Boron Status in the irrigated fields of semi arid north Ethiopia

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Abstract

In many regions of the earth, notably in the subtropics, the annual rainfall is not enough to meet the evaporative need of a complete vegetative cover on the soil. Likewise, the drylands in Ethiopia, which fall within the range of UNEP's definition of desertification cover 860 000 km^2 or 71.5% of the country's total land area. In spite of the fact that the irrigation potential is estimated to be *3* 637 000 ha Ethiopia uses only about 300000 ha currently. Basically, irrigation is an agricultural operation, which supplies the need of a plant for water. Moreover, irrigation adds salts to soil including boron if it isn't used systematically. Soil salinization in its early stages of development reduces soil productivity, but in advanced stages kills all vegetation and consequently transforms fertile and productive land to barren land, leading to loss of habitat and reduction of biodiversity. Hence a soil survey was conducted in the irrigated fields of cereal growing areas of semi arid north Ethiopia in order to examine the concentration of soil boron. Twelve soil profile pits in six different areas were opened wherein soil samples from three depths, viz. 0-30, 30-70 and 70-100 cm were collected. The boron concentrations were determined in a hot 0.01 M $CaCl_2$ extracts using Inductively- Coupled Plasma Atomic Emission Spectrometry (ICP-AES). The study revealed that hot water extractable boron contents of 0-30 cm depth soils varied from 0.19-1.38 ppm and the average value was 0.74 ppm. If 0.3 ppm is taken as the critical value for deficiency then the potential boron deficient areas occupy 16.6 %, if the critical value is accepted as 0.5 ppm for deficiency then the potential boron deficient areas occupy 33.3 % of the soils in the semi arid north Ethiopia. If 2.5 ppm is accepted as the possible critical level for boron toxicity then all the studied soils were found is potentially non-toxic for boron. The average boron levels of the soils did not significantly differ along the soil depth. The average boron values were 0.74, 0.69 and 0.65 ppm in the soil depths of 0-30, 30-70 and 70-100 cm, respectively. Emerging boron toxicity was observed in the Luvisols of *Hizat* at depth of 30-70 cm where the soil boron content was 2.35 ppm. Besides, pH of all the studied soils was alkaline (pH>7.0). Generally, boron concentrations in the irrigated fields of semi arid north Ethiopia were varied from 0.14 to 2.35 ppm with an average and median of 0.69 and 0.42 ppm, respectively. Besides, 25.7% of the soils were boron deficient and boron deficiency seems a greater problem than the boron toxicity in the rainfed cereal growing areas of the arid north Ethiopia.

Keywords: Boron, deficiency, irrigated field, semi arid north Ethiopia, toxicity

Introduction

Boron is an element of great concern because for many plants the ratio of toxic to adequate B concentrations is the smallest among the essential micronutrients. Boron concentrations in soil water in the range of 0.05 to 0.5 mmol L^{-1} have a deleterious effect on plant growth (U.S. Salinity Laboratory Staff, 1954; Gupta, 1968).

Boron is an essential element for the plant growth and taken into the plant as boric acid. Boron is one of the trace elements that cause a major problem in soil management. Only a small amount is necessary for optimal plant growth, while values slightly above this optimal amount affect the plant growth negatively and reduce plant growth. Toxic and deficiency values are very close to each other. Boron is of interest in crop production both from the viewpoint of its effects in deficiency and toxicity. According to Reisenauer et al (1973) deficiencies of Boron occur in a wider range of crops and climatic conditions than deficiencies of any other trace element. Boron is also probably more important than any other micronutrient in obtaining high quality crop yields.

