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Distribution of Different Fractions of Boron in Soils of Konkan Region of India

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The present study was conducted to assess the status of boron fractions in different soils of Konkan region. Surface soil samples were collected representing eight soil types, namely, lateritic, medium black, deep black, coarse shallow, coastal alluvial, coastal saline, reddish brown and acid sulphate soils located in different parts of Konkan region of Maharashtra. In general, the soils of the Konkan region of Maharashtra are acidic to neutral in reaction (pH 4.50 to 7.39) with low electrical conductivity values. The soils are fairly supplied with organic carbon (9.10 to 24.4 g kg^{-1}). The available nitrogen and phosphorus content is low to medium in all types of the soils. The available potassium content is variable and ranges from low to high. The mean values of readily soluble boron (RsB), specifically adsorbed boron (SaB), oxide bound boron (OxB), organically bound boron (OrB), residual boron (ReB) and total boron (TB) were 0.32, 2.30, 58.90, 5.49, 85.72 and 152.73 mg kg^{-1}, respectively. Most of the soils in Konkan region showed low to medium concentrations of readily soluble boron which is the plant available fraction of boron. The readily soluble boron ranged between 0.28 ppm to 0.34 ppm in different soils of the Konkan region of Maharashtra.

(***Key words:*** *Boron fractions, Konkan soil, Organically bound, Oxide bound, Readily soluble, Residual, Specifically adsorbed*)

Boron (B) is a nutrient element that plants require in trace amounts (Marschner, 1995) and plays many roles in plants like in cell wall formation and stabilization, lignification, xylem differentiation, imparting drought tolerance, pollen germination and pollen tube growth and facilitating transport of potassium (K) in guard cells as well as stomata opening. In humid regions, rainfall can cause excessive leaching of B, and fertilization is often required to avoid deficiency symptoms. Boron availability in soils is affected by several factors including parent material, texture, nature of clay minerals, pH, liming, organic matter content, sources of irrigation, interrelationship with other elements and environmental conditions like moderate to heavy rainfall, dry weather and high light intensity (Goldberg and Foster, 1991; Mengel and Kirkby, 2001; Moraghan and Mascagni 1991; Niaz *et al*., 2007; Takkar *et al*., 1989).

Boron deficiencies are more commonly observed in coarse textured acidic Inceptisols and Entisols, in soils containing high amounts of calcium carbonate or sesquioxides and also in soils having low organic matter content (Sarkar *et al*., 2008; Singh, 2001; Singh and Behera, 2011). In acid soils, soluble B occurs as non-ionised $B(OH)_3$, whereas formation of borate anion $[B(OH)_4]$ takes place with a rise in soil pH. Thus leaching of B primarily as $B(OH)_3$ under high precipitation regimes and adsorption of soluble boron on Al and Fe oxides (Goldberg and Glaubig, 1985) are the major causes of B deficiency in acid soils. On the other hand, adsorption of borate on clay particles (Keren and Mezuman, 1981; Sims and Bingham, 1968), calcium carbonates (Goldberg and Foster, 1991) and organic compound is responsible for B deficiency in over-limed, calcareous and neutral to alkaline soils. The range of soil solution B concentration for deficiency and toxicity in plants is relatively narrow and both deficient and toxic levels of B in the soil solution can occur during a single growing season (Goldberg, 1997).

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 to study the different fractions of B (Chaudhary and Shukla, 2004; Datta *et al*., 2002).

Knowledge of B fractions is fundamental to understand the chemistry of B in soils as it enables to know about binding forms, dynamics, plant availability and possible environmental impacts of B. The knowledge

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of elemental distribution of boron in different fractions and the effect of different chemical fertilizers and amendments on native soil boron are also essential for the proper management of soils. Boron in the soil is found in five different fractions *viz*. readily soluble (solution plus non-specifically adsorbed), specifically adsorbed, oxide bound, organically bound, residual or occluded B. The relative concentration of these fractions in a soil at a given time depends on soil properties like amount and nature of clay, pH, lime status, organic matter, and soil moisture and plant factors. Only few forms of B are available to plants and their determination is important for evaluating its availability to plants. The knowledge of B fractions is essential for understanding its chemistry and potential contribution to plant uptake. Most of the soils in Konkan region of Maharashtra are lateritic type. Besides there also other soil types in less extents *viz*., medium black soil, coastal saline soil, coastal alluvial soil, acid sulphate (*Morik*) soil, *Manat* soil, coarse grain soils as well as red brown soil in different parts of the region (Anonymous, 2008). Different workers have studied the various fractions of macronutrients in the soils of Konkan. The information related to the boron fractions in the soils of Konkan is scanty. Keeping above facts in view, the present study was carried out to assess the status of boron fractions in different soils of Konkan region.

