INFLUENCE OF LIME AND ORGANIC MATTER ADDITION ON AVAILABILITY OF BORON

A thesis
submitted to the
Uttar Banga Krishi Viswavidyalaya
in partial fulfilment of the requirements for the Degree of
Master of Science (Agriculture)

In

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

By

MRINAL KANTI MANDAL

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
Faculty of Agriculture
UTTAR BANGA KRISHI VISWAVIDYALAYA
Pundibari, Cooch Behar, West Bengal

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2006

Dedicated to
my beloved
Grand Father
Kalipada Mandal
&
Grandmother
Niyoti Mandal

UTTAR BANGA KRISHI VISWAVIDYALAYA
FACULTY OF AGRICULTURE
DEPARTMENT OF SOIL SCIENCE & AGRICULTURAL CHEMISTRY
P.O. Pundibari, Cooch Behar, West Bengal 736165, India

From:
Dr. A. K. Ghosh
Lecturer
Chairman, Advisory Committee

Ref No. ....

Date 28.11.2006

CERTIFICATE

This is to certify that the work recorded in the thesis entitled **'INFLUENCE OF LIME AND ORGANIC MATTER ADDITION ON AVAILABILITY OF BORON'** submitted by **Shri Mrinal Kanti Mandal** in partial fulfilment of the requirements for the degree of Master of Science (Agriculture) in Soil Science and Agricultural Chemistry of the Uttar Banga Krishi Viswavidyalaya, is the faithful and bonafide research work carried out under my personal supervision and guidance. The results of the investigation reported in the thesis have not so far been submitted for any other Degree or Diploma. The assistance and help received from various sources during the course of investigation have been duly acknowledged.

Date: 28/11/06
Place: Pundibari, Cooch Behar

(A.K.Ghosh)
Chairman
Advisory Committee

APPROVAL OF EXAMINERS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE (AGRICULTURE) IN SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

We, the undersigned, having been satisfied with the performance of **Shri Mrinal Kanti Mandal**, in the Post-submission Seminar on Final Evaluation of thesis, conducted today, the 28. NOV.....2006, recommended that the thesis be accepted for the award of the degree of Master of Science (Agriculture) in Soil Science and Agricultural Chemistry.

	Name	**Signature**
1.	Dr. A.K.Ghosh Chairman, Advisory Committee	Amlan Ghosh
2.	Prof. (Dr.) A.K. Saha Head of the Department & Member, Advisory Committee	A. K. Saha
3.	Mr. A.K. Sinha Member, Advisory Committee	
4.	Dr. Asim Sinha Member, Advisory Committee	

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Mrinal Kanti Mandal
(Mrinal Kanti Mandal)

Place: **Pundibari, CoochBehar**
Date: 28\11\06

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Chapter-I

INTRODUCTION

INTRODUCTION

Boron is an essential micronutrient element required for normal growth of plants. The initial proof of this essentiality of boron in plants was established by Warington (1923) although the chemical species involved in boron's essentiality in plants have not been definitely proven and many hypothesis have been put forward (Loomis and Durst, 1991). Boron, along with its neighbours in the periodic table, Li and Be are not abundant elements in the earth's crust because they are bypassed in the normal chain of thermonuclear reactions in stars (Reeves, 1974). In spite of its low natural abundance, B is widely distributed both in the lithosphere and hydrosphere (Morgan, 1980).

Soils may be divided into two categories: those with low B content (<10 mg B kg^{-1}) or high Boron content (>10 mg kg^{-1}). Most soils have a low B content and hence out of all the micronutrient deficiencies in plants, B deficiency is most widespread. The rapid and specific inhibition of plant growth that occurs upon removal of B from growth media is because of the structural role B plays in the cell wall formation and the limited mobility of B in majority of plant species. Hence for optimum plant growth, B has to be supplied continuously through the life of the plant and usually through the root. Boron is absorbed from the soil solution by roots mainly as undissociated boric acid, which is a passive process. Hence Boron uptake by plants is primarily determined by B concentration in the uptake medium and transpiration rate of the plant (Hu and Brown, 1997).

The chemistry of B in soil is simple as it neither undergoes oxidation-reduction reactions nor volatization reactions. Boron containing minerals in soil are either too soluble or too insoluble and usually do not control the solubility of B in soil solution. The B concentration in soil solution is generally controlled by B adsorption reactions. Plants respond only to activity of boron in soil solution and not to adsorbed boron. However B in soil solution is prone to leaching losses and hence B deficiency is most likely in coarse textured soils of the humid tropics. Soils of the terai-agro climatic region of West Bengal are coarse in texture and prone to leaching losses due to high rainfall (>2500mm annual rainfall). Due to excessive leaching of bases the soils are acidic in reaction. A natural response of farmers to amend these soils is to apply lime. Boron deficiencies are known to be trigard by liming acid soils (Reisenauer *et al*, 1973). Organic matter in soil has the ability to complex large amounts of B (Yermiyaho *et al*, 1988) and is often held responsible as the cause of B deficiency. There is little information on the effect of addition of lime and or organic matter on the availability and or bioavailability of boron in soils of terai region of West Bengal.

The present study entitled **"Influence of lime and organic matter addition on availability of boron"** was under taken to study the relationship between B, lime and organic matter in terai agro-climatic zone with the following objectives.

1. To study the available B content and its relation to soil properties in some soil series of North Bengal.
2. To study the adsorption behaviour of B in soil amended with lime and organic matter.

Chapter-II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Review of literature has been presently restricted to the following sections-

- A. Distribution of available boron in soils.
- B. Soil properties effecting boron availability.
- C. Boron adsorbing surfaces in soil.
- D. Modeling boron in soil.

A. DISTRIBUTION OF AVAILABLE BORON IN SOILS:

A lot of information regarding status and distribution of boron has been generated in India. Takkar (1982) has reviewed the research on boron status of different soils in India. Das and Saha (1999) has reviewed the research on boron status of different soils of West Bengal. However only those reviews pertaining to alluvial acid soils are presented here.

Out of the 3853 soil samples analysed for boron in West Bengal, the available B content ranged from traces to 3.3.mg kg^{-1}with a mean value of 0.34 mg kg^{-1}.However these soil samples are skewed towards five districts only, belonging to acid soil regions and to two districts groups namely alluvial and laterite. Mandal *et al.* (1991) analysed 88 surface soils from three districts of North Bengal, namely, Jalpaiguri (25) Cooch Behar (59) and Dinajpur (4) and found available boron content to vary from traces to 1.02 (mean 0.29) ppm, traces to 1.14 (mean 0.36) ppm and 0.19 to 0.47 (mean 0.33) ppm respectively. Pakrashi (1991) analysed 30 soil samples from Cooch Behar and and 283 samples from Jalpaiguri district. The available boron content varied from 0.017 to 0.279 (mean 0.128) ppm and 0.070 to 0.437 (mean 0.137) ppm respectively for the above two districts. Later Saha (1992) analysed 65 soil samples from Cooch Behar and Jalpaiguri districts and found that the boron content varied from 0.065 to 0.456 (mean 0.261) ppm and 0.129 to 0.348 (mean 0.232) ppm respectively for the above two districts . The higher mean boron content as compared to previous reports may be because the extractant used was hot water in the first two cases and hot $CaCl_2$ in the third. Mandal (2004) analysed 45 surface soils of Cooch Behar district and reported hot water soluble boron to vary from 0.12 to 0.3ppm.

Barthakur (1992) analysed the available boron content of acidic surface soils of 5 districts of Assam. The available boron content varied from 0.21 to 0.723 (mean 0.441) ppm, 0.065 to 0.513 (mean 0.228) ppm and 0.096 to 0.423 (mean 0.189) ppm in the districts of Dibrugarh, Sibsagar, Nagaon, Kamrup and Goalpara, respectively. Ali (1992) reported the results of 12,165 soil analyses in the districts of Jorhat, Darrang, Nagaon, Kamrup and Goalpara. Available boron content ranged from 0.15 to 2.374, 0.16 to 7.56, 0.14 to 9.0, 0.36 to 3.92, and 0.16 to 6.74 respectively with mean value of 1.66, 1.72, 2.15, 1.61 and 1.37ppm.The mean boron contents reported by Ali (1992) seem to be higher than those reported by Barthakur (1992) for comparable districts.

Nongkynrih *et al.* (1996) analysed 136 acidic surface soils under rice cultivation in Meghalaya and found the available boron content to vary from 0.2 to 1.9 ppm. Dutta and Ram (1993) analysed soils under Ultisols, Inceptisols and Entisols in Tripura and found the available boron content to range from 0.4 to 2.7 with a mean of 1.33 ppm.

Analysis of 100 soils samples in two acid sedentary soil series of Chhotonagpur region revealed that available boron content varied from 0.01 to 0.58 ppm (mean 0.24) ppm in Jorsol 2 and 0.2 to 1.78 ppm (mean 0.77) ppm in Debatoli (Ghosh and Sarkar,1994) however, in Debatoli, Dumka and Laxmipur of South Chhotonagpur, Bihar, Kumar *et al.* (1994) observed hot water soluble boron content to vary from trace to 2.8 (mean 0.7) ppm, 0.1 to 1.9 (mean 0.6) ppm and trace to 3.5 (mean 0.7) ppm respectively.

Thus it may be seen that there is considerable variation in the available boron content within states and even within regions of a state.

B. SOIL PROPERTIES EFFECTING BORON AVAILABILITY

Relationship of available boron to soil properties:

A number of factors are reported to have a bearing on available boron status of the soil namely pH, organic matter, clay, sesquioxides, carbonates and management. The following review encompasses only the main factors as presented here under.

pH:

One of the most important factors affecting the availability of boron in soil is pH. With increasing soil solution pH, boron generally becomes less available to the plant. Soluble boron content in soil was highly significantly correlated to solution pH (Elrashidi and O'Connor, 1982) and boron uptake by plants at identical water soluble boron content was greater at lower soil solution pH (Wear and Patterson, 1962). Singh *et al.* (2006) summarized the results of boron analysis in soils of Bihar which showed that the magnitude of boron deficiency progressively increased with a rise in soil pH. At pH less than 7.5 only 16% soils were deficient in boron. Between pH 7.5 and 8 it was 45 and above pH 8 the value was 47%. Mathur *et al.* (1991) reported a decrease in available boron content with increase in pH in the Indira Gandhi Canal Area.

