DISTRIBUTION, TRANSFORMATION AND INTERACTIONS OF BORON IN SOIL ECOSYSTEM IN RELATION TO GROWTH AND NUTRITION OF RAPE (*Brassica campestris* L.)

A
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AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

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Dedicated
to
My Beloved
Parents

APPROVAL OF EXAMINERS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

We, the undersigned, having been satisfied with the performance of **Mitali Mandal**, in the *viva-voce* Examination, conducted today, the....................., 20......, recommended that the thesis be accepted for the award of the degree of Doctor of Philosophy in Agricultural Chemistry and Soil Science of Bidhan Chandra Krishi Viswavidyalaya.

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This to certify that the thesis entitled "**Distribution, transformation and interactions of boron in soil ecosystem in relation to growth and nutrition of rape (*Brassica campestris* L.)**" submitted by **Mitali Mandal** for the **award of the degree of Doctor of Philosophy** in **Agricultural Chemistry and Soil Science** of the Bidhan Chandra Krishi Viswavidyalaya, is the record of faithful and bonafide. The research work was carried out by Miss Mandal under my direct supervision and guidance. The results of the investigation, reported in this thesis have not so far been submitted for any other Degree or Diploma. The assistance and help received during the course of investigation have been duly acknowledged.

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Title of the Thesis : **Distribution transformation and interactions of boron in soil ecosystems in relation to growth and nutrition of rape (*Brassica campestris* L.)**

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Abstract

The present experiment was undertaken both in the laboratory and in the field to study the distribution of different fractions of boron using different extractants, transformation including interactions and adsorption reactions. Efficiency of sources of boron was evaluated in the presence of organic manure. With regards to the distribution of different forms of boron, soils of terai, old and new alluvial, red and laterite and coastal zones of West Bengal varied with boron contents extracting with hot calcium chloride, mannitol-calcium chloride and Mehlich-3 solution and soil properties. Adsorption of boron by inceptisol and alfisol has recorded an increase when soils are treated with organic matter. Adsorption of boron increased with the increasing concentration of applied boron but the percent of adsorption decreases. The supply parameter and maximum buffering capacity of boron in both soil was higher with higher amount of boron applied. With regards to the interaction effects of boron with sulphur, zinc and organic matter, it was found that the highest amount of boron was recorded in soils when boron and sulphur was applied combinedly. Comparing the results for the changing the biological indices it was observed that most of the biological parameters in rhizosphere soils viz. prolifireation and potentialities of nonsymbiotic nitrogen fixing bacteria and phosphate solubilizing microorganisms and microbial biomass carbon were proved superior when boron and organic matter were applied combinedly. It is evident that some of the biochemical indicators may be useful in predicting for diagnosing the boron deficiency in plants and so the results of the present investigation also suggested the activities of indoleacetic acid oxidase and polyphenol oxidase in plants were highest in soils not supplied with boron (control treatment) suggesting those indicators used for the predicting the boron deficiency in plants. The results further envisaged that irrespective of zones (rhizosphere and non-rhizosphere soils) and treatments Mehlich-3 was proved superior extractant for boron in soils.The yield , oil and protein content were recorded highest when boron at 0.5 kg ha^{-1} as calbor and organic matter at 5 t ha^{-1} as FYM was applied combinedly being 60.10, 13.86 and 25.77 percent increase over control respectively.

Key words: Adsorption, boron, extractants, interaction, organic matter, rape, yield

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Chapter I

Introduction

Introduction

Micronutrients especially the application of boron have received a great deal of importance in high responsive oil seed crops during the last few years, because of its widespread occurrence of deficiency from different parts of India as well as in West Bengal. Significant response of oil seed crops to the application of boron containing fertilizers have also been reported by many investigators (Chakraborty and Das, 2000; Mandal *et al.*, 2009). However, the main reason for becoming deficiency of boron is the adoption of intensive cropping programme with the high yielding varieties and modern agro-technologies like use of high analysis chemical fertilizers (off – farm inputs); pesticides etc. and very little or no use of on-farm inputs, organic manures.

Among oil seed crops grown in India, rape and mustard assume significance in the Nation's economy occupying second position in area and production next to groundnut. Rapeseed is now one of the most important sources for vegetable oil in the world. It is considered to be healthy edible oil due to its low content of saturated fatty acids and its moderate content of polysaturated fatty acid among vegetable oils. Rapeseed is also a potential bioenergy crop to alleviate the shortage of petrochemical resources in many nations (Wang, 2004).

Boron is one of the essential micronutrients required for normal growth of plants and it has a marked effect on plants from the stand point of both nutrition as well as toxicity since its range between deficiency and toxicity levels in soils is very narrow (Warington, 1923). Boron is mainly present in soil solution as a non-ionised molecule, $B(OH)_3$ over the pH range suitable for the plant growth and can be leached from the soil very easily particularly in high rainfall condition (Yan *et al.*, 2006). However, the information about the distribution of various fractions of boron in soils of West Bengal and its reaction with various soil components are still very limited because of its difficulty for the analysis and hence the present study was undertaken to address those above aspects.

The complexity of B both in the plant and soil systems makes it challenging to develop a soil B extraction method that can determine nutrient status matching with plant requirement under a wide range of soil conditions for various plant species (Shiffler *et al.*, 2005a). Boron availability in soil is modified by various soil characteristics such as pH, texture, moisture, temperature, organic matter, Fe – Al – oxides content and clay mineralogy. Soil tests for plant available B has been developed principally to predict deficiency, not to determine toxicity (Goldberg *et al.*, 2002). Assessment of available B status in soils is one of the most demanding and difficult task routinely performed in soil testing laboratories (Mahler *et al.*, 1984).

Boron occurs in soils as its various forms viz., water soluble, adsorbed and organically bound which undergo interaction reactions with different soil components like pH, moisture content, organic matter content, free $CaCO_3$ content, sesquioxides etc. modifying its availability to plants. Boron concentration in soil solution is largely regulated by its adsorption onto soil colloids and also by its reaction with other ions and different soil components. Adsorption sites of B in soils act as a pool for mobilizing and retaining boron in soils. Adsorption reaction affects the quantity intensity relationship of boron as well as the kinetic parameters and hence its availability to plants. Therefore, adsorption study of boron under different management system relating various adsorption parameters with different soil physical properties using Langmuir and Freundlich adsorption isotherms has been undertaken in the present investigation.

The role of soil organic matter content on B soil solution concentration and B uptake by plants is not fully understood rather contradictory. Therefore, it was felt necessary to study the transformation of applied boron in soils as well as its effect on rape affected by organic matter under field conditions growing rape (*Brassica campestris* L.) as a test crop.

It is also evident that the activity of IAA oxidase, polyphenot oxidase, ribonucleone are known to influence due to B apply. It has been also reported that an increase in IAA oxidase activity is believed to be a index of B deficiency in plants (Das, 2007). However, very little or no information is still available on these aspects and hence it is undertaken in the present study.

Keeping all these in view the present research programme was undertaken to study the distribution transformation and interactions of boron in soil ecosystems in relation to growth and nutrition of rape (*Brassica campestris* L.) with the following objectives.

- To study the distribution of boron in relation to soil properties and its transformation with reference to adsorption and interaction reactions.
- To study the distribution of boron in relation to soil properties and its transformation with reference to adsorption and interaction reactions.
- To evaluate the biological changes relating to the proliferation and potentialities of N_2– fixing and P–solubilising microorganisms as well as microbial biomass carbon in soils.
- To diagnose the boron deficiency based on biochemical indicator like LAA and polyphenol oxidase as well as transformation of boron in plants.
- To study the yield and quality attributes of crops.

Chapter II

Review of Literature

Review of Literature

Micronutrients play a vital role to maintain soil and plant health. Boron is an essential micronutrient, which needs a special attention for crop production especially for oilseed crops. Due to adoption of intensive cropping system with modern agro techniques, majority of soil nutrients particularly of B becomes deficient in soils. Therefore, an attempt is being made to collect the available information relating to factors influencing the distribution transformation and interactions of B in soils in relation to growth, yield and nutrition of rape.

2.1 Distribution of available boron in soils

Boron may be considered as a typical metalloid having properties in between metals and electronegative non-metals. Boric acid and $H_2BO_3^-$ ion dominates in soils greater than pH 9.2 (Lindsay, 1973)

The total boron content of normal soils ranges from 2 to 200μg g^{-1} (Swaine,1955).Higher values are found in soils formed from shales , loess and alluvium, while limestone is characteristically low in boron ,derived soils are usually high, a factor attributable to intensive concentration during soil formation. Inorganic boron in soils is mainly in the form of tourmaline except in arid climates where borates of alkali and alkaline earth metals predominate. Boron occurs in soils as its various chemical pools viz. soil solution boron (readily available boron). adsorbed boron (labile pool of boron),organically bound boron and boron in rocks and minerals and each form is in dynamic equilibrium with other forms. Each fraction of boron has its practical significance in plant nutrition . The concentration and composition of boron in soil solution boron is believed to be variable according to soil types and reaction . Adsorbed boron constitutes a labile pool of boron maintaining its soil solution phase , while organically bound boron is believed to be associated with diol type of compounds (Das, 2007).

Chude (1988) studied the distribution of extractable B in cocoa – growing soils in Nigeria and found that the hot water, 1.0 N NH_4O AC and

0.1% $CaCl_2$ extractable forms varied from 0.13 – 1.38, 0.03 – 0.56 and 0.44 – 1.20 with mean values of 0.66, 0.27 and 0.75 µg g^{-1} respectively. Schuppli (1986) also studied the distribution of different extractable forms of B for some reference soil samples of Canada and observed that hot water, hot 0.02 M $CaCl_2$ and Mannitol $CaCl_2$ extractable B varied from 0.11 – 6.79, 0.07 – 1.32 and 0.08 – 1.94 with mean values of 1.52, 0.44 and 0.55 µg g^{-1} respectively.

Cartwrignt *et al.* (1983) while studying the distribution of available B in soils used for cereal and pasture production in semi-arid regions of south Australia, compared alternative extractants for determination of easily soluble B against the hot water extraction and observed that hws and $CaCl_2$ + 0.5 M mannitol extractable B ranged from 0.02 – 2.52 and 0.11 – 1.91 with mean values of 1.2 and 0.58 µg g^{-1} respectively. Aitken *et al.* (1987) compared the extractability of different solutions for available B in some acidic Queensland soils and observed that the hot water, hot $CaCl_2$, mannitol $CaCl_2$, 1.0N NH_4OAC, 0.01 M tartaric acid and 5% glycerol – $CaCl_2$ extractable B content in the soils ranged from 0.12 – 0.93, 0.12 – 1.88, 0.01 – 0.11, 0.06 – 0.69, 0.02 – 0.58 and 0.01 – 0.23 with mean values of 0.41, 0.63, 0.02, 0.27, 0.23 and 0.05 µg g^{-1} respectively. They observed a very low B content in most of the soils with mannitol -$CaCl_2$ and 5% glycerol – $CaCl_2$ extractants indicating their unsuitability for acidic soils.

However, several investigators reported that the amount of hot $CaCl_2$ (HCC) extractable B content in soils was found to be varied widely , the values ranged from .065 to 0.485 mg kg^{-1} with a mean value of 0.246 mg kg^{-1}.

Further, it has been reported that out of total 3953 soil samples analysed the available boron content ranges from trace to 3.30 mg kg^{-1} with a mean value of 0.34 mg kg^{-1} . The B status was lowest (.02 mg kg^{-1}) in Balarampur Block of Purulia district and highest (3.30 mg kg^{-1}) in Onda Block of Bankura district . Overaall soil samples deficient in available B was 64 percent (based on the critical limit 0.36 mg kg^{-1}, HWS).However, it was also recorded that the district wise magnitude of deficiency was 57,53 and 80 % in Bankura, Midnapore and

Purulia districts respectively (Mani and Halder,1996; Giri, 1998; Saha and Haldar,1996;Chkraborty and Das, 2000 and Bose and Das,2005).

Mandal and De (1993) and De (1997) studied the depth – wise distribution of available B in some acidic Inceptisols of West Bengal and observed that tartaric acid (TA), ammonium acetate (AA), mannitol calcium chloride (MCC) and hot calcium chloride (HCC) extractable B content of the surface soils ranged from 0.16 to 1.35, 0.07 to 0.48, 0.15 to 049 and 0.07 – 0.50 with mean values of 0.35, 0.32, 0.28 and 0.27 $\mu g\ g^{-1}$ respectively.

Fleming (1980) categorized it into three main forms viz., B in silicate structures, B associated with clay minerals and sesque-oxides (adsorbed), B bound organically and that soluble in water. Their relative preponderance in soils and contribution to available form, however, vary. The latter two forms mainly control the plant available amount in soils while the first one is extremely resistant and can supply only a very little amount to the available pool. However, distribution of different fractions of B forms in soils has not been studied adequately. Xu *et al.* (2001) also worked on soils boron fractions and their relationship to soil properties in 13 Chinese soils. Their observations showed that 87.4 – 99.7% of the soil B was in the residual fraction, which generally does not have any relation with plant uptake. Non-specifically adsorbed B comprised 0.06 – 0.99% of the total soil B, specifically adsorbed B 0.01 – 0.61%, Mn oxyhydroxide – bound B 0.03 – 4.98%, B occluded in amorphous Fe and M oxides < 0.01 – 2.98% and B occluded in crystalline Fe and Al oxides 0.03 – 7.57%.

A study on profile distribution of B fractions in relation to soil properties in arid soils of western Rajasthan was carried out by Chaudhary and Sukla (2003). In profile samples the available B concentration varied from 0.40 – 3.70 mg kg^{-1}, with a mean value of 1.52 mg kg^{-1}. The available B contributed on an average, about 6.3% of the total while specificaally adsorbed fraction 2.1%, oxide – bound B 1.6%, organically – bound B 4.1% and residual B 91.1%.

Patil *et al.* (1989) reported that the available B in Indian soils varied from 0.03 – 3.02 $\mu g\ g^{-1}$. Katyal and Sharma (1979) reported that available B content in Indian soils ranged from 0.03 – 3.82 with a mean of 0.58 $\mu g\ g^{-1}$ in 2929 samples. Singh and Sinha (1976) also found that about 50% soil samples collected from Purnea district of Bihar were deficient in B. The medium black calcareous soils of western Gujarat, however, contained a higher amount (0.95 – 1.47 with a mean of 1.21 $\mu g\ g^{-1}$) of available B (Hadwani *et al.*, 1989). The salt affected soils of Punjab were also observed to contain a higher amount (0.1 – 15.5 with a mean value of 2.8 $\mu g\ g^{-1}$) of hws B (Sharma and Bajwa, 1989).

Arora and Chahal (2005) studied the available boron content in some benchmark soils of Punjab under different moisture regime in relation to soil characteristics. Available boron (hot water soluble) ranged from 0.28 to 0.84 mg kg^{-1} in the surface and 0.12 to 0.72 mg kg^{-1} in the subsurface. Available boron was positively correlated with soil Ph (r=0.47 *) and EC(r= 0.57*) but negatively with clay (r=-0.38*) and CEC(r=-0.37*).

Information regarding the distribution of B in soils of West Bengal is very much limited.

Therefore, it is felt necessary to study the distribution of boron in soils in relation to different physicochemical properties of soils.

2.2 Plant response for boron

Boron deficiency is a widespread nutritional disorder. Under high rainfall conditions boron is readily leached from soils as $B(OH)_3$. Boron has a marked effect on plants from the stand point of both nutrition as well as toxicity . The range between the level of soil boron resulting in deficiency and that causing toxicity in plants, is relatively small. Various maladies and disorders relating to growth and production of many field and horticultural crops such as Chaffy grain of wheat, heart rot of Beet; hollow of Cabbage; brown heart of Cauliflower and poor growth and yield of some crops have been found to be reported in India due to boron deficiency in soils(Das, 2007).

The amount of B required for normal crop growth and reproduction is different with various plant types. Based on B requirement, plants could be divided into three groups: graminacious plants, which have the lowest demand for B; the remaining, monocots and most dicots with an intermediate requirement; and the latex forming plants, with the highest B requirement among the plant species.

In barley and triticale, there are also additional effects on degeneration of terminal spikelets, which give the ear the rattail symptom and fewer spikelets per ear (Wongmo *et al.*, 2004). Boron deficiency often produces 'chaffy grains' of wheat (*Triticum aestivum* L.) (Pal and Mandal, 1985; Chatterjee *et al.*, 1980), which occurs in B deficient soils of north Bengal.

It is commonly accepted that floral and fruiting organs are especially sensitive to B deficiency (Dell and Huang, 1997; Dell *et al.*, 2002). In many crops there is much higher demand for B during flowering and seed set even in crops where the B levels of leaves are in sufficient amount. Many investigators reported that the application of boron through different sources either a soil or foliar spray was found to be beneficial plant growth as well as increasing yield of crops like wheat (Mandal and Das,1988 and Mondal,1991),mustard (Chakraborty and Das, 2000). On the contrary , Singh and Singh (1984) reported that the dry matter production of Lentil and barley decreased with the application of boron. However, a number studies have increased the significance of the role of foliar nutrient application on the productivity of the plant (Asad *et al.*, 2003; Perica *et al.*, 2001). The effect of foliar application of B at the rate of 0.3 to 1.3 kg B ha^{-1} increased the yield or seed weight of soybean (*Glycine max* L.) and cotton (Gascho, 1993; Oplinger *et al.*, 1993). It was also reported that there was an increase in fruit set and yield with foliar applications (Perica *et al.*, 2001).

Wheat stertility is a widespread problem in rice-wheat cropping system of Asian countries, such as Bangladesh, Thailand, Nepal, China and India, leading to significant losses of grain yield (Rerkasem,1996a). Many factors may contribute to the formation of sterile florets of wheat, of which B deficiency (Rerkasem, 1996 a, b) is most influential. In many cases, B deficiency is at least partially responsible for the induction of floret sterility and low grain set and its impact may be exacerbated by environmental factors (Rawson, 1996; Rerkasem, 1996a). Wheat vegetative parts show no obvious leaf symptom or growth reduction even when the new leaves have less than 2 mg B kg^{-1} dry matter, but the B requirement in anthers for successful grain set is 10 mg B kg^{-1} dry matter (Rerkasem *et al.*, 1997). The striking difference in the susceptibility to B deficiency between vegetative and reproductive growth makes the early detection and prediction of B deficiency difficult in the field. Therefore, identification of critical periods of anther and floret development would allow timely application of corrective B fertilizer treatments, as foliar B sprays, to reverse the effect of B deficiency on wheat fertility. Low B content in soils and incidences of B deficiency are prevalent in the Indian north – western states of Bihar, West Bengal, Orissa, Meghalaya and Assam and Uttar Pradesh (Sakal and Singh, 1995; Giri,1998; Saha and Haldar,1996 and Bose and Das, 2005), where failure of grain set and responses to B in wheat have been reported (Mandal and Das, 1988; Ali and Roy, 1989; Mandal and Chakraborty, 1988).

Rapeseed mustard is sensitive to B deficiency, and hence B fertilization is important for maintaining a high yield of rape (Myers *et al.*, 1983). Fertilization of a clay soil at 0.7 mg kg^{-1} B improved plant height, pod-bearing branches and pod number per plant, seed number per pod, seed yield and oil content of *Brassica napus* L. (Hu *et al.*, 1994).

Lu *et al.* (2000) reported that application of B containing fertilizer contributed 48.5% increase in yield of rapeseed. Salroo *et al.* (2002) conducted a field experiment to study the effect of integrated nutrient management (INM) practices on yield and yield attributes of brown sarson (*Brassica campestris* var *Sarson*) and reported that the yield and yield attributes are superior where the fertilizer level was FYM at 10 t + 40 kg S + 25 kg $ZnSO_4$ + 1 kg B ha^{-1} than the control treatment where no application of boron.

Sarkar *et al.* (2004) conducted an experiment to identify and characterize 14 cultivars at rapeseed and mustard based on grain yield and its component characters under high rainfall (300 mm per annum) and sandy soil, due to which boron leaches through the soil layer resulting in their deficiency. They have given boron treatments where 0, 2 and 5 kg boron (0, 0.221 and 0.553 kg B respectively) and classified 14 cultivars of rapeseed and mustard as highly boron responsive, moderately responsive and non-responsive based on the grain yield and its component character in highly boron deficient soil.

Bose *et al.* (2002) showed that the amount of B in rape has been found to be increased with the application of both B and lime separately, being further enhanced due to combined application of B at lower level and lime at both levels suggesting a beneficial effect exists in relation to growth and nutrition of rape.

Li *et al.*(2004) reported that the application of boron at its higher level (5.1 kg ha^{-1}) increased the biomass yield with simultaneously decreased the grain yield.

Eori (2000) studied the effect of B application as foliar spray (4 or 6 kg ha^{-1} of boron) on rape and reported that a significant increase (29.1%) yields was recorded over that of control treatment.

Hu *et al.* (1994) evaluated different levels of B growing rape in the field and reported that out of different levels ,the application of 0.7 mg kg^{-1} B was proved an optimum level where the different growth attributes ,seed and oil yield increased significantly.

Zou *et al.* (2008) studied thc effects of boron fertilizer on the growth and yield of rape (*Brassica napus*).The application of B enhanced the vegetative growth and yield component of rape. The average increment due to B fertilizer application was 428 kg ha^{-1} and the increase rate was 19.2% for all 30 trails. Compared to the control (no application of B), about 70% of the trails was significantly increased due to B application. The yield increment due to B application had a significant negative correlation with soil available B content.

In a field experiment in Assam, wheat cv. Sonalika was given 40 : 20 : 20, 50 : 25 : 25 or 60 : 30 : 30 kg N : P_2O_5 : K_20 / ha or 10 kg borax and / or 10 t ha^{-1} farm yard manure. Grain yield increased with increasing NPK ratio. The application of 60 : 30 : 30 kg N : P_2O_5 : K_2O produced the grain yield of 1.94 t ha^{-1}. The application of 10 kg borax + 10 t FYM produced the highest grain yield of 2.07 t ha^{-1} which was not significantly different from 1.92 t ha^{-1}

obtained alone. The application of boron alone did not significantly increase grain yield (Das and Guha, 1998).

Sharma *et al.* (1999) reported that the combined application of FYM and B at 0.5 mg kg^{-1} soil significantly influence the B concentration in stable and total B accumulation in sunflower. They also found that the application of FYM increased the availability of native and applied B to sunflower crop.

Shukla *et al.* (1983) reported that oil content of Rai (*Brassica juncoa*) was found to be significantly improved due to application of boron either alone or in combination with sulfur and zinc.

2.3 Evaluation of extractants for assessing plant available boron in soils

Studies on B fertilization have shown that the ranges between deficiency and toxicity of B are quite narrow, and that an application of B can be extremely toxic to plants at concentrations only slightly above the optimum (Keren and Bingham, 1985; Gupta *et al.*, 1985). This emphasizes the need for careful appraisal of B status through soil and plant tests for judicious application of B fertilizers.

`The complex behaviour of B in the plant and soil systems makes it difficult to develop a suitable soil B extraction method that can determine the available nutrient status relative to plant needs under a wide range of soil conditions and plant species. A suitable soil analysis for determining available B must be taken into account a number of chemical, pedological and environmental factors and at the same time be amenable to routine operation in the laboratory. Soil test for plant available B has been developed principally to diagnose deficiency, not to determine toxicity (Goldberg *et al.*, 2002). It should also be appreciated that since a single soil test cannot be recommended for all soils, selection of an extractant that may predict B availability in relation to crop nutrition in a particular group of soil climate is important. While most of the Indian work deals with the correction of B toxicity in saline soils of arid zone and B - deficiency in calcareous soils (Chauhan and Asthana, 1981; Sakal *et al.*, 1987). However, information regarding suitable extractants for prediction of B availability in acid alluvial soils of the country is very much limited or lacking. The hot – water extractable B (Berger and Truog, 1944) is the most common method of obtaining an index of plant available B is soil (Bingham, 1982; Cartwright *et al.*, 1983). The hot water method has the capacity to extract B from the organic, adsorbed and soluble pools of the soils (Offiah and Axley, 1993). Several workers postulated that hot water extraction may not predict B supplying power of soil (Baird and Dawson, 1955; Baker and Mortensen, 1966; Colwell, 1943).

Several attempts have been made to identify suitable alternatives to hot water extraction - ammonium oxalate, saturation bicarbonate – DTPA (Nable *et al.*, 1977). Colwell (1943) proposed a biological test for available B using sunflower wherein a high B demand is placed on the soil. Baird and Dawson (1955) suggested a six hour soxhlet hot water extraction . Soxhlet extractable B appeared to include all forms of soil B available to plants including that in the adsorbed form. Hatcher *et al.* (1959) thought that plants responded only to B in solution and were not affected by adsorbed B. These results would indicate little use of considering soil adsorbed B (capacity factor) in assessing B availability in soils. Besides, this method (soxhlet extractable) is time consuming and not outstandingly better than the original one. Baker (1964) and Baker and Mortensen (1966) reported that refluxing with 1.0% $CaCl_2$, $2H_2O$ extracted essentially the same amount of B as did hot water with less turbidity.

`The use of acid extractants for solubilizing B has also been investigated (Woodbridge, 1940; Cook and Miller, 1939; Cox and Kamprath, 1972; Dwivedi *et al.*, 1993; Rashid *et al.*, 1994). Some obtained a good correlation with plant B concentration (Rashid *et al.*, 1994), while others found it less efficient for prediction of B availability in soils (Berger and Truog, 1944; Rogers, 1947; Cox and Kamprath, 1972; Dwivedi *et al.*, 1993). Philipson (1953) also favoured acid extraction provided the final pH was less than 2.8. Baker (1964) extracted soils with 85% (V : V) H_3PO_4 but concluded that this reagent was less suitable than boiling water. Cartwright *et al.* (1983) recommended the use of 0.1 M $CaCl_2$ – 0.05 M mannitol for extraction of B in soil and noted that this extractant is as effective as hot water in predicting B uptake by wheat plants in soils from South

Australia. Several investigators (Rashid *et al.*,1994, Dwivedi *et al.*,1993 and Bose and Das,2005) have also used mannitol as an extractant for assessing soil B availability. Vaughan and Howe (1994) proposed the use of a chelator, sorbitol rather than mannitol in extracting B from a group of soils with diverse chemical and physical properties. Although sorbitol extractable B has not yet been correlated with plant B uptake, DTPA – sorbitol method is being recommended by the North American Proficiency Testing Programme for assessing the potential availability of Zn, Cu, Mn, Fe and B (Miller *et al.*, 2000).

Correlation between extractable B and yield, or B concentration in plant, or B uptake by plants is sometimes poor and some improvement has been achieved by including pH, texture, clay and organic matter content (Wear and Patterson, 1962; Lombin, 1985; Gestring and Soltanpour, 1984; Bingham *et al.*, 1971; Gupta, 1968; Matsi *et al.*, 2000) in multiple correlation (Miljkovic *et al.*, 1966; Martens, 1968).

The deficiency of Boron limits crop yields on clay soils rich in organic matter. Simard *et al.* (1996) reported that Mehlich 3 solution extracted less boron (2.8 mg kg^{-1}) than Sr – citrate (3.2 mg kg^{-1}), but more than hot water (1.3 mg kg^{-1}), mannitol – $CaCl_2$ (0.8 mg ha^{-1}), $CaCl_2$ (0.6 mg kg^{-1}) and cold water (0.5 mg kg^{-1}). The response to B fertilizer was cultivar specific. The 0.01 M $CaCl_2$ solution was most closely related to barley B uptake ($r = 0.65^{**}$), whereas Mehlich 3 ($r = 0.61^{*}$) best predicted fertilizer response.

Chaudhary and Shukla (2003) studied the availability of soil boron fractions to mustard (*Brassica juncea*) in arid soils of Rajasthan ,India. The simple correlation study showed significant and positive correlation of B concentration and its uptake by mustard with readily soluble, specifically adsorbed and organically bound B fractions. The soil characteristics that influenced the B concentration and its uptake by mustard plants were pH, electrical conductivity and organic carbon.

The hot 0.01 M $CaCl_2$ extractant for B has been proved a better extracting solution for mustard grown in acid soils of Rajasthan as evidenced from the relationships between fractions of B and extractant.

2.4 Effect of boron on biochemical attributes

Boron deficiency is associated with a range of morphological modifications and changes in differentiation of tissues similar to those induced by either suboptimal or supraoptimal levels of IAA . It is evident that auxins accumulated in boron deficient tissues. Several physiological impairments are known to be caused by boron deficiency such as inhibitions of mitosis and cell elongation, along with of cell differentiation and development, and suppression of respiration, and photosynthesis, an increase in auxin content (Cohen and Bandurski, 1978). According to Dugger (1983), boron deficiency plays an important role in auxin biosynthesis in the meristem of the plant. For example, a decrease in the level of free auxin, an increase in the level of bound auxin, and also a reduction of IAA – oxidase activity have been observed in case of boron deficiency (Cohen and Bandurski, 1978).

Eaton (1940) reported that boron – deficient plants were also IAA deficient. Neales (1960) proposed that instead of boron – deficient plants lacking sufficient IAA, they may actually contain supra optimal levels which impair normal growth. Similar results were found by Bohnsack and Albert (1977). It is evident that higher levels of IAA in the apical regions of boron deficient plants and have speculated that the increase in IAA might be due to an inactivation or change in the activity of IAA oxidase (Coke and Whittington, 1968; Jaweed and Scott, 1967).

Furthermore it has been found that sunflowers with boron deficiency contained more IAA than control group, that IAA – oxidase was inhibited due to high level of phenolic acid (Cohen and Bandurski, 1978). On the other hand, Robertson and Loughman (1974) showed that boron has an effect on the transport metabolism and activity of auxins, Bohnsack and Albert (1977) showed a severe inhibition in root growth of squash and increase in IAA oxidation by boron deficiency. Resupply of boron to boron deficient squash plants rapidly stimulated root growth and reduced IAA oxidation.

It has been obtained that the auxin level in plant rises with boron deficiency was noted by some other researchers (Crisp *et al.*, 1976; Hirsch *et al.*, 1982).

Hussanien *et al.* (2001) conducted an experiment on *Vigna sinensis* spraying with boron or zinc at 10.50 and 250 mg/litre. They observed that low concentration of boron or zinc caused highly significantly increases in most of the growth parameters and yield components concomitantly with increase in auxin contents, catalase activity and reductions in growth inhibitor level and activities of IAA oxidase and peroxidase.

The effects of Zn (0.5%) and boron (0.1%) fertilizers on the biochemical and quality parameters of pawpaw cv. Co5 were investigated in Tamil Nadu, India by Kavitha *et al.* (2000). Treatments were control; Zn foliar spray at 4 and 12, and at 4, 8 and 16 months after planting (MAP); B foliar spray at 4 and 12 and at 4, 8, 12 and 16 MAP; Zn + B foliar spray at 4 and 12, and at 4, 8, 12 and 16 MAP and soil application of 10 g Zn + 5 g B at 4 and 12 MAP. Foliar application of Zn + B at 4, 8, 12 and 16 MAP, however, registered the lowest IAA oxidase activity (673.08 mg^{-1} g^{-1} h^{-1}), while the control recorded the highest activity of this enzyme (677.34).

Therefore, the study of IAA Oxidase should be studied in order to predict the deficiency of B in plants.

Phenolics are among the most influential and widely distributed natural products in the plant kingdom, and carry strong physiological and ecological implications (Delalonde *et al.*, 1996). Boron is one of the nutrients which may cause changes in the phenol content and metabolism. The accumulation of phenols is characteristics of B – deficient tissues due to increased synthesis and inhibited utilization of phenols in cell – wall synthesis. In response to high phenol accumulation, polyphenol oxidase activity rises in B – deficient tissues (Loomis and Durst, 1991).

Oxidative enzyme activity appears to be modified by boron deficiency. High polyphenol oxidase activity and an increased O_2 consumption by tissue homogenates have been reported for boron – deficient plants (Mac Vicar and Burris, 1948; Reed, 1947).

Boron at 40 ppm caused a large decrease in the activity of peroxidase and polyphenol oxidase enzymes in both leaves and roots of sugarbeet (Besheit *et al.*, 1992). Nawar and Ezz (1994) proposed that B treatments reduced the activity of polyphenol oxidase (PPO) activity compared with controls.

Singh *et al.* (2001) studied the boron deficiency and physiological disorders in brinjal. They reported that B deficiency decreased the biomass, concentration of B and increased the activity of polyphenol oxidase (PPO).

At harvest, B treated pears exhibited a significantly lower membrane permeability and lower content of lipid peroxidase in connection with reduced activities of polyphenol oxidase (Xuan *et al.*, 2002).

The effects of increasing concentrations of boron (0, 0.1, 1, 10 and 20 mm) as boric acid on the rate of germination and polyphenol oxidase activities in embryo and endosperm tissues at maize cv. Arifiyl were studied by Olcer and Kocacalskan (2007). The distilled water and lower boron concentrations (0.1 and 1 mm) increased polyphenol oxidase activities at the beginning of germination upto 12 h, whereas its excess levels (10 and 20 mm) decreased polyphenol oxidase activities in embryos and endosperm during germination.

2.5 Adsorption and desorption mechanism of boron

Adsorption – desorption processes play a major role in governing the solubility of boron (B) in soil solution and consequently its availability to growing plants. Boron is one of the seven essential micronutrients required for the normal growth of most plants. However, the range of B concentrations in the soil solution causing neither deficiency nor toxicity symptoms in plants is narrow. The amount of B adsorbed by soils varies greatly with the contents of various soil constituents, mostly clay minerals, sesquioxides, and organic matter (Keren and Bingham, 1985). Boron adsorption and desorption from soil adsorption sites regulate the B concentration in the soil solution. This regulation depends on the changes in solution B concentration and on the affinity of the soil constituents for B (Mezuman and Keren, 1981). Thus, adsorbed B may buffer fluctuations in solution B concentration and B concentration in soil solutions may vary only slightly with changes in soil water content.

The role of organic matter in B distribution between the liquid and solid phases of soils is not yet fully understood. Boron deficiency has been observed in soils with high organic matter content (Hue *et al.*, 1988; Mascarenhas *et al.*, 1988; Liu *et al.*, 1989). This deficiency has been shown to be related to the high affinity of organic matter to B (Berger and Pratt, 1963; Yermiyahu *et al.*, 1988, 1995; Liu *et al.*, 1989). Yermiyaho *et al.* (1988) observed that B adsorption capacity of composted organic matter was at least four times higher than that of clays and soils. This observation suggests that small amount of organic matter in soils may change significantly the B distribution between solid and liquid phases and thereby it availability to plants. In fact, organic matter is one of the main sources of B in acid soils as relatively little B adsorption occurs on the mineral fraction at low pH values (Okazaki and Chao, 1968).

With regards to the role of organic matter in adsorption desorption of B in soils, there are contradictory reports in the literature. Many investigators (Pavan and Correa, 1988; Awad and Maki, 1990) have observed that B adsorption maximum values in acidic as well as calcareous soils increased with soil organic matter content. On the contrary, Mezuman and Keren (1981) noted only negligible effect of organic matter on B adsorption by a soil containing 1.2% organic matter, while Sarkar and Das (1990) reported an increase in B adsorption capacity of acidic soil after removal of organic matter. As regards the effect of applied organic manure on boron adsorption desorption characteristics of soils, very few attempts have been made. Yermiyaho *et al.* (1995) reported that B sorption by composted organic matter – soil mixture increased with increasing rates of composted organic matter. Zerrari *et al.* (2001) reported that incorporation of organic manures increased the reversibility of adsorbed B from soil. Yermiyaho *et al.* (2001) found that composted organic matter decreased B concentration in bell pepper plants and the effect was more prominent at high B rates. In India, about 33% soils are deficient in B and deficiency has been recorded in oilseeds, food grains, vegetables and fruit crops (Singh, 2000).

Application of FYM increased the retention of added B in soils and may help reduce the leaching losses (Sharma *et al.*, 2006).

The binding between B and organic matter becomes stronger with an increase in the number of receptive – OH and – COOH groups, which occur with an increase in the state of decay of organic matter. Since the sorption is probably by ligand exchange mechanisms or dihydroxy or hydroxyl – carboxy functional groups (Boeseken, 1949; Kustin and Pizer, 1969).

Arora and Chahal (2007) studies the effect of clay content and organic matter on adsorption of boron (B) in alkaline soils of Punjab. They reported that the adsorption of B increased with its increasing concentration in equilibrium solution, yet the percentage of adsorbed B decreased. Adsorption of B by these soils was positively and significantly correlated with organic carbon content (r = 0.998*) clay content (r = 0.994) and CEC (r = 0.902) of the soil.

The amount of B adsorbed was considerably greater after the organic matter had been removed from the soil, and the release of B showed a hysteretic trend (Marzadori *et al.*, 1991). Sarkar and Das (1991) studied the boron adsorption and desorption reaction in six acid soils from they found that boron adsorption capacity of the soils was significantly correlated with clay, CEC, Al_2O_3 and organic carbon. They also reported that boron desorption was reversible in all soils studied. The application of boron reduced the hysteretic desorption effect on plant uptake, enabling the plant to absorb higher amounts of boron from the soil (Zhu *et al.*, 1998).

The adsorption – desorption study showed that Fe_2O_3 and clay wee primarily responsible for retaining added B, organic carbon, pH and cation exchange capacity positively influenced the adsorption of B while free Fe_2O_3, organic carbon and clay retarded release of B from these soils. the degree of irreversibility (hysteresis) of B adsorption / desorption increased with increase in organic carbon and CEC of these soils. the Freundlich isotherm proved more effective in describing B adsorption in soils than the Langmuir equation (Datta and Bhadoria, 1999). Wojcik and Wojcik (2001) indicated that adsorption of B was relatively high on the soil rich in organic matter, clay and oxides of Fe, Al and Mn.

Chaudhary and Shukla (2004) observed that Freundlich equation proved more effective in describing B adsorption in soils compared to Langmuir equation. Organic carbon, cation exchange capacity and clay content positively influenced the adsorption of B, while cation exchange capacity and clay content retarded the release of B soils. The degree of irreversibility (hysteresis) of B adsorption / desorption increased with increase in pH, organic carbon, cation exchange capacity and clay content of soil.

Adsorbed boron was significantly correlated with that in soil solution at equilibrium boron sorption conformed to the Langmuir adsorption isotherm over a limited concentration range, while the Freundlich adsorption range (0.0 to 80 mg / ml) was adequate for all the soils studied. Statistical analysis showed that clay content, acid extractable – B, $CaCO_3$ % and cation exchange capacity (CEC) were significantly correlated with the Freundlich (k) value, while only organic matter and clay contents were significantly correlated with the Langmuir (b) value. Boron uptake by barley was linearly correlated with the boron content of soil solutions (Murtadha *et al.*, 1988).

Zhu *et al.* (1998) reported that the application of boron reduced the hysteretic desorption effect on plant uptake, enabling plants to absorb higher amounts of boron from the soil.

The high organic matter content of humic gley soil provided higher B adsorption capacity, which was highly correlated with organic matter specific surface area, kaolinite and exchangeable aluminium (Azevedo *et al.*, 2001). The adsorption of B, in the form of boric acid was studied by Gu and Lowe (1996) reported that boron adsorption by humic acid(HA) was strongly pH – dependent, being low in the pH range 3.0 – 6.5, increased markedly to a peak at near pH 9.5, and then decreased at still higher pH values. The role of HA in B adsorption is expected to be minor in most acid and near neutral soils, but may be of greater significance in soils of higher pH and above average organic matter content.

2.6 Effect of organic matter on the availability of boron in soil

Most cultivated soils contain hardly 1-5 % organic matter, this small amount can significantly modify the chemical, physical and biological properties of soils affecting the availability of boron. It has been observed that the amount of B sorbed on organic matter is much higher than those on soils.

Organic colloids are generally known to function as a sink for metal ions but very little information is available regarding the proportion of the micronutrients in soil that occurs in insoluble combination with organic matter or of the factors affecting the availability of the bound nutrients to plants and microorganisms. However, the available information on these aspect so far collected are presented in this section.

Berger and Truog (1945) reported an apparent correlation between organic matter and availability of boron in acid soils. They found higher amount of available boron in soils having higher organic matter content. Correlation co-efficient between organic matter and available boron in both virgin and cultivated surface samples were highly significant. They further reported that available boron decreased with increasing acidity probably due to the fact that organic matter also decrease with increasing acidity. Elrashidi and O'Connor (1982), Gupta (1968), Evans (1987) and Goldberg (1997) made similar sort of observation. Ghani and Haque (1945) although did not observe any correlation between available boron and organic matter content of the Chittagong, Midnapore and Sunderban soils, but obtained higher values of available boron on ignition of those soils and attributed the increase to the boron present in organic combination. Singh and Randhawh (1997) also reported that a negative relationship between organic matter and available B content was observed in saline alkaline soils of Punjab.

Parks and White (1952) suggested a view of the magnitude of boron retention by the humus systems and the chemical reaction between boron and di-hydroxy organic compounds that boron united with favourable diols of the organic matter or those, which are gradually released as intermediates of the microbial breakdown of organic matter in soil.

Page and Paden (1954) also noted the association between organic matter and available B in acid soils and were of opinion that organic matter exerted a great influence on B availability than either pH or soil texture.

Berger and Pratt (1963) later reported that a large part of the total B in soils was associated with organic matter in tightly bound form. However, this B can be released to soil solution, in forms available to plants, by microbial activities (Berger. 1962). Unfortunately little is known about the role of soil organic matter and the influence of microbial activity on availability of B in soils (Reisenauer *et al.*, 1973; Keren and Bingham, 1985). Olson and Berger (1946) also found that oxidation of soil organic matter resulted in a significant release of B in forms available to plants.

Available B recorded significant increase with increase in organic matter content of acid soils of Western Rajasthan and 'bhuna' soils of Harjana (Satyanarayan, 1958; Sharma and Shukla, 1972).

Miljkovic *et al.* (1966) indicated that water soluble boron was closely related to the organic matter content in quadratic regressions ($R^2 = 0.691$) where pH and clay content were included in regressions. However, these findings are in contrary to those reported by some European workers (Katalymov, 1960; Lehr and Henkens, 1962).

Grewal *et al.* (1969) observed no relationship between available boron and organic mater in the soil profiles of different agro-climatic soil zones of Punjab, Haryana and Himachal Pradesh. Lodha and Baser (1971) reported that the available boron had positive relationship with organic matter content of soils. although relationship obtained were non-significant in most of the soil groups except mixed red and black and grey brown soils where significant positive co-relationship were obtained.

Purves and Mackenzie (1973) reported that municipal compost applied to soil and produced significant enhancement on available boron. Pleseviciene *et al.* (1997) also reported that amount of mobile boron in soil increased as a result of external application of manure @ 120 t ha^{-1}. On the contrary, Talati and Agarwal (1974) observed that organic matter content of North-West

Rajasthan soil did not give any significant relationship with available as well as total boron content of soils.

Singh *et al.* (1976) and Khetawat and Varhistha (1977) made similar sort of observations. Shinde *et al.* (1979) reported a negative and significant correlation between available boron and organic carbon in soils from sugarcane growing areas of Pune district of Maharastra. Similar observations were made by Chavan *et al.* (1980). Chakraborty *et al.* (1982) reported a significant relationship between total boron and organic matter content of the soil, whereas, available boron content in soils did not show any relationship with organic matter content of the soil.

In a study of depth wise distribution of different forms of boron in relation to soil properties in medium black calcareous soil of western Gujarat, Hadwani *et al.* (1989) found that there existed a significant positive correlation between available boron and organic carbon content in soils. Daudu *et al.* (1994)and Patil *et al.* (1989) also reported similarly.

Pakrashi and Halder (1992) reported that the application of organic matter at higher level maintained a relatively higher proportion of boron in hot water soluble form, the extent of increasing being more when organic matter at higher levels was applied to soil under 60% W.H.C. moisture condition.

Perveen *et al.* (1993) studied 30 soil series of the North – West Frontier province, Pakistan and reported that zinc and boron were positively and significantly correlated with organic matter. Similar type of observation was made by Oyewole and Aduayi (1992), Bansal (1999).

Singh and Nayyar (1999) observed boron deficiency in crop plants grown on light textured sandy soils, calcareous soils and soils with relatively low amounts of organic mater. Sharma *et al.* (2000) conducted an experiment to observe the effect of different carbon sources and incubation temperatures on extractability of added boron in soil. They concluded that though in general organic matter had been reported to increase the recovery of added boron in all the extractable form, however, in the presence of the same the availability of added boron in soil might be hindered at low temperatures.

Sakal (2001) reported that the application organic matter addition to boron deficient soil increased the utilization and recovery of applied boron. He explained that complexation of added boron and coating of the surface of Fe and Al oxides by soluble organic compounds might be the possible reasons for increasing boron efficiency in soil.

2.7 Interaction with other ions

Interactions among nutrients in crop production assumes special significance as it affects crop productivity and returns from investment by farmers in fertilization. There have been many conflicting reports to the effect of boron on the other elements affecting productivity of crops. There have been cases where, because boron was the limiting factor, the content of the other elements in the plants have increased. When boron was adequately supplied, the amounts of other elements in the plant declined. Under condition of boron toxicity, the normal physiology of plant is so upset as to cause either abnormal accumulation on lowered accumulation of both cations and anions.

2.7.1 Interaction between boron and sulphur

Shukla *et al.* (1983) and Chakraborty and Das (2000) reported a synergistic relationship between boron and sulphur was recorded with respect to seed yield , oil and protein content of *Brassica juncea* (Rai). Chatterjee *et al.*, 1985, in their field experiment at Kalyani, West Bengal though observed effective increase of seed yield of mustard individually by both S (39%) and B (34%), failed to detect any synergistic relationship between them which they attributed to the fact that the soil was deficient in S but not in available boron content. However, field data from a medium black soil (deficient in both S and B) at Parbhani, Maharastra showed that B and S acted in a highly synergistic manner with groundnut as a test crop (Karle and Babuler, 1985). Out of the total response to 120 kg S + 15 kg borax / ha interaction effect accounted for 22% and 43% increase in kernel and oil yield respectively. The positive interaction between S and B was thus much more pronounced in oil production. Sulphur increased oil yield by 73%, boron raised it by 29% and their combined application raised it by 18%. Using groundnut as test crop grown on calcareous soils of Dholi in Bihar, Sakal *et al.* (1987), though observed significant interaction effect of B and S, failed to note statistically significant increase in boron concentration in the groundnut kernels. However, they showed a tendency towards synergism between B and S. In a field experiment conducted in acid sandy loam soil of Coochbehar district in Terai region of West Bengal, Sinha *et al.* (1990) though observed significant yield increase of 36.8% of rapeseed due to 1.2 kg B ha^{-1} and 32% increase in yield following application of 20 kg S ha^{-1} over control, failed to observed any synergistic relationship between boron and sulphur when both were applied @ 1.2 kg B ha^{-1} and 20 kg S ha^{-1} as a treatment which resulted only 52% increase in yield.

On the contrary, Islam *et al.* (1997) showed that the application of B at 3 kg ha^{-1} resulted a significant increase in the rice yield (14%) over control. The application of sulphur at 25 kg ha^{-1} caused a significant increase in grain yield by 23% over control, being further increased (30.6%) when B and S was applied combindely, but failed to show synergistic relationship between them.

Motamed (2006) observed that the highest grain yield and protein content were obtained from the treatment in which the highest levels of S and B fertilizers was used. Agasimani *et al.* (1993) reported that application of 20 kg S or 10 kg S + 2.5 kg B gave high pod yields of groundnut. In field trails on a sandy loam in West Bengal in rabi season, application of 20 kg S and 1 kg B ha^{-1} to rapeseed mustard (*Brassica juncea*) significantly increase plant height, leaf area index at flowering , oil content and seed yield.

Chakraborty and Das (2000) observed in their field trials in West Bengal that quality parameters like oil content and protein content were significantly and glucosinolate content non-significantly influenced by the fertilizer treatments. Oil, protein and glucosinolate content generally increased with increasing S and B levels.

The interaction effect of S and B application on root and sugar yield, leaf B, K, Na and N contents. TSS, juice purity, soil pH and soil extractable B was significant. A significant effect for the interaction between B and S application on these parameters was also observed by Hussein, 2002.

Giri *et al.* (2003) studied the effects of B fertilizer, S fertilizer and their combination on the performance of rice in Terai, West Bengal, India. They found that the greatest increase in grain (40.47%) and straw (31.87%) yields over the control wee recorded for 15 kg B + 150 kg S ha^{-1}. Based on the maximum response of B uptake by grains as 83.32, 6.93 and 9.75% of the B uptake was due to the response of B fertilizer, S fertilizer, and B × S interaction, respectively.

Suman *et al.* (2002) reported that the treatment combination at 40 kg S + 1 kg B ha^{-1} gave the highest net return and benefit : cost ratio.

Kumar *et al.* (2006) studied the effects of boron and sulphur (single super phosphate) on the performance of *Cicer arictinum*. They found that borax, borax + sulfur and boric acid + sulfur resulted in the highest number of pods per plant (41.4, 47.9 and 47.6 respectively), seed yields (14.6, 16.0 and 15.7 q ha^{-1}) and straw yields (17.2, 18.8 and 18.4 q ha^{-1}).

2.7.2 Interaction between boron and zinc

In a pot culture experiment, Sreedharan and George (1969) with rice as test crop grown in a red loam soil at Vellayani, Kerala observed 7% increase in grain yield over control due to application of borax @ 11 kg ha^{-1}, but upon Zn fertilization @ 28 kg $ZnSO_4$ ha^{-1} resulted a suppression of 19% yield over control. But when both B and Zn wee applied together resulted 26% increase in grain yield. Hence, though the soil is non-responsive to zinc fertilization, the interaction of Zn × B showed synergistic response over boron alone. Shukla *et al.* (1983) in their study on the effect of zinc and boron application on seed yield, oil and protein content and Zn and B concentration as well as, their uptake in *Brassica juncea* grown in alluvial soil of Kanpur, U.P. observed significant increase in seed yield, oil and protein content in seeds of mustard due to individual application of Zn and B separately.

On the contrary, an antagonistic effect was noted in both the crops registering 21.4% increase in seed yield of mustard and 41.4% increase in grain yield of rice over control due to combined application of B and Zn. Similarly, Das (1992) using groundnut as test crop also failed to observe any synergistic relationship between B and Zn in the soil of Central Research Station of OUAT at Bhubaneswar. Whereas the results of a field experiment with rice followed by mustard crop grown on a silt loam soil (Aeric Haplaquept) of Bangladesh by Islam *et al.* (1997) though failed to show any synergistic relationship between B and Zn on rice crop, the residual interaction effect of B × Zn was noticed in the seed yield of mustard crop.

A green house experiment involving 4 levels of boron (0, 5, 10 and 20 mg kg^{-1}) and 3 levels of zinc (0, 10 and 20 mg kg^{-1}) was conducted on tomato cv. Lale by Gunes *et al.* (1999). They reported the increased levels of B increased the concentrations of B in plant tissues to a great extent in the absence of applied zinc. Both Zn and B treatments increased Zn concentration in the plant.

Mustard (*Brassica campestris*) cv. T9 was grown in refined Sand at three levels of boron (B) : deficient (0.0033 ppm), normal (0.33 ppm), and excess (3.3 ppm), each at three levels of zinc (Zn) : low (0.00065 ppm), adequate (0.065 ppm) and excess (6.5 ppm). The B deficiency effects wee accentuated by low zinc, viz., the decreased biomass, B and Zn concentrations in leaves and seeds. Synergism was also observed between the two nutrients when both B and Zn were in excess together, as excess B accelerated the effects of high Zn by lowering further the reduced biomass and raised further the increased concentrations of B and Zn in leaves and seeds (Sinha *et al.*, 2000).

Yadav *et al.* (2001) conducted a field experiment at Hisar, Haryana to study the effect of zinc (0, 5, 10 and 20 kg Zn sulfate/ ha) and boron (0, 1, 2 and 4 kg ha^{-1}) on the yield and nutrient content and uptake by tomato plant cv. Pusa – 120. The maximum yield was obtained with 15 kg $ZnSO_4$ / ha and 2 kg B ha^{-1}. The highest concentration and uptake of zinc and boron were recorded for 20 kg $ZnSO_4$ and 4 kg boron ha^{-1} respectively.

Using mustard as a test crop grown on Typic Haplustert in Maharastra, India, Malewar *et al.* (2001) observed that stover and seed yield significantly increased with each levels of either zinc or boron which was attributed to the positive interaction between them.

Rajni and Meitei (2004) conducted a field experiment in Imphal, Manipur, India on French bean (*P. vulgaris*) cv. JRO Nabin to determine the effect of foliar spray of boron (0.5 and 1.0 ppm) and zinc (0.01 and 0.10 ppm), their combinations and a control. A combined application of boron (1.0 ppm) and zinc (0.10 ppm) after 20 and 40 days of sowing of the seeds was found to be beneficial for growth with respect to plant height, leaf number, branch number and shoot weight, earliness; yield with respect to number, length, fresh weight and number of seeds per pod and protein content.

Effect of zinc (Zn at 3.15, 4.20 and 5.25 kg ha^{-1}) and boron (B at 2.1, 4.2 and 6.3 kg ha^{-1}) application on yield in sunflower was studied in Maharastra, India by Gitte *et al.* (2005). The study revealed that combined application of Zn (5.25 kg ha^{-1}) and boron (6.3 kg ha^{-1}) exihibited an increase in yields of straw and seed over control. Patil *et al.* (2006) also reported similarly..

Rao *et al.* (2006) evaluated the response of mustard to zinc (0.5% zinc sulfate), boron (1.0 ppm borax) and molybdenum (0.1%) ammonium molybdate) application in addition to the recommended NPK and FYM alone. Zn + B + Mo gave the highest values for most yield attributes.

Hosseini *et al.* (2007) revealed that there was a significant B × Zn interaction on plant growth and tissue nutrient concentration which were rate dependent. In general the effect of B × Zn interaction was found antagonistic on nutrient concentration and synergistic on growth.

2.8 Effect of organic amendment on microbial population

Heavy application of dung and those of mineral fertilizer considerably increased microbial counts. Combined application of manure and fertilizer resulted in a meager increase in the no of microorganism as compared to that of dung along (Koepke and Haanel, 1969). Monib *et al.* (1974) found a differential stimulation of *Azotobacter*, nitrogen fixing bacteria in soils by the addition of organic matter. That was due to the chemical composition of the materials applied and their C : N ratio. The bacterial count was higher in treatment receiving clover than those of saw dust or dry leaves. Application of clover straw and saw dust resulted in an increase in *Azotobacter* count.

Application of organic manures influenced the bacterial population greatly in an alluvial soil of the lot, FYM (with 2% organic carbon) increase the bacterial population from 32.08 million per g soil in control plots to 141.18 million per g soil in the manure plots and wheat or rice straw (with 2% organic carbon) incorporation reached the bacterial population to as high as 197.76 million g^{-1} soil (Gaur *et al.*, 1984). N – fixation by free living non symbiotic N fixing microorganism in soil amended with wheat straw contributed to the N status of soil (Roper, 1983).

Nuntagij *et al.* (1989) suggested that nitrogen fixation occurred when low molecular weight carbon compound were released through lignocellulose hydrolyses and available to N fixers under the condition of severe N – deficiency. Non-symbiotic N – fixation was enhanced by pH values near to neutrality. An initial input of urea speed up the sawdust decay and thus promoted the N fixation, the number of N_2 – fixer were not consistently correlated with N_2 - fixing capacity, organic matter (rice straw, FYM) and NH_4 – N significantly decreased the fixer in soil (Nugroho and Kumatsuka, 1992). Plant residues and in particular straw, contain large amount of carbon (cellulose and hemicellulose) which can serve as substrates for the production of microbial biomass and for biological N – fixation by a range of free living diazotrophic bacteria (Roper and Ladha, 1995).

Saha *et al.* (1995) reported that organic matter augmented significantly aerobic non – symbiotic nitrogen fixing bacteria. Deep application of fertilizer with or without compost in upland areas in autumn was shown to improve soil fertility by enhancing the increase in microbial biomass, soil respiration, nitrogen – fixing capacity, cellulose decomposing capacity and rhizosphere effect of crops (Yuzhen *et al.*, 1997).

2.9 Effect of organic amendment on biochemical properties

2.9.1 Microbial biomass carbon

Manna and Ganguly (1998) conducted a field experiment in which soybean, mustard, chickpea or wheat residues compost of 3 – 5 cm length were chopped and mixed with FYM, pyrites, rock phosphates. They reported with wheat straw mixture irrespective of grain crop compared with inorganic N, P, K fertilizer.

Paul and Solaiman (2004) studied the periodic change in microbial biomass carbon in an incubation experiment. They found significantly higher amount of microbial biomass carbon in amendment soil over control. Biomass carbon were increased with 7 days and decreased thereafter and reached a constant level after 28 – 42 days of incubation.

2.10 Effect on boron on microbial population

The effect of B on microorganisms in situ is largely unknown , however, several studies using pure cultures have shown B can inhibit growth of bacteria (Bringman and Kuhn, 1980), fungi (Bowen and Gauch ,1966) and algae (Guhl, 1996), mainly at high concentrations. B is not an essential growth elements for bacteria or fungi with exception of some cyanobacteria(Bonilla *et al.*,1990).Rhizosphere soil is an intricate system of chemical,physical and microbial interactions that are inexorably linked. It appeared that the addition of B and NaCl to soil changed rhizosphere microbial community structure indirectly through increased soil moisture and subtle changes in root exudates patterns, the addition of later producing a more distinct change through increased osmotic pressure, leading to a greater increase in rhizodeposition of nutrients, especially carbohydrates (Nelson and Mele, 2007).Bolanos *et al.*,1994 studied the effect of B deficiency on symbiotic N fixation in peas cv. Argona .They observed that in the absence of B the number, size and weight of nodules decreased and nodule development changed leading to an inhibition of nitrogenase activity.

2.11 Effect of Zinc on microbial population and biochemical attributes

The microbial population of the contaminated soil was increased after removal of metals by biosurfactant indicating the decrease of toxicity of metals to soil microflora (Juwarkar *et al.*,2007).

A laboratory incubation experiment was conducted by Khan *et al.*,1998 to study the influence of Cd, Pb and Zn on the size of the microbial biomass in red soil. They found that in comparison to uncontaminated soil, the microbial biomass carbon and biomass nitrogen decreased markedly in soils contaminated with Cd, Pb and Zn.

Chapter III

Materials and Methods

Materials and Methods

The materials used in the present investigation and the methods followed with respect to soil and plant analysis along with statistical analysis are being presented in this section.

3.1 Materials

3.1.1 Soil

Two types of soil viz., alfisol and inceptisol were selected for laboratory experiment. Alfisols and inceptisols were collected from the farmer's field (0-15cm depth) of Jhargram (acidic reaction) in the district of Midnapore (W) and Mathabhanga in the district of Coochbehar , West Bengal respectively. The soil samples were then air dried, ground and passed through 80 mesh sieve. These samples were stored into properly marked polyethylene packets, appropriately sealed and stored in the laboratory for different experiments. The physico-chemical,microbial and biochemicaal properties of these soils are presented in Table 3.1

Table 3.1. Physico-chemical properties of the experimental soil

Particulars	Alfisol	Inceptisol
Sand (%)	77.20	66.8
Silt (%)	8.00	22.2
Clay (%)	14.80	11.00
pH (1:2.5)	5.49	5.7
EC (1:2.5) dSm^{-1}	0.180	0.155
Organic carbon (%)	0.49	0.85
CEC [c mol (p^+) kg^{-1} soil]	9.10	12.10
Hot $CaCl_2$-extractable B (mg kg^{-1})	0.134	0.146
Mannitol-$CaCl_2$-extractable B (mg kg^{-1})	0.110	0.117
Mehlich 3-extractable B (mg kg^{-1})	0.070	0.098
Phosphate solubilizing capacity(mg g^{-1})	18.9 $x10^5$	$23.23x10^5$
Phosphate solubilizing microorganisms ($x10^5g^{-1}$ soil)	0.021	0.024
Non- symbiotic nitrogen fixing capacity (mg of N fixed g^{-1} of soil g^{-1} sucrose consumed)	2.96	3.03
Non- symbiotic nitrogen fixing bacteria($x10^5g^{-1}$ soil)	20.50	27.47
Microbial biomass carbon (μg/g dry soil	102.34	108.31

3.1.2 Borax

Borax as a source of boron containing 10.5% B was used for the laboratory experiment.

3.1.3 Calbor

Calbor was used as an source of boron for the field experiment. The chemical composition of calbor are presented in the Table 3.2

Table 3.2 Composition of calbor

Properties	Particulars
B (%)	3.5 – 4.5 %
K (%)	1.7 % as K_2O
Ca (%)	11 % as CaO
S (%)	12 %
Mg (%)	1 %

3.1.4 Farmyard manure (FYM)

Well decomposed farmyard manure was used both for the laboratory and the field experiments. The chemical composition of FYM is presented in Table 3.3

Table 3.3 Chemical composition of farmyard manure (FYM)

Particulars	FYM
Nitrogen (%)	0.85
Phosphorus (%)	0.21
Potassium (%)	0.65

3.1.5 Elemental sulfur

Laboratory grade elemental sulfur was used for the laboratory incubation study.

3.1.6 Zinc

Zn-EDTA (Chelamin containing 12% Zn) was used for the laboratory incubation study.

3.1.7 Location of the experimental field

Field experiments on rape (*Brassica campestris* L.) cv. B- 9 were conducted during *rabi* seasons (winter season) of the year 2006-2007 and 2007-2008 in the Instructional Farm of Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia , West Bengal (22.93°N latitude and 88.53°E longitude, average altitude of 9.75 m above mean sea level).The soil of the experimental field was sandy clay loam belongs to the order of inceptisol (Aeric endoaquept), whose relevant physico-chemical, microbial and biochemical characteristics are presented in the Table 3.4

Table 3.4: Physico-chemical properties of the experimental soil (Field)

Particulars	Inceptisol
Sand (%)	57.56
Silt (%)	16.82
Clay (%)	25.62
pH (1:2.5)	6.48
EC (1:2.5) dSm^{-1}	0.21
Organic carbon (%)	0.52
CEC [c mol (p^+) kg^{-1} soil]	12.50
Hot $CaCl_2$-extractable B (mg kg^{-1})	0.330
Mannitol-$CaCl_2$-extractable B (mg kg^{-1})	0.590
Mehlich 3-extractable B (mg kg^{-1})	0.540
Phosphate solubilizing capacity (mg g^{-1})	0.018
Phosphate solubilizing microorganisms (x 10^5 $^{-1}$g soil)	40.91x10^5
Non- symbiotic nitrogen fixing capacity (mg of N fixed g^{-1} of soil g^{-1} sucrose consumed)	7.92
Non- symbiotic nitrogen fixing bacteria(x 10^5 g^{-1} soil)	45.32x10^5
Microbial biomass carbon (μg g^{-1} dry soil)	115.31

3.2 Methods

3.2.1 Laboratory experiments

3.2.1.1 Distribution of boron in relation to soil properties

Altogether 25 soil samples of different agro-climatic zones were collected from the surface soil layers (0-15 cm depth) of cultivated fields in the 12 districts viz. Birbhum, Bankura, Purulia, Midnapore, Nadia, 24-Parganas(North), 24 –Parganas(South),Dinajpur(South), Dinajpur(North), Coochbeher, Jalpaiguri and Darjeeling.The soils were air dried, powered with wooden mortar, sieved with 80- mesh nylon sieve, stored in plastic jars and used whenever necessary. All the soil samples were analysed for pH,EC,CEC.organic carbon and mechanical composition following the standard analytical procedure described by Jackson (1973).In addition to these ,all soil samples were analysed for hot $CaCl_2$ (HCC) extractable boron(Parker and Gardner, 1989), Mannitol-$CaCl_2$ (MCC) boron (Cartwright *et al.*,1983) and Mehlich –3 (MH3) (Jin *et al.*,1988) extractable boron. An attempt was made to correlate these fractions with different soil properties.

3.2.1.2 Studies on adsorption of applied boron in soil

Soils without and treated with 1% well rotten farm yard manure (soil weight basis) were used for the study. A stock solution of 100 mg B l^{-1} was prepared by dissolving requisite quantity of boric acid in B free distilled water. Five gram of air dried soil was taken in polypropylene tubes in duplicate and equilibrated with 25 ml of 0.01 M $CaCl_2$ solution containing 0,0.5,1,2,3,4 and 5 mg B l^{-1} for 24 h at room temperature (25^0C) after shaking for 2h on a horizontal shaker.After equilibration , the content were centrifuged at 7000 rpm for 10 min.The supernatant were decanted in plastic vials until analysed for B by Azomethine –H method(Wolf,1974).The quantity of B adsorbed by soil was calculated as the difference between the initially added B level and the B concentration remaining in the supernatant after subtracting the concentration of native soil B present in solution (0 mg B l^{-1}) from the latter.

All adsorbed data for B were fitted into Langmuir and Freundlich adsorption equations and determined various adsorption parameters as follows.

Freundlich adsorption equation

$$\text{Log } x/m = 1/n \text{ Log } C + \log K$$

Where C is the equilibrium concentration in ppm, K and n are empirical constants which depend on the nature of adsorbent, adsorbate and temperature. A plot of Log x/m Vs. log C gives a straight line with slope of 1/n and an intercept of Log K.

Langmuir adsorption equation

$$C/x/m = 1/kb + C/b$$

Where C is the equilibrium concentration in ppm, x/m is the amount adsorbed per unit mass of the material, b is the adsorption maxima and k is a constant related to bonding energy. A plot of C/x/m Vs. C gave a straight line of slope 1/b and intercept 1/kb.where from the Langmuir constants k and b values were calculated.

Supply parameter of boron

The availability of boron in soils is governed by the mutual interaction of quantity (q) , intensity (c) and kinetic parameters as regulated by the adsorption, desorption, chelation and diffusion of boron from soils to the plant roots.

Supply parameter

$$SP = qc^{1/2}/k_1k_2^{1/4}$$

Where q is the quantity,c is the intensity, and k_1 (b) and k_2 (k) are constants.

Maximum buffering capacity

It was calculated by multiplying adsorption maxima (b) and constant (k) related to bonding energy derived from the Langmuir adsorption isotherm.

