BORON STATUS AND TRANSFORMATION IN RELATION TO CAULIFLOWER (*Brassica oleracea* L. var. *botrytis*) GROWTH AND YIELD IN SOME SOILS OF HIMACHAL PRADESH

THESIS

By

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This thesis

is

dedicated

to my

respected teacher,

Dr. M. Haldar,

Papa ji, Mammi ji

and

Dadi Ji

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CERTIFICATE - I

This is to certify that the thesis entitled **"Boron status and transformation in relation to cauliflower (*Brassica oleracea* L. var. *botrytis*) growth and yield in some soils of Himachal Pradesh"**, submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Soil Science** of Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mr. Girish Chander** son of **Sh. Mahesh Chander** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

TSVerma
(T.S. Verma)
Chairman,
Advisory Committee

Place : Palampur
Dated: the 17th June, 2004.

CERTIFICATE - II

This is to certify that the thesis entitled **"Boron status and transformation in relation to cauliflower (*Brassica oleracea* L. var. *botrytis*) growth and yield in some soils of Himachal Pradesh"** submitted by **Mr. Girish Chander** son of **Sh. Mahesh Chander** to the Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Soil Science** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Place : Palampur
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Chapter-I

INTRODUCTION

It is rightly said that, "Everything else can wait but not agriculture". Despite great agricultural advances in the past, millions still go hungry. The problem is further compounded by the fast growing human numbers. We have no option except to produce more on less land. The only way to make this possible is to spur on an evergreen revolution, rooted in the principles of ecology, economy and equity, so very fundamental to sustainable agriculture. Due to green revolution, during the past four decades, spectacular progress has been achieved in agricultural production in the country. But if the green revolution becomes a greed revolution and we start over-exploiting our soil resources, then surely we are entering an era of agricultural disaster, not progress. An aspect of concern in recent years is that crop productivity has decelerated as compared to that obtained in eighties. One of the reasons for the productivity improvement not being able to keep pace with time is that our attention for fertilization of crops is primarily on three major nutrients namely, nitrogen, phosphorus and potassium. The problem of micronutrient application has not received desired attention. With the cultivation of fertilizer responsive high yielding varieties of crops throughout the year causes serious depletion of limited micronutrient reserves in soil which is subsequently manifested in the form of showing a deficiency of micronutrients and reduction in crop yields. The problem seems to be accentuated due to greater and greater use of high analysis chemical fertilizers with lesser and lesser use of bulky organic manures and farm wastes in the fields. In the context of yet unharnessed yield potential of several crops grown in the country, the target to feed a billion population is very much attainable through better management of agricultural production system. Proper nutrient management of the crops is one important factor in the said system.

Boron is one of the essential micronutrients(Warington, 1923) required for normal growth and development of crop plants and thereby in crop production. Boron-deficiency decreases or inhibits the growth of vegetative and reproductive plant parts, depending on the timing and extent of B-deficiency. During vegetative growth, stunted root and shoot tips are commonly observed in severely B-deficient plants. Several physiological impairements as a result of B-deficiency were reported by Parr and Loughman (1983), such as sugar transport, cell wall synthesis, lignification, cell wall structure, carbohydrate metabolism, RNA metabolism, respiration, indole acetic acid (IAA) metabolism, phenol metabolism and membrane integrity. In addition, it has been reported that B-deficiency may impair ascorbate metabolism (Lukaszewski and Blevins, 1996) and induce oxygen activation (Marschner, 1995). So for, the well described roles of B are its involvement in (a) cell wall intactness and synthesis, possibly by formation of B-pectin complexes (Loomis and Durst, 1991; 1992; Hu *et al.*, 1996) and (b) plasma membrane integrity (Shelp, 1993; Cakmak *et al.*, 1995; Marschner, 1995). Moreover, B-toxicity is also an important disorder which can adversely limit plant growth. Although of considerable importance, our understanding of B-toxicity is rather fragmented and limited.

Boron occupies a unique position among the essential nutrients, since it is the only element which is present in soil solution, chiefly as non-ionised molecule, $B(OH)_3$ over the pH range (neutral or slightly acidic) suitable for plant growth (Raven, 1980). Because of its non-ionic nature, it may be leached rapidly from soil solution on release from soil minerals, organic matter and other adsorptive surfaces. This is the main reason for the occurrence of widespread deficiency of this element. Moreover, there is a relatively small range between the B levels causing deficiency and that resulting in toxicity symptoms in plants (Keren and Bingham, 1985), therefore, an application of B only slightly above the optimum level proves to be extremely toxic to plants. All these make the element difficult to manage in the field.

Among the micronutrients, B-deficiency is reported to be the most widespread in the world (Tisdale *et al.*, 1995). Himachal Pradesh is also not an exception in this respect (Kapur and Dev, 1977; Bhandari and

Randhawa, 1978, 1985; Bhandari and Tripathi, 1979). Shillanpaa (1982) concluded that B-deficiency would be possible on crops at some locations in almost every country but the likelihood of deficiency was greater in several countries in the Far-East including India. There are only a few regions in the world where B-deficiency occurs sufficiently frequently on crops, elsewhere, B-deficiency, exists on relatively small areas and is more dependent on local conditions and crops (Shorrocks, 1997).

Boron-deficiency in plants may be corrected through application of B-fertilizers. Efficient recovery of soil applied fertilizers by plants is desirable but seldom possible. Many soil and plant factors are involved in reduced recovery of added fertilizer. Boron-adsorption on the surfaces of colloidal materials largely regulate B-concentration in soil solution. The use of organic manures may influence the transformation of essential plant nutrient elements in soil and thus, their availability to crops grown thereon. Soil organic matter adsorbs more B than mineral soil constituents on a weight basis (Yermiyaho *et al.*, 1988; Gu and Lowe, 1990). Moreover, added organic matter may coat the B fixing mineral surfaces by soluble organic compounds which may increase B-efficiency in soil. Also, it is well established fact that much of the B in soil is associated with organic matter in tightly bound compounds that are formed within growing plants themselves, which is released in available form by microbial action when added to the soil (Berger, 1962; Berger and Pratt, 1963).

Among different species, *Brassica sp.* has high B requirement. Cauliflower (*Brassica oleracea* L. var. *botrytis*) is one of the most important sp. of this genera grown in India. In Himachal Pradesh, its importance is much more as an off-season vegetable, as it fetches remunerative price to the farmers of the Pradesh and improve their economic status. Though, the average cauliflower yield of 18.2 Mt ha^{-1} in H.P. (Anonymous, 2002) is quite comparable to that of 18.5 Mt ha^{-1} at national level (Anonymous, 2003), however, considering the agroclimatic conditions in the state, there is vast scope to further improve its productivity. The cauliflower crop in H.P. often shows the deficiency symptoms of boron (Bhandari and Thakur, 1985), consisting of browning of the curd, marginal mottling of the leaves and hollow condition of the stem. These disorders render curds unfit for human consumption and reduce the curd yield considerably. No doubt, B is an essential constituent of the soil solution for normal plant growth, but the difference between adequate and toxic concentration is very narrow. So, at its high level, plants develop B-toxicity symptoms characterized by poor plant vigour, stunted growth, small cup shaped leaves, leaf necrosis at the tip and margins, impaired head formation or formation of tiny brown coloured heads.

The bibliographical antecedents in scientific literature on the B status in H.P. soils and the availability of native as well as applied B as influenced by the application of organic matter and subsequently their concentration and uptake in different parts of the vegetables, in general, and cauliflower in particular, are scanty. Therefore, to elucidate the problem properly, a study entitled, "Boron status and transformation in relation to cauliflower (*Brassica oleracea* L. var. *botrytis*) growth and yield in some soils of Himachal Pradesh" was undertaken with the following main objectives:

1. To screen out the representative soils of cauliflower growing belt of Himachal Pradesh with respect to their available-B content.
2. To study the transformation of B as influenced by organic matter in laboratory-incubation.
3. To study the concentration and uptake of B by cauliflower in green-house experiment under the treatment combinations studied in laboratory-incubation.