However Mondal *et al.* (1991) failed to observe any significant correlation between pH and available boron in 88 surface soils of three Northern districts of West Bengal. Similarly Nandi *et al.* (1992) did not observe any relationship between pH and available boron content in soils of Purulia, Bankura and Midnapur districts of West Bengal.

Organic Matter:

Berger and Truog (1945) concluded from their study that in acid soils, the available boron content increased with an increase in organic matter content, however in alkali soils available calcium content had more effect on boron availability. In presence of free calcium, available boron gets fixed in a temporarily unavailable form, partially by organic matter and partially by soil minerals.

However in literature all types of relationship have been reported by workers working on different and even similar soils. For example Mondal *et al*. (1991) and Pakrashi (1991) observed and inverse (statistically non-significant) relationship between available boron and organic matter content, Saha (1992) observed a positive relationship (statistically non-significant) between organic matter and boron availability. Nandi *et al*. (1992) observed a similar positive relationship but working with red and lateritic soils of West Bengal.

In calcareous and recent alluvial soils of North Bihar, Sakal *et al.* (1987) observed a positive correlation between organic carbon and available boron. Similarly positive correlation has been reported by Kumar (2003) in old alluvial soils of Nawada district of Bihar. Ghosh and Sarkar (1994) also reported similarly, working with acid sedentary light textured soils of Bihar. Saha *et al.* (1998) observed significant and positive correlation between available boron and organic carbon content in shrink-swell and red-yellow soils of Madhya Pradesh.

However Singh and Sinha (1987) failed to observe any significant relationship between available boron and organic carbon content in red loamy soils of Chhotonagpur region of Bihar. Similar results were also reported by Tewari *et al.* (1988) for soils of Rajghat area of Madhya Pradesh. Singh and Sinha (1975) even reported fixation of boron in the sandy soils of North-East Bihar with increase in organic matter content.

Singh *et al.* (2006) reported that boron deficiency was continuously decreased with increase in organic matter content. The percentage of soils in deficient in boron was 55 at organic carbon values of less than 0.35%, 29 when it ranged from 0.35-0.5% and 22 at organic carbon content above 0.50%.

Texture:

Berger (1949) had reported that in the humid regions, the available boron content increased with clay content. Sing *et al.* (2006) reported wide spread boron deficiency in North-Eastern part of Bihar due to predominance of coarse textured soils. Ghosh and Sarkar (1994) reported non-significant but negative correlation between available boron and clay content in Jarsol 2 and Debatoli soil series of Bihar.

Bhattacharjee (1956) observed that the available boron content increased with the increase in percentage of silt and clay in soils of Murshidabad districts of West Bengal. For the Terai region of West Bengal, Mondal *et al.* (1991) reported that the available boron content increased with increase in clay content. However Pakrashi (1991) observed negative relation between clay content and hot water soluble boron.

Positive relationship between available boron and clay plus silt fraction in semi arid region of Punjab and Haryana was reported by Singh (1970). Positive correlation between boron and clay has also been reported in sub soils of Dir district of Pakistan (Ahmed *et al.* 1990). However Perveen *et al.* (1993) failed to observe any relationship between available boron and clay content in soils of NWFP of Pakistan.

Mathur *et al.* (1991) reported the available boron content to increase with increase in clay content in flood plain soils of Indira Gandhi Canal Area. However in an earlier study Mathur *et al.* (1964) observed a significant decrease in available boron content with increase in clay plus silt content in Rajasthan soils.

Moisture:

Boron availability generally decreases as soils dry making boron deficiency in plant more likely (Fleming, 1980). Diffusivity of boron decreases with decreasing water content because drying reduces soil solution mobility and increases the diffusion path length. Moisture stress also restricts the release of boron from organic and inorganic complexes and impairs the availability of the plant to extract boron from the soil. Under high rainfall condition, the availability of boron decreases due to leaching losses (Singh *et al.* 2006).

Mondal, (1991) studied the effect of moisture regimes in two acid soils of North Bengal and found that the available boron content was higher under submergence than at field capacity moisture. The available boron content also increased up to 30 days of submergence and there after decreased at both moisture regimes.

Wetting and drying cycles increased the amount of boron fixation. The effect of boron became more pronounced with increasing additions of boron (Biggar and Fireman, 1960).

Other Ions:

Singh (2006) reported that and increase in available P_2O_5 decreased the magnitude of boron deficiency, which was 42% when available P_2O_5 was less than 30 kg ha^{-1}, 38% at P_2O_5 ranging from 30-40 kg ha^{-1} and 29% at P_2O_5 above 40 kg ha^{-1}. Soil available K_2O showed positive effect on soil available boron up to 600 kg ha^{-1} K_2O. The boron deficient soil samples were 45%when available K_2O was less than 350 kg ha^{-1} and decreased to 34% at available K_2O ranging between 350-600 kg ha^{-1}. The association of boron deficiency with soil available P_2O_5 and K_2O is attributed to better soil fertility, high organic matter and recycling of boron bound with organic matter.

C. BORON ADSORBING SURFACES IN SOIL:

Oxides:

Al and iron oxides play an important role in boron adsorption behavior in soils (Elrashidi and O'Connor, 1982). Boron adsorption is highly specifically correlated with the aluminium and iron oxide content of soils. Numerous studies have investigated boron adsorption on crystalline and amorphous iron and aluminium oxides. Results indicate that boron adsorption increases with increase in pH up to an adsorption maximum at pH 6 to 8 for aluminum oxides and pH 7 to 9 for iron oxides (Sims and Bingham, 1968). Above the maximum, boron adsorption decreased. Boron adsorption was maximum on freshly precipitated solids and decreased with aging due to increased crystallinity, adsorption being greater for aluminium than iron oxides because of more surface area of aluminium oxides (Goldberg and Glaubig, 1985).

The mechanism of boron adsorption on aluminium and iron oxides is considered to be ligand exchange with reactive surface hydroxyl group and boron is thought to be specially adsorbed as inner sphere complex (Su and Suarez, 1995). Competing ions such as silicate, sulfate, phosphate and oxalate decrease the magnitude of boron adsorption on oxides in the order phosphate> arsenate> sulfate> chloride (Metwally *et al.*1974).

Magnesium hydroxide has an appreciable capacity of boron adsorption which is not affected by aging (Rhodes *et al.* 1970). Arid zone soils have considerable boron adsorbing capacity in the silt / sand / clay fraction. The site of this adsorption is the hydroxyl magnesium clusters or coatings that exist on the weathering surfaces of ferromagnesium minerals as well as hydroxyl aluminium, hydroxyl iron and the micaceous layer silicates.

Clay Minerals:

Layer silicate clays are important boron adsorbing surfaces in soil, the order of magnitude being kaolinite< montmorillonite< illite (Keren and Mezuman, 1981). Clay minerals exhibit increasing boron adsorption with increasing solution pH with adsorption maxima occurring at pH 8 to10 and boron adsorption decreases with increasing pH above the maximum (Sims and Bingham, 1967). The rate of boron adsorption on clay minerals consists of a fast adsorption reaction and a slow fixation reaction. At first boron adsorbs onto the particle edges and subsequently migrates and gets structurally incorporated into tetrahedral sides replacing structural silicon and aluminium (Couch and Grim, 1968) by the process of ligand exchange.

Boron adsorption for long reaction times (12 hours to 60 days) increased with increasing temperature (Singh, 1971). Boron adsorption on clays also increased with increasing ionic strength of solution (Keren and Sparks, 1994). Decrease in water content decreased boron adsorption on clays. Wetting and drying cycles increased boron fixation with the greatest increase occurring during the first wetting and drying cycle (Keren and Mezuman, 1981). Competiting ions specially phosphate can appreciably reduce boron adsorption (Jasmund and Linder, 1973), whereas the presence of chloride, nitrate and sulphate had little effect. Boron adsorption on clay surfaces is also affected by exchangeable cation (Keren and Mezuman, 1981). Calcium clays adsorb more boron than sodium or potassium clays. On a per gram basis, boron adsorption by soil clays is much less than most oxide minerals.

Organic Matter:

Organic matter is important soil constituent affecting soil boron availability. Native soil boron and hot water soluble boron are highly significantly correlated with organic carbon content (Elrashidi and O'Connor, 1982). Berger and Pratt (1963) reported that large part of the total boron in soil is associated with organic matter in tightly bound compounds. However this boron can be released to soil solution in forms available to plants, by microbial activities. Oxidation of organic matter resulted in increase in plant available boron and decrease in boron fixation.

Soil humus has a chemical affinity for boron and it appears to have an important role in the retention of boron by soils (Parks and White, 1952). Complex formation between diols and boron can explain the fact that boron is not leached from soils high in organic matter. Humus extracted from soil retained significant amounts of boron and was considered to play an important role in boron adsorption (Parks and White, 1952).Soil organic matter adsorbs more boron than mineral soil constituents on a weight basis (Gu and Lowe, 1990). Yermiyaho *et al.* (1988) reported that boron adsorption increased with increasing additions of composted organic matter and this adsorption increased with increasing pH. Boron adsorption on composted organic matter occurred rapidly, reached equilibrium, after three hours and increased with increasing solution ionic strength (Yermiyaho *et al.* 1988).