MATERIALS AND METHODS

Soil sampling and processing

Sampling points were selected in eight representative areas of Konkan region. The details about the soil series, location and classification are given in Table 1. Twenty four soil samples (three from each soil type) were collected from 0-15 cm depths, using a stainless steel soil auger. Two composite soil samples were pooled into a bucket and mixed thoroughly to homogenize it. Then a sub sample of 500 g from each pooled soil sample was taken. Soil samples were air-dried, debris were removed and sieved (2 mm) before analysis.

Soil analysis

Physico-chemical properties

The soils were analysed for the physico-chemical properties following standard analytical methods. The bulk density (BD) of soil samples was determined using clod method and particle density (PD) of initial soil was determined by using pycnometer as described by Black (1965). The maximum water holding capacity (MWHC) of soil samples was determined by using Keen's boxes as described by Piper (1950). The pH of soil was determined in 1:2.5 soil: water suspension with the help of a Systronics - pH analyser having glass and calomel reference electrode with thermo probe while

Table 1. *Details about collected soil samples - soil types, location and classification*

Sl. No.	Soil type	Location	Classification
1	Lateritic soil	Farm of SSAC, College of Agriculture, Dapoli	Loamy- skeletal, mixed, isohypothermic, Typic Haplustepts
2	Medium black soil	Regional Agril. Research Station, Karjat, Dist. Raigad	Fine-loamy, mixed, isohypothermic, Typic Haplustepts
3	Deep black (*Manat*) soil	Krishi Vigyan Kendra, Roha, Dist. Raigad	Clayey-skeletal, mixed, isohypothermic, Typic Haplustepts
4	Coarse shallow soil	Farmer's field at Asud village, Tal. Dapoli, Dist. Ratnagiri	Loamy, mixed, isohypothermic, Lithic Ustorthents
5	Coastal alluvial soil	Farmer's field at Murud village, Tal. Dapoli, Dist. Ratnagiri	Loamy, mixed, isohypothermic, Lithic Ustorthents
6	Coastal saline soil	Kharland Research Station, Panvel, Dist. Raigad	Loamy, mixed, isohypothermic, Typic Haplustepts
7	Reddish brown soil	Farm of College of Agril., Saralgaon, Tal. Murbad, Dist. Thane	Loamy, mixed, isohypothermic, Lithic Ustorthents
8	Acid sulphate (*Morik*) soil	Farmer's field at Ubhadanda village, Tal. Vengurle, Dist. Sindhudurg	Fine, mixed, isohypothermic, Typic Haplustepts

the electrical conductivity of soil was determined with the help of conductivity meter in the same suspension. The organic carbon (OC) content was determined by Walkley and Black chromic acid wet oxidation method (Jackson, 1973).

Fractionation of boron

Determination of boron fractions was done using sequential extraction method described by Raza *et al.* (2002).

Readily soluble boron

5 g of soil samples were weighed into 50 ml polyethylene centrifuge tubes to which 10 ml of 0.01 M calcium chloride was added and the tubes were shaken at 25° C for 16 h (Hou *et al*., 1994 and 1996); after centrifuging at 10,000 rpm for 30 min, the suspension was filtered through Whatman no. 42 filter paper. Boron was determined in clear extracts using Azomethine-H (Bingham, 1982). Calcium chloride does not interfere with this colorimetric estimation of B as shown by Aitken *et al*. (1987) and Datta *et al*. (1998).

Specifically adsorbed boron

The residue from above was extracted with 10 ml of 0.05 M potassium dihydrogen phosphate by shaking for 1 h. The suspension was centrifuged and filtered as described previously. After centrifugation, B could be measured in the clear supernatant as described in the previous step because KH_2PO_4 was also not found to interfere with the estimation of B with Azomethine-H.

Oxide bound boron

The residue from the previous step was extracted with 20 ml of 0.2 M acidic ammonium oxalate, pH 3.25 (Hou *et al*., 1994, 1996; Jin *et al*., 1987; McLaren and Crawford, 1973) by shaking for 4 h (Hou *et al*., 1994, 1996). 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.

