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Studies on Boron Fractions with Different Physico-Chemical Properties of Cultivated Soils of Himachal Pradesh, India

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A B S T R A C T

Sorption of boron (B) an important phenomenon in soils regulates its supply for plant growth. However, there are many soil characteristics which influence B adsorption-desorption capacity. Therefore, 80 soil samples (0-0.15m depth) varying in mechanical soil separates (sand, silt and clay), soil pH, organic carbon (OC), cation exchange capacity (CEC) and clay content were collected from different districts of Himachal Pradesh and their B fractions and soil properties were determined. Soil pH (1:2.5), OC (g kg^{-1}), CEC (cmol (p^+) kg^{-1}), textural class of the soils in the range of 5.48-7.45, 5.3-23.5, 4.6-15.4 and sandy loam to sandy clay, respectively. Different B fractions *viz.* readily soluble, specifically adsorbed, oxide bound, organically bound, residual and total were characterized according to fractionation scheme and their contents varied in the range of 0.12-0.55, 0.21-0.62, 0.26-1.67, 0.32-2.34, 19.5-25.7 and 20.6-29.5 mg kg^{-1}, respectively. Residual B was the most dominant pool of soil B contributing about 90.3 per cent of total. The relative contribution of other fractions was in the order, organically bound B > oxide bound B > specifically adsorbed B > readily soluble B. Soil pH, OC and CEC were positively correlated with all boron fractions whereas oxide bound B was negatively correlated.The results emanating from the study revealed that with increase in boron concentration, the boron adsorption by soils increased. Higher CEC, clay and organic carbon content in fine textured soils favoured higher adsorption of boron.

Keywords

Boron fraction, Physical and Chemical properties.

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Introduction

It is estimated that by the year 2050, world human population will climb to 9.7 billion and India's population is projected to overtake that of China, will rise to 1.6 billion, from its current level of 1.23 billion. Skewed use of major fertilizer nutrients without micronutrients is a major concern for achieving the agricultural intensification required to feed the growing world population nutritious food. A challenge for agricultural scientists is to feed the world population with nourishing food. On the other hand, expectations for higher grain productivity in the past caused decreased content of micronutrients in grains. The issue of deficiency of micronutrients is related with food and nutritional security. Role of micronutrients in food production is well recognized and documented but their importance in nutritional security and human health is increasing in current era. Boron (B) is one of the important micronutrient required for balanced growth of plants. In India, the extent of boron deficiency was initially reported about 2% in the year 1980 (Katyal and Vlek, 1985) which has now increased to

18.3% (Shukla *et al.,* 2014). Boron deficiency has been widely found in highly calcareous soils of Bihar, Tamil Nadu, Eastern Uttar Pradesh and Saurashtra, sandy soils of Haryana and Rajasthan, hill and sub-mountaneous soils of north Himalayan and NEH states and in red and lateritic soils of Orissa, Karnataka, Andhra Pradesh and Kokan region. In Himachal Pradesh, the extent of B deficiency has been found to be 18 to 50% across different districts.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. Correction of soil acidity by liming also retards B availability due to its adsorption on freshly precipitated Al and Fe hydroxides (Tsadilas and Kassioti, 2005). Continuous neglect of B replenishment over the years led to emergence of B deficiency across the soils and crops in India, and widespread deficiencies are now noticed in the areas that were generally considered rich in B. Recent estimates suggested B deficiency in one-third of over 40 thousand soil samples analysed (Shukla *et al.,* 2012). Most of the research on soil B in India remained confined to the determination of hot water soluble B (Moafpouryan and Shukla, 2002; Sarkar *et al.,* 2008), with only sporadic attempts of B fractionation (Datta *et al.,* 2002; Chaudhary and Shukla, 2004).

Boron is unique, not only in its chemical properties, but also in its roles in biology. Since the discovery of boron as an essential plant nutrient, the importance of this element as an agricultural chemical has grown very rapidly and its availability in soil and irrigation water is an important determinant of agricultural production. Boron plays a major role in translocation of sugars, formation and maintenance of cell wall and cell membrane integrity. Boron deficiency is the most common and widespread problem which impairs plant growth and reduces yield. Normal healthy plant growth requires a continuous supply of B, once it is taken up and used in the plant; it is not Trans located from old to new tissue. That is why, deficiency symptoms starts with the youngest growing tissues. Therefore, adequate B supply is necessary for obtaining high yields and good quality of agricultural crops. The present investigation therefore, aimed at sorption studies on boron fraction with different physico-chemical properties of cultivated soils of Himachal Pradesh.