Calcium carbonate:

Application of lime increases boron fixation by soils because it raises the soil solution pH. In addition to its effect on soil pH, calcium carbonate also acts as an important boron adsorbing surface in calcareous soils (Goldberg and Forster, 1991). Boron adsorption was greater on soils having higher calcium carbonate content (Elrashidi and O'Connor, 1982). Acid soluble boron was highly significantly correlated with calcium carbonate content of soil. Retention of boron on calcium carbonate occurs via an adsorption mechanism but it could be exchange with carbonate group also. The magnitude of boron adsorption maxima for soil samples treated to remove calcium carbonate were statistically significantly lower than those for untreated soil samples indicating that calcium carbonate acts as an important sink for boron adsorption in calcareous soils (Goldberg and Forster, 1991). Boron adsorption on reference calcite increased with increase in pH from 6 to 9, exhibited a maximum at pH 9.5 and decreased with increasing solution pH from pH 10 to 11 (Goldberg and Forster, 1991).

Models of Boron Adsorption:

There are two types of models of boron adsorption-one the empherical models and to the chemical models. Empherical models provide descriptions of experimental absorption data without a theoretical basis. The most popular being Langmuir, Freundlich but Tempkin and Brunauer-Emmett-Teller (BET) adsorption isotherms are also being used (Mondal *et al.*1993). Chemical models provide a molecular description of adsorption using an equilibrium approach. In these models boron adsorption occurs via complex formation with surface hydroxyl groups. Surface complexation models define surface species, chemical reactions, mass balance, charge balance and calculate thermodynamic properties such as activity coefficients and equilibrium constants mathematically. Surface complexation models take consideration of charge both on adsorbate ion and adsorbent surface. However these models have large data requirement and involve complex calculations. The most common models used in this category being constant capacitance model, triple layer model and Stern variable surface charge variable surface potential model. Review of only the empherical models are being presented here.

The Langmuir adsorption isotherm equation was developed to describe gas adsorption on to clean solids, but has often been used to describe boron adsorption by soil materials. The equation is-

$$x/m = kbc / (1+kc)$$

Where x is the amount of adsorbed boron,
m is the amount of adsorbent,
k is the affinity coefficient of the adsorbent to boron,
b is the maximum capacity of the adsorbents for monolayer coverage and
c is the equilibrium boron concentration in solution.

Langmuir adsorption isotherm equation is obeyed only for a uniform adsorbent surface without lateral interactions i.e. imply a constant free energy of adsorption. The Langmuir adsorption isotherm has been used to describe boron adsorption on aluminium and iron oxides, clays, calcite, humic acid and soils. For many studies Langmuir adsorption isotherm equation was able to describe boron adsorption only under conditions of low solution boron concentration (Elrashidi and O'Connor, 1982). When wider boron concentration ranges were taken into consideration (up to 60ppm) the relationship followed a quadratic curve which could be described by BET adsorption equation (Singh, 1964).

It was found that the maximum capacity value (b) for the monolayer of adsorbed boron increases with pH, and the affinity of the adsorbent for boron (k) apparently decreases with pH for kaolinite and montmorillonite but increases slightly for illite (Hingston,1964). The variation in adsorption coefficients with pH was related to changes in the surface of the clays favouring formation of more adsorption sites and a decrease at higher pH resulting from a decline in molecular boric acid relative to borate ions. This adsorption model has two disadvantages:

(i) it does not account for the existence of two boron species of different affinities for the clay, and their varying proportion in the equilibrium solution with varying pH; and

(ii) Different values of the Langmuir coefficients, maximum adsorption and binding energy constants, must be assigned to boron adsorption at any given pH value.

The Freundlich adsorption isotherm equation has often been used to describe boron adsorption by soil materials and its use implies heterogeneity of adsorption sites. The equation may be written as-

$$x/m = KC^{\beta}$$

where β is heterogeneity parameter. The smaller the β the greater the expected heterogeneity. The expression reduces to a linear adsorption isotherm when $\beta=1$. The Freundlich equation is strictly valid only for ion adsorption at solution ion concentration (Sposito, 1984), it has often been used to describe ion adsorption by soil across the entire ion concentration range investigated. The isotherm does not obey Henry's law at low ion concentration nor does it reach an adsorption maximum at high ion concentration. The Freundlich adsorption isotherm has been used to describe boron adsorption on aluminium oxide, clay minerals, calcite and soil. In Freundlich adsorption isotherm, the affinity terms are distributed approximately log normally implying heterogeneity of boron adsorbing sites.

Mondal *et al.* (1993) investigated the adsorption characteristics of 16 acidic alluvial soils of West Bengal and its relationship to soil properties. It was found that the boron adsorption capacity was low for these soils making to susceptible to leaching losses. Adsorption capacity was significantly influenced by organic carbon, cation exchange capacity and different forms of aluminum in soil. The energy related constant were influenced by forms of aluminium.

Jin *et al.*(1988) studied boron adsorption using Langmuir equation in Virginia, USA and found that maximum boron adsorption was related to clay content, surface area, ammonium oxalate extractable iron and aluminium and acidified hydroxyl amine hydrochloride extractable manganese but did not correlate to either soil pH or organic matter content.

Reynaldo *et al.* (2000) studied boron adsorption in soils of Brazil. Adsorption was higher in clayey Oxisols followed by Alfisols. Calcium carbonate prompted an increased in amount of adsorbed boron in all soils. Adsorbed boron was correlated to clay, free aluminium oxide and specific surface area.

Langmuir and Freundlich isotherm fitted well the adsorbed data and highest values of maximum boron adsorption were found in clayey soils which were significantly correlated with contents of total, free and amorphous iron and oxides.

Chapter-III

MATERIALS AND METHODS

MATERIALS AND METHODS

Physiographic Information:

West Bengal has been divided into three agro-climatic regions by the Planning Commission, Govt. of India. But depending on distinctly identifiable landform-hydrology-soil combinations and climate prevailing, Directorate of Agriculture, Govt. of West Bengal, has dividing West Bengal into six agro-climatic sub regions within the three agro-climatic regions.

The area of West Bengal, north of the river Ganges, comprising the districts of Malda, North Dinajpur, South Dinajpur, Darjeeling, Jalpaiguri and Coochbehar is commonly called North Bengal. The area of North Bengal encompasses three agro-climatic sub regions namely Northern Hilly, Tista-Terai flood plain and Gangetic flood plain, comprises an area of 2185.4 thousand hectares.

Soils under study and their collection:

The National Bureau of Soil Survey & Land Use Planning has identified twenty-seven soil series in North Bengal. (Nayak *et al.*, 2001). We collected composite surface and subsurface soil samples from ten soil series of North Bengal. All soils were collected in the month of March to April 2005, before the onset of monsoon. Soils were air dried in shade and ground to pass through a 2 mm sieve and retained for analysis. A portion of the soil was oven dried at 105° C for eight hours for calculation of moisture percentage. All results are reported on oven dry basis. The details of the soil under study is presented in table 1.

Table 1. Selection of sites for sampling:

Site of collection	Depth (cm.)	Police Station and District	Soil series name
Balarampur	0-16	Tufanganj, Coochbehar	Balampur
	16-28	Do	Do
Rajpur	0-17	Coochbehar sadar, Coochbehar	Rajpur
	17-36	Do	Do
Matiar Kuthi	0-16	Coochbehar sadar, Coochbehar	Matiarkuthi
	16-28	Do	Do
Lotafela	0-14	Dinhata, Coochbehar	Lotafela
	14-31	Do	Do
Chunabhati	0-19	Debagram, Darjeeling	Chunabhati
	19-34	Do	Do
Kumargram	0-13	Kumargram, Jalpaiguri	Kumargram
	13-36	Do	Do
Kharibari	0-10	Kharibari, Darjeeling	Kharibari
	10-20	Do	Do
Darbaska	0-10	Phanoidewa, Darjeeling	Daraboyjot
	10-20	Do	Do
Binnaguri	0-10	Rajgunj, Jalpaiguri	Binnaguri
	10-20	Do	Do
Durgapur	0-10	Raigunj, North Dinajpur	Durgapur
	10-20	Do	Do

Methods Used:

Mechanical Analysis:

The percent of sand, silt and clay was determined by the Bouyoucos Hydrometer method after removal of organic matter as described by Day (1965).

Maximum Water Holding Capacity:

Maximum water holding capacity of the soils were determined by Keen and Rockzowski's method (Baruah and Barthakur, 1997).

pH :

pH of this soils were determined in water using soil suspension ratio of 1 : 2.5 with a glass electrde pH meter (Systronics model 303).

Electrical conductivity (EC):

Electrical conductivity of the soil samples were determined in 1: 2.5 soil water suspension at room temperature using a conductivity meter (Systronics model 303).

Cation Exchange Capacity (CEC):

Cation exchange capacity was determined using sodium as index ion. Soils were saturated with sodium acetate (pH 8.2) and leached with ammonium acetate (pH 7.0). Sodium in the leachate was analysed flame photometrically (Hesse, 1994).

Free Oxides of Iron and Aluminium:

Free oxides of iron and aluminium were extracted using citrate-bicarbonate-dithionite (Mehra and Jackson, 1960). Iron in the extract was determined colorimetrically using ortho-phenanthrolein and aluminium by aluminon reagent (Page *et al.*, 1982).

Organic Carbon (OC):

Organic carbon was determined by the Walkley and Black method as described by Page *et al.*, (1982).

Available phosphorus :

Available phosphorus was extracted using Bray PI extracant and determined colorimetrically by the ammonium molibdate–ascorbic acid method (Page *et al.*, 1982).

Available Potassium:

Available potassium was determined in a neutral normal ammonium acetate extract using a flame photometer (Baruah and Barthakur, 1997).

Exchangeable (Ca^{+2} + Mg^{+2}):

Exchangeable (Ca^{+2} +Mg^{+2}) was determined in neutral normal ammonium acetate extract of soil by direct titration with EDTA using Eriochrome Black T as indicator (Tandon, 1999).

Components of soil acidity

Total acidity :

Total acidity was determined by using the procedure of Kappen (1934). Soils were extracted with 1N Na-acetate and the extract titrated with 0.1N NaOH using phenolphthalein indicator.