REVIEW
OF
LITERATURE

Chapter-II

REVIEW OF LITERATURE

In this chapter, a critical review of research, related to the present study is presented under the following heads:

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2.1 Boron availability in Indian soils

A knowledge of status and distribution of available-B in soils is essential for the proper management of soils with regard to its deficiency and toxicity. There have been numerous individual studies into the B levels in soils, however, an all India picture of the B fertility status of Indian soils is far from available at present. Literature pertaining to soil fertility surveys in Indian soils has shown wide variations in available-B as discussed below:

Soils were analysed in India way back in 1945 when Ghani and Haque reported that available-B in Bengal soils ranged from 0.40 to 2.00 mg kg^{-1}. Similarly, in hill soils of U.P. (Almora, Pithoragarh and Chamoli districts), available-B varied from 0.30 to 3.20 mg kg^{-1} (Rawat and Mathpal, 1981) and in upland soils series of Tripura, it varied from 0.40 to 2.70 mg kg^{-1}, whereas, in lowland soils series, it varied from 0.30 to 1.50 mg kg^{-1} (Datta and Munna Ram, 1993). However, water soluble-B in various cultivated soils from different regions of Udaipur ranged from 0.08 to 0.42 mg kg^{-1} (Baser and Saxena, 1967). Similarly, Tiwari *et al.* (1988) reported that available-B ranged from 0.16 to 0.56 mg kg^{-1} in Rajghat command area in Madhya Pradesh. In Bhind district of M.P., hot water soluble-B ranged from 0.19 to 0.55 mg kg^{-1} (Sharma *et al.*, 1995). In the surface soils of Sikkim collected from varied altitudinal zones ranging from 300 to >2700 m, the available-B ranged from 0.05 to 0.80 mg kg^{-1} (Avasthe and Avasthe, 1995).

In soils belonging to Ganga and Vindhya alluvium families in the district of Murshidabad in West Bengal, water soluble-B ranged from 0.31 to 0.78 mg kg^{-1} (Bhattacharjee, 1956). In Gengetic alluvium soils in Ballia, Jaunpur and Varanasi districts of U.P., immediately available-B content ranged from 0.04 to 3.00 mg kg^{-1} (average 0.12 mg kg^{-1}) in alkali soil profiles and from 0.04 to 0.17 mg kg^{-1} (average 0.09 mg kg^{-1}) in adjoining cultivated profiles. The absolutely available-B content varied from 0.18 to 1.10 mg kg^{-1} (average 0.50 mg kg^{-1}) and 0.18 to 0.82 mg kg^{-1} (average 0.37 mg kg^{-1}), respectively (Singh and Singh, 1967). Similarly, Chakraborty *et al.* (1982) reported that in soil samples representing old alluvium of Nowgong in Assam, available-B varied from 0.02 to1.10 mg kg^{-1} (average 0.34 mg kg^{-1}), whereas, in soil samples representing new alluvium of Tejpur, it varied from 0.33 to 1.25 mg kg^{-1} (average 0.88 mg kg^{-1}). The 0.02 M $CaCl_2$ extractable-B content in cultivated acidic alluvial soils of Coochbehar, Jalpaiguri and West Dinajpur was in the range of traces to 1.14 mg kg^{-1} (average 0.36 mg kg^{-1}), traces to 1.02 mg kg^{-1} (average 0.29 mg kg^{-1}) and 0.19 to 0.47 mg kg^{-1} (average 0.33 mg kg^{-1}), respectively (Mondal *et al.*, 1991). However, in soil samples from recent alluvium non-calcareous soils comprising Purnea, Saharsa and Katihar districts of Bihar, the available-B ranged from 0.20 to 5.60 mg kg^{-1} (Bhogal *et al.*, 1993). Similarly, Singh and Nayyar (1999) reported that in some alluvium derived arid and semi-arid soils of Punjab, available-B content in Ferozepur district ranged between 0.22 to 2.40 mg kg^{-1} (average 0.92 mg kg^{-1}) and in Faridkot district between 0.20 to 3.85 mg kg^{-1} (average 1.53 mg kg^{-1}).

In red loam soils (hyperthermic ultic paleustalf) from cultivated fields of Ranchi, Singh and Sinha (1987) found available-B in the range of 0.15 to1.26 mg kg^{-1} (average 0.64 mg kg^{-1}). While, Mahapatra and Sahu (1996) studied soil samples covering three major soil groups of Orissa viz., red (Alfisols), lateritic (Inceptisols and Ultisols) and alluvial (Entisols) and reported that mean available-B (district-wise) ranged from 0.10 to 0.13 mg kg^{-1} in red soils, 0.16 mg kg^{-1} in lateritic soils and 0.11 to 0.41 mg kg^{-1} in alluvial soils, indicating thereby the deficiency of B in these soils.

The water soluble-B content of India's desert soils is quite high, varying from 2.60 to 12.20 mg kg^{-1}. The surface desert soils of West Rajasthan contain on an average 3.50 mg kg^{-1} of water soluble-B, and that of central Rajasthan, 6.60 mg kg^{-1} (Satyanarayan, 1958). In arid to semi-humid climatic zones in Haryana and Punjab, Singh (1970) found immediately available-B to vary from 0.13 to 2.13 mg kg^{-1} (average 0.68 mg kg^{-1}) and absolutely available-B from 0.50 to 5.75 mg kg^{-1} (average 2.21 mg kg^{-1}) in surface soils. Similarly, in semi-arid region of Rajasthan i.e. Nawa tehsil of Nagaur district, the available-B ranged from 0.20 to 2.00 mg kg^{-1} with a mean value of 0.68 mg kg^{-1} (Sharma *et al.*, 2003).

Hot water soluble-B ranging from 0.96 to 1.80 mg kg^{-1} in irrigated medium black surface soils in Rajasthan was reported by Nathani *et al.* (1969). In shallow black soil zone of Madhya Pradesh, available-B ranged from 0.30 to 3.89 mg kg^{-1} (average 1.10 mg kg^{-1}) in soils from Betul district, from 0.30 to 2.41 mg kg^{-1} (average 1.05 mg kg^{-1}) in soils from Chhindwara district and from 0.16 to 6.23 mg kg^{-1} (average 1.01 mg kg^{-1}) in soils from Seoni district (Rai *et al.*, 1972). In another study with medium black calcareous soils from 28 places in Junagarh and Rajkot districts in Western Gujarat, Hadwani *et al.* (1989) reported that available-B in surface soils varied from 0.85 to 1.48 mg kg^{-1}.

Mathur *et al.* (1964) reported that in Jodhpur and Pali districts of Rajasthan, the available-B ranged from 1.50 to 2.40 mg kg^{-1} in surface soils irrigated with waters containing high B, while, it varied from 0.20 to 0.50 mg kg^{-1} in unirrigated surface soils. Similarly, hot water soluble-B ranged from 0.90 to 3.20 mg kg^{-1} in surface soils of Kota and Bhilwara irrigated with saline waters high in B (Paliwal and Mehta, 1973).

In a study of some acidic Inceptisols of the Northern part of West Bengal, Mandal and De (1993) reported that the amounts of B extracted by different extractants viz., tartric acid, ammonium acetate, mannitol calcium chloride and hot calcium chloride in the surface soils ranged from 0.16 to 1.35 (average 0.35 mg kg^{-1}), 0.07 to 0.48 (average 0.32 mg kg^{-1}), 0.15 to 0.49 (average 0.28 mg kg^{-1}) and 0.08 to 0.50 mg kg^{-1} (average 0.27 mg kg^{-1}), respectively. Similarly, in a study of acid sedentary soils of Chotanagpur region, Ghosh and Sarkar (1994) found available-B of Jarsol-2 series of Subernarekha command area of Singhbhum to range from 0.01 to 0.58 mg kg^{-1} (average 0.24 mg kg^{-1}), whereas, in Debatoli series of Jumar river catchment area of Ranchi, it varied from 0.20 to 1.78 mg kg^{-1} (average 0.77 mg kg^{-1}).