Elimination of colour by treating the extracts with NaOH and $HClO_4$

To remove the colour, a 14 ml aliquot of the extract was taken into a 50 ml teflon beaker and the weight of the beaker plus aliquot was noted. The content was then warmed on a hot plate and 2 ml of 5 N NaOH solution was added to completely precipitate the dissolved Fe as $Fe(OH)_3$. Jackson (1973) has also suggested a similar procedure to separate Fe and other metals in total elemental analysis of soil and rocks. The beaker with the aliquot was weighed again and the loss in weight was made up by adding distilled water. While doing so, the weight of the 2 ml 5 N NaOH was also taken into account. The suspension was filtered through Whatman no. 42 filter paper and thus Fe was separated. A 9 ml aliquot of the filtrate was taken into a 50 ml teflon beaker and 4 ml concentrated H_2SO_4 and 1 ml $HClO_4$ (60%) were added and heated on hot plate at 135± 5°C to destroy the organic matter. Heating the samples at temperature > 140°C led to B losses (Hou *et al*., 1994, 1996). Care was also taken not to allow the samples to dry because B losses have been reported under these conditions. When the volume was reduced to about 6 ml, $HClO_4$ was added in an increment of 0.5 ml until the solution became colourless and the volume reduced to 4 to 5 ml. The content was then transferred to a 15 ml graduated polyethylene tube and the final volume was made up to 6 ml. After centrifuging at 10,000 rpm for 15 min, B in the clear extracts was determined by the carmine method (Bingham, 1982).

Organically bound boron

The residue from the above was extracted by adding 3 ml of 0.02 M HNO_3 and 5 ml of 30% H_2O_2 at pH 2.0. The mixture was heated at 85°C in a water bath for 2 h with the occasional agitation. A second 3 ml aliquot of 30% H_2O_2 (at pH 2.0) was then added and the sample was heated again to 85°C for 3 h with intermittent agitation. After cooling, 5 ml of 3.2 M ammonium acetate in 20% HNO_3 was then added to the solution, which was then diluted to 20 ml with water, mechanically shaken for 30 min and separated by centrifugation.

Residual boron

The residue from the above was transferred to a PTFE beaker to which 5 ml of aqua regia and 5 ml of HF was added. The beaker was placed on a hotplate at 140°C and evaporated to a volume of 1-2 ml. Care was taken not to allow the digest solution to dry because B losses have been reported (Zarcinas and Cartwright, 1987). The procedure was repeated with further 5 ml of each acid. A solution of 10 ml of $AlCl_3$ was then added and the solution was warmed at 60°C in a water bath for approximately 5 minutes. The suspension was allowed to cool, transferred to a 50 ml polyethylene volumetric flask and made up to volume. The solution from the volumetric flask was filtered through a Whatman membrane filter paper and the filtrate was collected for B analysis.

Total boron

In case of total boron, its values were obtained by adding values of all the boron fractions.

Statistical analysis

The data have been subjected to appropriate method of statistical analysis as described by Panse and Sukhatme (1995). Interpretation of result was based on 'F' test. The comparison among means was made by calculating critical difference (CD) at 1% level of significance.

RESULTS AND DISCUSSION

Physiochemical properties of soils

The physiochemical properties of different soil types of the Konkan region are given in the Table 2. The bulk density of soils under study varied from 1.13 to 1.31 Mg m^{-3} and coastal alluvial soil recorded minimum bulk density *i.e.* 1.13 Mg m^{-3}. Similarly the coastal alluvial soils found along the river banks in the coastal areas of Konkan recorded highest particle density (3.08 Mg m^{-3}) and varied from 2.33 to 3.08 Mg m^{-3} in all types of the Konkan soils. On an average, the water holding capacity of the soils of Konkan varied from 45.38 to 56.66 per cent and medium black soil which is predominant in north Konkan region recorded maximum water holding capacity.

The soil pH varied from 4.50 to 7.39 in the Konkan region. The acid sulphate soils recorded the lowest pH *i.e.* 4.50. The acid sulphate soils are poorly drained with high content of pyrites, while the medium black soils of north Konkan region are highly argillaceous with fine texture and dark in colour, recorded pH of 7.39. The electrical conductivity (EC) varied from 0.08 to 1.11 dS m^{-1}. Most of the soils of Konkan region are susceptible for the leaching losses because of which the salt content is low except in coastal saline soils where the salt content is high due to sea water induced salinity. However, in our study the EC recorded was low in the coastal saline soils (1.11 dS m^{-1}) as the soil sampling was done in the month of August, during which the monsoon showers had washed out the salts in the soil. The Konkan region is blessed with full of biodiversity having deciduous types of forest cover, due to which the soils are quite rich in soil organic carbon as compared to rest of soils in Maharashtra. The average soil organic carbon content was 14.8 g kg^{-1} and varied from 7.50 to 24.4 g kg^{-1}.