3.2.1.3 Interaction effect between boron and sulphur on their changes in soil in relation to some microbial and biochemical attributes

Triplicate samples of 25g each of the air dried soils were taken in a series of incubation tubes and three levels of S at 0, 15 and 30 mg kg^{-1} as elemental sulfur and three levels of boron at 0, 1 and 2 mg kg^{-1} as borax were added and the moisture content was maintained at sixty percent of maximum water holding capacity of the soil. After addition of appropriate amount of water, the soils were allowed to incubate at room temperature (30 ± 2)° C for a period of 10, 20,30 and 40 days. Loss of moisture due to evaporation was replenished by the addition of double distilled water on every alternate day by difference in weight. After the lapse of each incubation period, the B concentration in soils was determined with the help of spectrophotometer by Azomethine – H method (Wolf, 1971) after extracting the soil with hot $CaCl_2$ (Parker and Gardner, (1989), Mannitol-$CaCl_2$ (Cartwright *et al.*, 1983). and Mehlich-3 extractant (Jin *et al.*, 1988). Available S of soil samples was determined by turbidimetric procedure by using 0.15% $CaCl_2$ extractable S by the help of spectrophotometer (Ensminger, 1954).

Experimental details

Treatments combinations : 9 **Replications :** 3 **Design:** Factorial CRD

Levels of boron : B_0 = No boron, B_1= B at 1 mg kg^{-1} as Borax, B_2= B at 2 mg kg^{-1} as Borax

Levels of sulfur : S_0 = No sulfur, S_{15}=S @ 15 mg kg^{-1} as elemental sulfur, S_{30} = S @ 30 mg kg^{-1} as elemental sulfur

Treatments	Description of treatments
$B_0 S_0$	Only soil (Control)
$B_0 S_{15}$	Soil+ sulfur at 15 mg kg^{-1} as elemental sulfur
$B_0 S_{30}$	Soil + sulfur at 30 mg kg^{-1} as elemental sulfur
$B_1 S_0$	Soil + B at 1 mg kg^{-1} as Borax
$B_1 S_{15}$	Soil + B at 1 mg kg^{-1} as Borax + sulfur at 15 mg kg^{-1} as elemental sulfur
$B_1 S_{30}$	Soil + B at 1 mg kg^{-1} as Borax + sulfur at 30 mg kg^{-1} as elemental sulfur
$B_2 S_0$	Soil + B at 2 mg kg^{-1} as Borax
$B_2 S_{15}$	Soil + B at 2 mg kg^{-1} as Borax + sulfur at 15 mg kg^{-1} as elemental sulfur
$B_2 S_{30}$	Soil + B at 2 mg kg^{-1} as Borax + sulfur at 30 mg kg^{-1} as elemental sulfur

3.2.1.4 Interaction effect between boron and zinc on their changes in soil in relation to some microbial and biochemical attributes

Triplicate samples of 25g each of the air dried soils were taken in a series of incubation tubes. Three levels of Zn at 0, 5 and 10mg kg^{-1} as Zn-EDTA and three levels of boron i.e., 0, 1 and 2 mg kg^{-1} was added under sixty percent of maximum water holding capacity. After addition of appropriate amount of water, the soils were allowed to incubate at room temperature $(30\pm2)^0C$ for a period of 10, 20, 30 and 40 days. Loss of moisture due to evaporation was replenished by the addition of double distilled water on every alternate day by difference in weight. After lapse of each incubation period, the Zn concentration in soils was determined with the help of Atomic Absorption Spectrophotometer (Perkin Elmer; Model – AAnalyst 100) after extracting the soil with 0.005 M DTPA (Lindsay and Norvell, 1978), and boron was determined with the help of spectrophotometer by Azomethine – H method (Wolf, 1971) after extracting the soil with hot $CaCl_2$ (Parker and Gardner, (1989), Mannitol-$CaCl_2$ (Cartwright *et al.*, 1983) and Mehlich-3 extractant (Jin *et al.*, 1988).

Experimental details

Treatments : 9 **Replications :** 3 **Design :** Factorial CRD

Levels of boron: B_0 = No boron, B_1= B at 1 mg kg^{-1} as Borax, B_2= B at 2 mg kg^{-1} as Borax

Levels of zinc: Zn_0 = no zinc, Zn_5= zinc at 5 mg kg^{-1} as Zn-EDTA, Zn_{10} = zinc at 10 mg kg^{-1} as Zn-EDTA

Treatments	Description of treatments
$B_0 Zn_0$	Only soil (Control)
$B_0 Zn_5$	Soil+ Zinc at 5 mg kg^{-1} as Zn-EDTA
$B_0 Zn_{10}$	Soil + Zinc at 10 mg kg^{-1} as Zn-EDTA
$B_1 Zn_0$	Soil + B at 1 mg kg^{-1} as Borax
$B_1 Zn_5$	Soil + B at 1 mg kg^{-1} as Borax + Zinc at 5 mg kg^{-1} as Zn-EDTA
$B_1 Zn_{10}$	Soil + B at 1 mg kg^{-1} as Borax + Zinc at 10 mg kg^{-1} as Zn-EDTA
$B_2 Zn_0$	Soil + B at 2 mg kg^{-1} as Borax
$B_2 Zn_5$	Soil + B at 2 mg kg^{-1} as Borax + Zinc at 5 mg kg^{-1} as Zn-EDTA
$B_2 Zn_{10}$	Soil + B at 2 mg kg^{-1} as Borax + Zinc at 10 mg kg^{-1} as Zn-EDTA

3.2.1.5 Effect of organic matter on the changes in the level of boron in soil

Triplicate samples of 25g each of the air dried soils were taken in a series of incubation tubes. Three levels of B at 0, 1 and 2 mg kg^{-1} as Borax and three levels of organic matter i.e., 0%, 1% and 2% by weight of soil as FYM were added under 60% moisture holding capacity. After application of appropriate amount of water, the soils were allowed to incubate at room temperature (30 ± 2)° C for a period of 10, 20, 30 and 40 days. Loss of moisture due to evaporation was replenished by the addition of double distilled water on every alternate day by difference in weight. After the lapse of each incubation period, the B concentration in soils was determined with the help of spectrophotometer by Azomethine – H method (Wolf, 1971) after extracting the soil with hot $CaCl_2$ (Parker and Gardner, (1989), Mannitol-$CaCl_2$ (Cartwright *et al.*, 1983) and Mehlich-3 extractant (Jin *et al.*, 1988).

Experimental details

Treatment : 9 **Replications :** 3 **Design :** Factorial CRD

Levels of Boron: B_0 = no boron, B_1= B at 1 mg kg^{-1} as Borax, B_2= B at 2 mg kg^{-1} as Borax

Levels of Organic Matter: OM0= no FYM, OM_1= FYM at 1% by weight of soil , OM_2= FYM at 2% by weight of soil

Treatments	Description of treatments
B_0 OM_0	Only soil (Control), no application of organic matter
B_0 OM_1	Soil+ O.M. as FYM @ 1% by weight of soil
B_0 OM_2	Soil + O.M. as FYM @ 2% by weight of soil
B_1 OM_0	Soil + B at 1 mg kg^{-1} as Borax
B_1 OM_1	Soil + B at 1 mg kg^{-1} as Borax + O.M. as FYM @ 1% by weight of soil
B_1 $0M_2$	Soil + B at 1 mg kg^{-1} as Borax + O.M. as FYM @ 2% by weight of soil
B_2 OM_0	Soil + B at 2 mg kg^{-1} as Borax
B_2 OM_1	Soil + B at 2 mg kg^{-1} as Borax + O.M. as FYM @ 1% by weight of soil
B_2 $0M_2$	Soil + B at 2 mg kg^{-1} as Borax + O.M. as FYM @ 2% by weight of soil

All these above treatments (boron and FYM) were used for both alfisol and inceptisol in the laboratory.

3.2.2 Field experiment

3.2.2.1 Climatic conditions

The relevant climatic parameters prevailing during the period of field experimentation are presented in Table 3.5.

Table 3.5 Monthly, meteorological observation during the course of investigation (2006 to 2008)

Month	Temperature (^0C)		Total rainfall (mm)	Relative humidity (%)	
	Maximum	Minimum		Maximum	Minimum
2006					
November	29.8	19.6	10.2	91.4	52.0
December	26.4	13.6	0.0	91.4	45.6
2007					
January	24.8	11.5	0.0	91.8	40.2
February	27.7	15.5	24.5	93.6	47.2
November	28.81	18.39	2.2	97.9	62.2
December	25.6	11.2	0.0	97.6	48.6
2008					
January	24.8	11.4	2.0	97.0	52.3
February	25.3	13.2	0.4	98.0	53.3

3.2.2.2 Field preparation

In both the years the experimental field was ploughed to have a soil pulverised for a good tilth. The experimental field soil, so prepared was laid out with a number of micro plots measuring 5 m long and 2 m width having an area of 10 m^2 surrounded by bunds of 0.30 m width with sufficient height to check the mixing of different treatment materials as well as overflow of water. Irrigation channels measuring 0.5m width were in between the replications in order to ensure easy and uninterrupted flow of irrigation water where individual plot was made independently irrigated from this irrigation channels.

3.2.2.3 Experiment : Influence of boron sources and organic manure on the changes in chemical, biochemical and microbial properties in relation to yield and quality of rape (*Brassica campestris* L.).

Experimental details

Layout and design

The layout of the experimental field is shown in the Fig. 3.1. The experiment was laid out in a randomized block design (RBD) and the respective treatments were applied to each plot. There were six treatments including control. Each treatment was replicated thrice comprising of eighteen (18) plots.

Details of the experiment

Crop	Rape (*Brassica campestris* L.)
Variety	cv. B-9
Design	Randomized Block Design (RBD)
Replications	3
Total number of plots	18
Spacing	25 × 10 cm
Size of each plot	5 m × 2 m
Bund between two plots	0.5 m
Path – cum irrigation channel	1.00 m
Boundary line	0.3 m

Treatment details

First year (2006-2007)

Treatments	Description of treatments
T_1	Control (only NPK as recommended)
T_2	NPK as recommended + Organic matter (5t/ha)
T_3	NPK as recommended + Boron as calbor (1 kg B/ha)
T_4	NPK as recommended + Boron as calbor (0.5 kg B/ha) + Organic matter (5 t/ha)
T_5	NPK as recommended + Boron as Borax (B at 1 kg /ha1)
T_6	NPK as recommended + Boron as Borax (0.5 kg B/ha) + Organic matter (5 t/ha)

Recommended dose of N, P and K

Soil nutrient status is medium so recommended dose of NPK for irrigated Benoy variety of rape is 80 : 40 : 40 kg/ha. Urea (46% N), SSP (16% P_2O_5) and MOP (60% K_2O) were used as N, P and K source respectively.

Second year (2006-2007)

Experimental design, treatments etc. in the year 2007-2008 were same with previous year (2006-2007) of experiment.

3.2.2.4 Biometric observations

Yield components

Number of branches per plant

Total number of branches per plant was recorded from ten randomly selected plants of each plot, at harvest

Number of siliqua per plant

Total number of filled siliqua per plant was recorded from ten randomly selected plants of each plot, at harvest.

Yield

Seed yield

Net plots were demarcated at first from the portion of the plot kept for recording grain yield. Plants from demarcated net plot area were harvested, tied in bundles and then taken to the threshing floor for drying and threshing. After threshing the seeds were cleaned, sun-dried and their weights were recorded. The yields in kg per plot were converted to tones per hectare at 14 % moisture basis.

Stover yield

The weights of the harvested plants after sun-drying and before threshing were recorded. The stover yields were obtained by deducting the seed weight from the total weight. A sample of stover was sun-dried to get the desired moisture percentage and the stover yield was adjusted accordingly. The stover yield was then converted to tones per hectare.

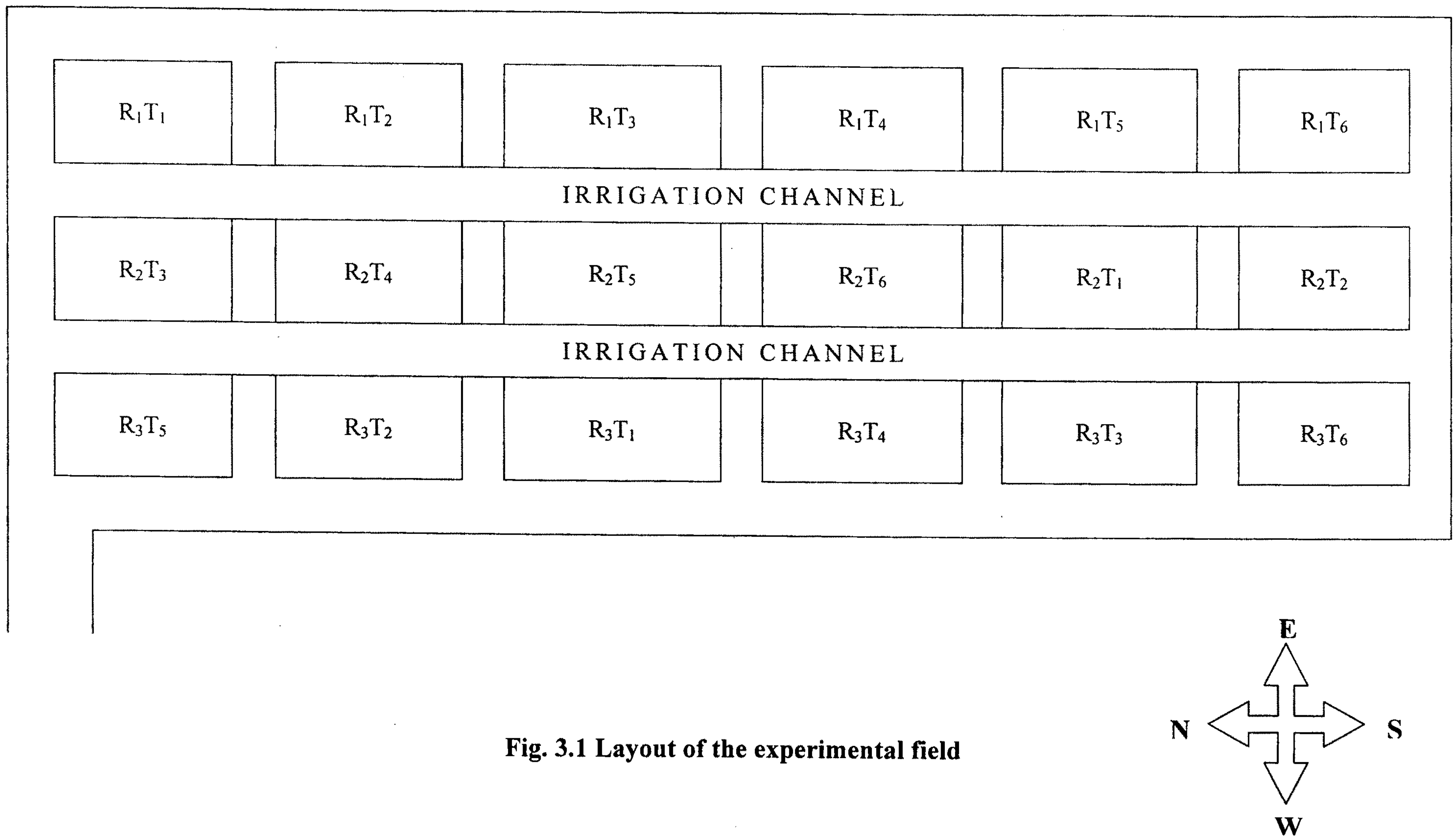

Fig. 3.1 Layout of the experimental field

3.2.2.5 Collection of samples

Soil samples

Soil samples were collected at an interval of 30 days from five to six randomly selected locations in each plot in submerged condition from the rhizosphere and non-rhizosphere region up to 70 days after showing and at harvest i.e. 90 days after showing.

Plant samples

Plant samples were collected periodically from five to six randomly selected locations of each plot up to 63 days of transplanting and again at harvest. Plant samples were cut at the ground level randomly from one meter row length. They were washed initially with tap water followed by dilute hydrochloric acid (0.05N), deionised water and finally with B free double distilled water. The plant samples were dried in an air oven at a temperature of 65 ± 5° C.

3.2.3 Methods of analysis

3.2.3.1 Soil pH

The pH of the soil samples were determined in a soil water ratio of 1: 2.5 by using electrical pH meter (Jackson, 1973).

3.2.3.2 Soil EC

The electrical conductivity (EC) of the soil samples were determined in a soil water ratio of 1: 2.5 by using conductivity meter (Jackson, 1973).

3.2.3.3 Soil organic carbon

The organic carbon of the soil samples were determined by method described by Walkley and Black (1934).

3.2.3.4 Cation exchange capacity (CEC)

The cation exchange capacity of the soil samples were determined by method described by Jackson (1973).

3.2.3.5 Maximum water holding capacity (MWHC)

Maximum water holding capacity of the soil sample was determined by Keen-Rackzowski Box method as described by Piper (1950).

3.2.3.6 Mechanical analysis

Mechanical analysis was carried out following the international pipette method (Piper. 1950).

3.2.3.7 Extractable Boron

The extractable B content of the soils for different experiments was determined by extracting the soil samples with a number of extractants viz., hot-$CaCl_2$ (Parker and Gardner, 1981), Mannitol-$CaCl_2$ (Cartwright *et al.*, 1983), Mehlich 3 (Jin *et al.*, 1988). After extractation, B in the soil solution was analysed spectrophotometrically by the Azomethine-H method of Wolf (1971) slight modifications as suggested by Gupta (1979).

Five (5.0) ml of sample aliquot, 2.0 ml of ammonium acetate buffer (pH 5.5) and 2.0 ml of 0.02 M EDTA (Gupta, 1979) were added in 20.0 ml B free test tube and vortexed , allowed to stand for one hour at 20- 25° C, vortexed again and the readings were taken at 420 nm using a Spectrophotometer.

Table 3.6 : Extractants used for determination of available B

Fraction	Extractant	Soil:Extractant	Condition	References
1. HCC	0.02 M hot CaCl2	1:2	Reflux 10 min on hot plate	Parker and Gardner (1981)
2. MCC	0.01 M $CaCl_2$+0.05 mannitol(pH 8.5)\	1:2	Shake 1 h	Cartwright *et al.* (1983)
3. MH-3	0.2 N acetic acid , 0.015 N NH4F, 0.25 N NH4NO3 and 0.001 EDTA	1:10	Shake 5 minutes	Jin *et al.* (1988)

HCC, MCC and MH-3 were hot caclcium chloride, mannitol- calcium choloride and Mehlich-3.

3.2.3.8 Microbial analysis

Counting of aerobic non – symbiotic nitrogen – fixing bacteria

For counting of total number of nitrogen fixing bacteria in soil, Jenson's nitrogen free agar medium (Jensen, 1930a) was used.

Non-symbiotic Nitrogen – fixing power

Non – symbiotic N – fixing power of the soil was examined by estimating nitrogen after incubating 1 g moist soil at 30°C ± 1°C in 50 mL sterile nitrogen free Jenson's broth containing 20 g sucrose in 250 mL conical flask. The idea of providing double amount of energy material was to have profuse growth of aerobic non – symbiotic N – fixing bacteria. Four flasks were kept for each soil, of which two flasks were sterilized after addition of soil. All the four flasks were incubated for 15 days. After 15 days of incubation, all the flasks were analysed for total nitrogen, following Kjeldahl method (Jackson, 1973). The difference in the amount of nitrogen in the non-sterilized and sterilized flasks were the Nitrogen – fixing power of soils, expressed as mg of nitrogen fixed per g of soil per g sucrose consumed.

P-solubilizing microorganisms

For phosphate solubilizing microorganisms, sucrose-tricalcium phosphate agar media (Pikovskaia, 1948) was used.

P-solibilizing capacity

Phosphate solubilizing capacity was determined by estimating soluble phosphorous in 15 ml of sucrose –tricalcium phosphate both containing 1% sucrose after incubating 1 g of soil in culture tubes at 30 ± 1° C for 15 days (Olsen and Dean,1982). For estimating phosphate solubilizing capacity of soil, 1 g soil was added aseptically in each of the four culture tubes containing 15 ml broth having 15 mg insoluble phosphorous in 75 mg of tricalcium phosphate and 0.15 g of sucrose. Two tubes were sterilized immediately after addition of soil and all the four tubes were incubated at 30 ± 1° C for 15 days. After incubation, the tubes were centrifuged at 6000 rpm for 20 minutes. After filtering, the supernatant through Whatman filter paper (No. 42), 5 ml sterilized and 1 ml non-sterilized aliquot were taken separately and water soluble phosphorous was estimated with the help of a double cell photoelectric colorimeter following chloromolybdic stannous chloride method (Olsen and Dean, 1982).The difference in the amount of soluble phosphorous in non-sterilized tubes would be the phosphate solubilizing capacity of the soil sample.

3.2.3.9 Biochemical analysis

Microbial biomass carbon

Microbial biomass carbon was determined in soil samples by fumigation extraction procedure (Joergenson, 1995)

Indole acetic acid oxidase (IAAO)

Indole acetic acid oxidase was determined by measuring residual IAA following dark incubation with shaking at 30° C .The IAA was determined Salkowski reaction (Byrant and Lane, 1979.

Polyphenol oxidase (PPO)

The intensely yellow 2-nitro-5-thiobenzoic acid (TNB) with an absorption maximum at 412 nm reacts with the quinones generated through enzymatic oxidation of 4-methylcatechol (catechol oxidase) and 1, 4 dihydroxybenzene (laccase) to yield colourless adducts .The decrease in the absorbance of yellow-colour due to enzyme activity is measured (Esterbaner *et al.*, 1977).

3.2.3.10 Boron content in plant

Whole shoot (leaf and stem) was used for B content in dry matter up to 63 days of transplanting while at harvest the plant was separated in to seed and stover and analyzed for B content separately. One gram (1 g) dried plant sample was digested with ternary acid mixture (HNO_3 : $HClO_4$: H_2SO_4 :: 10:4:1; Jackson, 1973). Digested plant samples were then ready for the determination of B. Total B from periodic collection plant samples as well as from seed and stover were determined with the help of spectrophotometer by Azomethine – H method (Wolf, 1971).

3.2.3.11 Oil content

The percentage of oil content of rapeseed was determined by adopting Soxhlet's Ether Extraction method (AOAC, 1984).

3.2.3.12 Protein Content

The crude protein of rape seed determined by microkjeldhal digestion method (Jackson, 1973). The amount of protein content was obtained by multiplying the nitrogen content with a constant factor of 6.25.

3.2.3.13 Uptake of nutrients by plant

Nutrient content of stover and seeds were multiplied by their respective dry weight/ seed yield to workout nutrient uptake.

3.2.3.14 Statistical analysis

Duncan's test at 5% was followed to compare the treatment means i.e. different level of main effect means. Field study of different days after sowing were analysed by simple RBD for each DAS .General Linear Model technique repeated over 4 DAS was used further to compare the main effects . Such study was followed both for R and NR i.e. rhizosphere and non-rhizosphere soils. Similar technique was also used to compare the mean difference between R and NR in different of DAS and treatments. All main effects means were subjected to Post – hoc tests like Duncan's test and day means along with R and NR means were tested by LSD (Least Significant Difference) to identify the homogeneous means at 5% level of significance for field. Means due to interaction effect between B and S or B and Zn or B and OM will be described using LSD test without any alphabets. Duncan's test and LSD test results will be displayed beside the mean value using different set of alphabets. Similar alphabets denote homogeneous means resulted by Duncan's test at 5% level of significance.

(A, B, C) and (P, Q, R,...) sets of alphabets were used to compare main effects means due to B and S at laboratory study.

Similar sets were further used for B vs Zn, B vs OM study.

Within DAS study treatment means were compared using (a,b,c,...) sets of alphabets , both for R and NR

Indifferent of DAS treatments were compared using (A, B, C,...) set of alphabets , for R and (I, J, K,....) for NR.

Within R and NR, day means were compared using (P, Q, R,.....) and (W, X, Y,....) set of alphabets respectively.

Overall means of R and NR were compared using (U, V) set of alphabets for field study.

Multiple regression: It estimates the coefficients of the linear equation, involving number of independent variables, that best predict the value of the dependent variable. For each model: regression coefficients, R^2, adjusted R^2 and standard error of the estimate are calculated. Predictors sometimes can be independent measurements observed at varying DAS or sometimes can be regression factor scores as an weighted score over DAS for those predictors which were measured repeatedly.

Program CANOCO Version 4.5 February 2002 - written by Cajo J.F. Ter Braak, (C) 1988-2002 Biometrics - quantitative methods in the life and earth sciences, Plant Research International, Wageningen University and Research Centre, Box 100, 6700 AC Wageningen, the Netherlands, performs (partial) (detrended) (canonical) correspondence analysis, principal components analysis and redundancy analysis.

Multivariate statistics (correspondence analysis) was employed using Canoco 4.5 to analyze the relationship between three methods of boron estimation and five physico- chemical parameters of soil by means of Redundancy Analysis, constrained linear ordination method. Such direct gradient analysis is a constrained form of PCA and also called reduced-rank regression. “Redundancy” expresses how much of the variance in one set of variables can be explained by the other set. Here our interest is to extract patterns from the explained variation only. The focus scaling was kept symmetric with no post transformation of method scores but standardization of goal variables i.e. methods of boron estimation was done by corresponding error variance and physico-chemical parameters were standardized by norms.

Automatic forward selection of relevant predictors will be made by using Monte Carlo permutation tests with 499 permutations. Variables with high

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Chapter IV

Results and Discussion

(variance) inflation factors (VIFs) are well correlated with other variables in the predictor set. Results will be presented as a triplot to examine how set of physico-chemical parameters relate to set of independent methods location wise.

C_p statistic, suggested by C. L. Mallows is as given below

$C_p = RSS_p / s^2 - (n-2p)$

Where RSS_p is the residual sum of square from a model containing p parameters, p is the number of parameters in the model including intercept and s^2 is the residual mean square. As R. W. Kennard pointed out that C_p is closely related to Adjusted R^2. For an adequate model C_p should be very close to p i.e. $C_p = p$ line. Because of random variation, points representing well-fitting equations can also fall below the $C_p = p$ line. C_p statistic will be calculated in present study to find out the adequate model with maximum adjusted R^2 for each type of boron extractant versus PSC, PSM, NFC, NFB, MBC study of Jhargram and North Bengal. Similar study was also followed to for sulphur and zinc treated soils respectively. Whole analysis was done by using the software Minitab (Release 13.31).

Canonical Correlation Analysis (CCA)

This analysis seeks to determine the linear association between a set of predictor variables and a set of criterion measures. In canonical correlation analysis we seek two linear combinations, one for the predictor set of variables and one for the criterion set of variables, such that their ordinary correlation is maximal.

Principal Component Analysis

Factor analysis attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables. Factor analysis is often used in data reduction to identify a small number of factors that explain most of the variance observed in a much larger number of manifest variables. Principal Component Analysis (PCA) is a factor extraction method which is used to form uncorrelated linear combinations of the observed variables. The first component has maximum variance. Successive components explain progressively smaller portions of the variance and are all uncorrelated with each other. Principal components analysis is used to obtain the initial factor solution. It can be used even when a correlation matrix is singular.

Results and Discussion

4.1 Laboratory experiments

4.1.1 Distribution of boron in relation to soil properties

The results (Table 4.1) reveal that the distribution of different fractions of boron viz. HCC, MCC and MH-3 extractable B has been found to be varied with different soil properties and zones. Comparing the distribution of different fractions of B in different zones it was found that HCC, MCC and MH-3 extractable B in Terai soils ranged from 0.178- 0.447, 0.072-0.101and 0.104-0.192 with mean values of 0.245, 0.083 and 0.0164 mg kg $^{-1}$ respectively, while the same distribution in old alluvial soil ranged from 0.201 to 0.336, 0.201-0.372 and 0.192-0.485 with mean values of 0.227, 0.296 and 0.328 mg kg^{-1} respectively. The distribution of HCC, MCC and MH-3 extractable B in New alluvial , Red and Latarite and costal zones ranged from 0.378-0.382, 0.189-0.231, 0.463-0.481; 0.110-0.332, 0.084-0.480,0.094-0.299 and 0.118-0.130, 0.259-0.261 and 0.232-0.242 with mean values of 0.380, 0.210, 0.472; 0.225, 0.175,0.196 and 0.124 , 0.260, 0.237 mg kg^{-1} respectively. The results further reveal that in case of Terai and Red and Laterite soil zones the extractability of B has been found to be highest with HCC solution while that of the same extractability in old and new alluvial zone soils the extractability of boron with MH-3 solution was recorded highest excepting the coastal zone soil where MCC extraction solution exhibited a greater amount of extracted boron.

The results (Table 4.2) show that the physicochemical properties of five different zones soil, namely Terai, Old and New alluvial, Red and Laterite and Coastal with corresponding soil taxonomy has been found to be varied with each other, however, out of five zones, the soils of two zones (Terai and Red & Laterite) are acidic in reaction and the rest (Old and New alluvial and Costal) are neutral in reaction. The average organic carbon EC, CEC, and clay content in Terai , Old and New Alluvial and Red and Laterite and Coastal zones were recorded 0.74,0.54,0.46,0.42 and 0.53; 0.13,0.17,0.23,0.14 and 1.33 ; 11.29, 14.06,12.36, 10.78 and 20.64; 17.2, 21.44,35.60,21.04 and 38.80 mg kg^{-1} respectively.

Table 4.1. Distribution of different fractions of boron in some soils of West Bengal

Zones	Location	HCC extractable B(mg kg^{-1})	MCC extractable B (mg kg^{-1})	MH-3 extractable B(mg kg^{-1})
Terai	Siliguri	0.216	0.081	0.183
	Moinaguri	0.203	0.094	0.192
	Dhupguri	0.179	0.101	0.104
	Falakata	0.447	0.067	0.182
	Tasatte Tea Estate	0.178	0.072	0.159
	Mean	**0.245**	**0.083**	**0.164**
	Range	**0.178-0.447**	**0.072-0.101**	**0.104-0.192**
Old Alluvial	Nalhati	0.201	0.217	0.222
	Rampurhat	0.218	0.231	0.203
	Raiganj	0.184	0.201	0.192
	Kalyani	0.336	0.342	0.357
	Haringhata	0.341	0.352	0.360
	Gayeshpur	0.329	0.357	0.485
	Mondowari	0.331	0.372	0.483
	Mean	**0.277**	**0.296**	**0.328**
	Range	**0.201-0.336**	**0.201-0.372**	**0.192-0.485**
New Alluvial	Mogra	0.382	0.189	0.481
	Palassey	0.378	0.231	0.463
	Mean	**0.380**	**0.210**	**0.472**
	Range	**0.378-0.382**	**0.189-0.231**	**0.463-0.481**
Red and Latarite	Dubrajpur	0.110	0.084	0.101
	Suri	0.198	0.152	0.172
	Sriniketan	0.204	0.178	0.192
	Nanoor	0.237	0.151	0.094
	Jhargram	0.237	0.182	0.240
	Onda	0.332	0.480	0.299
	Sonamukhi	0.292	0.141	0.290
	Mannbazar	0.200	0.099	0.178
	Purulia	0.212	0.110	0.194
	Mean	**0.225**	**0.175**	**0.196**
	Range	**0.110-0.332**	**0.084-0.480**	**0.094-0.299**
Coastal	Canning	0.130	0.259	0.232
	Kakdwip	0.118	0.261	0.242
	Mean	**0.124**	**0.260**	**0.237**
	Range	**0.118-0.130**	**0.259-0.261**	**0.232-0.242**

Table 4.2 Physicochemical properties of soils of different agro-climatic zone

Zones	Location	pH	EC (ds m^{-1})	Organic Carbon (%)	CEC (cmol (p+) kg $^{-1}$)	Clay content	Taxonomy
Terai	Siliguri	5.14	0.16	0.65	11.75	15.7	Typic Haplaequepts
	Moinaguri	5.25	0.14	0.98	12.00	18.9	Typic Fluvaquents
	Dhupguri	5.08	0.15	0.85	12.11	16.8	Typic Haplaequepts
	Falakata	5.07	0.13	0.60	11.72	18.1	Typic Haplaquents
	Tasatte Tea Estate	5.00	0.10	0.62	8.89	16.4	Typic Haplaquents
	Mean	5.10	0.13	0.74	11.29	17.1	
	Range	5.00-5.25	0.10-0.16	0.60-0.98	8.89-12.11	15.7-18.9	
Old Alluvial	Nalhati	6.37	0.12	0.49	11.10	15.3	Vertic Ochraqualfs
	Rampurhat	6.00	0.13	0.45	11.24	20.4	Vertic Ochraqualfs
	Raiganj	6.40	0.075	0.59	12.50	20.7	Typic Ustorthents
	Kalyani	7.23	0.15	0.55	16.85	21.9	Typic Haplaquepts
	Haringhata	6.80	0.20	0.61	14.40	21.5	Aeric Haplaquepts
	Gayeshpur	6.54	0.23	0.55	14.50	25.8	Aeric Haplustalfs
	Mondowari	6.85	0.30	0.60	17.85	24.5	TypicEndoaquepts
	Mean	6.59	0.17	0.54	14.06	21.44	
	Range	6.00-7.23	0.075-0.30	0.45-0.60	11.10-17.85	15.3-25.8	

New Alluvial	Mogra	7.53	0.23	0.51	11.93	34.5	Aeric Endoaquepts
	Palassey	7.60	0.24	0.42	12.80	36.7	Aeric Endoaquepts
	Mean	7.56	0.23	0.46	12.36	35.6	
	Range	7.53-7.60	0.23-0.24	0.42-0.51	11.93-12.80	34.5-36.7	
Red and Latarite	Dubrajpur	5.80	0.13	0.37	11.10	12.8	Vertic Ochraqualfs
	Suri	5.27	0.07	0.40	11.44	16.8	Typic Haplustalfs
	Sriniketan	4.95	0.14	0.44	11.24	20.7	Vertic Haplustalfs
	Nanoor	4.99	0.16	0.45	11.85	22.6	Vertic Haplustalfs
	Jhargram	5.49	0.18	0.49	9.16	21.7	Typic Haplustalfs
	Onda	5.55	0.13	0.44	10.35	20.8	Vertic Ochraqualfs
	Sonamukhi	5.08	0.15	0.45	10.85	21.3	Vertic Haplustalfs
	Mannbazar	5.20	0.17	0.41	10.13	27.8	Lithic Rhodustalfs
	Purulia	5.32	0.13	0.38	10.98	24.9	Lithic Rhodustalfs
	Mean	5.29	0.14	0.42	9.16-11.85	21.04	
	Range	4.95-5.80	0.07-0.18	0.37-0.49	20.40	12.8-27.8	
Coastal	Canning	6.91	1.31	0.54	20.89	37.9	Aeric Endoaquepts
	Kakdwip	7.02	1.35	0.52	20.64	39.7	Aeric Endoaquepts
	Mean	6.96	1.33	0.53	20.40-20.89	38.8	
	Range	6.91-7.02	1.31-1.35	0.52-0.54	?	37.9-39.7	

The highest clay and CEC content was recorded in Coastal zone soil. The average organic carbon content in Terai soils (0.74%) was highest compared to other zones of soils. The maximum amount of HCC extractable B in Terai soils might be due to high organic matter content of the soils resulting from the release of B from diol-organic complexes extracting with HCC extracting solution. The highest extraction of B with MH-3 in new and old alluvial zones of soil might be due to the neutral soil reaction as well as relatively medium organic matter and CEC of the soil.

Table 4.3 Co-efficient of correlation (r) between fractions of boron and soil properties

Soil properties	HCC extractable-B	MCC extractable B	MH-3 extractable B
Ph	0.285	0.594**	0.741**
EC	-0.333	0.224	0.084
Organic carbon	-0.014	-0.144	-0.067
CEC	-0.053	0.481*	0.363
Clay content	-0.219	-0.328	0.311

** significant at 1% level

*significant at 5 % level

The MCC and MH-3 extractable B content in soil have been found to be significant and positively correlated with pH of the soil while MCC extractable B exhibited a significant positive correlation with CEC of the soil (Table 4.3). Milijkovic *et al.* (1966) obtained a positive correlation between water soluble, organic matter and pH indicating that increases in water soluble boron associated with pH are greater in soils containing higher organic matter.

With respect to statistical interpretation of the data, it was revealed that weights for methods of boron estimation after weighting by their error variance were 1.53, 0.74 and 0.73 respectively. Following the automatic selection of predictors for RDA, all variables viz. clay concentration (F=14.30, p=0.002), CEC (F=2.83, p=0.064), pH (F=1.89, p=0.170), OC (F=0.56, p=0.576) and EC (F=0.21, p=0.856) were sequentially selected where only clay concentration was found significant predictor statistically. The first 2 axes represented 98.9% of the relationship. Axis 1 was largely correlated positively to clay concentration, pH, CEC and EC. Axis 2 correlated most strongly to OC positively. Table 4.4 includes the values of VIF of all the physico-chemical parameters. Table 4.5 includes the results of association between two sets of variables with respect to first four axes, though the Fig.4.1 is included here as the triplot using CanoDraw 4.0 only on the basis of first two axes.

Table 4.4 Inflation factor values of all physico-chemical parameters observed in 25 locations

Name	(weighted) mean	SD	inflation factor
pH	5.9376	0.8776	6.1663
EC	0.2510	0.3222	12.1997
OC	0.5344	0.1383	3.3292
CEC	12.7212	3.0778	6.8262
Clay con	24.5240	9.0360	14.1584

Table 4.5 Canonical correspondence analysis results of distribution study

Axes	1	2	3	4	Total variance
Eigenvalues :	0.463	0.049	0.006	0.279	1.000
Species-environment correlations:	0.803	0.430	0.556	0.000	
Cumulative percentage variance					
of species data :	46.3	51.2	51.8	79.7	
of species-environment relation:	89.5	98.9	100.0	0.0	
Sum of all eigen values	1.000				
Sum of all canonical eigen values	0.518				

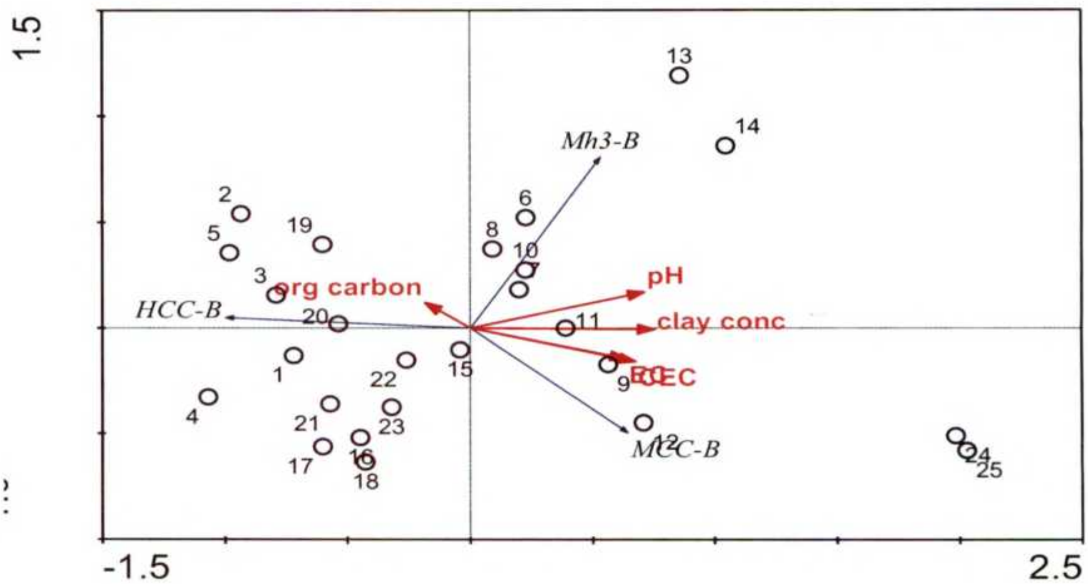


Fig. 4.1 : Triplot showing association among two sets of variables and location wise distribution due to first two axes where locations are coded as given below

code	1	2	3	4	5	6	7	8	9
location	Siliguri	Moinaguri	Dhupguri	Falakata	Tasatte Tea Estate	Nalhati	Rampurhat	Raiganj	Kalyani
code	10	11	12	13	14	15	16	17	18
location	Haringhata	Gayeshpur	Mondowri	Mogra	Palassey	Dubrajpur	Suri	Sriniketan	Nanoor
code	19	20	21	22	23	24	25		
location	Jhargram	Onda	Sonamukhi	Mannbazar	Purulia	Canning	Kakdwip		

MH-3 solution has been proved a superior extractant for B in saoils of locations indicated, being higher extractability in soils of increased pH and clay content while that of the same extractability with MCC and HCC solutions were proved superior in soils of respective locations depicted in Fig. 4.1, being responded more in soils having increase amount of CEC and clay content respectively. Zbiral *et al* (2009) also reported that the determination of B in MH-3 was found to be the most cost and time effective way of soil testing.

4.1.2 Studies on adsorption of applied boron in soil

4.1.2.1 Langmuir Adsorption isotherms

4.1.2.1.1 Adsorption of applied boron in soil with the addition of organic matter

The results (Table 4.6) reveal that the amount of boron adsorbed was recorded an increase with increasing concentration of applied boron as well as equilibrium concentration of B in soils of alfisol and inceptisol treated with organic matter , but the percentage adsorption decreased with increasing equilibrium concentration of B. However, the relative amount of boron adsorbed was higher in alfisol compared to inceptisol which might be explained by the greater amount of sesquioxides present in the soil as well as applied organic matter. Zerrari *et al.* (2001) reported that the adsorption capacity of the composted manure was 3-13 times more than that of soils and incorporation of manures to the soils increased adsorption capacities. However, the results of the present study are in conformity to that of Yermiyaho *et al.* (1995) who attributed increased B adsorption by composted organic matter-soil mixture to higher B adsorption capacity of the decomposition products of organic matter or microbial polysaccharides. The relatively lower amount of B adsorption in an inceptisol due to organic matter application might be ascribed to slightly higher pH resulting to much dominancy of $B(OH)_4^-$ species causing less adsorption of B in organic matter applied soil being adsorption maxima -18.86 and 22.22 mg g^{-1} and constant related to bonding energy – 0.229 and 0.402 ppm in soils of inceptisol and alfisol supplied with organic matter respectively (Table 4.7). The results suggest that inceptisol treated with organic matter exihibited very little adsorption of B compared to alfisol. Chemical bonding between B and organic molecules particularly carbohydrate and humic substances present in the applied organic matter may be responsible for boron adsorption (Yermiyaho *et al.* ,1988). The adsorption maxima (b) and constant related to bonding energy (k) were varied with soils.

Table 4.6 Adsorption of applied boron in two soils of West Bengal with the addition of organic matter

Soil	Applied Boron (ppm)	Equilibrium concentration (C) (ppm)	Adsorbed B (ppm)	x/m (□g g^{-1})	C/x/m	Log C	Log x/m
Inceptisol	0.5	0.16	0.34	0.68	0.266	-0.795	-0.221
	1	0.27	0.73	1.46	0.184	-0.568	0.164
	2	0.58	1.42	2.84	0.204	-0.236	0.453
	3	0.75	2.25	4.50	0.166	-0.125	0.653
	4	1.02	2.98	5.96	0.171	0.008	0.775
	5	1.33	3.67	7.34	0.181	0.124	0.865
Alfisol	0.5	0.10	0.40	0.80	0.125	-100	-0.096
	1	0.18	0.82	1.64	0.109	-0.740	0.214
	2	0.44	1.56	3.12	0.141	-0.350	0.404
	3	0.64	2.36	4.72	0.135	-0.193	0.673
	4	0.98	3.02	6.04	0.162	-0.008	0.781
	5	1.381.26	3.74	7.48	0.168	0.100	0.873

The results (Fig. 4.2) show that the amount adsorption of B in both the soils were followed a similar trend to that of the same soils without the application organic matter. However, the magnitude of B adsorption was greater in an alfisol compared to inceptisol. The application of organic matter to inceptisol might have no positive effect on the adsorption of B which possibly due to the formation strong linkages with polyvalent metals in forming clay-organic matter complexes preventing adsorption of B (Sarkar and Das, 1990)

The results (Fig. 4.3) show that the ratio of equilibrium B concentration to the amount adsorbed in an inceptisol consistently decreased with the equilibrium B concentration in soil solution, while the ratio of the same in an alfisol slightly increased with the equilibrium B concentration in the soil solution when organic matter was not applied which might be due to higher values of adsorption maxima (b) and constant related to bonding energy in the alfisol as evidenced from the present study.

Table 4.7 Langmuir adsorption isotherms for boron in soils applied with and without organic matter

Soils	With organic matter		Without organic matter	
	(b) Adsorption maxima ($\mu g\ g^{-1}$)	(k) Constant related to bonding energy(ppm)	(b) Adsorption maxima ($\mu g\ g^{-1}$)	(k) Constant related to bonding energy(ppm)
Inceptisol	-18.86	-0.229	-4.23	-8.33
Alfisol	22.22	0.402	41.66	0.149

The results (Fig. 4.4) show that the amount of B adsorbed in both soils of inceptisol and alfisol was linearly increased the equilibrium concentration of B in the soil solution when both soils were not treated with organic matter. However, the magnitude of such linear increase varied with soil properties affecting adsorption maxima and bonding energy, being greater in alfisol as the soil was exhibited a much greater adsorption maximum in absence of organic matter.

The results (Fig. 4.5) reveal that the ratio of concentration in equilibrium to amount adsorbed of B was recorded relatively higher in an alfisol , being consistent increase with increasing concentration of B in equilibrium solution which might be due to its adsorption onto specific adsorption sites soil colloids caused by organic matter application, while the ratio of the same in inceptisol decreased with increasing concentration of B in equilibrium solution which might be due to relatively less adsorption of B in soils caused by less availability of specific sites for B adsorption.

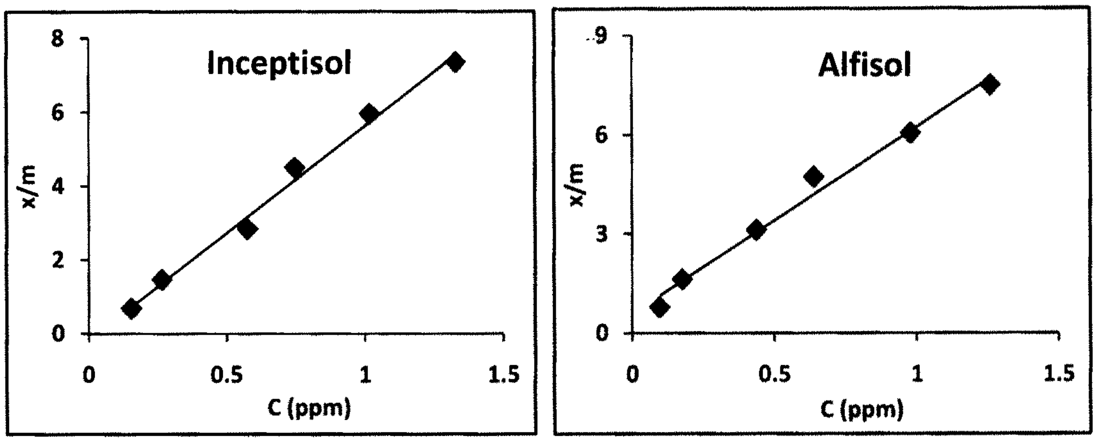


Fig. 4.2 : Relationship between equilibrium concentration (C) and adsorbed amount of boron (x/m) in organic matter treated soils

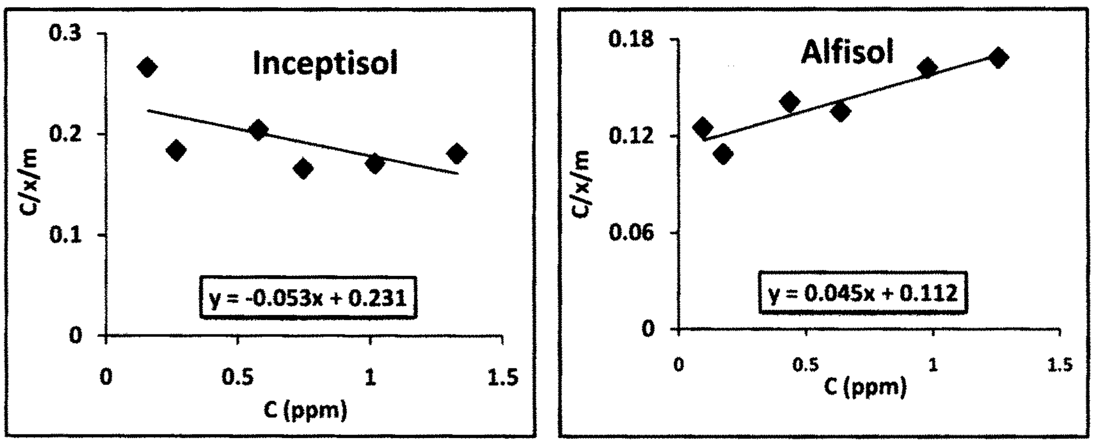


Fig. 4.3 : Relationship between C and C/x/m for adsorption of boron in soils with addition of organic matter

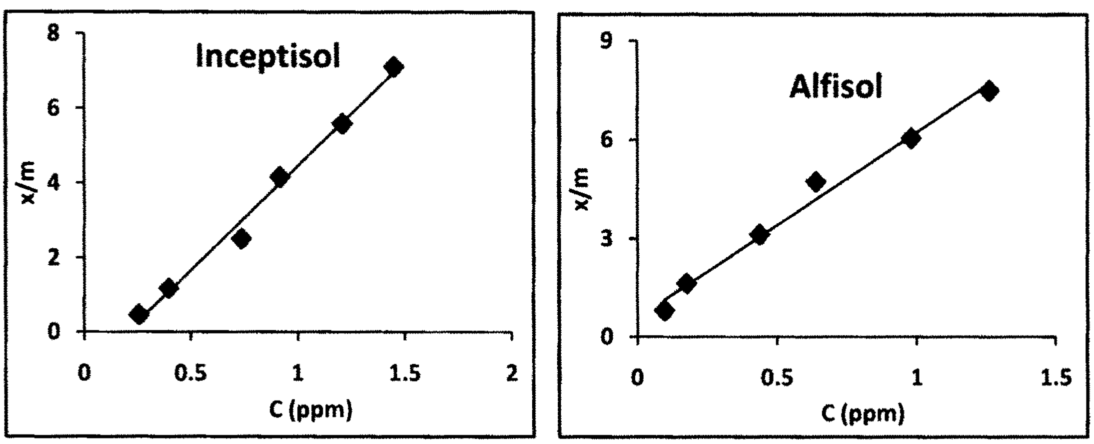


Fig. 4.4 : Relationship between equilibrium concentration (C) and adsorbed amount of boron (x/m) without organic matter treated soils

4.1.2.1.2 Adsorption of applied boron in soil without the addition of organic matter

The results (Table 4.8) show that the amount of B adsorbed exhibited a similar trend of changes in both the soils without the application of organic matter. However, the magnitude of B adsorption without the application of organic matter was much less in both alfisol and inceptisol, being adsorbed at a higher rate in an alfisol where oxides of iron and aluminium content was high. Such decrease in adsorption due to non treating the soil with organic matter might be attributed to the fact that organic matter might be existed as clay-metal organic matter complexes where clay and organic matter are combined by strong linkages with polyvalent metals. The oxidation of native organic matter relates clay and polyvalent metals which may form hydroxides immediately and such released inorganic colloids participate in B adsorption. The results suggest that small amount of organic matter in soils may change significantly the B adsorption between solid and liquid phases and thereby its availability to plants. The soils of the present study was acidic in reaction and in fact in such soils , organic matter is one of the main sources of B as little occurs on the mineral fraction at low pH values (pH <5.0)(Okazaki and Chao, 1968). Mezuman and Keren (1981) also reported similarly that organic matter has little effect on B adsorption by a soil containing 1.21% organic matter, while Sarkar and Das (1990) reported an increase in B adsorption capacity of acidic soil after removal of organic matter . Comparing the two soils , it was observed that the amount of B adsorbed with varying concentration of applied B was recorded a higher values in an alfisol compared to inceptisol without the application of organic matter which might be due to highest value of adsorption maxima(b) 41.66 mg g^{-1} in alfisol . The adsorption maxima (b) and constant related to bonding energy (k) in soils of inceptisol and alfisol without application of organic matter were recorded as -4.23 and 41.66 mg g^{-1} and -8.33 and 0.149 ppm respectively (Table 4.7) suggesting an acidic reaction of inceptisol has no specific sites for B adsorption while the alfisol having acidic in reaction has specific sites and strong affinity for B adsorption which has also been reflected for the adsorption of B in soils.

Table 4.8 Adsorption of applied boron in two soils of West Bengal without the addition of organic matter

Soil	Applied Boron (ppm)	Equilibrium concentration (C) (ppm)	Adsorbed B (ppm)	x/m (μg g-1)	C/x/m	Log C	Log x/m
Inceptisol	0.5	0.26	0.24	0.48	0.542	-0.585	-0.319
	1	0.40	0.60	1.20	0.333	-0.398	0.079
	2	0.74	1.26	2.52	0.294	-0.130	0.401
	3	0.92	2.08	4.16	0.221	-0.036	0.619
	4	1.21	2.79	5.58	0.217	0.083	0.747
	5	1.45	3.55	7.10	0.204	0.161	0.851
Alfisol	0.5	0.1	0.40	0.80	0.125	-1.000	-0.096
	1	0.28	0.72	1.44	0.194	-0.552	-0.158
	2	0.62	1.38	2.76	0.224	-0.207	0.440
	3	0.72	2.28	4.56	0.157	-0.142	0.658
	4	1.12	2.88	5.76	0.194	-0.049	0.760
	5	1.38	3.62	7.64	0.180	-0.139	0.883

4.1.2.2 Freundlich adsorption isotherm for B in soils

The results for the changes in Freundlich adsorption isotherm in an alfisol and inceptisol with and without addition of organic matter are presented in Table 4.9, Fig. 4.6 and 4.7.

Table 4.9 Freundlich adsorption isotherms for boron in soils applied with and without organic matter

Soils	With organic matter		Without organic matter	
	(n)	(k)	(n)	(k)
Inceptisol	0.859	6.378	0.650	4.219
Alfisol	1.162	5.715	0.939	6.095

Among two soils there was a considerable variation in B adsorption capacity (k) and order of adsorption (n) values which was obviously due to the variation of their properties. The highest values of n 91.162) and k (6.378) was recorded in alfisol when it was not supplied with organic matter, whereas in inceptisol the highest values of n and k were recorded as 0.859 and 5.715 respectively. In both the soils, n and k values were recorded lower when these

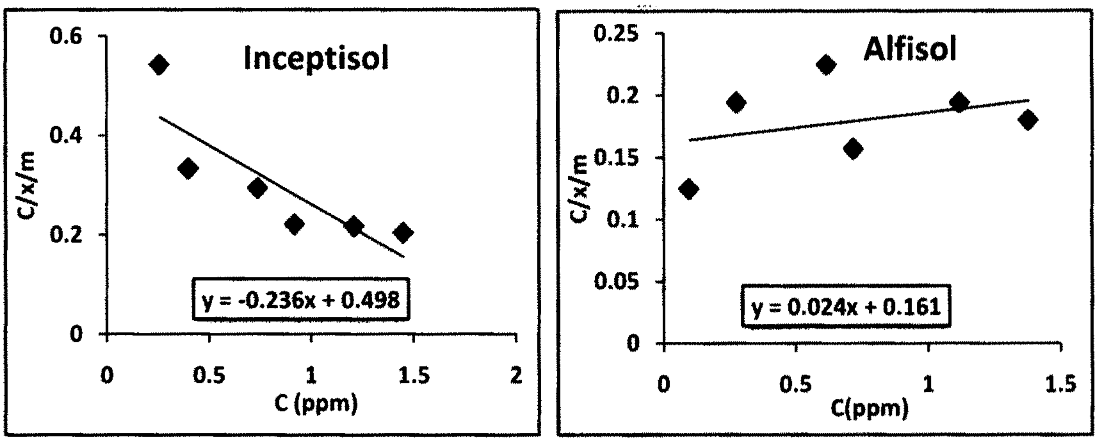


Fig. 4.5 : Relationship between C and C/x/m for adsorption of boron in soils without addition of organic matter

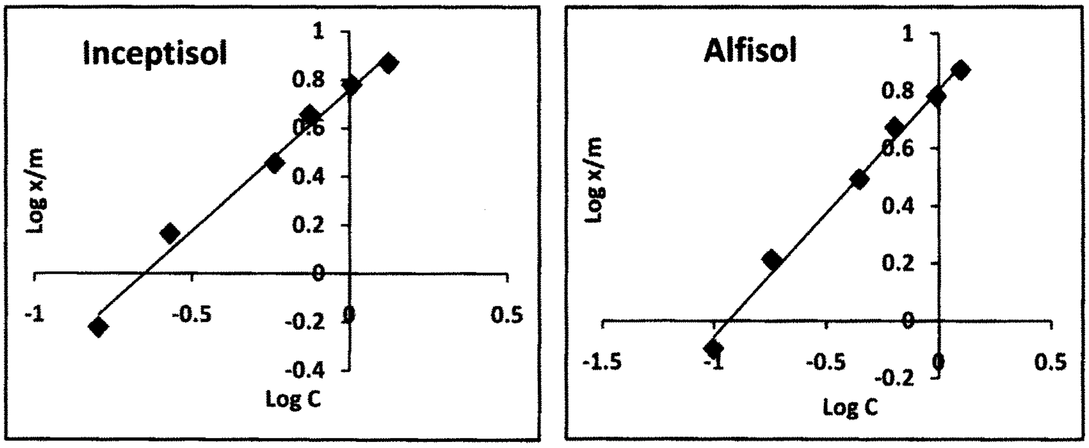


Fig. 4.6 : Relationship between Log C and Log x/m for asdorption of boron with addition of organic matter

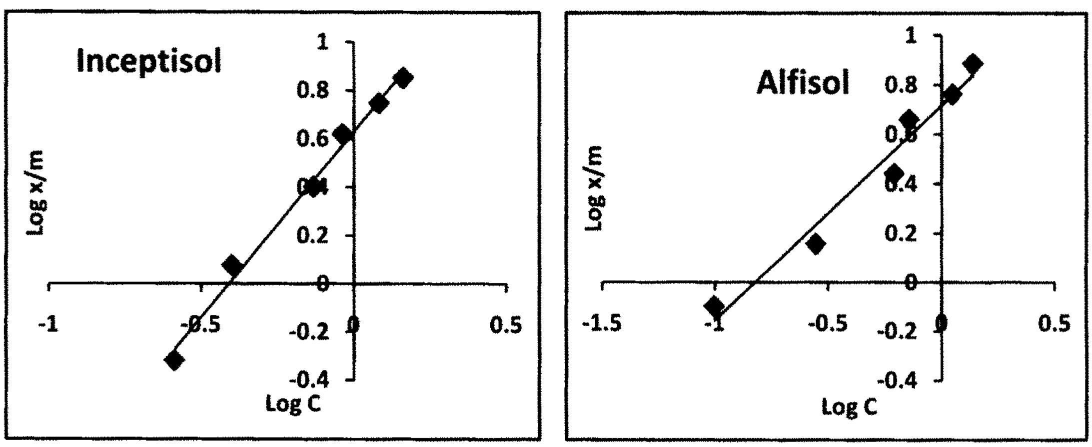


Fig. 4.7 : Relationship between Log C and Log x/m for adsorption of boron without addition of organic matter

soils were treated with organic matter. Such decreased values of n and k with the addition of organic matter might be attributed to greater competition for the adsorption of B on adsorption sites of soils. Keren and Bringham (1985) also reported similarly to that of the present study. However, the decrease in values of n in both soils treated with organic matter might be due to provide of additional B adsorption sites of lower bonding energy suggesting very little loss of B due to leaching in acid soils of the present study . The present investigation also finds support with the results reported by Sharma *et al.* (2006) who showed that the increase in B adsorption due to organic matter application to the alfisol having low initial organic matter content.

4.1.2.3 Supply parameter of boron in soils

The results (Table 4.10) show that the supply parameters of boron in soils of inceptisol and alfisol have been found to be increased with the application of boron, being increased a greater magnitude in an inceptisol when supplied with organic matter. The magnitude of such increase, however, varied with types of soils and organic matter application. The relatively higher supply parameters recorded in an inceptisol due to the low value of adsorption maxima and bonding energy compare to alfisol. On the contrary, the supply parameters of boron in an alfisol without the supply of organic matter was recorded a higher value compare to inceptisol , being greater magnitude of supply parameter recorded with the higher boron concentration .

Table 4.10 Changes in supply parameter (SP) of applied B with and without application of organic matter in soils

Concentration (ppm) of B applied	With organic matter		Without organic matter	
	Inceptisol	Alfisol	Inceptisol	Alfisol
0.5	0.229	0.164	0.145	0.179
1	0.436	0.314	0.284	0.402
2	0.891	0.677	0.560	0.828
3	1.28	1.00	0.802	1.15
4	1.71	1.41	1.06	1.61
5	2.17	1.77	1.31	2.06

The higher supply parameter of B in an alfisol without addition of organic matter might be due to the highest value of adsorption maxima resulting from the greater amount of Fe/Al oxide present in the soil. The results further revealed that the highest supply parameter of boron (2.17) was recorded in an inceptisol when 5 ppm B was applied when it is supplied with organic matter whereas the same value was recorded highest (2.06) in an alfisol without the application of organic matter which might be due to the contribution of organic matter favourably in case of inceptisol resulting from little specific sites for B adsorption and adversely in case of alfisol resulting from the higher availability of the specific sites in the later soil. The results confirmed the results reported by Sarkar and Das (1990) who reported an increase in B adsorption in soils after removal of organic matter.

4.1.2.4 Maximum Buffering Capacity in soils treated with and without organic matter

The results (Table 4.11) reveal that the maximum buffering capacity in inceptisol and alfisol treated with organic matter was recorded as 4.32 and 8.93, while that of the same without the application of organic matter was 35.23 and 6.21. In an inceptisol, the highest maximum buffering capacity was 35.23 when it was not supplied with organic matter which suggests that the release of boron or conversely the adsorption of boron does not depend so much on organic matter rather much dependent on clay content while the adsorption of B in an alfisol may be dependent on organic matter as evidenced from the maximum buffering capacity value (8.93). The lowest value of maximum buffering capacity (4.32) with added organic matter in an inceptisol suggested that soil does not act as a strong buffer with respect to B supply capacity compared to alfisol recorded relatively greater value (8.93). The highest maximum buffering capacity (35.23) was recorded in inceptisol when it is not supplied with organic matter which suggested that the soil itself has a strong buffer with respect to B supplying capacity

Table 4.11 Maximum buffering capacity of boron in soils treated with and without organic matter

With organic matter		Without organic matter	
Inceptisol	**Alfisol**	**Inceptisol**	**Alfisol**
4.32	8.93	35.23	6.21

4.1.3 Interaction effect between boron and sulphur on their changes in relation to some microbial and biochemical attributes

4.1.3.1Changes in hot $CaCl_2$ (HCC)-extractable boron content in an inceptisol

The result for the changes in HCC-extractable B in inceptisol as affected by the interaction between B and S are presented in Table 4.12. The results show that the amount of HCC-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.234 mg kg^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 37.64 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 39.62 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.8a).

With regards to the application of sulphur, it was observed that the amount of HCC-Extractable B was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 14.58 was recorded in the treatment S_2 where S at 30 mg kg^{-1} was applied at 30 days of incubation. The highest mean percent increase (13.36) was recorded in the S_2 treatment where S at 30 mg kg^{-1} was applied (Fig. 4.8a).

Table 4.12 Interaction between boron and sulphur on the changes in hot $CaCl_2$ (HCC) extractable B content (mg kg^{-1}) in an inceptisol (Mean of three replications)

Treatments	HCC-extractable B			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.165^C	0.169^C	0.170^C	0.159^C
B_1	0.209^B	0.218^B	0.223^B	0.207^B
B_2	0.227^A	0.227^A	0.234^A	0.222^A
SEm (±)	0.002	0.002	0.002	0.002
C.D. at 5%	0.006	0.006	0.006	0.006
Sulphur levels				
S_0	0.185^R	0.191^R	0.192^R	0.181^R
S_{15}	0.203^Q	0.208^Q	0.214^Q	0.201^Q
S_{30}	0.209^P	0.214^P	0.220^P	0.207^P
SEm (±)	0.002	0.002	0.002	0.002
C.D. at 5%	0.006	0.006	0.006	0.006
Interaction				
$B_0 S_0$	0.149	0.152	0.147	0.141
$B_0 S_{15}$	0.168	0.171	0.175	0.161
B_0 S30	0.179	0.183	0.187	0.176
$B_1 S_0$	0.188	0.199	0.203	0.184
$B_1 S_{15}$	0.219	0.226	0.23	0.217
$B_1 S_{30}$	0.221	0.229	0.235	0.22
$B_2 S_0$	0.218	0.223	0.227	0.217
$B_2 S_{15}$	0.223	0.227	0.236	0.224
$B_2 S_{30}$	0.227	0.232	0.239	0.226
SEm (±)	0.003	0.003	0.004	0.003
C.D. at 5%	0.009	0.009	0.012	0.009

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, S_0= no Sulphur, S_{15}=S at 15 mg kg^{-1} as elemental sulphur, S_{30}= S at 15 mg kg^{-1} as elemental sulphur.