Materials and Methods

Himachal Pradesh is predominantly a mountainous state located in North – West India. The state has highly dissected mountain ranges interspersed with deep gorges and valleys. It is also characterized with diverse climate that varies from semi tropical in lower hills, to semi arctic in the cold deserts areas of Spiti and Kinnaur. Altitude ranges from 350 meters to 6975 meters above mean sea level and is situated between 30°22′40″N to 33°12′40″ N latitudes and 75°45′55″ E to 79°04′20″ E longitudes. The state has different kinds of soils due to variations in climate, parent material, vegetation and topography etc. and different textured soils have different effect on boron sorption behaviour. Owing to these variations, soil samples from almost all the agro-climatic situations across the state have been used for accomplishing the present study. One hundred ten soil samples (0-0.15 m depth) were collected randomly from different locations (Figure 1) across different districts of Himachal Pradesh and used in the present study. The collected soil samples were separately air dried, ground and passed through 2 mm size sieve for laboratory analysis. Particle size distribution was done by the standard Bouyoucos hydrometer method (Day, 1965). Soil pH was determined by glass electrode with calomel as standard (Jakson, 1973). Organic carbon was estimated by wet digestion method of Walkey and Black (1934). The cation exchange capacity was determined by leaching the soil with 1N NH_4OAC and subsequently displacing the adsorbed NH_4following the methods of Schollenberger and Simon (1945). The soils samples were extracted for available B by the method of Wear (1965). Activated charcoal was used so as to obtain colourless extract. Boron was estimated in clear filtrate colorimetrically using azomethine–H-method (Wolf, 1971).

Results and Discussion

Physical characteristic

Mechanical analysis

The data regarding soil separates from different locations have been given in table 1. The soils varied quite appreciably with respect to different soil separates *i.e.* sand, silt and clay contents. Sand, silt and clay contents in the selected soils varied from 19.3-74.6, 14.6-43.6and5.8-36.2 per cent. About 88 per cent samples had more than 40 per cent sand whereas, 34 per cent samples had more than 60 per cent sand. About 60 per cent samples had silt content either equal to or lower than 25 per cent. Around 61 per cent samples recorded less than 25 per cent clay content. On the basis of relative proportion of different soil separates, the textural classes of the soils were determined. The texture varied from sandy loam to sandy clay. Forty nine per cent samples were sandy loam, 9 per cent were loam, 36 per cent samples were sandy clay loam and clay loam in texture and remaining 6 per cent were sandy clay in texture. Such variations in soil texture and separates could very well be explained due to the development of these soils under different climatic conditions, vegetation, topography and having varied parent materials.

Chemical characteristics

Soil pH, organic carbon and cation exchange capacity

The data presented in table 1 revealed that soils under study possessed wide variations in soil pH, organic carbon (OC) and cation exchange capacity (CEC). It ranged from 5.48-7.45, 5.30- 23.5 g kg^{-1} and 4.60-15.4 cmol (p^+) kg^{-1} with a mean value of 6.55 ± 0.46,11.4 ± 4.01 g kg^{-1} and 10.5 ± 2.67 cmol (p^+) kg^{-1}. Around 14 per cent soils were acidic in nature (pH<6.0), 67 per cent samples had pH between 6.0 and 7.0 and 19 per cent of soil samples possessed alkaline soil reaction (pH>7.0). A cursory look at data revealed that 60 per cent of the soil samples were high in organic carbon and 40 per cent samples were medium. Overall 49 per cent of samples had organic carbon <10.8 g kg^{-1}. Similar results had been reported by Sharma *et al.,* (1996) and Minhas *et al.,* (1997).The wide variation in CEC across different locations was due to differences in soil texture and organic carbon content observed in the current study. Another reason for this variation might be varied $CaCO_3$ content in the soils due to sedimentary parent material (Sharma and Kanwar, 2010). The higher CEC in the soils having higher organic matter were also reported by Mahajan *et al.,* (2007).