Boron fractions

Data regarding boron fractions in different soils of Konkan are given in Table 3. The observed range of readily soluble B, specifically adsorbed B, oxide bound

Table 2. *Physico-chemical properties of different soil types of Konkan region*

Soil type	BD	PD	MWHC (%)	pH	EC (dS m^{-1})	OC (g kg^{-1})
	(Mg m^{-3})					
Lateritic soil	1.27	2.66	45.38	5.63	0.09	18.0
Medium black soil	1.27	2.33	56.66	7.39	0.23	9.10
Deep black/*Manat* soil	1.22	2.50	56.58	6.83	0.08	9.50
Coarse shallow soil	1.24	2.60	50.21	6.83	0.10	24.4
Coastal alluvial soil	1.13	3.08	56.00	5.90	0.19	23.7
Coastal saline soil	1.27	2.32	45.50	7.24	1.11	10.7
Reddish brown soil	1.14	2.73	46.14	6.03	0.13	15.5
Acid sulphate soil	1.31	2.33	41.16	4.50	0.10	7.50
Mean	1.23	2.57	49.70	6.29	0.25	14.8

Table 3. *Distribution of different boron fractions in soils of Konkan region*

Soil type	Boron fractions (mg kg^{-1})					
	RsB	SaB	OxB	OrB	ReB	TB
Lateritic soil	0.34	2.58	54.88	4.93	88.31	151.03
Medium black soil	0.28	2.18	56.99	5.21	83.38	148.04
Deep black/*Manat* soil	0.28	1.93	59.26	5.10	85.96	152.53
Coarse shallow soil	0.31	1.99	57.24	5.77	87.30	152.61
Coastal alluvial soil	0.34	2.49	57.07	6.72	81.03	147.65
Coastal saline soil	0.39	2.52	71.15	6.10	81.59	161.76
Reddish brown soil	0.34	2.38	59.68	5.15	89.32	156.87
Acid sulphate soil	0.31	2.35	54.96	4.93	88.82	151.37
Mean	0.32	2.30	58.90	5.49	85.72	152.73

RsB: Readily soluble boron; SaB: Specifically adsorbed boron; OxB: Oxide bound boron; OrB: Organically bound boron; ReB: Residual boron; TB: Total B

B, organically bound B, residual B and total B in the soils was 0.28 to 0.39, 1.93 to 2.58, 54.88 to 71.15, 4.93 to 6.72, 81.03 to 89.32 and 147.65 to 161.76 mg kg^{-1} with mean values of 0.32, 2.30, 58.90, 5.49, 85.72 and 152.73 mg kg^{-1} respectively.

Readily soluble B *i.e.* available boron content was found to be minimum in both medium black and deep black (*manat*) soils (0.28 mg kg^{-1}) and maximum in coastal saline soil (0.39 mg kg^{-1}). The average mean value of readily soluble B was 0.32 mg kg^{-1} in the soils of Konkan region. The available boron content in soils of Konkan were found to be low to medium.

Data on specifically adsorbed B revealed that, its content was maximum in lateritic soil (2.58 mg kg^{-1}) and minimum in deep black *manat* soil (1.93 mg kg^{-1}). While highest value of oxide bound B was recorded in coastal saline soil (71.15 mg kg^{-1}) and minimum in lateritic soil (54.88 mg kg^{-1}). In general it was observed that of the mean total boron content (152.73 mg kg^{-1}) in Konkan soils of Maharashtra, residual boron and oxide boron fractions relatively recorded the maximum contribution. The soils of Konkan are developed on basaltic parent material and higher amounts of Al and Fe oxides are present in them particularly they are high in lateritic soils (Kadrekar *et al.*, 1981). Some workers have reported that B retention by hydroxyl Al and Fe was absolutely pH reliant. It was accomplished that the hydroxyl ions in these solutions encouraged hydrolysis of the precipitate of hydroxyl-Al and -Fe and consequently B (as borate) is released from precipitate (Evans, 1987).

Amongst all the soils, organically bound B content was highest in coastal alluvial soil (6.72 mg kg^{-1}) and lowest in lateritic and acid sulphate soil (4.93 mg kg^{-1}). Hou *et al*. (1994) reported that the average readily soluble and specifically adsorbed B fractions accounted for less than 2% of total soil B and mean contents of extractable B were 2.3% associated with various oxides and hydroxides and 8.6% in organically bound forms.

