Truog E. Boron availability in relation to soil reaction and organic matter content. Soil Sci. Soc. Am. Proc. 1945; 10:113-116.
2. Borkakati K, Takkar PN. Forms of boron in acid alluvial and lateritic soils in relation to ecosystem and rainfall distribution. In International Conference on Managing Resources for Sustainable Agricultural Production in the 21st century. Crops Prog. Fmg. 2000; 21:13-22.
3. Bray RH, Kurtz LT. Determination of total organic and available forms of phosphorus in soils. Soil Sci. 1945; 59:39-46.
4. Chhabra G, Srivastava PC, Ghosh D, Agnihotri AK. Distribution of available micronutrient cations as related to soil properties in different soil zones of Gola-Kosi interbasin. Crop Res. 1996; 11(3):296-303.
5. Datta SP, Kumar A, Singh RP, Singh KP, Sarkar AK. Critical limit of available boron for soybean in acid sedentary soils of Chotanagpur region. J Ind. Soc. Soil. Sci. 1994; 42(1):93-96.
6. Diana G. Boron in the soil, from deficit to toxicity. Inform. Agrario. 2006; 62:54-58.
7. Evans CM, Sparks DL. On the chemistry and mineralogy of boron in pure and mixed systems: a review. Com. Soil Sci. Plant Anal. 1983; 14(19):827-846.
8. Goldberg S. Chemistry and mineralogy of boron in soils. In: Boron and its Role in Crop Production. Ed. U.C. Gupta. CRC Press, Boca Raton, USA, 1993, 3-44.
9. Gupta UC. Relationship of total and hot water soluble boron and fixation of added boron to properties of podzol soils. Soil Sci. Soc. Am. J 1968; 32:45-48.
10. Gupta UC, Jame YW, Campbell CA, Leyshon AJ, Nicholaichuk W. Boron toxicity and deficiency: a review. Can. J Soil Sci. 1985; 65**(**3):381-409.
11. Hou J, Spier GA, Evans LJ. Chemical fraction of soil Boron: Method development. Canadian J Soil Sci. 1996; **76**:485-490.
12. Hou LJ, Evans LJ, Spiers GA. Boron fractionation in soils. Commun. Soil Sci. Pl. Anal. 1994; 25:1841-1853.
13. Hou LJ, Evans LJ, Spiers GA. Boron fractionation in soils. Commun. Soil Sci. Pl. Anal. 2008; 25:1841-1853.
14. Jackson ML. In soil chemical analysis. Prentice Hall of India. Pvt. Ltd., New Delhi, 1973.
15. Jin JY, Martens DC, Zelazny LW. Distribution and plant availability of soil boron fractions. Soil Sci. Soc. Am. J 1987; 51:1228-1231.
16. Keren R, Bingham FT. Boron in waters, soils and plants. Adv. Soil Sci. 1985; 1:229-276.
17. Keren R, Bingham FT, Rhoades JD. Plant uptake of boron as affected by boron distribution between liquid and solid phases in soil. Soil Sci. Soc. Am. J 1985; 49:297-302.
18. Khan RU. Boron dynamics and availability in *Pinus ratiata* plantaion. Institute of Natural Resource, College of Sciences Massey University, Palmerston North, New Zealand, 2012.
19. Khattak JK, Nazif S. Boron status of Peshawer valley soils. Pakisthan J Agric. Res. 1983; 4(4).
20. Mathur R, Sudan P. Relationship and distribution of various forms of boron with different physico-chemical properties of soil in bikaner district. J Chem. Pharm. Res. 2011; 3(3):290-294.
21. Moafpouryan GR, Shukla LM. Forms of boron in Inceptisols of Delhi and their relationship with soil characteristics and sunflower plant parameters. J Ind. Soc. Soil. Sci. 2004; 52(1):109-111.
22. Nayar VK. Micronutrient management for sustainable intensive agriculture. J Ind. Soc. Soil Sci. 1999; 47(4):666-680.
23. Nazif W, Perveen S, Saleem I. Status of micronutrients in soils of district bhimber (Azad Jammu and Kashmir). J Agric Bio. Sci. 2006; 1(2):1990-6145.
24. Olykan ST, Xue JM, Clinton PW, Skinner MF, Graham DJ, Leckie AC. Effect of boron fertilizer, weed control and geonotype and foliar nutrients and tree growth of juvenile *pinus radiata* at two contrasting sites in New Zealand. Forest Ecol. Mgnt. 2008; 255:1196-1209.
25. Oyinlolaa EY, Chude VO. Status of available micronutrients of the basement complex rock – derived alfisols in Northern Nigeria. Savanna Trop. Subtrop. Agroecosys. 2010; 12:229-237.
26. Rashid A, Yasin M, Ashraf M, Mann RA. Boron deficiency in calcareous soils reduces rice yield and impairs grain quality. Intern. Rice Res. 2004; 29:58-60.
27. Reisenauer HM, Walsh LM, Hoeft RF. Testing soils for sulfer, boron, molybdenum and chlorine. In ‘soil testing and plant analysis’ (Eds L.M. Walsh, J.D. Beaton) Soil Sci. Soc. Amer. J 1995, 173-200.
28. Sharma CP. Plant Micronutrients. Science Publishers, Enfield, USA, 2006.
29. Sharma JC, Chaudhary SK. Vertical distribution of micronutrient cations in relation to soil characteristics in lower Shiwaliks of Solan district in North-West Himalayas. J Indian Soc. Soil Sci. 2007; 55(1):40-44.
30. Shorrocks VM. The occurrence and correction of boron deficiency. Plant Soil. 1997; 193:121-148.
31. Spouncer LR, Nable RO, Cartwright B. A procedure for the determination of soluble boron in soils ranging widly in boron concentration, sodicity and pH. Commun. Soil Sci. Plant Anal. 1992; 23:441- 453.
32. Subbaiah BV, Asija GC. A Rapid Procedure for Determination of Available Nitrogen in Soils. Curr. Sci. 1956; 25:259-260.
33. Warington K. The effect of boric and borax on the broad bean and certain other plants. Ann. Bot. 1923; 37:629-672.
34. Wilson CM, Lovvorn RL, Woodhouse WW. Movement and accumulation of water soluble boron within the soil profile. Agron. J 1951; 43:363-367.
35. Xue JM, Wang K, Bell RW, Yang YA, Huang LB. Division S-4-Soil fertility and plant nutrition: Soil boron fractions and their relationship to soil properties. Soil Sci. Soc. Amer. J 2001; 64:133-138.