Generally B behaves conservatively in natural waters. Occurs mainly as undissociated $B(OH)_3$ at pH < 9, and as $B(OH)_4$- at pH > 9. Primary and secondary aluminosilicates often contain B, as it substitutes for Si and Al. In dry environments it may be a major threat to irrigated agriculture due to its phytotoxic effects and conservative behaviour. Bioaccumulation to levels toxic to wildlife can occur (US Fish and Wildlife service, 1986). B can be highly correlated with groundwater salinity (Deverel and Millard, 1988). B concentrations may be affected by interactions with minerals. Adsorption onto various minerals is highly dependent on pH, with maximum adsorption at pH 7 – 10. Soluble B in irrigated soils may regenerate or increase in concentration after reaching a constant low concentration. This may be due to slow release from adsorption sites and diffusion of B from small to large pores (Peryea et al, 1985a). B deficiency is rarely a problem in saline soils, but is common in temperate, semi-humid and humid regions. It is probably the most troublesome trace element in saline and alkaline soils – while low concentrations are essential for plant growth it becomes toxic at concentrations only slightly higher than those needed for optimum growth. In soil solutions it occurs mainly as undissociated boric acid [$B(OH)_3$], and is much more soluble than other trace elements like As, Cd, Ni and Cu. Crops differ in their response to B – some grow well in soils where levels of B extracted in hot water are < 0.1 mg kg^{-1}, while others show deficiency symptoms if the level falls below 1 mg kg^{-1}. For sensitive crops, the margin of safety between deficiency and toxicity is narrow.

Table 1. Minimum concentrations of hot-water soluble B associated with optimum yields for various crops (Keren & Bingham, 1985)

< 0.1 mg B kg^{-1} soil	0.1 – 0.5 mg B kg^{-1} soil	0.5 – 1.0 mg B kg^{-1} soil
Barley	Tobacco	Apple
Oats	Tomato	Alfalfa / lucerne
Wheat	Lettuce	Clover
Maize	Peach	Red beet
Soybean	Pear	Turnip
Pea	Cherry	Mustard
Bean	Olive	Asparagus
Strawberry	Sweet potato	Celery
Potato	Peanut	
Flax	Carrot	

Crops on saline soils suffer more from B toxicity than deficiency, with the excess B coming from both the soil and the irrigation water. Sensitive crops (Ayers & Westcot, 1976) show reduced yield or injury symptoms with soil B > 0.3 mg l^{-1}, while tolerant crops can withstand soil B > 4 mg l^{-1}. Maas (1984) developed a more realistic threshold-type model similar to that he developed for salinity (Table 2). The relative B tolerance as assessed by Maas (1984) and based on concentrations in the soil solution was similar to that developed by Ayers and Westcot (1985) on tolerance to B in irrigation water. Useful reviews that cover other crops are by Keren and Bingham (1984) and Gupta *et al* (1985).

Table 2. The relative B tolerance as assessed by Maas (1984).

Sensitive		Moderately sensitive	Moderately tolerant	Tolerant	Very tolerant
(0.05 mg l^{-1})	(0.75 mg l^{-1})	(1.0 mg l^{-1})	(2.0 mg l^{-1})	(4 mg l^{-1})	(6 mg l^{-1})
Avocado	Garlic	Broccoli	*Lettuce*	Tomato	Sorghum (6 mg l^{-1})
Grapefruit	Sweet potato	Red pepper	*Cabbage*	*Alfalfa*	
Orange	Wheat	*Pea*	*Celery*	*Purple vetch*	Cotton (10 mg l^{-1})
Apricot	Sunflower	Carrot	Turnip	*Parsley*	
Peach	*Mung bean*	Radish	*Bluegrass*	Red beet	*Asparagus*
Cherry	*Sesame*	Potato	Barley	Sugarbeet	
Plum	*Lupin*	Cucumber	Oats		
Persimmon	*Strawberry*		Maize		
Fig (kadota)	*Kidney bean*		*Tobacco*		
Grape	*Lima bean*		*Mustard*		
Walnut	Peanut		*Sweet clover*		
Pecan			Squash		
Cowpea			*Muskmelon*		
Onion			Cauliflower		
0.75 mg l^{-1}	1.0 mg l^{-1}	2.0 mg l^{-1}	4 mg l^{-1}	6 mg l^{-1}	15 mg l^{-1}