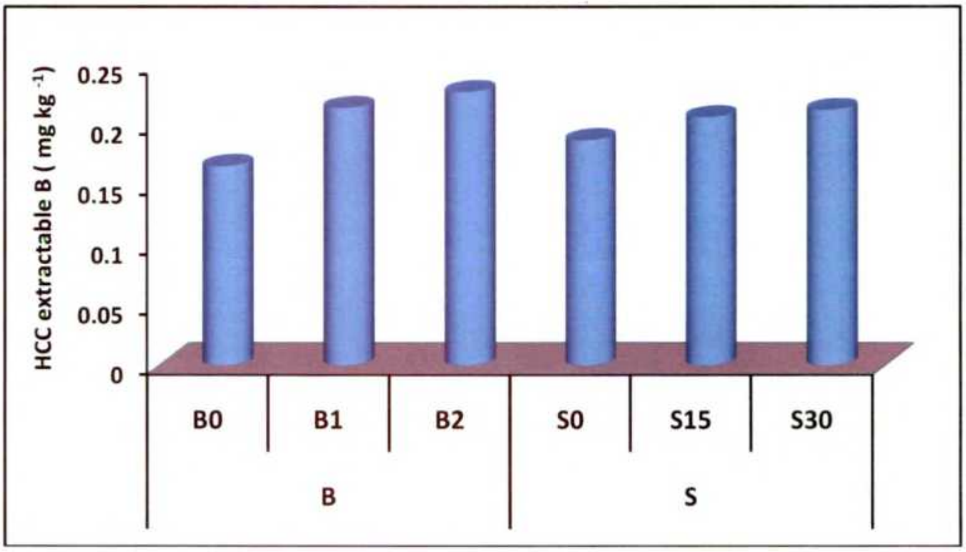


Fig. 4.8a : Mean effect of boron and sulphur on the changes in HCC extractable B content in an inceptisol

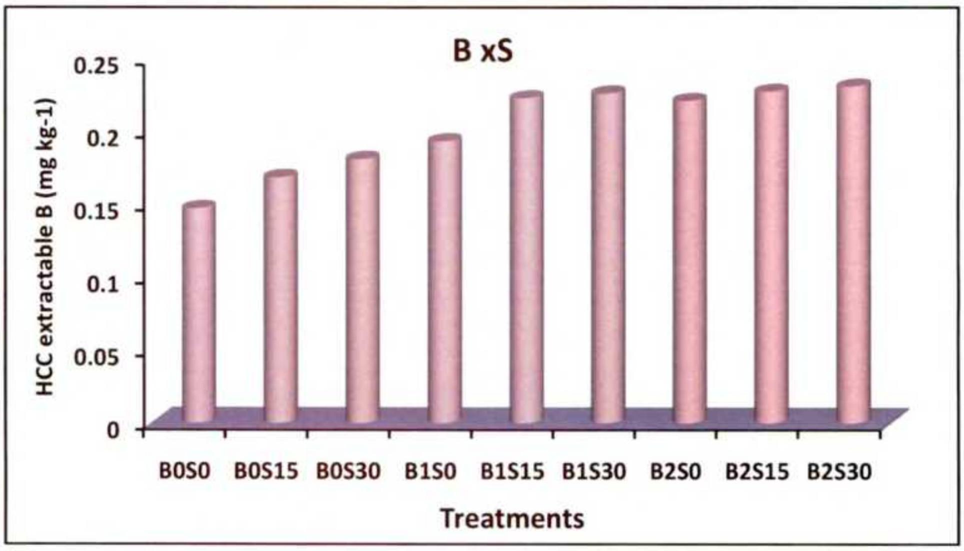


Fig. 4.8b : Mean interaction effect between boron and sulphur on the changes of HCC extractable B content in an inceptisol

As regards to the interaction effect between B and S , it was observed that the amount of HCC extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.239 mg kg^{-1}) in the treatment B_2S_{30} where B at 2 mg kg^{-1} and S at 30 mg kg^{-1} were applied combinedly with percent increase of 62.58 at 30 days of incubation. The results further indicated that the highest mean percent increase of 57.14 was also recorded in the B_2S_{30} treatment combinations (Fig.4.8b)

The results suggested that the individual applications of both B and S increased the HCC-extractable B, but due to their combined applications, the amount of HCC- extractable B has been found to be further increased significantly and hence the interaction between B and S was found positive with respect to HCC- extractable B content in soil. Sakal *et al.* (1987) and Chakraborty and Das (2000) also reported similarly where the relationship between B and S with respect to the release of boron in soils exhibited a positive relationship.

4.1.3.2 Changes in Mannitol- $CaCl_2$ (MCC)-extractable boron content in an inceptisol

The result for the changes in MCC-extractable B in inceptisol as affected by the interaction between B and S are presented in Table 4.13. The results show that the amount of MCC-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes ,however, varied with levels of B, being highest (0.179 mg kg^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 28.77 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 32.82 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.9a).

Table 4.13 Interaction between boron and sulphur on the changes in Mannitol $CaCl_2$ (MCC) extractable B (mg kg^{-1}) in an inceptisol (Mean of three replications)

Treatments	MCC-extractable B			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.127^C	0.135^C	0.139C	0.124^C
B_1	0.161^B	0.167^B	0.172B	0.164^B
B_2	0.171^A	0.176^A	0.179A	0.172^A
SEm (±)	0.001	0.002	0.002	0.001
C.D. at 5%	0.003	0.006	0.006	0.003
Sulphur levels				
S_0	0.143^R	0.151^Q	0.155^Q	0.144^Q
S_{15}	0.156^Q	0.161^P	0.165^P	0.157^P
S_{30}	0.161^P	0.166^P	0.169^P	0.160^P
SEm (±)	0.001	0.002	0.002	0.001
C.D. at 5%	0.003	0.006	0.006	0.003
Interaction				
$B_0 S_0$	0.118	0.130	0.135	0.116
$B_0 S_{15}$	0.129	0.135	0.139	0.127
B_0 S30	0.135	0.139	0.142	0.130
$B_1 S_0$	0.146	0.155	0.161	0.150
$B_1 S_{15}$	0.168	0.172	0.176	0.170
$B_1 S_{30}$	0.17	0.173	0.179	0.172
$B_2 S_0$	0.165	0.167	0.17	0.165
$B_2 S_{15}$	0.172	0.177	0.181	0.174
$B_2 S_{30}$	0.177	0.185	0.187	0.177
SEm (±)	0.002	0.003	0.002	0.003
C.D. at 5%	NS	NS	NS	NS

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, S_0= no Sulphur, S_{15}=S at 15 mg kg^{-1} as elemental sulphur, S_{30}= S at 15 mg kg^{-1} as elemental sulphur.

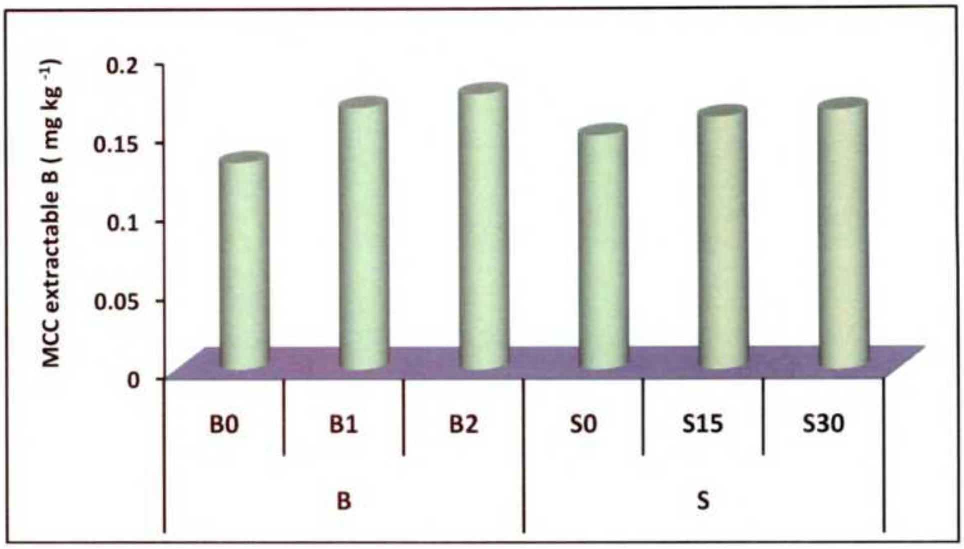


Fig. 4.9a : Mean effect of boron and sulphur on the changes in MCC extractable B content in an inceptisol

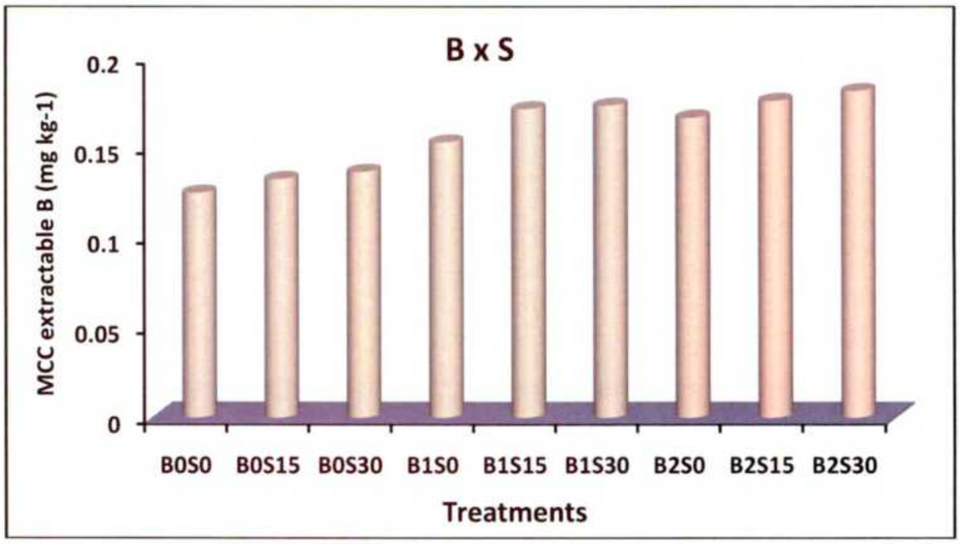


Fig. 4.9b : Mean interaction effect between boron and sulphur on the changes of MCC extractable B content in an inceptisol

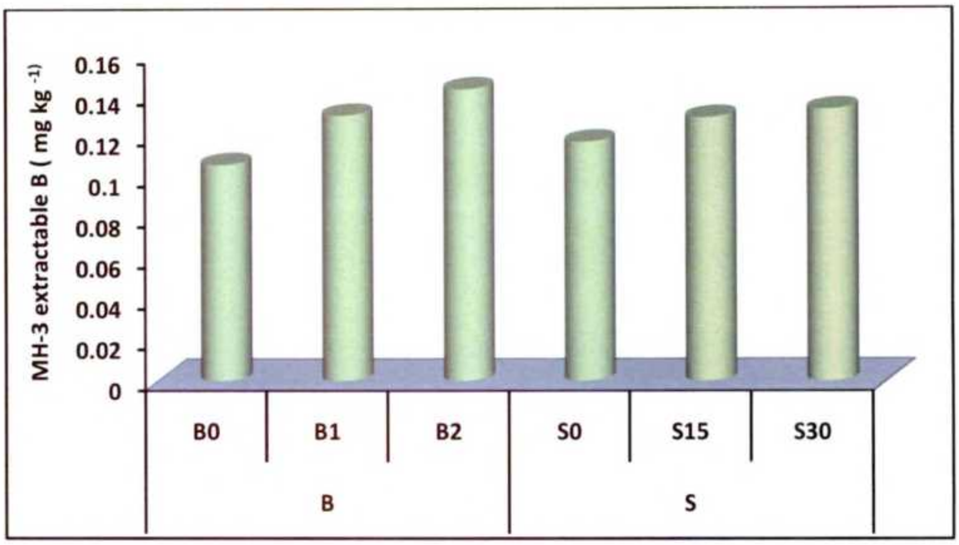


Fig. 4.10a : Mean effect of boron and sulphur on the changes in MH-3 extractable B content in an inceptisol

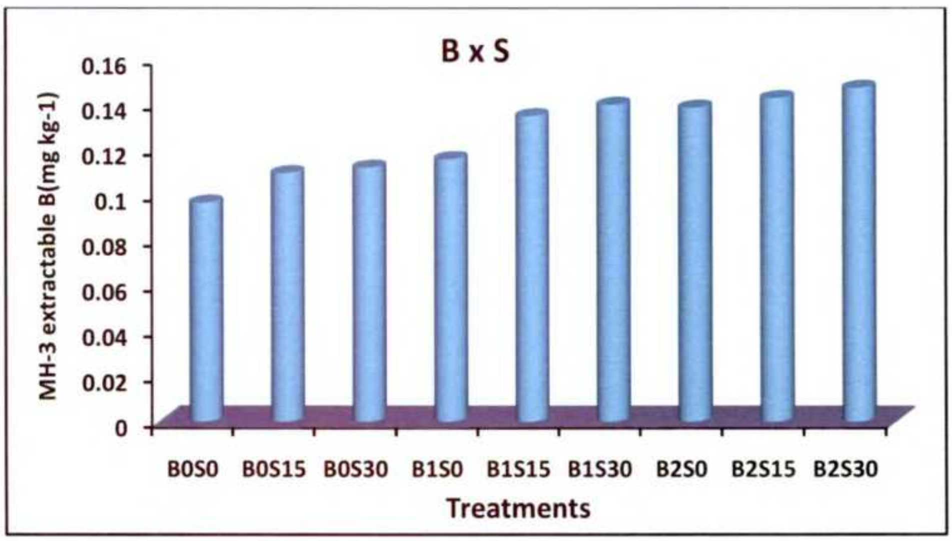


Fig. 4.10b : Mean interaction effect between boron and sulphur on the changes of MH-3 extractable B content in an inceptisol

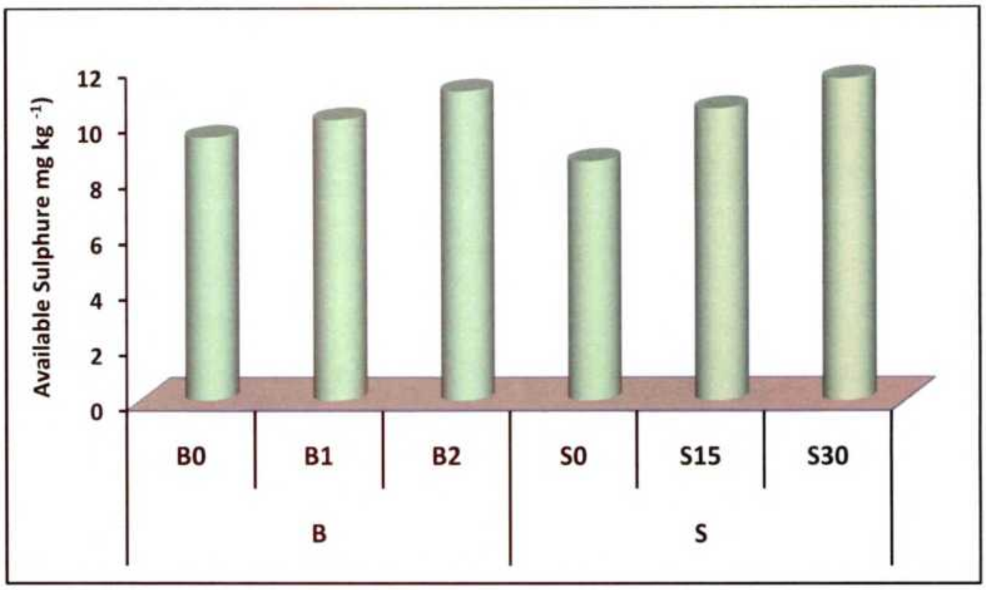


Fig. 4.11a : Mean effect of boron and sulphur on the changes in available sulphur content in an inceptisol

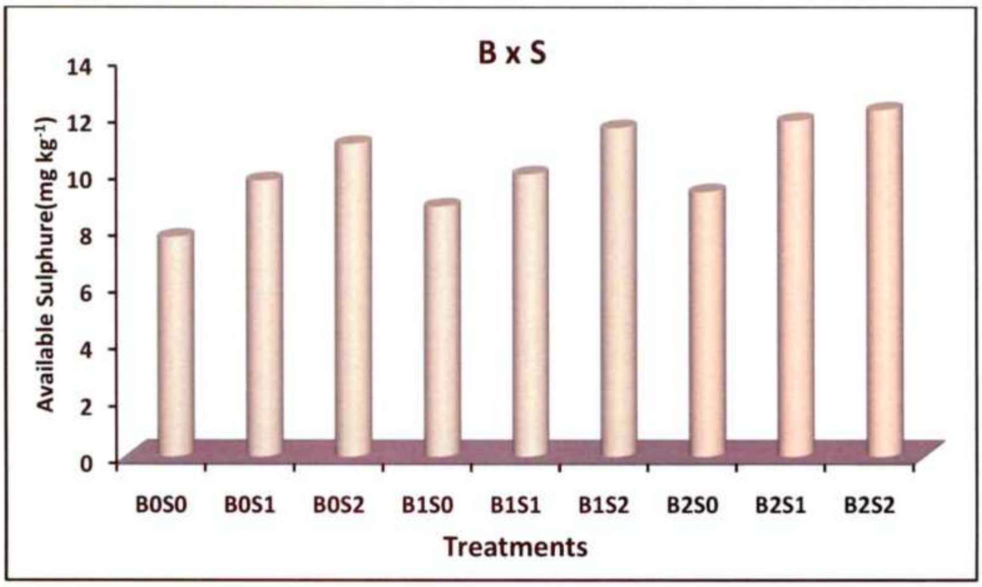


Fig. 4.11b : Mean interaction effect between boron and sulphur on the changes of available sulphur content in an inceptisol

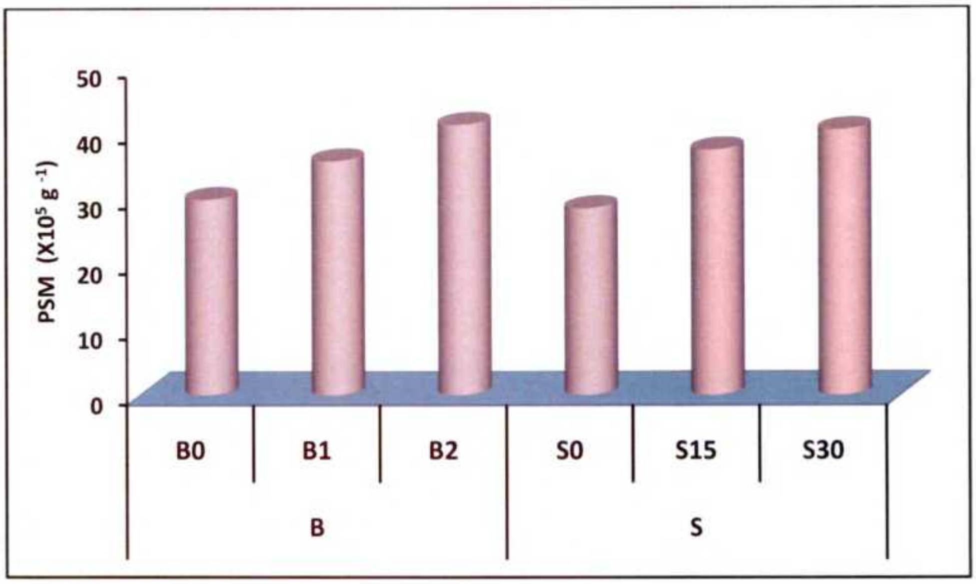


Fig. 4.12a : Mean effect of boron and sulphur on the changes in PSM in an inceptisol

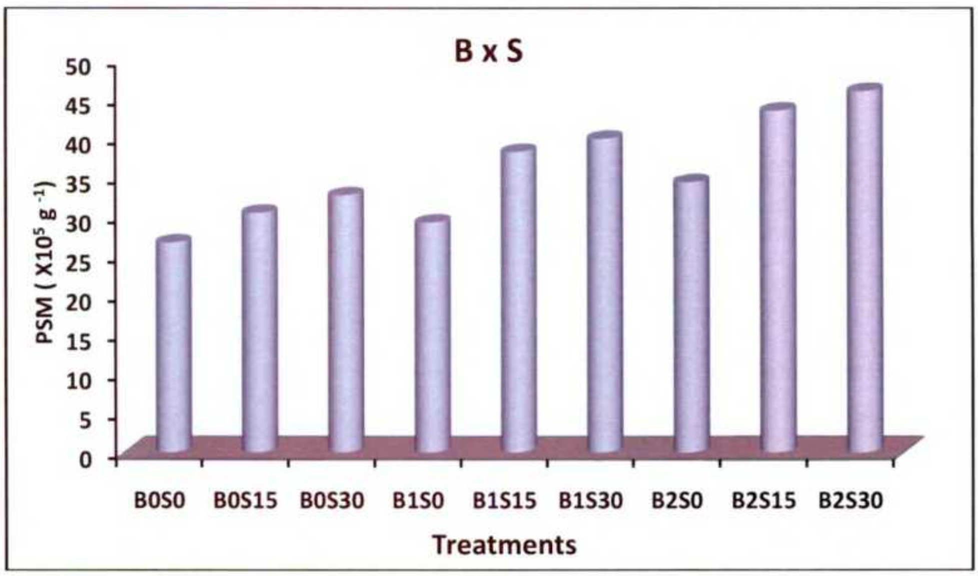


Fig. 4. 12b : Mean effect of boron and sulphur on the changes of PSM in an inceptisol

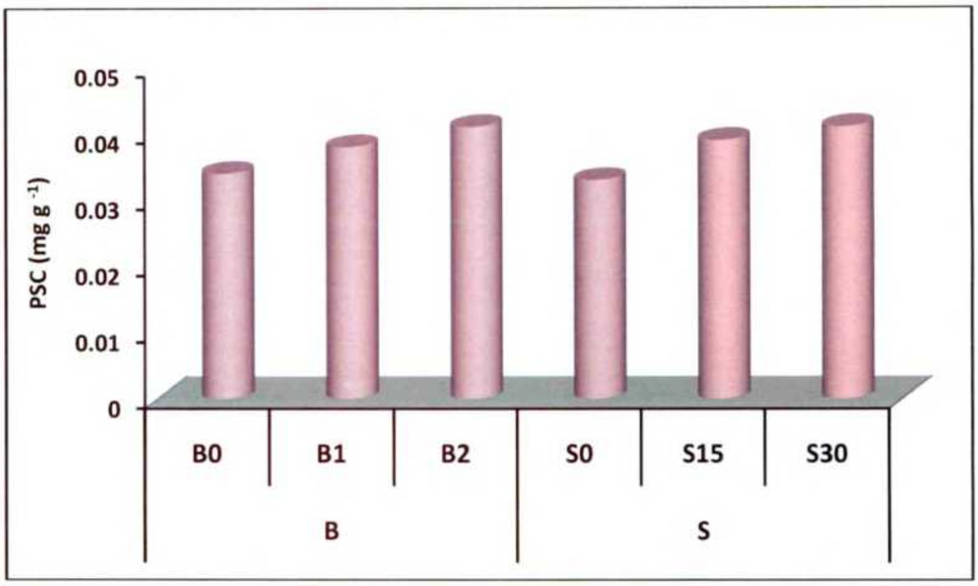


Fig. 4. 13a : Mean effect of boron and sulphur on the changes in PSC in an inceptisol

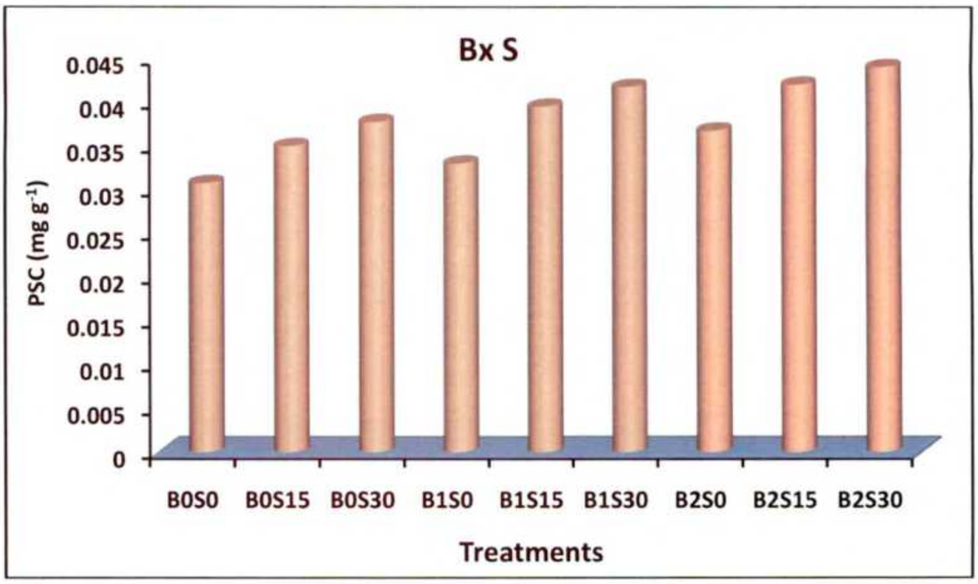


Fig. 4. 13b : Mean effect of boron and sulphur on the changes of PSC in an inceptisol

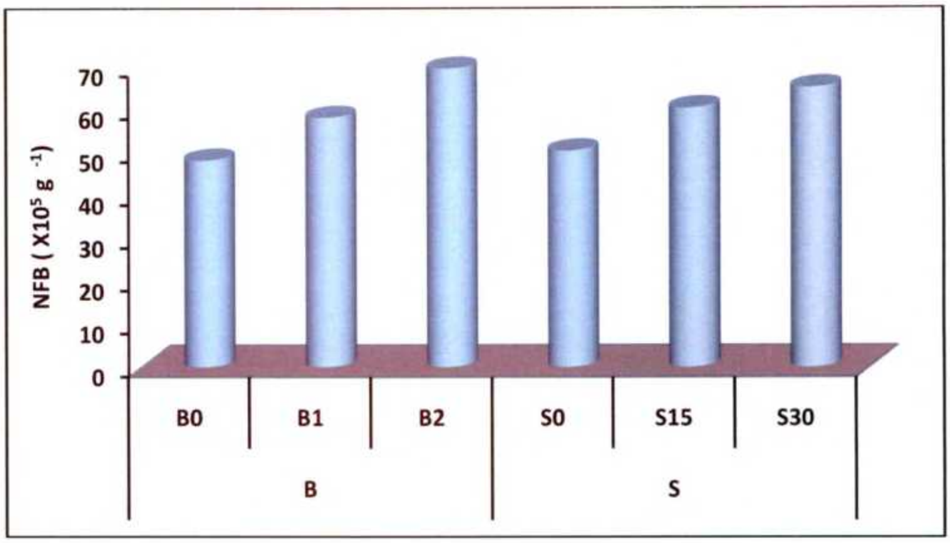


Fig. 4.14a : Mean effect of boron and sulphur on the changes in NFB in an inceptisol

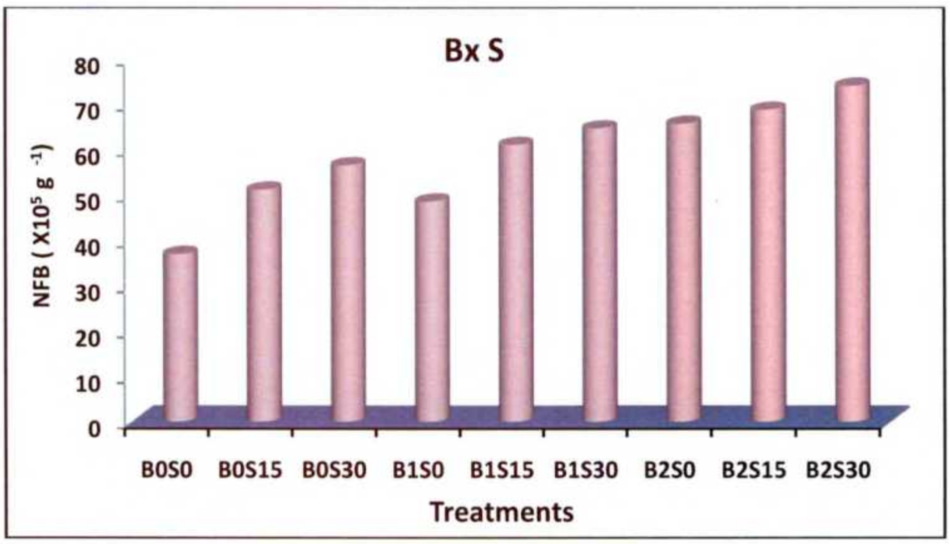


Fig. 4.14b : Mean interaction effect between boron and sulphur on the changes of NFB in an inceptisol

With regards to the application of sulphur, it was observed that the amount of MCC-Extractable B was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 9.03 was recorded in the treatment S_2 where S at 30 mg kg^{-1} was applied at 30 days of incubation. The highest mean percent increase (10.81) was recorded in the S_2 treatment where S at 30 mg kg^{-1} was applied (Fig.4.9a)

As regards to the interaction effect between B and S , it was observed that the amount of MCC extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.187 mg kg^{-1}) in the treatment B_2S_{30} where B at 2 mg kg^{-1} and S at 30 mg kg^{-1} was applied combinedly with percent increase of 38.51 at 30 days of incubation. The results further indicated that the highest mean percent increase of 45.96 was also recorded in the B_2S_{30} treatment combinations (Fig.4.9b). Chakraborty (1999) studied the interaction effect between B and S on the availability of B in soil growing rape (*Brassica campestris* L.) and reported that the amount of periodic changes in B content in soils was found to increase significantly with the application of sulphur, being highest with the application of 60 kg ha^{-1} which might be due to increase soil acidity and also party due to very little chance of biniding of applied boron with soil organic matter forming diol type compounds and Fe and Al –oxy and hydroxyl compounds of soils releasing native as well as applied boron in soil solution.

The results suggested that the individual applications of both B and S increased the MCC-extractable B, but due to their combined applications, the amount of MCC- extractable B has been found to be further increased significantly and hence the interaction between B and S was found positive with respect to MCC- extractable B content in soil

4.1.3.3 Changes in Mehlich 3(MH-3)-extractable boron content in an inceptisol

The result for the changes in MH-3-extractable B in inceptisol as affected by the interaction between B and S are presented in Table 4.14. The results show that the amount of MH-3-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.147 mg kg^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 37.38 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 33.96 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.10a).

With regards to the application of sulphur, it was observed that the amount of MH-3 extractable B was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 13.33 was recorded in the treatment S_2 where S at 30 mg kg^{-1} was applied at 30 days of incubation. The highest mean percent increase (12.82) was recorded in the S_2 treatment where S at 30 mg kg^{-1} was applied (Fig.4.10a.)

As regards to the interaction effect between B and S , it was observed that the amount of MH-3 extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.151 mg kg^{-1}) in the treatment B_2S_{30} where B at 2 mg kg^{-1} and S at 30 mg kg^{-1} was applied combinedly with percent increase of 58.94 at 30 days of incubation. The results further indicated that the highest mean percent increase of 53.12 was also recorded in the B_2S_{30} treatment combinations (Fig.4.10b)

The results suggested that the individual applications of both B and S increased the MH-3-extractable B, but due to their combined applications, the amount of MH-3- extractable B has been found to be further increased significantly and hence the interaction between B and S was found positive with respect to MH-3- extractable B content in soil

Table 4.14 Interaction between boron and sulphur on the changes in Mehlich 3 (MH-3) extractable B (mg kg^{-1}) in an inceptisol (Mean of three replications)

Treatments	MH-3-extractable B			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.106^C	0.110^C	0.107^C	0.101^C
B_1	0.127^B	0.131^B	0.135^B	0.127^B
B_2	0.138^A	0.145^A	0.147^A	0.141^A
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003
Sulphur levels				
S_0	0.115^Q	0.122^R	0.120^Q	0.111^R
S_{15}	0.126^P	0.130^Q	0.133^P	0.126^Q
S_{30}	0.130^P	0.134^P	0.136^P	0.131^P
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003
Interaction				
$B_0 S_0$	0.100	0.106	0.095	0.085
$B_0 S_{15}$	0.108	0.110	0.113	0.107
B_0 S30	0.110	0.113	0.114	0.111
$B_1 S_0$	0.113	0.117	0.121	0.112
$B_1 S_{15}$	0.133	0.137	0.139	0.130
$B_1 S_{30}$	0.136	0.140	0.144	0.139
$B_2 S_0$	0.132	0.142	0.143	0.137
$B_2 S_{15}$	0.139	0.144	0.147	0.141
$B_2 S_{30}$	0.143	0.150	0.151	0.145
SEm (±)	0.002	0.002	0.002	0.002
C.D. at 5%	0.006	0.006	0.006	0.006

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, S_0= no Sulphur, S_{15}=S at 15 mg kg^{-1} as elemental sulphur, S_{30}= S at 15 mg kg^{-1} as elemental sulphur.

4.1.3.4 Changes in available sulphur content in an inceptisol

The result for the changes in available sulphur content in inceptisol as affected by the interaction between B and S are presented in Table 4.15.The results show that the amount of available sulphur content has been found to be increased initially and thereafter, the amount of the same decreases irrespective of levels of B. The magnitude of such changes, however, varied with the levels of boron, being highest (13.6mg kg^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied with percent increase of 21.4 with respect to available sulphur content over control at 30 days of incubation. The mean percent of available sulphur increase over control due to application of B at 2 mg kg^{-1} was recorded highest as 17.4 (Fig.4.11a)

The results further reveal that the amount of available sulphur has been found to be followed a similar trend of changes to that of the applied boron excepting a greater magnitude of available sulphur which is obvious. However, the highest percent increase of available sulphur over control was recorded as 45.2 in the S_2 treatment where S at 30 mg kg^{-1} was applied at 30 days of incubation. The mean percent increase of 34.3 was also recorded highest in S_2 treatment (Fig.4.11a)

As regards to the interaction effect between B and S , it was observed that the amount of available sulphur has been found to be further increased in absolute values following the similar pattern of changes with the individual application of both B and S (Fig.4.11b) . However, the highest percent increase (60) over control was recorded in the treatment B_2S_{30} where B at 2 mg kg^{-1} and S at 30 mg kg^{-1} was applied combinedly at 30 days of incubation. Hussein (2002) also finds support the results of present investigation who reported a positive relationship between them.

Table 4.15 Interaction between boron and sulphur on the changes in sulphur ($mgkg^{-1}$) content in an inceptisol (Mean of three replications)

Treatments	Available sulphur			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	8.57^C	9.76^C	11.2^C	8.31^C
B_1	9.09^B	10.44^B	11.81^B	9.08^B
B_2	9.49^A	11.28^A	13.6^A	10.13^A
SEm (±)	0.085	0.099	0.117	0.087
C.D. at 5%	0.255	0.297	0.351	0.261
Sulphur levels				
S_0	7.97^R	8.95^R	9.87^R	7.67^R
S_{15}	9.30^Q	10.87^Q	12.42^Q	9.39^Q
S_{30}	9.89^P	11.66^P	14.33^P	10.46^P
SEm (±)	0.085	0.099	0.117	0.087
C.D. at 5%	0.255	0.297	0.351	0.261
Interaction				
$B_0 S_0$	7.21	8.03	8.99	6.65
$B_0 S_{15}$	8.82	10.23	11.55	8.28
B_0 S30	9.70	11.04	13.30	10.00
$B_1 S_0$	8.23	9.00	9.95	8.06
$B_1 S_{15}$	9.12	10.47	11.10	9.07
$B_1 S_{30}$	9.93	11.85	14.39	10.12
$B_2 S_0$	8.47	9.81	10.69	8.31
$B_2 S_{15}$	9.96	11.92	14.62	10.82
$B_2 S_{30}$	10.04	12.11	15.40	11.27
SEm (±)	0.147	0.171	0.202	0.151
C.D. at 5%	0.441	0.513	0.606	0.453

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, S_0= no Sulphur, S_{15}=S at 15 mg kg^{-1} as elemental sulphur, S_{30}= S at 15 mg kg^{-1} as elemental sulphur.

4.1.3.5 Changes in the number of phosphate solubilising microorganisms (PSM) in an inceptisol

The results for the changes in the proliferation of PSM in inceptisol as affected by the interaction between B and S are presented in Table 4.16. The results show that the number of PSM has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest ($47.34x10^5$ g^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 35.56 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 37.96 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.12a).

With regards to the application of sulphur, it was observed that the number of PSM was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 72.59 was recorded in the treatment S_2 where S at 30 mg kg^{-1} was applied at 30 days of incubation. The highest mean percent increase (41.76) was recorded in the S_2 treatment where S at 30 mg kg^{-1} was applied (Fig.4.12a)

As regards to the interaction effect between B and S , it was observed that the number of PSM was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (52.63 x 10^5 g^{-1}) in the treatment B_2S_{30} where B at 2 mg kg^{-1} and S at 30 mg kg^{-1} was applied combinedly with percent increase of 78.70 at 30 days of incubation. The results further indicated that the highest mean percent increase of 72.53 was also recorded in the B_2S_{30} treatment combinations(Fig.4.12b).Such increase in the proliferation of PSM in soil due to combined application of B and S might be due to the stimulating effect of B and S on PSM in soil resulting from the suppressive effect of S oxidation in presence of B. Davies (1980) reported that the equilibrium between available forms of B is conditioned by microbial growth as well as mineralization of organic matter.

Table 4.16 Interaction between boron and sulphur on the changes in phosphate solubilizing microorganisms (× 10^5 g^{-1} soil) in an inceptisol (Mean of three replications)

Treatments	Phosphate Solubilising microorganisms (PSM)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	27.68^C	31.62^C	34.92^C	25.48^C
B_1	32.93^B	37.23^B	41.51^B	31.49^B
B_2	36.14^A	44.54^A	47.34^A	37.13^A
SEm (±)	0.306	0.362	1.254	0.304
C.D. at 5%	0.918	1.086	3.762	0.912
Sulphur levels				
S_0	28.24^R	31.29^R	26.78^R	27.78^R
S_{15}	33.93^Q	39.53^Q	43.51^Q	32.61^Q
S_{30}	34.59^P	46.22^P	46.22^P	34.71^P
SEm (±)	0.306	0.362	1.254	0.304
C.D. at 5%	0.918	1.086	3.762	0.912
Interaction				
$B_0 S_0$	25.00	28.12	29.45	24.03
$B_0 S_{15}$	28.92	32.33	35.51	25.03
B_0 S30	29.12	34.43	39.8	27.38
$B_1 S_0$	27.63	29.53	33.35	26.39
$B_1 S_{15}$	35.05	39.53	44.93	33.44
$B_1 S_{30}$	36.11	42.63	46.24	34.64
$B_2 S_0$	32.09	36.23	39.32	29.93
$B_2 S_{15}$	37.81	46.73	50.08	39.35
$B_2 S_{30}$	38.53	50.67	52.63	42.12
SEm (±)	0.530	0.627	2.172	0.527
C.D. at 5%	1.59	1.881	6.516	1.581

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, S_0= no Sulphur, S_{15}=S at 15 mg kg^{-1} as elemental sulphur, S_{30}= S at 15 mg kg^{-1} as elemental sulphur.

The results suggested that the individual applications of both B and S increased the number of PSM, but due to their combined applications, the number of PSM has been found to be further increased significantly and hence the interaction between B and S was found positive with respect to PSM in soil.

4.1.3.6 Changes in the phosphate solubilising capacity (PSC) in an inceptisol

The result for the changes in PSC in inceptisol as affected by the interaction between B and S are presented in Table 4.17. The results show that the amount of PSC has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.046mg g^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 24.32 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 20.58 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.13a).Higher PSC in soil might be due to stimulating effect of B on PSM resulting an enhancement of PSC in soil. Nelson and Mele (2007) also reported similarly who showed that the application of B to soil significantly changes the microbial community structure including phosphate solubilizing microorganism which in turn enhances PSC of the soil.

With regards to the application of sulphur, it was observed that the amount of PSC was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 18.42 was recorded in the treatment S_2 where S at 30 mg kg^{-1} was applied at 30 days of incubation. The highest mean percent increase (24.24) was recorded in the S_2 treatment where S at 30 mg kg^{-1} was applied (Fig.4.13a). The results clearly pointed out that the PSC of soil has been found to be influenced more favourably with sulphur application compared to boron application suggesting sulphur plays a greater role in solubilising phosphorous in soils.

Table 4.17 Interaction between boron and sulphur on the changes in phosphate solubilizing capacity (mg g^{-1}) in an inceptisol (Mean of three replications)

Treatments	Phosphate solubilising capacity (PSC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.032^C	0.035^C	0.037^C	0.034^B
B_1	0.035^B	0.039^B	0.042^B	0.036^A
B_2	0.039^A	0.042^A	0.046^A	0.037^A
SEm (±)	0.00035	0.00041	0.00041	0.00037
C.D. at 5%	0.00105	0.00123	0.00123	0.00111
Sulphur levels				
S_0	0.031^R	0.034^R	0.038^R	0.030^Q
S_{15}	0.036^Q	0.039^Q	0.042^Q	0.038^P
S_{30}	0.039^P	0.042^P	0.045^P	0.038^P
SEm (±)	0.00035	0.00041	0.00041	0.00037
C.D. at 5%	0.00105	0.00123	0.00123	0.00111
Interaction				
$B_0 S_0$	0.029	0.032	0.035	0.027
$B_0 S_{15}$	0.031	0.034	0.036	0.039
B_0 S30	0.035	0.039	0.041	0.036
$B_1 S_0$	0.03	0.033	0.037	0.032
$B_1 S_{15}$	0.036	0.041	0.044	0.037
$B_1 S_{30}$	0.039	0.042	0.046	0.04
$B_2 S_0$	0.034	0.038	0.042	0.033
$B_2 S_{15}$	0.04	0.043	0.047	0.038
$B_2 S_{30}$	0.042	0.045	0.049	0.04
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, S_0= no Sulphur, S_{15}=S at 15 mg kg^{-1} as elemental sulphur, S_{30}= S at 15 mg kg^{-1} as elemental sulphur.

As regards to the interaction effect between B and S , it was observed that the amount of PSC was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.049 mg g^{-1}) in the treatment B_2S_{30} where B at 2 mg kg^{-1} and S at 30 mg kg^{-1} was applied combinedly with percent increase of 40 at 30 days of incubation. The results further indicated that the highest mean percent increase of 46.66 was also recorded in the B_2S_{30} treatment combinations (Fig.4.13b).

The results suggested that the individual applications of both B and S increased the PSC, but due to their combined applications, the amount of PSC has been found to be further increased significantly and hence the interaction between B and S was found positive with respect to PSC in soil.

4.1.3.7 Changes in aerobic non-symbiotic nitrogen fixing bacteria (NFB) in an inceptisol

The result for the changes in the proliferation of NFB in inceptisol as affected by the interaction between B and S are presented in Table 4.18. The results show that the number of NFB has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (82.35×10^5 g^{-1} soil) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 47.18 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 44.17 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.14a).Mateo et al(1986) reported that nitrogenase activity of boron deficient cells was reduced to about 40 % of that of boron supplied cells. They also suggested an involvement of boron in the N_2 –fixation.

Table 4.18 Interaction between boron and sulphur on the changes in aerobic non symbiotic nitrogen fixing bacteria ($\times 10^5 g^{-1}$ soil) in an inceptisol (Mean of three replications)

Treatments	Nitrogen Fixing Bacteria (NFB)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	43.88^C	52.74^C	55.95^C	40.25^C
B_1	52.88^B	62.66^B	68.27^B	48.53^B
B_2	60.28^A	73.78^A	82.35^A	61.58^A
SEm (±)	0.497	0.600	0.664	0.481
C.D. at 5%	1.491	1.800	1.992	1.443
Sulphur levels				
S_0	46.24^R	54.03^R	59.70^R	41.62^R
S_{15}	53.91^Q	65.05^Q	70.83^Q	51.43^Q
S_{30}	56.90^P	70.10^P	76.05^P	57.30^P
SEm (±)	0.497	0.600	0.664	0.481
C.D. at 5%	1.491	1.800	1.992	1.443
Interaction				
$B_0 S_0$	35.12	39.53	42.93	30.24
$B_0 S_{15}$	46.19	56.64	59.65	41.95
B_0 S30	50.32	62.05	65.26	48.56
$B_1 S_0$	45.70	52.54	57.25	38.75
$B_1 S_{15}$	55.92	65.55	70.56	52.07
$B_1 S_{30}$	57.03	69.90	77.01	54.76
$B_2 S_0$	57.89	70.03	78.92	55.87
$B_2 S_{15}$	59.62	72.95	82.27	60.28
$B_2 S_{30}$	63.34	78.36	85.87	68.58
SEm (±)	0.861	1.038	1.150	0.832
C.D. at 5%	2.583	3.114	3.45	2.496

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, S_0= no Sulphur, S_{15}=S at 15 mg kg^{-1} as elemental sulphur, S_{30}= S at 15 mg kg^{-1} as elemental sulphur

With regards to the application of sulphur, it was observed that the number of NFB was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 27.38 was recorded in the treatment S_2 where S at 30 mg kg^{-1} was applied at 30 days of incubation. The highest mean percent increase (29.15) was recorded in the S_2 treatment where S at 30 mg kg^{-1} was applied (Fig.4.14a).

As regards to the interaction effect between B and S , it was observed that the number of NFB was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest ($85.87x10^5$ g^{-1}soil) in the treatment B_2S_{30} where B at 2 mg kg^{-1} and S at 30 mg kg^{-1} was applied combinedly with percent increase of 100 at 30 days of incubation. The results further indicated that the highest mean percent increase of 100.35 was also recorded in the B_2S_{30} treatment combinations (Fig.4.14b).

The results suggested that the individual applications of both B and S increased the NFB, but due to their combined applications, the number of NFB has been found to be further increased significantly and hence the interaction between B and S was found positive with respect to proliferation of NFB in soil.

4.1.3.8 Changes in aerobic non-symbiotic nitrogen fixing capacity (NFC) in an inceptisol

The result for the changes in NFC in inceptisol as affected by the interaction between B and S are presented in Table 4.19. The results show that the amount of NFC has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes ,however, varied with levels of B, being highest (3.74 mg of N $g^{-1}$of soil g^{-1} sucrose consumed) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 10.97 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 12 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.15a).Garcia *et al.* (1990) reported that the requirement of B in N_2 fixation is independent of its effects on photosynthesis and reductant supply. Bolanos *et al.* (1994) also reported the essentiality of boron for symbiotic dinitrogen fixation.

Table 4.19 Interaction between boron and sulphur on the changes in aerobic non symbiotic nitrogen fixing capacity (mg of N fixed g^{-1} of soil g^{-1} sucrose consumed) in an inceptisol (Mean of three replications)

Treatments	Nitrogen Fixing Capacity (NFC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	3.19^C	3.27^C	3.37^C	3.18^C
B_1	3.33^B	3.42^B	3.47^B	3.29^B
B_2	3.61^A	3.68^A	3.74^A	3.53^A
SEm (±)	0.032	0.069	0.033	0.031
C.D. at 5%	0.096	0.207	0.099	0.093
Sulphur levels				
S_0	3.20^Q	3.28^P	3.34^Q	3.16^R
S_{15}	3.43^P	3.51^P	3.58^P	3.36^Q
S_{30}	3.50^P	3.58^P	3.65^P	3.48^P
SEm (±)	0.032	0.069	0.033	0.031
C.D. at 5%	0.096	0.207	0.099	0.093
Interaction				
$B_0 S_0$	3.10	3.19	3.23	3.05
$B_0 S_{15}$	3.22	3.30	3.41	3.2
B_0 S30	3.26	3.33	3.46	3.29
$B_1 S_0$	3.16	3.25	3.31	3.12
$B_1 S_{15}$	3.38	3.47	3.52	3.35
$B_1 S_{30}$	3.45	3.53	3.57	3.39
$B_2 S_0$	3.34	3.4	3.47	3.31
$B_2 S_{15}$	3.69	3.75	3.82	3.53
$B_2 S_{30}$	3.80	3.89	3.92	3.76
SEm (±)	0.055	0.120	0.057	0.055
C.D. at 5%	NS	NS	NS	NS

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, S_0= no Sulphur, S_{15}=S at 15 mg kg^{-1} as elemental sulphur, S_{30}= S at 15 mg kg^{-1} as elemental sulphur.

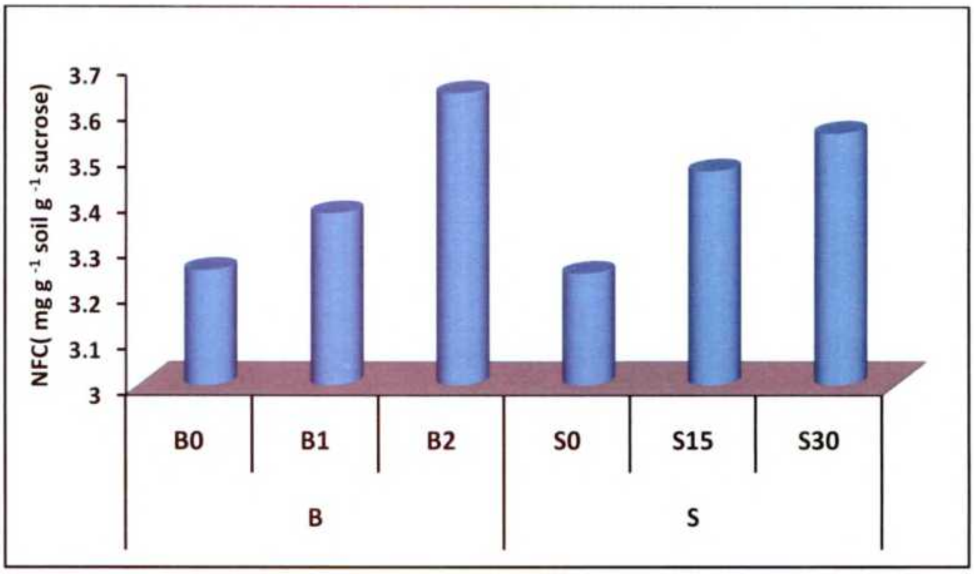


Fig. 4.15a : Mean effect of boron and sulphur on the changes in NFC in an inceptisol

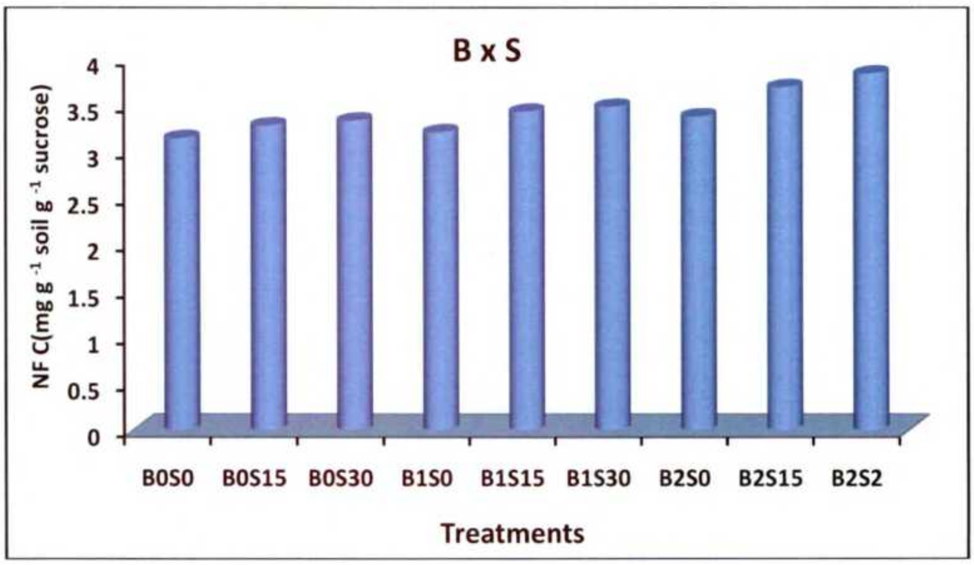


Fig. 4.15b : Mean interaction effect between boron and sulphur on the changes of NFC in an inceptisol

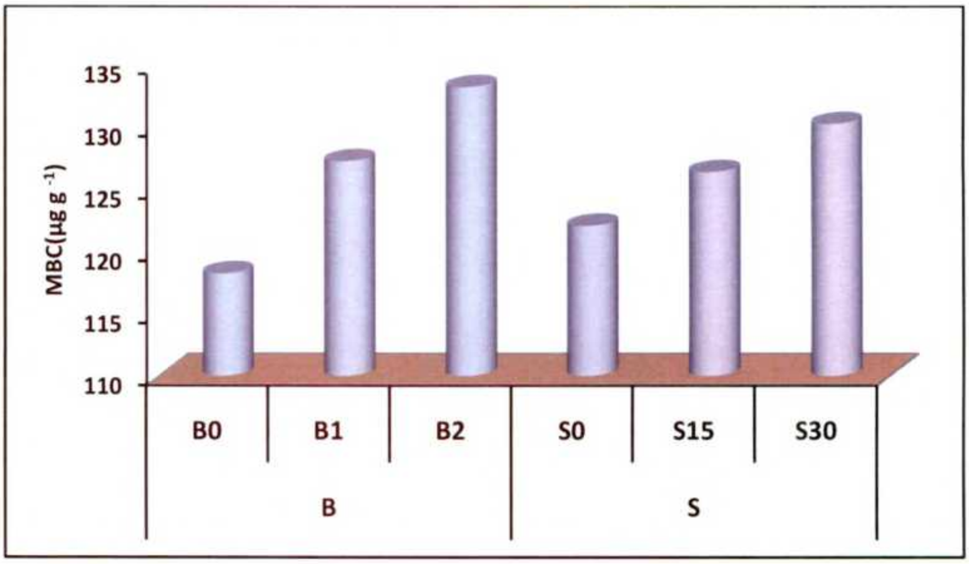


Fig. 4.16a : Mean effect of boron and sulphur on the changes in MBC content in an inceptisol

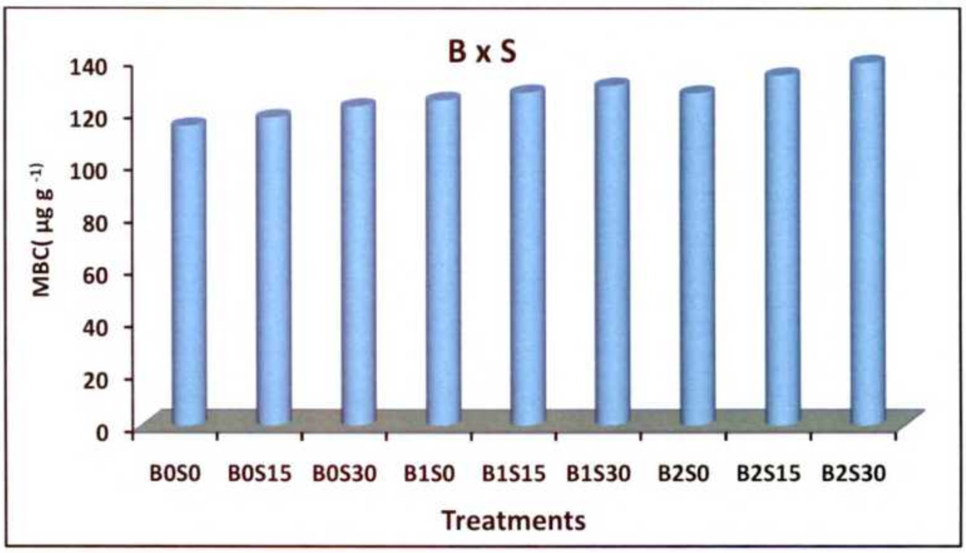


Fig. 4.16b : Mean interaction effect between boron and sulphur on the changes of MBC content in an inceptisol

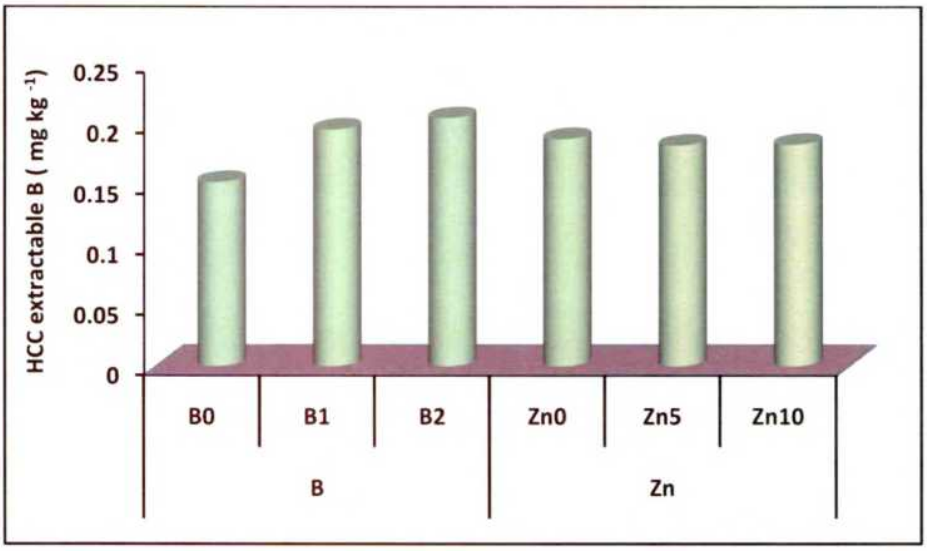


Fig. 4.18a : Mean effect of boron and zinc on the changes in HCC extractable B content in an inceptisol

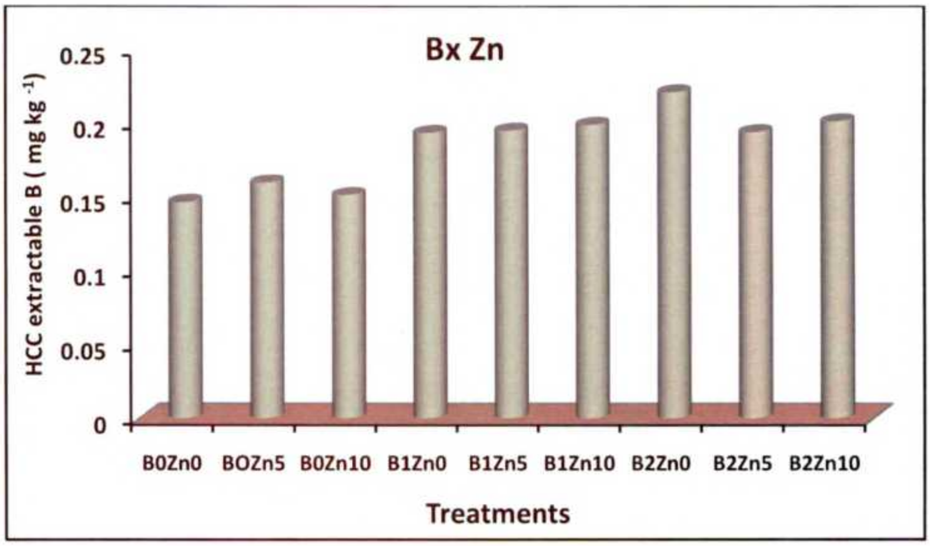


Fig. 4.18b : Mean interaction effect between boron and zinc on the changes of HCC extractable B content in an inceptisol

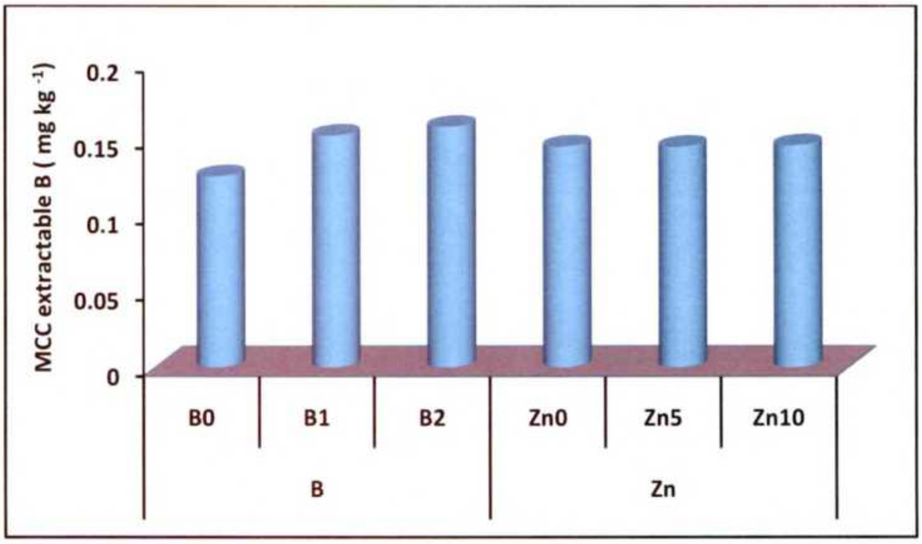


Fig. 4.19a : Mean effect of boron and zinc on the changes in MCC extractable B content in an inceptisol

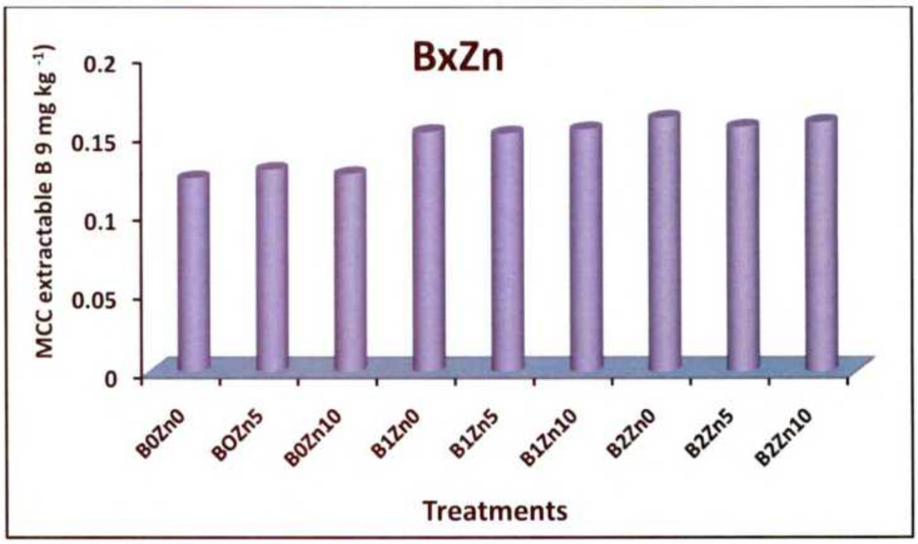


Fig. 4.19b : Mean interaction effect between boron and zinc on the changes of MCC extractable B content in an inceptisol

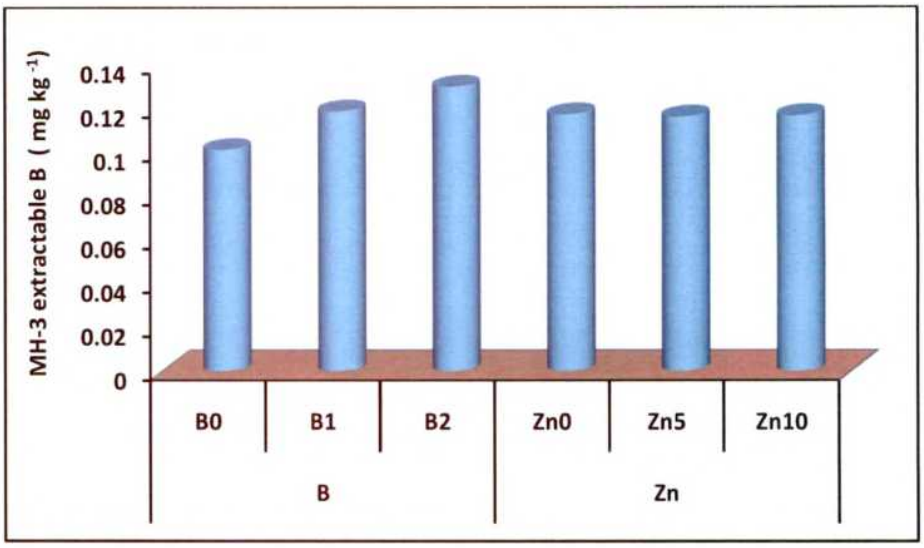


Fig. 4.20a : Mean effect of boron and zinc on the changes in MH-3 extractable B content in an inceptisol

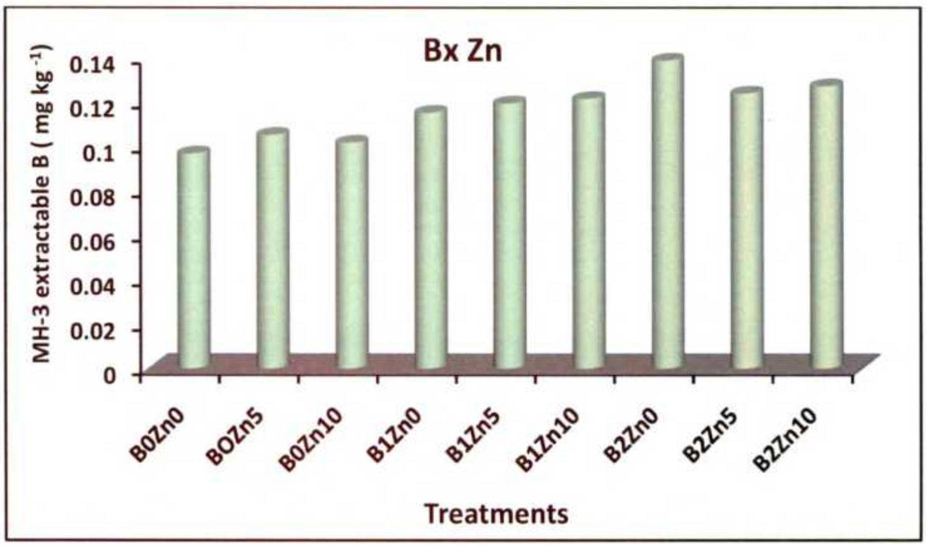


Fig. 4.20b : Mean interaction effect between boron and zinc on the changes of MH-3 extractable B in an inceptisol

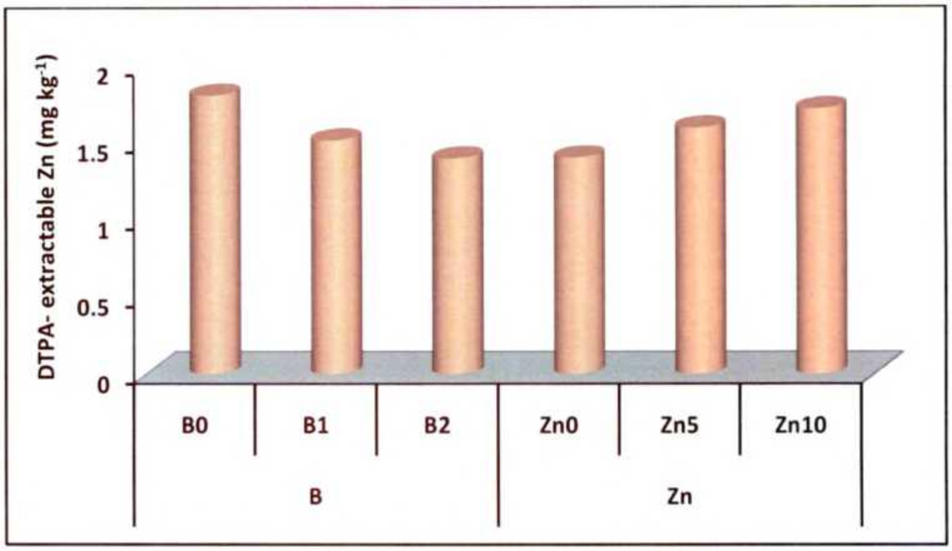


Fig. 4.21a : Mean effect of boron and zinc on the changes in DTPA- extractable zinc in an inceptisol

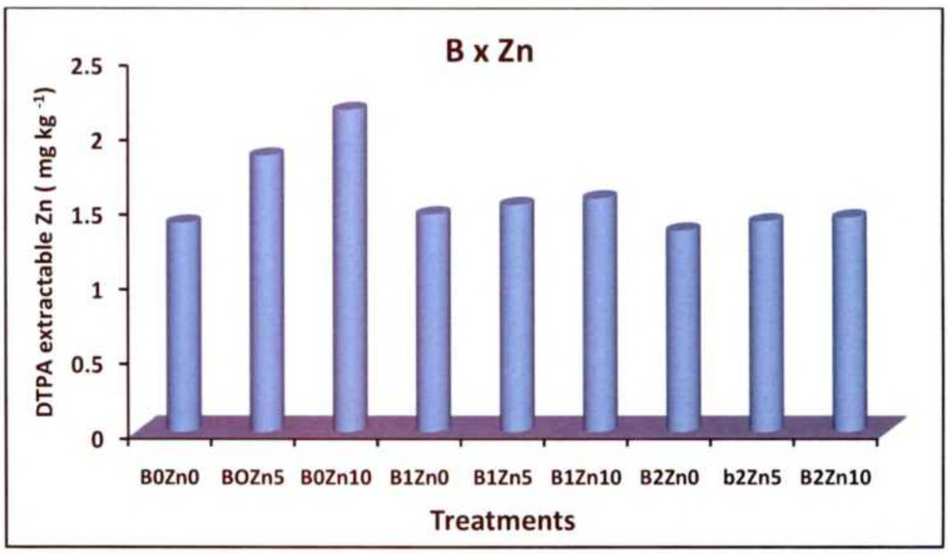


Fig. 21b : Mean interaction effect between boron and zinc on the changes of DTPA extractable zinc in an inceptisol

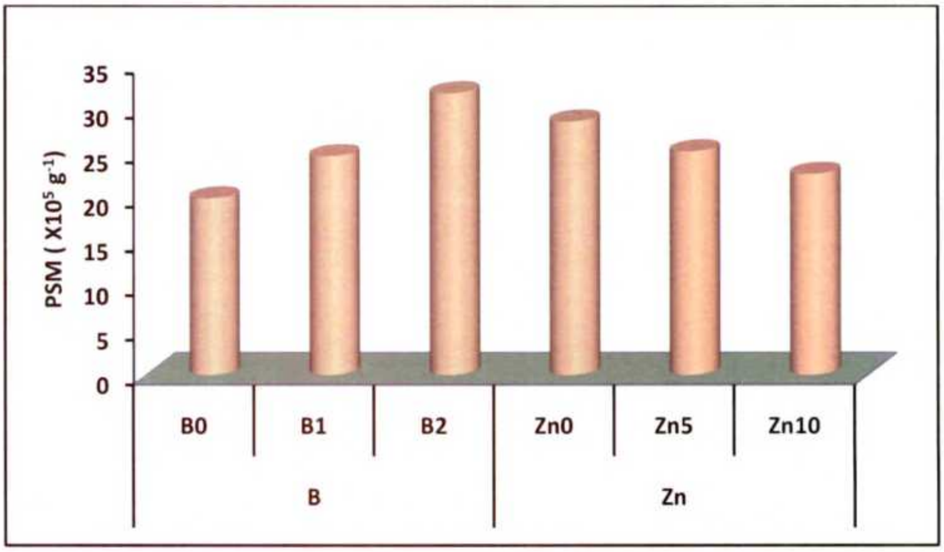


Fig. 4.22a : Mean effect of boron and zinc on the changes in PSM in an inceptisol

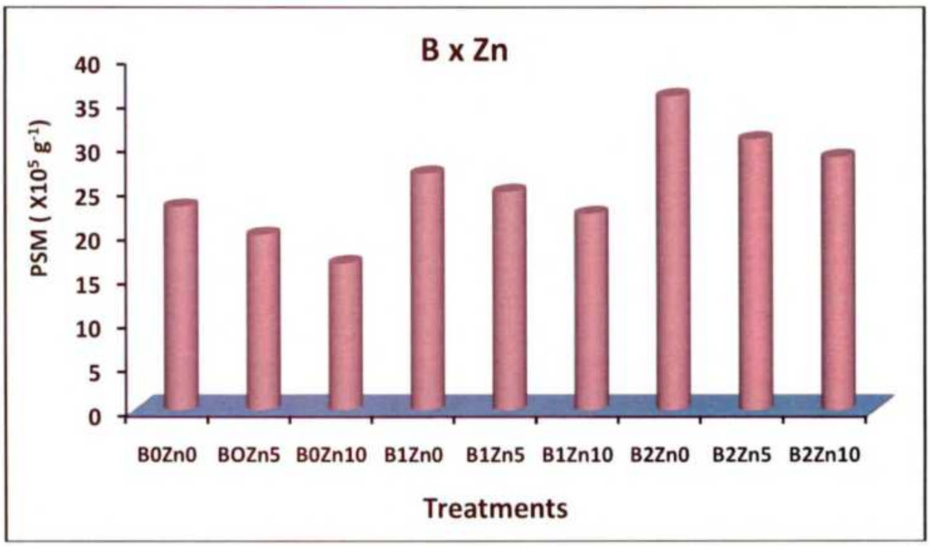


Fig. 4.22b : Mean interaction effect between boron and zinc on the changes of PSM in an inceptisol

With regards to the application of sulphur, it was observed that the amount of NFC was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 9.28 was recorded in the treatment S_2 where S at 30 mg kg^{-1} was applied at 30 days of incubation. The highest mean percent increase (9.56) was recorded in the S_2 treatment where S at 30 mg kg^{-1} was applied (Fig.4.15a).