Total potential soil acidity :

A given amount of soil was leached with an extractant, consisting of 0.5 N $BaCl_2$ and 0.055 N triethanolamine buffer at pH 8.2. The leachate was titrated with standard acid with a bromocresol green-methyl red mixed indicator to determine total potential acidity (Baruah and Barthakur, 1997).

pH-dependent soil acidity :

The pH-dependent acidity was determined by subtracting exchangeable acidity from total potential acidity (Baruah and Barthakur, 1997).

Exchangeable acidity :

Exchangeable acidity was determined by the method of Sokolov (1939) as described by McLean (1965). Soils were extracted with 1N KCl and the extract was then titrated with 0.1N NaOH using phenolphthalein indicator.

Exchangeable Al:

Exchangeable Al was determined in 1N KCl extract of soils colorimetrically using aluminon reagent. (Jackson 1973).

Lime requirement (LR):

LR was determined by New Woodruff's method as described by Brown and Cisco (1984).

Labile carbohydrates

Labile carbohydrates was extracted by autoclaving at 103 kpa at 1210C for one hour. The extracted carbohydrates was filtered and analysed by the method of Dubios *et al.*(1956).

Available B:

Available boron content of the experimental soils were measured by three methods. HWS and hot $CaCl_2$ soluble B was determined by extracting 10g of each soil with 20 ml. of either hot water or 0.01 M $CaCl_2$ and boiled for 10 min. followed by colorimetric measurement of boron by Azomethine-H.(Gupta, 1979). For the mannitol - $CaCl_2$ method, 5 g soil was shaken with 0.01M mannitol - 0.01 M $CaCl_2$ for sixteen hours and B in the resultant filtrate measured colorometrically using Azomethine H. HCl extractable B was extracted by shaking 10 g soil with 20 ml 0.05 N HCl for 10 minutes. Boron in the extract was measured colorometrically using Azomethine H.

Laboratory incubation:

Field soil was collected in bulk, air dried and processed. Salient characteristics of the soil are presented in table 2. One kilogram of soil was taken in plastic containers to which three doses lime namely 0, 0.5 and 1 times of three lime requirement was superimposed with three doses of well composed FYM (which was leached with di-ionized water to minimized boron content) at 0, 10, 20, tons / ha. Thus a total of nine treatments were obtained which was replicated thrice in a Completely Randomized Design (CRD). The soils were watered to field capacity moisture content with deionized water and total of nine wetting and drying cycles were performed within a period of one month. After a month the soils were thoroughly mixed, oven dried at 40^0C and ground in mortar and pestle and sieved to pass 0.2mm. pH, EC, organic carbon, exchangeable acidity, exchageable aluminium and labile carbohydrates were measured using standard method.

Adsorption study:

For the adsorption study, ten grams of soil, each, from the nine treatments of the incubated soil of the previous experiment, was shaken with 20 ml of 0.01 M $CaCl_2$ solutions containing various strength of boron viz. 0, 0.5, 1, 2, 4 ppm respectively for a period of 24 hrs. They were then filtered through Whatman 42 filter paper and boron was estimated in the filtrate using Azomethine H. The data obtained used to calculate percentage of boron adsorbed by soil.

Statistical analysis: The statistical analysis was done following the procedure of Gomez and Gomez (1984). All correlations and regressions were done by SPSS (Version 12.0).

Chapter-IV

RESULTS AND DISCUSSION

RESULT AND DISCUSSION

The results obtained are discussed in the following sections to follow-

(A)Physico-Chemical properties of the experimental soils:

The physico-chemical properties of the experiment soil are presented in table 2. All the soils were strongly to moderately acidic in reaction with pH ranging from 4.16 to 6.76 in top soil and 4.21 to7.28 in sub soil except Balarampur soil series which had neutral top soil and alkaline sub-soil, (pH 7.29). In general the pH of the top soil was less than the sub-soil. This may be probably because of leaching of bases from top, and migration to sub-soil under the influence of heavy rainfall experienced in these regions. A similar trend was also noticed in pH measured in $CaCl_2$ with higher soil pH in the sub-soil than in the top soil. The range of the pH in the top soil being 3.59 to 6.31 and in the sub-soil being 3.55 to 7.02. In general the pH measured in 0.01M $CaCl_2$ was lower than that measured in water.

The electrical conductivity of all the soils were low and all soils were non-saline with EC ranging from 0.02 to 0.24 dSm^{-1}. The EC in the top soil was in general higher than the sub-soil . This is probably because top soil is the site for fertilizer application / salt addition, which results in higher EC of top soil.

The maximum water holding capacity varied from 27.2% to 55.1% in top soil and 25.2% to 54.4% in sub soils. In general the top soil had more water holding capacity than the sub soil, except Kumargram soil series where a reverse trend was observed.

Texture of this soil varied from loam to sandy clay loam with most of the soil having sandy clay loam texture. The clay content varied from 10.0% to 31.6% in top soil and 16.5% to 25.6% in the sub soil. In general the top soil contained more clay than the sub soil except Balarampur, Matiharkuthi, Kumargram and Durgapur.

The oxidisable organic carbon was low to high, varying from 0.42% to 1.17% in top soil and 0.27% to 1.44% in sub soils. Only the Durgapur soil was low in oxidisable organic carbon. Higher content of oxidisable organic carbon was found in sub soils of Lotafela and Kharibari soil series. In rest of soils, oxidisable organic carbon was higher in the top soils than in the sub soils.

The cation exchange capacity was in general low and varied from 3.0 to 19.8 cmol (p^+) kg^{-1} in the top soils and 2.5 to 21.2 cmol (p^+) kg^{-1} in sub soils. The general trend in most of the soil series being lower CEC in the top soil than in the subsoil, a result which could not be explained from the existing data.

The 1 N NH_4OAc (pH 7) extractable Ca+Mg was in general greater in the top soils than in the sub soils. Available Ca+Mg varied between 0.23 to 1.21 cmol (p^+) kg^{-1} in the top soil and 0.31 to 1.05 cmol(p^+) kg^{-1} in the sub soil.

The available P content of all the soils were generally low. The available P content varied from 13.45 to 31.94 kg ha^{-1} in the top soils and 7.22 to 31.73 kg ha^{-1} in the sub soil. Kumargram soil series had the highest P content and Chunabhati soil series the least.

The available K content varied from 72.42 to 203.84 kg ha^{-1} in the top soil and 58.24 to 206.08 kg ha^{-1} in the sub soils. The available K content was low to medium and more K was present in the sub soils of four out of the ten soil series under study.

The CBD extractable Fe ranged between 287 to 1780 μg g^{-1} in the top soil and 587 to 4325 μg g^{-1} in the subsoil. Higher CBD extractable Fe in the subsoil is noticed. Heighest CBD extractable Fe was present in subsoil in Rajpur. Cbd Extractable Al also followed the same trend with lower values in the top soil than the subsoil. The range being 43.97 to 124.74 in the top soil and 50.10 to 347.65 in the sub soil.

(B) Nature of soil acidity

Some important components of soil acidity viz. exchangeable Al, exchange acidity, total potential acidity and pH dependent acidity was studied in the surface and subsurface soils of ten soil series and is presented in table 3.

Table: 2. Physico-chemical properties of soils under study

Soils	Depth	pH		EC dS m^{-1}	Max WHC %	Sand %	Silt %	Clay %	Texture
		Water	$CaCl_2$						
Balarampur	0-16	6.76	6.31	0.11	48.2	55.2	20	24.8	Sandy Clay loam
	16-28	7.29	7.02	0.09	33.5	38.4	36	25.6	Loam
Rajpur	0-17	4.68	4.34	0.12	35.6	40.8	35	23.2	Loam
	17-36	5.23	4.66	0.04	25.2	28.8	51	19.2	Silty loam
Matiar Kuthi	0-16	4.5	4.08	0.07	46.8	54.8	25.9	19.3	Sandy Clay loam
	16-28	5.04	4.42	0.05	40.9	46.9	28.1	22	Sandy Clay loam
Notafela	0-14	5.46	5.39	0.19	49.1	56.8	21	23.2	Sandy Clay loam
	14-31	5.58	5.42	0.15	41.2	47.2	34	16.8	Sandy Clay loam
Chunabhati	0-19	5.21	4.95	0.24	42.9	49.1	19.3	31.6	Sandy Clay loam
	19-34	5.74	5.64	0.05	41.1	47.1	23.3	29.6	Silty loam
Kumargram	0-13	4.16	3.59	0.12	27.2	31.2	52	16.8	Sandy loam
	13-36	4.21	3.55	0.11	49.4	70.4	12	17.6	Sandy Clay loam
Kharibari	0-10	4.73	4.45	0.23	50.2	71.1	8	20.9	Sandy loam
	10-20	4.8	4.2	0.06	48.6	69.1	12.3	18.6	Sandy Clay loam
Darbaska	0-10	4.75	4.17	0.06	55.1	63.1	11.3	25.6	Sandy Clay loam
	10-20	4.89	4.55	0.02	51.5	59.1	15.3	25.6	Sandy Clay loam
Binnaguri	0-10	4.96	4.46	0.21	44.5	51.1	17.3	31.6	Sandy Clay loam
	10-20	4.68	4.51	0.09	43.8	51.1	19.3	29.6	Sandy loam
Durgapur	0-10	4.4	4.26	0.12	50.2	71.1	18.9	10	Sandy loam
	10-20	4.52	4.36	0.07	54.4	62.3	21.2	16.5	Sandy Clay loam
Range (TopSoil)		4.16-6.76	3.59-6.31	0.02-0.24	27.2-55.1	31.2-71.1	31.2-71.1	8.0-52.0	Loam-sandy clay loam
Mean (TopSoil)		4.96	4.6	0.147	44.98	54.43	54.43	22.87	
Range (SubSoil)		4.21-7.29	3.55-7.02	0.02-0.15	25.2-54.4	28.8-70.4	28.8-70.4	12.0-51.0	Loam-sandy clay loam
Mean (SubSoil)		5.198	4.833	0.073	42.96	52.04	52.04	25.7	
Overall mean		5.0795	4.7165	0.11	43.97	53.235	24.06	22.405	