Of all the trace elements, B is the most likely to be toxic in saline soils Pratt PF & Suarez, DL (1990) irrigation water quality assessments. B toxicity occurs within the microgram per litre range in soil solutions, and when toxic plants respond to B in the soil solution (B_s) rather than to B adsorbed on soil particles. Early recommendations on B tolerance were largely based upon visual symptoms, but these were shown by Francois (1984) not to correlate with marketable yield, at least in tomato. Yield decreases depend upon the crop tolerance to B, and to B_s, which in turn depends upon the concentration of B in the irrigation water (B_{iw}), the leaching fraction (LF) and the departure from a steady-state relationship between adsorbed B and B_s. At steady-state input and output of B from the rootzone, mean Bs is related to B_{iw} and to LF. As B is adsorbed onto and released from the soil particle surfaces, soil solutions are buffered against rapid changes in B concentration: if B_{iw} increases B is adsorbed, resulting in a smaller increase in B_s than in B_{iw}. The time needed to reach a steady-state B concentration depends upon the increased B concentration, the amount of water used, the LF, and the sorption capacity of the soil volume in the root zone, and can be up to 150 years! If B_{iw} is decreased, the soil releases B and time is needed to reduce B_s. The volume of low-B water needed to reduce B_s from toxic to non-toxic levels is 2 or 3 times more than that needed for a comparable reduction in Cl. The B concentration of the saturation extract (usually used to measure salinity) is not a good indicator of B toxicity in field conditions due to these buffering changes.

In general, toxic levels of soil B are only found in arid regions. Most surface irrigation levels contain acceptable levels of B, but levels may be toxic in well water in some areas. Water that is marginal for some crops can be used for irrigating more tolerant ones. Much of the data on crop tolerance to B is over 60 years old, and is largely empirical. Most of it is based upon response to different B levels in sand culture. Thresholds derived from this work are useful, but some crops may exhibit injury at lower levels that do not reduce yield. B tolerance varies with climate, soil and crop. Symptoms may include chlorotic and necrotic leaf patterns.

Table 1 shows that wheat is regarded as sensitive to B, with a threshold of 0.75 – 1.0 g m^{-3}, and slope of 3.3% per g m^{-3}. Of the other cereals, barley is moderately tolerant (3.4 and 4.4% respectively), as are oats and maize (thresholds 2.0 – 4.0, no slope given). No values are given for millet, but sorghum is regarded as very tolerant to B, with a threshold of 7.4 and a slope of 4.7.

B deficiency is commonly found on acid light-textured soils low in OM – it can be induced in these soils by liming and especially by over-liming (Walsh & Golden, 1952). It is most common in UK in hot dry summers. Crops take up more B from light than from heavy soils, and from acid than from limed soils.

Critical soil levels for deficiency appear to be around 0.3 – 1.0 mg kg^{-1} soil, although this varies with the crop, on the soil (lower on sand than on clay), and the pH (lower on acid than neutral soils). If irrigation water has > 0.3 mg l^{-1} B care is needed. Water containing 2 – 4 mg l^{-1} will restrict cropping to B tolerant crops,

The soils on which Boron deficiency occurs include those which are inherently low in B such as soils derived acid igneous rocks. Sandy acid soils in particular need regular treatment of boron fertilizers. The same treatment is also required when acid soils are limed, as excess amounts of lime can induce Boron deficiency (Walsh and Golden, 1952). Boron availability decreases with increasing soil pH, Inadequate Boron availability has thus frequently on calcareous soils. High clay contents also impair boron availability, probably due to borate adsorption (Welte, 1955). Crop differs in their sensitivity to B deficiency. The most sensitive crops are sugar beets, mangolds and celery. Various Brassica crops such as turnips, cauliflower, cabbage, brussels sprouts also have a high Boron requirement. Of the fruit trees apples and pears are known to be particularly sensitive to Boron deficiency (Bradford, 1966). Gartel (1974) claims that Boron deficiency is one of the most severe non-parasitic diseases in wine growing and yield depression may be up to 80%. In general dicots have higher Boron requirement than monocots.

Hitherto there existed no data on extractable boron for semi arid region of north Ethiopia. The overall aim of this study has been to quantify the distribution of boron in soils irrigated fields of semi arid region of north Ethiopia.

Materials and Methods

Study sites

This study was conducted in major irrigated areas of Tigray and Aba'ala district of the Afar regions, which both are located in semi arid north Ethiopia. The brief biophysical settings of these areas are highlighted as follows.