Gandhi and Mehta (1958) in a study in Gujarat and Saurashtra found that in sandy or sandy loam soils of Khaira, Baroda, Ahmedabad, Mehsana and Sabarkantha districts have a range of 0.20 to 1.50 mg kg^{-1} water soluble-B. In calcareous clay loam or sandy loam Saurashtra soils and typical Broach and Surat district soils also have the same range of water soluble-B leaving aside the exceptional cases of soils of Harni in Baroda district with 3.50 mg kg^{-1} and Jadeshwar in Saurashtra with 3.00 mg kg^{-1}, which were highly saline. Bansal *et al.* (1991) reported that in calcareous and alkaline loamy sand to loam surface soils from different locations in Kapurthala district of Punjab, hot water soluble-B ranged from 0.30 to 2.00 mg kg^{-1}. Similarly water soluble-B in normal soils of Punjab varied from 0.15 to 2.44 mg kg^{-1}, whereas in saline-alkali surface soils, it varied from 3.00 to 11.80 mg kg^{-1} (Singh and Kanwar, 1961). The B-concentration of the saturated extract of cultivated saline-alkali surface soils of Delhi in Khanjawal block ranged from 0.80 to 3.20 mg kg^{-1} (Paliwal and Anjaneyulu, 1967). Similarly, Sharma and Shukla (1972) reported that water soluble-B varied from 0.11 to 1.68 mg kg^{-1} in surface alkaline soils of Bhuna block in Haryana. In Mg rich saline-alkali areas of South-West tracts of Bihar, the water soluble-B in surface soils was ranging from 1.70 to 2.00 mg kg^{-1} (Singh and Singh, 1972). Similarly in a profile study, Talati and Agarwal (1974) reported that available-B varied from 0.11 to 2.00 mg kg^{-1} (average 1.08 mg kg^{-1}) in normal surface soils and was found to be 1.80 mg kg^{-1} in sodic soil, 1.55 mg kg^{-1} in saline-sodic and 2.25 mg kg^{-1} in saline soil. In Malerkota block of Sangrur district of Punjab, the concentration of water soluble-B in surface soils of saline-sodic, sodic and normal soils ranged from 1.90 to 4.00 mg kg^{-1} (average 2.90 mg kg^{-1}), 0.80 to 2.00 mg kg^{-1} (average 1.20 mg kg^{-1}) and 0.40 to 1.40 mg kg^{-1} (average 0.80 mg kg^{-1}), respectively (Singh and Randhawa, 1977). Similarly, in surgacane growing soils of Pune district in Maharashtra, rich in calcium carbonate, hot water soluble-B varied form traces to 2.06 mg kg^{-1} and 0.21 to 3.61 mg kg^{-1} in soils from Haveli and Baramati tehsils, respectively. The average available-B was 1.29 mg kg^{-1} considering both the tehsils (Shinde *et al.*, 1979). In Delhi soils, Gajbhiye *et al.* (1980) found that the content of water soluble-B varied from 0.43 to 1.29 mg kg^{-1} (average 0.73 mg kg^{-1}) in non-saline and from 0.43 to 2.58 mg kg^{-1} (average 1.21 mg kg^{-1}) in low saline soils. The average concentration of hot water soluble-B in surface soils from salt affected areas in Punjab was 5.20 mg kg^{-1} as reported by Sharma and Bajwa (1989).

Grewal *et al.* (1969) reported that available-B content in surface soils of grey brown podzolic soils in Manali, Palampur and Nagrota in H.P. varied from 0.56 to 0.75 mg kg^{-1} (average 0.64 mg kg^{-1}), whereas in non-calcic brown soils in Katrain, Kullu and Bajaura, it varied from 0.56 to 0.88 mg kg^{-1} (average 0.76 mg kg^{-1}). The available-B content in tropical arid brown soils, arid brown soils and sierozem soils in Punjab and Haryana was 0.68 to1.98 mg kg^{-1} (average 1.21 mg kg^{-1}), 1.22 to 5.00 mg kg^{-1} (average 2.76 mg kg^{-1}) and 1.96 to 2.80 mg kg^{-1} (average 2.44 mg kg^{-1}), respectively. The available-B in surface apple orchard soils of Kullu district of H.P. fell in the range of 0.05 to 0.70 mg kg^{-1} with an average value of 0.31 mg kg^{-1} (Kapur and Dev, 1977), whereas in Shimla soils, it varied from 0.10 to 1.00 mg kg^{-1} with a mean value of 0.50 mg kg^{-1} (Bhandari and Randhawa, 1978, 1985). In Sproon valley of Himachal Pradesh, hot water soluble-B varied from 0.20 to 0.80 mg kg^{-1} with a mean of 0.40 mg kg^{-1} (Thakur and Bhandari, 1986). The available-B content in the soils of zone-I (low hills, sub-tropics) of Himachal Pradesh varied from 0.60 to 1.30 mg kg^{-1} with a mean value of 0.90 mg kg^{-1}, while, in zone-II (mid-hills sub-humid), it varied between 0.60 to 1.80 mg kg^{-1} with a mean value of 0.99 mg kg^{-1} (Mahajan, 2000). Similalry, in the apple belt of district Shimla, Kullu, Mandi and Chamba, the available-B ranged from 0.12 to 0.78, 0.16 to 1.09, 0.40 to 0.74 and 0.36 to 1.25 mg kg^{-1} with a mean value of 0.40, 0.56, 0.57 and 0.63 mg kg^{-1}, respectively (Singh, 2002).

2.2 Effect of organic matter on the availability of boron in soil and plant

Organic colloids are generally known to function as a sink for nutrient 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 availability of the bonded nutrients to plants and microorganisms. Although most cultivated soils contain hardly 1-5 per cent organic matter, this small amount can significantly modify the chemical properties of soil and thereby affect the availability of B in soil (Das, 2000). The greater availability of B in surface soils compared with subsurface soils is undoubtly related to the higher quantity of organic matter in the former. In this regard, Tisdale *et al.* (1995) reported that application of organic materials to soils could raise substantially the concentration of B in plants and even cause phytotoxicity.

Berger and Truog (1945) reported an apparent correlation between organic matter and availability of B in acid soils. They found higher amount of available-B in soils having higher organic matter content. Correlation coefficient between organic matter and available-B in both virgin and cultivated surface samples were highly significant. They further reported that available-B decreased with increasing acidity probably due to decrease in organic matter with increasing acidity. Similar observations have also been recorded by Gupta (1968), Evans (1987) and Goldberg

(1997). Ghani and Haque (1945) although did not observe any correlation between available-B and organic matter content of the Chittagong, Midnapore and Sunderban soils, but obtained higher values of available-B on ignition of those soils and attributed this increase because of B present in organic combination. Similarly, Bansal *et al.* (1991) reported that organic matter content did not influence significantly the availability of B.

Olsen and Berger (1946) observed that with the removal of organic matter, the clay separate fixed most of the soluble-B and rendered it unavailable to the plants. Berger (1949) reported that in the presence of free Ca, B was fixed in a temporary unavailable form, partially by organic matter and partially by minerals.

Parks and White (1952) suggested a view of the B-retention by the humus system and the chemical reaction between B and di-hydroxy organic compounds that boron united with favourable diols of the organic matter or those which were gradually released as intermediates of the microbiological breakdown of organic matter in soil. The formation of these complexes has been observed using nuclear magnetic resonance, spectroscopy (Coddington and Taylor 1989).

Page and Paden (1954) reported that in uncropped acid soils, there was a positive relation between water soluble-B and organic matter content of the soil. Satyanarayan (1958) studied desert soils of arid and semi-arid regions of India and observed a significant positive correlation between available-B and organic matter. In a similar type of study, Yermiyahu *et al.* (1988) observed that sorption of B on organic matter was significantly higher than on clay at similar pH levels and total-B concentration. It was also found that B-sorption on composted organic matter (simulation to soil organic matter) increased with pH (upto atleast pH 8.9) and that the sorption model proposed by Keren *et al.* (1981) can be used to describe B-sorption on organic matter. It was also observed that the sorptivity of the organic matter for B was much higher than that of Montmorillonite, Kaolinite or Illite (Keren and Bingham, 1985). To the contrary, Marzadori *et al.* (1991) showed that the amount of B-sorption was considerably greater after the organic matter had been removed from the soil and a hysteric trend was observed. Similar type of observation was made by Singh and Singh (1967) where they observed a significant negative correlation between available-B and organic matter content in some alkali soils and adjoining soil profiles of Uttar Pradesh, whereas, Gandhi and Mehta (1958) found no relationship between available-B and organic matter content in both Gujarat and Saurashtra soils.