Residual B contributed maximum in the total B content. Reddish brown soil (89.32 mg kg^{-1}) recorded maximum value of residual B and that of lowest value was recorded in coastal alluvial soil (81.03 mg kg^{-1}). Maximum total B was seen in coastal saline soil (161.76 mg kg^{-1}) while its minimum value was recorded in coastal alluvial soil (147.65 mg kg^{-1}). The highest amount of soil boron originated from residual form, generally ranged from 70 to 99% of total soil B (Raza *et al*., 2002; Tsadilas *et al*., 1994) but this fraction was not related to boron available for plant uptake.

Organically bound (Om-B), extracted by dilute HNO_3 and 30% H_2O_2 to degrade the organic material and to solubilize manganese dioxide (Hou et al., 1994), ranged from 5.44 to 6.98 mg B kg^{-1} soil (3.88-4.91% of total B). The adsorption of boron in soil is influenced by various soil components such as pH, clay minerals, Fe and Al oxides, organic matter, carbonates and tillage management that may change the content of extractable B, and transformation among different soil B fractions (Mandal *et al*., 1993; Marzadori *et al*., 1991; Yermiyahu et al., 1995)

The results from this study suggest that the concentrations of all the different fractions of boron in different soil types under study are found variable. Amongst all boron fractions, it found that the oxide bound boron and residual boron are the dominant forms in the soils of the Konkan region. In general, it was observed that readily soluble boron which has great importance in agriculture was found to be low to medium in all types of the soil. Hence, site specific boron management options need to be considered in these soils.

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REFERENCES

Aitken, R. L., Jeffrey, A. J. and Compton, B. L. (1987): Evaluation of selected extractants for boron in some Queensland soils. *Australian Journal of Soil Research* **25**: 265-273.

Anonymous, (2008). *Soil Series of Maharashtra*. NBSS & LUP, Nagpur, India. pp 7-77.

Bingham, F. T. (1982). Boron. In: *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*, Second edition, A. L. Page, R. H. Miller and D. R. Keeney (eds.), ASA and SSSA, Madison, WI, USA. pp 431-447.

Black. C. A. (1965). *Methods of Soil Analysis*, Part-I, American Society of Agronomy, Madison, Wisconsin, U. S. A.

Chaudhary, D. R. and Shukla, L. M. (2004). Boron forms and their relationships with characteristics of arid soils of Western Rajasthan. *Journal of the Indian Society of Soil Science* **52**: 197-199.

Datta, S. P., Bhadoria, P. B. S. and Kar, S. (1998). Availability of extractable boron in some acid soils of West Bengal, India. *Communications in Soil Science and Plant Analysis* **29**(15 & 16): 2285-2306.

Datta, S. P., Rattan, R. K., Kandregula Suribabu and Datta, S. C. (2002) Fractionation and colorimetric determination of boron in soils. *Journal of Plant Nutrition and Soil Science* **165**: 179-184.

Evans, L. J. (1987). Retention of boron by agricultural soil from Ontario. *Canadian Journal of Soil Science* **67**: 33-42.

Goldberg, S. (1997). Reactions of boron with soils. *Plant and Soil* **193**: 35-48.

Goldberg, S. and Foster, H. S. (1991). Boron sorption on calcareous soils and reference calcites. *Soil Science* **152**: 304-310.

Goldberg, S. and Glaubig, R. A. (1985). Boron adsorption on aluminium and iron oxide minerals. *Soil Science Society of America Journal* **49**: 1374-1379.

Hou, J., Evans, L. J. and Spiers, G. A. (1994). Boron fractionation in soils. *Communications in Soil Science and Plant Analysis* **25**: 9-10.

Hou, J., Evans, L. J. and Spiers, G. A. (1996). Chemical fractionation of soil boron: i. method development. *Canadian Journal of Soil Science* **76**: 485-491.

Jackson, M. L. (1973). *Soil Chemical Analysis*, Prentice Hall of India Pvt. Ltd., New Delhi, India. pp 134-182.

Jin. J., Martens, D. C. and Zelazny, L. W. (1987). Distribution and plant availability of soil boron fractions. *Soil Science Society of America Journal* **51**: 1228-1231.