Boron fractions

Data pertaining to different fractions of boron have been presented in table 2. A close look at the data embodied in table 2 revealed that readily soluble boron ranged between 0.12 and 0.55 mg kg^{-1} with an average value of 0.30 ± 0.12 mg kg^{-1} which is 1.16 per cent of total boron. Similar results have also been reported by other researchers (Chaudhary and Shukla, 2003; Diana and Beni, 2006). The data on specifically adsorbed boron indicated that the values ranged from 0.21 to 0.62 mg kg^{-1} with a mean of 0.42 ± 0.12 mg kg^{-1}. Specifically adsorbed B represents that fraction of B which is specifically adsorbed onto clay surfaces or associated with organic matter in soil (Jin *et al.*, 1987) and it is just a small component of total B. The overall relative proportion of this fraction worked out to be just 1.6 per cent of total B. This is in agreement with the findings of other workers (Wojcik, 2000; Xu *et al.*, 2001). Oxide bound boron varied from 0.26 to 1.67 mg kg^{-1} with a mean value of 0.63 ± 0.27 mg kg^{-1}, comprised 2.4 per cent of total boron (Table 2). This fraction did not follow a regular pattern of increase or decrease from coarse textured to fine textured soils, because the amount of oxide bound fraction mainly depended upon presence or absence of iron or aluminium oxides and hydroxides as well as organic matter. There will be more adsorption of carboxylic and phenolic groupson the exchange sites present on Al and Fe oxides and their hydroxides due to greater organic-matter content, rendering lesser sites for the adsorption of B species (Kaundal *et al.*, 2014). The organically bound boron ranged between 0.32 and 2.34 mg kg^{-1} with an average value of 1.16 ± 0.46mg kg^{-1} (Table 2). This fraction constituted 4.5 per cent of total boron. Such a high proportion of this fraction in soil may be ascribed to low-temperature conditions in Himachal Pradesh, restricting mineralization of organic matter and release of adsorbed boron. Organic carbon content in soils has been reported as the contributor for this fraction (Hou *et al.*, 1994; Chaudhary and Shukla, 2003). Residual B was the most dominant pool of B, contributing about 90.3 per cent towards the total B. Many workers have reported greater proportion of residual B fraction (more than 90%), irrespective of soil and climatic conditions (Hou *et al.*, 1994; Xu *et al.*, 2001; Raza *et al.*, 2002; Chaudhary and Shukla, 2003). The amount of residual boron varied as 19.5 to 25.7 mg kg^{-1} with a mean value of 23.3 ± 1.39 mg kg^{-1}.

Fig.1 Locations of the soil samples

Table.1 Soil physio-chemical properties of mechanical separates (sand, silt, clay) and Soil pH (1:2.5), organic carbon (OC) (g kg^{-1}) and cation exchange capacity (CEC) (cmol (p^{+}) kg^{-1})

S.N.	Districts		Physical			Chemical		
			Sand	Silt	Clay	pH	OC	CEC
1	Shimla	Range	36.6-72.2	18.4-29.1	6.9-33.9	6.32-6.88	9.6-15	6.2-14.3
		Mean	50.38	24.33	22.48	6.54	12.00	11.20
		SD(±)	16.96	4.46	12.63	0.24	2.28	3.59
2	Hamirpur	Range	33.0-69.9	16.5-31.2	6.1-34.7	6.01-7.21	8.1-20.1	7.3-15
		Mean	50.52	23.12	24.67	6.84	13.60	12.23
		SD(±)	15.62	5.39	12.20	0.43	4.30	2.82
3	Kangra	Range	19.3-65.5	21.5-43.6	10.1-33.4	5.48-6.6	6.9-12.9	8.4-13.7
		Mean	47.59	29.77	20.90	5.98	9.33	10.71
		SD(±)	17.60	8.21	9.91	0.36	2.08	2.17
4	Mandi	Range	32.7-66.5	20.5-40.4	10.7-34.8	5.71-7.45	6.8-16.8	9.3-13.1
		Mean	48.80	28.76	20.94	6.49	12.10	10.89
		SD(±)	10.01	6.78	8.43	0.61	3.67	1.56
5	Una	Range	41.2-66.3	17.2-30.8	9.4-34.8	5.89-7.14	5.5-12.1	4.8-12.4
		Mean	52.81	23.44	22.03	6.52	8.72	9.28
		SD(±)	10.20	5.11	9.82	0.37	2.23	2.77
6	Chamba	Range	41.2-66.3	17.2-30.8	9.4-34.8	5.82-7.1	7.2-16.2	7.8-15.2
		Mean	52.81	23.44	22.03	6.51	10.90	11.09
		SD(±)	10.20	5.11	9.82	0.53	3.48	2.92
7	Kullu	Range	46.2-60.1	17.6-32.1	15.3-30.2	6.34-6.98	9.9-21.4	9.9-14.9
		Mean	51.43	23.07	23.53	6.67	16.05	11.87
		SD(±)	5.34	5.00	5.68	0.22	3.83	1.79
8	Kinnaur	Range	38.7-74.6	14.6-36.1	5.8-33.8	6.01-7.38	5.8-19.7	4.6-13.9
		Mean	56.71	23.25	18.35	6.76	11.80	10.08
		SD(±)	15.11	6.58	9.89	0.51	4.65	3.39
9	Solan	Range	36.5-72.2	18.8-34.0	7.6-36.2	5.86-6.82	7.6-12.9	7.1-13.6
		Mean	46.79	28.39	23.41	6.48	10.49	10.73
		SD(±)	11.74	5.35	9.52	0.36	1.66	2.11
10	Bilaspur	Range	30.5-70.8	17.2-23.5	10.3-34.9	6.02-7.03	7.6-23.5	7.5-15.4
		Mean	54.63	21.73	21.25	6.59	13.29	10.53
		SD(±)	13.78	5.59	10.80	0.34	5.37	3.16
11	Lahul&Spiti	Range	42.6-73.2	18.4-34.6	6.3-28.8	5.98-7.07	5.3-19.8	6.3-28.8
		Mean	60.61	23.16	14.24	6.64	9.57	8.46
		SD(±)	11.77	5.57	8.11	0.46	4.26	2.28
	Total Samples	**Range**	**19.3-74.6**	**14.6-43.6**	**5.8-36.2**	**5.48-7.45**	**5.3-23.5**	**4.6-15.4**
		Mean	**53.2**	**24.7**	**20.3**	**6.55**	**11.4**	**10.5**
		SD(±)	**13.0**	**6.13**	**9.54**	**0.46**	**4.01**	**2.67**