As regards to the interaction effect between B and S , it was observed that the amount of NFC was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (3.92 mg of N g^{-1} 0f soil g^{-1} sucrose consumed) in the treatment B_2S_{30} where B at 2 mg kg^{-1} and S at 30 mg kg^{-1} was applied combinedly with percent increase of 21.36 at 30 days of incubation. The results further indicated that the highest mean percent increase of 22.29 was also recorded in the B_2S_{30} treatment combinations (Fig.4.15b).

The results suggested that the individual applications of both B and S increased the NFC, but due to their combined applications, the amount of NFC has been found to be further increased significantly and hence the interaction between B and S was found positive with respect to NFC in soil

4.1.3.9 Changes in Microbial biomass carbon (MBC) content in an inceptisol

The result for the changes in MBC content in inceptisol as affected by the interaction between B and S are presented in Table 4.20. The results show that the amount of MBC content has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (139.35 µg g^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 11.03 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 12.65 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.16a).The application of B to the soil modified the utilization of different carbon sources and substrate groups which might affect the microbial community structure (MCS) and hence affect the MBC in soil (Nelson and Mele, 2007).

Table 4.20 Interaction between boron and sulphur on the changes in microbial biomass carbón content (μg g^{-1} dry soil) in an inceptisol (Mean of three replications)

Treatments	Microbial Biomass Carbon (MBC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	112.15^C	121.00^C	125.50^C	114.38^C
B_1	121.55^B	126.55^B	134.61^B	126.42^B
B_2	127.04^A	134.33^A	139.35^A	132.21^A
SEm (±)	1.134	1.206	1.251	1.179
C.D. at 5%	3.402	3.618	3.753	3.537
Sulphur levels				
S_0	115.27^Q	124.26^Q	129.80^R	119.08^R
S_{15}	121.09^P	$127.59P^Q$	132.49^Q	124.46^Q
S_{30}	124.38^P	130.04^P	137.17^P	129.47^P
SEm (±)	1.134	1.206	1.251	1.179
C.D. at 5%	3.402	3.618	3.753	3.537
Interaction				
$B_0 S_0$	109.29	119.82	121.01	108.83
$B_0 S_{15}$	111.32	120.71	126.27	113.38
B_0 S30	115.84	122.48	129.21	120.92
$B_1 S_0$	116.24	124.01	135.05	122.72
$B_1 S_{15}$	123.92	126.23	132.29	126.92
$B_1 S_{30}$	124.49	129.42	136.49	129.63
$B_2 S_0$	120.28	128.95	133.34	125.7
$B_2 S_{15}$	128.03	135.82	138.92	133.07
$B_2 S_{30}$	132.81	138.23	145.8	137.85
SEm (±)	1.964	2.090	2.167	2.042
C.D. at 5%	5.892	6.270	6.501	6.126

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, S_0= no Sulphur, S_{15}=S at 15 mg kg^{-1} as elemental sulphur, S_{30}= S at 15 mg kg^{-1} as elemental sulphur.

With regards to the application of sulphur, it was observed that the amount of MBC content was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 5.67 was recorded in the treatment S_2 where S at 30 mg kg^{-1} was applied at 30 days of incubation. The highest mean percent increase (6.69) was recorded in the S_2 treatment where S at 30 mg kg^{-1} was applied (Fig.4.16a).

As regards to the interaction effect between B and S, it was observed that the amount of MBC content was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (145.8 $\mu g\ g^{-1}$) in the treatment B_2S_{30} where B at 2 mg kg^{-1} and S at 30 mg kg^{-1} was applied combinedly with percent increase of 20.48 at 30 days of incubation. The results further indicated that the highest mean percent increase of 20.85 was also recorded in the B_2S_{30} treatment combinations (Fig.4.16b).

The results suggested that the individual applications of both B and S increased the MBC content, but due to their combined applications, the amount of MBC content has been found to be further increased significantly and hence the interaction between B and S was found positive with respect to MBC content in soil.

4.1.3.10 PCA on boron versus sulphur study

As regards to the statistical interpretation of the data, Principal Component Analysis (PCA) was made. PCA technique was used in present study to find out the best or homogeneous treatment combinations (Boron vs. Sulphur) separately for four days after incubation due to mean magnitude of Sulphur, Phosphate Solubulizing Capacity (PSC), Phosphate Solubulizing Microorganisms (PSM), Nitrogen Fixing Capacity (NFC), Nitrogen Fixing Bacteria (NFB) and Microbial Biomass Carbon (MBC). Component matrix will include the loadings of each variable under all extracted components corresponding to eigen values more than one. Regression factor scores will be calculated to draw the scatter diagram to find out the homogeneous treatment combinations for first two components explaining first two larger variances as mentioned in the component matrices for each day after incubation.

Tab 4.21 Component matrices for each day after incubation

Variable	Day 10		Day 20		Day 30		Day 40	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
S	0.889	0.454	0.906	-0.322	0.900	0.420	0.952	0.149
PSC	0.980	0.081	0.967	-0.133	0.966	-0.087	0.801	0.587
PSM	0.979	-0.097	0.995	0.057	0.956	-0.070	0.953	-0.225
NFC	0.958	-0.141	0.810	0.569	0.977	0.078	0.973	-0.099
NFB	0.951	-0.050	0.929	-0.295	0.946	-0.210	0.969	-0.093
MBC	0.966	-0.213	0.942	0.187	0.965	-0.108	0.944	-0.224
Eigen value	5.463	0.290	5.153	0.571	5.439	0.251	5.231	0.486
% of Variance	91.058	4.831	85.886	9.514	90.651	4.177	87.177	8.092
Cumulative %	91.058	95.890	85.886	95.400	90.651	94.828	87.177	95.269

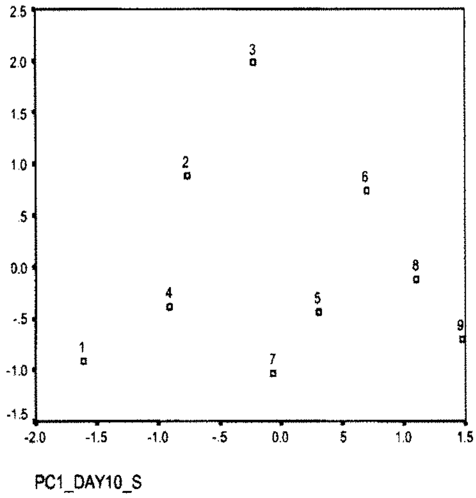
The component matrices for the changes in boron vs. sulphur interactions for four incubation days are being discussed.

Boron vs. Sulphur study at 10 DAI

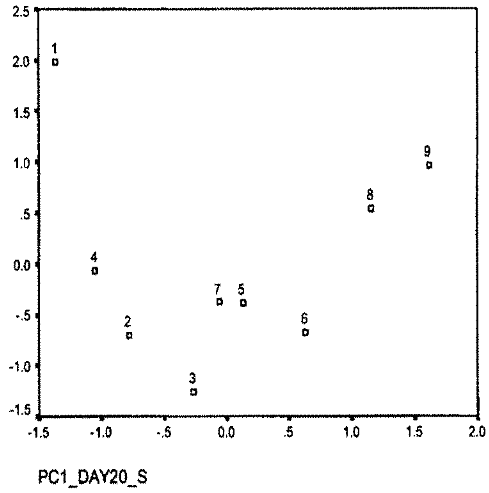
First component explained 91.06 % of variance indicating the increase in all parameters. Second component explained 4.83 % of variance further indicating the increase in Sulphur content and PSC resulted decrease in PSM, NFB ,NFC and MBC and *vice versa*. Treatment combinations B_2S_{15} and B_1S_{30} resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Sulphur study at 20 DAI

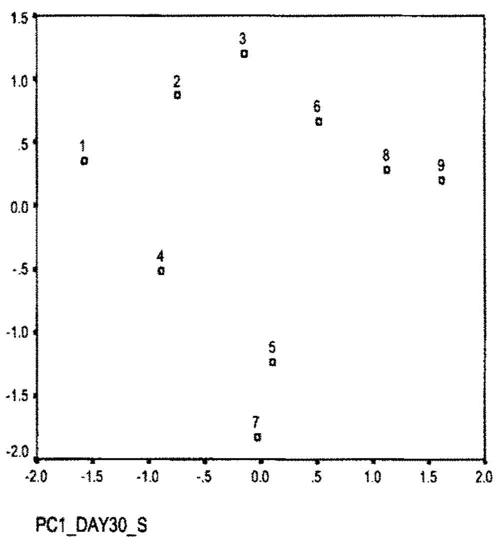
First component explained 85.89 % of variance indicating the increase in all parameters. Second component explained 9.51 % of variance further indicating the increase in PSM , NFC and MBC resulted decrease in S content, PSC and NFB and *vice versa*. Treatment combinations B_2S_{15} and B_2S_{30}



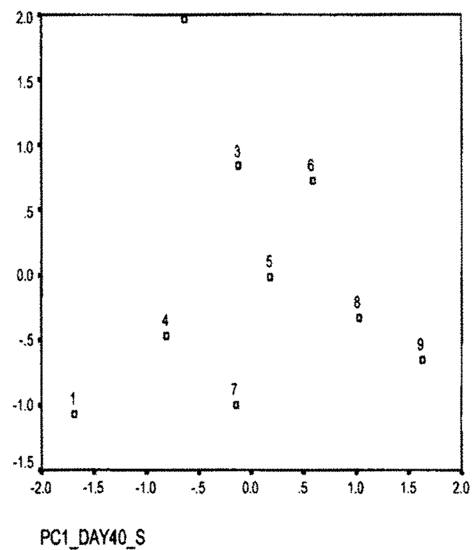
10 DAI



20 DAI



30 DAI



40 DAI

Treatment combinations	1	2	3	4	5	6	7	8	9
Boron (unit)	0	0	0	1	1	1	2	2	2
Sulphur (unit)	0	0	0	5	5	5	10	10	10

Fig. 4.17 : Scatter diagrams of regression factor scores of nine treatment combinations (B x S) corresponding to first two components for four different days after incubation

resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Sulphur study at 30 DAI

First component explained 90.65 % of variance indicating the increase in all parameters. Second component explained 4.17 % of variance further indicating the increase in Sulphur content, and NFC resulted decrease in PSC, PSM, NFB and MBC and *vice versa*. Treatment combinations B_2S_0, B_1S_{30}, B_2S_{15} and B_2S_{30} resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Sulphur study at 40 DAI

First component explained 87.17 % of variance indicating the increase in all parameters. Second component explained 8.09 % of variance further indicating the increase in Sulphur content and PSC resulted decrease in PSM, NFC, NFB and MBC and *vice versa*. Treatment combinations B_1S_{15} and B_1S_{30} resulted higher content for all those variables which are positively loaded in both the first two axes.

Table 4.22 Best subsets regression for HCC extrctable B with S, PSM, PSC, NFB, NFC and MBC

Response is B_1

Vars	R-Sq	R-Sq(adj)	C-p	S	sulphur	psc	psm	nfc	nfb	mbc
1	69.2	68.9	79.7	0.016646					X	
1	68.2	67.9	85.8	0.016920						X
2	75.3	74.8	45.3	0.014976	X				X	
2	73.4	72.9	56.4	0.015532					X	X
3	82.1	81.6	6.5	0.012797	X				X	X
3	78.0	77.4	31.2	0.014204	X	X			X	
4	82.8	82.2	4.3	0.012603	X	X			X	X
4	82.2	81.5	8.0	0.012831	X		X		X	X
5	**83.0**	**82.1**	**5.5**	**0.012616**	**X**	**X**		**X**	**X**	**X**
5	82.9	82.0	6.2	0.012656	X	X	X		X	X
6	**83.1**	**82.0**	**7.0**	**0.012645**	**X**	**X**	**X**	**X**	**X**	**X**

Table 4.23 Best subsets regression for MCC extractable B with S, PSM, PSC, NFB, NFC, MBC

Response is B_2

Vars	R-Sq	R-Sq(adj)	C-p	S	sulphur	psc	psm	nfc	nfb	mbc
1	75.7	75.4	82.3	0.010439						X
1	64.9	64.6	164.7	0.012537					X	
2	78.9	78.5	59.4	0.0097608	X					X
2	76.6	76.2	77.0	0.010280					X	X
3	85.2	84.8	13.1	0.0082124	X				X	X
3	83.1	82.6	29.4	0.0087824	X		X			X
4	86.1	85.6	8.5	0.0080072	X		X		X	X
4	86.0	85.5	9.1	0.0080304	X	X			X	X
5	**86.7**	**86.0**	**6.2**	**0.0078802**	**X**	**X**	**X**		**X**	**X**
5	86.2	85.5	10.0	0.0080278	X		X	X	X	X
6	**86.8**	**86.0**	**7.0**	**0.0078738**	**X**	**X**	**X**	**X**	**X**	**X**

Table 4.24 Best subsets regression for MH-3 extractable B with S, PSM, PSC, NFB, NFC, MBC

Response is B_3

Vars	R-Sq	R-Sq(adj)	C-p	S	sulphur	psc	psm	nfc	nfb	mbc
1	73.0	72.7	123.0	0.0092409					X	
1	72.9	72.7	123.3	0.0092471						X
2	78.8	78.4	76.0	0.0082224	X				X	
2	78.0	77.6	82.9	0.0083789					X	X
3	86.6	86.2	12.8	0.0065756	X				X	X
3	83.3	82.8	40.3	0.0073353	X			X	X	
4	87.6	87.1	6.0	0.0063453	X	X			X	X
4	87.2	86.7	9.8	0.0064605	X			X	X	X
5	**87.9**	**87.3**	**5.3**	**0.0062945**	**X**	**X**		**X**	**X**	**X**
5	87.8	87.2	6.8	0.0063388	X	X	X		X	X
6	**88.0**	**87.3**	**7.0**	**0.0063149**	**X**	**X**	**X**	**X**	**X**	**X**

Mallows (1966) suggested the Cp statistical interpretation to find out the adequate model with maximum adjusted R^2 for each extracting solution of B with PSC, PSM,NFC, NFB and MBC parameters in inceptisol.It was found that all model were fitted resulting Cp= p. However considering the distance between Cp =p line and corresponding Cp values it was recorded an ascending order of 3>2>1 in inceptisol that means MH-3 extracting solution proved best with the interaction with sulphur in inceptisol for the extraction of B.

4.1.4 Interaction effect between boron and zinc on their changes in soil in relation to some microbial and biochemical attributes

4.1.4.1 Changes in hot $CaCl_2$ (HCC) - extractable B Content in an inceptisol

The results for the changes in HCC-extractable boron content in an inceptisol due to interaction between B and Zn are presented in Table 4.25. With regards to individual application of boron it was found that the amount of HCC extractable B has been found to be significantly increased upto 20 days of incubation thereafter the amount decrease irrespective of levels of B. The magnitude of such changes, however, varied with the levels of boron, being highest (0.213 mg kg^{-1}) in the treatment B_2 where B at 2 mg kg^{-1} was applied with percent increase of 34.81 % over control at 20 days of incubation. The mean percent increase of HCC-extractable of B content in an inceptisol (Fig.4.18a) was recorded as 34.86 % over control in the treatment B_2 where B at 2 mg kg^{-1} was applied.

As regards to the separate application of zinc , it was observed that the amount of HCC-extractable B content in an inceptisol although recorded a slight increase at 20 days of incubation but it was non-significant rather consistently decreased upto 40 days of incubation.The results further envisaged that the amount of HCC extractable B content did not vary significantly with the levels of Zn.The application of Zn at their different levels did not show any definite relationship on the availability of HCC extractable B in soils.

With regards to the interaction effect between boron and zinc (Table 4.25) it was observed that the amount of HCC extractable B content in an inceptisol has been found to be varied differently with different combinations of boron and zinc.

Table 4.25 Interaction between boron and zinc on the changes in hot $CaCl_2$ (HCC) - extractable B (mg kg^{-1}) in an inceptisol (Mean of three replications)

Treatments	HCC-extractable B			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.153^A	0.158^C	0.152^B	0.147^B
B_1	0.194^B	0.201^B	0.200^A	0.188^A
B_2	0.207^C	0.213^A	0.204^A	0.197^A
SEm (±)	0.002	0.002	0.002	0.003
C.D. at 5%	0.006	0.006	0.006	0.009
Zinc levels				
Zn_0	0.189P	0.191P	0.192P	0.180P
Zn_5	0.185P	0.190P	0.182Q	0.174P
Zn_{10}	0.185P	0.190P	0.182Q	0.177P
SEm (±)	0.002	0.002	0.002	0.003
C.D. at 5%	NS	NS	0.006	NS
Interaction				
$B_0 Zn_0$	0.148	0.152	0.146	0.140
$B_0 Zn_{15}$	0.159	0.165	0.161	0.154
B_0 Zn10	0.153	0.156	0.150	0.146
$B_1 Zn_0$	0.189	0.198	0.203	0.184
$B_1 Zn_5$	0.195	0.201	0.196	0.188
$B_1 Zn_{10}$	0.199	0.205	0.200	0.192
$B_2 Zn_0$	0.218	0.222	0.227	0.217
$B_2 Zn_5$	0.200	0.206	0.189	0.181
$B_2 Zn_{10}$	0.204	0.210	0.197	0.194
SEm (±)	0.003	0.003	0.003	0.006
C.D. at 5%	0.009	0.009	0.009	0.018

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, Zn_0= no Zinc, Zn_5=Zn at 5 mg kg^{-1} as Zn-EDTA, Zn_{10}= Zn at 10 mg kg^{-1} as Zn-EDTA

However, the results show that the amount of HCC extractable B content was recorded a depressive effect in the treatment combinations where different levels of zinc and no application of boron was applied while that of the same content found increased in the treatment combinations where different levels of boron and no application of zinc was applied, being increase a greater magnitude with higher level of boron application. The results further reveal that such depressive effect of zinc on HCC extractable boron content has been found to be counteracted by the simultaneous applications of boron and zinc , being more pronounce with lower level of boron in combinations with zinc i.e. B_1Zn_5 and B_1Zn_{10} .Such decrease amount of HCC extractable B in an inceptisol might be due to high organic matter content of the soil which resulted strong linkage between boron and organic matter with an increase in the number of OH-group of organic matter as well as preventing organic matter to become further associated with the applied B in presence of applied Zn. The results of the present investigation also find support with the results reported by Davis (1980).However, the mean percent increase was recorded highest (51.36) in the treatment where boron at 2 mg kg^{-1} and no application of zinc was applied combinedly (Fig.4.18b). The following trend of changes in HCC extractable B due to interaction between B and Zn was recorded as $B_2Zn_0 > B_2Zn_{10} > B_1Zn_{10} > B_1Zn_5 > B_2Zn_5 > B_1Zn_0 > B_0Zn_5 > B_0Zn_{10} > B_0Zn_0$.

4.1.4.2 Changes in Mannitol- $CaCl_2$ (MCC) - extractable B Content in an inceptisol

The results for the changes in MCC-extractable boron content in an inceptisol due to interaction between B and Zn are presented in Table 4.26. With regards to individual application of boron it was found that the amount of MCC extractable B has been found to be significantly increased upto 20 days of incubation thereafter the amount decrease irrespective of levels of B. The magnitude of such changes, however, varied with the levels of boron, being highest (0.164 mg kg^{-1}) in the treatment B_2 where B at 2 mg kg^{-1} was applied with percent increase of 22.38 over control at 20 days of incubation. The mean percent increase of HCC-extractable of B content in an inceptisol (Fig.4.19a) was recorded as 26.40 over control in the treatment B_2 where B at 2 mg kg^{-1} was applied.

Table 4.26 Interaction between boron and Zinc on the changes in mannitol-$CaCl_2$ (MCC) - extractable B (mg kg^{-1}) in an inceptisol (Mean of three replications)

Treatments	MCC-extractable B			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.124^{C}	0.134^{C}	0.127^{B}	0.118^{C}
B_1	0.150^{B}	0.157^{B}	0.155^{A}	0.149^{B}
B_2	0.159^{A}	0.164^{A}	0.158^{A}	0.153^{A}
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003
Zinc levels				
Zn_0	0.143^{P}	0.151^{P}	0.148^{P}	0.140^{P}
Zn_5	0.144^{P}	0.152^{P}	0.145^{P}	0.140^{P}
Zn_{10}	0.146^{P}	0.152^{P}	0.147^{P}	0.140^{P}
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	NS	NS	NS	NS
Interaction				
$B_0 Zn_0$	0.120	0.131	0.125	0.110
$B_0 Zn_{15}$	0.128	0.137	0.129	0.120
B_0 Zn10	0.125	0.133	0.128	0.117
$B_1 Zn_0$	0.146	0.155	0.160	0.149
$B_1 Zn_5$	0.15	0.157	0.151	0.148
$B_1 Zn_{10}$	0.153	0.16	0.154	0.15
$B_2 Zn_0$	0.164	0.168	0.159	0.155
$B_2 Zn_5$	0.155	0.161	0.156	0.151
$B_2 Zn_{10}$	0.159	0.163	0.160	0.153
SEm (±)	0.002	0.003	0.003	0.002
C.D. at 5%	0.006	NS	NS	NS

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, Zn_0= no Zinc, Zn_5=Zn at 5 mg kg^{-1} as Zn-EDTA, Zn_{10}= Zn at 10 mg kg^{-1} as Zn-EDTA

As regards to the separate application of zinc , it was observed that the amount of MCC-extractable B content in an inceptisol although recorded a slight increase at 20 days of incubation but it was non-significant rather consistently decreased upto 40 days of incubation.The results further envisaged that the amount of MCC extractable B content did not vary significantly with the levels of Zn.The application of Zn at their different levels did not show any definite relationship on the availability of MCC extractable B in soils.

With regards to the interaction effect between boron and zinc (Table 4.26) it was observed that the amount of MCC extractable B content in an inceptisol has been found to be varied differently with different combinations of boron and zinc. However, the results show that the amount of MCC extractable B content was recorded a depressive effect in the treatment combinations where different levels of zinc and no application of boron was applied while that of the same content found increased in the treatment combinations where different levels of boron and no application of zinc was applied, being increase a greater magnitude with higher level of boron application. The results further reveal that such depressive effect of zinc on MCC extractable boron content has been found to be counteracted by the simultaneous applications of boron and zinc, being more pronounce with lower level of boron in combinations with zinc i.e. B_1Zn_5 and B_1Zn_{10} .However, the mean percent increase was recorded highest (30.89) in the treatment where boron at 2 mg kg^{-1} and no application of zinc was applied combinedly (Fig.4.19b). The following trend of changes in MCC extractable B due to interaction between B and Zn was recorded as $B_2Zn_0>B_2Zn_{10}>B_1Zn_{10}>B_1Zn_5>B_2Zn_5>B_1Zn_0>B_0Zn_5>B_0Zn_{10}>B_0Zn_0$

4.1.4.3 Changes in Mehlich 3(MH-3) - extractable B Content in inceptisol

The results for the changes in MH-3-extractable boron content in an inceptisol due to interaction between B and Zn are presented in Table 4.27. With regards to individual application of boron it was found that the amount of MH-3 extractable B has been found to be significantly increased upto 20 days of incubation thereafter the amount decrease irrespective of levels of B.

Table 4.27 Interaction between boron and zinc on the changes in Mehlich 3 (MH-3) extractable boron (mg kg^{-1}) in an inceptisol (Mean of three replications)

Treatments	MH-3-extractable B			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.105^{C}	0.109C	0.100^{C}	0.091^{C}
B_1	0.116^{B}	0.124^{B}	0.121^{B}	0.114^{B}
B_2	0.128^{A}	0.135^{A}	0.132^{A}	0.125^{A}
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003
Zinc levels				
Zn_0	0.115^{P}	0.122^{P}	0.119^{Q}	0.111^{P}
Zn_5	0.116^{P}	0.122^{P}	0.117^{Q}	0.110^{P}
Zn_{10}	0.117^{P}	0.124^{P}	0.117^{P}	0.109^{P}
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	NS	NS	0.003	NS
Interaction				
$B_0 Zn_0$	0.102	0.107	0.094	0.084
$B_0 Zn_{15}$	0.107	0.110	0.106	0.098
B_0 Zn10	0.105	0.109	0.101	0.092
$B_1 Zn_0$	0.112	0.117	0.12	0.112
$B_1 Zn_5$	0.117	0.126	0.121	0.114
$B_1 Zn_{10}$	0.119	0.129	0.123	0.115
$B_2 Zn_0$	0.132	0.142	0.144	0.137
$B_2 Zn_5$	0.124	0.129	0.125	0.118
$B_2 Zn_{10}$	0.127	0.135	0.127	0.120
SEm (±)	0.002	0.002	0.002	0.002
C.D. at 5%	0.006	0.006	0.006	0.006

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, Zn_0= no Zinc, Zn_5=Zn at 5 mg kg^{-1} as Zn-EDTA, Zn_{10}= Zn at 10 mg kg^{-1} as Zn-EDTA

The magnitude of such changes, however, varied with the levels of boron, being highest (0.135 mg kg^{-1}) in the treatment B_2 where B at 2 mg kg^{-1} was applied with percent increase of 23.85 % over control at 20 days of incubation. The mean percent increase of MH-3-extractable of B content in an inceptisol (Fig. 4.20a) was recorded as 28.71 % over control in the treatment B_2 where B at 2 mg kg^{-1} was applied.

As regards to the separate application of zinc , it was observed that the amount of MH-3-extractable B content in an inceptisol although recorded a slight increase at 20 days of incubation but it was non-significant rather consistently decreased upto 40 days of incubation.The results further envisaged that the amount of MH-3 extractable B content did not vary significantly with the levels of Zn.The application of Zn at their different levels did not show any definite relationship on the availability of MH-3 extractable B in soils.

With regards to the interaction effect between boron and zinc (Table 4.27) it was observed that the amount of MH-3 extractable B content in an inceptisol has been found to be varied differently with different combinations of boron and zinc. However, the results show that the amount of MH-3 extractable B content was recorded a depressive effect in the treatment combinations where different levels of zinc and no application of boron was applied while that of the same content found increased in the treatment combinations where different levels of boron and no application of zinc was applied, being increase a greater magnitude with higher level of boron application. The results further reveal that such depressive effect of zinc on MH-3 extractable boron content has been found to be counteracted by the simultaneous applications of boron and zinc , being more pronounced with lower level of boron in combinations with zinc i.e. B_1Zn_5 and B_1Zn_{10} .However, the mean percent increase was recorded highest (43.75) in the treatment where boron at 2 mg kg^{-1} and no application of zinc was applied combinedly (Fig.4.20b). The relatively lower amount of MH-3 extractable B in an inceptisol might be due to low pH of the soil (pH 5.7) where MH-3 extractable is not able to extract B from soils adequately. Further, the applied B may be adsorbed onto oxides and hydroxides of Al in such acidic soil which may not be able to extract by the MH-3 solution (Das, 2007). The following trend of changes in MH-3 extractable B due to interaction between B and Zn was recorded as $B_2Zn_0 > B_2Zn_{10} > B_1Zn_{10} > B_1Zn_5 > B_2Zn_5 > B_1Zn_0 > B_0Zn_5 > B_0Zn_{10} > B_0Zn_0$.

4.1.4.4 Changes in DTPA extractable Zn in an inceptisol

The results for the changes in DTPA extractable zinc content in an inceptisol due to interaction between B and Zn are presented in Table 4.28. With regards to individual application of boron, it was found that the amount of DTPA extractable Zn has been found to be significantly increased upto 20 days of incubation thereafter the amount decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of boron, being highest (1.96 mg kg^{-1}) in the treatment B_0 where B at 0 mg kg^{-1} was applied at 20 days of incubation.

As regards to separate application of Zinc, it was observed that the amount of DTPA extractable Zn has been found to be significantly increased upto 20 days incubation thereafter the amount decreased irrespective of levels of Zn. The magnitude of such changes, however, varied with levels of Zinc, being highest (1.97 mg kg^{-1}) in the treatment Zn_{10} where Zn at 10 mg kg^{-1} was applied at 20 days of incubation. However, the highest percent increase was recorded as 27 in the treatment Zn 10 at 20 days of incubation over control. The mean percent increase was recorded highest as 21.98 in the treatment where highest level of Zn at 10 mg kg^{-1} was applied.

As regards to the interaction effect between B and Zn, it was observed that the DTPA extractable Zn has been found to be significantly increased upto 20 days of incubation and thereafter , the value of the same decreased. The magnitude of such changes, however, varied with different combination of Zn and B, being highest (2.46 mg kg^{-1}) at 20 days of incubation in the treatment B_0Zn 10 where B at 0 mg kg^{-1} and Zn at 10 mg kg^{-1} was applied combinedly. The highest percent increase of DTPA – extractable Zn was recorded (54.28) over absolute control in the B_0Zn_{10} treatment combination (Fig.4.21b) However, the following mean trend for the changes in DTPA- extractable Zn was recorded as $B_0Zn_{10} > B_0Zn_5 > B_1Zn_{10} > B_1Zn_5 > B_1Zn_0 > B_2Zn_{10} > B_2Zn_5 > B_0Zn_0 > B_2Zn_0$. Interaction between B and Zn was found antagonistic with respect to DTPA-extractable Zn content in soil.

Table 4.28 Interaction between boron and zinc on the changes in zinc content (mg kg^{-1}) in an inceptisol (Mean of three replications)

Treatments	DTPA extractable-Zn			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	1.87^{A}	1.96^{A}	1.79^{A}	1.61^{A}
B_1	1.66^{B}	1.74^{B}	1.51^{B}	1.16^{B}
B_2	1.52^{C}	1.60^{C}	1.42^{C}	1.06^{C}
SEm (±)	0.015	0.016	0.014	0.060
C.D. at 5%	0.045	0.048	0.042	0.180
Zinc levels				
Zn_0	1.50^{R}	1.55^{R}	1.42^{Q}	1.15^{Q}
Zn_5	1.69^{Q}	1.78^{Q}	1.59^{Q}	1.33^{P}
Zn_{10}	1.85^{P}	1.97^{P}	1.71^{P}	1.35^{P}
SEm (±)	0.015	0.016	0.014	0.060
C.D. at 5%	0.045	0.048	0.042	0.180
Interaction				
$B_0 Zn_0$	1.42	1.47	1.40	1.32
$B_0 Zn_{15}$	1.89	1.94	1.82	1.76
B_0 Zn10	2.29	2.46	2.14	1.75
$B_1 Zn_0$	1.59	1.66	1.47	1.12
$B_1 Zn_5$	1.67	1.75	1.51	1.16
$B_1 Zn_{10}$	1.72	1.80	1.54	1.20
$B_2 Zn_0$	1.49	1.52	1.38	1.01
$B_2 Zn_5$	1.52	1.64	1.43	1.06
$B_2 Zn_{10}$	1.54	1.65	1.46	1.10
SEm (±)	0.026	0.028	0.024	0.105
C.D. at 5%	0.078	0.081	0.072	NS

B_0= no boron. B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, Zn_0= no Zinc, Zn_5=Zn at 5 mg kg^{-1} as Zn-EDTA, Zn_{10}= Zn at 10 mg kg^{-1} as Zn-EDTA.

4.1.4.5 Changes in phosphate solubilizing microorganisms (PSM) in an inceptisol

The results for the changes in PSM in an inceptisol due to interaction between B and Zn are presented in Table 4.29. With regards to individual application of boron it was found that the number of PSM has been found to be significantly increased upto 20 days of incubation and thereafter, the amount decreases irrespective of levels of B. The magnitude of such changes, however, varied with the levels of boron, being highest (37.62 $x10^5$ g^{-1}) in the treatment B_2 where B at 2 mg kg^{-1} was applied with percent increase of 50.60 over control at 20 days of incubation. The mean percent increase of PSM in an inceptisol (Fig.4.22a) was recorded as 59.38 over control in the treatment B_2 where B at 2 mg kg^{-1} was applied.

As regards to the separate application of zinc , it was observed that the number of PSM in an inceptisol although recorded a slight increase at 20 days of incubation but it was non-significant rather consistently decreased upto 40 days of incubation

As regards to the interaction effect between Zn and B, the PSM has been found to be increased slightly upto 20days of incubation and thereafter, the values of the same decreased. The magnitude of such changes however, varied with different combinations of Zn and B, being highest ($42.27x10^5$ g^{-1}) at 20 days of incubation in the treatment B_2Zn_0 where B at 2 mg kg^{-1} and Zn at 0 mg kg^{-1} was applied combinedly which suggested that Zn has not so much of definite role to play with the changes in PSM in an an inceptisol. The highest percent increase of PSM was recorded (46.97) over absolute control in the B_2Zn_0treatment combination. Juwarkar *et al.* (2007) reported that the microbial population including Phosphate solubilizing microorganisms of the heavy metal contaminated soils was increased after removal of heavy metals which includes Zn.However, the following mean trend for the changes in PSM was recorded as $B_2Zn_0 > B_2Zn_5 > B_2Zn_{10} > B_1Zn_0 > B_1Zn_5 > B_0Zn_0 > B_1Zn_{10} > B_0Zn_5 > B_0Zn_{10}$.

Table 4.29 Interaction between boron and zinc on the changes in phosphorous solubilizing microorganism (× 10^5 g^{-1} soil) in an inceptisol (Mean of three replications)

Treatments	Phosphate solubilizing microorganism (PSM)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	20.50^C	24.98^C	18.44^C	15.79^C
B_1	26.34^B	30.87^B	22.96^B	18.54^B
B_2	33.54^A	37.62^A	30.73^A	25.13^A
SEm (±)	0.278	0.315	0.252	0.206
C.D. at 5%	0.834	0.945	0.756	0.618
Zinc levels				
Zn_0	29.81^P	34.71^P	26.71^P	23.05^P
Zn_5	26.61^Q	30.20^Q	24.33^Q	19.60^Q
Zn_{10}	23.96^R	28.56^R	21.09^R	16.82^R
SEm (±)	0.278	0.315	0.252	0.206
C.D. at 5%	0.834	0.945	0.756	0.618
Interaction				
$B_0 Zn_0$	24.13	28.76	21.03	18.63
$B_0 Zn_{15}$	20.17	23.63	19.11	16.84
B_0 Zn10	17.21	22.55	15.18	11.90
$B_1 Zn_0$	28.83	33.10	25.26	20.36
$B_1 Zn_5$	26.63	31.29	23.27	18.1
$B_1 Zn_{10}$	23.55	28.22	20.36	17.17
$B_2 Zn_0$	36.47	42.27	33.85	30.15
$B_2 Zn_5$	33.03	35.68	30.61	23.85
$B_2 Zn_{10}$	31.11	34.92	27.72	21.38
SEm (±)	0.482	0.546	0.436	0.357
C.D. at 5%	NS	1.638	NS	1.071

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, Zn_0= no Zinc, Zn_5=Zn at 5 mg kg^{-1} as Zn-EDTA, Zn_{10}= Zn at 10 mg kg^{-1} as Zn-EDTA

The mean percent increase (Fig. 4.22b) (54.25) was highest in the treatment B_2Zn_0 which was closely followed by 33.11 and 24.42 in the treatment B_2Zn_5 and B_2 Zn_{10} respectively.

4.1.4.6 Changes in phosphate solubilizing capacity (PSC) in an an inceptisol

The results for the changes in PSC in an inceptisol due to interaction between B and Zn are presented in Table 4.30. With regards to individual application of boron it was found that the amount of PSC has been found to be significantly increased upto 20 days of incubation thereafter the amount decrease irrespective of levels of B. The magnitude of such changes, however, varied with the levels of boron, being highest (0.044mg g^{-1} dry soil) in the treatment B_2 where B at 2 mg kg^{-1} was applied with percent increase of 37.5 over control at 20 days of incubation. The mean percent increase of PSC in an inceptisol (Fig.4.23a) was recorded as 42.85 over control in the treatment B_2 where B at 2 mg kg^{-1} was applied.

As regards to the separate application of zinc , it was observed that the amount of PSC in an inceptisol although recorded a slight increase at 20 days of incubation but it was non-significant rather consistently decreased upto 40 days of incubation. However, the mean percent increase (Fig.4.23a) (5.88) was recorded in the treatment where Zn at 5 mg kg^{-1} was applied being decreased with the increasing levels of Zinc.

As regards to the interaction effect between Zn and B, the PSC has been found to be slightly increased upto 20days of incubation and thereafter, the values of the same decreased. The magnitude of such changes however, varied with different combination of Zn and B being highest (0.046 mg g^{-1}) at 20 days of incubation in the treatment B_2Zn_0 where B at 2 mg kg^{-1} and Zn at 0 mg kg^{-1} was applied combinedly which suggested that Zn has not so much of definite role to play with the moderation of PSC in an an inceptisol. The highest percent increase of PSCwas recorded (64.28) over absolute control in the B_2Zn_0treatment combination. However, the following mean trend for the changes in PSC was recorded as $B_2Zn_0 > B_2Zn_5 > B_2Zn_{10} > B_1Zn_0 > B_1Zn_5 > B_0Zn_0 > B_1Zn_{10} > B_0Zn_5 > B_0Zn_{10}$.

Table 4.30 Interaction between boron and zinc on the changes in phosphorous solubilizing capacity (mg kg^{-1} dry soil) in an inceptisol (Mean of three replications)

Treatments	Phosphate solubilizing capacity (PSC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.030^C	0.032^C	0.028^C	0.024^C
B_1	0.038^B	0.041^B	0.035^B	0.031^B
B_2	0.042^A	0.044^A	0.040A	0.036^A
SEm (±)	0.00040	0.00042	0.00035	0.00033
C.D. at 5%	0.00120	0.00126	0.00105	0.00099
Zinc levels				
Zn_0	0.036^Q	0.039^Q	0.034^Q	0.030^Q
Zn_5	0.038^P	0.041^P	0.036^P	0.032^P
Zn_{10}	0.035^Q	0.037^R	0.033^R	0.028^R
SEm (±)	0.00040	0.00042	0.00035	0.00033
C.D. at 5%	0.00120	0.00126	0.00105	0.00099
Interaction				
$B_0 Zn_0$	0.026	0.028	0.024	0.020
$B_0 Zn_{15}$	0.034	0.037	0.032	0.029
B_0 Zn10	0.030	0.032	0.028	0.022
$B_1 Zn_0$	0.039	0.044	0.037	0.032
$B_1 Zn_5$	0.038	0.042	0.035	0.031
$B_1 Zn_{10}$	0.036	0.037	0.032	0.030
$B_2 Zn_0$	0.043	0.046	0.042	0.038
$B_2 Zn_5$	0.042	0.045	0.040	0.036
$B_2 Zn_{10}$	0.040	0.042	0.038	0.033
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, Zn_0= no Zinc, Zn_5=Zn at 5 mg kg^{-1} as Zn-EDTA, Zn_{10}= Zn at 10 mg kg^{-1} as Zn-EDTA

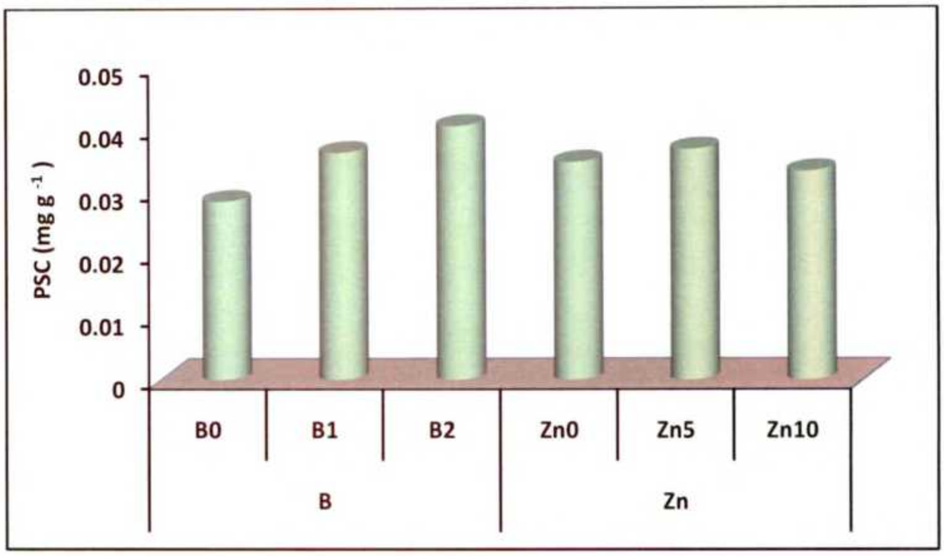


Fig. 4.23a : Mean effect of boron and zinc on the changes in PSC in an inceptisol

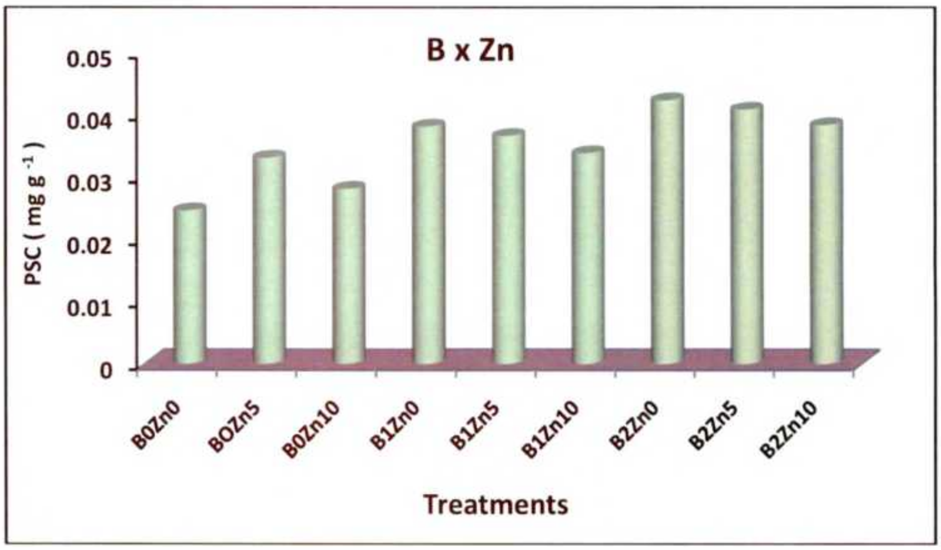


Fig. 4.23b : Mean interaction effect between boron and zinc on the changes of PSC in an inceptisol

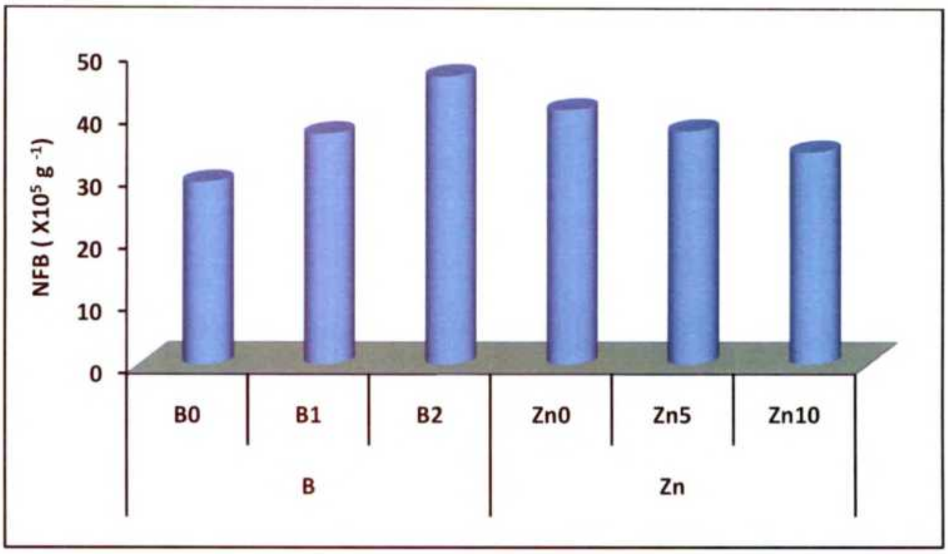


Fig. 4.24a : Mean effect of boron and zinc on the changes in NFB in an inceptisol

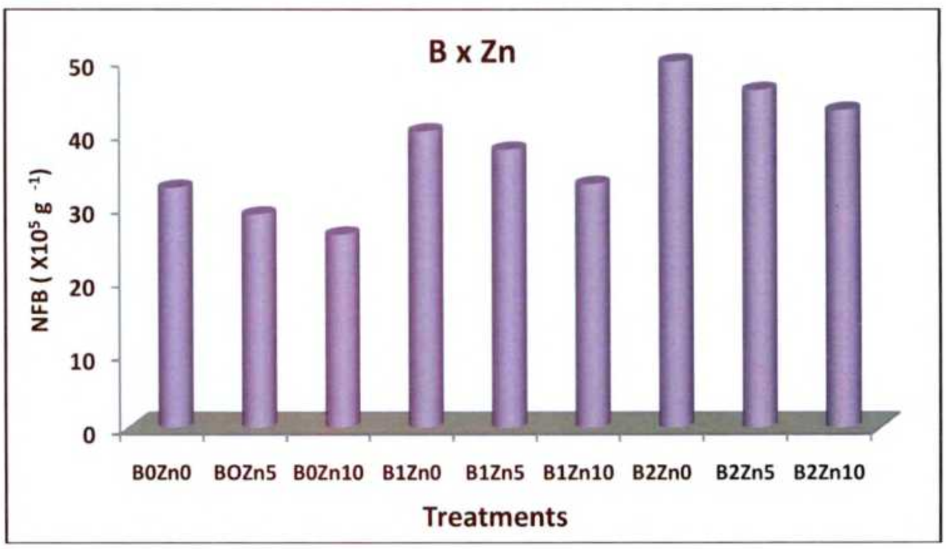


Fig. 4.24b : Mean interaction effect between boron and zinc on the changes of NFB in an inceptisol

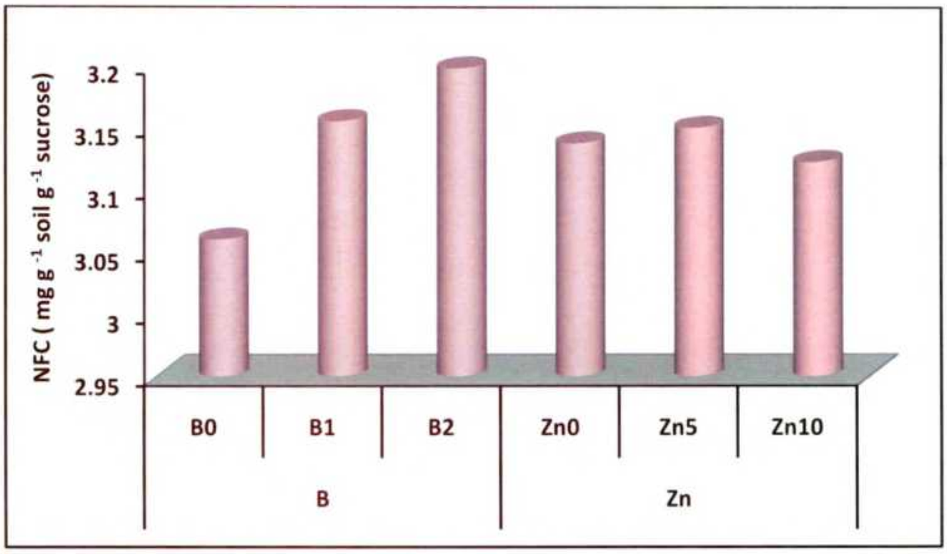


Fig. 4.25a : Mean effect of boron and zinc on the changes in NFC in an inceptisol

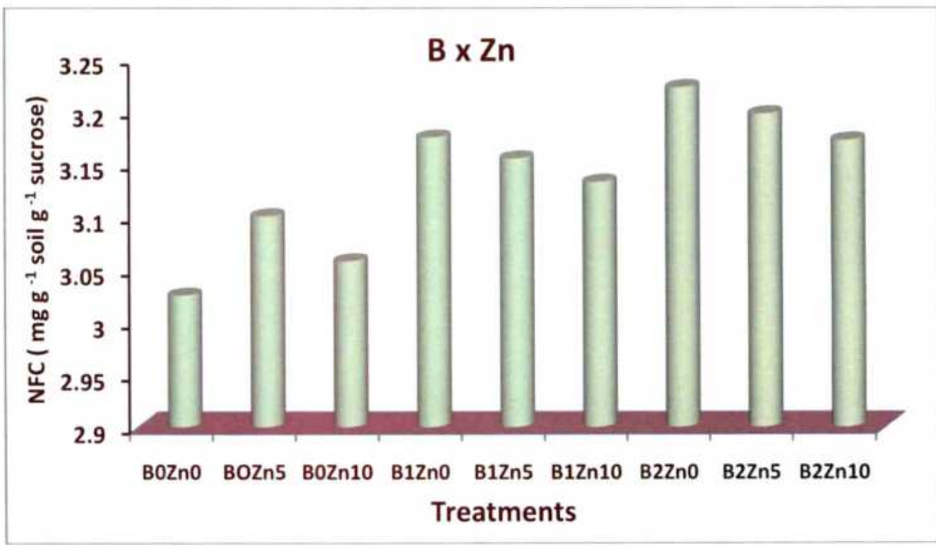


Fig. 4.25b : Mean interaction effect between boron and zinc on the changes of NFC extractable in an inceptisol

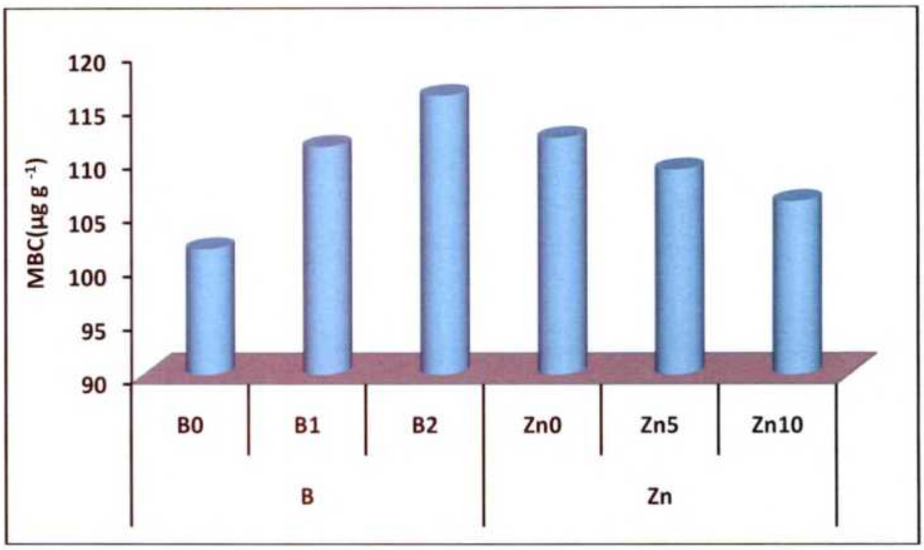


Fig. 4.26a : Mean effect of boron and zinc on the changes in MBC content in an inceptisol

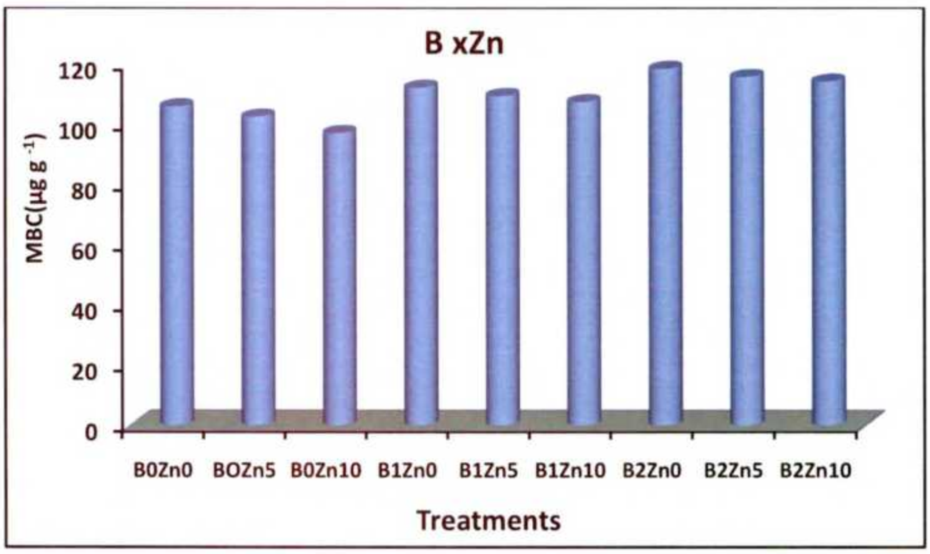


Fig. 4.26b : Mean interaction effect between boron and zinc on the changes of MBC content extractable in an inceptisol

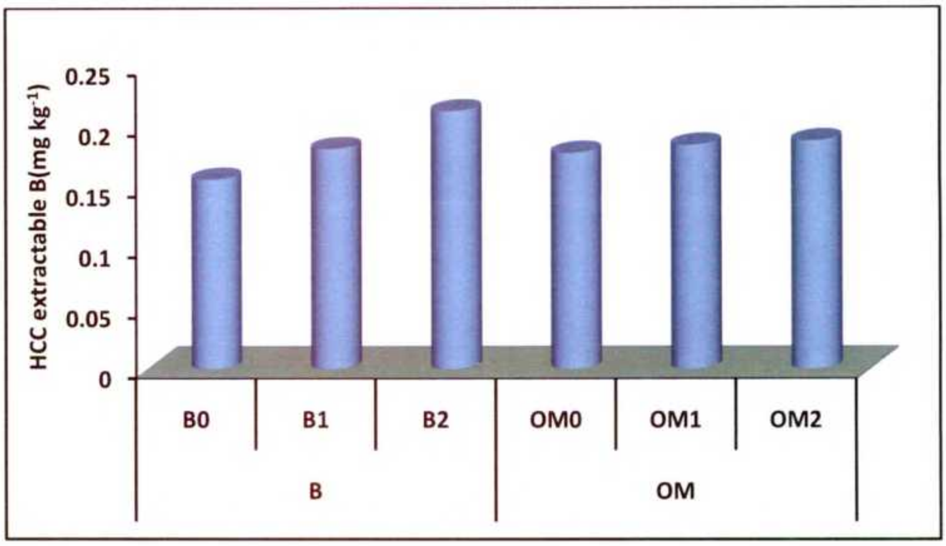


Fig. 4.28a : Mean effect of boron and organic matter on the changes in HCC extractable B content in an inceptisol

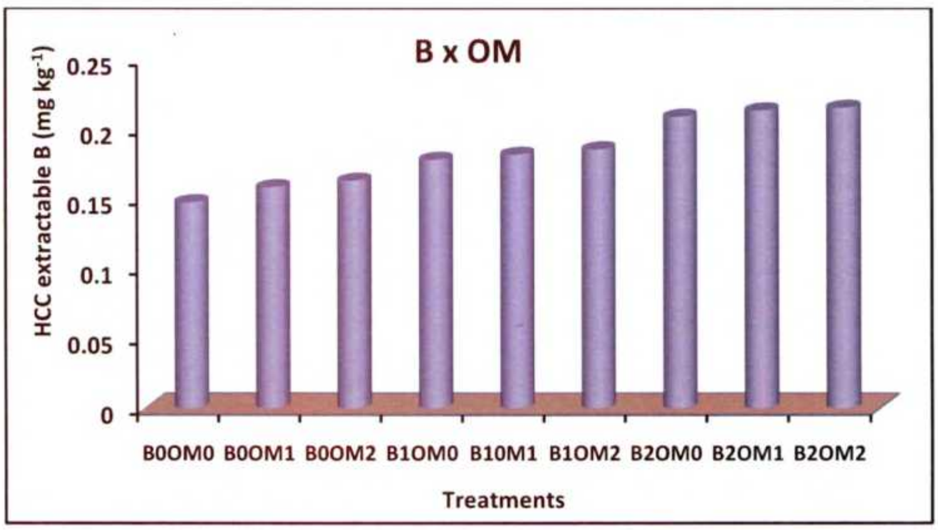


Fig. 4.28b : Mean interaction effect between boron and organic matter on the changes of HCC extractable B content in an inceptisol

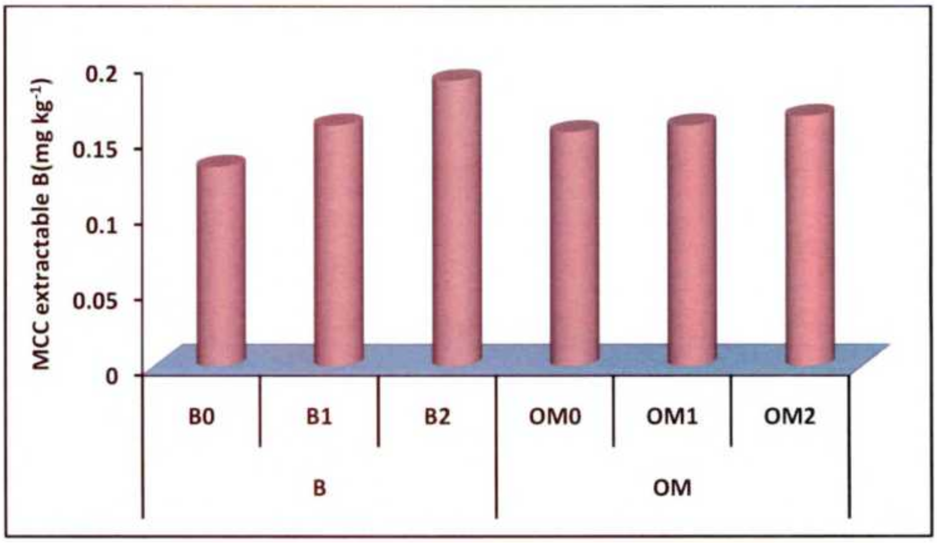


Fig. 4.29a : Mean effect of boron and organic matter on the changes in MCC extractable B content in an inceptisol

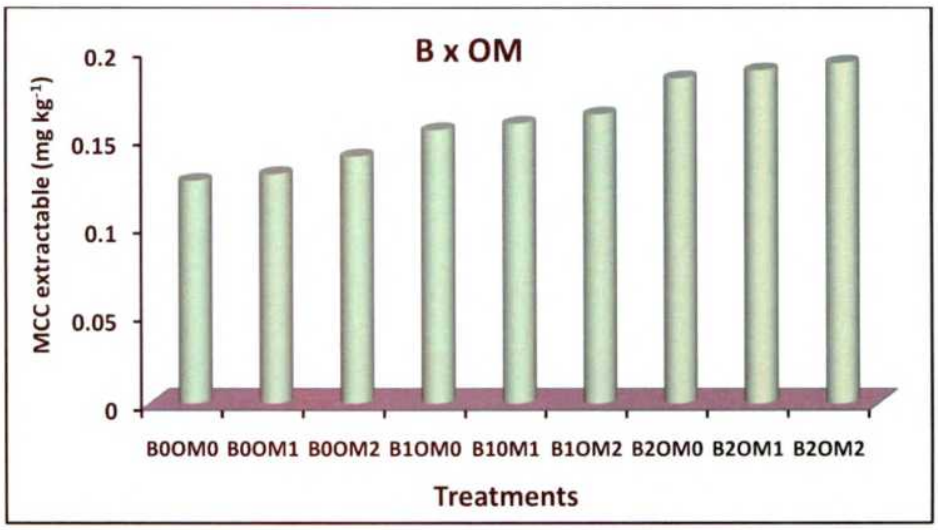


Fig. 4.29b : Mean interaction effect between boron and organic matter on the changes of MCC extractable B content in an inceptisol

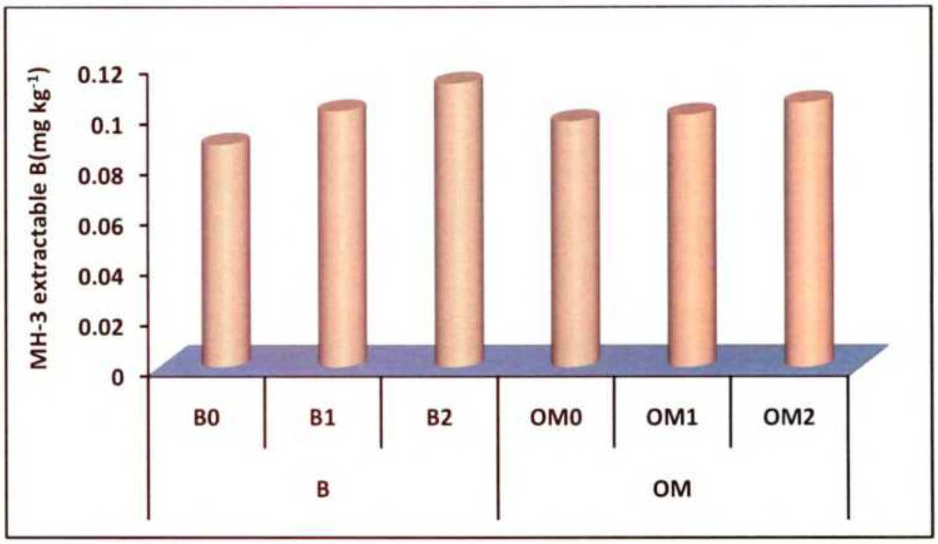


Fig. 4.30a : Mean effect of boron and organic matter on the changes in MH-3 extractable B content in an inceptisol

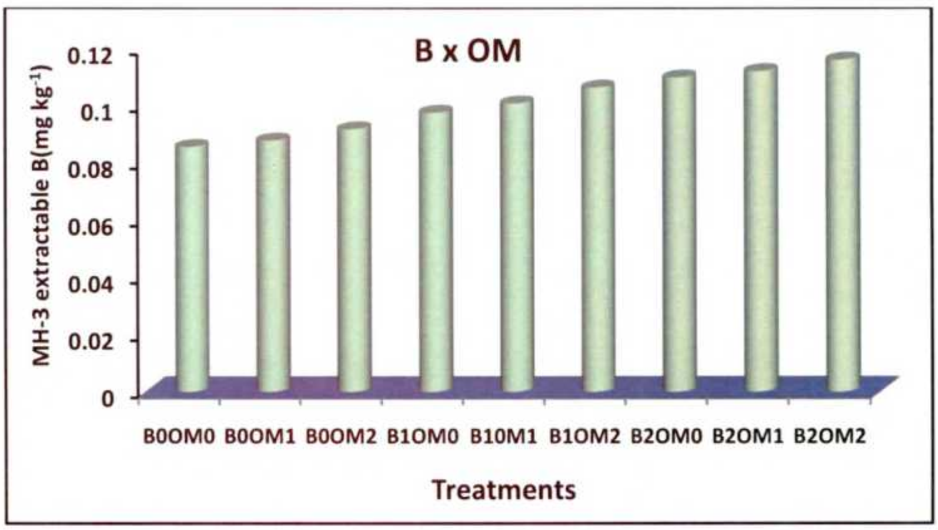


Fig. 4.30b : Mean interaction effect between boron and organic matter on the changes of MH-3 extractable content in an inceptisol

The mean percent increase (Fig. 4.23b) (75) was highest in the treatment B_2Zn_0 which was closely followed by 66.66 and 58.33 in the treatment B_2Zn_5 and B_2 Zn_{10} respectively.