Table: 2. (cont.). Physico-chemical properties of soils understudy

Soils	Depth	Ox Org C	CEC	Av Ca+Mg	Av P	Av K	CBD Fe	CBD Al
		%	cmole(p+) kg^{-1}		kg ha^{-1}		µg gm^{-1}	
Balarampur	0-16	0.99	10.00	0.65	13.55	72.42	424.20	51.12
	16-28	0.48	11.20	0.51	10.18	68.70	658.28	55.21
Rajpur	0-17	0.75	11.00	0.36	25.21	94.82	287.21	60.33
	17-36	0.63	12.30	0.58	16.91	92.58	4325.67	68.51
Matiar Kuthi	0-16	0.93	9.20	0.71	18.49	134.40	843.92	52.15
	16-28	0.75	10.60	0.65	9.59	89.60	830.69	50.10
Notafela	0-14	0.57	9.00	0.70	12.06	178.46	936.75	48.06
	14-31	1.08	6.00	0.65	21.36	202.34	543.48	57.26
Chunabhati	0-19	1.02	4.00	0.85	24.12	120.22	1466.78	58.28
	19-34	0.48	4.90	0.55	7.22	58.24	3742.72	60.33
Kumargram	0-13	1.17	7.00	0.36	31.94	109.76	463.89	43.97
	13-36	0.90	7.60	0.31	32.73	89.60	2244.56	81.80
Kharibari	0-10	0.78	19.80	1.21	29.56	122.46	1206.25	108.38
	10-20	1.44	21.20	0.95	22.54	59.74.	662.76	85.89
Darbaska	0-10	0.93	10.80	0.23	13.45	203.84	1780.67	69.53
	10-20	0.42	11.30	0.32	7.71	206.08	2063.40	71.57
Binnaguri	0-10	0.81	3.00	0.86	22.05	136.64	755.58	124.74
	10-20	0.69	2.50	0.75	25.81	159.04	587.65	347.65
Durgapur	0-10	0.42	9.10	0.95	19.38	129.92	932.26	60.33
	10-20	0.27	10.50	1.05	7.91	147.10	1519.92	334.36
Range	Top Soil	0.42-1.17	3.0-19.8	0.23-1.21	13.45-31.94	72.42-203.84	287-1780	43.97-124.74
Mean	Top Soil	0.837	9.29	0.688	20.98	103.294	909.75	67.69
Range	Sub Soil	0.27-1.44	2.5-21.2	0.31-1.05	7.22-32.73	58.24-206.08	587-4325	50.10-347.65
Mean	Sub Soil	0.714	9.81	0.632	16.19	117.302	1717.91	121.27
Overall mean		0.78	9.55	0.68	18.32	123.80	1313.83	94.48

Exchangeable Al varied from 0.63 to 1.75 meq 100^{-1} gm of soil in the top soils and 0.50 to 2.38 meq 100^{-1} gm of soil in the subsurface soils. Exchangeable Al is an extremely important cation in the exchange equilibria and acidifying process and has deleterious influence on plant growth when present in high concentrations. Exchangeable Al is a measure of reserve acidity and is related to root growths and yield. Exchangeable Al consists of both hydroxyl Al monomeric and polymeric species and is extracted by rather concentrated (0.5 to 1 M) unbuffered salt (KCl /$BaCl_2$) solution. It is the Al that is exchanged from the surface is equilibrium. Exchangeable Al was more in the top soil than in the subsoil. But in the Rajpur and Kumargram soil series, the amount exchangeable Al was more in the subsoil, emphasizing the importance of subsoil acidity in crop production.

Exchange acidity ranged from 0.25 to 1.75 meq 100^{-1} g of soil in the top soil and 0.25 to 2.75 meq 100^{-1} g soil in the sub soil. Exchangeable acidity arises out of the hydrogen and Al ions retained on the exchange complex and is an important component of soil acidity. Exchange acidity was in general greater in the top soil than in the sub soil except in Balarampur and Chunabhati soil series

Total potential acidity, also known as potential acidity comprises a large part of total soil acidity and is due to hydrogen was in various chemical combinations and adsorbed on the surface of soil particles. This form of acidity was measured by extraction with $BaCl_2$-TEA. The total potential acidity ranged from 3.50 to 12.00 meq 100^{-1} g soil for top soil and 4.00 to 12.00 meq 100^{-1} g soil in subsoil. Top soils contained usually higher total potential acidities than sub soils except in Kumargram and Binnaguri soil series.

pH dependent acidity generally arises due to ,ionization of carboxylic and phenolic groups in soil organic matter. Ionization of terminal hydroxyl group associated with sesquioxides also contributes to pH dependent acidity. As can be seen from table 3, pH dependent acidity ranged from 2.50 to 10.50 meq 100^{-1} g soil in the top soil and 3.25 to 9.75 meq 100^{-1} g soil in the sub soil. Sub soil pH dependent acidities in Darabaska, Binnaguri and Durgapur soil series was marginally greater than top soil but for Kumargram, sub soil acidity was much greater than top soil acidity.

Lime requirement varied from 0.5 to 14.5 cmol(p$^+$) kg^{-1} in the top soil and 0 to 15 cmol(p$^+$) kg^{-1} in the subsoil. Average lime requirement in the top soil was 7.69 cmol(p$^+$) kg^{-1}

Table: 3. Nature of soil acidity (meq 100^{-1} g) of soils under study

Soils	Depth (in cm.)	Exchange-ble Al	Exchange acidity	Total potential acidity	pH dependant acidity	Lime Requirement
Balarampur	0-16	0.88	0.50	4.50	4.00	0.5
	16-28	0.75	0.75	4.00	3.25	0.0
Rajpur	0-17	0.75	0.75	7.00	6.25	8.4
	17-36	1.25	0.50	6.50	6.00	6.4
Matiar Kuthi	0-16	0.75	0.63	5.00	4.38	7.5
	16-28	0.50	0.50	5.00	4.50	6.0
Notafela	0-14	0.88	0.75	4.50	3.75	3.8
	14-31	0.63	0.75	4.00	3.25	3.7
Chunabhati	0-19	0.63	0.50	9.50	9.00	5.9
	19-34	0.50	1.00	6.50	5.50	5.5
Kumargram	0-13	1.75	1.75	7.00	5.25	14.5
	13-36	2.38	2.75	12.00	9.25	15.0
Kharibari	0-10	1.25	1.50	12.00	10.50	11.6
	10-20	1.13	0.50	10.00	9.50	9.2
Darbaska	0-10	1.25	1.00	3.50	2.50	7.7
	10-20	0.88	0.25	4.00	3.75	7.4
Binnaguri	0-10	1.13	0.50	9.50	9.00	11.5
	10-20	0.88	0.25	10.00	9.75	4.4
Durgapur	0-10	0.75	0.25	3.50	3.25	5.4
	10-20	0.75	0.25	4.00	3.75	4.7
Range (Top Soil)		0.63-1.75	0.25-1.75	3.50-12.00	2.50-10.50	0.5-14.5
Mean (Top Soil)		1.002	0.813	6.60	5.788	7.69
Range (Sub Soil)		0.50-2.38	0.25-2.75	4.00-12.00	3.25-9.75	0-15
Mean (Sub Soil)		0.965	0.75	6.60	5.85	6.23
Overall mean		0.98	0.78	6.60	5.82	7.0

and the subsoil was 6.23 cmol(p^+) kg^{-1}. the soils of Balampur being neutral in pH had almost no lime requirement.

C. Boron in soils as extracted by different extractants:

All the soils (both top and subsoil) were extracted with different extractants for estimation of available boron, and is presented in table 4. Boron extracted by hot water after boiling for 10 minutes ranged between 0.03 to 1.3 ppm in the top soil with a mean value of 0.66 ppm. The lowest hot water soluble boron (HWS-B) was found in top soil of Kharibari and highest in top soil of Balarampur. This is a matter of concern because Kharibari is a vegetable growing region with predominance of Cole crops being grown which has a higher boron requirement. Only the top soils of Kharibari and Darbaska soil series are different in boron considering 0.5 ppm as the critical limit, the rest of the soils are sufficient in boron. Sufficiency in boron in top soil of major soil series of North Bengal is probably because of repeated application of boron by farmers as a result of increase in consciousness among farmers regarding boron deficiency. In the sub soil also the above mentioned soil series are deficient in boron probably because of lack of hot water soluble boron (HWS-B) was above the critical limit.

The hot $CaCl_2$ extractable boron in top soils ranged between 0.07 to 0.73 ppm with a mean value of 0.38 ppm. In the subsoil the values ranged between 0.04 and 0.68 ppm with a mean of 0.2 ppm. The Mannitol $CaCl_2$ boron ranged between 0.03 to 1.51 ppm in the top soil (mean 0.37 ppm) and 0.13 to 2.48 ppm in the subsoil (mean 0.46 ppm). The HCl extractable boron ranged from 0.52 to 1.08 ppm in the top soil (mean 0.76 ppm) and 0.35 to 0.71 ppm (mean 0.50 ppm) in the subsoil.

Comparison of the mean values of boron, extracted by various extractants reveal that in general the extraction efficiency of HCl >HW>Hot $CaCl_2$>Mannitol $CaCl_2$. However in the sub soil the extraction efficiency was HW>HCl>Mannitol $CaCl_2$>Hot $CaCl_2$. Extraction efficiency is generally related to the mechanism of extraction and boron adsorbing surfaces of the soil.