Miljkovic *et al.* (1966) indicated that water soluble-B 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 were contrary to those reported by some European workers (Katalymov, 1960; Lehr and Henkens, 1962). Baser and Saxena (1967) studied thirty soils from Mewar region of Rajasthan for their B status and found that water soluble-B was significantly correlated with organic matter content of soil. Similar type of observation was made by Gupta (1968). Martin (1968) reported that multiple and partial correlation data depicted that contents of water soluble-B increased with an increase in soil organic matter content.

Okazaki and Chao (1968) reported that organic matter was one of the main sources of B in acid soils as relatively little B-adsorption on mineral fraction occurred at low pH levels. Harda and Tamai (1968) studied correlation between B-adsorption of soil and organic matter content. They found that destruction of organic matter led to an increase in B-adsorption of soils and volcanic ash soils adsorbed apparently more B than the non-volcanic ash soils. Consequently, it was assumed reasonably that organic matter acts rather to decrease B-adsorption of soils by forming clay-metal-organic matter complexes in soils, especially in volcanic ash soils.

However, no correlation between available-B and organic matter was observed in soil profiles of different agroclimatic soil zones of Punjab, Haryana, Himachal Pradesh (Grewal *et al.*, 1969), and in irrigated medium black soils of Rajasthan (Nathani *et al.*, 1969). Similarly, Singh (1970) found no significant correlation between organic-carbon and available-B in arid and semi-arid soils of Haryana and Punjab. Singh and Sinha (1976) also reported no relation between available-B and organic-carbon, but reported that B tended to increase with the increase of organic-carbon in North-Eastern part of Bihar. Lodha and Baser (1971) reported that the available-B had positive relationship with organic matter content of soils, although relationship obtained were not found significant in most of the soil groups except mixed red and black, and grey brown soils where significant positive relationship were obtained. Available-B was related positively with organic-carbon in shallow black soils of Madhya Pradesh (Rai *et al.*, 1972), and in Bhuna soils of Haryana (Sharma and Shukla, 1972). Singh and Singh (1972) studied Mg rich saline-alkaline soils of South-West tracts of Bihar and observed that no significant correlation existed between organic-carbon and water soluble-B. Singh and Randhawa (1977), however, observed a significantly negative correlation between organic-carbon and water soluble-B in Sangrur district of Punjab.

In an experiment conducted by Purves and Mackenzie (1973), it was reported that municipal compost (the municipal compost employed contained 34 to 100 mg kg^{-1} water extractable-B) applied to soil had produced significant enhancement on available-B in soil and a significant increase in the uptake of B by lettuces, beans, potatoes and peas. Compost treatment at the rates of 50-100 tonnes was associated with severe phytotoxic effects in the experiment with beans and with yield responses in the experiments with peas and potatoes. Valk *et al.* (1989), however, reported that increasing organic matter in the soil, without adding trace element B, had adverse effect on tulip bulb yield, dry matter, B-content, the percentage of malformed (B-deficient) flowers and leaves from these bulbs and was associated with reduction in flower B content and increase in B-deficiency symptoms. Carino *et al.* (1990) reported B-deficiency in grapevine crop grown in soils low in organic matter content and observed correlation between available-B content and organic matter content in soil. Similarly, Adams *et al.* (1991) reported that hot water soluble-B was significantly correlated with soil organic-carbon content and dry matter yield and B-uptake by radish. Hu and Brown (1997) reported soil organic matter content as one of the most important environmental factor, which directly influences the absorption of B by plant roots. On the contrary, Blatt and McRae (1998) observed no significant change of B-concentration in carrot and cabbage leaves due to addition of different organics in soil.

Paliwal and Mehta (1973) reported that organic matter modified the toxic effect of B in problematic soils of Kota and Bhilwara regions of Rajasthan and retention of B increased with an increase in the organic matter content of the soils. In a similar type of experiment conducted by Pleseviciene *et al.* (1997) in some moderately podzolized dermopodzolic soil in Lithuania, it was reported that the amount of mobile B in soil increased as a result of external application of manure @ 120 t ha^{-1}. To the contrary, Talati and Agarwal (1974) observed that organic matter content of North-West Rajasthan soil did not give any significant relationship with available and total B content. Singh and Sinha (1975) reported that the sandy soils of North-West Bihar fixed B to the extent of 30 to 80 per cent and the fixation was found to enhance with the increase in organic matter content. On the contrary, Khetawat and Vashistha (1977) depicted no significant correlation between available-B and organic-carbon in soils from sugarcane growing areas of Pune district of Maharashtra. Similar type of observations were made by Chavan *et al* (1980) and Rawat and Mathpal (1981). In Assam soils, Chakraborty *et al* (1982) reported a significant relationship between total-B and organic matter content of the soil, whereas, available-B did not show any relationship with organic matter. Awad and Mikhael (1980) studied B contents and its relationship with organic matter in Egypt soils representing two transects and found that correlation coefficient between organic matter and hot water soluble-B was positively significant in the Burullus transect.

Garai and Haldar (1985) while studying the effect of organic matter on availability of hot water soluble-B in an alluvial soil observed that the application of farmyard manure resulted in an increase in the content of hot water soluble-B in soils. Combined application of B with farmyard manure recorded further increase in the hot water soluble-B in the soil. Combined application of B and starch recorded almost a similar trend.

Singh and Sinha (1987) analysed red loam soils of Chotanagpur region and found no significant correlation between available-B and organic matter content of the soil. Tiwari *et al.* (1988) also observed no significant correlation between available-B and organic-carbon content, in soils of Rajghat command area of Madhya Pradesh.

In a study of depthwise distribution of different forms of B in relation to soil properties in medium black calareous soil of Western Gujarat, Hadwani *et al.* (1989) found that there existed a significant positive correlation between available-B and organic-carbon. Similar type of observation was made by Patil *et al.* (1989). In soil samples collected from two volcanic areas in Italy, Silva *et al.* (1990) found that water soluble-B was strongly correlated with organic matter, free metal oxides and to a lesser extent with pH. However, in cultivated semi-arid soil profiles of Central-Western Spain, Moyano *et al.* (1990) reported that the presence of organic matter had a slight influence on water soluble-B content.

Sarkar and Das (1990) conducted an experiment on the effect of removal of organic matter on B-adsorption by some soils of West Bengal. They reported an increased B-adsorption capacity when they were made organic matter free. But Simarad *et al.* (1996) reported B-deficiency in clay, which is rich in organic matter in Eastern Canada.

In an experiment conducted by Pakrashi and Haldar (1992), it was reported that application of organic matter at higher level maintained a relatively higher proportion of B in hot water soluble form, the extent of increase being more when organic matter at higher level was applied to soil under 60 per cent water holding capacity moisture condition. Similarly, Tapan Adhikari *et al.* (1993) found that application of organic matter increased the extractable-B content of the soils irrespective of the nature of the extractants and the soil type. The increase in the availability of B in the soils might be attributed to a possible complexation of the element by soluble organic compounds produced by the decomposition of added organic matter by the microorganisms.

Bhogal *et al.* (1993) observed a positive and significant relationship between available-B and organic-carbon content in soils of Bihar. Mandal and De (1993) also found that B showed a highly significant positive correlation with organic-carbon in some acid Inceptisols of India. Ghosh and Sarkar (1994) arrived at a similar conclusion in their studies with acid sedentary light textured soils of Bihar. Sharma *et al.* (1995) reported a significant and positive relationship between available-B and organic-carbon in soils of Bhind district of Madhya Pradesh. Similarly, Saha and Haldar (1996) found that available-B was positively correlated with organic-carbon in some soils of terai zone of West Bengal. Similarly, Sharma *et al.* (2003) recorded a significant positive correlation of available-B with organic-carbon in semi-arid region soils of Rajasthan. But Mondal *et al.* (1991) observed an inverse relationship between available-B and organic-carbon in North Bengal terai region soils, but the relationship was not statistically significant. But Mahaptra and Sahu (1996) failed to observe any significant relationship between them in red, lateritic and alluvial soils of Orissa.

Yermiyahu *et al.* (1995) reported a significant decrease in B concentration in soil solution, especially in a pH range of 7.0 to 8.5 due to the presence of organic matter in soil. This might be the result of high rate of adsorption of B by organic matter in soil at that particular pH range. To the contrary, Marzadori *et al.* (1991) showed that the amount of B-sorption was considerably greater after the organic matter had been removed from the soil.