4.1.4.7 Changes in aerobic non –symbiotic nitrogen fixing bacteria (NFB) in an inceptisol

The results for the changes in NFB in an inceptisol due to interaction between B and Zn are presented in Table 4.31. With regards to individual application of boron it was found that the number of NFB has been found to be significantly increased upto 20 days of incubation thereafter the amount decrease irrespective of levels of B. The magnitude of such changes, however, varied with the levels of boron, being highest ($53.36x\ 10^5\ g^{-1}$) in the treatment B_2 where B at 2 mg kg^{-1} was applied with percent increase of 53.73 over control at 20 days of incubation. The mean percent increase of NFB in an inceptisol (Fig. 4.24a) was recorded as 58.05 over control in the treatment B_2 where B at 2 mg kg^{-1} was applied.

As regards to the separate application of zinc , it was observed that the number of NFB in an inceptisol although recorded a slight increase at 20 days of incubation but it was non-significant rather consistently decreased upto 40 days of incubation.

As regards to the interaction effect between Zn and B, the NFB has been found to be slightly increased upto 20days of incubation and thereafter, the values of the same decreased. The magnitude of such changes however, varied with different combination of Zn and B ,being highest ($56.65x\ 10^5\ g^{-1}$) at 20 days of incubation in the treatment B_2Zn_0 where B at 2 mg kg^{-1} and Zn at 0 mg kg^{-1} was applied combinedly which suggested that Zn has not so much of definite role to play with the changes of NFB in an an inceptisol. The highest percent increase of NFB was recorded (51.75) over absolute control in the B_2Zn_0treatment combination.The results further indicated that the suppressive effect of Zn on NFB might be counteracted by the application of B suggesting a positive effect of B on the changes in NFB in soil.High concentration of Zn in soil either native or applied might have marked inhibitory effect on microbial activity expecially on NFB (Angle and Chaney, 1991). However, the following mean trend for the changes in NFC was recorded as $B_2Zn_0 > B_2Zn_5 > B_2Zn_{10} > B_1Zn_0 > B_1Zn_5 > B_1Zn_{10} > B_0Zn_0 > B_0Zn_5 > B_0Zn_{10}$.

Table 4.31 Interaction between boron and zinc on the changes in aerobic non symbiotic nitrogen fixing bacteria (× 10^5 g^{-1} soil) in an inceptisol (Mean of three replications)

Treatments	Nitrogen fixing bacteria (NFB)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	30.25^C	34.71^C	28.12^C	24.13^C
B_1	38.40^B	43.52^B	36.75^B	29.75^B
B_2	47.78^A	53.36^A	44.61^A	39.51^A
SEm (±)	0.400	0.448	0.376	0.324
C.D. at 5%	1.200	1.344	1.128	0.972
Zinc levels				
Zn_0	42.01^P	47.16^P	40.12^P	34.43^P
Zn_5	38.95^Q	44.56^Q	36.43^Q	30.40^Q
Zn_{10}	35.48^R	39.87^R	32.92^R	28.55^R
SEm (±)	0.400	0.448	0.376	0.324
C.D. at 5%	1.200	1.344	1.128	0.972
Interaction				
$B_0 Zn_0$	33.12	37.33	31.22	28.90
$B_0 Zn_{15}$	30.33	35.48	27.32	22.83
B_0 Zn10	27.29	31.32	25.83	20.65
$B_1 Zn_0$	41.83	47.49	39.87	32.19
$B_1 Zn_5$	38.85	45.54	37.75	29.20
$B_1 Zn_{10}$	34.52	37.52	32.63	27.86
$B_2 Zn_0$	51.07	56.65	49.28	42.21
$B_2 Zn_5$	47.66	52.67	44.23	39.18
$B_2 Zn_{10}$	44.62	50.78	40.31	37.15
SEm (±)	0.693	0.775	0.651	0.561
C.D. at 5%	2.079	2.325	1.953	1.683

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, Zn_0= no Zinc, Zn_5=Zn at 5 mg kg^{-1} as Zn-EDTA, Zn_{10}= Zn at 10 mg kg^{-1} as Zn-EDTA

The mean percent increase (Fig. 4.24b) (53.06) was highest in the treatment B_2Zn_0 which was closely followed by 40.71 and 32.33 in the treatment B_2Zn_5 and B_2 Zn_{10} respectively.

4.1.4.8 Changes in aerobic non-symbiotic nitrogen fixing capacity (NFC) in an inceptisol

The results for the changes in NFC in an inceptisol due to interaction between B and Zn are presented in Table 4.32.The results for the changes in NFC in an inceptisol revealed that the amount of NFC in soil did not show any significant variation with the progress of incubation irrespective of levels of boron. However, the magnitude of NFC varied with levels of boron being greater with its higher level (B at 2 mg kg^{-1}). The mean percent increase of NFC over control was recorded as (42.48) in the treatment where B at 2 mg ka^{-1} was applied. The results suggested that the boron played an important role in stimulating the activity of non-symbiotic nitrogen fixing microorganisms in soil.

With regards to the individual application of Zn, it was observed that NFC also did not vary significantly with the progress of incubation and also with the levels of Zn. However, the mean percent increase (Fig. 4.25a) (6.38) was recorded highest in the treatment where Zn at 0.5 mg kg^{-1} were applied being decreased with the increasing levels of Zinc.

As regards to the interaction effect between Zn and B, the NFC has been found to be slightly increased upto 20days of incubation and thereafter, the values of same the decreased. The magnitude of such changes however, varied with different combination of Zn and B, being highest (3.27 mg kg^{-1}) at 20 days of incubation in the treatment B_2Zn_0 where B at 2 mg kg^{-1} and Zn at 0 mg kg^{-1} was applied combinedly which suggested that Zn has not so much of definite role to play with the moderation of NFC in an an inceptisol. The highest percent increase of NFC was recorded (6.51) over absolute control in the B_2Zn_0treatment combination.Similar explanations may be offered for the changes in NFC in soil relating to NFB. However, the following mean trend for the changes in NFC was recorded as $B_2Zn_0 > B_2Zn_5 > B_2Zn_{10} > B_1Zn_0 > B_1Zn_5 > B_2Zn_{10} > B_0Zn_5 > B_0Zn_{10} > B_0Zn_0$.

Table 4.32 Interaction between boron and zinc on the changes in aerobic non symbiotic nitrogen fixing capacity (mg of N fixed g^{-1} of soil g^{-1} sucrose consumed) in an inceptisol (Mean of three replications)

Treatments	Nitrogen fixing capacity (NFC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	3.07^{B}	3.12^{B}	3.06^{B}	2.99^{B}
B_1	3.16^{A}	3.24^{A}	3.14^{AB}	3.08^{AB}
B_2	3.21^{A}	3.24^{A}	3.19^{A}	3.15^{A}
SEm (±)	0.030	0.030	0.030	0.029
C.D. at 5%	0.090	0.090	0.090	0.087
Zinc levels				
Zn_0	3.14^{P}	3.19^{P}	3.13^{P}	3.09^{P}
Zn_5	3.16^{P}	3.22^{P}	3.14^{P}	3.08^{P}
Zn_{10}	3.14^{P}	3.18^{P}	3.12^{P}	3.05^{P}
SEm (±)	0.030	0.030	0.030	0.029
C.D. at 5%	NS	NS	NS	NS
Interaction				
$B_0 Zn_0$	3.02	3.07	3.03	2.98
$B_0 Zn_{15}$	3.12	3.18	3.09	3.01
B_0 Zn10	3.07	3.11	3.06	2.99
$B_1 Zn_0$	3.18	3.24	3.16	3.12
$B_1 Zn_5$	3.16	3.25	3.13	3.08
$B_1 Zn_{10}$	3.15	3.23	3.12	3.03
$B_2 Zn_0$	3.23	3.27	3.21	3.18
$B_2 Zn_5$	3.21	3.24	3.19	3.15
$B_2 Zn_{10}$	3.19	3.2	3.17	3.13
SEm (±)	0.051	0.052	0.051	0.050
C.D. at 5%	NS	NS	NS	NS

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, Zn_0= no Zinc, Zn_5=Zn at 5 mg kg^{-1} as Zn-EDTA, Zn_{10}= Zn at 10 mg kg^{-1} as Zn-EDTA

The mean percent increase (Fig.-4.25b) (6.62) was highest in the treatment B_2Zn_0 which was closely followed by 5.62 and4.96 in the treatment B_2Zn_5 and B_2 Zn_{10} respectively.

4.1.4.9 Changes in microbial biomass carbon (MBC) content in an inceptisol

The results for the changes in MBC in an inceptisol due to interaction between B and Zn are presented in Table 4.33. With regards to individual application of boron it was found that the amount of MBC has been found to be significantly increased upto 20 days of incubation thereafter the amount decreased irrespective of levels of B. The magnitude of such changes, however, varied with the levels of boron, being highest (109.92 $\mu g\ g^{-1}$) in the treatment B_2 where B at 2 mg kg^{-1} was applied with percent increase of 10.63 over control at 20 days of incubation. The mean percent increase of MBC in an inceptisol (Fig. 4.26a) was recorded as 14.03 over control in the treatment B_2 where B at 2 mg kg^{-1} was applied.

With regards to the individual application of Zn, it was observed that MBC also did not vary significantly with the progress of incubation and also with the levels of Zn. The results further indicated that the application of Zinc at its different levels did not affect significantly the MBC in an inceptisol.

As regards to the interaction effect between Zn and B, the MBC has been found to be slightly increased upto 20days of incubation and thereafter, the values of the same decreased. The magnitude of such changes however, varied with different combination of Zn and B ,being highest (122.01 $\mu g\ g^{-1}$) at 20 days of incubation in the treatment B_2Zn_0 where B at 2 mg kg^{-1} and Zn at 0 mg kg^{-1} was applied combinedly which suggested that Zn has not so much of definite role to play with the changes in MBC content in an inceptisol. The highest percent increase of MBC was recorded (8.64) over absolute control in the B_2Zn_0 treatment combination. Khan *et al.* (1998) and Moreno *et al.* (2002) reported that the microbial biomass carbon content decreased markedly in soil contaminated with Zn and Cd. However, the following mean trend for the changes in MBC was recorded as $B_2Zn_0 > B_2Zn_5 > B_2Zn_{10} > B_1Zn_0 > B_1Zn_5 > B_0Zn_0 > B_1Zn_{10} > B_0Zn_5 > B_0Zn_{10}$.

Table 4.33 Interaction between boron and zinc on the changes in microbial biomass carbon content (μg g^{-1} dry soil) in an inceptisol (Mean of three replications)

Treatments	Microbial biomass carbón(MBC)			
	Days after incubation			
Boron levels				
B_0	104.74^{C}	108.62^{C}	99.91C	93.45^{C}
B_1	118.84^{B}	115.35^{B}	109.51^{B}	101.12^{B}
B_2	118.07^{A}	120.17^{A}	115.66^{A}	109.92^{A}
SEm (±)	1.067	1.098	1.043	0.981
C.D. at 5%	3.201	3.294	3.129	2.943
Zinc levels				
Zn_0	114.35^{P}	117.54^{P}	111.21^{P}	104.95^{P}
Zn_5	111.45^{PQ}	115.28^{P}	108.57^{P}	100.89^{P}
Zn_{10}	108.85^{Q}	111.51^{Q}	105.32^{Q}	98.65^{Q}
SEm (±)	1.067	1.098	1.043	0.981
C.D. at 5%	3.201	3.294	3.129	2.943
Interaction				
$B_0 Zn_0$	108.50	112.30	103.31	98.85
$B_0 Zn_{15}$	105.42	110.28	101.39	92.21
B_0 Zn10	100.31	103.28	95.02	89.28
$B_1 Zn_0$	114.28	118.31	112.13	103.36
$B_1 Zn_5$	111.92	115.35	109.27	100.44
$B_1 Zn_{10}$	109.31	112.98	107.14	99.55
$B_2 Zn_0$	120.28	122.01	118.12	112.63
$B_2 Zn_5$	117.01	120.21	115.06	110.02
$B_2 Zn_{10}$	116.92	118.28	113.81	107.11
SEm (±)	1.849	1.902	1.806	1.699
C.D. at 5%	NS	NS	NS	NS

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, Zn_0= no Zinc, Zn_5=Zn at 5 mg kg^{-1} as Zn-EDTA, Zn_{10}= Zn at 10 mg kg^{-1} as Zn-EDTA

The mean percent increase (Fig. 4.26b) (11.84) was highest in the treatment B_2Zn_0 which was closely followed by 9.29 and 7.83 in the treatment B_2Zn_5 and B_2 Zn_{10} respectively.

4.1.4.10 PCA on Boron versus Zinc study

This technique was used in present study to find out the best or homogeneous treatment combinations (Boron vs. Zinc) separately for four days after incubation due to mean magnitude of Zinc, Phosphate Solubulizing Capacity (PSC), Phosphate Solubulizing Microorganisms (PSM), Nitrogen Fixing Capacity (NFC), Nitrogen Fixing Bacteria (NFB) and Microbial Biomass Carbon (MBC). Component matrix will include the loadings of each variable under all extracted components corresponding to eigen values more than one. Regression factor scores will be calculated to draw the scatter diagram to find out the homogeneous treatment combinations for first two components explaining first two larger variances as mentioned in the component matrices for each day after incubation.

Tab 4.34 : Component matrices for each day after incubation

Variable	Day 10		Day 20		Day 30		Day 40	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
Zn	-0.725	0.666	-0.721	0.645	-0.642	0.754	-0.932	0.256
PSC	0.891	0.443	0.886	0.449	0.928	0.298	0.882	0.452
PSM	0.979	-0.134	0.947	-0.158	0.974	-0.032	0.947	-0.128
NFC	0.892	0.436	0.825	0.494	0.947	0.271	0.951	0.247
NFB	0.988	-0.028	0.974	-0.029	0.973	0.064	0.978	-0.141
MBC	0.988	-0.144	0.982	-0.165	0.986	-0.082	0.983	-0.138
Eigen value	5.029	0.869	4.793	0.915	5.037	0.743	5.369	0.386
% of Variance	83.809	14.478	79.889	15.252	83.953	12.377	89.491	6.440
Cumulative %	83.809	98.288	79.889	95.141	83.953	96.330	89.491	95.931

Boron vs. Zinc study at 10 DAI

First component explained 83.81 % of variance indicating the increase in zinc content resulted decrease in PSC, PSM, NFC, NFB and MBC and *vice versa*. Second component explained 14.48 % of variance further indicating the increase in zinc content, PSC and NFC resulted decrease in PSM, NFB and MBC and *vice versa*. Treatment combinations B_2Zn_0, B_2Zn_5, B_2Zn_{10} and B_1Zn_0 resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Zinc study at 20 DAI

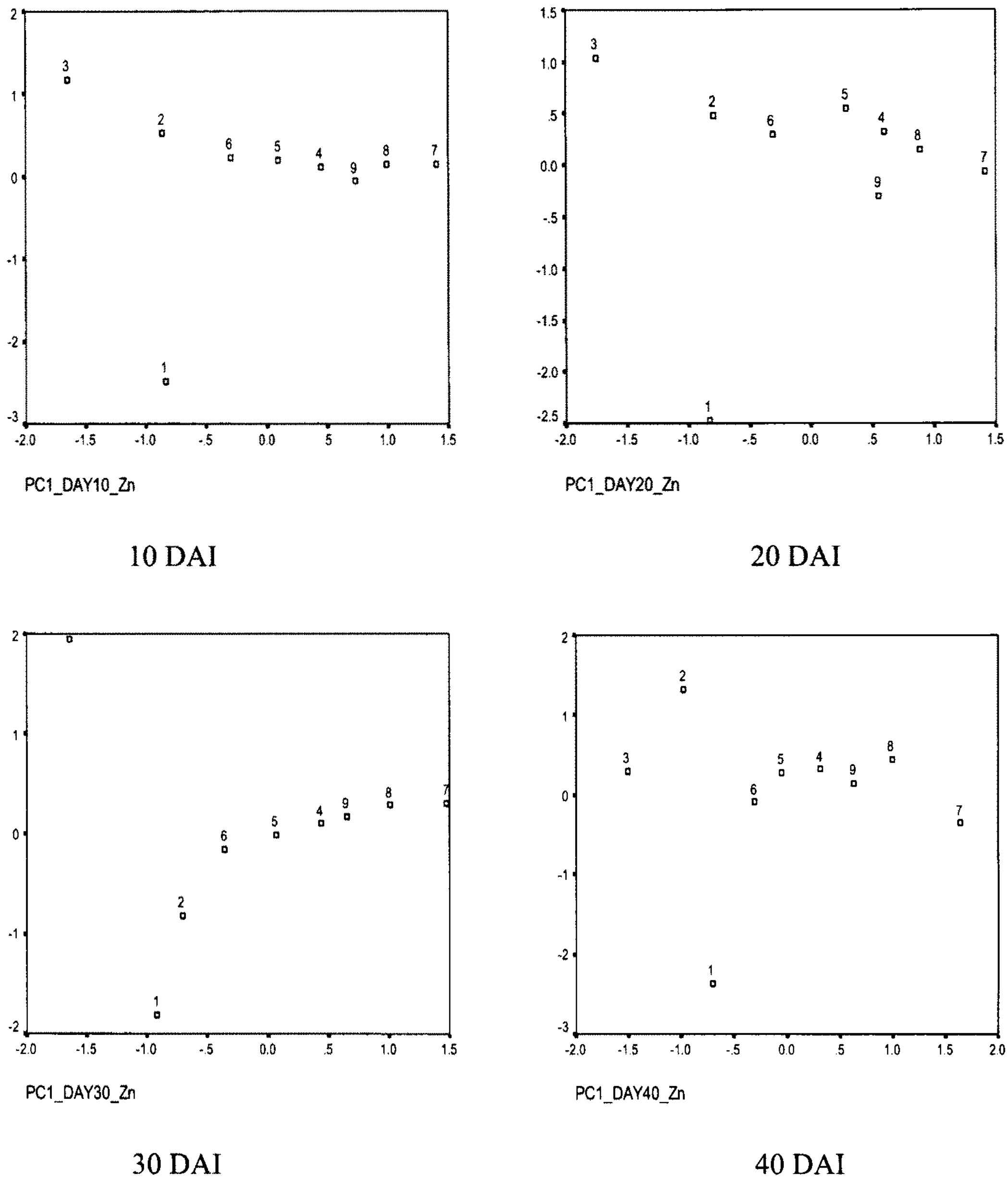
First component explained 79.89 % of variance indicating the increase in zinc content resulted decrease in PSC, PSM, NFC, NFB and MBC and *vice versa*. Second component explained 15.25 % of variance further indicating the increase in zinc content, PSC and NFC resulted decrease in PSM, NFB and MBC and *vice versa*. Treatment combinations B_1Zn_5, B_1Zn_0, B_2Zn_5 and B_2Zn_0 resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Zinc study at 30 DAI

First component explained 83.95 % of variance indicating the increase in zinc content resulted decrease in PSC, PSM, NFC, NFB and MBC and *vice versa*. Second component explained 12.38 % of variance further indicating the increase in zinc content, PSC , NFC and NFB resulted decrease in PSM and MBC and *vice versa*. Treatment combinations B_1Zn_5, B_1Zn_0, B_2Zn_{10}, B_2Zn_5 and B_2Zn_0 resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Zinc study at 40 DAI

First component explained 89.49 % of variance indicating the increase in zinc content resulted decrease in PSC, PSM, NFC, NFB and MBC and *vice versa*. Second component explained 6.44 % of variance further indicating the increase in zinc content, PSC and NFC resulted decrease in PSM, NFB and MBC and *vice versa*. Treatment combinations B_1Zn_0, B_2Zn_{10} and B_2Zn_5



Treatment combinations	1	2	3	4	5	6	7	8	9
Boron (unit)	0	0	0	1	1	1	2	2	2
Zinc (unit)	0	0	0	5	5	5	10	10	10

Fig. 4.27 : Scatter diagrams of regression factor scores of nine treatment combinations (B x Zn) corresponding to first two components for four different days after incubation

resulted higher content for all those variables which are positively loaded in both the first two axes.

Table 4.35 Best subsets regression of HCC extractable B with Zn, PSM, PSC, NFB, NFC and MBC

Response is B_1

Vars	R-Sq	R-Sq(adj)	C-p	S	Zn_1	psc	psm	nfc	nfb	mbc
1	69.3	69.0	53.0	0.014468		X				
1	62.5	62.1	87.7	0.015987					X	
2	77.5	77.1	12.7	0.012424	X	X				
2	70.6	70.1	48.0	0.014210		X			X	
3	79.2	78.6	6.4	0.012022	X	X		X		
3	77.8	77.2	13.3	0.012407	X	X				X
4	79.3	78.5	7.6	0.012037	X	X	X	X		
4	79.2	78.4	8.3	0.012074	X	X		X		X
5	**80.2**	**79.3**	**5.0**	**0.011829**	**X**	**X**	**X**	**X**	**X**	
5	79.5	78.5	8.8	0.012050	X	X	X		X	X
6	**80.2**	**79.0**	**7.0**	**0.011887**	**X**	**X**	**X**	**X**	**X**	**X**

Table 4.36 Best subsets regression of MCC extractable B with Zn, PSM, PSC, NFB, NFC and MBC

Response is B_2

Vars	R-Sq	R-Sq(adj)	C-p	S	Zn_1	psc	psm	nfc	nfb	mbc
1	73.2	72.9	66.2	0.0081820		X				
1	65.1	64.8	117.7	0.0093372					X	
2	79.6	79.2	27.6	0.0071727	X	X				
2	75.0	74.5	57.1	0.0079478		X				X
3	82.3	81.8	12.3	0.0067078	X	X		X		
3	80.3	79.7	25.4	0.0070904	X	X				X
4	82.6	81.9	12.7	0.0066921	X	X	X	X		
4	82.4	81.7	13.6	0.0067208	X	X	X			X
5	**84.0**	**83.2**	**5.5**	**0.0064417**	**X**	**X**	**X**	**X**	**X**	
5	83.3	82.4	10.3	0.0065920	X	X	X		X	X
6	**84.1**	**83.2**	**7.0**	**0.0064562**	**X**	**X**	**X**	**X**	**X**	**X**

Table 4.37 Best subsets regression of MH-3 extractable B with Zn, PSM, PSC, NFB, NFC And MBC

Response is B_3

Vars	R-Sq	R-Sq(adj)	C-p	S	Zn_1	psc	psm	nfc	nfb	mbc
1	74.0	73.8	31.6	0.0070746		X				
1	68.2	67.9	61.8	0.0078249					X	
2	78.5	78.1	10.2	0.0064674	X	X				
2	76.2	75.8	22.0	0.0067992		X				X
3	80.3	79.7	2.8	0.0062182	X	X		X		
3	79.6	79.0	6.3	0.0063245	X	X				X
4	80.6	79.9	3.1	0.0061964	X	X		X	X	
4	80.6	79.9	3.2	0.0062004	X	X	X	X		
5	**80.6**	**79.7**	**5.0**	**0.0062259**	**X**	**X**	**X**	**X**	**X**	
5	80.6	79.7	5.0	0.0062264	X	X		X	X	X
6	**80.6**	**79.5**	**7.0**	**0.0062559**	**X**	**X**	**X**	**X**	**X**	**X**

Mallows (1966) suggested the Cp statistical interpretation to find out the adequate model with maximum adjusted R^2 for each extracting solution of B with PSC, PSM.NFC. NFB and MBC parameters in inceptisol.It was found that all model were fitted resulting Cp= p. However considering the distance between Cp =p line and corresponding Cp values it was recorded an ascending order of 2>3>1 in inceptisol that means MCC extracting solution proved best with the interaction with zinc in inceptisol for the extraction of B.

4.1.5 Interaction effect between boron and organic matter in inceptisol on their changes in soil in relation to some microbial and biochemical attributes

4.1.5.1 Changes in hot $CaCl_2$ (HCC)-extractable boron content in an inceptisol

The result for the changes in HCC-extractable B in inceptisol as affected by the interaction between B and OM are presented in Table 4.38. The results show that the amount of HCC-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.219 mg kg^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 35.18 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 35.89 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.28a).

With regards to the application of organic matter, it was observed that the amount of HCC-Extractable B was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 5.43 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (5.61) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.28a)

As regards to the interaction effect between B and OM , it was observed that the amount of HCC extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.222 mg kg^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 46.05 at 30 days of incubation. The results further indicated that the highest mean percent increase of 46.25 was also recorded in the B_2OM_2 treatment combinations (Fig.4.28b).Borlan (1964) showed that the release of B from its organic complexes was favoured by a high soil to water ratio and hence more release can be expected under moist condition than under dry condition. Bhogal *et al.* (1993) also reported that available B was positively and significantly correlated with organic carbon content of the soil which might be the reasons for increasing HCC extractable B in soils.

The results suggested that the individual applications of both B and OM increased the HCC-extractable B, but due to their combined applications, the amount of HCC- extractable B has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to HCC- extractable B content in soil.

Table 4.38 Interaction between boron and organic matter in hot $CaCl_2$ (HCC)-extractable B content (mg kg^{-1}) in an inceptisol (Mean of three replications)

Treatments	HCC-extractable B			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.154^C	0.159^C	0.162^C	0.151^C
B_1	0.178^B	0.183^B	0.188^B	0.178^B
B_2	0.208^A	0.215^A	0.219^A	0.209^A
SEm (±)	0.002	0.002	0.002	0.002
C.D. at 5%	0.006	0.006	0.006	0.006
Organic Matter levels				
OM_0	0.174^Q	0.180^Q	0.184^Q	0.175^Q
OM_1	0.181^P	0.187^P	0.191^P	0.180^P
OM_2	0.184^P	0.190^P	0.194^P	0.184^P
SEm (±)	0.002	0.002	0.002	0.002
C.D. at 5%	0.006	0.006	0.006	0.006
Interaction				
$B_0 OM_0$	0.146	0.150	0.152	0.142
$B_0 OM_1$	0.155	0.161	0.165	0.152
B_0 OM2	0.160	0.165	0.168	0.159
$B_1 OM_0$	0.172	0.179	0.185	0.176
$B_1 OM_1$	0.179	0.183	0.187	0.178
$B_1 OM_2$	0.182	0.188	0.192	0.180
$B_2 OM_0$	0.204	0.210	0.215	0.207
$B_2 OM_1$	0.209	0.216	0.220	0.209
$B_2 OM_2$	0.21	0.218	0.222	0.212
SEm (±)	0.003	0.003	0.003	0.003
C.D. at 5%	0.009	0.009	0.009	0.009

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM.

4.1.5.2 Changes in mannitol- $CaCl_2$ (MCC)-extractable boron content in an inceptisol

The result for the changes in MCC-extractable B in inceptisol as affected by the interaction between B and OM are presented in Table 4.39. The results show that the amount of MCC-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.195 mg kg^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 41.30 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 43.18 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.29a).

With regards to the application of organic matter, it was observed that the amount of MCC-extractable B was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 6.83 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (6.45) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.29a)

As regards to the interaction effect between B and OM , it was observed that the amount of MCC extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.199 mg kg^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 50.75 at 30 days of incubation. The results further indicated that the highest mean percent increase of 53.17 was also recorded in the B_2OM_2 treatment combinations (Fig.4.29b).

Table 4.39 Interaction between boron and organic matter in mannitol-$CaCl_2$ (MCC)-extractable B content (mg kg^{-1}) in an inceptisol (Mean of three replications)

Treatments	MCC-extractable B)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.129^C	0.134^C	0.138^C	0.127^C
B_1	0.156^B	0.163^B	0.166^B	0.153^B
B_2	0.186^A	0.192^A	0.195^A	0.183^A
SEm (±)	0.001	0.002	0.002	0.001
C.D. at 5%	0.003	0.006	0.006	0.003
Organic Matter levels				
OM_0	0.152^R	0.158^Q	0.161^Q	0.149^R
OM_1	0.157^Q	0.162^Q	0.165^Q	0.154^Q
OM_2	0.163^P	0.168^P	0.172^P	0.160^P
SEm (±)	0.001	0.002	0.002	0.001
C.D. at 5%	0.003	0.006	0.006	0.003
Interaction				
$B_0 OM_0$	0.123	0.128	0.132	0.122
$B_0 OM_1$	0.127	0.131	0.134	0.128
B_0 OM2	0.138	0.143	0.147	0.132
$B_1 0M_0$	0.152	0.159	0.161	0.148
$B_1 OM_1$	0.156	0.162	0.166	0.151
$B_1 OM_2$	0.160	0.167	0.170	0.159
$B_2 OM_0$	0.181	0.188	0.191	0.178
$B_2 OM_1$	0.187	0.192	0.195	0.182
$B_2 OM_2$	0.190	0.195	0.199	0.189
SEm (±)	0.003	0.003	0.003	0.002
C.D. at 5%	0.009	0.009	0.009	0.006

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

The results suggested that the individual applications of both B and OM increased the MCC-extractable B, but due to their combined applications, the amount of MCC- extractable B has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to MCC- extractable B content in soil.The results are in agreement with findings of Sharma and Shukla, 1972.

4.1.5.3 Changes in Mehlich 3 (MH-3)-extractable boron content in an inceptisol

The result for the changes in MH-3-extractable B in inceptisol as affected by the interaction between B and OM are presented in Table 4.40. The results show that the amount of MH-3-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.117 mg kg^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 27.17 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 27.27 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.30a).

With regards to the application of organic matter, it was observed that the amount of MH-3-Extractable B was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 7.92 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (7.21) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.30a)

As regards to the interaction effect between B and OM, it was observed that the amount of MH-3 extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.122 mg kg^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 37.07 at 30 days of incubation.

Table 4.40 Interaction between boron and organic matter in Mehlich 3 (MH-3)-extractable B content (mg kg^{-1}) in an inceptisol (Mean of three replications)

Treatments	MH-3-extractable B			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.087^C	0.091^C	0.092^C	0.084^C
B_1	0.099^B	0.103^B	0.106^B	0.098^B
B_2	0.111^A	0.114^A	0.117^A	0.108^A
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003
Organic Matter levels				
OM_0	0.096^Q	0.100^Q	0.101^Q	0.093^R
OM_1	0.098^Q	0.102^Q	0.104^Q	0.096^Q
OM_2	0.103^P	0.106^P	0.109^P	0.101^P
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003
Interaction				
$B_0 OM_0$	0.084	0.088	0.089	0.081
$B_0 OM_1$	0.086	0.09	0.091	0.084
B_0 OM2	0.090	0.094	0.095	0.088
$B_1 OM_0$	0.096	0.099	0.102	0.093
$B_1 OM_1$	0.098	0.103	0.105	0.097
$B_1 OM_2$	0.105	0.107	0.110	0.103
$B_2 OM_0$	0.109	0.112	0.113	0.105
$B_2 OM_1$	0.110	0.114	0.116	0.108
$B_2 OM_2$	0.113	0.117	0.122	0.112
SEm (±)	0.002	0.002	0.002	0.002
C.D. at 5%	0.006	0.006	0.006	0.006

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

Sakal (2001) also supported the results of the present investigation who explained that the complexation of applied boron and coating of the surface of Fe and Al oxides by soluble organic compounds might be due ascribed for enhancing the extractability of B by MH-3 extracting solution. The results further indicated that the highest mean percent increase of 36.47 was also recorded in the B_2OM_2 treatment combinations (Fig.4.30b)

The results suggested that the individual applications of both B and OM increased the MH-3-extractable B, but due to their combined applications, the amount of MH-3- extractable B has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to MH-3- extractable B content in soil.

4.1.5.4 Changes in phosphate solubilising microorganisms (PSM) in an inceptisol

The result for the changes in the proliferation of PSM in inceptisol as affected by the interaction between B and OM are presented in Table 4.41. The results show that the number of PSM has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest ($66.14x10_5$ g^{-1} soil) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 59.75 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 58.38 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.31a).

With regards to the application of organic matter, it was observed that the number of PSM was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 62.40 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (63.65) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.31a)

Table 4.41 Interaction between boron and organic matter in phosphorous solubiling microorganisms (× 10^5 g^{-1} soil) in an inceptisol (Mean of three replications)

Treatments	Phosphate solubilizing microorganisms(PSM)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	30.83^C	36.40^C	41.40^C	38.83^C
B_1	38.75^B	48.46^B	54.73^B	51.07^B
B_2	47.50^A	57.44^A	66.14^A	62.46^A
SEm (±)	0.374	0.589	1.123	0.805
C.D. at 5%	1.122	1.770	3.369	2.415
Organic Matter levels				
OM_0	29.25^R	34.71^R	39.39^R	36.44^R
OM_1	40.94^Q	51.09^Q	58.91^Q	54.43^Q
OM_2	46.98^P	56.51^P	63.97^P	61.29^P
SEm (±)	0.374	0.589	1.123	0.805
C.D. at 5%	1.122	1.770	3.369	2.415
Interaction				
$B_0 OM_0$	25.03	29.29	31.73	30.03
$B_0 OM_1$	30.19	37.46	42.84	39.21
B_0 OM2	37.27	42.45	49.63	47.26
$B_1 0M_0$	27.72	34.81	39.52	35.25
$B_1 OM_1$	41.35	52.71	61.65	57.23
$B_1 OM_2$	47.27	57.87	63.03	60.72
$B_2 OM_0$	35.01	40.03	46.91	44.63
$B_2 OM_1$	51.29	63.09	72.24	66.85
$B_2 OM_2$	56.21	69.21	79.26	75.90
SEm (±)	0.647	1.020	1.945	1.394
C.D. at 5%	1.941	3.060	5.825	4.182

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

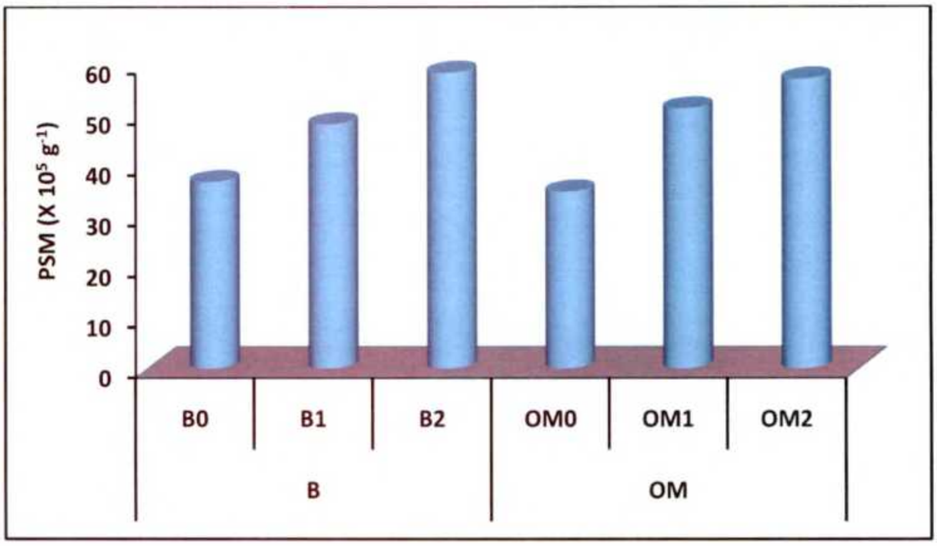


Fig. 4.31a : Mean effect of boron and organic matter on the changes in PSM in an inceptisol

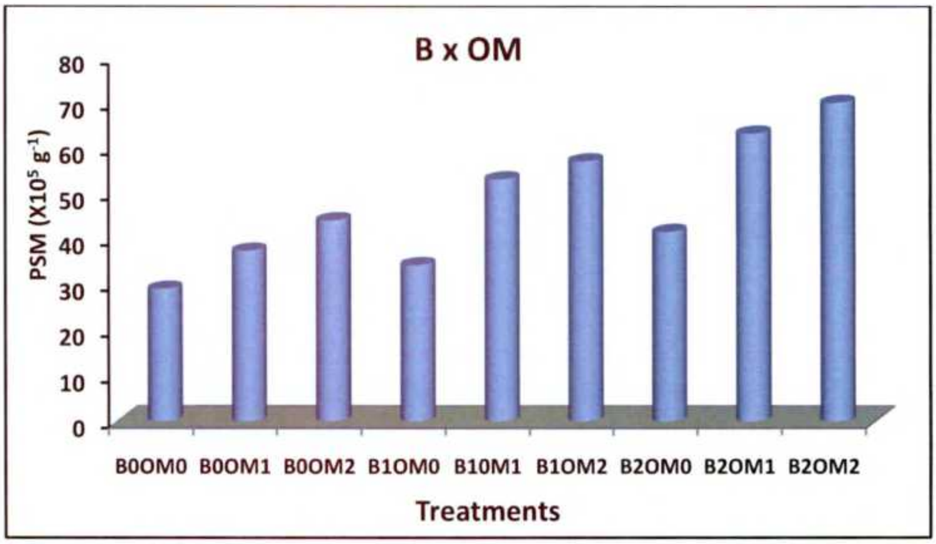


Fig. 4.31b : Mean interaction effect between boron and organic matter on the changes of PSM in an inceptisol

As regards to the interaction effect between B and OM, it was observed that the number of PSM was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (79.26 x10^5 g^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 149.79 at 30 days of incubation.Monib *et al.* (1974) also reported similarly where the application of dung considerably increased microbial counts including phosphate solubilizing microorganisms. The results further indicated that the highest mean percent increase of 141.69 was also recorded in the B_2OM_2 treatment combinations (Fig.4.31b)

The results suggested that the individual applications of both B and OM increased the number of PSM, but due to their combined applications, the number of PSM has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to PSM in soil.

4.1.5.5 Changes in phosphate solubilising capacity (PSC) in an inceptisol

The result for the changes in PSC in inceptisol as affected by the interaction between B and OM are presented in Table 4.42. The results show that the amount of PSC has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.056 mg g^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 33.33 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 29.72 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.32a).

With regards to the application of organic matter, it was observed that the amount of PSC was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 34.14 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (33.33) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.32a).

Table 4.42 Interaction between boron and organic matter in phosphate solubilizing capacity (mg g^{-1} dry soil) in an inceptisol (Mean of three replications)

Treatments	Phosphate solubilizing capacity(PSC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.032^{C}	0.038^{C}	0.042^{C}	0.039^{C}
B_1	0.036^{B}	0.042^{B}	0.048^{B}	0.045^{B}
B_2	0.041^{A}	0.047^{A}	0.056^{A}	0.051^{A}
SEm (±)	0.00040	0.00041	0.00049	0.00046
C.D. at 5%	0.00120	0.00123	0.00147	0.00138
Organic Matter levels				
OM_0	0.031^{R}	0.037^{R}	0.041^{R}	0.038^{R}
OM_1	0.038^{Q}	0.044^{Q}	0.050^{Q}	0.046^{Q}
OM_2	0.040^{P}	0.047^{P}	0.055^{P}	0.051^{P}
SEm (±)	0.00040	0.00041	0.00049	0.00046
C.D. at 5%	0.00120	0.00123	0.00147	0.00138
Interaction				
$B_0 OM_0$	0.029	0.034	0.035	0.033
$B_0 OM_1$	0.033	0.039	0.042	0.039
B_0 OM2	0.035	0.042	0.049	0.044
$B_1 0M_0$	0.031	0.036	0.042	0.038
$B_1 OM_1$	0.037	0.044	0.049	0.047
$B_1 OM_2$	0.040	0,047	0.054	0.050
$B_2 OM_0$	0.034	0.040	0.046	0.043
$B_2 OM_1$	0.043	0.049	0.059	0.052
$B_2 OM_2$	0.045	0.052	0.062	0.058
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	NS	0.003	NS

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

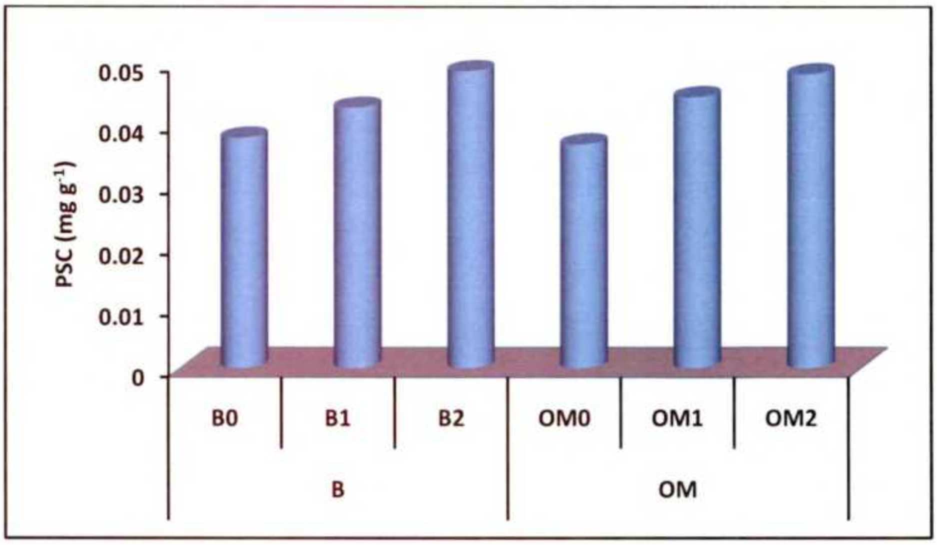


Fig. 4.32a : Mean effect of boron and organic matter on the changes in PSC in an inceptisol

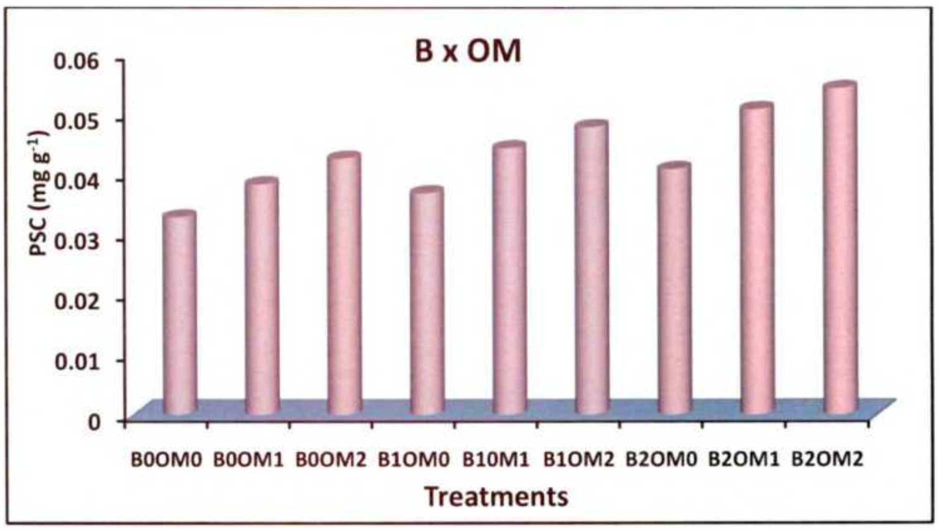


Fig. 4.32b : Mean interaction effect between boron and organic matter on the changes of PSC in an inceptisol

As regards to the interaction effect between B and OM, it was observed that the amount of PSC was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.062 mg g^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 77.14 at 30 days of incubation. The results further indicated that the highest mean percent increase of 68.75 was also recorded in the B_2OM_2 treatment combinations (Fig.4.32b).

The results suggested that the individual applications of both B and OM increased PSC, but due to their combined applications, the amount of PSC content has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to PSC in soil.

4.1.5.6 Changes in the number of aerobic nonsymbiotic nitrogen fixing bacteria (NFB) in an inceptisol

The result for the changes in the proliferation of NFB in inceptisol as affected by the interaction between B and OM are presented in Table 4.43. The results show that the number of NFB has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (79.27×10^5 g^{-1} soil) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 41.65 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 42.48 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.33a).

With regards to the application of organic matter, it was observed that the number of NFB was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 39.56 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (38.41) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.33a).

Table 4.43 Interaction between boron and organic matter in aerobic non symbiotic nitrogen fixing bacteria (× $10^5 g^{-1}$ soil) in an inceptisol (Mean of three replications)

Treatments	Nitrogen fixing bacteria (NFB)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	44.92^C	50.85^C	55.96^C	43.16^C
B_1	55.74^B	61.50^B	70.42^B	57.95^B
B_2	63.41^A	65.82^A	79.27^A	69.20^A
SEm (±)	0.514	0.568	0.643	0.549
C.D. at 5%	1.542	1.704	1.929	1.647
Organic Matter levels				
OM_0	45.00^R	50.35^R	55.38^R	46.19^R
OM_1	57.48^Q	63.76^Q	72.98^Q	59.76^Q
OM_2	61.59^P	69.35^P	77.29^P	64.35^P
SEm (±)	0.514	0.568	0.643	0.549
C.D. at 5%	1.542	1.704	1.929	1.647
Interaction				
$B_0 OM_0$	35.07	41.32	44.30	32.10
$B_0 OM_1$	47.31	51.61	57.85	42.07
B_0 OM2	52.39	59.63	65.72	55.31
$B_1 0M_0$	45.63	48.39	55.47	46.00
$B_1 OM_1$	59.21	67.28	76.89	62.38
$B_1 OM_2$	62.38	68.84	78.90	65.46
$B_2 OM_0$	54.31	61.34	66.37	60.47
$B_2 OM_1$	65.92	72.38	84.19	74.83
$B_2 OM_2$	70.01	79.59	87.25	72.29
SEm (±)	0.889	0.984	1.113	0.950
C.D. at 5%	2.667	2.952	3.339	2.85

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

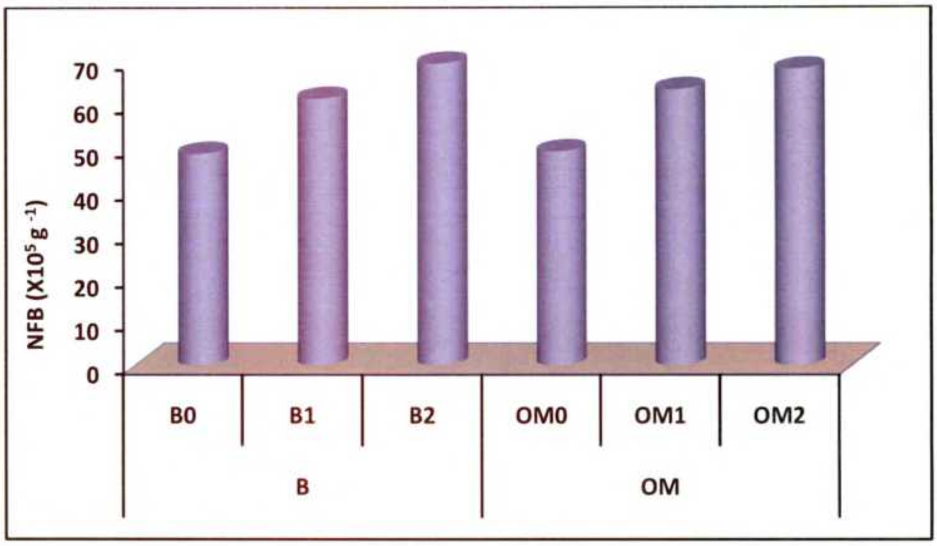


Fig. 4.33a : Mean effect of boron and organic matter on the changes in NFB in an inceptisol

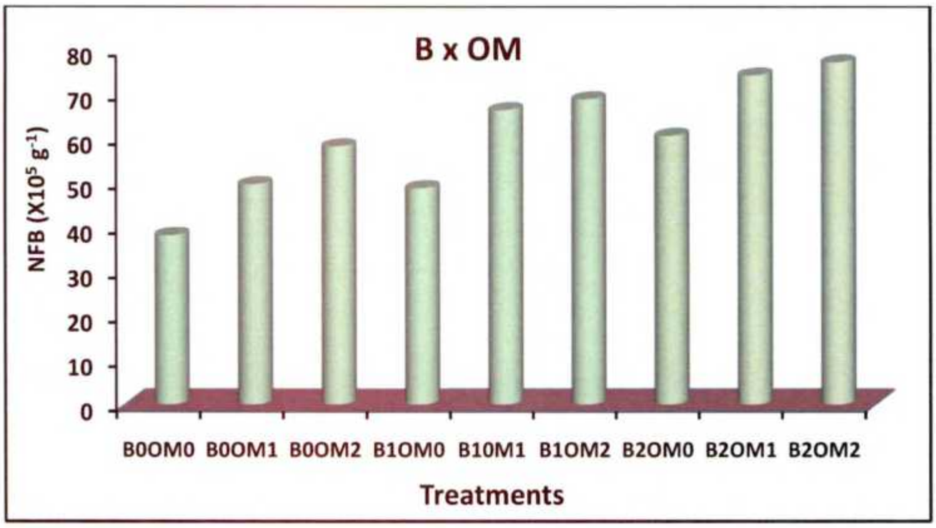


Fig. 4.33b : Mean interaction effect between boron and organic matter on the changes of NFB in an inceptisol

As regards to the interaction effect between B and OM, it was observed that the number of NFB was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (87.25x 10^5 g^{-1} soil) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 96.95 at 30 days of incubation.The results also find support with the results reported by Roper (1983) who showed that N fixation by free living non-symbiotic N-fixing microorganisms in soil amended with wheat straw contributed to the N status of the soil. The results further indicated that the highest mean percent increase of 102.35 was also recorded in the B_2OM_2 treatment combinations (Fig.4.33b).

The results suggested that the individual applications of both B and OM increased the number of NFB, but due to their combined applications, the number of NFB has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to NFB in soil.

4.1.5.7 Changes in aerobic non-symbiotic nitrogen fixing capacity (NFC) in an inceptisol

The result for the changes in NFC in inceptisol as affected by the interaction between B and OM are presented in Table 4.44. The results show that the amount of NFC has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (4.79 mg of N fixed g^{-1} soil g^{-1} sucrose consumed) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 19.45 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 19.68 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.34a).

Table 4.44 Interaction between boron and organic matter in aerobic non symbiotic nitrogen fixing capacity (mg of N fixed g^{-1} of soil g^{-1} sucrose consumed) in an inceptisol (Mean of three replications)

Treatments	Nitrogen fixing capacity (NFC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	3.40^C	3.75^C	4.01^C	3.90^C
B_1	3.74^B	4.34^B	4.55^B	4.46^B
B_2	4.00^A	4.56^A	4.79^A	4.67^A
SEm (±)	0.034	0.039	0.041	0.040
C.D. at 5%	0.102	0.117	0.123	0.120
Organic Matter levels				
OM_0	3.19^R	3.42^R	3.64^R	3.55^R
OM_1	3.78^Q	4.42^Q	4.66^Q	4.55^Q
OM_2	4.15^P	4.82^P	5.05^P	4.92^P
SEm (±)	0.034	0.039	0.041	0.040
C.D. at 5%	0.102	0.117	0.123	0.120
Interaction				
$B_0 OM_0$	3.12	3.32	3.52	3.42
$B_0 OM_1$	3.20	3.49	3.78	3.69
B_0 OM2	3.87	4.44	4.74	4.58
$B_1 0M_0$	3.15	3.4	3.62	3.54
$B_1 OM_1$	3.95	4.78	4.91	4.84
$B_1 OM_2$	4.12	4.85	5.12	4.99
$B_2 OM_0$	3.32	3.53	3.79	3.68
$B_2 OM_1$	4.20	4.98	5.30	5.12
$B_2 OM_2$	4.47	5.16	5.29	5.21
SEm (±)	0.060	0.068	0.072	0.070
C.D. at 5%	0.180	0.204	0.216	0.210

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

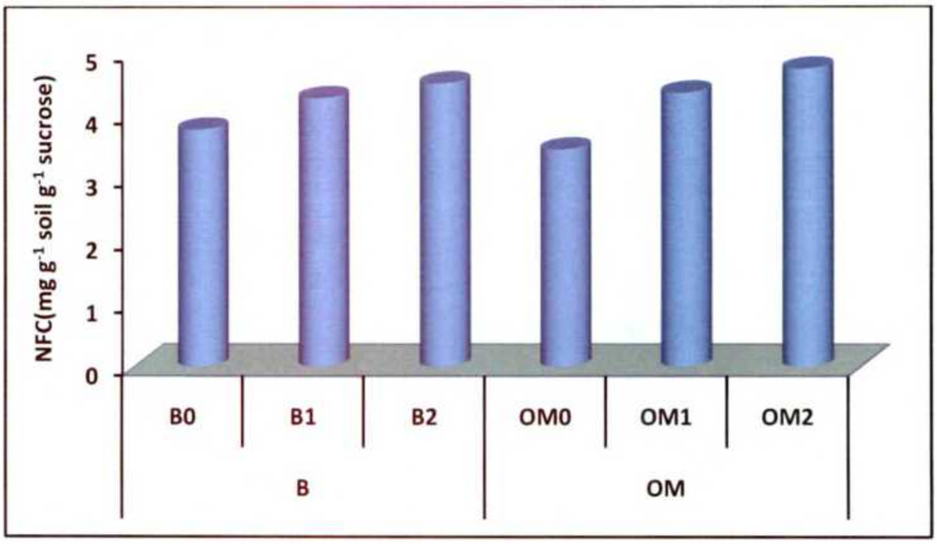


Fig. 4.34a : Mean effect of boron and organic matter on the changes in NFC in an inceptisol

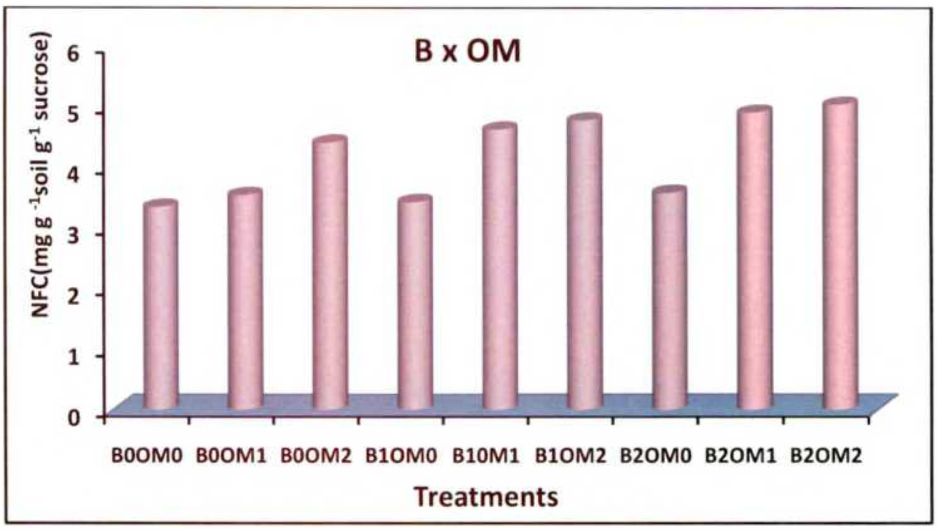


Fig. 4.34b : Mean interaction effect between boron and organic matter on the changes of NFC in an inceptisol

With regards to the application of organic matter, it was observed that the amount of NFC was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 38.73 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (37.10) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.34a). However the same explanation relating to NFB may be put forwarded for the NFC in soil.

As regards to the interaction effect between B and OM, it was observed that the amount of NFC was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (5.30 mg of N g^{-1} soil g^{-1} sucrose consumed) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 50.56 at 30 days of incubation. The results further indicated that the highest mean percent increase of 50.59 was also recorded in the B_2OM_2 treatment combinations (Fig.4.34b).Paul and Solaiman (2004) reported that a significant higher amount of MBC content was recorded in soil amended with organic matter.

The results suggested that the individual applications of both B and OM increased the NFC, but due to their combined applications, the amount of NFC content has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to NFC in soil.

4.1.5.8 Changes in Microbial biomass carbon (MBC) content in an inceptisol

The result for the changes in MBC content in inceptisol as affected by the interaction between B and OM are presented in Table4.45. The results show that the amount of MBC content has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B.

Table 4.45 Interaction between boron and organic matter in microbial biomass carbon (μg g^{-1} dry soil) content in an inceptisol (Mean of three replications)

Treatments	Microbial b iomass carbón(MBC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	119.68^C	128.54^C	130.27^B	125.60^B
B_1	128.61^B	139.17^B	142.14^A	139.38^A
B_2	134.19^A	144.88^A	145.84^A	142.78^A
SEm (±)	1.191	1.285	1.298	1.269
C.D. at 5%	3.573	3.855	3.894	3.807
Organic Matter levels				
OM_0	116.38^R	125.89^R	127.54^R	123.81^Q
OM_1	130.50^Q	141.25^Q	143.36^Q	140.59^P
OM_2	135.60^P	145.46^P	147.35^P	143.35^P
SEm (±)	1.191	1.285	1.298	1.269
C.D. at 5%	3.573	3.855	3.894	3.807
Interaction				
B_0 OM_0	110.09	119.02	120.68	112.38
B_0 OM_1	120.89	131.22	132.61	130.39
B_0 OM2	128.07	135.38	137.53	134.03
B_1 $0M_0$	117.67	126.81	129.55	128.13
B_1 OM_1	132.04	142.81	147.47	144.17
B_1 OM_2	136.12	147.90	149.41	145.83
B_2 OM_0	121.38	131.85	132.38	130.92
B_2 OM_1	138.56	148.71	150.01	147.22
B_2 OM_2	142.62	153.09	155.12	150.20
SEm (±)	2.063	2.226	2.249	2.199
C.D. at 5%	6.180	6.678	6.747	6.597

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

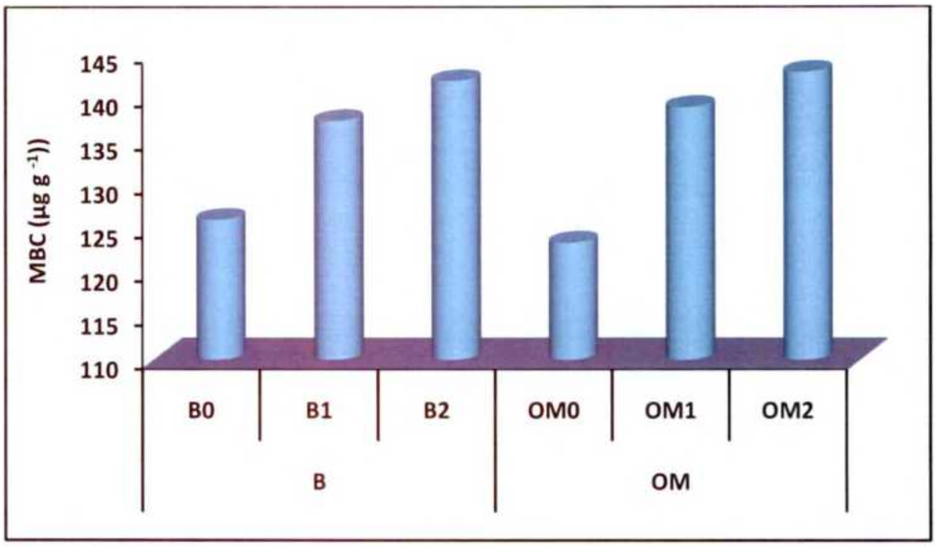


Fig. 4.35a : Mean effect of boron and organic matter on the changes in MBC content in an inceptisol

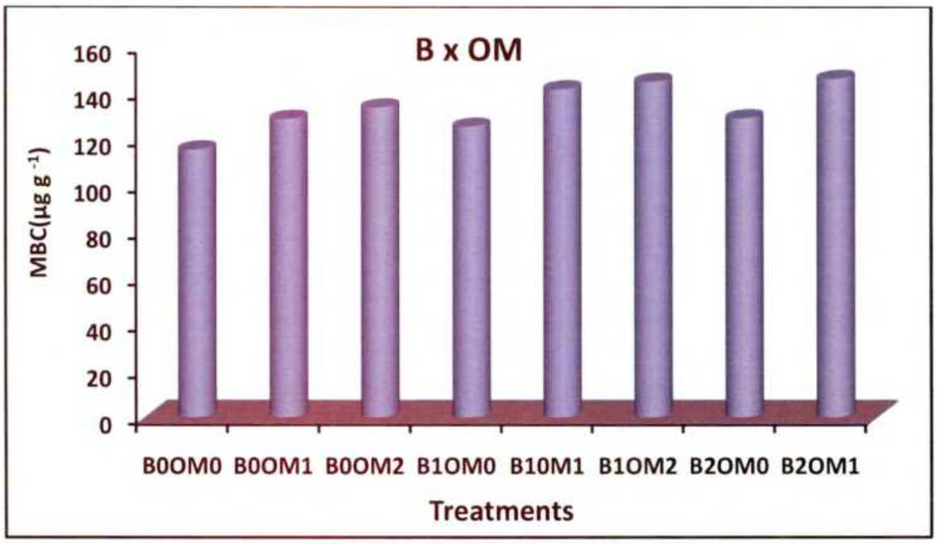


Fig. 4.35b : Mean interaction effect between boron and organic matter on the changes of MBC content in an inceptisol

The magnitude of such changes, however, varied with levels of B, being highest (145.84 µg g^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 11.95 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 12.61 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.35a).

With regards to the application of organic matter, it was observed that the amount of MBC content was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 15.53 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (15.83) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.35a).

As regards to the interaction effect between B and OM, it was observed that the amount of MBC content was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (155.12 µg g^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 28.53 at 30 days of incubation. The results further indicated that the highest mean percent increase of 30.04 was also recorded in the B_2OM_2 treatment combinations (Fig.4.35b).

The results suggested that the individual applications of both B and OM increased the MBC content, but due to their combined applications, the amount of MBC content has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to MBC content in soil.

4.1.5.9 PCA on boron versus organic matter study

This technique was used in present study to find out the best or homogeneous treatment combinations (Boron vs. Organic matter) separately for four days after incubation due to mean magnitude of Phosphate Solubilizing

Capacity (PSC), Phosphate Solubilizing Microorganisms (PSM), Nitrogen Fixing Capacity (NFC), Nitrogen Fixing Bacteria (NFB) and Microbial Biomass Carbon (MBC). Component matrix will include the loadings of each variable under all extracted components corresponding to eigen values more than one. Regression factor scores will be calculated to draw the scatter diagram to find out the homogeneous treatment combinations for first two components explaining first two larger variances as mentioned in the component matrices for each day after incubation.