Location, topography, climate, geology and soil types of Tigray Region

The Tigray Region is mainly the extension of the central highland and associated western lowlands, and is divided into two major blocks; the eastern block is comprised of highlands while the western block is predominantly lowland. Altitudes range from 500 meters up to 3,900 meters above sea level. It is situated between 12º 15' N and 14º 57'N and between 36º 59'E and 40º E longitude with an estimated area of 53 635 km^2. The regional Administration is divided into four zones. The mean annual rainfall of Tigray region ranges from 600 mm in the northeastern part to 1600 mm in the western part of Welkait Woreda. Temperature ranges between 16º C to 20º C in the highlands of eastern and central parts, while it is 38º C to 40º C in the lowlands of the western zones. The Geology of Tigray comprises low-grade Metamorphic, Paleozoic and Mesozoic rocks. Tertiary volcanic, quaternary deposit and acidic to basic/ultra basic intrusions. Major soil types of the region identified in a study conducted in 1976 as is quoted by the Bureau of Planning and Economic Development Report (1998) as: orthic Acrisels, chromic and Eutric cambisols, Humic cambisols, Vertic cambisols and Vertic luvisols, Eurthic fluvisols, dystric nitosols, Eutric Nitosols, Euric rogosols, Haplic Xerosols, Cambic Arenosols, and chromic Andisols.

Location, topography, climate, geology and soil types of Aba'ala District in Afar Region

Aba'ala district, Afar region of the semi arid north eastern Ethiopia, is located in the transition zone between the eastern Tigray escarpment and the northern Afar low land between 13º 15' and 13º 30' N and 39º 30' and 39º 55'E longitude, 50 km to the east of Mekelle, the capital of Tigray region. Topography of Aba'ala consists of flat plains occasionally interrupted by few undulating hills and a series of elongated ridges, surrounded by a highly broken hill with very few outlets joined to other areas. The average elevation of the area is approximately 1500m above sea level (Mitiku, *et al.,* 1999). The area is a product of volcanic activities that formed the Great Rift Valley. Exposed rocks and stones dominate most of the hills and ridges, while alluvial deposits cover the flat plains. Aba' ala is one of the areas having high temperature and low rainfall. The mean rainfall is 500 mm and the maximum temperature exceeds 40º C.

Sampling

In total 35 soil samples representing 12 soil profiles in the irrigated fields of semi arid north Ethiopia were collected from surface to more 100 cm soils depths. The soils were air dried, ground and passed through 2-mm sieves and prepared for further analyses.

Extraction of Boron

Hot water extracts of soils were prepared by refluxing 15 g soils in 30 ml of 0.02M $CaCl_2$ reagent using repipette dispenser and closed bag including the blank. Then the plastic bag was placed for 10 min in water bath. After removal, the plastic bags were cooled for one minute and filtered. Finally, the extractable soil boron was determined using ICP-AE using 249.699 nm wavelengths in the Laboratory of School of Chemistry, Bangor University, UK. Descriptive statistics was used to summarise and analyse the data.

Concurrently, pH, total salt level, available P and exchangeable cations in these soil samples were also determined following the routine procedure in order to identify the relationship of these factors with soil boron status in the study areas.

Results and Discussions

The study reveals that the average Boron content of surface soils of the irrigated field in semi arid north Ethiopia is 0.74 ppm. The Boron contents of all the studied soils range from 0.14 to 2.35 ppm. About 33.3 % of the samples have values less than 0.5 ppm, which may be stated as the critical value for soil Boron deficiency. All the samples have values less than 2.5 ppm, which may be stated as the critical value for soil Boron toxicity (Figs. 1-12). Boron deficiency seems as a more critical problem than the Boron toxicity in the study areas. The average boron values were 0.74, 0.69 and 0.65 ppm in the soil depths of 0-30, 30-70 and 70-100 cm, respectively whereas 0.74 ppm was the average hot water extractable boron contents for 0-30 cm depth.

The average boron content was the lowest in Arenosols (0.14 ppm) and the highest in Luvisols of Hizat (2.35 ppm) (Table 3). Sandy soils can be taken as an indicator of Boron deficiency. Higher probability of Boron deficiency in sandy soils was also reported by Gupta (1968) and Fleming (1980).