Singh and Nayyar (1999) observed B-deficiency in crop plants grown on light textured sandy soils, calcareous soils and soils with relatively low amounts of organic matter. Bansal (1999) reported that increased B-adsorption in the order of black > alluvial > red soil was according to their cation exchange capacity, organic matter and nature of clay minerals.

It was reported that organic matter addition to B-deficient soil increased the utilization and recovery of applied-B (Sakal, 2001). In this case complexation of added-B and coating of the surface of Fe and Al oxides by soluble organic compounds might be the possible reason for increasing B-efficiency in soil.

2.3 Effect of texture on the availability of boron in soil and plant

The finer fractions of the soil are known to be the seat of all chemical reactions and also the source of nutrient elements in soil.

Olsen and Berger (1946) reported that clay separate contained the highest percentage of available-B, the silt a lesser amount, and the sand the least. Similarly, Harda and Tamai (1968) reported that when soils were fractioned into sand, silt and clay separates, the clay fractions showed a relatively large B-adsorption as compared with the other two fractions and clay fraction from the volcanic ash soils adsorbed apparently more B than from non-volcanic ash soils. Removal of inorganic colloids led to a considerable decrease in B-adsorption of soils. Consequently, it was assumed that inorganic colloids participate to a great extent in B-adsorption of soils. Gupta (1968) also found that in general, the B-content was lower in coarse textured soils than in fine textured soils. Bansal *et al.* (1991) concluded that coarse textured soils having pH below 8.5 are more prone to B-deficiency.

Kubota *et al.* (1948) found that the rate of B movement in soils was related primarily to the soil texture. Where the soil was uniformly light textured throughout the profile, much of applied-B moved to a depth of 24 inches or deeper in six months. In the heavier soils, much of it was found at depths ranging to approximately 12 inches. Bhattacharjee (1956) reported that the water soluble-B had a positive significant correlation with the per cent silt and clay content in soils of Mushidabad, West Bengal. Similar results were found by Paliwal and Anjaneyulu (1967) in some saline alkali soils of Delhi, and Sharma *et al.* (2003) in semi-arid soils of Rajasthan.

Wear and Patterson (1962) reported that alfalfa grown on the coarse textured soil had the highest uptake of B per unit of water soluble-B in the soil and the plants from the fine textured soil had the least. Singh and Singh (1967) reported no significant correlation between finer fractions of the soil and B availability in alkali and adjoining soils of Uttar Pradesh. Nathani *et al.* (1969) found available-B to correlate with clay content in medium black soils. Similar results were obtained by Singh (1970), Sharma and Shukla (1972) and Singh and Singh (1972) in Punjab and Haryana soils, in Bhuna soils of Haryana, and saline alkali soils of South-West tract of Bihar, respectively. Similarly, Paliwal and Mehta (1973) reported that water soluble-B increased with the fineness of the texture in Kota and Bhilwara regions of Rajasthan. Significant positive correlations between available-B and finer fractions of soil were observed in North-Western Rajasthan soils (Talati and Agarwal, 1974) and Punjab soils (Singh and Randhawa, 1977). Contrary to this, Singh and Sinha (1976) reported that available-B did not indicate any relationship with clay content of soil in North-Eastern part of Bihar, though it tended to increase with increasing clay content.

Singh and Sinha (1975) found that finer fractions of the soil were significantly correlated with B-fixation. Mehta and Paliwal (1977) also observed that B-adsorption increased with the fineness of texture in Rajasthan soils. Gupta (1980) further reported that adsorption capacity of B increased with fineness of texture. The adsorption of B by soils was more at higher concentrations of equilibrium solution, but the percentage of added-B adsorbed decreased with the increase in the concentration of equilibrium solution.

Gajbhiye *et al.* (1980) reported that the relationship between B and silt plus clay fractions of Delhi soils were positive and significant in both non-saline as well as in low saline soils. Awad and Mikhael (1980) reported highly signifiant positive correlation between hot water soluble-B and clay content in some selected soils of Egypt. Similar results have also been reported by Adams *et al.* (1991) in New Zealand soils.

Chakraborty *et al.* (1982) found that available-B was not related to texture in soils from Assam. Ghosh and Sarkar (1994) reported a insignificant negative correlation between available-B and clay content in acid sedentary soils of Chotanagpur region.

Keren *et al.* (1985) found that higher the clay content of the soil, the lower is the B activity in solution for any given amount of B added. It was suggested that the soil adsorption sites act as a pool to which B can be stored or removed depending on the change in solution B-concentration in soil. The B-uptake by plants was higher as the sand increases for any amount of B added. Similarly, Ryan (1989) reported that the freundlich isotherm constant, k for B-retention was correlated with clay content.

Mondal *et al.* (1991) found insignificant correlation of available-B with clay in some alluvial acidic soils of North Bengal. Mahapatra and Sahu (1996) reported no relationship between available-B and soil texture in soils of Orissa. However, Saha and Haldar (1996) showed a negative and significant correlation between clay content and extractable-B content in some terai zone soils of West Bengal.

2.4 Effect of soil reaction (pH) on the availability of boron in soil and plant

The availability of B in soil is altered by the pH condition of the soil (Goldberg, 1997), although the availability of the element in general is reported to be high under low pH condition.

Berger and Truog (1945) showed that increased pH (above 7.0) was important in reducing the quantity of available-B. Similar findings were reported by Kubota *et al.* (1948). Truog (1948) reported that the availability of B increased as the pH of the soil increased upto 5.

remained constant upto 7, and decreased beyond this level upto pH 8.8 and finally increased above pH 8.8. Jordan and Powers (1946) also reported that in highly alkaline soils, the available-B content was higher.

Ghani and Haque (1945) could not find any correlation between the pH and water soluble-B content in Bengal soils. Bhattacharjee (1956), however, reported a negative but insignificant correlation between the two in soils of Murshidabad, West Bengal.

Olsen and Berger (1946) reported that fixation of B increased rapidly as the pH was raised above 7, while below this point there was little or no correlation between pH and B-fixation. The amount of calcium salts added to a soil has little influence on the percentage of B fixed unless the addition of the calcium salts increased the pH above 7. Similarly, Singh and Sinha (1975) found that B-fixation showed a positive and significant relationship with the pH of the soil. Kanwar and Singh (1961) reported a positive and significant correlation between pH and water soluble-B in saline-alkali and normal soils of Punjab.

Wear and Patterson (1962) observed that as the acidity decreased from the pH values of 5 to 7, less B was available at any level of water soluble-B in soil and showed that the concentration of B in alfalfa at a given texture was higher per unit of hot water soluble-B at a lower pH than at a higher pH. Similarly, Gupta and McLeod (1977) reported a decreased B-uptake by alfalfa and rutabagas due to increased soil pH.

Mathur *et al.* (1964) reported that there was a significant positive correlation between the pH and available-B in soils under irrigation, while, no such effect was observed in un-irrigated tracts. Gupta (1968) did not find any relationship between hot water soluble-B and pH in soils from Eastern Canada. Paliwal and Anjaneyulu (1967) found no relationship of B with pH in saline-alkali soils of Delhi. Singh and Sinha (1976) reported similar findings in soils from North-Eastern part of Bihar.

Nathani *et al.* (1969) reported that in medium black soils, available-B was found to be positively correlated with pH. Singh (1970) observed highly positive correlation between pH and immediately available-B, and pH and absolutely available-B in arid and sub-humid soils of Punjab and Haryana. Ladha and Baser (1971) found positive correlation between pH and available-B content in different soil types and showed that with increase in pH, available-B content of soil increased and thus the relationship was significant in red and yellow soils. A similar relationship was reported in Bhuna soils of Haryana (Sharma and Shukla, 1972) and in shallow black soils of Madhya Pradesh (Rai *et al.*, 1972).

Paliwal and Mehta (1973) studied soil profiles in Kota and Bhilwara regions of Rajasthan. They reported that soil pH influenced the availability of B and generally soils of high pH contained more water soluble-B. A significant positive correlation was obtained between pH and water soluble-B in profile samples. Similar results were also reported by

Talati and Agarwal (1974) and Singh and Randhawa (1977) in North-West Rajasthan and Punjab soils, respectively.