Table 4.46 Component matrices for each day after incubation

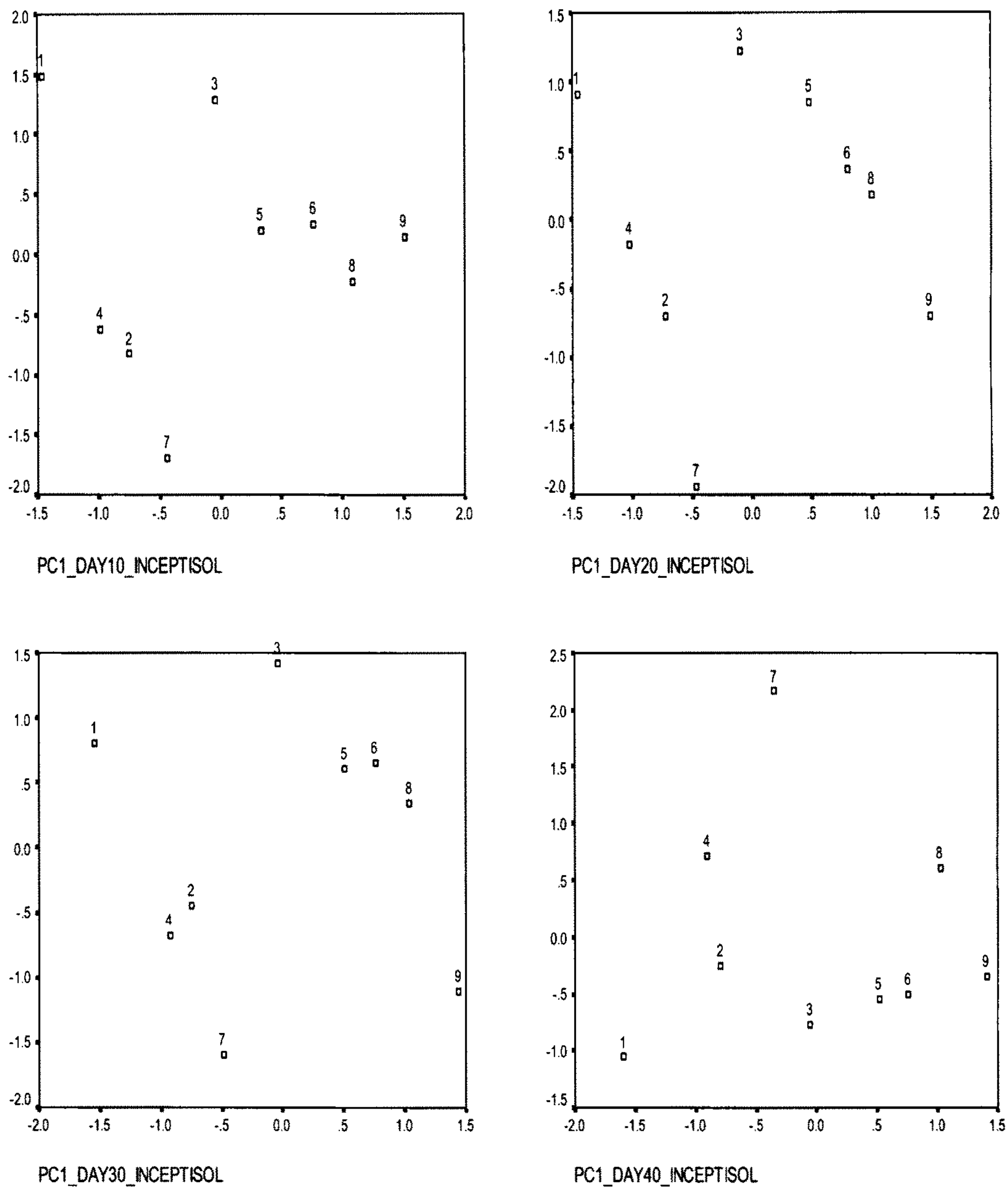
Variable	Day 10		Day 20		Day 30		Day 40	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
PSC	0.993	-0.029	0.995	-0.049	0.980	-0.085	0.990	0.029
PSM	0.995	0.064	0.991	-0.037	0.986	-0.099	0.983	-0.066
NFC	0.973	0.222	0.963	0.266	0.962	0.271	0.956	-0.248
NFB	0.978	-0.194	0.981	-0.145	0.988	-0.088	0.957	0.258
MBC	0.994	-0.003	0.993	-0.029	0.992	0.076	0.977	0.027
Eigen value	4.869	0.087	4.849	0.096	4.816	0.098	4.732	0.134
% of Variance	97.971	1.753	96.974	1.925	96.327	1.966	94.634	2.683
Cumulative %	93.371	99.124	96.974	98.899	96.327	98.293	94.634	97.317

Boron vs. Organic matter study at 10 DAI

First component explained 97.97 % of variance indicating the increase in all parameters. Second component explained 1.75 % of variance further indicating the increase in PSM and NFC resulted decrease in PSC, NFB and MBC and *vice versa*. Treatment combinations B_1OM1, B_1OM_2 and B_2OM_2 resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Organic matter study at 20 DAI

First component explained 96.97 % of variance indicating the increase in all parameters. Second component explained 1.92 % of variance further



Treatment combinations	1	2	3	4	5	6	7	8	9
Boron (unit)	0	0	0	1	1	1	2	2	2
Organic Matter (unit)	0	0	0	1	1	1	2	2	2

Fig. 4.36 : Scatter diagrams of regression factor scores of nine treatment combinations (B x OM) corresponding to first two components for four different days after incubation

indicating the increase in PSM and NFC resulted decrease in PSC, NFB and MBC and *vice versa*. Treatment combinations B_1OM1, B_1OM_2 and B_2OM1 resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Organic matter study at 30 DAI

First component explained 96.32 % of variance indicating the increase in all parameters. Second component explained 1.96 % of variance further indicating the increase in NFC and MBC resulted decrease in PSC, PSM and NFB *vice versa*. Treatment combinations B_0OM_2, B_1OM1, B_1OM_2 and B_2OM1 resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Organic matter study at 40 DAI

First component explained 94.63 % of variance indicating the increase in all parameters. Second component explained 2.68 % of variance further indicating the increase in PSC, NFB and MBC resulted decrease in PSM and NFC and *vice versa*. Treatment combinations B_2OM1 resulted higher content for all those variables which are positively loaded in both the first two axes.

Table 4.47 Best subsets regression of HCC extractable B with PSM, PSC, NFB, NFC and MBC

Response is B_1

Vars	R-Sq	R-Sq(adj)	C-p	S	psc	psm	nfc	nfb	mbc
1	66.0	65.7	54.8	0.014330				X	
1	48.9	48.4	134.8	0.017574					X
2	75.8	75.3	11.1	0.012154			X	X	
2	68.0	67.4	47.6	0.013977				X	X
3	77.3	76.6	6.2	0.011834		X	X	X	
3	76.9	76.2	8.0	0.011929			X	X	X
4	**78.1**	**77.3**	**4.3**	**0.011669**		**X**	**X**	**X**	**X**
4	77.4	76.5	7.6	0.011857	X	X	X	X	
5	**78.2**	**77.1**	**6.0**	**0.011709**	**X**	**X**	**X**	**X**	**X**

Table 4.48 Best subsets regression of MCC extractable B with PSM, PSC, NFB, NFC and MBC

Response is B_2

Vars	R-Sq	R-Sq(adj)	C-p	S	psc	psm	nfc	nfb	mbc
1	65.9	65.5	41.9	0.014420				X	
1	48.3	47.8	116.9	0.017741		X			
2	74.4	73.9	7.2	0.012536			X	X	
2	68.2	67.6	34.0	0.013990				X	X
3	**75.8**	**75.1**	**3.5**	**0.012260**		**X**	**X**	**X**	
3	74.9	74.2	7.1	0.012475			X	X	X
4	76.1	75.2	4.1	0.012237		X	X	X	X
4	75.8	74.9	5.5	0.012318	X	X	X	X	
5	**76.1**	**75.0**	**6.0**	**0.012291**	**X**	**X**	**X**	**X**	**X**

Table 4.49 Best subsets regression of MH-3 extractable B with PSM, PSC, NFB, NFC and MBC

Response is B_3

Vars	R-Sq	R-Sq(adj)	C-p	S	psc	psm	nfc	nfb	mbc
1	74.7	74.4	48.8	0.0056867				X	
1	57.8	57.4	150.5	0.0073402					X
2	81.5	81.1	9.7	0.0048852			X	X	
2	76.5	76.1	39.7	0.0055024	X			X	
3	82.6	82.1	5.1	0.0047621			X	X	X
3	82.1	81.6	7.7	0.0048214		X	X	X	
4	**83.0**	**82.4**	**4.2**	**0.0047192**		**X**	**X**	**X**	**X**
4	82.6	81.9	7.0	0.0047831	X		X	X	X
5	**83.1**	**82.3**	**6.0**	**0.0047369**	**X**	**X**	**X**	**X**	**X**

Mallows (1966) suggested the Cp statistical interpretation to find out the adequate model with maximum adjusted R^2 for each extracting solution of B with PSC, PSM,NFC, NFB and MBC parameters in inceptisol.It was found that all model were fitted resulting Cp= p. However considering the distance between Cp =p line and corresponding Cp values it was recorded an ascending order of 3>1>2 in inceptisol that means MH-3 extracting solution proved best in inceptisol for the extraction of B with the application of organic matter.

4.1.6 Interaction effect between boron and organic matter in alfisol on their changes in soil in relation to some microbial and biochemical attributes

4.1.6.1 Changes in hot $CaCl_2$ (HCC)-extractable boron content in an alfisol

The result for the changes in HCC-extractable B in alfisol as affected by the interaction between B and OM are presented in Table 4.50. The results show that the amount of HCC-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.174 mg kg^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 17.56 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 17.48 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.37a).

With regards to the application of organic matter, it was observed that the amount of HCC-Extractable B was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 5.09 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (5.26) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.37a)

As regards to the interaction effect between B and OM , it was observed that the amount of HCC extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.179 mg kg^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 26.05 at 30 days of incubation. The results further indicated that the highest mean percent increase of 24.24 % was also recorded in the B_2OM_2 treatment combinations (Fig.4.37b).

Table 4.50 Interaction between boron and organic matter in hot $CaCl_2$ (HCC) - extractable B content (mg kg^{-1}) content in an alfisol (Mean of three replications)

Treatments	HCC-extractable B			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.141^C	0.145^C	0.148^C	0.140^C
B_1	0.153^B	0.158^B	0.162B	0.152^B
B_2	0.167^A	0.171^A	0.174^A	0.162^A
SEm (±)	0.001	0.002	0.002	0.001
C.D. at 5%	0.003	0.006	0.006	0.003
Organic Matter levels				
OM_0	0.150^Q	0.154^Q	0.157^Q	0.147^Q
OM_1	0.153^P	0.158^P	0.162^{PQ}	0.152^P
OM_2	0.158^P	0.162^P	0.165P	0.155^P
SEm (±)	0.001	0.002	0.002	0.001
C.D. at 5%	0.003	0.006	0.006	0.003
Interaction				
$B_0 OM_0$	0.138	0.140	0.142	0.132
$B_0 OM_1$	0.141	0.146	0.149	0.141
B_0 OM2	0.145	0.149	0.154	0.147
$B_1 0M_0$	0.150	0.155	0.160	0.149
$B_1 OM_1$	0.152	0.157	0.162	0.153
$B_1 OM_2$	0.157	0.161	0.163	0.155
$B_2 OM_0$	0.162	0.166	0.170	0.159
$B_2 OM_1$	0.167	0.172	0.174	0.162
$B_2 OM_2$	0.172	0.176	0.179	0.164
SEm (±)	0.002	0.003	0.003	0.002
C.D. at 5%	0.006	0.009	0.009	0.006

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

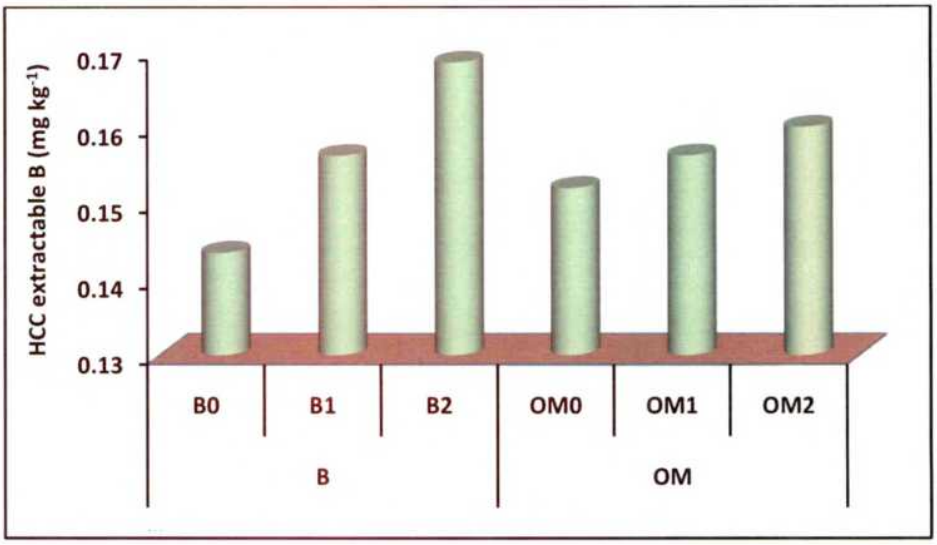


Fig. 4.37a : Mean effect of boron and organic matter on the changes in HCC extractable B content in an alfisol

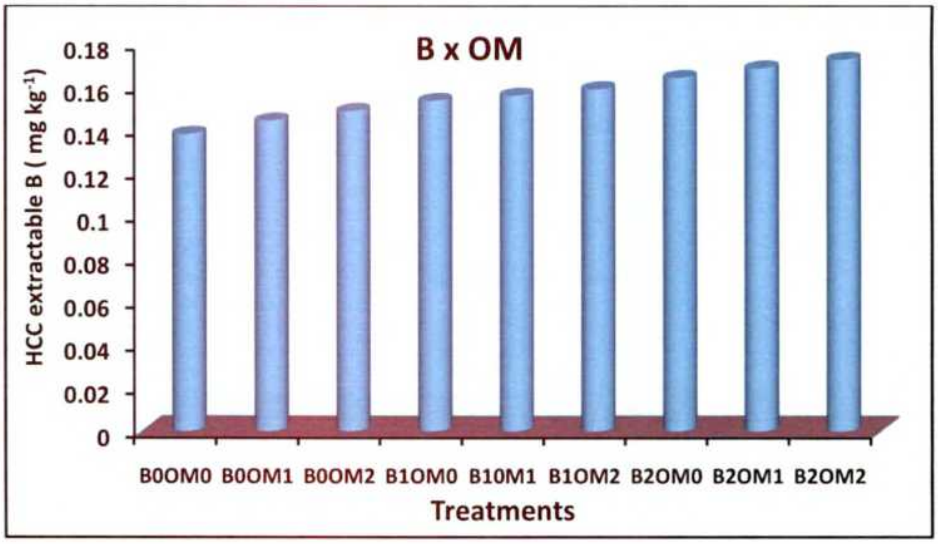


Fig. 4.37b : Mean interaction effect between boron and organic matter on the changes of HCC Extractable B content in an alfisol

Pakrashi and Haldar (1992) reported that the application of organic matter at higher level maintained a relatively higher proportion of boron in hot water soluble form, the extent of increasing being more when organic matter at higher levels applied to soil under 60 % W.H.C. moisture condition.

The results suggested that the individual applications of both B and OM increased the HCC-extractable B, but due to their combined applications, the amount of HCC- extractable B has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to HCC- extractable B content in soil.

4.1.6.2 Changes in mannitol-$CaCl_2$ (MCC)-extractable boron content in an alfisol

The result for the changes in MCC-extractable B in alfisol as affected by the interaction between B and OM are presented in Table 4.51. The results show that the amount of MCC-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.155 mg kg^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 24 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 24.36 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.38a).

With regards to the application of organic matter, it was observed that the amount of MCC-Extractable B was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 7.40 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (6.97) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.38a).

Table 4.51 Interaction between boron and organic matter in mannitol-$CaCl_2$ (MCC)-extractable B (mg kg^{-1}) content in an alfisol (Mean of three replications)

Treatments	MCC-extractable B			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.117^C	0.121^C	0.125^C	0.114^C
B_1	0.131^B	0.136^B	0.141^B	0.127^B
B_2	0.147^A	0.150^A	0.155^A	0.143^A
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003
Organic Matter levels				
OM_0	0.127^Q	0.131^R	0.135^R	0.124^Q
OM_1	0.132^P	0.136^Q	0.140^Q	0.127^Q
OM_2	0.135^P	0.140^P	0.145^P	0.132^P
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003
Interaction				
$B_0 OM_0$	0.113	0.115	0.117	0.110
$B_0 OM_1$	0.117	0.122	0.127	0.112
B_0 OM2	0.120	0.126	0.132	0.119
$B_1 0M_0$	0.127	0.131	0.137	0.123
$B_1 OM_1$	0.131	0.136	0.140	0.127
$B_1 OM_2$	0.135	0.140	0.145	0.131
$B_2 OM_0$	0.142	0.147	0.152	0.139
$B_2 OM_1$	0.148	0.150	0.154	0.142
$B_2 OM_2$	0.151	0.153	0.158	0.147
SEm (±)	0.002	0.002	0.002	0.002
C.D. at 5%	0.006	0.006	0.006	0.006

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

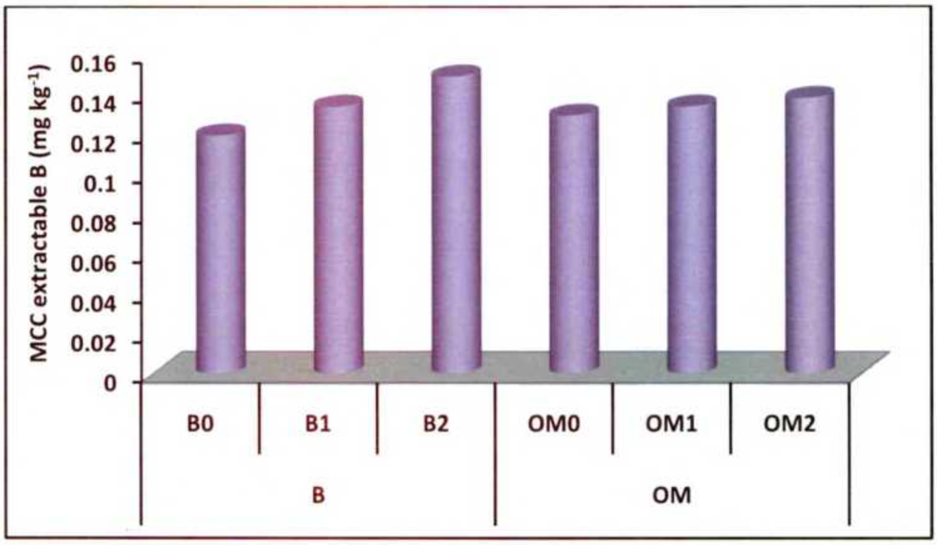


Fig. 4.38a : Mean effect of boron and organic matter on the changes in MCC Extractable B content in an alfisol

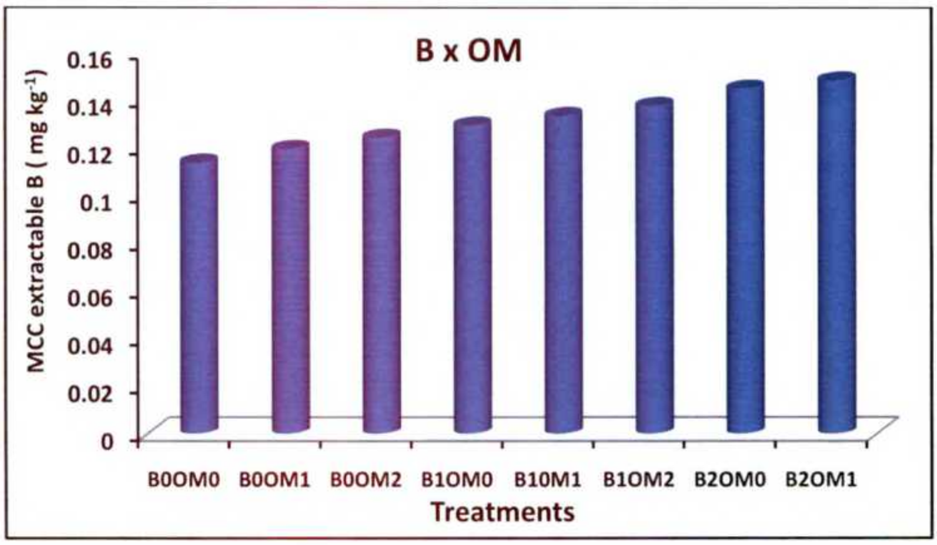


Fig. 4.38b : Mean interaction effect between boron and organic matter on the changes of MCC extractable B content in an alfisol

As regards to the interaction effect between B and OM , it was observed that the amount of MCC extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.158 mg kg^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 35.04 at 30 days of incubation. The results further indicated that the highest mean percent increase of 33.63 was also recorded in the B_2OM_2 treatment combinations (Fig.4.38b).Parks and white (1952) reported that boron associated with favourable diols of the organic matter or those which are gradually released as intermediate if the microbial breakdown of organic matter in soil.

The results suggested that the individual applications of both B and OM increased the MCC-extractable B, but due to their combined applications, the amount of MCC- extractable B has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to MCC- extractable B content in soil.

4.1.6.3 Changes in Mehlich 3 (MH-3)-extractable boron content in an alfisol

The result for the changes in MH-3-extractable B in alfisol as affected by the interaction between B and OM are presented in Table 4.52. The results show that the amount of MH-3-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.113 mg kg^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 31.39 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 34.17 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.39a).

Table 4.52 Interaction between boron and organic matter in Mehlich 3 (MH-3) extractable B content (mg kg $^{-1}$) in an alfisol (Mean of three replications)

Treatments	MH-3-extractable B			
	Days after incubation			
Boron levels				
B_0	0.076^C	0.082^C	0.086^C	0.073^C
B_1	0.088^B	0.095^B	0.100^B	0.084^B
B_2	0.104^A	0.108^A	0.113^A	0.099^A
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003
Organic Matter levels				
OM_0	0.085^R	0.090^R	0.095^R	0.081^R
OM_1	0.090^Q	0.090^Q	0.100^Q	0.085^Q
OM_2	0.094^P	0.100^P	0.105^P	0.091^P
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003
Interaction				
$B_0 OM_0$	0.072	0.075	0.079	0.069
$B_0 OM_1$	0.077	0.084	0.087	0.072
B_0 OM2	0.079	0.088	0.093	0.078
$B_1 0M_0$	0.084	0.092	0.097	0.080
$B_1 OM_1$	0.089	0.095	0.100	0.084
$B_1 OM_2$	0.092	0.099	0.104	0.089
$B_2 OM_0$	0.098	0.104	0.109	0.094
$B_2 OM_1$	0.103	0.108	0.114	0.099
$B_2 OM_2$	0.110	0.113	0.117	0.105
SEm (±)	0.002	0.002	0.002	0.002
C.D. at 5%	0.006	0.006	0.006	0.006

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

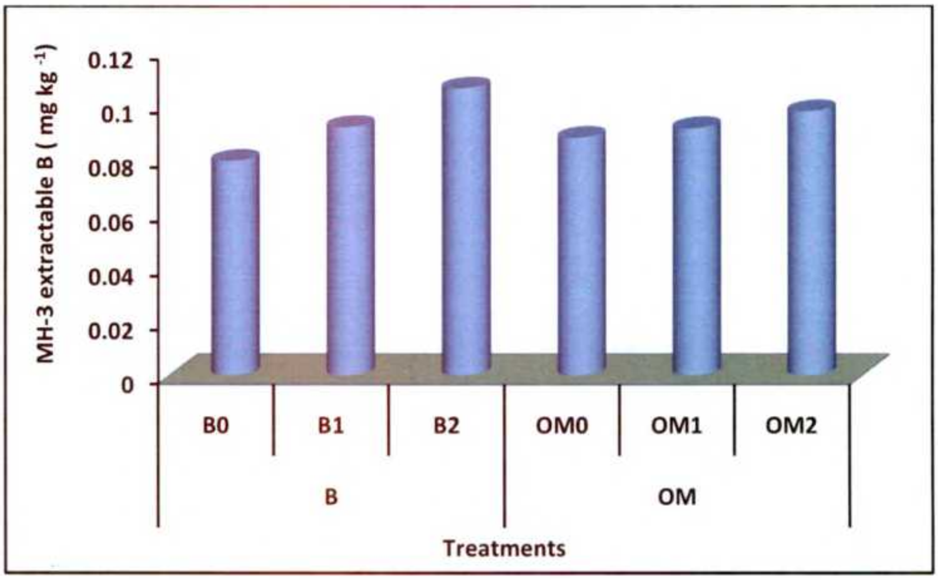


Fig. 4.39a : Mean effect of boron and organic matter on the changes in MH-3 extractable B in an inceptisol

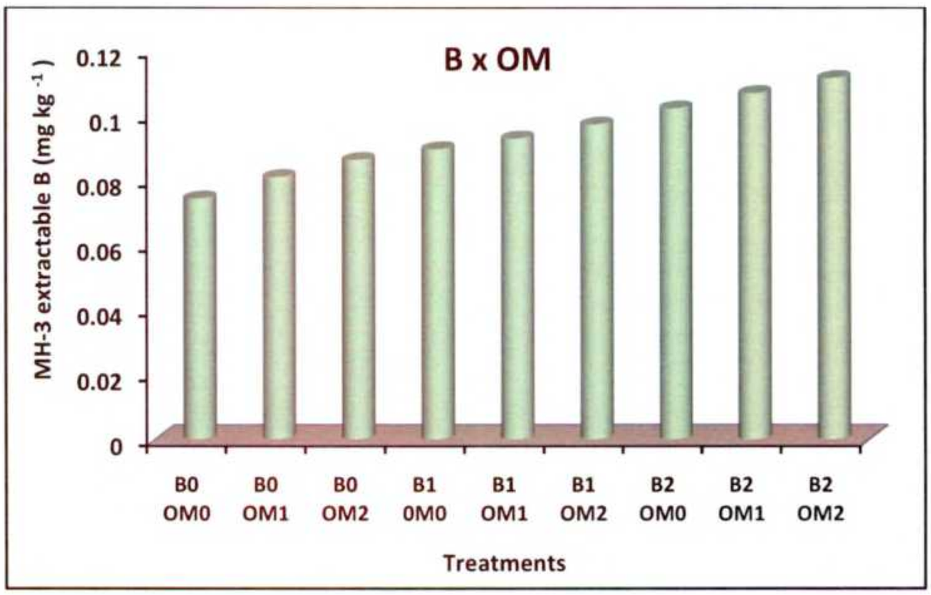


Fig. 4.39b : Mean interaction effect between boron and organic matter on the changes of MH-3 extractable B in an alfisol

With regards to the application of organic matter, it was observed that the amount of MH-3-Extractable B was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 10.52 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (11.49) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.39a).

As regards to the interaction effect between B and OM, it was observed that the amount of MH-3 extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.117 mg kg^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 48.10 at 30 days of incubation. The results further indicated that the highest mean percent increase of 52.05 was also recorded in the B_2OM_2 treatment combinations (Fig.4.39b). Hadwani *et al.* (1989) found a significant positive correlation between available boron and organic carbon content in soil which support the results of the present investigation.

The results suggested that the individual applications of both B and OM increased the MH-3-extractable B, but due to their combined applications, the amount of MH-3- extractable B has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to MH-3- extractable B content in soil.

4.1.6.4 Changes in the number of phosphate solubilising microorganisms (PSM) in an alfisol

The result for the changes in the number of PSM in alfisol as affected by the interaction between B and OM are presented in Table 4.53. The results show that the number of PSM has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B.

Table 4.53 Interaction between boron and organic matter in phosphate solubilizing microorganism ($\times 10^5 g^{-1}$ soil) in an alfisol (Mean of three replications)

Treatments	Phosphate solubilizing microorganism (PSM)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	26.60^C	31.46^C	38.79^C	35.15^C
B_1	34.28^B	41.54^B	48.49^B	44.22^B
B_2	43.51^A	51.34^A	59.13^A	56.81^A
SEm (±)	0.338	0.399	0.630	0.435
C.D. at 5%	1.014	1.197	1.890	1.305
Organic Matter levels				
OM_0	25.51^R	29.22^R	35.66^R	32.69^R
OM_1	36.90^Q	43.77^Q	50.89^Q	46.44^Q
OM_2	41.97^P	51.36^P	59.85^P	57.05^P
SEm (±)	0.338	0.399	0.630	0.435
C.D. at 5%	1.014	1.197	1.890	1.305
Interaction				
$B_0 OM_0$	21.22	23.36^i	27.64	24.03
$B_0 OM_1$	26.34	31.57	39.85	35.35
B_0 OM2	32.25	39.45	48.89	46.08
$B_1 0M_0$	24.63	28.40	36.96	32.11
$B_1 OM_1$	36.57	43.38	50.28	44.17
$B_1 OM_2$	41.63	52.85	58.22	56.38
$B_2 OM_0$	30.69	35.89	42.39	41.92
$B_2 OM_1$	47.79	56.36	62.56	59.81
$B_2 OM_2$	52.04	61.78	72.45	68.70
SEm (±)	0.586	0.691	1.091	0.754
C.D. at 5%	1.758	2.0731	3.273	2.262

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

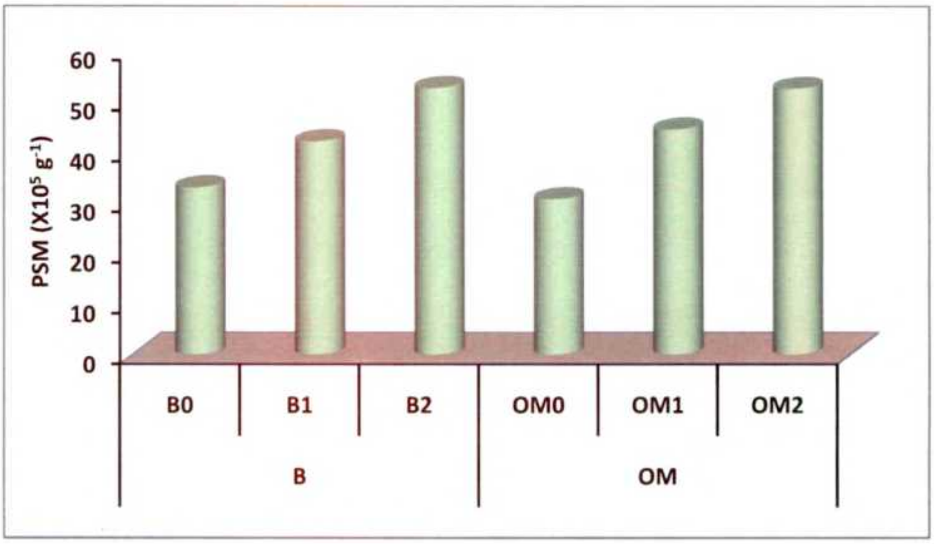


Fig. 4.40a : Mean effect of boron and organic matter on the changes in PSM in an inceptisol

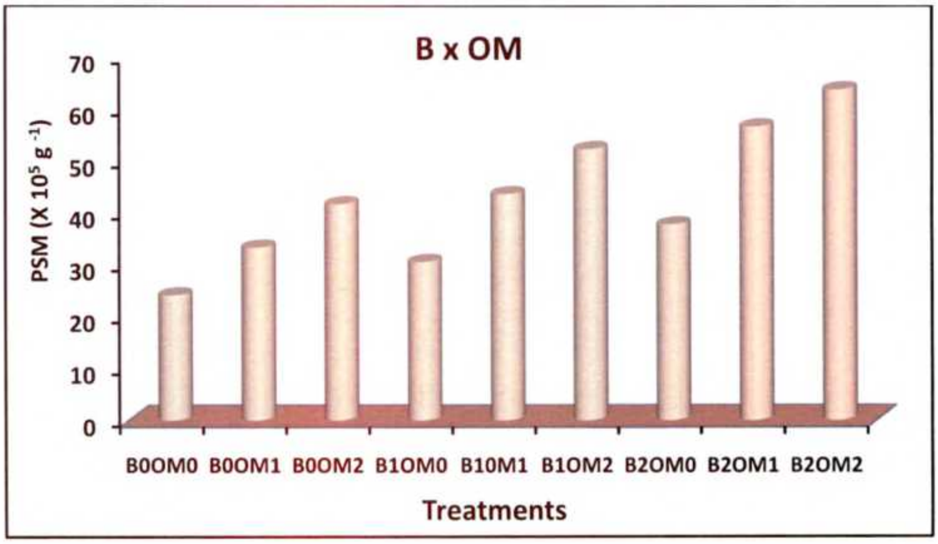


Fig. 4.40b : Mean interaction effect between boron and organic matter on the changes of PSM in an alfisol

The magnitude of such changes, however, varied with levels of B, being highest ($59.13x10^5$ g^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 52.35 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 59.66 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.40a).

With regards to the application of organic matter, it was observed that number of PSM was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 67.83was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (70.78) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.40a).

As regards to the interaction effect between B and OM, it was observed that the number of PSM was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest ($72.45x10^5$ g^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 162.12 at 30 days of incubation. The results further indicated that the highest mean percent increase of 164.92was also recorded in the B_2OM_2 treatment combinations (Fig.4.40b).

The results suggested that the individual applications of both B and OM increased the number of PSM, but due to their combined applications, the number of PSM has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to PSM in soil.

4.1.6.5 Changes in Phosphate solubilising capacity (PSC) in an alfisol

The result for the changes in PSC in alfisol as affected by the interaction between B and OM are presented in Table 4.54.

Table 4.54 Interaction between boron and organic matter in phosphate solubilizing capacity (mg g^{-1} dry soil) in an alfisol (Mean of three replications)

Treatments	Phosphate solubilizing capacity (PSC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	0.028^C	0.034^C	0.038^C	0.035^C
B_1	0.033^B	0.038^B	0.043^B	0.041^B
B_2	0.038^A	0.047^A	0.052^A	0.049^A
SEm (±)	0.00033	0.00039	0.00046	0.00046
C.D. at 5%	0.00099	0.00117	0.00138	0.00138
Organic Matter levels				
OM_0	0.028^R	0.032^R	0.036^R	0.034^R
OM_1	0.034^Q	0.042^Q	0.046^Q	0.044^Q
OM_2	0.038^P	0.045^P	0.050^P	0.048^P
SEm (±)	0.0033	0.0039	0.0046	0.0046
C.D. at 5%	0.00099	0.00117	0.00138	0.00138
Interaction				
$B_0 OM_0$	0.024	0.027	0.032	0.030
$B_0 OM_1$	0.029	0.035	0.037	0.036
B_0 OM2	0.032	0.039	0.044	0.041
$B_1 0M_0$	0.026	0.029	0.035	0.033
$B_1 OM_1$	0.034	0.041	0.044	0.042
$B_1 OM_2$	0.039	0.045	0.049	0.048
$B_2 OM_0$	0.033	0.040	0.042	0.038
$B_2 OM_1$	0.040	0.049	0.056	0.053
$B_2 OM_2$	0.042	0.051	0.058	0.055
SEm (±)	0.001	0.001	0.001	0.001
C.D. at 5%	0.003	0.003	0.003	0.003

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

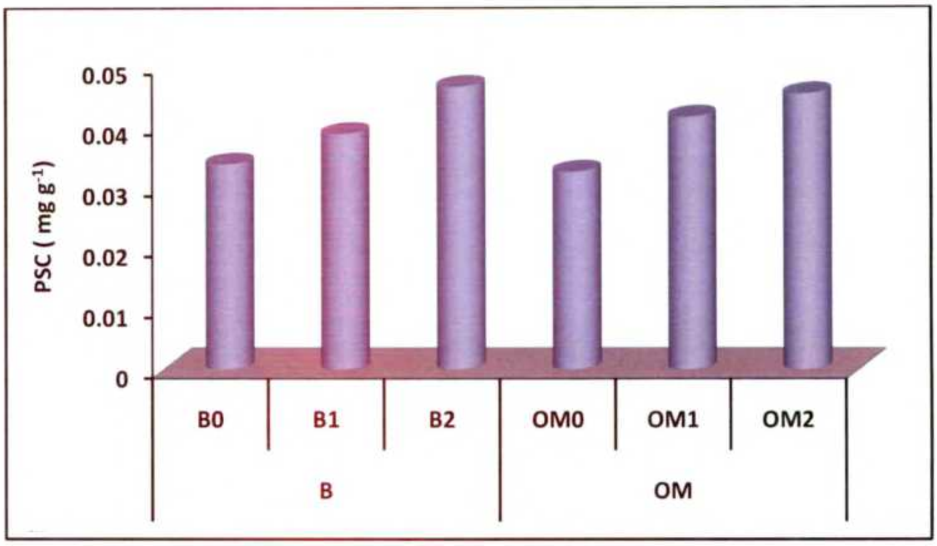


Fig. 4.41a : Mean effect of boron and organic matter on the changes in PSC in an alfisol

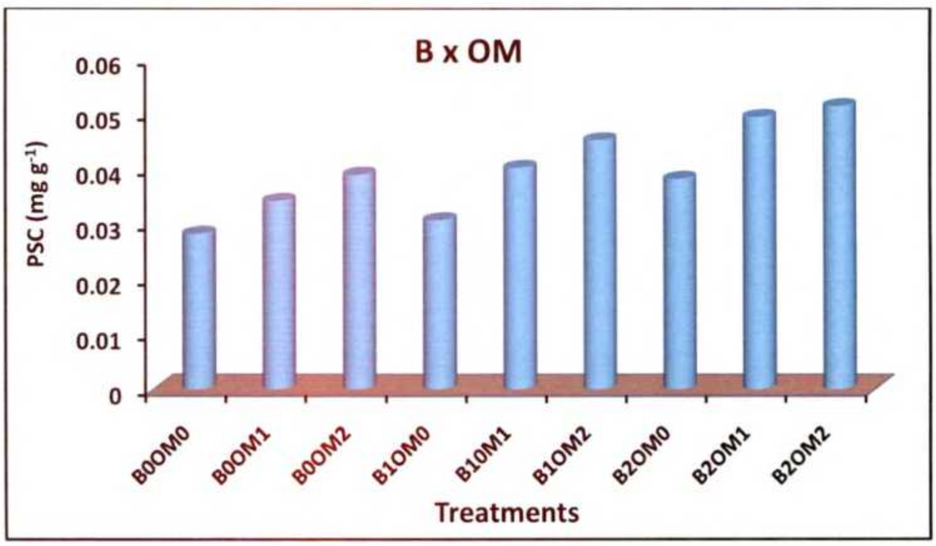


Fig. 4.41b : Mean interaction effect between boron and organic matter on the changes of PSC in an alfisol

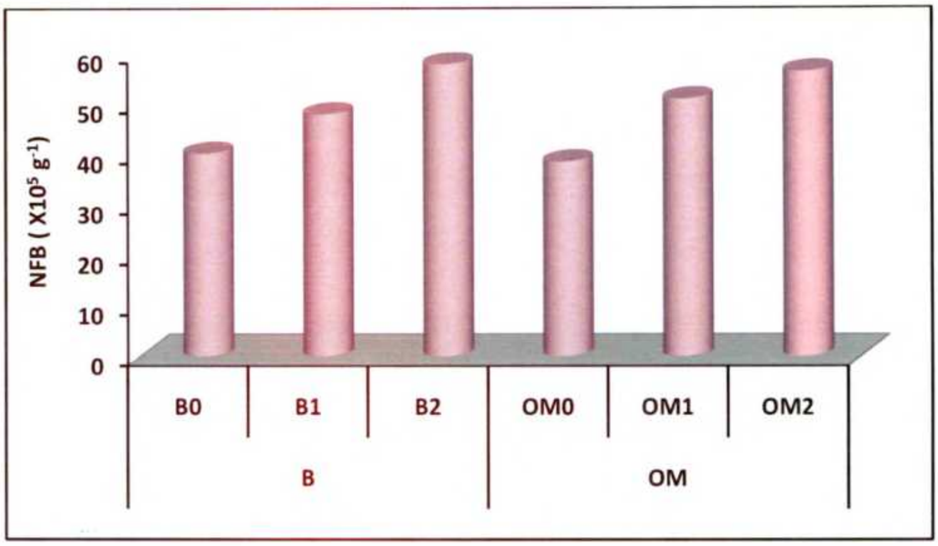


Fig. 4.42a : Mean effect of boron and organic matter on the changes in NFB in an alfisol

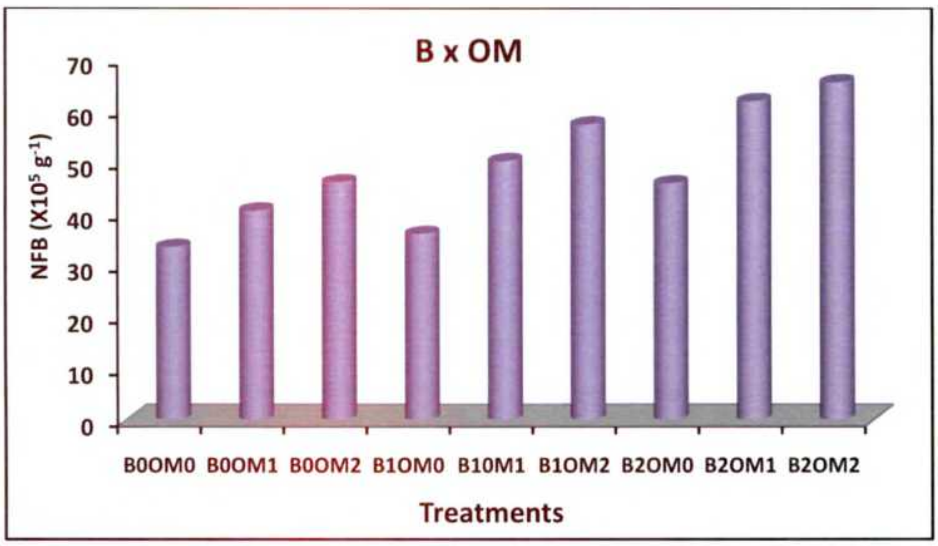


Fig. 4.42b : Mean interaction effect between boron and organic matter on the changes of NFB in an alfisol

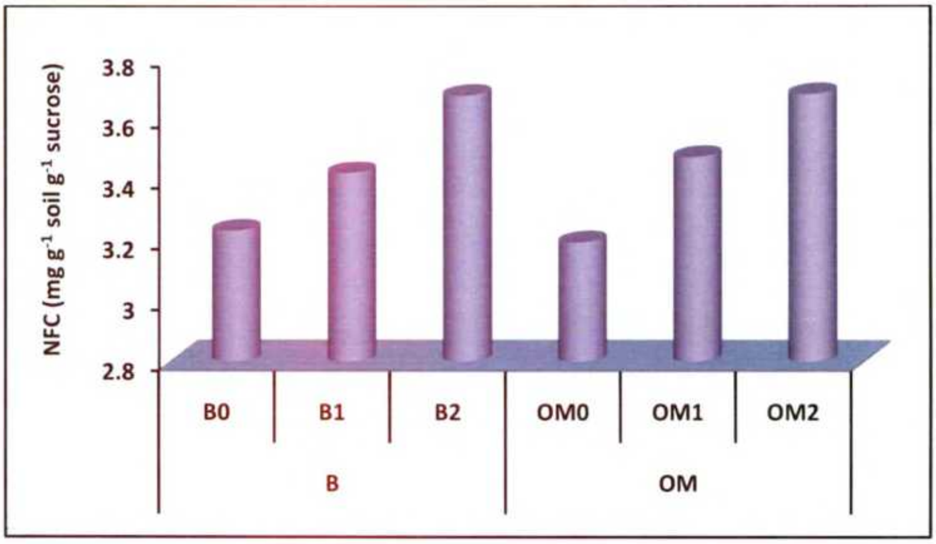


Fig. 4.43a : Mean effect of boron and organic matter on the changes in NFC in an alfisol

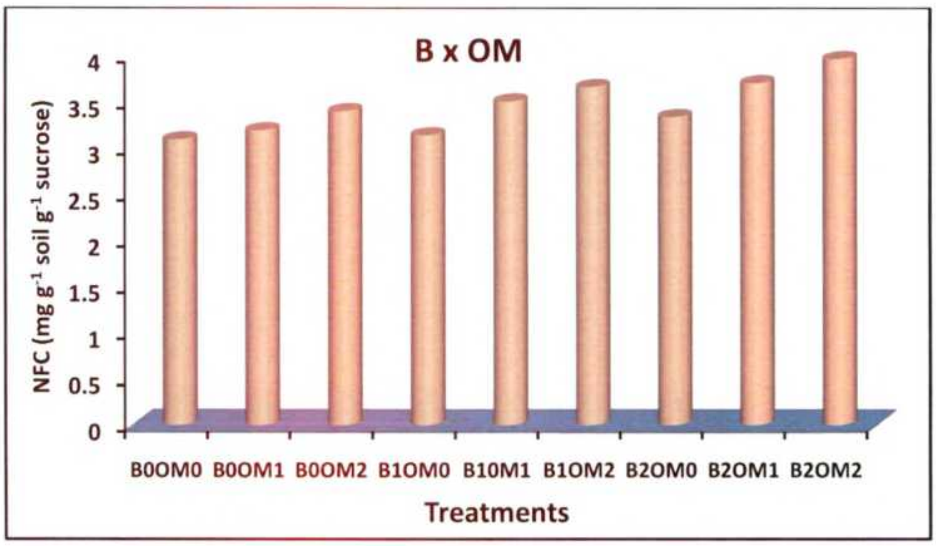


Fig. 4.43b : Mean interaction effect between boron and organic matter on the changes of NFC in an alfisol

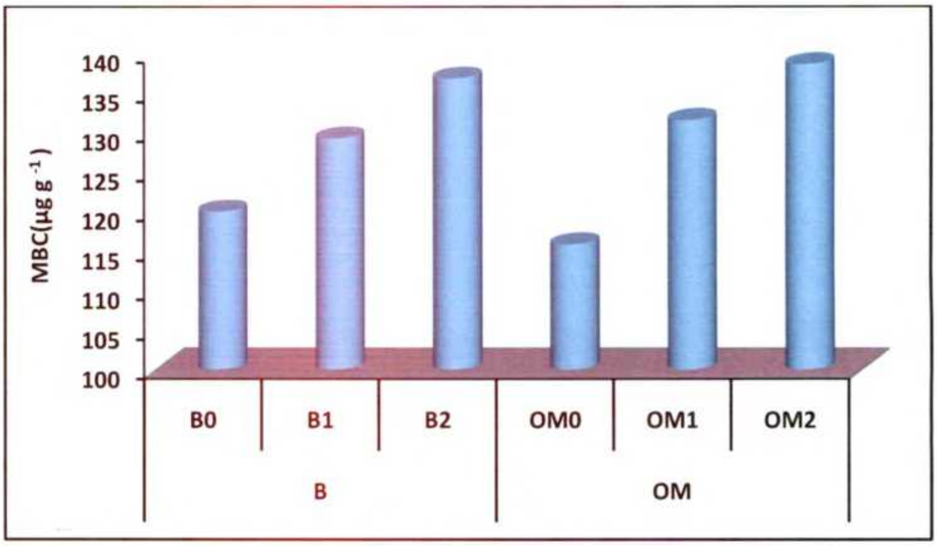


Fig. 4.44a : Mean effect of boron and organic matter on the changes in MBC content in an alfisol

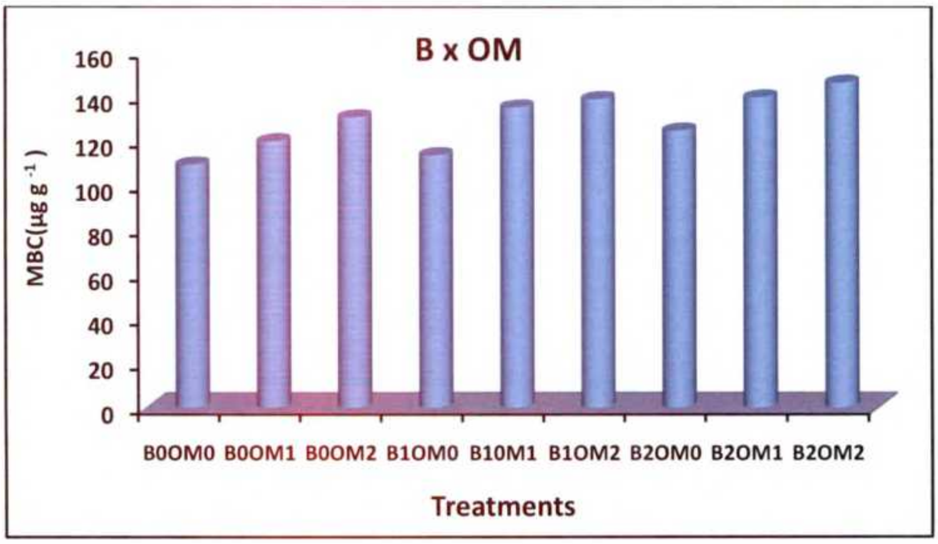


Fig. 4.44b : Mean interaction effect between boron and organic matter on the changes of MBC content in an alfisol

The results show that the amount PSC has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (0.052 mg g^{-1}) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 36.48 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 39.39 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.41a).

With regards to the application of organic matter, it was observed that the amount of PSC was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 38.88 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (40.62) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.41a).

As regards to the interaction effect between B and OM, it was observed that the amount PSC was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (0.058 mg g^{-1}) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 81.25 at 30 days of incubation. The results further indicated that the highest mean percent increase of 82.14 was also recorded in the B_2OM_2 treatment combinations (Fig.4.41b).

The results suggested that the individual applications of both B and OM increased the PSC, but due to their combined applications, the amount of PSC has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to PSC in soil.

4.1.6.6 Changes in the number of aerobic non-symbiotic nitrogen fixing bacteria (NFB) in an alfisol

The result for the changes in the number of NFB in alfisol as affected by the interaction between B and OM are presented in Table 4.55. The results show that the number of NFB has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (65.49x 10^5 g^{-1} soil) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 42.33 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 43.99 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.42a).

With regards to the application of organic matter, it was observed that the number of NEB was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 46.50was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (46.36) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.42a).

As regards to the interaction effect between B and OM, it was observed that the number of NFB was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (73.81x 10^5 g^{-1} of soil) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 87.76 at 30 days of incubation. The results further indicated that the highest mean percent increase of 95.26 was also recorded in the B_2OM_2 treatment combinations (Fig.4.42b).

The results suggested that the individual applications of both B and OM increased the number of NFB, but due to their combined applications, the number of NFB has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to proliferation of NFB in soil.

Table 4.55 Interaction between boron and organic matter on aerobic non symbiotic nitrogen fixing bacteria (× 10^5 g^{-1} soil) in an alfisol (Mean of three replications)

Treatments	Nitrogen fixing bacteria(NFB)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	37.34^C	41.59^C	46.01^C	35.64^C
B_1	44.29^B	50.07^B	56.10^B	41.28^B
B_2	51.84^A	59.63^A	65.49^A	54.26^A
SEm (±)	0.420	0.475	0.527	0.426
C.D. at 5%	1.26	1.425	1.581	1.278
Organic Matter levels				
OM_0	35.27^R	40.00^R	44.23^R	34.58^R
OM_1	46.55^Q	52.84^Q	58.57^Q	45.80^Q
OM_2	51.66^P	58.30^P	64.80^P	50.76^P
SEm (±)	0.420	0.475	0.527	0.426
C.D. at 5%	1.26	1.425	1.581	1.278
Interaction				
B_0 OM_0	31.12	35.83	39.31	28.03
B_0 OM_1	37.32	40.92	46.32	38.15
B_0 OM2	43.59	48.01	52.39	40.73
B_1 $0M_0$	34.30	36.03	41.03	33.17
B_1 OM_1	46.82	53.87	59.07	41.32
B_1 OM_2	51.76	60.32	68.19	49.34
B_2 OM_0	40.39	48.61	52.35	42.53
B_2 OM_1	55.51	63.72	70.32	58.04
B_2 OM_2	59.63	66.57	73.81	62.21
SEm (±)	0.728	0.822	0.913	0.739
C.D. at 5%	2.184	2.466	2.739	2.217

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

4.1.6.7 Changes in aerobic non-symbiotic nitrogen fixing capacity (NFC) in an alfisol

The result for the changes in NFC in alfisol as affected by the interaction between B and OM are presented in Table 4.56. The results show that the amount of NFC has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (3.93 mg of N fixed g^{-1} of soil g^{-1} sucrose consumed) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 13.91 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 13.62 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.43a).

With regards to the application of organic matter, it was observed that the amount of NFC was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 14.95 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (15.36) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.43a).

As regards to the interaction effect between B and OM, it was observed that the amount of NFC was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (4.22 mg of N fixed g^{-1} of soil g^{-1} sucrose consumed) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 27.10 at 30 days of incubation. The results further indicated that the highest mean percent increase of 28.47 was also recorded in the B_2OM_2 treatment combinations (Fig.4.43b).

The results suggested that the individual applications of both B and OM increased the NFC, but due to their combined applications, the amount of NFC has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to NFC in soil.

Table 4.56 Interaction between boron and organic matter on aerobic non symbiotic nitrogen fixing capacity (mg of N fixed g^{-1} of soil g^{-1} sucrose consumed) in an alfisol (Mean of three replications)

Treatments	Nitrogen fixing capacity(NFC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	2.98^C	3.19^C	3.45^C	3.30^C
B_1	3.11^B	3.44^B	3.68^B	3.45^B
B_2	3.28^A	3.69^A	3.93^A	3.80^A
SEm (±)	0.029	0.032	0.034	0.033
C.D. at 5%	0.087	0.096	0.102	0.099
Organic Matter levels				
OM_0	2.95^R	3.16^R	3.41^R	3.25^R
OM_1	3.14^Q	3.46^Q	3.73^Q	3.56^Q
OM_2	3.27^P	3.70^P	3.92^P	3.83^P
SEm (±)	0.029	0.032	0.034	0.033
C.D. at 5%	0.087	0.096	0.102	0.099
Interaction				
$B_0 OM_0$	2.92	3.02	3.32	3.12
$B_0 OM_1$	2.98	3.15	3.42	3.23
B_0 OM2	3.04	3.40	3.62	3.55
$B_1 OM_0$	2.94	3.10	3.33	3.21
$B_1 OM_1$	3.11	3.52	3.78	3.63
$B_1 OM_2$	3.27	3.69	3.92	3.79
$B_2 OM_0$	3.00	3.37	3.57	3.43
$B_2 OM_1$	3.32	3.71	3.99	3.82
$B_2 OM_2$	3.51	4.01	4.22	4.15
SEm (±)	0.050	0.056	0.060	0.057
C.D. at 5%	0.150	NS	0.180	NS

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil as FYM, OM_2= O.M. at 2% by weight of soil as FYM

4.1.6.8 Changes in Microbial biomass carbon (MBC) content in an alfisol

The result for the changes MBC content in alfisol as affected by the interaction between B and OM are presented in Table 4.57. The results show that the amount of MBC content has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest (140.89 $\mu g\ g^{-1}$) in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. However, the highest percent increase was recorded as 12.98 in the treatment B_2 at 30 days of incubation over control. The mean percent increase was recorded highest as 14.06 in the treatment where highest level of B at 2 mg kg^{-1} was applied (Fig.4.44a).

With regards to the application of organic matter, it was observed that the amount of MBC content was showed a similar trend of changes to that of the same changes with B application. However, the highest percent increase of 20.60 was recorded in the treatment OM_2 where OM at 2% by weight of the soil was applied at 30 days of incubation. The highest mean percent increase (19.63) was recorded in the OM_2 treatment where OM at 2 % by weight of the soil was applied (Fig.4.44a).

As regards to the interaction effect between B and OM, it was observed that the amount of MBC content was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest (150.90 $\mu g\ g^{-1}$) in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2 % by weight of the soil was applied combinedly with percent increase of 34.34 at 30 days of incubation. The results further indicated that the highest mean percent increase of 33.76 was also recorded in the B_2OM_2 treatment combinations (Fig.4.44b).The changes in microbial and biochemical attributes in alfisol were similar to that of inceptisol and the explanation for those parameters of inceptisol may be applicable to the alfisol with the exception of the absolute amounts of those parameters.

Table 4.57 Interaction between boron and organic matter on microbial biomass carbon content (μg g^{-1} dry soil) in an alfisol (Mean of three replications)

Treatments	Microbial biomass carbón(MBC)			
	Days after incubation			
	10	20	30	40
Boron levels				
B_0	112.24^{C}	121.61^{C}	124.70^{C}	121.43^{C}
B_1	121.82^{B}	131.02^{B}	133.48^{B}	130.83^{B}
B_2	129.34^{A}	138.75^{A}	140.89^{A}	138.53^{A}
SEm (±)	1.174	1.207	1.227	1.347
C.D. at 5%	3.522	3.621	3.681	4.041
Organic Matter levels				
OM_0	109.21^{R}	117.76^{R}	119.06^{R}	117.56^{R}
OM_1	124.20^{Q}	132.65^{Q}	136.42^{Q}	133.17^{Q}
OM_2	129.99^{P}	140.97^{P}	143.59^{P}	140.06^{P}
SEm (±)	1.174	1.207	1.227	1.347
C.D. at 5%	3.522	3.621	3.681	4.041
Interaction				
$B_0 OM_0$	103.05	110.21	112.32	111.81
$B_0 OM_1$	112.21	121.29	125.37	120.70
B_0 OM2	121.47	133.32	136.42	131.78
$B_1 0M_0$	108.32	115.35	116.47	114.61
$B_1 OM_1$	127.03	135.82	140.52	137.59
$B_1 OM_2$	130.11	141.90	143.45	140.30
$B_2 OM_0$	116.26	127.73	128.40	126.27
$B_2 OM_1$	133.37	140.85	143.37	141.22
$B_2 OM_2$	138.38	147.68	150.90	148.11
Sm (±)	2.033	2.090	2.125	2.333
C.D. at 5%	6.099	6.270	6.375	6.999

B_0= no boron, B_1= B at 1 mg kg^{-1} as borax, B_2= B at 2 mg kg^{-1} as borax, OM_0= no organic matter, OM_1=O.M. at 1% by weight of soil asF YM, OM_2= O.M. at 2% by weight of soil as FYM

The results suggested that the individual applications of both B and OM increased the MBC content, but due to their combined applications, the amount of MBC content has been found to be further increased significantly and hence the interaction between B and OM was found positive with respect to MBC content soil.

4.1.6.9 PCA on Boron versus Organic Matter study

This technique was used in present study to find out the best or homogeneous treatment combinations (Boron vs. Organic matter) separately for four days after incubation due to mean magnitude of Phosphate Solubilizing Capacity (PSC), Phosphate Solubilizing Microorganisms (PSM), Nitrogen Fixing Capacity (NFC), Nitrogen Fixing Bacteria (NFB) and Microbial Biomass Carbon (MBC). Component matrix will include the loadings of each variable under all extracted components corresponding to eigen values more than one. Regression factor scores will be calculated to draw the scatter diagram to find out the homogeneous treatment combinations for first two components explaining first two larger variances as mentioned in the component matrices for each day after incubation.

Table 4.58 Component matrices for each day after incubation

Variable	Day 10		Day 20		Day 30		Day 40	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
PSC	0.987	-0.122	0.988	0.123	0.987	-0.125	0.993	-0.058
PSM	0.996	0.052	0.992	-0.091	0.989	-0.006	0.996	-0.031
NFC	0.972	0.232	0.990	-0.112	0.991	-0.045	0.988	0.100
NFB	0.999	-0.007	0.995	-0.007	0.991	-0.035	0.978	-0.201
MBC	0.986	-0.152	0.987	0.086	0.976	0.214	0.979	0.189
Eigen value	4.879	0.095	4.905	0.043	4.869	0.064	4.870	0.090
% of Variance	97.588	1.895	98.101	0.871	97.379	1.289	97.404	1.810
Cumulative %	97.588	99.583	98.101	98.972	97.379	98.668	97.404	99.214

Boron vs. Organic matter study at 10 DAI

First component explained 97.59 % of variance indicating the increase in all parameters. Second component explained 1.89 % of variance further indicating the increase in PSM and NFC resulted decrease in PSC, NFB and MBC and *vice versa*. Treatment combinations B_2OM1 and B_2OM_2 resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Organic matter study at 20 DAI

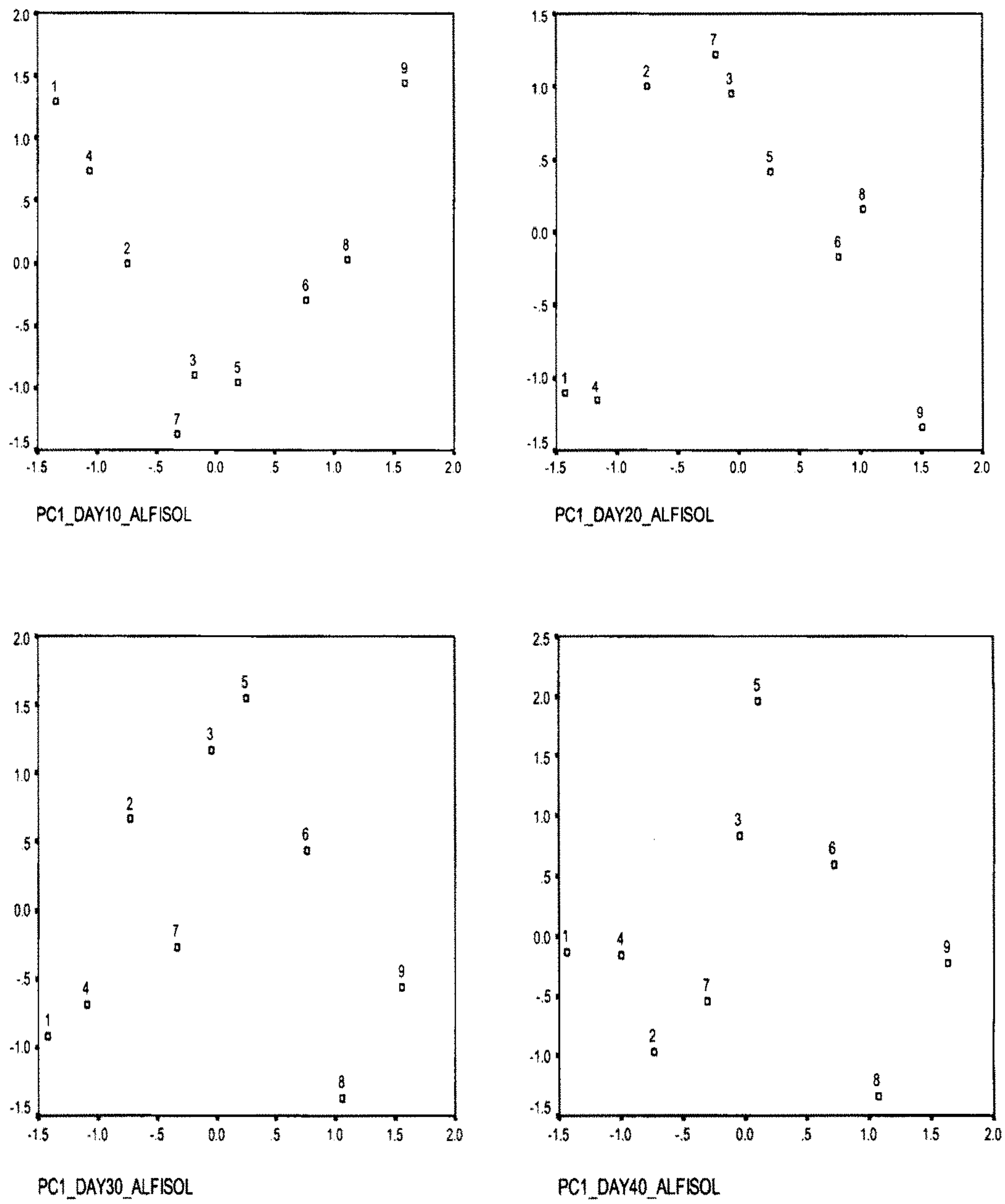
First component explained 98.10 % of variance indicating the increase in all parameters. Second component explained 0.871 % of variance further indicating the increase in PSC and MBC resulted decrease in PSM, NFC and NFB and MBC. Treatment combinations B_1OM_1 and B_2OM_1 resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Organic matter study at 30 DAI

First component explained 97.37 % of variance indicating the increase in all parameters. Second component explained 1.289 % of variance further indicating the increase in MBC resulted decrease in PSC, PSM, NFB and NFC and *vice versa*. Treatment combinations $B_1OM_1$and B_1OM_2 resulted higher content for all those variables which are positively loaded in both the first two axes.

Boron vs. Organic matter study at 40 DAI

First component explained 97.40 % of variance indicating the increase in all parameters. Second component explained 1.81 % of variance further indicating the increase in NFC and MBC resulted decrease in PSM, PSC, and NFB and *vice versa*. Treatment combinations $B_1OM_1$and B_1OM_2 resulted higher content for all those variables which are positively loaded in both the first two axes.



Treatment combinations	1	2	3	4	5	6	7	8	9
Boron (unit)	0	0	0	1	1	1	2	2	2
Organic Matter (unit)	0	0	0	1	1	1	2	2	2

Fig. 4.45 : Scatter diagrams of regression factor scores of nine treatment combinations (B x OM) corresponding to first two components for four different days after incubation

Table 4.59 Best subsets regression of HCC extractable B with PSM, PSC, NFB, NFC and MBC

Response is B_1

Vars	R-Sq	R-Sq(adj)	C-p	S	psc	psm	nfc	nfb	mbc
1	69.2	68.9	-1.1	0.0067957				X	
1	58.7	58.3	34.2	0.0078741		X			
2	69.4	68.8	0.5	0.0068144				X	X
2	69.3	68.7	0.8	0.0068228			X	X	
3	69.4	68.6	2.2	0.0068370	X			X	X
3	69.4	68.5	2.4	0.0068421		X		X	X
4	**69.5**	**68.3**	**4.0**	**0.0068622**	**X**		**X**	**X**	**X**
4	69.4	68.3	4.2	0.0068701	X	X		X	X
5	**69.5**	**68.0**	**6.0**	**0.0068957**	**X**	**X**	**X**	**X**	**X**

Table 4.60 Best subsets regression of MCC extractable B with PSM, PSC, NFB, NFC and MBC

Response is B_2

Vars	R-Sq	R-Sq(adj)	C-p	S	psc	psm	nfc	nfb	mbc
1	71.4	71.1	-1.7	0.0074297				X	
1	58.3	57.9	45.1	0.0089692		X			
2	71.4	70.9	0.0	0.0074556	X			X	
2	71.4	70.9	0.0	0.0074562		X		X	
3	71.4	70.6	2.0	0.0074909	X	X		X	
3	71.4	70.6	2.0	0.0074912	X		X	X	
4	**71.4**	**70.3**	**4.0**	**0.0075270**	**X**	**X**		**X**	**X**
4	71.4	70.3	4.0	0.0075271	X	X	X	X	
5	**71.4**	**70.0**	**6.0**	**0.0075637**	**X**	**X**	**X**	**X**	**X**

Table 4.61 Best Subsets Regression of MH-3 extractable B with PSM, PSC, NFB, NFC and MBC

Response is B_3

Vars	R-Sq	R-Sq(adj)	C-p	S	psc	psm	nfc	nfb	mbc
1	76.6	76.3	-0.2	0.0064176				X	
1	60.8	60.5	69.5	0.0082959		X			
2	76.9	76.5	0.1	0.0063955				X	X
2	76.9	76.4	0.5	0.0064085		X		X	
3	77.0	76.3	2.0	0.0064235		X		X	X
3	77.0	76.3	2.1	0.0064247	X			X	X
4	**77.0**	**76.1**	**4.0**	**0.0064538**		**X**	**X**	**X**	**X**
4	77.0	76.1	4.0	0.0064546	X	X		X	X
5	**77.0**	**75.8**	**6.0**	**0.0064850**	**X**	**X**	**X**	**X**	**X**

Mallows (1966) suggested the Cp statistical interpretation to find out the adequate model with maximum adjusted R^2 for each extracting solution of B with PSC, PSM,NFC, NFB and MBC parameters in alfisol.It was found that all model were fitted resulting Cp= p. However considering the distance between Cp =p line and corresponding Cp values it was recorded an ascending order of 3>2>1 in alfiisol that means MH-3 extracting solution proved best in inceptisol for the extraction of B with the application of organic matter.