The relation between the soil pH and boron content was significantly important for the Vertisols of Hawzen, Cambisols of Adigudom, Vertisols of Hizat and Vertisols of Axum (Table 4). High pH seems as an indicator for boron deficiency. Similar results were presented by Berger and Troug (1945) though, in this study, positive correlation was observed between the extractable Ca and boron concentration for Vertisols of Hizat, Arenosols of Hawzen, Vertisols of Adigudom, Vertisols of Hizat, Cambisols of Aba'ala, Luvisols of Axum and Vertisols of Korer (Table 4).

The relation between the soil salinity and boron content was significantly important for the Vertisols of Hawzen, Arenosols of Hawzen, Vertisols of Hawzen, Cambisols of Aba' ala, Vertisols of Kelamino, Vertisols of Axum and Luvisols of Axum (Table 4).

Conclusions

Boron is one of the seven recognized essential micronutriets required for the normal growth of most plants. Recent interpretations of the role of B are based on the formation cis-diol borate complexes (Thellier et al., 1979). Thus appreciating the role of boron in plant growth, this study revealed that boron toxicity was observed in Luvisols of Hizat (2.35 ppm), Vertisols of Hizat (1.1 ppm), Cambisols of Aba'ala (1.3 ppm), Vertic Cambisols of Kelamino (1.29 ppm) and Vertisols of Korer (1.2 ppm). Hence it is time to pay special attention for envisaging all rounded management strategy to minimize future B toxicity risk in these areas. In contrary, 33.3% of the studied soils are deficient in extractable B mainly in Arensols. Hence, effective B-fertilisation will help better crop production in the irrigated field of northern Ethiopia.