Table: 4. Boron content (ppm) as extracted by various extractants

Soils	Depth (cm.)	HWS	Hot $CaCl_2$	HCl	Mannitol-$CaCl_2$
Balarampur	0-16	1.30	0.72	0.74	1.51
	16-28	0.89	0.63	0.46	0.25
Rajpur	0-17	0.57	0.28	0.67	0.33
	17-36	0.06	0.06	0.35	0.22
Matiar Kuthi	0-16	0.58	0.15	1.02	0.17
	16-28	0.55	0.13	0.52	0.36
Notafela	0-14	0.60	0.43	0.89	0.17
	14-31	0.67	0.68	0.71	0.14
Chunabhati	0-19	1.03	0.56	1.08	0.03
	19-34	0.67	0.07	0.37	0.18
Kumargram	0-13	0.54	0.64	0.67	0.23
	13-36	0.55	0.16	0.45	0.13
Kharibari	0-10	0.03	0.11	0.65	0.08
	10-20	0.09	0.04	0.58	0.19
Darbaska	0-10	0.06	0.12	0.52	0.32
	10-20	0.10	0.04	0.39	0.47
Binnaguri	0-10	0.68	0.07	0.52	0.31
	10-20	0.67	0.09	0.61	0.14
Durgapur	0-10	1.24	0.73	0.80	0.56
	10-20	1.54	0.14	0.58	2.48
Range	(Top Soil)	0.03-1.30	0.07-0.73	0.52-1.08	0.03-1.51
Mean	(Top Soil)	0.66	0.38	0.76	0.37
Range	(Sub Soil)	0.06-1.54	0.04-0.68	0.35-0.71	0.13-2.48
Mean	(Sub Soil)	0.58	0.20	0.50	0.46
Overall mean		0.62	0.29	0.63	0.41

In the top soil, Mannitol $CaCl_2$ was positively correlated to pH_{H2O} (0.724*) and pH_{CaCl2} (0.652*). Available P was, negatively correlated to both HWS-B (-0.729*) and Mannitol-$CaCl_2$-B (-0.785**). Boron and P are .both anions and share the same exchange/adsorption sites. Hence a negative correlation between them is expected. HWS-B is negatively correlated to exchange acidity (-0.695*) and hot $CaCl_2$ extractable B to CBD-Al (0.646*). With increase in exchange acidity, there is likely to be increase in hydroxy aluminium surfaces which can adsorb boron. Hence a negative relationship obtained. But the positive correlation between CBD-Al and Hot $CaCl_2$-B can not be explained. Hot water soluble boron is positively and significantly correlated to hot $CaCl_2$ extractable boron i.e. to say that both these extractants extract similarly.

In the subsoil, hot $CaCl_2$ extractable boron was positively correlated to pH_{H2O} (0.672*), pH_{CaCl2} (0.681*) and EC (0.737*). HCl extractable boron was positively correlated to EC (0.683*) and negatively correlated to CBD-Fe (-0.799**). Hot water soluble boron was positively correlate to Mannitol $CaCl_2$ extractable boron (0.713*).

When all soils were together used for the correlation study, HWS-B was negatively correlated to lime requirement (-0.47*) and CEC (-0.446*), HCl-B was negatively correlate to CBD-Fe (-0.510*) and positively correlated to EC (0.557*). Hot $CaCl_2$-B was negatively correlated to CBD-Fe (-0.447*) and Mannitol $CaCl_2$-B positively correlated to CBD-Al (0.475*) which are presented in table 5.

Among the various extractants, HWS-B was positively correlated to hot $CaCl_2$ extractable and Mannitol $CaCl_2$ extractable boron (0.637**). Hot $CaCl_2$-B was positively correlated to HCl extractable-B (0.491*) only. No other forms of boron were correlated to each other (table 6) which are presented in table 6.

C. Incubation study:

An incubation experiment was conducted with farm soil, salient properties of which are presented in table7. The soil was incubated with three doses of lime viz. 0, 0.5, and 1 of lime requirement, over which three doses of FYM @ 0, 10, and 20 tonnes ha^{-1} was superimposed. The soils were wetted to field capacity moisture content and incubated for one month during which nine wetting-drying cycles were given. After one month the soils air

Fig. 1 . Change in pH of incubated soils

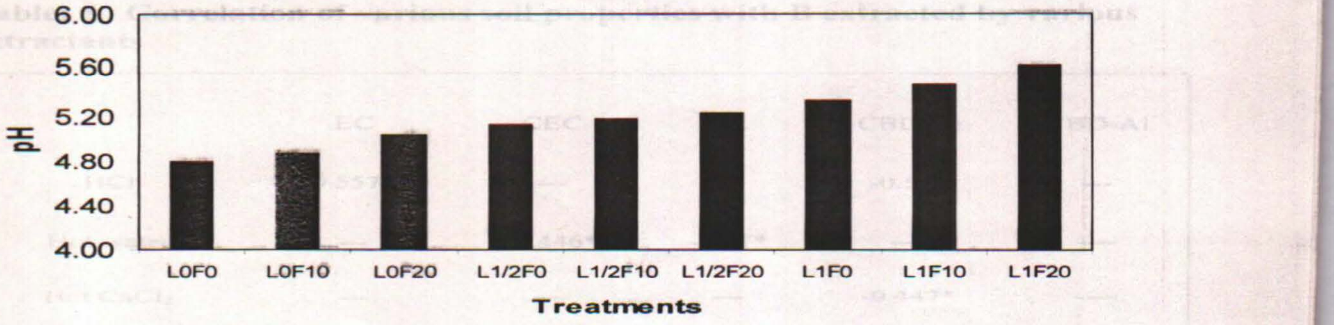


Fig. 2 . Change in exchange acidity of incubated soils

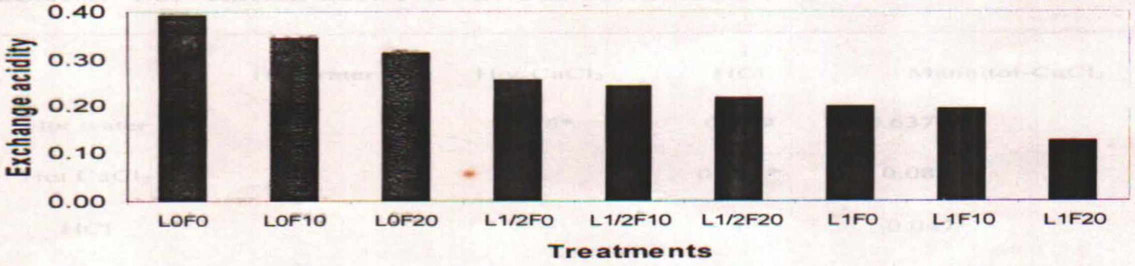


Table: 5 . Correlation of various soil properties with B extracted by various extractants

	EC	CEC	LR	CBD-Fe	CBD-Al
HCl	0.557*	---	---	-0.51*	---
Hot water	---	-0.446*	-0.47*	---	---
Hot $CaCl_2$	---	---	---	-0.447*	---
Mannitol-$CaCl_2$	---	---	---	---	0.475*

Table: 6. Correlation between various extractants of B

	Hot water	Hot $CaCl_2$	HCl	Mannitol-$CaCl_2$
Hot water	1	0.56*	0.369	0.637**
Hot $CaCl_2$		1	0.491*	0.081
HCl			1	-0.047
Mannitol-$CaCl_2$				1

Table: 7. Change in properties of incubated soil

Treatment	pH	Exchange Al meq 100^{-1} g soil	Exchange acidity meq 100^{-1} g soil	CBD Fe µg gm^{-1}	CBD Al µg gm^{-1}	Carbohydrate µg glucose C 100^{-1} gm soil
L_0F_0	4.80	4.94	0.39	2784.65	59.88	580.75
L_0F_{10}	4.88	4.50	0.34	3155.94	112.28	626.19
L_0F_{20}	5.04	3.94	0.31	4269.80	172.16	715.08
$L_{1/2}F_0$	5.13	3.88	0.26	3279.70	122.26	751.95
$L_{1/2}F_{10}$	5.19	2.93	0.24	3774.75	159.68	801.99
$L_{1/2}F_{20}$	5.23	2.81	0.22	4331.68	202.10	834.26
L_1F_0	5.34	3.38	0.20	3465.35	132.24	798.04
L_1F_{10}	5.46	2.25	0.19	4146.04	244.51	836.23
L_1F_{20}	5.62	2.14	0.13	4888.61	339.32	890.23
Overall mean	5.91	3.42	0.25	3788.50	171.60	759.41

dried then dried in an hot air oven at 40^0 C before performing any analysis. Result of the experiments are presented in table **8**.

The soil being acidic in reaction liming was an obvious proposition, and farmers of the region use a lot of FYM at least once a year before the rabi crops. The pH of the soil changed from 4.80 at L_0F_0 to 5.62 at L_1F_{20}, a change of 0.82 pH units. However the mean effect of lime was more prominent than FYM in increasing pH. At L_0 treatment the pH was 4.9 and at L_1 the pH increased to 5.47. However the increase in pH was more between $L_{1/2}$ and L_1 than between L_0 and $L_{1/2}$. The mean effect of FYM alone increased pH from 5.09 to 5.29 an increase 0.2 pH units, which is not much. However the combined effect of lime and FYM was beneficial in increasing pH which are presented in Fig. **1**.

Exchangeable Al was 4.94 meq 100^{-1} soil at L_0F_0 treatment and decreased to 2.14 meq 100^{-1} g soil by the combined effect of full doze of lime and 20 tonnes ha^{-1} FYM. The mean effect of lime was 4.46 at L_0 and 2.59 at L_1. The mean effect of FYM was 4.06 at no FYM addition and 2.96 at 20 tonnes ha^{-1} FYM addition. The decrease due to lime was 1.86 and that due to FYM was 1.1 meq 100^{-1} g soil. Exchange acidity followed a similar trend to exchangeable Al which are presented in Fig.**2**. Exchange acidity was 0.39 meq 100^{-1} g soil at no lime or FYM addition and decreased to 0.13 meq 100^{-1} g soil due to addition of full doses of lime and FYM. Decrease in exchange acidity was mainly an effect of lime addition. Without lime addition, the mean value of exchange acidity was 0.35 meq 100^{-1} g soil and it decreased to less than half (0.17 meq 100^{-1} g soil) at full dose of lime. FYM also decreased the exchange acidity but only by 0.06 meq 100^{-1} g soil by 20 tonnes ha^{-1} FYM addition. pH was highly and significantly correlated to exchange Al (-0.94**) and exchange acidity (-0.983**) which are presented in table **9**. The significant negative correlation of pH to exchange acidity and exchange Al has also been reported which is presented in Fig. **3**.