4.2 Field experiment

4.2.1 Experiment: Influence of boron sourdes and organic matter on the changes in chemical, biochemical and microbial properties in relation to yield and quality of rape (*B. Campestris* L.)

4.2.1.1 Influence of sources of boron and organic matter on changes in hot $CaCl_2$ (HCC) extractable boron content in soil during the year 2006-2007 and 2007-2008

The results (Table4.62a and 4.62b) reveal that the amount of hot $CaCl_2$ (HCC) extractable B has been found to be decreased consistently with the progress of crop growth irrespective of rhizosphere (R) and non-rhizosphere (NR) soils during both the years (2006-07 & 2007-08). Such consistent decrease might be due to depletion of B by crops. Among treatments, the amount of HCC-extractable B was maintained a higher value throughout crop growth period in both R and NR soils. Choudhury and Shukla (2003) reported that HCC extractable boron has been proved a superior extracting solution for mustard. However, the highest amount of HCC extractable B was found at the initial crop growth period in the treatment T_4 where recommended level of NPK (80:40:40), B as calbor at 0.5 kg ha^{-1} and organic manure at 5 t ha^{-1} was applied togetherly in both R and NR soils, which might be explained by the adoption of integrated B management system i.e., by using organic manure and B in an integrated manner.

Table 4.62a Effect of organic matter and boron application on the changes in hot $CaCl_2$ (HCC) extractable boron (mg kg^{-1}) in soil during the year 2006-2007 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	0.363^f	0.351^f	0.348^e	0.329^f	0.330^f	0.308^f	0.311^f	0.297^e	**0.338^F**	**0.321^M**
T_2	0.439^e	0.423^e	0.427^d	0.395^e	0.412^e	0.367^e	0.401^e	0.348^d	**0.420^E**	**0.383^L**
T_3	0.699^b	0.688^b	0.677^b	0.543^c	0.657^b	0.607^b	0.639^b	0.506^c	**0.668^B**	**0.586^J**
T_4	0.778^a	0.741^a	0.758^a	0.708^a	0.739^a	0.683^a	0.723^a	0.677^a	**0.750^A**	**0.702^I**
T_5	0.649^c	0.636^c	0.632^c	0.592^b	0.620^c	0.573^c	0.607^c	0.566^b	**0.627^C**	**0.592^J**
T_6	0.578^d	0.542^d	0.642^c	0.494^d	0.532^d	0.524^d	0.519^d	0.485^c	**0.568^D**	**0.511^K**
Mean	**0.584^P**	**0.564^W**	**0.581^Q**	**0.510^X**	**0.548^R**	**0.510^Y**	**0.533^S**	**0.480^Z**	**0.562^U**	**0.516^V**
SEm (±)	**0.008**	**0.008**	**0.008**	**0.008**	**0.008**	**0.008**	**0.008**	**0.007**	**0.008**	**0.007**
C.D. at 5%	**0.0252**	**0.0252**	**0.0252**	**0.0252**	**0.0252**	**0.0252**	**0.0252**	**0.0221**	**0.0252**	**0.0221**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.62b Effect of organic matter and boron application on the changes in hot $CaCl_2$ (HCC) extractable boron ($mg\ kg^{-1}$) in soil during the year 2007-2008 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	0.365^f	0.355^f	0.349^{ef}	0.337f	0.332e	0.307f	0.315e	0.300e	**0.340^F**	**0.325^M**
T_2	0.437^e	0.425^e	0.422^d	0.390e	0.417d	0.362e	0.403d	0.349d	**0.420^E**	**0.381^L**
T_3	0.701^b	0.680^b	0.683b	0.642b	0.650b	0.610b	0.632b	0.511c	**0.666^B**	**0.611^J**
T_4	0.785^a	0.745^a	0.759a	0.710a	0.742a	0.689a	0.728a	0.680a	**0.753^A**	**0.706^I**
T_5	0.642^c	0.630^c	0.630c	0.599c	0.626b	0.575c	0.610b	0.561b	**0.627^C**	**0.591^J**
T_6	0.577^d	0.549^d	0.644e	0.493d	0.530c	0.528d	0.517c	0.489c	**0.567^D**	**0.515^K**
Mean	**0.584^P**	**0.564^W**	**0.581^Q**	**0.528^X**	**0.549^R**	**0.512^Y**	**0.534^S**	**0.482^Z**	**0.562^U**	**0.521^V**
SEm (±)	**0.009**	**0.008**	**0.008**	**0.008**	**0.008**	**0.008**	**0.008**	**0.007**	**0.008**	**0.008**
C.D. at 5%	**0.0284**	**0.0252**	**0.0252**	**0.0252**	**0.0252**	**0.0252**	**0.0252**	**0.0221**	**0.0252**	**0.0252**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter ($5t\ ha^{-1}$); T_3 = NPK as recommended + Boron as calbor ($1\ kg\ B\ ha^{-1}$); T_4 = NPK as recommended + Boron as calbor ($0.5\ kg\ B\ ha^{-1}$) + Organic matter ($5\ t\ ha^{-1}$); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax ($0.5\ kg\ B\ ha^{-1}$) + Organic matter ($5\ t\ ha^{-1}$)

As regards to the HCC extractable B content in R and NR soils (Fig. 4.46a and 4.46b), it was observed that the absolute amount of B was maintained always higher in the R soil compared to NR soils which might be due to proving favourable condition in the R soil helps to maintain greater amount of HCC extractable B in soil. Another explanation might be put forwarded that calbor contains 11.5 % calcium which plays a positive role in releasing native as well as calbor B in the soil solution both in R and NR soils, but exhibited greater effect in R soils in presence of roots.

4.2.1.2 Influence of sources of boron and organic matter on changes in mannitol- $CaCl_2$ (MCC) extractable boron content in soil during the year 2006-2007 and 2007-2008

The results (Table 4.63a and 4.63b) showed a similar trend of changes for the availability of MCC extractable B in soils with that HCC extractable B both in R and NR soils during both the years (2006-07 & 2007-08). The highest amounts of B were recorded initially at 30 days of crop growth in rhizosphere (0.805 mg kg^{-1}) and non-rhizosphere soils (0.798 mg kg^{-1}) and thereafter, the amount of the same gradually decreased with the progress of crop growth which might be explained by the continuous removal of B by growing crop. The results (Fig.4.47a and 4.47b) further suggested that inspite of continuous depletion of B, the treatment T_4 has proved superior in maintaining B in soils of R and NR regions.

However, Cartwright *et al.* (1983) also recommended 0.1 M $CaCl_2$ and 0.05 M Mannitol as extractants for extracting boron from soils in predicting boron uptake by plants.

Table 4.63a Effect of organic matter and boron application on the changes in mannitol –$CaCl_2$ (MCC) extractable boron concentration (mg kg^{-1}) in soil during the year 2006-2007 (Mean of three replications)

Treatment	Days								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	0.629^d	0.593^d	0.612^c	0.553^e	0.583^c	0.494^f	0.540^d	0.425^f	**0.591^C**	**0.516^N**
T_2	0.642^d	0.631^c	0.631^c	0.596^d	0.607^c	0.547^e	0.585^c	0.458^e	**0.616^C**	**0.558^M**
T_3	0.766^{ab}	0.792^a	0.780^a	0.753^b	0.768^a	0.724^b	0.749^a	0.685b	**0.766^A**	**0.739^J**
T_4	0.803^a	0.800^a	0.795^a	0.787^a	0.783^a	0.778^a	0.758^a	0.770^a	**0.785^A**	**0.784^I**
T_5	$0.712b^c$	0.692^b	0.699^b	0.680^c	0.679^b	0.665^c	0.662^b	0.653^c	**0.688^B**	**0.673^K**
T_6	0.701^c	0.685^b	0.684^b	0.659^c	0.663^b	0.612^d	0.653^b	0.593^d	**0.675^B**	**0.637^L**
Mean	**0.709^P**	**0.699^W**	**0.700^Q**	**0.671^X**	**0.680^R**	**0.637^Y**	**0.658^S**	**0.597^Z**	**0.687^U**	**0.651^V**
SEm (±)	**0.0018**	**0.009**	**0.010**	**0.009**	**0.010**	**0.009**	**0.009**	**0.009**	**0.011**	**0.009**
C.D. at 5%	**0.0057**	**0.0284**	**0.0315**	**0.0284**	**0.0315**	**0.0284**	**0.0284**	**0.0284**	**0.0347**	**0.0284**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.63b Effect of organic matter and boron application on the changes in mannitol –$CaCl_2$ (MCC) extractable boron concentration (mg kg^{-1}) in soil during the year 2007-2008 (Mean of three replications)

Treatment	Days								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	0.632^c	0.597^d	0.617^c	0.558^f	0.580^c	0.491^f	0.547^d	0.422^f	**0.594^C**	**0.517^N**
T_2	0.640^c	0.630^c	0.630^c	0.590^e	0.610^c	0.549^e	0.588^c	0.460^e	**0.617^C**	**0.557^M**
T_3	0.788^a	0.795^a	0.785^a	0.757^b	0.770^a	0.730^b	0.750^a	0.690^b	**0.773^A**	**0.743^J**
T_4	0.808^a	0.799^a	0.799^a	0.790^a	0.779^a	0.780^a	0.767^a	0.773^a	**0.788^A**	**0.786^I**
T_5	0.710^b	0.690^b	0.692^b	0.685^c	0.682^b	0.666^c	0.665^b	0.659^c	**0.687^B**	**0.675^K**
T_6	0.703^b	0.682^b	0.687^b	0.652^d	0.665^b	0.612^d	0.659^b	0.590^d	**0.678^B**	**0.634^L**
Mean	**0.713^P**	**0.699^W**	**0.702^Q**	**0.672^X**	**0.681^R**	**0.638^Y**	**0.663^S**	**0.599^Z**	**0.690^U**	**0.652^V**
SEm (±)	**0.010**	**0.010**	**0.010**	**0.009**	**0.009**	**0.009**	**0.009**	**0.009**	**0.010**	**0.009**
C.D. at 5%	**0.0315**	**0.0315**	**0.0315**	**0.0284**	**0.0284**	**0.0284**	**0.0284**	**0.0284**	**0.0315**	**0.0284**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

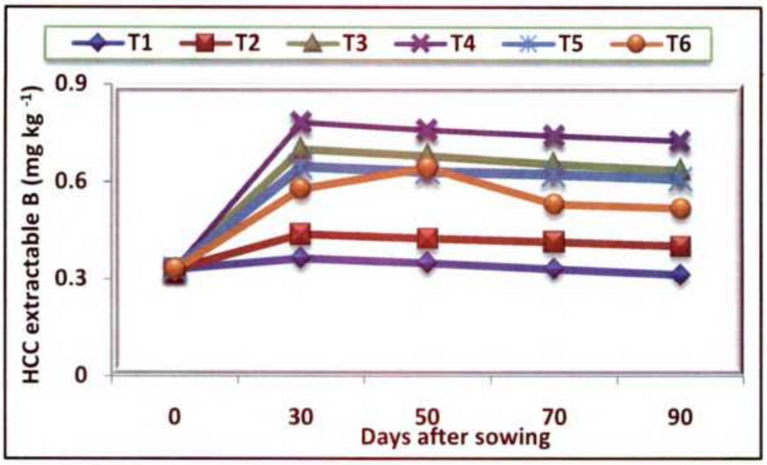


Fig. 4.46a : Effect of boron and organic matter on the changes in HCC extractable B in rhizosphere soil (pooled of two years)

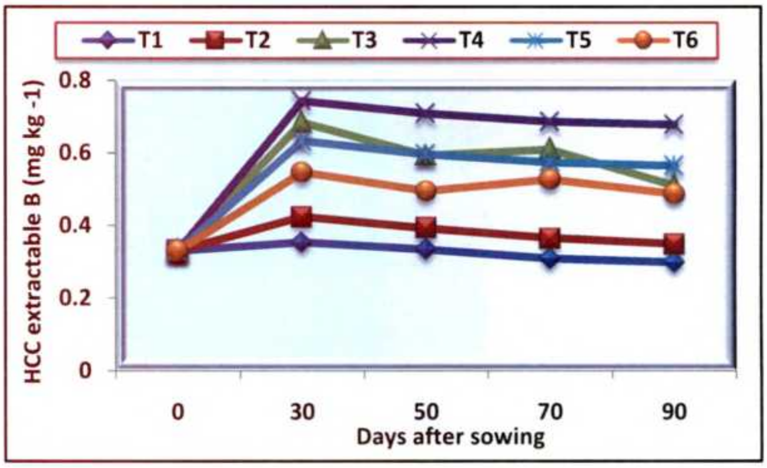


Fig. 4.46b : Effect of boron and organic matter on the changes in HCC extractable B in non-rhizosphere soil (pooled of two years)

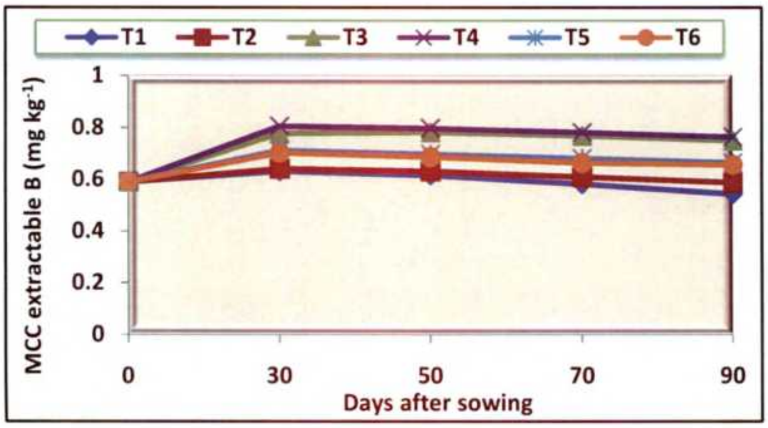


Fig. 4.47a : Effect of boron and organic matter on the changes in MCC extractable B in rhizosphere soil (pooled of two years)

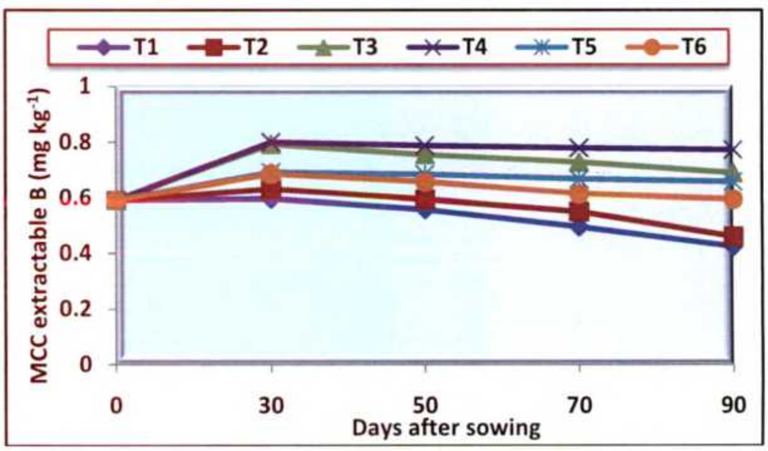


Fig. 4.47b : Effect of boron and organic matter on the changes in MCC extractable B in non-rhizosphere soil (pooled of two years)

4.2.1.3 Influence of sources of boron and organic matter on changes in Mehlich 3 (MH-3) extractable boron content in soil during the year 2006-2007 and 2007-2008

The result (Table 4.64a and 4.64b) show that the amount of Mehlich 3 (MH-3) extractable boron has been found to be increased with treatment throughout the crop growth period under both rhizosphere (R) and non-rhizosphere (NR) soils during both the years (2006-07 & 2007-08). The magnitude of such increase, however, varied with treatments in both R and NR soils.

With regards to the R soils, it was found that the amount of MH-3 extractable boron has been found to be increased over control, being highest increases (0.797 mg kg^{-1}) in the treatment T_4 where NPK (80:40:40), boron as calbor at 0.5 kg ha^{-1} and organic matter at 5 t ha^{-1} was applied togetherly.

The results (Fig. 4.48a and 4.48b) further envisaged that the amount of MH 3 extractable boron in the treatment T_4 was maintained highest followed by T_3 and T_5 treatment throughout the growth period of crop. Such increase in the treatment T_4 might ascribed by the application of organic matter as well as addition of calcium present in the calbor which help to release boron on a regulated basis from the calbor. The results of the present investigation also finds support from the results reported by Simard et.al (1996) who recorded a higher value of boron extracting with MH 3 solution. Relatively lower amount of B in rhizosphere soils over non-rhizosphere soils might be due to the formation of insoluble B complexes released from plant root exudates. As regards to its changes in NR soils, it was followed a similar trend to that of R soils, excepting a much higher absolute value of boron in soils. The treatment T_4 also maintained higher amount of boron throughout the growth period of the crop. The maintenance of boron in NR soils might be due to formation of soluble boron complexes or chelates with applied organic matter in the bulk soil.

Among extractant, the MH-3 extracted a greater amount of B compared to HCC and MCC extractants.

Table 4.64a Effect of organic matter and boron application on the changes in Mehlich -3 (MH-3) extractable boron concentration (mg kg^{-1}) in soil during the year 2006-2007 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	0.601^b	0.634^c	0.595^b	0.627^c	0.588^c	0.601^c	0.571^c	0.591^c	**0.589^C**	**0.613^K**
T_2	0.631^b	0.671b	0.627^b	0.660^b	0.620^b	0.651^b	0.612^b	0.642^b	**0.623^B**	**0.656^J**
T_3	0.795^a	0.801a	0.773^a	0.788^a	0.762^a	0.777^a	0.751^a	0.767^a	**0.770^A**	**0.783^I**
T_4	0.797^a	0.805^a	0.782^a	0.795^a	0.768^a	0.787^a	0.757^a	0.779^a	**0.776^A**	**0.791^I**
T_5	0.783^a	0.796^a	0.756^a	0.785^a	0.755^a	0.772^a	0.745^a	0.761^a	**0.760^A**	**0.779^I**
T_6	0.778^a	0.790^a	0.765^a	0.780^a	0.752^a	0.768^a	0.740^a	0.757^a	**0.759^A**	**0.774^I**
Mean	**0.731^P**	**0.750^W**	**0.716^Q**	**0.739^X**	**0.708^R**	**0.726^Y**	**0.696^S**	**0.716^Z**	**0.713^V**	**0.733^U**
SEm (±)	**0.010**	**0.010**	**0.010**	**0.010**	**0.009**	**0.010**	**0.009**	**0.010**	**0.009**	**0.010**
C.D. at 5%	**0.0315**	**0.0315**	**0.0315**	**0.0315**	**0.0284**	**0.0315**	**0.0284**	**0.0315**	**0.0284**	**0.0315**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.64b Effect of organic matter and boron application on the changes in Mehlich -3 (MH-3) extractable boron concentration (mg kg^{-1}) in soil during the year 2007-2008 (Mean of three replications).

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	0.608^b	0.635^c	0.599^c	0.620^c	0.590^c	0.603^c	0.577^c	0.588^c	**0.594^C**	**0.612^K**
T_2	0.635^b	0.677^b	0.630^b	0.662^b	0.622^b	0.650^b	0.615^b	0.647^b	**0.626^B**	**0.659^J**
T_3	0.790^a	0.810^a	0.778^a	0.788^a	0.765^a	0.780^a	0.750^a	0.761^a	**0.771^A**	**0.785^I**
T_4	0.792^a	0.815^a	0.787^a	0.799^a	0.775^a	0.792^a	0.760^a	0.780^a	**0.779^A**	**0.797^I**
T_5	0.787^a	0.793^a	0.770^a	0.781^a	0.756^a	0.770^a	0.749^a	0.759^a	**0.766^A**	**0.776^I**
T_6	0.775^a	0.789^a	0.767^a	0.777^a	0.750^a	0.763^a	0.741^a	0.752^a	**0.758^A**	**0.770^I**
Mean	**0.731^P**	**0.753^W**	**0.722^Q**	**0.738^X**	**0.710^R**	**0.726^Y**	**0.699^S**	**0.715^Z**	**0.715^V**	**0.733^U**
SEm (±)	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.009**	**0.010**	**0.010**	**0.010**
C.D. at 5%	**0.0315**	**0.0315**	**0.0315**	**0.0315**	**0.0315**	**0.0315**	**0.0315**	**0.0315**	**0.0315**	**0.0315**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

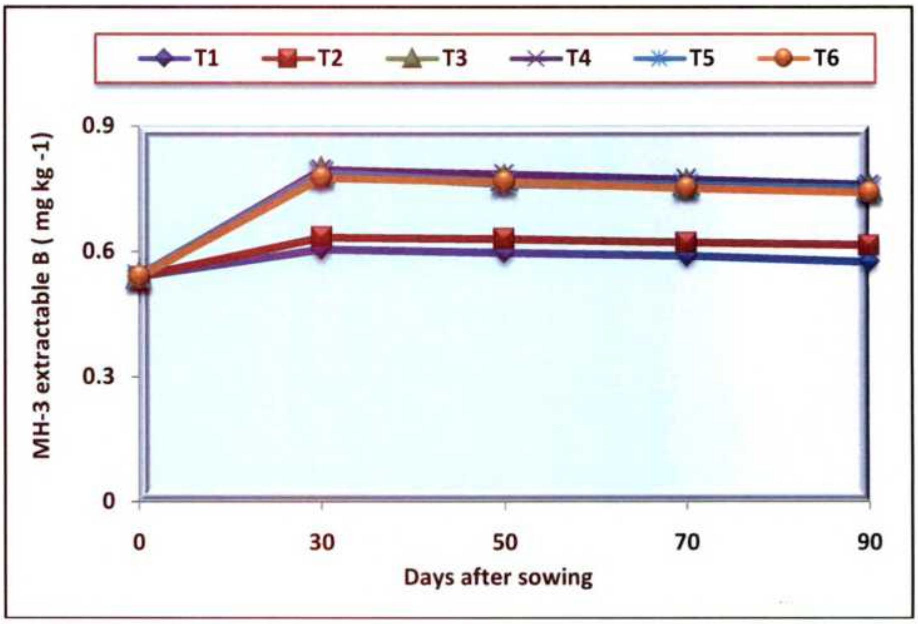


Fig. 4.48a : Effect of boron and organic matter on the changes in MH-3 extractable B in rhizosphere soil (pooled of two years)

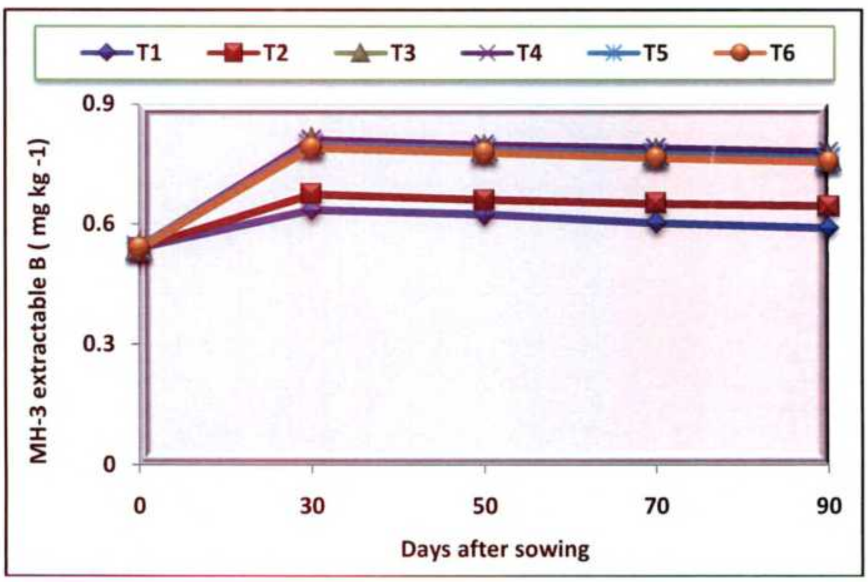


Fig. 4.48b : Effect of boron and organic matter on the changes in MH3 extractable B in non-rhizosphere soil (pooled of two years)

4.2.1.4 Influence of sources of boron and organic matter on changes in phosphate solubilizing microorganisms (PSM) in soil during the year 2006-2007 and 2007-2008

The results (Table 4.65a and 4.65b) reveal that the population of phosphate solubilizing microorganisms (PSM) has been found to be varied with treatments. The PSM was lowest in the control treatment where only recommended NPK was applied. Among treatments, the highest proliferation of PSM was maintained in the treatment T_4 where recommended NPK, boron at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} was applied combinedly compared to other treatments in both rhizosphere (R) and nobn rhizosphere (NR) soils which might be explained by the stimulating effect of calcium present in the calbor as well as applied organic manure.

However, the following trend on the changes in PSM was recorded in both R and NR soils.

$T_4 > T_6 > T_3 > T_5 > T_2 > T_1$

The results (Fig.4.49) further envisaged that the proliferation of PSM in NR soils was maintained always lower than that of R soils which might be explained by the effect of rhizodeposition where in the former case it is lowest or practically nil.

4.2.1.5 Influence of sources of boron and organic matter on changes in phosphate solubilizing capacity (PSC) in soil during the year 2006-2007 and 2007-2008

The results (Table 4.66a and 4.66b) reveal that the phosphate solubilizing capacity in rhizosphere (R) and non-rhizosphere (NR) soils has been found to be progressively decreased irrespective of treatments during both the years (2006-07 & 2007-08). However, comparing the results of different treatments it was observed that the phosphate solubilizing capacity was recorded highest (0.045 mg g^{-1} soil) in R and 0.034 mg g^{-1} in NR soils under the treatment T_4 where recommended levels of NPK (80:40 :40), boron at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} was applied combinedly at the initial 30 days period of crop growth.

Table 4.65a Effect of organic matter and boron application on the changes of phosphate solubilizing microorganisms ($\times 10^5$ g^{-1} soil) in soil during the year 2006-2007 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	62.84^{e}	48.94^{e}	49.63^{e}	36.24^{f}	42.85^{e}	28.92^{f}	29.91^{e}	19.26^{e}	**46.30^{E}**	**33.34^{M}**
T_2	75.16^{d}	61.26^{d}	62.25^{d}	52.55^{e}	55.64^{d}	46.44^{e}	44.53^{d}	35.57^{d}	**59.40^{D}**	**48.95^{L}**
T_3	81.27^{bc}	72.77^{b}	77.06^{b}	60.07^{c}	68.45^{b}	52.16^{c}	61.93^{b}	39.18^{c}	**72.18^{B}**	**56.04^{J}**
T_4	94.70^{a}	78.28^{a}	82.86^{a}	68.57^{a}	75.75^{a}	57.76^{a}	67.84^{a}	48.49^{a}	**80.29^{A}**	**63.28^{I}**
T_5	77.86^{cd}	68.17^{c}	71.51^{c}	57.36^{d}	63.94^{c}	49.85^{b}	58.31^{c}	37.77^{c}	**67.91^{C}**	**53.29^{K}**
T_6	84.27^{b}	72.08^{b}	80.36^{a}	63.2^{b}	72.55^{a}	55.26^{d}	62.24^{b}	42.48^{b}	**74.86^{B}**	**58.27^{J}**
Mean	**79.35^{P}**	**66.92^{W}**	**70.61^{Q}**	**56.34^{X}**	**63.19^{R}**	**48.40^{Y}**	**54.13^{S}**	**37.12^{Z}**	**66.92^{U}**	**52.20^{V}**
SEm (±)	**1.153**	**0.929**	**0.979**	**0.795**	**1.175**	**0.675**	**0.763**	**0.542**	**0.332**	**0.332**
C.D. at 5%	**3.63**	**2.92**	**3.08**	**2.50**	**3.70**	**2.12**	**2.40**	**1.70**	**1.045**	**1.045**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.65b Effect of organic matter and boron application on the changes of phosphate solubilizing microorganisms ($\times 10^5$ g^{-1} soil) in soil during the year 2007-2008 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	62.80^e	48.97^e	49.61^c	36.20^f	42.85^e	28.90^f	29.95^e	19.32^e	**46.30^E**	**33.35^M**
T_2	75.17^d	61.30^d	62.28^d	52.54^e	55.70^d	46.52^e	44.50^d	35.65^d	**59.41^D**	**49.00^L**
T_3	81.30^{bc}	72.71^b	77.12^b	60.01^c	70.39^b	52.20^c	62.00^b	39.23^c	**72.70^B**	**56.04^J**
T_4	94.85^a	78.20^a	82.90^a	68.60^a	75.77^a	57.82^a	67.80^a	48.40^a	**80.33^A**	**63.26^I**
T_5	77.90^{cd}	68.20^c	71.53^c	57.42^d	63.99^c	49.81^d	58.37^c	37.71^c	**67.95^C**	**53.29^K**
T_6	84.21^b	72.10^b	80.32^a	63.20^b	72.60^b	55.32^b	62.30^b	42.59^b	**74.86^B**	**58.30^J**
Mean	**79.37^P**	**66.91^W**	**70.63^Q**	**56.33^X**	**63.55^R**	**48.43^Y**	**54.15^S**	**37.15^Z**	**66.93^U**	**52.21^V**
SEm (±)	**1.125**	**0.927**	**0.979**	**0.795**	**0.887**	**0.675**	**0.763**	**0.544**	**0.329**	**0.329**
C.D. at 5%	**3.63**	**2.92**	**3.08**	**2.50**	**3.70**	**2.12**	**2.40**	**1.70**	**1.036**	**1.036**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.66a Effect of organic matter and boron application on the changes in phosphate solubilizing capacity (mg g^{-1} dry soil) in soil during the year 2006-2007(Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	0.032^f	0.024^e	0.026^e	0.021^d	0.022^e	0.015^e	0.017^e	0.015^a	**0.024^E**	**0.018^N**
T_2	0.035^e	0.026^d	0.029^d	0.022^d	0.025^d	0.019^{cd}	0.020^d	0.017^a	**0.027^D**	**0.021^M**
T_3	0.040^c	0.039^b	0.037^b	0.025^c	0.032^b	0.020^c	0.028^b	0.023^a	**0.034^B**	**0.026^K**
T_4	0.045^a	0.034^a	0.040^a	0.030^a	0.036^a	0.027^a	0.033	0.037^a	**0.038^A**	**0.032^I**
T_5	0.037^d	0.027^c	0.032^c	0.022^d	0.028^c	0.018^d	0.022^c	0.014^a	**0.029^C**	**0.020^L**
T_6	0.042^b	0.031^b	0.038b	0.027^b	0.034^b	0.023^b	0.029^b	0.019^a	**0.035^B**	**0.025^J**
Mean	**0.039^P**	**0.029^W**	**0.034^Q**	**0.025^X**	**0.030^R**	**0.020^Y**	**0.025^S**	**0.032^Z**	**0.031^U**	**0.023^V**
SEm (±)	**0.001**	**0.001**	**0.001**	**0.0009**	**0.001**	**0.0009**	**0.001**	**0.001**	**0.0009**	**0.009**
C.D. at 5%	**0.003**	**0.003**	**0.003**	**0.002**	**0.003**	**0.002**	**0.003**	**NS**	**0.002**	**0.002**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.66b Effect of organic matter and boron application on the changes in phosphate solubilizing capacity (mg g^{-1} dry soil) in soil during the year 2007-2008 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	0.033^{e}	0.025^{c}	0.026^{f}	0.022^{e}	0.026^{e}	0.015^{f}	0.018	0.015	**0.025^{E}**	**0.019^{N}**
T_2	0.037^{d}	0.029^{b}	0.030^{e}	0.023^{de}	0.028^{d}	0.020^{d}	0.021	0.017	**0.029^{D}**	**0.022^{M}**
T_3	0.040^{b}	0.032^{a}	0.035^{c}	0.026^{c}	0.031^{c}	0.022^{c}	0.026	0.023	**0.033^{B}**	**0.025^{K}**
T_4	0.046^{a}	0.034^{a}	0.041^{a}	0.031^{a}	0.037^{a}	0.027^{a}	0.035	0.037	**0.039^{A}**	**0.032^{I}**
T_5	0.038^{c}	0.028^{b}	0.032^{d}	0.024^{cd}	0.029^{d}	0.018^{e}	0.023	0.014	**0.030^{C}**	**0.021^{L}**
T_6	0.040^{b}	0.030^{b}	0.039^{b}	0.029^{b}	0.035^{b}	0.024^{b}	0.030	0.019	**0.036^{B}**	**0.025^{J}**
Mean	**0.039^{P}**	**0.030^{W}**	**0.034^{Q}**	**0.026^{X}**	**0.031^{R}**	**0.021^{Y}**	**0.026^{S}**	**0.032^{Z}**	**0.032^{U}**	**0.024^{V}**
SEm (±)	**0.001**	**0.001**	**0.001**	**0.0009**	**0.001**	**0.0009**	**0.001**	**0.001**	**0.0009**	**0.0009**
C.D. at 5%	**0.003**	**0.003**	**0.003**	**0.002**	**0.003**	**0.002**	**0.003**	**NS**	**0.002**	**0.002**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

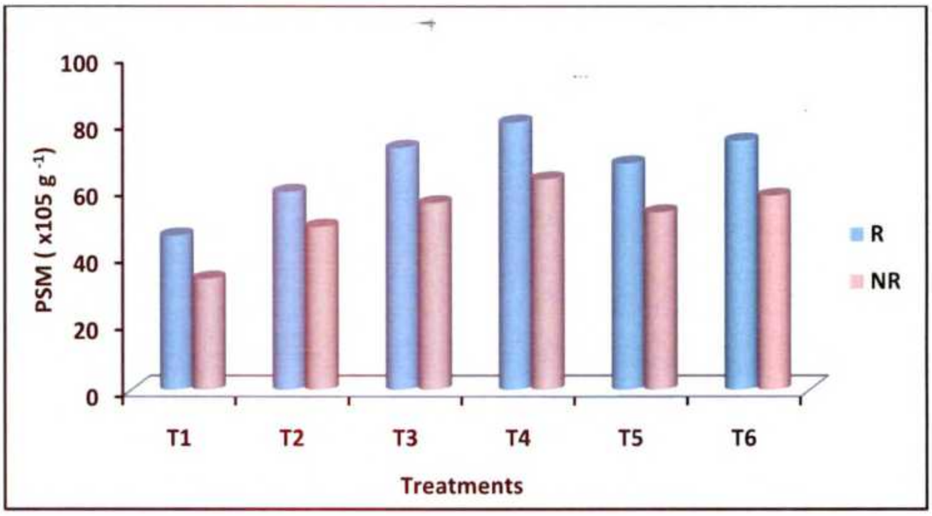


Fig. 4.49 : Effect of boron and organic matter on the changes in PSM in soil (pooled of two years)

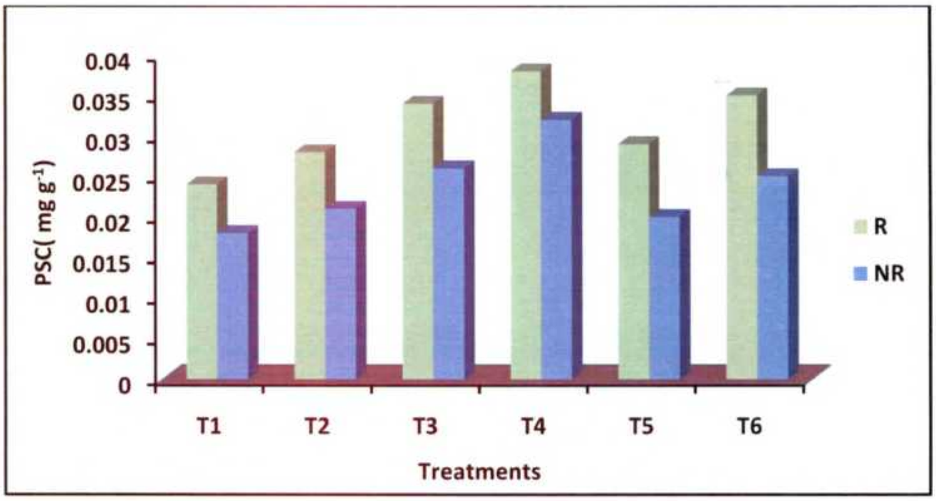


Fig. 4.50 : Effect of boron and organic matter on the changes in PSC soil (pooled of two years)

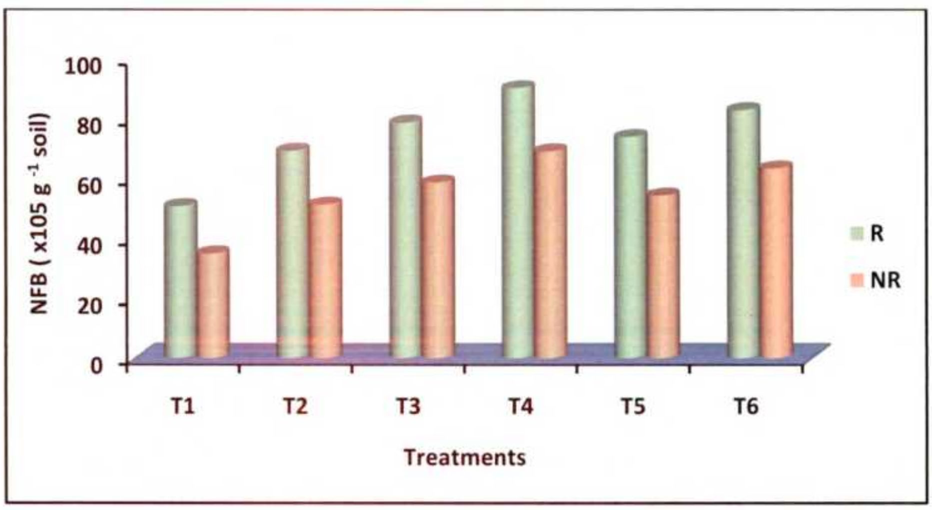


Fig. 4.51 : Effect of boron and organic matter on the changes in NFB in soil (pooled of two years)

The decrease of the same at the latter period of crop growth might be due to its continuous uptake by crops caused by greater biomass production. Comparing the resultsb(Fig. 4.50) of R and NR soils, it was found that the amount of phosphate solubilized was far greater in R soils than that of NR soils which possibly due to favourable effect of root exudates for the solubilisation of insoluble phosphatic compounds. Abou-El-Yazeid *et al.* (2007) also reported similarly where they found a positive and significant microbial activity in soil rhizosphere expressing by activity of dehydrogenase , phosphatase and nitrogenase enzymes and available phosphorous reacting a maximum value due to inoculation of P. *polymyxa* and B. *megatarium* and B application.

4.2.1.6 Influence of sources of boron and organic matter on changes in aerobic non-symbiotic nitrogen fixing bacteria (NFB) in soil during the year 2006-2007 and 2007-2008

The results (Table 4.67a and 4.67b) show that the amount of N_2 – fixing bacteria was also showed a similar pattern of changes to that of N_2 – fixing capacity in soils in both rhizosphere (R) and non-rhizosphere (NR)soils during both the years (2006-07 & 2007-08). However, the N_2 – fixing bacteria was found varied with treatments, being followed in the order of

R and NR soils : $T_4 > T_6 > T_3 > T_5 > T_2 > T_1$.

The results(Fig. 4.51) further suggested that the proliferation of N_2 – fixing bacteria was recorded always highest in rhizosphere (R) soil compared to non-rhizosphere (NR) soil, which might be explained by stimulating effect of root exudates on bacterial growth.

4.2.1.7 Influence of sources of boron and organic matter on changes in aerobic non-symbiotic nitrogen fixing capacity (NFC) in soil during the year 2006-2007 and 2007-2008

The results (Table 4.68a and 4.68b) reveal that the amount of N_2 – fixing capacity was followed a similar pattern of changes with that of P – solubilizing capacity in soil during both the years (2006-07 & 2007-08) but varied with amounts.

Table 4.67a Effect of organic matter and boron application on the changes in non symbiotic nitrogen fixing bacteria ($\times 10^5 g^{-1}$ soil) in soil during the year 2006-2007 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	69.32^e	50.32^e	53.12^f	38.94^e	49.13^e	31.23^e	32.02^e	20.11^e	**50.90^F**	**35.15^N**
T_2	84.19^d	62.12^d	75.08^e	55.40^d	62.94^d	49.55^d	55.93^d	39.17^d	**69.54^E**	**51.56^M**
T_3	94.48^{bc}	75.83^b	86.26^c	62.27^c	72.45^c	54.26^c	62.34^b	43.28^c	**78.88^C**	**58.91^K**
T_4	107.33^a	89.47^a	98.85^a	72.58^a	85.56^a	65.07^a	70.05^a	50.03^a	**90.45^A**	**69.29^I**
T_5	90.92^c	70.28^c	82.58^d	55.56^d	65.15^d	51.85^d	58.04^d	40.92^d	**74.17^D**	**54.65^L**
T_6	96.72^b	79.03^b	90.04^b	67.81^b	77.95^b	59.76^b	67.84^a	48.21^b	**83.14^B**	**63.70^J**
Mean	**90.49^P**	**71.18^W**	**80.99^Q**	**58.76^X**	**68.86^R**	**51.95^Y**	**57.70^S**	**40.29^Z**	**74.51^U**	**55.54^V**
SEm (±)	**1.271**	**1.026**	**1.145**	**0.868**	**0.993**	**0.746**	**0.813**	**0.574**	**0.368**	**0.368**
C.D. at 5%	**4.00**	**3.23**	**3.60**	**2.73**	**4.14**	**2.34**	**2.56**	**1.80**	**1.159**	**1.159**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.67b Effect of organic matter and boron application on the changes in non symbiotic nitrogen fixing bacteria (×10^5 g^{-1} soil) in soil during the year 2007-2008 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	69.35^e	50.31^e	53.13^f	38.98^e	49.15^e	31.21^e	32.08^d	20.10^e	**50.93^F**	**35.15^N**
T_2	84.24^d	62.15^d	75.15^e	55.31^d	62.97^d	49.53^d	55.80^c	39.15^d	**69.54^E**	**51.54^M**
T_3	94.50b^c	75.87^b	86.33^c	62.30^c	72.41^c	54.20^c	62.42^b	43.35^c	**78.92^C**	**58.93^K**
T_4	107.30^a	89.49^a	98.90^a	72.52^a	85.50^a	65.10^a	70.00^a	50.43^a	**90.42^A**	**69.38^I**
T_5	90.96^c	70.25^c	82.57^d	55.51^d	65.11^d	51.82^d	58.10^c	40.90^d	**74.18^D**	**54.62^L**
T_6	96.71^b	79.10^b	90.00^b	67.79^b	77.93^b	59.70^b	67.86^a	48.25^b	**83.13^B**	**63.71^J**
Mean	**90.51^P**	**71.19^W**	**81.01^Q**	**58.74^X**	**68.85^R**	**51.93^Y**	**57.71^S**	**40.36^Z**	**74.52^U**	**55.55^V**
SEm (±)	**1.271**	**1.027**	**1.145**	**0.843**	**0.993**	**0.746**	**0.812**	**0.682**	**0.369**	**0.369**
C.D. at 5%	**4.00**	**3.23**	**3.60**	**2.73**	**4.14**	**2.34**	**2.56**	**1.80**	**1.162**	**1.162**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.68a Effect of organic matter and boron application on the changes in nitrogen fixing capacity (mg of N_2 fixed g^{-1} of soil g^{-1} sucrose) in soil during the year 2006-2007 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	10.45^{c}	8.33^{c}	10.32^{c}	8.12^{c}	10.21^{b}	7.96^{c}	10.07^{c}	7.65^{c}	**10.26^{C}**	**8.02^{K}**
T_2	11.35^{b}	9.28^{b}	11.24^{b}	9.16^{b}	11.13^{a}	9.02^{b}	10.92^{b}	8.89^{b}	**11.16^{B}**	**9.09^{J}**
T_3	11.48^{ab}	9.62^{ab}	11.37^{ab}	9.49^{ab}	11.22^{a}	9.32^{ab}	11.01^{ab}	9.17^{ab}	**11.27^{AB}**	**9.40^{J}**
T_4	11.96^{a}	9.89^{a}	11.82^{a}	9.70^{a}	11.63^{a}	9.55^{a}	11.49^{a}	9.39^{a}	**11.73^{A}**	**9.63^{I}**
T_5	11.42^{b}	9.53^{ab}	11.30^{b}	9.40^{ab}	11.12^{a}	9.26^{ab}	10.99^{ab}	9.10^{ab}	**11.21^{AB}**	**9.32^{IJ}**
T_6	11.69^{ab}	9.76^{a}	11.60^{ab}	9.58^{a}	11.52^{a}	9.42^{ab}	11.40^{ab}	9.27^{ab}	**11.55^{AB}**	**9.51^{IJ}**
Mean	**11.39^{P}**	**9.40^{W}**	**11.28^{Q}**	**9.24^{X}**	**11.14^{R}**	**9.09^{Y}**	**10.98^{S}**	**8.91^{Z}**	**11.20^{U}**	**9.16^{V}**
SEm (±)	**0.154**	**0.127**	**0.152**	**0.123**	**0.151**	**0.123**	**0.149**	**0.120**	**0.054**	**0.054**
C.D. at 5%	**0.485**	**0.400**	**0.478**	**0.387**	**0.475**	**0.387**	**0.469**	**0.378**	**0.170**	**0.170**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.68b Effect of organic matter and boron application on the changes in nitrogen fixing capacity (mg of N_2 fixed g^{-1} of soil g^{-1} sucrose) in soil during the tear 2007-2008 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	10.44^{c}	8.30^{c}	10.35^{c}	8.10^{c}	10.24^{c}	7.92^{c}	10.09^{d}	7.69^{c}	**10.28^{C}**	**8.00^{K}**
T_2	11.37^{b}	9.30^{b}	11.25^{b}	9.17^{b}	11.17^{ab}	9.08^{b}	10.90c	8.90^{b}	**11.17^{B}**	**9.11^{J}**
T_3	11.50^{a}b	9.65^{ab}	11.38^{ab}	9.54^{ab}	11.20^{ab}	9.35^{ab}	11.05^{abc}	9.18^{ab}	**11.28^{AB}**	**9.43^{J}**
T_4	11.92^{a}	9.90^{a}	11.85^{a}	9.77^{a}	11.62^{a}	9.57^{a}	11.52^{a}	9.35^{a}	**11.73^{A}**	**9.65^{I}**
T_5	11.45^{ab}	9.50^{ab}	11.34^{ab}	9.47^{ab}	11.10^{b}	9.30^{ab}	10.98^{bc}	9.12^{ab}	**11.22^{AB}**	**9.35^{IJ}**
T_6	11.72^{ab}	9.77^{a}	11.65^{ab}	9.62^{a}	11.52^{ab}	9.40^{ab}	11.43^{ab}	9.30^{ab}	**11.58^{AB}**	**9.52^{IJ}**
Mean	**11.40^{P}**	**9.40^{W}**	**11.30^{Q}**	**9.28^{X}**	**11.14^{R}**	**9.10^{Y}**	**11.00^{S}**	**8.92^{Z}**	**11.21^{U}**	**9.18^{V}**
SEm (±)	**0.154**	**0.127**	**0.152**	**0.125**	**0.151**	**0.123**	**0.149**	**0.120**	**0.054**	**0.054**
C.D. at 5%	**0.486**	**0.400**	**0.478**	**0.387**	**0.475**	**0.387**	**0.469**	**0.378**	**0.170**	**0.170**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

At the initial 30 days period of growth , N_2 – fixing capacity has been found to be increase in both rhizosphere (R) and non-rhizosphere (NR) soils, being highest (11.96 mg N g^{-1} sucrose) in the treatment T_4 where recommended NPK (80 : 40 : 40), boron at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} combinedly in the rhizosphere (R) soil, while that of the same was highest (9.89 mg N g^{-1}sucrose) in the non-rhizosphere (NR) soil. The results (Fig.4.52) further envisaged that the N_2 – fixing capacity was maintaining a higher value in the T_4 treatment throughout the crop growth period upto 90 days. The following trends of changes at the end of incubation period were in the order of rhizosphere (R) and non-rhizosphere (NR) soil :

$T_4 > T_6 > T_3 > T_5 > T_2 > T_1$.

The highest N_2 – fixing capacity in the R soil might be partly due to accretion of nitrogen resulting from the secretion of plant roots (root exudates).

4.2.1.8 Influence of sources of boron and organic matter on changes in microbial biomass Carbon content (MBC) in soil during the year 2006-2007 and 2007-2008

The results (Table 4.69a and 4.69b) show that the amount of microbial biomass carbon (MBC) has been found to be consistently lower in both rhizosphere (R) and non-rhizosphere (NR) soils throughout the growth period of the crop irrespective of treatments during both the years (2006-07 & 2007-08). All the treatments always maintained higher value of MBC content over that of the control, only recommended NPK fertilizers. However, comparing the results of different treatments it was found that the amount of MBC content was maintained highest in the treatment T_4 receiving recommended NPK, boron at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} throughout the crop growth period in both R and NR soils. Nelson and Mele (2007) also reported that the application of B and NaCl to soil changed rhizosphere microbial community structure (MCS) indirectly through increased soil moisture and subtle changes in root exudate patterns resulting greater rhizodeposition which favours greater proliferation of microorganisms in the rhizosphere compared to non-rhizosphere soil.

Table 4.69a Effect of organic matter and boron application on the changes in microbial biomass carbon (µg g^{-1} dry soil) in soil during the year 2006-2007 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		60		90		120			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	145.89^{c}	121.34^{d}	138.14^{d}	112.62^{d}	126.15^{c}	110.40^{e}	110.84^{d}	103.56^{c}	**130.25^{D}**	**111.98^{L}**
T_2	165.31^{b}	149.62^{c}	151.78^{c}	142.42^{c}	147.13^{b}	132.27^{d}	122.43^{c}	126.54^{b}	**146.66^{C}**	**137.71^{K}**
T_3	167.30^{b}	153.34^{bc}	156.90^{bc}	147.55^{abc}	149.31^{b}	135.51^{cd}	124.61^{c}	128.52^{b}	**149.53^{BC}**	**141.23^{K}**
T_4	175.83^{a}	161.92^{a}	164.29^{a}	152.85^{a}	159.37^{a}	147.4^{a}	138.58^{a}	135.91^{a}	**159.52^{A}**	**149.54^{I}**
T_5	169.46^{ab}	150.42^{c}	159.47^{ab}	146.24^{bc}	151.38^{b}	139.1^{bc}	127.42^{bc}	122.82^{b}	**151.93^{BC}**	**139.65^{K}**
T_6	172.19^{ab}	158.64^{ab}	160.75^{ab}	150.32^{ab}	153.49^{ab}	142.31^{ab}	132.61^{b}	125.39^{b}	**154.72^{AB}**	**144.16^{IJ}**
Mean	**166.00P**	**149.21^{W}**	**155.19^{Q}**	**142.00^{X}**	**147.81^{R}**	**134.52^{Y}**	**126.08^{S}**	**123.79^{Z}**	**148.71^{U}**	**137.38^{V}**
SEm (±)	**2.239**	**2.025**	**2.092**	**1.951**	**2.004**	**1.829**	**1.730**	**1.696**	**0.758**	**0.758**
C.D. at 5%	**7.04**	**6.37**	**6.58**	**6.14**	**6.31**	**5.76**	**5.44**	**5.34**	**2.387**	**2.387**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.69b Effect of organic matter and boron application on the changes in microbial biomass carbon (μg g^{-1} dry soil) in soil during the year 2007-2008 (Mean of three replications)

Treatment	Days after sowing								Mean	
	30		50		70		90			
	R	NR	R	NR	R	NR	R	NR	R	NR
T_1	145.95^{c}	121.39^{d}	138.20^{d}	112.60^{d}	122.89^{c}	110.32^{e}	110.89^{d}	103.66^{d}	**129.48^{D}**	**111.99^{L}**
T_2	165.28^{b}	149.72^{c}	151.72^{c}	142.52^{c}	147.20^{b}	132.32^{d}	122.30^{c}	126.60^{bc}	**146.62^{C}**	**137.79^{K}**
T_3	167.39^{b}	153.42^{bc}	153.62^{bc}	147.60^{abc}	149.42^{b}	135.57^{cd}	124.52^{c}	128.41^{b}	**148.74^{BC}**	**141.25^{JK}**
T_4	175.90^{a}	161.99^{a}	164.21^{a}	152.81^{a}	159.30^{a}	147.50^{a}	138.50^{a}	136.00^{a}	**159.48^{A}**	**149.58^{I}**
T_5	169.39^{ab}	150.31^{c}	159.60^{ab}	145.99^{bc}	151.45^{ab}	139.20^{bc}	127.49^{bc}	121.98^{c}	**151.98^{BC}**	**139.37^{JK}**
T_6	172.11^{ab}	158.60^{ab}	160.75^{ab}	150.21^{ab}	153.42^{ab}	142.37^{ab}	132.80^{b}	125.78^{bc}	**154.77^{AB}**	**144.24^{IJ}**
Mean	**166.00P**	**149.24^{W}**	**154.68^{Q}**	**141.96^{X}**	**147.28^{R}**	**134.55^{Y}**	**126.08^{S}**	**123.74^{Z}**	**148.51^{U}**	**137.37^{V}**
SEm (±)	**2.240**	**2.025**	**2.292**	**1.911**	**2.503**	**1.829**	**1.730**	**1.696**	**0.764**	**0.764**
C.D. at 5%	**7.04**	**6.37**	**6.58**	**6.02**	**6.31**	**5.76**	**5.44**	**5.34**	**2.406**	**2.406**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

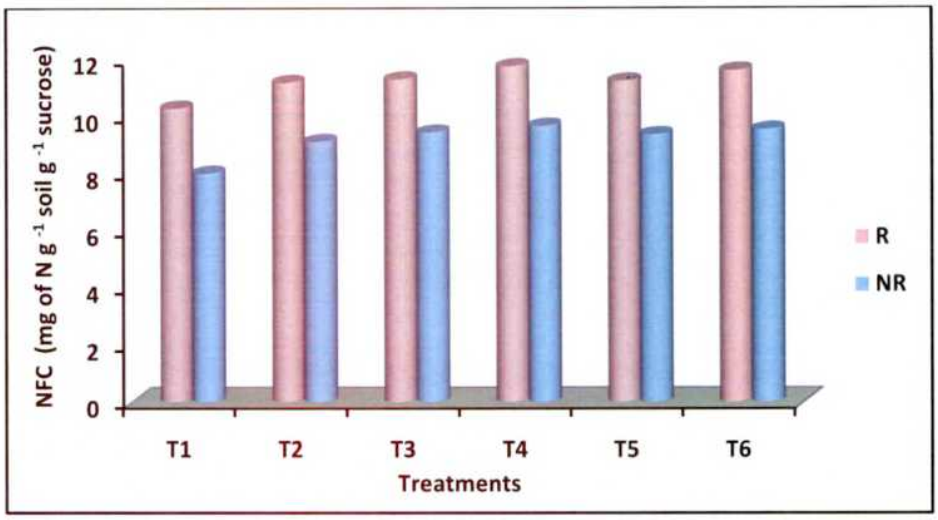


Fig. 4.52 : Effect of boron and organic matter on the changes in NFC in soil (pooled of two years)

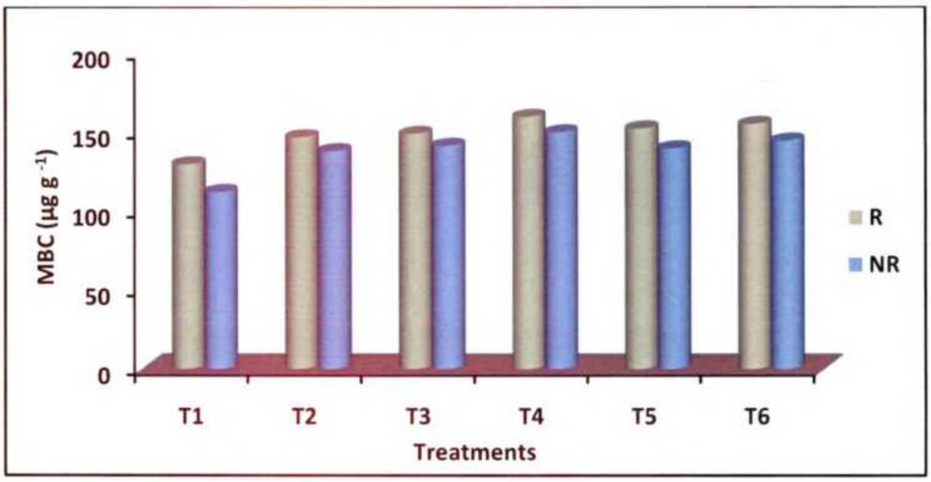


Fig. 4.53 : Effect of boron and organic matter on the changes in MBC content in soil (pooled of two years)

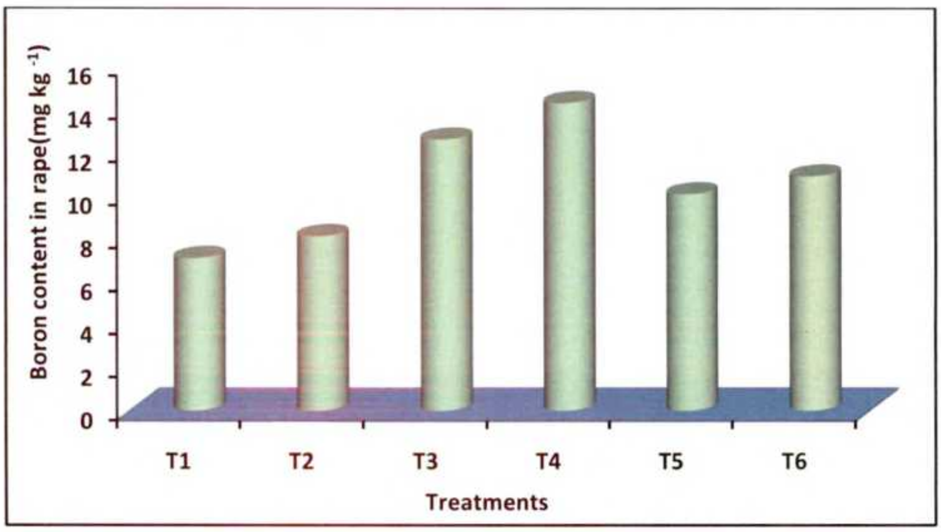


Fig. 4.54 : Effect of boron and organic matter on the changes on the boron content in rape(pooled of two years)

From the results it was observed that the application of organic manure at 5 t ha^{-1} along with recommendation NPK fertilizer, however, increased the MBC content in soil over that control receiving only recommended NPK fertilizer. Such increase of MBC content, however, has been found to be further enhanced with the application of boron irrespective of sources, being increased more with boron at 0.5 kg ha^{-1} applied as calbor. This might be due to the presence of calcium and nitrogen in the calbor in addition to boron in both R and NR soils. The effect of B on microorganisms in situ is largely unknown. Boron can inhibit growth of bacteria expecially at higher concentration of applied B (Guhl, 1996).

As regards to the rhizosphere (R) and non-rhizosphere (NR) soils, it was found that the amount of MBC content (Fig.4.53)was recorded for greater in the treatment receiving boron as calbor in R soils which might be explained by the greater proliferation of microbial population resulting from the root exudates.

The following trend of changes were observed in both R and NR soils:

NR : $T_4 > T_3 > T_2 > T_6 > T_5 > T_1$

R : $T_4 > T_6 > T_5 > T_3 > T_2 > T_1$

4.2.1.9 Application of CCA to study the association between the set of boron content measured at two different zones by each of three different extractant vs. the set of varying microbial parameters

Extractant 1

In the present study CCA is used to find out the linear association between boron content of two different zones of soil as predictor set and the set of varying microbial parameters as criterion measures or dependent set.

Significant correlations exist between predictor and dependent set of variables only for first and second canonical variates. So the present study will be confined to first two sets of canonical variates depending upon eigen values (0.91 and 0.51) and significance of chi square tests (= 134.54, d.f.= 20 and 19.43 and d.f 9; P<0.01). First set of canonical variate, if considered, it was found that predictor and dependent sets shared 91 % of variance. Similarly, second set of canonical variate shared 51 % of variance by both the predictor and dependent sets.

Canonical weights of dependent set and predictor set under first canonical variate if compared it was found that boron at rhizosphere measured by Hot- Calcium chloride solution is highly associated with phosphate solubilizing capacity and phosphate solibilizing microorganisma at rhizosphere zone, nitrogen fixing capacity ,phosphate solubilizing capacity and microbial biomass carbon at non-rhizosphere zone of dependent set. Again boron at non-rhizosphere measured by Hot – Calcium chloride solution is highly associated with nitrogen fixing capacity, nitrogen fixing bacteria and microbial biomass carbon at rhizosphere zone and nitrogen fixing bacteria and phosphate solubulizing microorganism at non-rhizosphere zone of dependent set.

Canonical weights of dependent set and predictor set under second canonical variate if compared it was found that boron at rhizosphere measured by Hot Calcium chloride solution is highly associated with nitrogen fixing capacity, phosphate solubilizing capacity and phosphate solubilising microorganisms at rhizosphere zone, nitrogen fixing bacteria, phosphate solubulizing microorganisms and microbial biomass carbon at non-rhizosphere zone of dependent set. Again boron at non-rhizosphere measured by Hot Calcium chloride solution is highly associated with nitrogen fixing bacteria and microbial biomass carbon at rhizosphere zone and nitrogen fixing capacity and phosphate solubulizing capacity at non-rhizosphere zone of dependent set.

Redundancy coefficient of criterion set of variables only shows the sufficiency of predictor set to explain its variation. In this study 78 % of dependent set's variability was explained by the predictor set.

Table 4.70 Results of linear association study between the set of boron content measured at two different zones by extractant 1 vs. the set of varying microbial parameters following CCA

Statistics	**Root 1**	**Root 2**
Eigen value/ Canonical R sq.	0.91	0.51
Chi-sqr.	134.54	19.43
Df	20.00	9.00
P	0.00	0.00
Redundancy	0.76	0.02
canonical score		
Dependent set		
Variables	**Root 1**	**Root 2**
$NFCZ_1$	1.44	-0.38
$NFBZ_1$	0.16	3.50
$PSCZ_1$	-1.11	-0.50
$PSMZ_1$	-0.43	-0.97
$MBCZ_1$	0.51	3.19
$NFCZ_2$	-2.44	2.30
$NFBZ_2$	0.19	-0.39
$PSCZ_2$	-0.16	0.42
$PSBZ_2$	1.07	-1.55
$MBCZ_2$	-0.22	-4.60
Predictor set		
BZ_1E_1	-2.45	-6.57
BZ_2E_1	1.49	6.86

Extractant 2

Significant correlations exist between predictor and dependent set of variables only for first and second canonical variates. So the present study will be confined to first two sets of canonical variates depending upon eigen values (0.87 and 0.50) and significance of chi square tests (= 108.94, d.f.= 20 and 18.73 and d.f 9; $P<0.01$). First set of canonical variate, if considered, it was found that predictor and dependent sets shared 87 % of variance. Similarly, second set of canonical variate shared 50 % of variance by both the predictor and dependent sets.

Canonical weights of dependent set and predictor set under first canonical variate if compared it was found that boron at rhizosphere measured by Mannitol- Calcium chloride solution is highly associated with nitrogen fixing bacteria,phosphate solubilizing capacity and microbial biomass carbon at rhizosphere zone, nitrogen fixing capacity and phosphate solubilizing capacity at non-rhizosphere zone of dependent set. Again boron at rhizosphere and non-rhizosphere measured by mannitol calcium chloride solution is highly associated with nitrogen fixing bacteria, phosphate solubilizing capacity and microbial biomass carbon at rhizosphere zone and nitrogen fixing capacity and phosphate solubulizing capacity at non-rhizosphere zone of dependent set.

Canonical weights of dependent set and predictor set under second canonical variate if compared it was found that boron at rhizosphere measured by Mannitol- Calcium chloride solution is highly associated with nitrogen fixing bacteria and phosphate solubilizing capacity at rhizosphere zone, nitrogen fixing capacity and phosphate solubulizing capacity at non-rhizosphere zone of dependent set. Again boron at non-rhizosphere measured by Mannitol- Calcium chloride solution is highly associated with nitrogen fixing capacity,phosphate solubilizing nicroorganisms and microbial biomass carbon at rhizosphere zone and nitrogen fixing bacteria, phosphate solubilizing microorganisms and microbial biomass carbon at non-rhizosphere zone of dependent set.

Redundancy coefficient of criterion set of variables only shows the sufficiency of predictor set to explain its variation. In this study 74 % of dependent set's variability was explained by the predictor set.

Table 4.71 Results of linear association study between the set of boron content measured at two different zones by extractant 2 vs. the set of varying microbial parameters following CCA

Statistics	**Root 1**	**Root 2**
Eigen value/ Canonical R sq.	0.87	0.50
Chi-sqr.	108.94	18.73
Df	20.00	9.00
P	0.00	0.00
Redundancy	0.74	0.00
Canonical scores for cross correlation study		
Dependent set		
Variables	**Root 1**	**Root 2**
$NFCZ_1$	1.95	1.91
$NFBZ_1$	-0.70	-3.04
$PSCZ_1$	-1.96	-3.55
$PSMZ_1$	0.53	4.13
$MBCZ_1$	-0.35	0.15
$NFCZ_2$	-3.45	-3.86
$NFBZ_2$	0.13	0.11
$PSCZ_2$	-0.18	-0.43
$PSBZ_2$	2.35	3.82
$MBCZ_2$	0.54	0.54
Predictor set		
BZ_1E_2	-0.66	-4.88
BZ_2E_2	-0.35	4.92

Extractant 3

Significant correlations exist between predictor and dependent set of variables only for first and second canonical variates. So the present study will be confined to first two sets of canonical variates depending upon eigen values (0.94 and 0.39) and significance of chi square tests (= 208.54, d.f.= 20 and 31.75 and d.f 9; $P<0.01$). First set of canonical variate, if considered, it was found that predictor and dependent sets shared 94 % of variance. Similarly, second set of canonical variate shared 39 % of variance by both the predictor and dependent sets.

Canonical weights of dependent set and predictor set under first canonical variate if compared it was found that boron at rhizosphere measured by Mehlich 3 solution is highly associated with nitrogen fixing capacity of rhizosphere zone, nitrogen fixing bacteria, phosphate solubulizing bacteria and microbial biomass carbon at non-rhizosphere zone of dependent set. Again boron at non-rhizosphere measured by Mehlich 3 solution is highly associated with nitrogen fixing bacteria, phosphate solubulizing capacity, phosphate solubulizing bacteria and microbial biomass carbon at rhizosphere zone and nitrogen fixing capacity and phosphate solubulizing capacity at non-rhizosphere zone of dependent set.