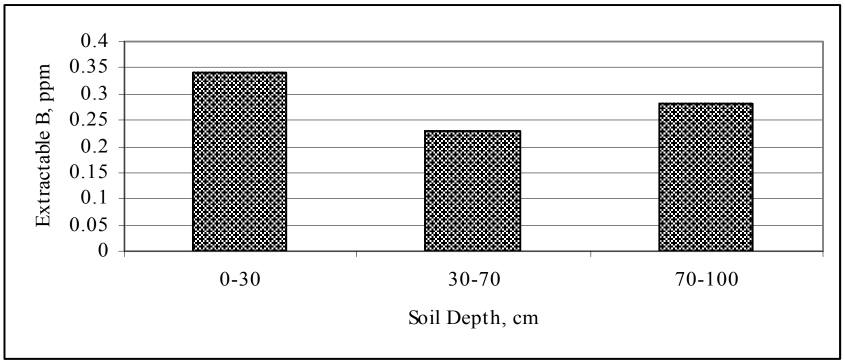

Fig. 1. Hot water extractable boron contents in the Vertisols of Hawzen

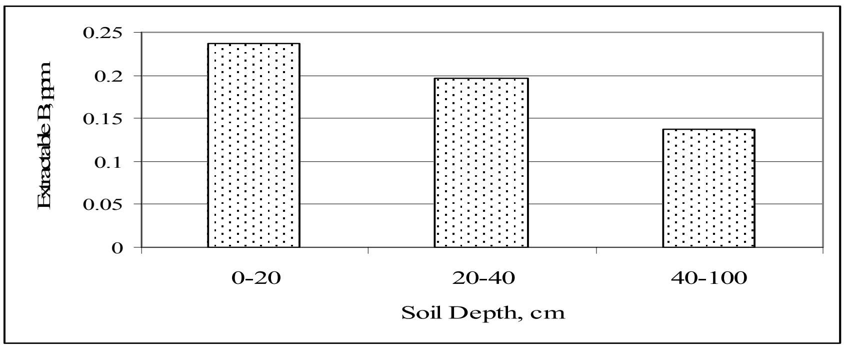

Fig. 2. Hot water extractable boron contents in Arenosols of Hawzen

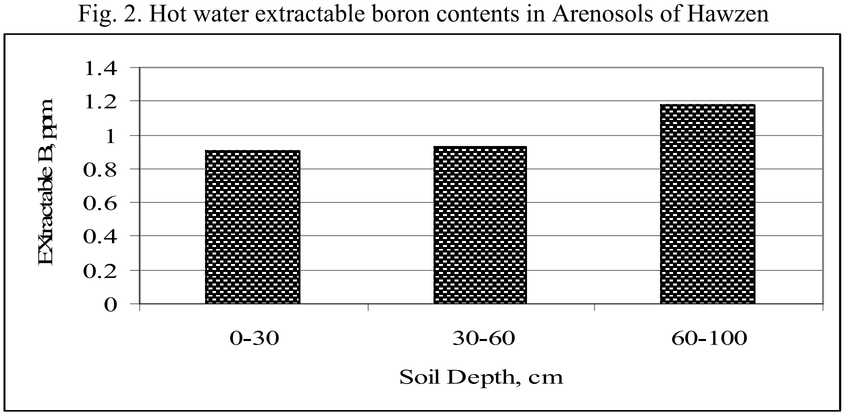

Fig. 3. Hot water extractable boron contents in Vertisols of Adigudom

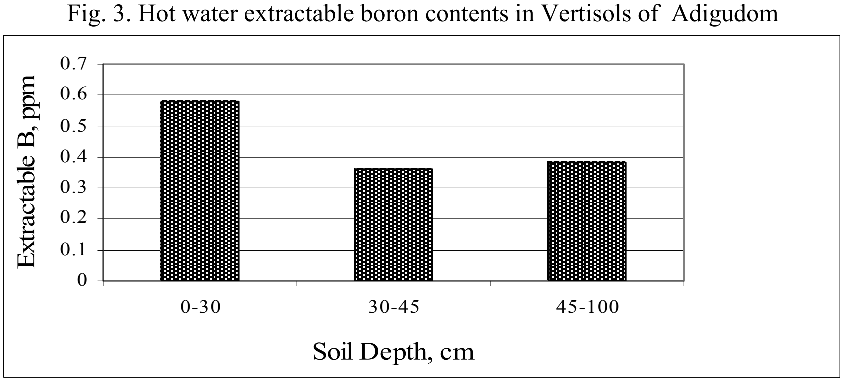

Fig. 4. Hot water extractable boron contents in Cambisols of Adigudom

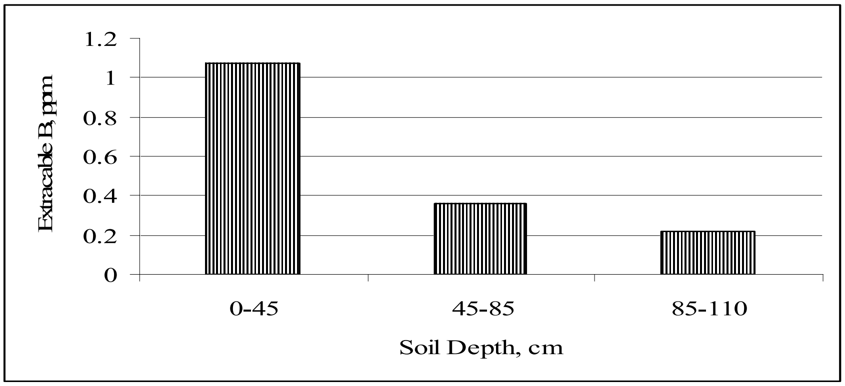