Table.2 Boron fractions (mg kg^{-1}) of soils in mechanical separates

Category		Readily soluble B	Specifically adsorbed B	Oxide bound B	Organically bound B	Residual B	Total B
Coarse textured (n = 39)	**Range**	0.12-0.38	0.21-0.52	0.27-1.36	0.32-1.68	19.5-23.9	20.6-26.7
	Mean	0.21	0.33	0.66	0.91	22.3	24.4
	SD(±)	0.08	0.09	0.27	0.30	1.16	1.57
Medium textured (n = 36)	**Range**	0.14-0.48	0.25-0.59	0.26-1.67	0.32-2.34	22.7-25.7	24.2-29.5
	Mean	0.37	0.49	0.61	1.35	24.1	26.9
	SD(±)	0.09	0.08	0.28	0.45	0.82	1.30
Fine textured (n = 5)	**Range**	0.49-0.55	0.60-0.62	0.41-0.70	1.18-2.21	24.9-25.3	27.9-29.2
	Mean	0.52	0.61	0.60	1.78	25.1	28.7
	SD(±)	0.02	0.01	0.13	0.44	0.15	0.60
Overall	**Range**	0.12-0.55	0.21-0.62	0.26-1.67	0.32-2.34	19.5-25.7	20.6-29.5
	Mean	0.30	0.42	0.63	1.16	23.3	25.8
	SD(±)	0.12	0.12	0.27	0.46	1.39	1.99

Table.3 Relationship of boron fractions with mechanical separates and chemical properties

Soil Properties	Physical			Chemical		
	Sand	**Silt**	**Clay**	**pH**	**OC**	**CEC**
Readily soluble B	-0.74**	0.21	0.88**	0.43**	0.71**	0.95**
Specifically adsorbed B	-0.75**	0.25*	0.87**	0.40**	0.70**	0.95**
Oxide bound B	0.01	0.22*	-0.17	-0.82**	-0.20	-0.12
Organically bound B	-0.52**	0.09	0.65**	0.38**	0.97**	0.76**
Residual B	-0.79**	0.33**	0.86**	0.31**	0.73**	0.96**
Total B	-0.77**	0.31**	0.84**	0.25*	0.79**	0.95**

Table.4 Relationship among different boron fractions

	Readily soluble	Specifically adsorbed	Oxide bound	Organically bound	Residual	Total
Readily soluble	1.00					
Specifically adsorbed	0.98**	1.00				
Oxide bound	-0.29**	-0.28*	1.00			
Organically bound	0.77**	0.75**	-0.21	1.00		
Residual	0.88**	0.86**	-0.06	0.81**	1.00	
Total	0.87**	0.88**	0.01	0.86**	0.99**	1.00