Robertson *et al.* (1975) reported no close relationship between soil-B and soil pH in Michigan soils. The results of Awad and Mikhael (1980) also indicated no relationship between hot water soluble-B and pH in some selected soils of Egypt. McLean and Langille (1976), however, reported that the hot water soluble-B increased with rising percentage of organic matter and clay content, but decreased with rising pH.

Peterson and Newman (1976) concluded that a 2.5 fold drop in B-uptake by tall fescue occurred between pH 6.3 and 7.4 as compared with other pH levels (4.7-6.3) indicating substantial fixation of B.

Goldberg and Glaubig (1988) reported that B-adsorption increased at low pH, exhibited a peak near pH 8.0 and decreased at higher pH. Hu *et al.* (1988) reported that increased pH resulting from liming increased B-sorption. Similar type of observation was made by Goldberg and Glaubig (1986) & Barrow (1989).

Patil *et al.* (1989) observed that pH, EC, organic matter and texture of soils are the most predominant factors influencing B availability. Moyano *et al.* (1990) found that water soluble-B content in cultivated semi-arid soil profiles in Central Western Spain was related to pH in surface and sub-surface horizons.

Adams *et al.* (1991) extracted B from six Canterbury, New Zealand soils by four extractants and found no correlation with pH. On the contrary, Shuman *et al.* (1992) extracted B from soils of the major physiographic regions of Mid-Atlantic and South-Eastern states of USA by three different extractants and found positive correlation with soil pH. Similarly, Sharma and Bajwa (1989) and Sharma *et al.* (1995) found significant and positive relationship of available-B with pH in salt affected Punjab soils and soils of Madhya Pradesh, respectively.

Oyewole and Aduayi (1992) reported a negative correlation between water soluble-B and pH in soil culture. Similar type of observation was made by Sakal *et al.* (1993) in calcareous soils of North Bihar. Bhogal *et al.* (1993) in Bihar soils and Datta and Munna Ram (1993) in upland soils of Tripura also reported significant and negative correlation between available-B and pH.

Lehto and Malkonen (1994) reported a decrease in B concentrations in new needles (*Picea abies*) from 22 to 9 mg kg^{-1} as a result of increased pH of soil from 4.1 to 6.1 due to liming. Saha and Haldar (1998), reported that due to increase in pH of soil from initial value of 5.4 to near neutrality as a result of liming, the content of extractable native-B in soil increased.

Saha and Haldar (1996) reported that available-B correlated negatively and insignificantly with pH in some soils of terai zone of West

Bengal. Mondal *et al.* (1991) reported insignificant correlation of B with pH in some alluvial acidic soils of North Bengal. In semi-arid region soils of Rajasthan, Sharma *et al.* (2003) found that available-B correlated negatively with pH.

2.5 Boron availability in soil and plant as affected by other nutrient elements

2.5.1 Nitrogen

Scientific information on the effect of interaction between N and B in soil as well as plant is very meagre and non-voluminous.

Nusbaum (1947) observed increasing severity of B-deficiency symptoms with increasing application of either N or K. Contrary to this, Gupta *et al.* (1982) reported increased leaf tissue B concentration in crops grown on podzol soils with application of N fertilizers. Similarly Yang *et al.* (1989) found increased B- uptake by rapeseed at high N rates.

Tiwari *et al.* (1988) reported that variation in available-B content in surface as well as sub-surface soils of Madhya Pradesh was closely and inversely related to available-N contents. However, Sharma *et al.* (1995) did not show any significant relationship between available-B and N contents in Madhya Pradesh soils.

2.5.1 Phosphorus

In plants, P and B are reported to show similarities in biochemical behaviour. Both are adsorbed as inorganic anions or acids. In plant cell they occur as such or are bound largely by hydroxyl group of sugar forming phosphate and borate-esters (Mengel and Kirkby, 1979). Scientific information on the interaction of P and B on the availability of B in soil and plant are very limited and inconsistent.

Nusbaum (1947) in his studies of B-deficiency in sweet potatoes concluded that the effect of P on the availability of B in soil was not very direct and conspicuous, but there definitely existed a relationship between P and B with respect to deficiency of B, which was severe in case of low P in sweet potatoes.

Harda and Tamai (1968) determined statistically the phosphate sorption capacity of soil with B-adsorption by using soils widely different in texture, organic matter, sesquioxide, clay and kind of clay mineral. They reported a positive correlation between phosphate sorption capacity of soil and B-adsorption. These relationships implied that B was adsorbed on the same soil constituents as phosphate. Presence of various anions such as chloride, nitrate, sulphate, phosphate in soil affected the B-adsorption on clays. Goldberg (1997) reported that the presence of phosphate appreciably reduced B-adsorption both on clays and oxides, thus increased its availability in soil.

Stoyanov (1971) reported that high P increased the severity of B-deficiency in tobacco. On the contrary, Tanaka (1967) reported that with the increase of P supply in soil, there was an increase in B-uptake in case of radish. Bartlett and Picarelli (1973) in their study on the availability of B and P as affected by liming on acid soil reported that high rate of P application appeared to intensify toxicity of B to corn. Bennet and Mathias (1973) also worked on the same line and deduced that liming reduced P-concentration of plant, which in turn, also reduced the B-uptake by plants. Gupta *et al.* (1982) studied the factors affecting B-concentration of crop grown on podzol soil with special emphasis on leaf tissue B concentration and reported that the P fertilization of plant did not show any pronounced effect on the leaf tissue B concentration of the plant.

Haldar and Mondal (1987) reported that application of P at higher level recorded a synergistic influence on the availability of hot water soluble-B in an acid soil of North Bengal and the growth and yield of pulse crop. Similarly, Saha (1992) observed that with the increase of P supply in soil, there was an increase in the content of hot calcium chloride extractable-B in soil over no-P control, he further reported an increased B-uptake due to the increased application of the same in green gram.

Tiwari *et al.* (1988) in an experiment on the status of available-B in soils of Rajghat area of Madhya Pradesh reported a significant negative correlation between available-B and available-P content of the soil. Similarly, available-B was negatively correlated with available-P in some soils of terai zone of West Bengal (Saha and Haldar, 1996). However, Sharma *et al.* (1995) reported no significant relationship between available-B and available-P content in Madhya Pradesh soils.

James *et al.* (1995) reported negative effect of soil-P on concentration of B in plants grown on a highly calcareous red silty loam soil. Saha and Haldar (1998), however, reported that application of P increased the content of available-B in aeric haplaquept soil. Similarly, Singh *et al.* (1999) reported an overall increase in available-B by single super phosphate treatment.

2.5.3 Potassium

The effect of K on the availability of B to plants is less clear. The first study on this subject conducted by Reeve and Shive (1943), indicated that the K-concentration of the substrate had a definite influence on the accumulation of B in the tissues of tomato and corn plants. The B-toxicity symptoms on these crops increased in severity with the increase in K-concentration in the substrate. However, they observed that at low levels of B, deficiency of B was progressively intensified with increasing concentration of K in the growth medium. Reeve and Shieve (1944) further reported toxic effects of B only when K in the growing medium was supplied at concentrations in excess of that required for optimal plant growth. High levels of K accentuated B-deficiency and toxicity symptoms by narrowing down the tolerance range, apparently by suppression of Ca-activity.

Nusbaum (1947) reported that, without added B, low rates of K and low rates of P and K together resulted in slight B-deficiency symptoms in sweet potatoes. However, the B-content of petioles of celery decreased with increasing K in the nutrient solution regardless of the B level in the nutrient solution (Yamauchi *et al.*, 1958). Sinha (1961) attributed the B-deficiency due to application of K on low B soils to physiological interactions. Patel and Mehta (1966) showed that B-deficiency symptoms of bidi tobacco increased and toxicity symptoms decreased with increasing K:B ratios. Leaf B content at toxic levels decreased with increasing supply of K. Studies of Tanaka (1967) showed that B and Ca uptake was decreased when K in the medium increased. Budbine and Guzman (1969) observed that excessive fertilization with N and K [illegible] together reduced the severity of the symptoms. Hill and Morill (1975) in a greenhouse experiment found that increasing the application rate of K to Spanish peanuts receiving B lowered the total B-uptake by peanut plants. Li *et al.* (1989) in a field experiment on a paddy soil in Hunan, investigated interactive effect of K and B on rapeseed yield and K and B status in rape plants. Plant B concentration increased with increasing B rate, but decreased with increasing K rate. Plant K concentration also decreased with increasing B rate. It was concluded that the optimum K:B ratio in rape plants was 1000. Oertli (1961) observed that barley seedlings absorbed more B from single K salt solutions than from single salt solutions of other alkaline earth metals.