The CBD extractable Fe was 2784.65 μg100^{-1} gm soil at no lime or FYM addition. It increases to 4888.61 μg100^{-1} gm soil at full lime and FYM dose. The increase in CBD extractable Fe was 22.42% due to full lime dose over no lime application and was 41.55% due to full dose of FYM application over no FYM application. Increase in CBD extractable Fe due to either lime or FYM was probably due to decrease in solubilization of Fe brought about as a result of increase in pH and subsequent neutralization and chelation of Fe by organic legends in organic matter and or formation of α-FeOOH or $Fe(OH)_3$ precipitates, which could be extracted by CBD. CBD-Fe was significantly negatively correlated to

Table: 8. Some Physico-chemical properties of experimental field soil

Particular	Value
pH	5.70
EC (dSm^{-1})	0.14
Organic Carbon (%)	1.42
CEC (meq 100^{-1} g)	8.23
Particle size distribution (%)	
Sand	62.31
Silt	20.87
Clay	16.82
Available Phosphorus (mg kg^{-1})	12.71
Available Potassium (mg kg^{-1})	114.90
Maximum Water Holding Capacity (%)	49.20
Lime requirement (tonnes/ha)	4·1

Fig. 3. Change in exchangeable Al of incubated soils

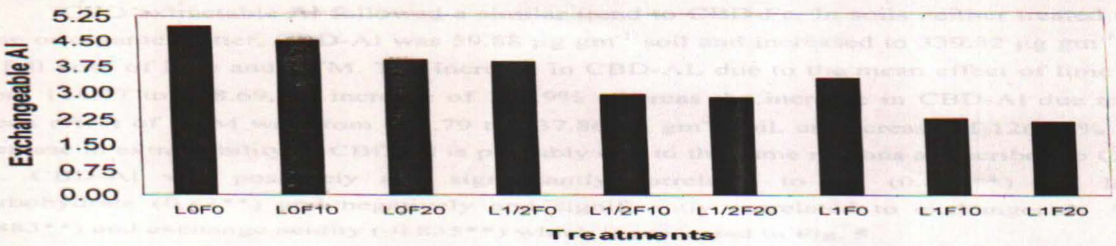
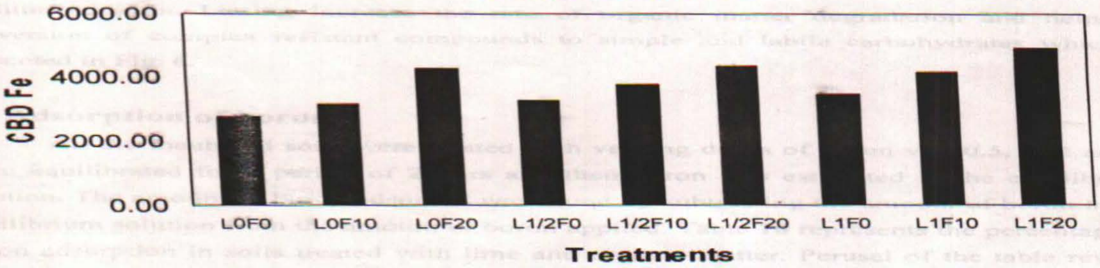


Fig.4 . Change in CBD-Fe (μg gm^{-1}) of incubated soils



exchangeable Al (-0.825**) and exchange acidity (-0.747*) and positively correlated to pH (0.766*), CBD-Al (0.932**) and labile carbohydrate content of the soil (0.807**) which is presented in Fig. **4**.

CBD extractable Al followed a similar trend to CBD-Fe. In soils neither treated with lime or organic matter, CBD-Al was 59.88 μg gm^{-1} soil and increased to 339.32 μg gm^{-1} soil at full dose of lime and FYM. The increase in CBD-AL due to the mean effect of lime was from 114.77 to 238.69, an increase of 107.9% whereas the increase in CBD-Al due to the mean effect of FYM was from 104.79 to 237.86 μg gm^{-1} soil, an increase of 126.98%. The increase in extractability of CBD-Al is probably due to the same reasons as ascribed to CBD-Fe. CBD-Al was positively and significantly correlated to pH (0.873**) and labile carbohydrate (0.83**) and negatively and significantly correlated to exchangeable Al (-0.883**) and exchange acidity (-0.835**) which is presented in Fig. **5**.

Labile carbohydrate increased from 580.75 μg glucose C 100^{-1} gm soil without any treatment to 890.23 μg glucose C 100^{-1} gm soil by full dose of lime and FYM. The mean effect of lime was 640.67 at L_0 and 841.50 at L_1, an increase of 31.34 %. Whereas the mean effect of FYM was 710.25 at F_0 to 813.19 μg glucose C 100^{-1} gm soil at F_{20}, an increase of 14.49%. Thus it may be seen that the increase in liability of carbohydrate is more so an effect of lime addition. Liming increase the rate of organic matter degradation and helps in conversion of complex resistant compounds to simple and labile carbohydrates which is presented in Fig. **6**.

E. Adsorption of boron:

All the incubated soils were treated with varying doses of boron viz. 0.5, 1, 2 and 4 ppm, equilibrated for a period of 24 hrs and then boron was estimated in the equilibrium solution. The amount of boron adsorbed was found by subtracting the amount of boron in the equilibrium solution from the amount of boron applied. Table **10** represents the percentage of boron adsorption in soils treated with lime and organic matter. Perusal of the table reveals that boron adsorption was around 29 % to 32 % with neither lime nor FYM addition over all the concentration of boron applied with an average of 30.93 %. At no lime application, with the increase in FYM addition, boron adsorption decreased, the mean decrease being from 30.93 % to 15.60 %. The decrease was similar over all the concentrations tested but was more

Table: 9 Correlation between properties of incubated soil

	pH	Exchange Al	exchange acidity	CBD Fe	CBD Al	Labile Carbohydrate
pH	1	-0.94**	-0.983**	----	----	----
Exchange Al	----	1	-----	----	----	---
exchange acidity	----	----	1	----	----	----
CBD Fe	0.766*	-0.825**	-0.747**	1	0.932**	0.807**
CBD Al	0.873**	-0.883**	-0.835**		1	0.83**
Labile Carbohydrate	----	----	----	----	----	1

Table: 10 . Adsorption (%) of Boron at various levels of addition

Treatment	1	2	4	8	Mean
			μg gm^{-1}		
L_0F_0	32.54	31.87	30.20	29.12	30.93
L_0F_{10}	28.12	25.45	25.45	21.35	25.09
L_0F_{20}	17.75	16.26	14.57	13.83	15.60
$L_{1/2}F_0$	25.66	22.03	19.99	18.29	21.49
$L_{1/2}F_{10}$	18.91	16.18	15.95	13.54	16.15
$L_{1/2}F_{20}$	15.36	14.97	12.28	11.70	13.58
L_1F_0	89.80	81.98	82.83	79.34	83.49
L_1F_{10}	51.38	45.31	45.12	44.90	46.67
L_1F_{20}	29.77	29.39	28.05	26.05	28.32
Overall mean	34.37	31.49	30.49	28.68	

Fig.5. Change in CBD Al (μg gm^{-1}) of incubated soils

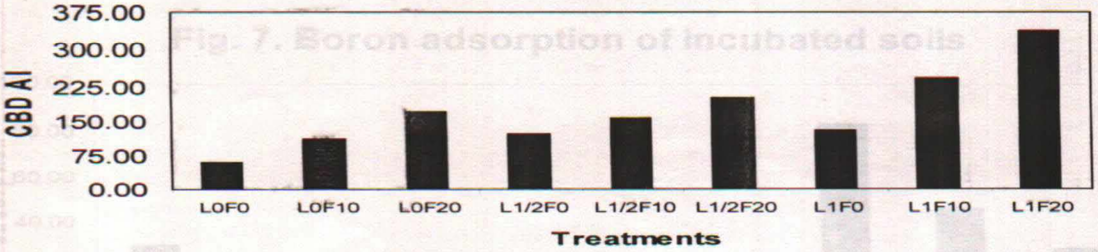
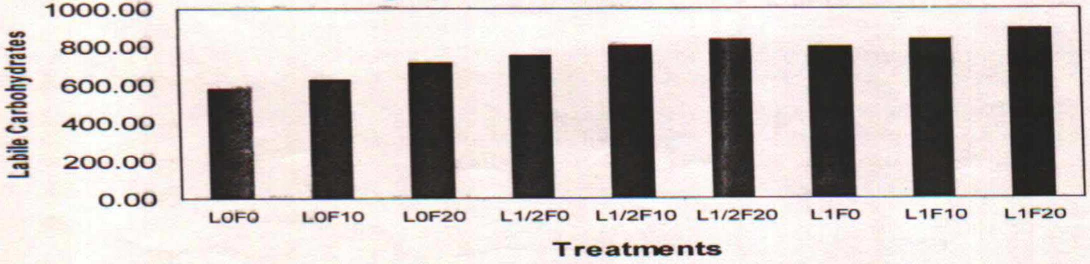


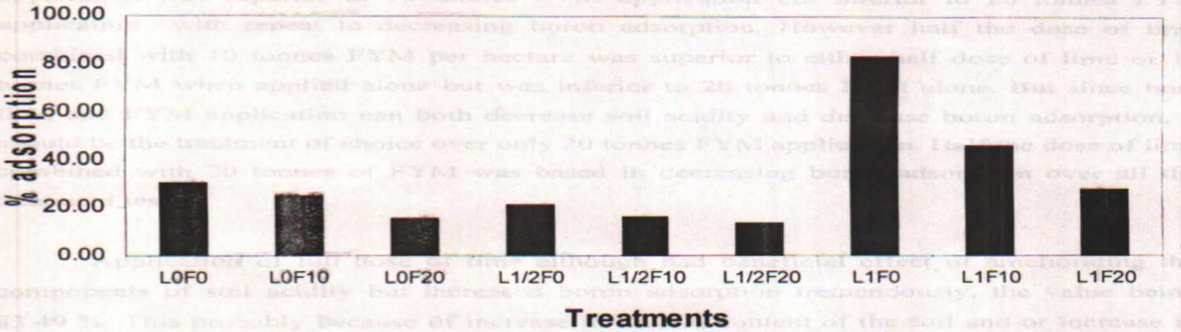
Fig.6. Change in labile carbohydrate (μg glucose C 100^{-1} gm) of incubated soils



at higher concentrations of boron application, than at lower concentrations which is presented in Fig. 7. Thus, only by addition of FYM, a decrease in boron adsorption could be achieved. This is probably because addition of organic matter decreased/marked the sites of boron adsorption. Fixation of boron by boron-diol complex formation was not evident.