It can be inferred that this fraction constituted highest fraction of boron in comparison to other fractions in all types of soils. The residual boron showed a variation in different textured soils. All the above fractions *i.e.* readily soluble, specifically adsorbed, oxide bound, organically bound and residual boron were summed up to get total B content of the soil. The total boron content varied from 20.6 to 29.5 mg kg^{-1} with an average value of 25.8 ± 1.99 mg kg^{-1}. The results are in agreement with the findings Hadwani *et al.,* (1989) who reported significant positive relationship between total and available boron fraction. Zerrari *et al.,* (1999) reported that the adsorbed B content of the soils was 0.87% of the total B fractions.

Relationship of boron fractions with mechanical separates and chemical properties

The correlation of different boron fractions with mechanical separates (*i.e.* sand, silt and clay) have been presented in the table 3 and it can be seen from the table that sand content had significant and negative relationship with all the boron fractions except oxide bound (r = 0.01).The silt content had a significant and positive correlation with specifically adsorbed boron (r = 0.25*), oxide bound (r = 0.22*), residual boron (r = 0.33**) and total boron (r = 0.31**) and positive but non- significant relationship with readily soluble boron (r = 0.21) and organically bound boron (r = 0.09). Clay content showed significantly positive correlation with all boron fractions *viz.* readily soluble (r = 0.88**), specifically adsorbed (r = 0.87**), organically bound (r = 0.65**), residual (r = 0.86**) and total boron (r = 0.84**), except oxide bound boron (r = -0.17). Anitha *et al.,* (2013) also found positive correlation of clay with boron fractions. Correlation coefficients of boron fractions with soil properties *viz.* soil pH, organic carbon and CEC were worked out and reported in table 3. Soil pH showed significantly positive correlation with all boron fractions except oxide bound boron (r = -0.82**). The negative relationshipprobably might bedue to decrease in sesquioxide contents present with an increase in soil pH (Dey *et al.,* 2015). Organic carbon was highly correlated with readily soluble (r = 0.71**), specifically adsorbed (r = 0.70**), organically bound B (r = 0.97**). These three soil B fractions mostly contributed to B availability in the soil and can be termed as labile B pools (Table 4). Significant correlation of these fractions with organic carbon indicated that soil organic matter is an important parameter contributing towards availability of B in soils (Mathur and Sudan, 2011). Organic carbon also had a significant and positive correlation with residual (r = 0.73**) and total boron (r = 0.79**). This positive relationship may be explained as that organic carbon is source of boron due to which there is not much transformation from the residual to other pools, resulting higher residual boron in the soils having higher organic matter. Oxide bound boron was negatively and non- significantly related with organic carbon (r = -0.20). This may be due to adsorption of carboxylic and phenolic groups on the exchange sites on Al and Fe oxides and their hydroxides, due to greater organic-matter content, rendering fewer sites for the adsorption of B species. Cation exchange capacity also followed the same pattern as that of soil pH and OC and possessed significantly positive correlation with all the boron fractions except oxide bound boron (r = -0.12). These results were in line with the findings of Kaundal *et al.,* (2014) and Dey *et al.,* (2015).

Relationship among different boron fractions

All the boron fractions except oxide bound boron were significantly and positively correlated with each other. Similar findings have been stated by various other researchers (Datta *et al.,* 2002 and Sarkar *et al.,* 2008). The greatest significant correlation was observed between residual boron and total boron (r = 0.99**) followed by relationship between readily soluble and specifically adsorbed boron (r = 0.98**). The greatest correlation between residual B and total B might be due to the dominant role played by residual B fraction among all the extracted fractions as it contributed to the tune of 90.3 %. The negative correlation between oxide bound and other fractions can be due to reason that these fractions show positive correlation with soil pH, OC and CEC while oxide bound fraction is negatively associated with these properties.

The cultivated soils of Himachal Pradesh are variable in texture, acidic in reaction and have medium to high organic matter, and CEC in the soils are generally moderate. Boron is an important micronutrient in the soil because of numerous important functions it performs in the metabolism, growth and development of crops. Residual fraction of B was the dominant fraction, constituting about 90.3% of total boron. The relative contribution of other fractions was in the order: organically bound B > oxide bound B > specifically adsorbed B > readily soluble B.

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