Canonical weights of dependent set and predictor set under second canonical variate if compared it was found that boron at rhizosphere measured by Mehlich 3 solution is highly associated with phosphate solubilizing capacity and microbial biomass carbon of rhizosphere zone, nitrogen fixing capacity,nitrogen fixing bacteria and phosphate solubulizing capacity at non-rhizosphere zone of dependent set. Again boron at non-rhizosphere measured by Mehlich 3 solution is highly associated with nitrogen fixing capacity, nitrogen fixing bacteria and phosphate solubulizing microorganisms at rhizosphere zone and phosphate solubulizing microorganisms and microbial biomass carbon at non-rhizosphere zone of dependent set.

Redundancy coefficient of criterion set of variables only shows the sufficiency of predictor set to explain its variation. In this study 89 % of dependent set's variability was explained by the predictor set.

Table 4.72 Results of linear association study between the set of boron content measured at two different zones by extractant 3 vs. the set of varying microbial parameters following CCA

Statistics	**Root 1**	**Root 2**
Eigen value/ Canonical R sq.	0.94	0.39
Chi-sqr.	208.54	31.75
Df	20.00	9.00
P	0.00	0.00
Redundancy	0.86	0.03
Canonical scores for cross correlation study		
Dependent set		
Variables	**Root 1**	**Root 2**
$NFCZ_1$	0.95	4.30
$NFBZ_1$	-0.38	0.21
$PSCZ_1$	-0.54	-3.10
$PSMZ_1$	-0.25	1.60
$MBCZ_1$	-0.35	-0.48
$NFCZ_2$	-2.37	-5.97
$NFBZ_2$	0.61	-2.21
$PSCZ_2$	-0.11	-0.70
$PSBZ_2$	0.89	3.48
$MBCZ_2$	0.49	2.16
Predictor set		
BZ_1E_3	2.96	-12.12
BZ_2E_3	-3.92	11.84

4.2.1.10 Influence of sources of boron and organic matter on boron content in rape during the year 2006-2007 and 2007-2008

The results (Table 4.73a and 4.73b) show that the amount of B content in rape dry matter during the year 2006 – 07 and 2007 – 08 showed a consistent decrease with the progress of crop growth irrespective of treatments. However, such decrease varied with treatments. The consistent decrease in B content might be due to the dilution effect resulting from the increased biomass production. The results (Fig. 4.54) reveal that the amount of B was recorded significantly highest initially (17.18 mg kg^{-1}) at 30 days of crop growth and also maintained calbor highest amount in the treatment T_4 receiving NPK (80:40:40), B and organic matter throughout the crop growth period during both the years which is possibly due to higher amount of B content in the soil solution making greater absorption of B by the plant. Sharma *et al.* (1999) also reported similarly where the combined applications of boron and FYM significantly affect the boron concentration in stalk as well as total boron accumulation in sunflower. Li *et al.* (2004) confirmed the results of present investigation and reported that the application of boron at its higher level increased the biomass yield and boron content in rape.

4.2.1.11 Influence of sources of boron and organic matter on activity of indole acetic acid oxidase in rape during the year 2006-2007 and 2007-2008

The results (Table 4.74a and 4.74b) show that the acting of IAA oxidase has been found to be consistently increased with the progress of crop growth irrespective of treatments during both the years (2006-07 & 2007-08). The magnitude of such increase, however, varied with treatments, being maximum increase in the T_1 where only recommended NPK fertilizer was applied.

Comparing the results (Fig.4.55) of different treatments, it was found that the lowest value of IAA oxidase was recorded in the treatment T_4 where recommended NPK, boron at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} was applied togetherly. The results suggest that boron deficiency might not be exhibited on the plant when the activity of IAA recorded a lowest value.

Table 4.73a Effect of boron and application on the changes in boron content (mg kg^{-1}) in rape (*Brassica campestris* L.) during the year 2006-2007(Mean of three replications)

Treatments	Days After Sowing				
	30	50	70	90	Mean
T_1	8.03^f	7.63^f	6.65^f	6.15^f	**7.12^F**
T_2	9.07^e	8.57^e	7.74^e	7.03^e	**8.08^E**
T_3	15.77^b	12.89^b	11.37^b	10.41^b	**12.61^B**
T_4	17.17^a	15.32^a	13.14^a	11.56^a	**14.30^A**
T_5	12.36^d	10.16^d	9.27^d	8.46^d	**10.06^D**
T_6	13.12^c	11.05^c	10.33^c	9.12^c	**10.91^C**
Mean	**12.59^P**	**10.94^Q**	**9.73^R**	**8.79^S**	
SE.m (±)	0.189	0.168	0.146	0.129	1.58
CD (P=0.05)	**0.595**	**0.529**	**0.459**	**0.406**	**4.97**

Table 4.73b Effect of boron and organic matter application on the changes in boron content (mg kg^{-1}) in rape (*Brassica campestris* L.) during the year 2007-2008(Mean of three replications)

Treatments	Days After Sowing				
	30	50	70	90	Mean
T_1	8.05^f	7.60^f	6.62^f	6.18^f	**7.11^F**
T_2	9.11^e	8.60^e	7.85^e	7.07^e	**8.16^E**
T_3	15.80^b	12.92^b	11.40^b	10.43^b	**12.64^B**
T_4	17.18^a	15.35^a	13.18^a	11.60^a	**14.33^A**
T_5	12.40^d	10.20^d	9.30^d	8.49^d	**10.10^D**
T_6	13.10^c	11.07^c	10.35^c	9.10^c	**10.91^C**
Mean	**12.61^P**	**10.96^Q**	**9.78^R**	**8.81^S**	
SE.m (±)	0.189	0.168	0.146	0.129	1.59
CD (P=0.05)	**0.595**	**0.529**	**0.459**	**0.406**	**4.97**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Table 4.74a Effect of boron and organic matter application on the changes in Indole acetic acid (IAA) oxidase (mg g^{-1} fwt. h^{-1}) in rape (*Brassica campestris* L.) during the year 2006-2007(Mean of three replications

Treatments	**Days After Sowing**				
	30	**50**	**70**	**90**	**Mean**
T_1	360.00^a	421.00^a	450.00^a	490.00^a	**430.25^A**
T_2	332.00^b	352.00^b	384.00^b	413.00^b	**370.25^B**
T_3	310.00^c	321.00^c	348.00^c	361.67^c	**335.17^C**
T_4	290.00^d	307.00^c	312.00^d	320.33^d	**307.33^D**
T_5	300.00^{cd}	310.00^c	320.67^d	330.67^d	**315.34^D**
T_6	295.00^d	308.00^c	315.00^d	328.00^d	**311.50^D**
Mean	**314.50^S**	**336.50^R**	**354.94^Q**	**373.94^P**	
SE.m (±)	**4.135**	**4.493**	**4.748**	**5.104**	4.614
CD (P=0.05)	10.03	14.15	14.95	16.08	14.52

Table 4.74b Effect of boron and organic matter application on the changes in Indole acetic acid (IAA) oxidase (mg g^{-1} fwt. h^{-1}) in rape (*Brassica campestris* L.) during the year 2007-2008(Mean of three replications)

Treatments	**Days After Sowing**				
	30	**50**	**70**	**90**	**Mean**
T_1	358.00^a	425.00^a	457.00^a	499.00^a	**434.75^A**
T_2	335.00^b	356.00^b	387.67^b	418.00^b	**374.17^B**
T_3	315.00^c	319.00^c	345.00^c	359.67^c	**334.67^C**
T_4	288.00^d	310.00^c	317.00^d	322.33^d	**309.33^D**
T_5	299.00^d	317.00^c	325.67^d	334.67^d	**319.09^D**
T_6	292.00^d	312.00^c	316.00^d	331.00^d	**312.75^D**
Mean	**314.50^S**	**339.83^R**	**358.06^Q**	**377.44^P**	
SE.m (±)	**4.135**	**4.493**	**4.758**	**5.104**	4.617
CD (P=0.05)	10.03	14.15	14.95	16.08	14.52

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

Hassanein *et al.* (2001) reported that the foliar application of boron upto 250 mg litre^{-1} increased the yield attributes with concomitantly increased the activities of IAA oxidase, catalase and peroxidase in *vigna sinensis.* In the control treatment, the value of IAA was recorded highest suggesting crops may suffer due to boron deficiency. The present study also confirms the result of Kavitha *et al.*(2000) who reported that the foliar application of boron(0.1%) and zinc(0.5%) in combinations exhibited lowest IAA oxidase activity while the activity of the same recorded highest when neither boron nor zinc was applied , control treatment. Cohen and Banburski (1978) also reported that with an increasing boron deficiency in plants, the activity of IAA oxidase increased which also support the findings of present investigation.

4.2.1.12 Influence of sources of boron and organic matter on activity of polyphenol oxidase in rape during the year 2006-2007 and 2007-2008

The results (Table 4.75a and 4.75b) reveal that the activity of polyphenol oxidase was recorded a similar trend of changes to that of IAA oxidase, being varied with its absolute value during both the years (2006-07 & 2007-08). The highest and lowest polyphenol activity were recorded in the treatment T_1 and T_4 where no boron and boron at 0.5 kg ha^{-1} along with 5 t ha^{-1} organic manure was applied respectively. The results (Fig. 4.56) suggest that the highest value of polyphenol oxidase exhibited boron deficiency while that of the same lowest value did not show any boron deficiency. The results also suggested that the greater absorption of boron within the plant resulting from its higher rate of application might have interference with the metabolic processes of the polyphenol oxidase activity causing lowest value of PPO in boron treated soils. Similar observations have been reported by several investigators (Singh *et al.*2001, Xuan *et al.* 2002 and Olcer and Kocacalskan 2007) which also confirmed the results of the present study.

The following trend was recorded

$$T_1 > T_2 > T_5 > T_3 > T_6 > T_4$$

Table 4.75a Effect of boron and organic matter application on the changes in Polyphenol (PP) oxidase (μ mol caffeic acid oxidized mg^{-1} protein min^{-1}) in rape (*Brassica campestris* L.) during the year 2006-2007 (Mean of the three replications)

Treatments	Days After Sowing				
	30	50	70	90	Mean
T_1	5.12^a	5.20^a	5.45^a	5.65^a	**5.36^A**
T_2	4.92^b	5.01^b	5.19^b	5.43^b	**5.14^B**
T_3	3.30^d	3.42^d	3.57^c	3.70^d	**3.50^D**
T_4	3.15^d	3.18e	3.25^d	3.30e	**3.22^E**
T_5	3.62^c	3.72^c	3.75^c	3.92^c	**3.75^C**
T_6	3.49^c	3.55^{cd}	3.64^c	3.77^{cd}	**$3.61C^D$**
Mean	**3.93^S**	**4.01^R**	**4.14^Q**	**4.29^P**	
SE.m (±)	0.053	0.054	0.055	0.056	0.054
CD (P=0.05)	**0.167**	**0.170**	**0.173**	**0.176**	**0.170**

Table 4.75b Effect of boron and organic matter application on the changes in Polyphenol (PP) oxidase (μ mol caffeic acid oxidized mg^{-1} protein min^{-1}) in rape (*Brassica campestris* L.) during the year 2007-2008(Mean of three replications)

Treatments	Days After Sowing				
	30	50	70	90	Mean
T_1	5.20^a	5.27^a	5.52^a	5.72^a	**5.43^A**
T_2	4.90^b	5.10^b	5.22^b	5.45^b	**5.17^B**
T_3	3.36^d	3.40e	3.55^d	3.72^d	**3.51^D**
T_4	3.18e	3.25e	3.29e	3.30e	**3.25^E**
T_5	3.60^c	3.79^c	3.77^c	3.99^c	**3.78^C**
T_6	3.50^{cd}	3.61^d	3.65^{cd}	3.80^d	**$3.64C^D$**
Mean	**3.96^S**	**4.07^R**	**4.17^Q**	**4.33^P**	
SE.m (±)	0.053	0.054	0.056	0.058	0.055
CD (P=0.05)	**0.167**	**0.170**	**0.176**	**0.182**	**0.173**

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

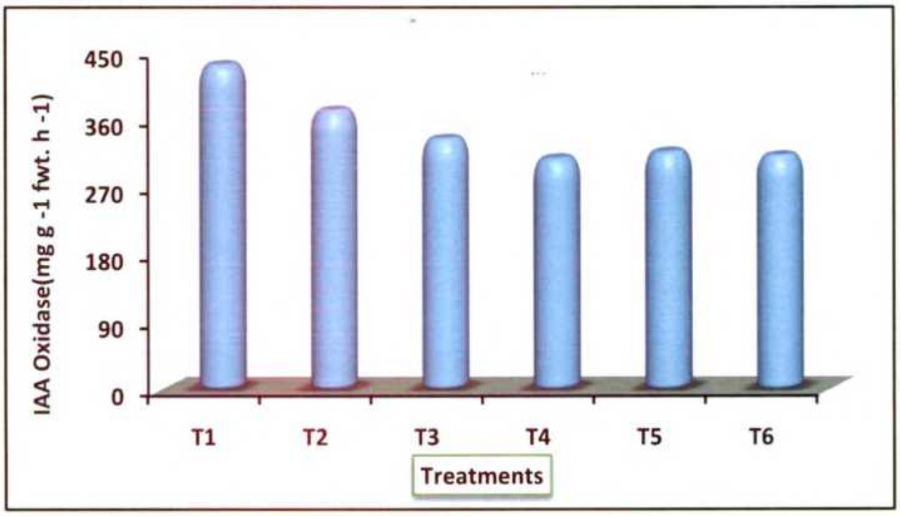


Fig. 4.55 : Effect of boron and organic matter on the changes on the IAAO activity (pooled of two years)

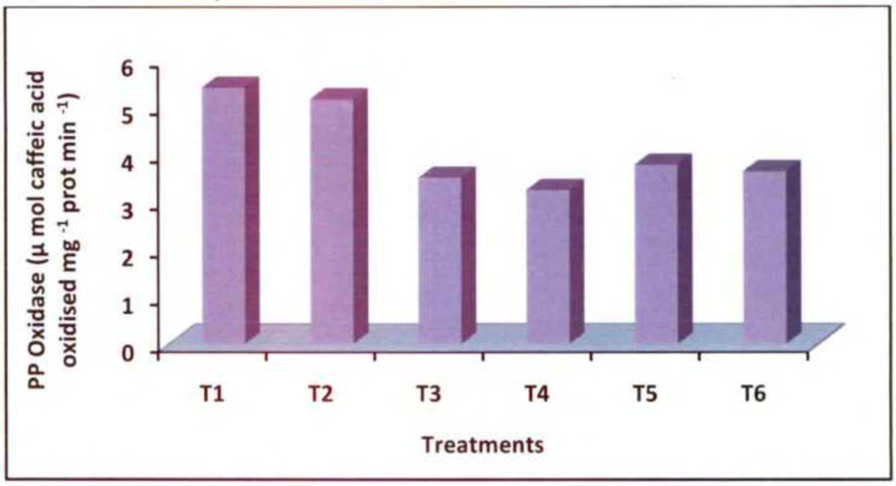


Fig. 4.56 : Effect of boron and organic matter on the changes on the PPO activity (pooled of two years)

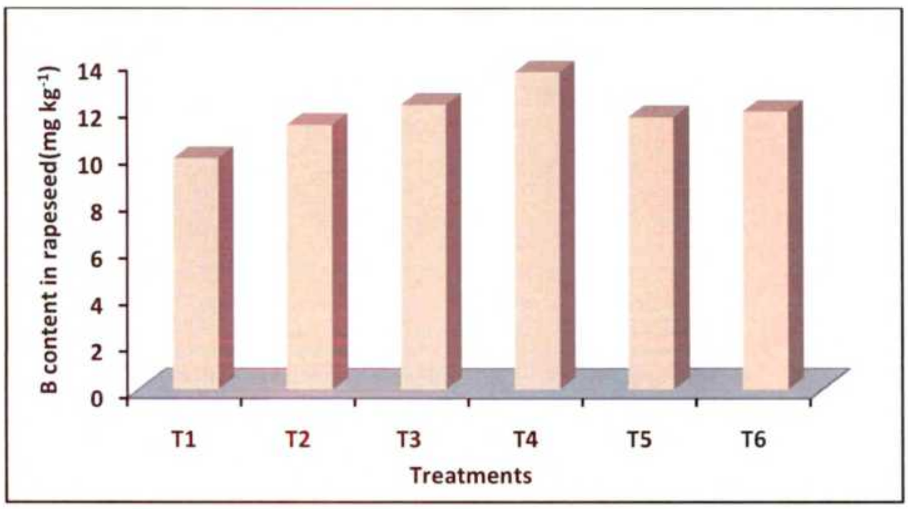


Fig. 4.57 : Effect of boron and organic matter application on the changes in the B content in rapeseed (pooled of two years)

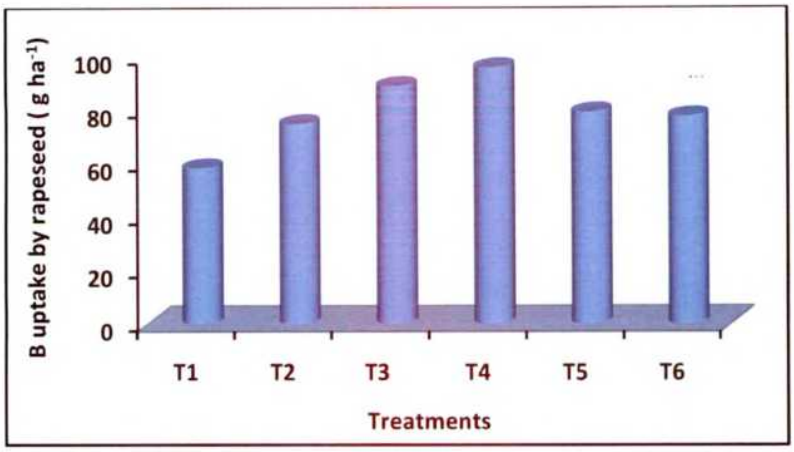
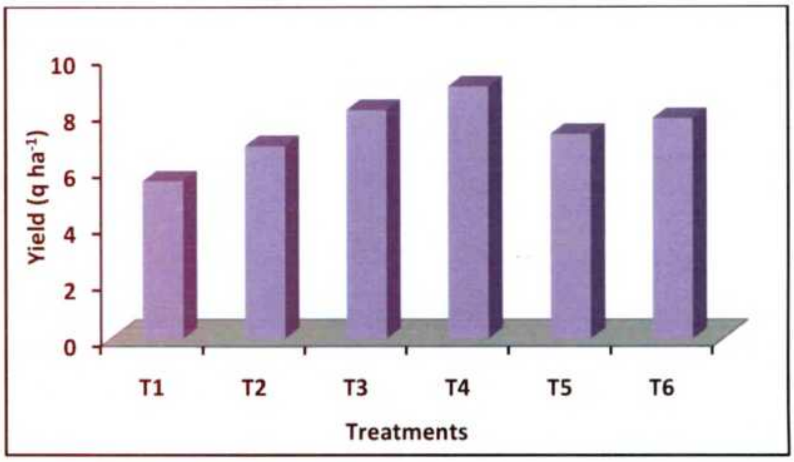


Fig. 4.58 : Effect of boron and organic matter application on the changes in the B uptake by rapeseed (pooled of two years)

Fig. 4.59 : Effect of boron and organic matter application on the changes in the yield of rapeseed (pooled of two years)



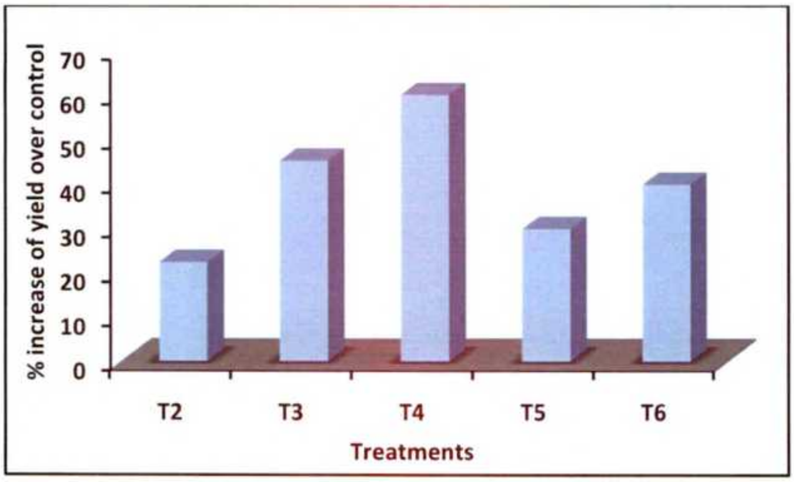
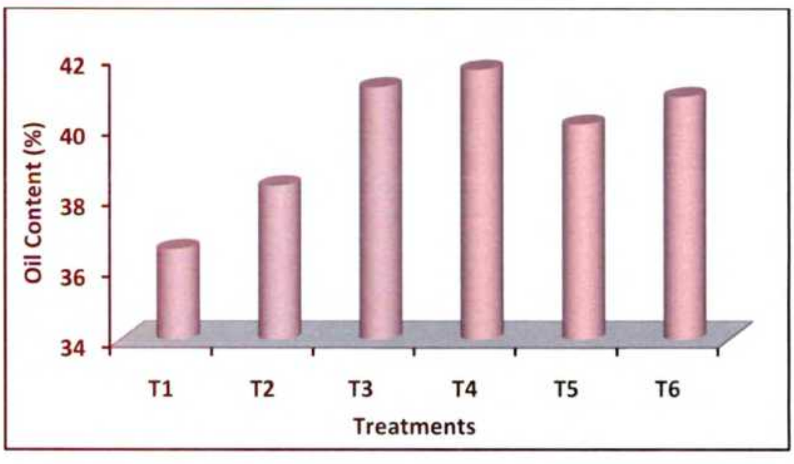


Fig. 4.60 : Effect of boron and organic matter application on the changes in percent increase of yield over control (pooled of two years)

Fig. 4.61 : Effect of boron and organic matter application on the changes in the oil content in rapeseed (pooled of two years)



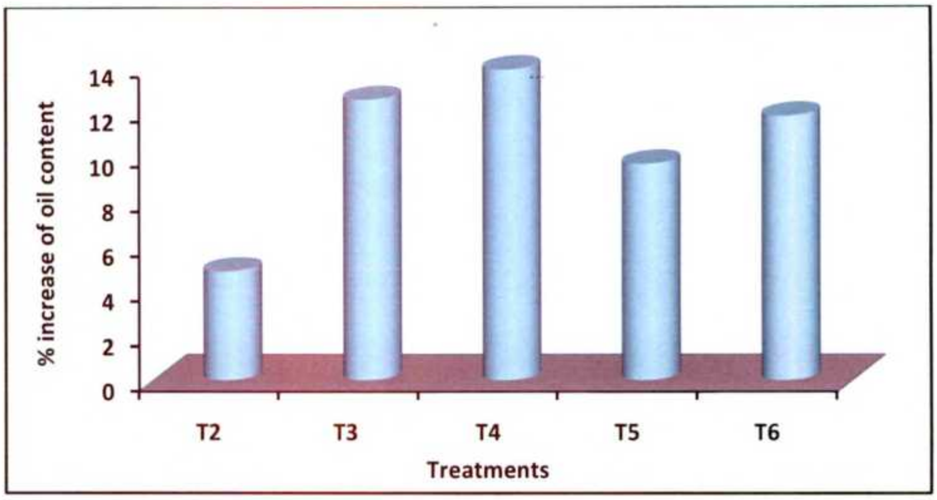


Fig. 4.62 : Effect of boron and organic matter application on the changes on the percent increase of oil content over control. (pooled of two years)

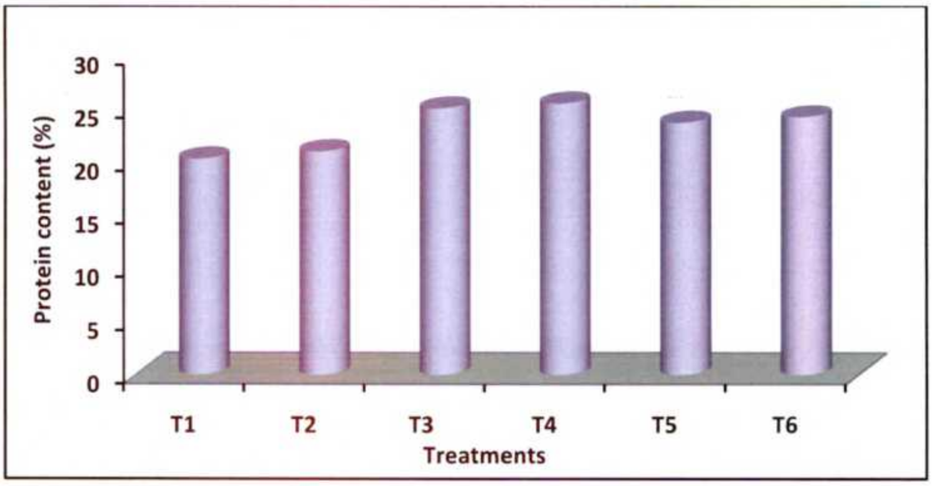


Fig. 4.63 : Effect of boron and organic matter application on the changes in protein content in rapeseed. (pooled of two years)

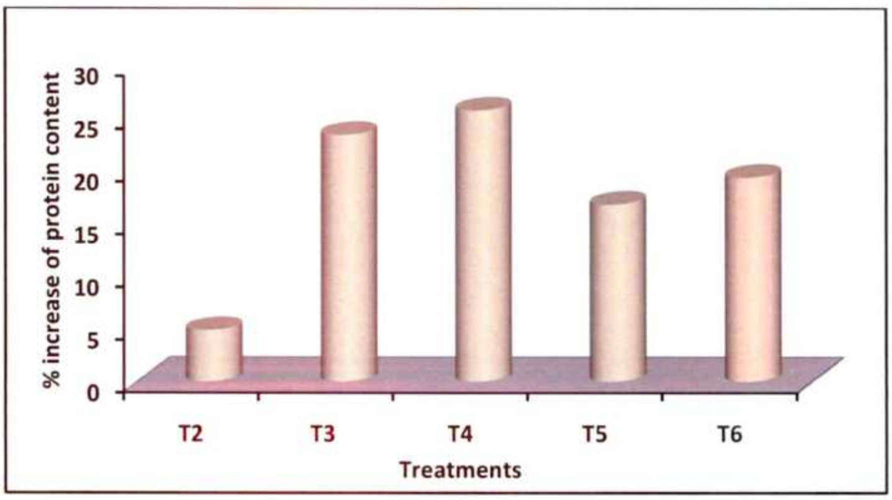


Fig. 4.64 : Effect of boron and organic matter on the changes on the percent increase of protein content over control (pooled of two years)

The results (Fig. 4.56) show that the mean PPO activity (pooled data) showed highest value in control treatment while the same value was recorded lowest in boron treated soil, being greater decrease with highest level of boron.

4.2.1.13 Influence of sources of boron and organic matter on yield attributes of rapeseed during the year 2006-2007 and 2007-2008

The results (Table 4.76) show that the number of branches/ plant and number of siliqua / plant were recorded higher with treatments during both the years (2006 – 07 and 2007 – 08), being highest in the treatment T_4 where NPK, B at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} was applied togetherly. The trend of changes was record in the following order: $T_4 > T_3 > T_6 > T_2 > T_5 > T_1$.

The results show that the average number of branches and siliqua per plant was also recorded highest in the treatment T_4 followed by T_3 treatment where NPK, B at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1}, and NPK and B at 0.5 kg ha^{-1} as calbor were applied combinedly. The present study also confirms the results reported by Hu *et al.* (1994) who showed that the application of 0.7 mg kg^{-1} B proved an optimum level in enhancing the growth attributes of rape significantly.

4.2.1.14 Influence of sources of boron and organic matter on boron content in and uptake by rapeseed during the year 2006-2007 and 2007-2008

The boron content in and uptake by rape seed is presented in Table 4.77 and Fig. 4.57 and 4.58 and showed that the boron content and uptake during the year 2006 – 07 and 2007 – 08 was recorded an increase with different treatments. The pooled amount of B(Fig.4.57) content (13.56 mg kg^{-1}) and uptake(Fig.4.58) (95.85 g ha^{-1}), however, recorded highest in the treatment T_4 where NPK (80:40:40), at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} were applied togetherly. The results revealed that the amount of B content in and uptake by rape seed has been found to be contributed towards an increase in yield of rape seed suggesting a great role of B towards increase in yield. Bowszys and Krauze (2000) reported that the foliar application of boron at 0.4 kg ha^{-1} as water solution of boric acid increased the yield as well as the boron uptake by summer rape (seeds and stems).

Table 4.76 Effect of boron and organic matter application on the changes in no. of branches /plant and no. of siliqua/plant of rape seed

Treatments	No of branches /plant			No. of siliqua /plant		
	2006-07	2007-08	Pooled	2006-07	2007-08	Pooled
T_1	6.67^{b}	9.00^{c}	7.83^{E}	83.67^{f}	85.67^{d}	**84.67^{F}**
T_2	8.00^{b}	11.33^{b}	9.66^{C}	102.67^{e}	110.00^{c}	**106.33^{E}**
T_3	11.33^{a}	12.00^{b}	11.66^{B}	133.00^{b}	142.00^{a}	**137.5^{B}**
T_4	12.00^{a}	17.00^{a}	14.5^{A}	142.00^{a}	146.00^{a}	**144.00^{A}**
T_5	7.67^{b}	8.67^{c}	8.17^{D}	111.67^{d}	113.67^{c}	**112.67^{D}**
T_6	8.00^{b}	11.00^{b}	9.50^{C}	118.00^{c}	121.00^{b}	**119.5^{C}**
SE.m (±)	0.404	0.408	0.348	1.630	1.689	1.658
C.D. at 5%	**1.273**	**1.285**	**1.096**	**5.134**	**5.320**	**5.222**

Table 4.77 Effect of boron and organic matter application on the changes in boron content (mg kg^{-1}) in and uptake (g ha^{-1}) by rape seed

Treatments	B content			B uptake		
	2006-07	2007-08	Pooled	2006-07	2007-08	Pooled
T_1	9.88^{d}	9.92^{d}	**9.90^{D}**	58.28^{e}	58.26^{e}	**58.27^{E}**
T_2	11.2^{c}	11.36^{c}	**11.32^{C}**	74.77^{d}	74.82^{d}	**74.80^{D}**
T_3	12.0^{b}	12.35^{b}	**12.18^{B}**	88.89^{b}	88.99^{b}	**88.94^{B}**
T_4	13.5^{a}	13.60^{a}	**13.57^{A}**	95.79^{a}	95.90^{a}	**95.85^{A}**
T_5	11.6^{bc}	11.61^{bc}	**11.65^{BC}**	79.12^{c}	79.20^{c}	**79.16^{C}**
T_6	11.8^{b}	11.92^{b}	**11.88^{B}**	77.56^{cd}	77.61^{cd}	**77.59^{CD}**
SE.m (±)	0.163	0.164	0.164	1.121	1.123	1.122
C.D. at 5%	0.513	0.516	0.516	3.531	3.537	3.534

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

4.2.1.15 Influence of sources of boron and organic matter on seed and stover yield of rapeseed during the year 2006-2007 and 2007-2008

The results (Table 4.78) show that the yield of rape and seed during the year 2006 – 07 and 2007 – 08 showed a significant variation with different treatments. However. the yield of rape seed and stover have been found to be increased due to different treatments, being recorded highest yield of rape seed (8.90 and 8.99 q ha^{-1}) and stover (26.80 and 26.89 q ha^{-1}) in the treatment T_4 where NPK (80:40:40), B at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} was applied togetherly. Such increase might be explained by the greater mean number of branches and siliqua per plant as well as well as maintain greater amount of B in T_4 soil solution. The percent increase of rape seed yield (Fig.4.59) in the treatment over control was (37.54) followed by the treatment T_3. Lu *et al.* (2000) and Salroo *et al.* (2002) also reported that integrated boron management practices increased the yield of brown sarson. The pooled data of the yield of rape seed and stover are being presented in Fig.4.60. The pooled yield of rape seed and stover were followed in the order of $T_4 > T_3 > T_6 > T_5 > T_2 > T_1$. Zou *et al.* (2008) also reported similarly who showed that the application of boron increased the yield and yield components of rape.

4.2.1.16 Influence of sources of boron and organic matter on oil and protein content of rapeseed during the year 2006 - 2007 and 2007 - 2008

The result (Table 4.79) show that the oil and protein content have been found to be increased significantly with the application of different treatments during both the years (2006 – 07 and 2007 – 08). However, the oil and protein contents did not show any significant variation during both the years. The highest mean oil (Fig.4.61) (41.65 percent) and protein content (Fig.4.62) (25.52 percent) was recorded in the treatment T_4 receiving recommended level of NPK (80: 40 : 40), B at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1}. The oil and protein contents of rape and soybean have been found to be increased with different levels of boron fertilizers (Deosarkar *et al.*, 2002 and Hu *et al.* 1994). However, the following trend of changes were recorded for oil and protein content in rape.

$T_4 > T_3 > T_6 > T_5 > T_2 > T_1$

4.2.1.15 Influence of sources of boron and organic matter on seed and stover yield of rapeseed during the year 2006-2007 and 2007-2008

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4.2.1.16 Influence of sources of boron and organic matter on oil and protein content of rapeseed during the year 2006 - 2007 and 2007 - 2008

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$T_4 > T_3 > T_6 > T_5 > T_2 > T_1$

Table 4.78 Effect of boron and organic matter application on the changes in seed yield (q ha^{-1}) and stover yield (q ha^{-1}) of rape seed

Treatments	Seed yield			Stover yield		
	2006-07	2007-08	Pooled	2006-07	2007-08	Pooled
T_1	5.60^{e}	5.58^{e}	**5.59^{E}**	21.40^{c}	21.45^{c}	**21.42^{C}**
T_2	6.80^{d}	6.87^{d}	**6.84^{D}**	23.43^{b}	23.52^{b}	**23.48^{B}**
T_3	8.10^{b}	8.15^{b}	**8.12^{B}**	26.00^{a}	26.12^{a}	**26.06^{A}**
T_4	8.90^{a}	8.99^{a}	**8.95^{A}**	26.80^{a}	26.89^{a}	**26.85^{A}**
T_5	7.20^{c}	7.31^{c}	**7.26^{C}**	23.92^{b}	24.14^{b}	**24.043^{B}**
T_6	7.80^{b}	7.83^{b}	**7.82^{B}**	24.41^{b}	24.44^{b}	**24.43^{B}**
SE.m (±)	0.105	0.106	0.105	0.334	0.335	0.334
C.D. at 5%	**0.330**	**0.333**	**0.330**	**1.052**	**1.055**	**1.052**

Table 4.79 Effect of boron and organic matter application on the changes in oil and protein content in rape (*Brassica campestris* L.)

Treatments	Oil content (%)			Protein content (%)		
	2006-07	2007-08	Pooled	2006-07	2007-08	Pooled
T_1	36.56^{c}	36.60^{c}	**36.58^{C}**	20.26^{d}	20.32^{d}	**20.29^{D}**
T_2	38.30^{b}	38.41^{b}	**38.36^{B}**	21.00^{d}	21.02^{d}	**21.01^{D}**
T_3	41.11^{a}	41.20^{a}	**41.16^{A}**	24.99^{ab}	25.10^{ab}	**25.05^{AB}**
T_4	41.63^{a}	41.66^{a}	**41.65^{A}**	25.49^{a}	25.55^{a}	**25.52^{A}**
T_5	40.07^{a}	40.15^{a}	**40.11^{A}**	23.65^{c}	23.76^{c}	**23.71^{C}**
T_6	40.87^{a}	40.92^{a}	**40.89^{A}**	24.15^{bc}	24.32^{bc}	**24.23^{BC}**
SE.m (±)	0.535	0.535	0.535	0.316	0.318	0.317
C.D. at 5%	1.68	1.68	1.68	0.995	1.00	0.998

T_1 = Control (only NPK as recommended); T_2 = NPK as recommended + Organic matter (5t ha^{-1}); T_3 = NPK as recommended + Boron as calbor (1 kg B ha^{-1}); T_4 = NPK as recommended + Boron as calbor (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1}); T_5 = NPK as recommended + Boron as Borax (B at 1 kg ha-1); T_6 = NPK as recommended + Boron as Borax (0.5 kg B ha^{-1}) + Organic matter (5 t ha^{-1})

The highest percent increase in oil (Fig.4.63)(13.86) and protein content (Fig.4.64) (25.77) over control was recorded in the treatment T_4. Li *et al.* (2005) reported that the oil and protein content in rape seed was in the order of N > B>P_2O_5> K_2O suggesting a greater role played by boron compared to phosphate and potash.

Table 4.80 Regression results following stepwise method of analysis where both criterion measure and predictors observed over all four days after sowing with allowed tolerance = 0.0001

Predictors	Equation number	Equations	R^2	Adj. R^2	SE (est)
IAA,PPO	1	Total boron= 22.15-2.83 PPO**	0.69**	0.68	1.65
BZ_1E_1,BZ_2E_1	2	Total boron = 1.06 + 16.85 BZ_1E_18**	0.69**	0.69	1.64
BZ_1E_2,BZ_2E_2	3	Total boron =5.68 + 24.88 BZ_2E_2**	0.72**	0.71	1.57
BZ_1E_3,BZ_2E_3	4	Total boron = -12.09 +30.85 BZ_2E_3**	0.60**	0.59	1.87

** significant at 1% level

Total boron measured at 4 different after sowing was considered as dependent variable to fit a stepwise multiple regression model where the predictor set was plant enzymes viz.,IAA and PPO also measured at those 4 days after sowings for same set of treatments.The best fitted model is included in Table 4.80. Similar model was also tried with the predictor set as boron content at two zones of soil separately for each type of extractant. These results are also included in the same Table.The multiple regression results revealed that the PPO is only important predictor out of two predictors considered which can explain 69 % of total variance (equation 1). For extractant 1 i.e. HCC extractable B , the boron concentration at zone 1 i.e. rhizosphere soil is only important predictors which can explain 69 % of total variance (equation 2). Similarly for extractant 2 and 3 i.e.,MCC extractable and MH-3 extractable B , the boron concentration at zone 2 i.e. non-rhizosphere soil are the important predictors which can explain 72 and 60 % of total variance respectively (equation 3 and 4).

Table 4.81 Regression results following stepwise method of analysis where both criterion measure and predictors are mean results over all four days after sowing with allowed tolerance = 0.0001

Predictors	Equation number	Equations	R^2	Adj. R^2	SE (est)
NFC at Z_1 & Z_2, NFB at Z_1 & Z_2, PSC at Z_1 & Z_2, PSM at Z_1 & Z_2, MBC at Z_1 & Z_2	5a	Seed yield =-0.11-0.24NFBZ_1** +27.00PSCZ_2** +0.26PSMZ_2** +0.25PSMZ_1**-0.03MBCZ_2**-0.05NFBZ_2**-7.31PSCZ_1	0.99**	0.99	0.008
NFC at Z_1 &Z_2, NFB at Z_1 & Z_2, PSC at Z_1&Z_2, PSM at Z_1&Z_2, MBC at Z_1&Z_2, BZ_1E_1, BZ_2E_1, IAA, PPO, total B	6a	Seed yield =-0.06 +0.18NFBZ_1**+0.21totalB**-2.81BZ_2E_1**-0.09NFBZ_2**-0.02MBCZ_1**+0.001MBCZ_2*	0.99**	0.99	0.004
NFC at Z_1 &Z_2, NFB at Z_1 &Z_2, PSC at Z_1&Z_2, PSM at Z_1&Z_2, MBC at Z_1&Z_2, BZ_1E_2, BZ_2E_2, IAA, PPO, total B	7a	Seed yield =-0.03+0.06NFBZ_1**+0.47 total B**-0.47PPO**+0.13MBCZ_2**-0.32PSMZ_2**	0.99**	0.99	0.004
NFC at Z_1 &Z_2, NFB at Z_1 &Z_2, PSC at Z_1&Z_2, PSM at Z_1&Z_2, MBC at Z_1&Z_2, BZ_1E_3, BZ_2E_3, IAA, PPO, total B	8a	Seed yield =-0.03 +0.06NFBZ_1**+0.47total B** -0.47PPO**+0.13MBCZ_2**-0.32 PSM Z_2**	0.99**	0.99	0.004

** significant at 1% level

*significant at 5 % level

Mean values of NFC at Z_1 and Z_2 , NFB at Z_1 and Z_2 , PSC at Z_1 and Z_2 , PSM at Z_1 and Z_2 and MBC at Z_1 and Z_2 were calculated over four different time period prior to regression analysis as described before. Similar model was also tried where the predictor set had additional variables like boron content at 2 zones of soil separately for each type of extractant, total boron, IAA and PPO. These resulted are included in the Table 4.81. When predictors variables are used to predict the yield (equation 5a). The stepwise technique of multiple regression revealed that the NFB at Z_1 and Z_2 , PSC at Z_1 &Z_2 , PSM at Z_1 &Z_2 and MBC at Z_2 are only important predictors which can explain 99 % of total variance .PSC at Z_1 was important predictor but nonsignificant for regression . Similarly, for equation 6a it was found that that NFB at Z_1 and Z_2, total B, BZ_1E_1, and MBC at Z_1 and Z_2 are only important predictors which can explain 99% of total variance. Two regression equations (7a and 8a) were resulted for yield with explainable variation of 99 %. For both the equation, the best predictor variables are NFB at Z_1, total B, PPO, and MBC at Z_2 and PSM at Z_2.

Table 4.82 Regression results where predictors are weighted by principal component based component loadings (Principal Component Regression based upon regression factor scores of predictors) #

Predictors	Equation number	Equations	R^2	Adj. R^2	SE (est)
NFC at Z_1 & Z_2, NFB at Z_1 & Z_2, PSC at Z_1 & Z_2, PSM at Z_1 & Z_2, MBC at Z_1 & Z_2	5b	Seed yield =7.43+0.70PSMZ_1**+0.39 PSMZ_2*	0.97**	0.96	0.209
NFC at Z_1 &Z_2, NFB at Z_1 & Z_2, PSC at Z_1&Z_2, PSM at Z_1&Z_2, MBC at Z_1&Z_2, BZ_1E_1, BZ_2E_1, IAA, PPO, totalB	6b	Seed yield=7.43+0.87 total B** +0.53MBCZ_2**-0.21BZ_1E_1**-0.03IAA**-0.06NFCZ_2**	0.99**	0.99	0.003
NFC at Z_1 &Z_2, NFB at Z_1 &Z_2, PSC at Z_1&Z_2, PSM at Z_1&Z_2, MBC at Z_1&Z_2, BZ_1E_2, BZ_2E_2, IAA, PPO, total B	7b	Seed yield =7.43-0.08PSMZ_1** +1.04 total B** +0.58MBCZ_2**-0.29BZ_2E_2**-0.03MBCZ_1**-0.07NFBZ_1**	0.99**	0.99	0.003
NFC at Z_1 &Z_2, NFB at Z_1 &Z_2, PSC at Z_1&Z_2, PSM at Z_1&Z_2, MBC at Z_1&Z_2, BZ_1E_3, BZ_2E_3, IAA, PPO, total B	8b	Seed yield=7.43 +0.58total B** +0.47MBCZ_2**-0.20NFCZ_1**+0.41NFBZ_2** +0.20IAA**+0.04BZ_1E_3**+0 .02PSCZ_1*	0.99**	0.99	0.002

Note: Component weights used for regression factor scores used for each predictor is listed in Table 4.83

** significant at 1% level

*significant at 5 % level

Table 4.83 Principal component weights for first component explaining largest variance

Variable	Days After Sowing				Variance accounted for
	30	50	70	90	
BZ_1E_1	1.00	1.00	1.00	1.00	99.58%
BZ_1E_2	0.99	1.00	1.00	1.00	99.37%
BZ_1E_3	1.00	1.00	1.00	1.00	99.91%
BZ_2E_1	1.00	1.00	1.00	1.00	99.58%
BZ_2E_2	1.00	0.99	1.00	1.00	99.31%
BZ_2E_3	1.00	1.00	1.00	1.00	99.96%
Total B	1.00	0.99	1.00	1.00	99.32%
IAA	1.00	1.00	1.00	1.00	98.75%
PPO	1.00	1.00	1.00	1.00	99.88%
NFC at Z_1	1.00	1.00	1.00	1.00	99.69%
NFB at Z_1	0.99	1.00	0.99	0.98	98.03%
PSC at Z_1	0.99	0.99	1.00	0.99	98.34%
PSM at Z_1	0.97	1.00	1.00	0.99	97.52%
MBC at Z_1	0.99	0.99	0.99	0.98	97.86%
NFC at Z_2	1.00	1.00	1.00	1.00	99.77%
NFB at Z_2	0.98	1.00	1.00	0.98	97.90%
PSC at Z_2	0.98	0.95	0.98	-0.58	78.97%
PSM at Z_2	0.99	1.00	1.00	0.99	98.87%
MBC at Z_2	1.00	0.99	0.99	0.97	97.40%

Principal component regression technique was further used following similar technique and same predictor variables but here the predictor are nothing but the regression factor score resulted by principal component analysis. Each predictors which were measured at 4 different time periods was actually constructed this factor score and the principal component weights will dictate the contribution of variance of each day in such score according to the importance to total variance of this predictors(Table 4.82). The results revealed that PSM at Z_1 and Z_2 are the only important predictors which can explain 97 % of total variance (equation 5b). For equation 6b, it was found that total B , MBC at Z_2 , BZ_1E_1,IAA and NFC at Z_2 are only important predictors which can explain 99 % of total variance. The results further revealed that PSM at Z_1, total B, MBC at Z_1 and Z_2 , BZ_2E_2 and NFB at $Z_1$are the only important predictors which can explain 99 % of total variance(equation 7b). For equation 8b , it was found that total B , MBC at Z_1, NFC at Z_1 , NFB at Z_2 , IAA, BZ_1E_3 and PSC at Z_1 are only important predictors which can explain 99 % of total variance.

Chapter V

Summary and Conclusion

Summary and Conclusion

Boron is one of the essential micronutrient elements whish exhibits high responsive to oilseed crops. The chemistry of transformation of native as well as applied boron in soils have been found to be affected by various soil factors viz. clay content, effect of other ions, moisture regimes etc. However, transformation of boron is chiefly dependent on adsorption- desorption reactions, precipitation reactions, soil reaction, effect of ions i.e. nutrient interactions etc. Therefore, the present investigation was undertaken to study the "Distribution, transformation and interactions of boron in soil ecosystem in relation to growth and nutrition of rape (*Brassica campestris* L.)"

The present study was conducted both in the laboratory and field to fulfil the objectives. Laboratory experiments were conducted in alfisol and inceptisol with different treatment combinations. For the laboratory experiment , there were three sets which includes interaction study in between BxS ,B x Zn , B x Organic matter (OM) in different combinations apart from the distribution study of boron in soils of five agroclimatic zones in West Bengal.

For the distribution study the soil samples were collected from different agroclimatic zones of West Bengal viz. Terai, Old alluvial, New alluvial, Red and Laterite and Coastal zones and different extractants for extracting boron and relevant physicochemical properties were determined. The results reveal that the distribution of different fractions of boron viz. hot calcium chloride (HCC), mannitol-calcium chloride (MCC) Mehlich 3 (MH-3) extractable boron has been found to be varied with different soil properties and zones. The results further reveal that the extractability of B in Terai and Red and Laterite zones have been found to be highest with HCC solution while that of the same extractability in soils of old and new alluvial zones the amount of boron extracted with MH-3 solution was recorded highest excepting the coastal zones soil where MCC extraction solution exhibited a greater amount of extracted boron. The results show that the physicochemical properties in soils of five agro-climatic zones have been found to be varied with each other, however, out of five zones, the soils of two zones (Terai and Red and Laterite) are acidic in reaction and the rest (old , new and coastal) are neutral in reaction. The highest clay and CEC content were recorded in coastal zone soil. The average organic carbon content in 1erai soils (0.74%) was highest compared to other zones of soils. The MCC and MH-3 extractable B content in soil have been found to be significant and positively correlated with pH of the soil while MCC extractable B exhibited a significant positive correlation with CEC of the soil.

It is evident that the adsorption- desorption reactions play an important role in controlling the availability of boron in soils affecting plant growth. Keeping this in view, a laboratory experiment was conducted to study the adsorption of applied boron in different concentration of 0, 0.5, 1, 2, 3, 4 and 5 mg B l^{-1} in an inceptisol and alfisol affected by the application of organic matter. The results reveal that the amount of B adsorbed was consistently higher with the higher amount of applied boron but the percent adsorbed decreased with higher amount of applied boron in both inceptisol and alfisols irrespective of organic matter applications.As regards to the application of organic matter, the adsorption of boron was recorded a relatively higher amount compared to soils not supplied with organic matter which might be due to the greater surface area available in the former for its adsorption. Comparing the results of soil types, it was observed that the amount of B adsorption in an inceptisol treated with organic matter has been found to be very little compared to alfisol. Such variation in boron adsorption in both soils might be due to variation in adsorption maxima (b) and constant related to bonding energy (k).

Nutrient interactions play a significant role in modifying nutrient use efficiency in soils vis-a vis crop production. However, nutrient interactions especially in between micronutrients and secondary and micronutrients are observed very frequently. Therefore, it was worthwhile to undertake some laboratory experiments on the interaction between boron (B_0, B_1, B_2), and sulphur (S_0, S_{15}, S_{30}), zinc (Zn_0, Zn_5, Zn_{10}) and organic matter (OM_0, OM_1, OM_2) in all possible combinations and the experiments were conducted in alfisol and inceptisols in a factorial CRD with ~~replicated thrice~~.

The results of laboratory experiment on the interaction effect between B and S on their changes in relation to some microbial and biochemical attributes in an inceptisol showed that , the amount of HCC, MCC and MH-3-extractable B have been found to be increased initially and therefore, the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. With regards to the application of sulphur, it was observed that the amount of HCC, MCC and MH-3-Extractable B showed a similar trend of changes to that of the same changes with B application.

As regards to the interaction effect between B and S , it was observed that the amount of HCC extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest in the treatment B_2S_2 where B at 2 mg kg^{-1} and S at 30 mg kg^{-1} was applied combinedly. The results suggested that the individual applications of both B and S increased the HCC, MCC and MH-3-extractable B, but due to their combined applications, the amount of HCC- extractable B has been found to be further increased significantly and hence the interaction between B and S was found positive with respect to HCC, MCC and MH-3- extractable B content in soil. As regards to different extractants , it was recorded that the amount of boron was highest in soil extracting with hot $CaCl_2$ solution followed by mannitol-$CaCl_2$ and MH-3 extracting solution. The results further showed that the amount of available sulphur content has been found to be increased initially and thereafter, the amount of the same decreases irrespective of levels of B. The magnitude of such changes, however, varied with the levels of boron, being highest (13.6mg kg^{-1}) in the treatment B2 where boron at 2 mg kg^{-1} was applied. The results further reveal that the amount of available sulphur has been found to be followed a similar trend of changes to that of the applied boron excepting a greater magnitude of available sulphur which is obvious. As regards to the interaction effect between B and S , it was observed that the amount of available sulphur has been found to be further increased in absolute values following the similar pattern of changes with the individual application of both B and S.

The result for the changes in the proliferation and potentialities of phosphate solubilising microorganism, non-symbiotic nitrogen fixing bacteria and microbial biomass carbon in inceptisol as affected by the interaction between B and S showed that it has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B and S. The magnitude of such changes ,however, varied with levels of B and S, being highest in the treatment B_2 where boron at 2 mg kg^{-1} and S_{30} where sulphur at 30 mg kg-1 was applied at 30 days of incubation. As regards to the interaction effect between B and S , it was observed that the highest level of proliferation and potentialities of phosphate solubilising microorganisms, aerobic non-symniotic nitrogen fixing bacteria and microbial biomass carbon was found in the treatment combination B_2S_{30} where boron at 2 mg kg^{-1} and sulphur at 30 mg kg^{-1} was applied combinedly.

A laboratory experiment was carried out to study the effect between B and Zn on their changes in relation to some microbial and biochemical attributes in inceptisol. The results envisaged that amount of HCC, MCC and MH-3-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest in the treatment B_2 where boron at 2 mg kg^{-1} was applied at 20 days of incubation. As regards to the separate application of zinc , it was observed that the amount of HCC, MCC and MH-3-extractable B content in an inceptisol although recorded a slight increase at 20 days of incubation but it was non-significant rather consistently decreased upto 40 days of incubation. The results further envisaged that the amount of HCC, MCC and MH-3 extractable B content did not vary significantly with the levels of Zn. The application of Zn at their different levels did not show any definite relationship on the availability of HCC, MCC and MH-3 extractable B in soils. However, the results show that the amount of HCC, MCC and MH-3 extractable B content was recorded a depressive effect in the treatment combinations where different levels of zinc and no application of boron was applied while that of the same content found increase in the treatment combinations where different levels of boron and no application of zinc was applied, being increase a greater magnitude with higher level of boron application. The results further showed that the amount of available Zn content has been found to be increased initially and thereafter, the amount ~~of the same~~ decreases irrespective of levels of B. The magnitude of such changes, however, varied with the levels of boron, being highest (1.80 mg kg^{-1}) in the treatment B_0 where boron at 0 mg kg^{-1} was applied. The results further reveal that the amount of available zinc has been found to be highest in the treatment Zn10 where Zn at 10 mg kg^{-1} was applied. Due to application of Zn at its different levels, the microbial and biochemical attributes have been recorded to be suppressive with varying magnitudes.

The results of laboratory experiment on the interaction effect between B and OM on their changes in relation to some microbial and biochemical attributes in both inceptisol and alfisol showed that , amount of HCC,MCC and MH-3-extractable B has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B. The magnitude of such changes, however, varied with levels of B, being highest in the treatment B2 where boron at 2 mg kg^{-1} was applied at 30 days of incubation. With regards to the application of organic matter, it was observed that the amount of HCC, MCC and MH-3-Extractable B was showed a similar trend of changes to that of the same changes with B application. As regards to the interaction effect between B and OM, it was observed that the amount of HCC, MCC and MH-3 extractable B was recorded an increase compared to their individual application with the progress of incubation upto 30 days and thereafter the amount decreases. However, the magnitude of such increase was varied with treatment combinations, being highest in the treatment B_2OM_2 where B at 2 mg kg^{-1} and OM at 2% by weight of the soil was applied combinedly. The results suggested that the individual applications of both B and OM increased the HCC, MCC and MH-3-extractable B, but due to their combined applications, the amount of HCC, MCC and MH-3- extractable B has been found to be further increased significantly and hence the interaction between B and S was found positive with respect to HCC, MCC and MH-3- extractable B content in soil. As regards to different extractants , it was recorded that the amount of boron was highest in soil extracting with hot $CaCl_2$ solution followed by mannitol-$CaCl_2$ and MH-3extracting solution.

The result for the changes in the proliferation and potentialities of phosphate solubilising microorganism, non-symbiotic nitrogen fixing bacteria and microbial biomass carbon in both inceptisol and alfisol as affected by the interaction between B and OM showed that it has been found to be increased initially and therefore the amount of the same decreased irrespective of levels of B and OM. The magnitude of such changes, however, varied with levels of B and OM, being highest in the treatment B2 where boron at 2 mg kg^{-1} and OM2 where OM at 2% by weight of the soil was applied at 30 days of incubation.As regards to the interaction effect between B and OM , it was observed that the highest level of proliferation and potentialities of phosphate solubilising microorganisms, aerobic non-symniotic nitrogen fixing bacteria and microbial biomass carbon has been found in the treatment combination B_2OM_2 where boron at 2 mg kg^{-1} and OM at 2% by weight of the soil was applied combinedly. Mallows (1966) suggested the Cp statistical interpretation to find out the adequate model with maximum adjusted $R2$ for each extracting solution of B with PSC, PSM, NFC, NFB, MBC parameters in inceptisol and alfisol. Considering the distance between Cp = p line corresponding Cp values it was found that the rank of the extractant was recorded in ascending order of 3>2>1 in alfisol that means MH-3 extracting solution proved best in alfisol treated with organic matter for the extraction of B. Similar observations was also recorded for the ranking of extractant due to interaction between B and S in inceptisol, which that of MCC extractable B ranked first due to interaction between B and Zn in an inceptisol. The MH-3 extractable B was proved superior in soils of inceptisol due to interaction between B and organic matter.

The field experiment was conducted to study "Influence of boron sources and organic matter on the changes in chemical, biochemical and microbial properties in relation to yield and quality of rape (*Brassica campestris* L.). The results show that amount of HCC, MCC and MH-3 extractable B has been found to be decreased consistently with the progress of crop growth irrespective of rhizosphere (R) and non-rhizosphere (NR) soils. However, the highest amount of HCC, MCC and MH-3 extractable B was found at the initial crop growth period in the treatment T_4 where recommended level of NPK (80 : 40 : 40), B as calbor at 0.5 kg ha^{-1} and organic manure at 5 t ha^{-1} was applied togetherly in both R and NR soils. As regards to the HCC and MCC extractable B content in R and NR soils, it was observed that the absolute amount of B was maintained always higher in the R soil compared to NR soils, but with regards to fractions of B, MH-3 extractable B was maintained higher in the NR soils compared to R soils.

The results further reveal that proliferation and potentialities of phosphate solubilising microorganisms, non-symbiotic nitrogen fixing bacteria and microbial biomass carbon in rhizosphere were recorded highest compared to nonrhizosphere.

The results show that the amount of B content in rape dry matter showed a consistent decrease with the progress of crop growth irrespective of treatments. However, such decrease varied with treatments. The results reveal that the amount of B recorded significantly highest initially (17.18 mg kg^{-1}) at 30 days of crop growth and also maintained highest amount in the treatment T_4 receiving NPK (80:40:40), B and organic matter throughout the crop growth period. The pooled amount of B content in (13.56 mg kg^{-1}) and uptake (95.85 g ha^{-1}) by rapeseed, however, recorded highest in the treatment T_4 where NPK (80 : 40 : 40), at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} were applied togetherly.

However, the yield of rape seed and stover have been found to be increased due to different treatments, being recorded highest yield of rape seed (8.94 q ha^{-1}) and stover (26.84 q ha^{-1}) in the treatment T_4 where NPK (80 : 40 : 40), B at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} was applied togetherly. Such increase might be explained by the greater mean number of branches and siliqua per plant as well as well as maintain greater amount of B in

T_4 soil solution. The percent increase of rape seed yield in the treatment over control was (60 %) followed by the treatment T_3.

The highest mean oil (41.65 percent) and protein content (25.52 percent) was recorded in the treatment T_4 receiving recommended level of NPK (80 : 40 : 40), B at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1}. The highest percent increase in oil (13.86) and protein content (25.77) over control was recorded in the treatment T_4.

The results show that the activity of IAA oxidase has been found to be consistently increased with the progress of crop growth irrespective of treatments. The magnitude of such increase, however, varied with treatments, being maximum increase in the T_1 where only recommended NPK fertilizer was applied.

Comparing the results of different treatments, it was found that the lowest value of IAA oxidase (308.33 mg g^{-1} fwt. h^{-1}) was recorded in the treatment T_4 where recommended NPK, boron at 0.5 kg ha^{-1} as calbor and organic manure at 5 t ha^{-1} was applied togetherly. The highest and lowest polyphenol activity were recorded in the treatment T_1 and T_4 where no boron and boron at 0.5 kg ha^{-1} along with 5 t ha^{-1} organic manure was applied respectively.

CCA is used to find out the linear association between boron content of two different zones of soil as predictor set and the set of varying microbial parameters as criterion measures or dependent set.

Canonical weights of dependent set and predictor set under first canonical variate if compared it was found that boron at rhizosphere measured by Hot-Calcium chloride solution is highly associated with phosphate solubilizing capacity and phosphate solibilizing microorganisms at rhizosphere zone, nitrogen fixing capacity ,phosphate solubilizing capacity and microbial biomass carbon at non-rhizosphere zone of dependent set. Again boron at non-rhizosphere measured by Hot – Calcium chloride solution is highly associated with nitrogen fixing capacity, nitrogen fixing bacteria and microbial biomass carbon at rhizosphere zone and nitrogen fixing bacteria and phosphate solubulizing microorganism at non-rhizosphere zone of dependent set.

Canonical weights of dependent set and predictor set under second canonical variate if compared ~~it was found~~ that boron at rhizosphere measured by hot Calcium chloride solution is highly associated with nitrogen fixing capacity, phosphate solubilizing capacity and phosphate solubilising microorganisms at rhizosphere zone, nitrogen fixing bacteria , phosphate solubulizing microorganisms and microbial biomass carbon at non-rhizosphere zone of dependent set. Again boron at non-rhizosphere measured by hot calcium chloride solution is highly associated with nitrogen fixing bacteria and microbial biomass carbon at rhizosphere zone and nitrogen fixing capacity and phosphate solubulizing capacity at non-rhizosphere zone of dependent set.

Canonical weights of dependent set and predictor set under first canonical variate if compared ~~it was found~~ that boron at rhizosphere measured by Mannitol-Calcium chloride solution is highly associated with nitrogen fixing bacteria,phosphate solubilizing capacity and microbial biomass carbon at rhizosphere zone, nitrogen fixing capacity and phosphate solubilizing capacity at non-rhizosphere zone of dependent set. Again boron at rhizosphere and non-rhizosphere measured by mannitol calcium chloride solution is highly associated with nitrogen fixing bacteria, phosphate solubilizing capacity and microbial biomass carbon at rhizosphere zone and nitrogen fixing capacity and phosphate solubulizing capacity at non-rhizosphere zone of dependent set.

Canonical weights of dependent set and predictor set under second canonical variate if compared ~~it was found~~ that boron at rhizosphere measured by Mannitol- Calcium chloride solution is highly associated with nitrogen fixing bacteria and phosphate solubilizing capacity at rhizosphere zone, nitrogen fixing capacity and phosphate solubulizing capacity at non-rhizosphere zone of dependent set. Again boron at non-rhizosphere measured by Mannitol- Calcium chloride solution is highly associated with nitrogen fixing capacity,phosphate solubilizing nicroorganisms and microbial biomass carbon at rhizosphere zone and nitrogen fixing bacteria, phosphate solubilizing microorganisms and microbial biomass carbon at non-rhizosphere zone of dependent set.

Canonical weights of dependent set and predictor set under first canonical variate if compared it was found that boron at rhizosphere measured by Mehlich 3 solution is highly associated with nitrogen fixing capacity of rhizosphere zone, nitrogen fixing bacteria, phosphate solubulizing bacteria and microbial biomass carbon at non-rhizosphere zone of dependent set. Again boron at non-rhizosphere measured by Mehlich 3 solution is highly associated with nitrogen fixing bacteria, phosphate solubulizing capacity, phosphate solubulizing bacteria and microbial biomass carbon at rhizosphere zone and nitrogen fixing capacity and phosphate solubulizing capacity at non-rhizosphere zone of dependent set.

Canonical weights of dependent set and predictor set under second canonical variate if compared it was found that boron at rhizosphere measured by Mehlich 3 solution is highly associated with phosphate solubilizing capacity and microbial biomass carbon of rhizosphere zone, nitrogen fixing capacity,nitrogen fixing bacteria and phosphate solubulizing capacity at non-rhizosphere zone of dependent set. Again boron at non-rhizosphere measured by Mehlich 3 solution is highly associated with nitrogen fixing capacity, nitrogen fixing bacteria and phosphate solubulizing microorganisms at rhizosphere zone and phosphate solubulizing microorganisms and microbial biomass carbon at non-rhizosphere zone of dependent set.

The stepwise technique of multiple regression revealed that the NFB at Z_1 and Z_2 , PSC at Z_1 &Z_2 , PSM at Z_1 & Z_2 and MBC at Z_2 are only important predictors which can explain 99 % of total variance .PSC at Z_1 was important predictor but non significant for regression . Similarly, for equation 6a it was found that that NFB at Z_1 and Z_2, total B, BZ_1E_1, and MBC at Z_1 and Z_2 are only important predictors which can explain 99% of total variance. Two regression equation were resulted for yield with explainable variation of 99 %. For both the equation, the best predictor variables are NFB at Z_1, total B, PPO, MBC at Z_2 and PSM at Z_2.

The overall results reveal that the distribution of various fractions of B (HCC, MCC and MH-3 extractable B) was varied with types of soils and no extractable B has been found to be suitable for all types of soils. The transformation of B with particular reference to adsorption reactions varied with soil types and organic matter application, being higher with soils supplied with organic matter by influencing adsorption maxima and constant related ~~by~~ to bonding energy. Transformation of HCC, MCC and MH-3 extractable B and changes in soil biological indices (PSM,PSC,NFB,NFC and MBC etc)due to interaction with other nutrients (S and Zn) and organic matter have been found to be varied significantly , being varied with greater magnitude when B interacted with organic matter.

As regards to fractions of B in rhizosphere (R) and non-rhizosphere (NR) soils, the HCC, MCC extractable B were recorded higher in rhizosphere while that of the MH-3 extractable B was recorded highest in non-rhizosphere with the simultaneous improvement in soil biological indices especially in the rhizosphere. The yield and quality of rape was recorded highest when NPK (80 : 40 : 40), 0.5 kg ha^{-1} and organic matter at 5 t ha^{-1} were applied ~~togetherly~~ in combination.

Chapter VIII

Future Scope of Research

Future Scope of Research

Based on the available information so far collected about the distribution, behaviour of B in soils and plants, extracting reagents for B, adsorption of boron etc. in the form of review of literature, the following research gaps have been identified and subsequently further research should be concentrated on those aspects in future to fulfill the objectives.

- Distribution of boron has been studied with very limited number of soil samples and such study should be carried out extensively taking large number of soil samples covering all agro-climatic zones of West Bengal.
- Interaction between B and Zn, B and S and B and organic matter have been studied taking of two soils and hence these studies should be further undertaken taking soils from different agro-climatic zones and different other interactive nutrient elements.
- In the present research programme only three fractions of boron were studied and hence, some other fractions of boron taking other appropriate extractants should be given an emphasis on a priority basis.
- Very few biochemical and microbiological parameters relating to boron both in soils and plants were studied and hence an emphasis should be given to study those parameters in details taking large number of diversified type of soils taking leguminous and cereals as test crops.

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