Kadrekar, S. B., Chavan, A. S., Chavan, K. N., Sahu, R. K., Ingle, B.V. and Joshi, R. G. (1981). *Summary of Research on Coastal Saline Soils of Maharashtra. A brochure*, Dr. B. S. Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India.

Keren, R. and Mezuman, U. (1981). Boron adsorption by clay minerals using a phenomenological equation. *Clays and Clay Minerals* **29**: 198-204.

Mandal, B., Adhikari, T. K. and De, D. K. (1993). Effect of lime and organic matter application on the availability of added boron in acidic alluvial soils. *Communications in Soil Science and Plant Analysis* **24**: 15-16.

Marschner, H. (1995). *Mineral Nutrition of Higher Plants*, Second edition, Academic Press, Orlando, Florida, USA.

Marzadori, C., Antisari, L. V., Ciavatta, C. and Sequip (1991). Soil organic matter influence on adsorption and desorption of boron. *Soil Science Society of America Journal* **55**: 1582-1585.

McLaren, R. G. and Crawford, D. V. (1973). Studies on soil copper. I. the fractionation of Cu in soils. *Journal of Soil Science* **24**: 172-181.

Mengel, K., Kirkby, E. A., Kosegarten, H. and Appel, T. (2001). Boron. In: *Principles of Plant Nutrition*, Fifth edition, K. Mengel and E. A., Kirkby (eds.), Kluwer Academic Publishers, Netherlands. pp 621-638.

Moafpouryan, G. R. and Shukla, L. M. (2002). Status of available boron in major soil series of Delhi. *Annals of Agricultural Research* **23**: 554-557.

Moraghan, J. T. and Mascagni, H. J. (1991). Environmental and soil factors affecting micronutrient deficiencies and toxicities. In: *Micronutrients in Agriculture*, Second Edition, R. J. Luxmoore (ed.), Soil Science Society of America, Madison, WI, U.S.A. pp 371-425.

Niaz, A., Ranjha, A. M., Rahmatullah, Hannan, A. and Waqas, M. (2007). Boron status of soils as affected by different soil characteristics - pH, $CaCO_3$, organic matter and clay contents. *Pakistan Journal of Agricultural Science* **44**(3): 428-435.

Panse, V. G. and Sukhatme, P. V. (1995). *Statistical Methods for Agricultural Workers*, Fourth edition, Indian Council of Agricultural Research, New Delhi, India. pp 9-82.

Piper, C. S. (1950). *Soil and Plant Analysis*, Inter Science Publisher, New York, USA. 368 p.

Raza, M., Mermut, A. R., Schoenau, J. J. and Malhi. S. S. (2002). Boron fractionation in some Saskatchewan soils. *Canadian Journal of Soil Science* **82**: 173-179.

Sarkar, D., Mandal, B., Kundu, M. C. and Bhat, J. A. (2008). Soil properties influence distribution of extractable boron in soil profile. *Communications in Soil Science and Plant Analysis* **39**: 2319-2332. doi:101080/00103620802292418.

Sims, J. R. and Bingham, F. T. (1968). Retention of boron by layer silicates, sesquioxides and soil materials. II. Sesquioxides. *Soil Science Society of America Journal* **32**(3): 364-369.

Singh, M. V. (2001). Evaluation of current micronutrient stocks in different agro-ecological zones of India for sustainable crop production. *Fertilizer News* **46**: 25-28, 31-38 and 41-42.

Singh, M. V. and Behera, S. K. (2011). *All India Coordinated Research Project of Micro - and Secondary Nutrients and Pollutant Elements in Soils and Plants - A profile*. Research Bulletin No. 10. All India Coordinated Research Project of Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants, Indian Institute of Soil Science, Bhopal, India. pp 1-57.

Takkar, P. N., Chibba, I. M. and Mehta, S. K. (1989). *Twenty Years of Coordinated Research on Micronutrient in Soils and Plants*. Bulletin No. 314, Indian Institute of Soil Science, Bhopal, India.

Tsadilas, C. D., Yassoglou, N., Kosmas, C. S. and Kallianou, Ch. (1994). The availability of soil boron fractions to olive trees and barley and their relationships to soil properties. *Plant and Soil* **162**: 211-217.

Yermiyahu, Karen, R. and Chen, Y. (1995). Boron sorption on composted organic matter. *Soil Science Society of America Journal* **59**: 405-409.

Zarcinas, B. A. and Cartwright, B. (1987). Acid dissolution of soils and rocks for the determination of boron by inductively coupled plasma atomic emission spectrometry. *Analyst* **112**: 1107-1112.