Fig. 5. Hot water extractable boron contents in Vertisols of Hizat

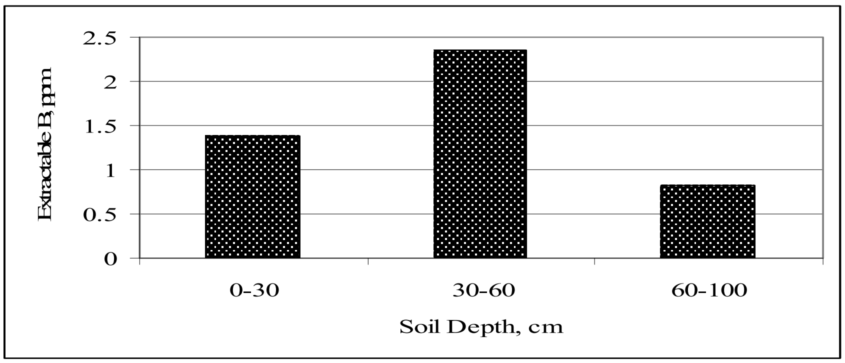

Fig. 6. Hot water extractable boron contents in Luvisols of Hizat

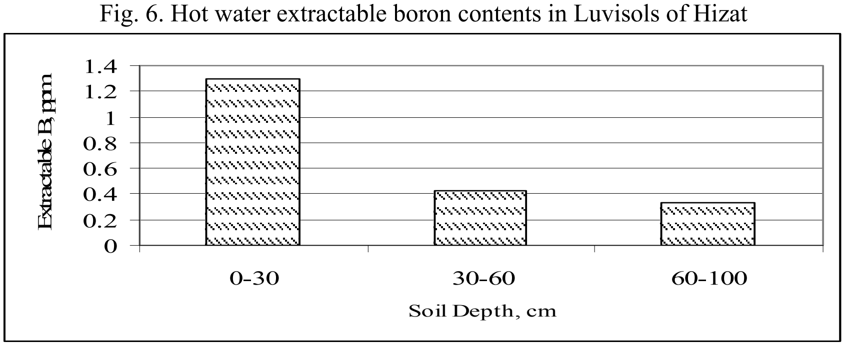

Fig. 7. Hot water extractable boron contents in Cambisols of Aba'ala,

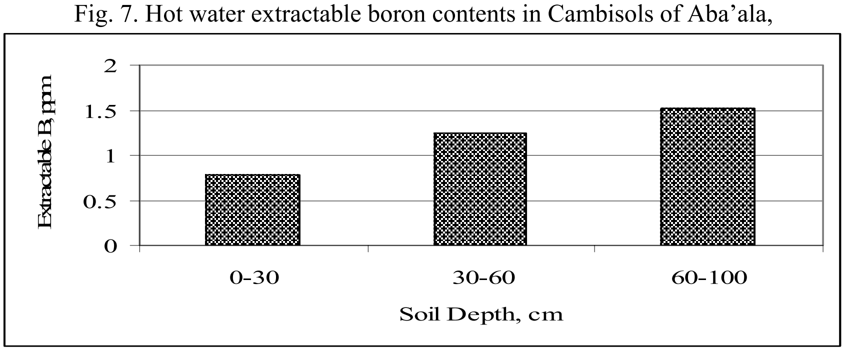

Fig. 8. Hot water extractable boron contents in Vertisols of Kelamino, Mekelle

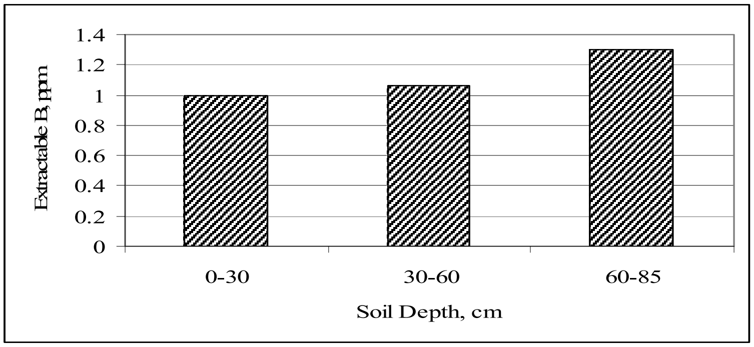

Fig. 9. Hot water extractable boron contents in Vertic Cambisols of Mekelle, Kelamino