At half of the dose of recommended lime addition, boron adsorption was 21.49 %. On comparison it may be seen that this value is less than L_0F_{10} treatment but more than L_0F_{20} treatment [illegible] the dose of lime application was superior to 10 tonnes FYM application but inferior to 20 tonnes FYM application with repect to decreasing boron adsorption. However half the dose of lime combined with 10 tonnes FYM per hectare was superior to either half dose of lime or 10 tonnes FYM when applied alone but was inferior to 20 tonnes [illegible] alone. But since both lime and FYM application can both decrease soil acidity and decrease boron adsorption, it should be the treatment of choice over only 20 tonnes FYM application. Half the dose of lime combined with 20 tonnes of FYM was based in decreasing boron adsorption over all the treatments.

Fig. 7. Boron adsorption of incubated soils



Application of full dose of lime although had beneficial effect of ameliorating the components of soil acidity but increased boron adsorption tremendously, the value being 81.49 %. This probably because of increase in [illegible] content of the soil and or increase in Ca-saturated clay which cause boron to become adsorbed and or fixed. The full dose of lime should not be applied to crops that are sensitive to boron deficiency. But when 10 tonnes FYM was applied in combination with full dose of lime, there was considerable decrease in boron adsorption. The increase in availability of boron over L_1F_0 treatment is due to complexation or covering of surfaces of $CaCO_3$, that act as sites of boron adsorption and or adsorption of humus on to Ca saturated clays. This effect was more when 20 tonnes of FYM was combined with full dose of lime but the overall effect was not better than $L_{1/2}F_{20}$. Hence $L_{1/2}F_{20}$ should be treatment of choice for further experimentation.

When the data were no significant positive correlation was found between boron adsorption and any of the properties of the incubated soils under study. But when three treatments containing full dose of lime was removed from the correlation study, significant negative correlation between boron adsorbed and CBD extractable Fe (-0.938**) at higher concentrations of boron application, than at lower concentrations which is presented in Fig. 7. Thus, only by addition of FYM, a decrease in boron adsorption could be achieved. This is probably because addition of organic matter decreased/marked the sites of boron adsorption. Fixation of boron by boron-diol complex formation was not evident.

At half of the dose of recommended lime addition, boron adsorption was 21.49 %. On comparison it may be seen that this value is less than L_0F_{10} treatment but more than L_0F_{20} treatment, meaning thereby that decrease in boron adsorption by half the dose of lime application was superior to 10 tonnes FYM application but inferior to 20 tonnes FYM application with repeat to decreasing boron adsorption. However half the dose of lime combined with 10 tonnes FYM per hectare was superior to either half dose of lime or 10 tonnes FYM when applied alone but was inferior to 20 tonnes FYM alone. But since both lime and FYM application can both decrease soil acidity and decrease boron adsorption, it should be the treatment of choice over only 20 tonnes FYM application. Half the dose of lime combined with 20 tonnes of FYM was based in decreasing boron adsorption over all the treatment tested.

Application of full dose of lime although had beneficial effect of ameliorating the components of soil acidity but increased boron adsorption tremendously, the value being 83.49 %. This probably because of increase in $CaCO_3$ content of the soil and or increase in Ca-saturated clay which cause boron to become adsorbed and or fixed. The full dose of lime should not be applied to crops that are sensitive to boron deficiency. But when 10 tonnes FYM was applied in combination with full dose of lime, there was considerable decrease in boron adsorption. The increase in availability of boron over L_1F_0 treatment is due to complexation or covering of surfaces of $CaCO_3$, that act as sites of boron adsorption and or adsorption of humus on to Ca-saturated clays. This effect was more when 20 tonnes of FYM was combined with full dose of lime but the overall effect was not better than $L_{1/2}F_{20}$. Hence $L_{1/2}F_{20}$ should be treatment of choice for further experimentation.

When the data were no significant positive correlation was found between boron adsorption and any of the properties of the incubated soils under study. But when three treatments containing full dose of lime was removed from the correlation study, significant negative correlation between boron adsorbed and CBD extractable Fe (-0.938**) and CBD extractable Al (-0.887**) was observed. Thus these are the main adsorbing surfaces of boron in acidic soils under study.

Chapter-V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSIONS

Boron is an essential micronutrient element required for normal growth of plants. In spite of its low natural abundance, B is widely distributed both in the lithosphere and hydrosphere; but B deficiency is most widespread. Soils of the terai region are acidic in reaction and farmers amend these soils by applying lime, but B deficiencies are known to be trigard by liming acid soils. Organic matter in soil has the ability to complex large amounts of B and decrease B availability. There being little information on the effect of combined application of lime and or organic matter on the availability of boron in soils of terai region of West Bengal, the present study was under taken to study the

(i) Available B content and its relation to soil properties and

(ii) To study the adsorption behaviour of B in soil amended with lime and organic matter.

Ten surface soil and ten sub-surface soil was collected from various soil series of North Bengal for fulfilling the first objective and UBKV farm soil was used for the second experiment. All the soils were strongly to moderately acidic in reaction with pH. In general the pH of the top soil was less than the sub-soil. The electrical conductivity of all the soils were low and all soils were non-saline. In general the top soil had more water holding capacity than the sub soil. Texture of these soils varied from loam to sandy clay loam with most of the soil having sandy clay loam texture. The oxidisable organic carbon was low to high, varying from 0.42% to 1.17% in top soil and 0.27% to 1.44% in sub soils. The cation exchange capacity was in general low and varied from 3.0 to 19.8 cmol (p^+) kg^{-1} in the top soils and 2.5 to 21.2 cmol(p^+) kg^{-1} in sub soils.

Exchangeable Al varied from 0.63 to 1.75 meq 100^{-1} gm of soil in the top soils and 0.50 to 2.38 meq 100^{-1} gm of soil in the subsurface soils. Exchange acidity ranged from 0.25 to 1.75 meq 100^{-1} gm of soil in the top soil and 0.25 to 2.75 meq100^{-1} gm soil in the sub soil. The total potential acidity ranged from 3.50 to 12.00 meq100^{-1} gm soil for top soil and 4.00 to 12.00 meq100^{-1}gm soil in subsoil. pH dependent acidity ranged from 2.50 to 10.50 meq100^{-1} gm soil in the top soil and 3.25 to 9.75 meq100^{-1} gm soil in the sub soil. Liming these soils could be beneficial for crop production, except Balarampur soils, which were neutral in reaction.

Boron was extracted with hot water, hot-calcium chloride, hydrochloric acid and Mannitol- calcium chloride. Boron extracted by hot water ranged between 0.03 to 1.3 ppm in the top soil with a mean value of 0.66 ppm. Only the top soils of Kharibari and Darbaska soil series are deficient in boron considering 0.5 ppm as the critical limit, the rest of the soils are sufficient in boron. The hot $CaCl_2$ extractable boron in top soils ranged between 0.07 to 0.73 ppm with a mean value of 0.38 ppm. The Mannitol $CaCl_2$ boron ranged between 0.03 to 1.51 ppm in the top soil (mean 0.37 ppm) The HCl extractable boron ranged from 0.52 to 1.08 ppm. Comparison of the mean values of boron, extracted by various extractants reveal that in general the extraction efficiency of HCl >HW>Hot $CaCl_2$>Mannitol $CaCl_2$. HWS-B was negatively correlated to lime requirement (-0.47*) and CEC (-0.446*), HCl-B was negatively correlate to CBD-Fe (-0.510*) and positively correlated to EC (0.557*). Hot $CaCl_2$-B was negatively correlated to CBD-Fe (-0.447*) and Mannitol $CaCl_2$-B positively correlated to CBD-Al (0.475*).

The pH of the soil changed on incubation from 4.8 at L_0F_0 to 5.62 at L_1F_{20}, on incubation with lime (full LR) and FYM (20 tonnes ha^{-1}). Exchangeable Al was 4.94 meq 100^{-1}g soil at L_0F_0 treatment and decreased to 2.14 meq 100^{-1} g at L_1F_{20}. Exchange acidity followed a similar trend to exchangeable Al but decrease in exchange acidity was mainly an effect of lime addition. The increase in CBD extractable Fe was 22.42% due to full lime dose over no lime application and was 41.55% due to full dose of FYM application over no FYM application. CBD extractable Al followed a similar trend to CBD-Fe, but results were lower. Labile carbohydrate increased due to both lime and organic matter addition.

Boron adsorption was around 30.93 % with neither lime nor FYM application. Boron adsorption decreased, with the increase in FYM addition, the decrease was similar over all the concentrations tested but was more at higher concentrations. Half the dose of lime combined with 10 tonnes FYM per hectare was superior to either half dose of lime or 10 tonnes FYM when applied alone. Application of full dose of lime although had beneficial effect of ameliorating the components of soil acidity but increased boron adsorption tremendously and hence should not be recommended for soils growing boron sensitive crops.

Chapter-VI

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