The degree of K-saturation plays an important role regarding B-retention in soil. Hadas and Hagin (1972) found that K-saturated soils fixed more B than unsaturated soils. The relationship between the adsorption of B by two soils, clay and sandy loam, and both the pH and the exchangeable bases was investigated by Karam and Cescas (1984). Boron retention was determined on various portions of the two soils, which were previously treated with different amounts of Ca^{++}, Mg^{++}, K^{++} and H^{++} ions. The B-adsorption data was described by the linear form of the freundlich equation. For the two soil series, a highly significant correlation was found between the freundlich A constant and both the sum of exchangeable bases and the soil pH. But, Singh and Sinha (1975) found insignificant relation between B-fixation and K in Bihar soils.

Kar and Motiramani (1976) working on various soil types from Madhya Pradesh, noted a significant positive relationship between available-B and exchangeable-K in soil. Similarly, available and total B were positively correlated with available-K contents of the medium black calcareous soils in Western Gujarat (Hadwani *et al.*, 1989). Similar type of observation was made by Mohammadi *et al.* (1992). Moyano *et al.* (1990) studied water soluble-B content in cultivated semi-arid soil profiles in Central-Western Spain. Statistical evaluation of B-content in relation to other soil properties showed that B was related to available-Ca and available-K in surface and sub-surface horizons.

Cutcliffe and Gupta (1980) showed that B-concentration of cauliflower leaf tissues was not greatly affected by K treatments. Gupta *et al.* (1982) studied factors affecting the B-concentration of crops grown on podzol soils. They reported that P and K fertilization did not affect the leaf tissue B concentration. However, James *et al.* (1995) reported that soil K had a negative effect on B-content of *Medica sativa* plant.

Tisdale *et al.* (1995) observed that at low levels of B nutrition with increased rates of applied K might accentuate B-deficiency symptoms. They reported enhanced uptake of B by tomato caused by high K in combination with high B. Similarly, Yang *et al.* (1989) observed reduced B-uptake by rapeseed due to K application when B was deficient. Sakal *et al.* (1988) in an experiment on the effect of B application on black gram, found a synergistic relationship between B and K when the B supply to the plant was adequate.

Ryan (1989) studied B-adsorption on soils of *Pinus radiata* plantation in New South Wales. Boron-adsorption isotherms varied within individual soil profiles by horizon and also between soil profiles in the catena. The freundlich isotherm constant was found to be significantly correlated with exchangeable-K.

Sharma *et al.* (1995) did not find any significant correlation between available-B in soil with exchangeable-K. Similarly, Saha and Haldar (1996) found an insignificant negative correlation between the two in some soils of terai zone of West Bengal.

2.5.4 Calcium

The relationship between Ca and B apparently is very real one and because the symptoms of B-deficiency and of Ca-deficiency which appear in the growing point are very similar, it appears logical that these two elements are related in their function in plant growth. Further evidence that their function is related was given by Smith (1944), who found 50 per cent of B and 70 per cent of the Ca immobilized in the cell wall or intercellular spaces. Cook and Miller (1940) list active Ca as one of the factors affecting B availability. Muhr (1940) working on different soil types indicated that active Ca-content of soil influenced the fixation of B.

Reeve and Shive (1944) found that when plants have access to increasing amounts of Ca, they require more B to prevent deficiency. With high amounts of Ca, plants are able to withstand larger amounts of B without becoming toxic. They found that there is marked decrease in B-content in plant tissue with increase in the Ca-concentration in the nutrient solution. However, Ca-concentration in the tissue is largely determined by the Ca-concentration in the growing medium and appears to be independent of B.

Patel and Mehta (1966) showed that B-deficiency symptoms of bidi tobacco increased and toxicity symptoms decreased with increasing Ca:B ratio. Leaf B contents at toxic levels decreased with increasing supply of Ca. No symptoms of deficiency or toxicity were observed when B in nutrient solution varied from 0.10 to 0.50 mg kg^{-1} and Ca:B ratio in the leaf varied from 365 to 1568. Tanaka (1967) reported that B-uptake by radish was reduced when the Ca-content of the medium increased. Likewise, Drake *et al.* (1941) working on tobacco concluded that soils known to be high in available-Ca should be suspected of producing B-deficient plants. Tanaka (1967) and Drake *et al.* (1941) reported that a higher Ca:B ratio in the plant tissue was related to B starvation symptoms in radish and tobacco respectively. Wolf (1940), however, found Mg to have a greater effect on reduced uptake of B than Ca, but the differences between Ca and Mg effects were very small.

Hill and Morril (1975) in an experiment found that concentration of B in the vegetative portion of peanuts was related to the B and Ca levels. Highest concentrations of B were found in the absence of applied-Ca. At each rate of B, the increase in the application of Ca resulted in a lower B-concentration within the tops. However, Keren and O'Connor (1982) reported little effect of exchangeable cations including Ca^{++} on B adsorption by layer silicates. Keren and Gast (1981) reported similar results for montmorillonite at pH values less than 8.

Lehto and Molkonen (1994) confirmed results of B-uptake by Norway spruce in a pot experiment in which additionally the role of increased soil pH and increased soil Ca concentration were separated by means of comparing the effects of $CaCO_3$ and $CaSO_4$. The doses of lime increased the pH of the soil and correspondingly decreased the B-concentration in new needless. However, $CaSO_4$ did not affect the pH of the soil or needle B concentration. Hence this proved liming effect on B availability caused by the increased pH rather than increased Ca-concentration. Similar findings were reported by Gupta and Mcleod (1977).

Saha and Haldar (1996) in a study on some soils of terai zone of West Bengal reported that available-B content showed a significant negative correlation with exchangeable-Ca. However, Singh and Singh (1972) reported an insignificant correlation between exchangeable-Ca percentage and water soluble-B in saline alkali soils of South West tracts of Bihar.

2.6 Boron transformation in soil

Gupta (1968) reported that higher amounts of B were fixed by soils after incubation period of 8 to 12 weeks than after 2 and 4 weeks and higher percentage of B were fixed by sandy clay loam soil than in the sandy loam soil with all incubation periods. Mani and Haldar (1996) reported that application of B could maintain 11.5 and 12.5 per cent of the added-B in hot water soluble form at 5 kg and 10 kg borax levels respectively in an acid soil at 10 days incubation. A decrease in hot water soluble-B content was found over the initial amount present in soil, however, a slight increase was followed in the hot water soluble-B content in the later period of incubation.

Saha and Haldar (1998) in a study on changes in available-B content of aeric haplaquept found that extractable-B content decreased significantly within initial 15 days of incubation over initial amount present in the soil. The trend of change followed almost throughout the period of incubation. Application of B increased significantly the content of available-B in soil during first 15 days of incubation, but smaller fraction (about 10%) of applied-B was found to be present in the extractable form in soil, while, major portion (about 90%) got transformed into some non-extractable form attributed to probable fixation or complexation of B with certain organic and inorganic components of the soil. During the later period of incubation, the recovery of the applied-B showed an increasing trend probably due to release of B from the complexed form.

2.7 Response of cauliflower to boron

2.7.1 Effect of boron on plant and curd weight, morphological characters and physiological parameters

Cauliflower is particularly susceptible to B-deficiency, the symptoms consisting of browning of the curd, marginal mottling of the leaves and a hollow condition of the stem (Wallace, 1951).

Gupta (1971) reported that cauliflower was more responsive to applied-B. An application of 0.5 mg kg^{-1} B to sandy clay loam soil with 0.50 mg kg^{-1} available-B, doubled the yield, but additional application had no further effect. Mishra (1972) also reported that treating NPK fertilized soil with 17 kg ha^{-1} borax increased cauliflower yields from 4.2 to 13.0 t ha^{-1}. Mehrotra *et al.* (1975) also reported that application of B along with NPK increased curd size and weight as well as ascorbic acid content.