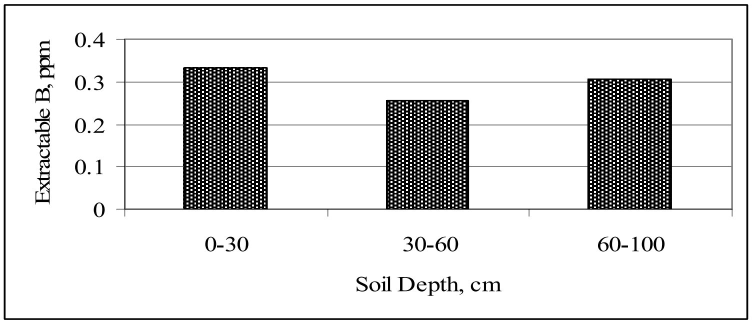

Fig. 10. Hot water extractable boron contents in Vertisols of Axum

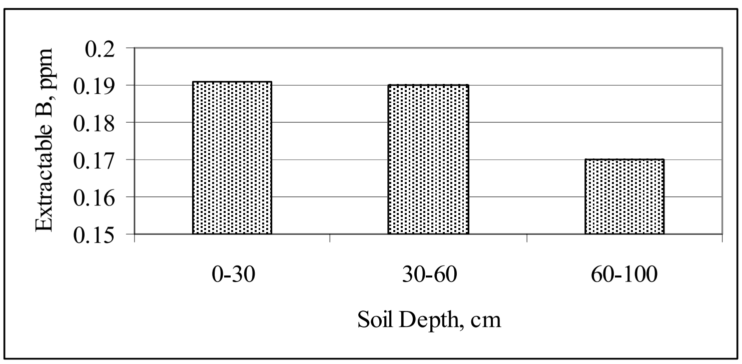

Fig. 11. Hot water extractable boron contents in Luvisols of Axum

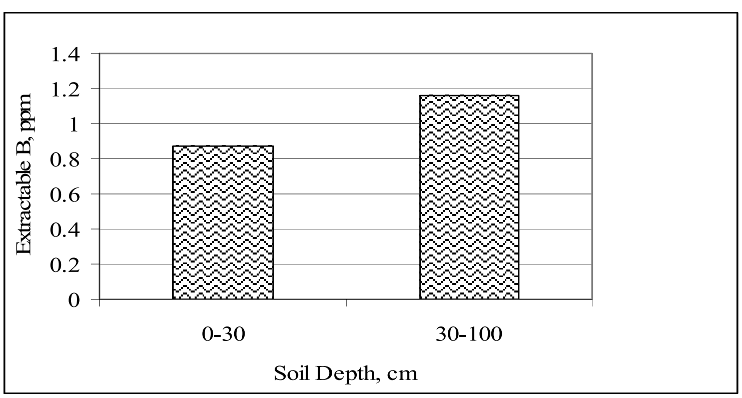

Fig. 12. Hot water extractable boron contents in Vertisols of Korer

Table 3. Hot water extractable B distribution in the soils of the irrigated fields on semi arid north Ethiopia

Soil types	Ave. B ppm	Min. B ppm	Max. B ppm	Distribution of boron, %					
				<0.5 ppm	0.5-1.0 ppm	1.0-1.5 ppm	1.5-2.0 ppm	2.0-2.5 ppm	>2.5 ppm
Arenosols	0.19	0.14	0.24	100	-	-	-	-	-
Cambisols	0.96	0.58	1.29	-	33.3	66.7	-	-	-
Luvisols	0.79	0.19	2.35	50.0	-	50.0	-	-	-
Vertisols	0.67	0.33	1.52	33.2	49.8	17.0	-	-	-

Table 4. Boron concentration correlation with other soil properties

No.	Name of the irrigated fields	pH	EC	Extractable Na	Extractable Ca
1	Hawzen, Vertisols	0.417**	0.980**	-0.995	0.790**
2	Hawzen, Arenosols	-0.946	0.300**	0.905**	0.988**
3	Adigudom, Vertisols	-0.626	0.858**	0.905**	0.925**
4	Adigudom, Cambisols	0.813	-0.751	0.804**	-1.000
5	Hizat, Vertisols	-0.965	-0.499	0.594**	-0.933
6	Hizat, Vertisols	0.567**	-0.146	-0.461	0.301**
7	Aba'ala, Cambisols	-0.921	1.000**	-0.897	0.137**
8	kelamino, Vertisols	-0.786	0.871**	0.728**	-0.870
9	Kelamino,Vertic Cambisols	-0.023	1.000**	-0.528	-0.561
10	Axum, Vertisols	0.777**	0.691**	-0.177	-0.992
11	Axum, Luvisols	-0.985	0.634**	-0.862	0.606**
12	Korer, Vertisols	-1.000	-1.000	1.000**	1.000**

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