Gupta and Cutcliffe (1973) did not find significant differences in the yield of cauliflower due to B application (0 to 4.48 kg B ha^{-1}) in Prince Edward Island soils (sandy loam ranging in available-B from 0.30 to 0.50 mg kg^{-1}) in Canada. They also reported that B-toxicity was not observed even when the rate of applied-B was 4.48 kg ha^{-1} and the incidence of hollow stem was not affected by the B treatments.

Pandey *et al.* (1974) studied the effect of B along with NPK on yield and quality of cauliflower on a sandy loam soil with 2.64 mg kg^{-1} available-B. They reported decreased curd as well as leaf yields with B application. The plants developed B-toxicity symptoms characterised by poor plant vigour, stunted growth, small cup shaped leaves with pinkish margin and impaired head formation or formation of tiny brown coloured heads.

Gupta and Cutcliffe (1975) found that under greenhouse conditions, on a sandy loam soil containing 0.28 mg kg^{-1} hot water soluble-B, cauliflower grown without added-B showed B-deficiency symptoms. However, application of B increased plant growth about 3 fold under greehouse and 20 per cent in the field experiment. The decreased yield of cauliflower with B-deficiency leaf disorders under greenhouse condition was associated with plant tissue B concentration of 4.2 mg kg^{-1}. Lukovnikova and Kuliev (1976) reported that B raised the dry matter content of cauliflower.

Chakraborty (1976) conducted an experiment on the effect of B on cauliflower in Assam and reported that application of B resulted both the highest yield and a near perfect curd over NPK control. The percentage of hollow stem was remarkably low in plants treated with B. Randhawa and Bhail (1976) reported that application of borax @ 15 kg ha^{-1} increased the yield of cauliflower in a loamy sand with 0.45 mg kg^{-1} available-B. However, increased application of borax @ 20 kg ha^{-1} proved to be toxic and decreased the yield. However, there was no significant difference in number of leaves and plant height with the application of various levels of B.

Francois (1986) studied the effect of excess B and reported that cauliflower showed a significant yield reduction for both total and trimmed weight with B >4.0 mg $litre^{-1}$. Shelp and Shattuck (1987) reported optimum plant and head weight, maximum fresh weight, harvest index at 1.0 mg B $litre^{-1}$. In the absence of added-B, the head showed slight internal signs of necrosis and browning, and curd surface discoloration. Prasad and Singh (1988) reported that application of B (Boric acid @ 15 kg ha^{-1}) significantly increased the yield, curd weight, curd diameter, number of marketable curds and total plant weight.

Prasad *et al.* (1988) found that different genotypes of cauliflower recorded heavy losses in yield due to B-deficiency in the soil (sandy loam and hws-B of 0.12 mg kg^{-1}). The reduction in yield under deficient conditions compared to control (boric acid @ 15 kg ha^{-1}) among the genotypes varied from 43.8 to 63.4 per cent. The mechanism of tolerance of B-deficiency in the genotypes seemed due to an efficient uptake of B from the deficient soil.

Kotur and Kumar (1989) found from a field experiment on B-deficient soil that both deficiency and toxicity stresses killed the seedlings and reduced the crop stand. Marketable curd yield increased from 0.4 t ha^{-1} in the control to 9.1 t ha^{-1} at 1.6 kg B ha^{-1} and decreased thereafter at 1.6 to 6.4 kg B ha^{-1} due to toxicity. The symptoms of toxicity were poor plant vigour, stunted growth, reduced leaf size, cup shaped brittle chlorotic leaves with yellowness decreasing towards the midrib, the leaves turning necrotic at later stages and the curds atrophied and brown coloured. Panigrahi *et al.* (1990) reported that application of 0.2 per cent B as seedling root dip with 1 kg B ha^{-1} applied to the soil resulted in 97 per cent increase in cauliflower diameter and the highest seed yield as compared with the control (NPK).

Scaife and Wurr (1990) reported that B-concentration in the curd and in young and mature leaves showed no significant relationship with the incidence of hollows and an examination of the literature suggests that, despite popular belief, there is virtually no evidence to link hollow stem with B-deficiency.

Singh and Thakur (1991) found greater number of leaves, increased net weight of curd and higher total curd yield due to B application (10 to 20 kg borax ha^{-1}). Similarly Thakur *et al.* (1991) found that application of B in a sandy loam soil deficient in B increased gross plant weight, net curd weight, dry matter content and number of leaves. However, B had significant adverse effect on size of the leaf and stalk length. With the application of B there was significant earliness in curd maturity.

Sharma and Ramchandra (1991) reported that B-deficiency resulted in reduced and stunted growth in cauliflower. The young leaves appeared thick, brittle and stiff. With age, major veins also developed 'measles' like outgrowth and mild intervenal chlorosis along the margins of older leaves. Mishra (1992) in a study on effect of B on cauliflower seed production reported that application of B did not have any effect on plant height, however, application of B resulted in the highest 1000-seed weight and seed yield.

Kotur (1992) from an experiment on a sandy loam soil with 0.10 mg kg^{-1} hot water soluble-B, observed that B application (0 to 3.75 kg ha^{-1}) significantly increased curd yield upto 1.5 kg ha^{-1} and significantly reduced the curd rot due to correction of B-deficiency and reduced incidence of black rot. Vinay Singh and Dixit (1994) observed that the application of B @ 0.5 mg kg^{-1} in a sandy loam soil (with 0.50 mg kg^{-1} hot water soluble-B) produced significantly higher curd yield over the control. However, its application @ 2.0 mg kg^{-1} tended to decline the yield. Similarly, Vinay Singh *et al.* (1994) found that cauliflower yield increased with increasing B application in a sandy loam soil upto 0.5 mg kg^{-1}, but decreased at higher rates. Singal and Saraf (1995) also reported higher yields with B sprays. The addition of B, however, did not affect either curd formation date, curd weight or plant weight in a heavy clay soil (Farag *et al.*, 1994).

Ghosh and Hasan (1997) in an experiment carried out in the farmer's fields found that soil application of 15 kg borax ha^{-1} increased leaf number, curd size, curd weight and finally the yield of cauliflower over the control. Kotur (1997) reported that application of B (0.0125 and 0.125%, each applied thrice through foliar spray) in a B-deficient (hws-B, 0.10 mg kg^{-1}) red sandy loam soil (ultic haplustalf) significantly increased curd weight, curd diameter, curd yield and reduced the severity of stem hollow and curd rot. The severe incidence of stem hollow and curd rot at no-B and its correction through increased B supplies confirmed that stem hollow is a direct manifestation of B-deficiency in cauliflower (Snowball group).

Batal *et al.* (1997) recorded that on clay loam soil (low B status), increasing B from 2.2 to 8.8 kg ha^{-1} as solubar (20.5% B) reduced hollow stem, but had no effect on yield or curd mass. However, on sandy loam soil (very low B status), B at 4.4 kg ha^{-1} as solubar maximised yield and curd mass, but hollow stem continued to decrease as B rates were increased from 2.2 to 8.8 kg ha^{-1} as solubar. Kotur (1998) reported that foliar and soil application (@ 1.5 kg B ha^{-1}) on a red sandy loam soil deficient in available-B significantly overcame brown rot and enhanced curd yield. Foliar application of 3 sprays of 0.125 per cent boric acid was optimum for high curd yield, low curd rot, negligible residual hot water soluble-B in soil and high net returns per rupee invested corresponding to 23.5 mg kg^{-1} of B and Ca:B ratio of 678 in leaf tissue. Similarly, Malewar *et al.* (1999a) indicated significant increase in dry matter yield due to B application particularly in B low and medium soils. Sharma (2002) reported that maximum plant height, number of branches per plant, number of seeds per pod, seed yield, 1000-seed weight and per cent seed germination were obtained when 25 kg borax ha^{-1} was applied in a sandy loam soil. Similarly, Singh *et al.* (2002) reported that soil application of B upto 1.0 kg ha^{-1} significantly increased the cauliflower yield.

2.7.2 Effect of boron on nutrient (N, P, K and Ca) contents in cauliflower

Chemical composition is the index of development of plant which determines the magnitude of yield production. Randhawa and Bhail (1976) reported that the application of B @ 10 and 15 kg of borax ha^{-1} did not influence the N-content in cauliflower leaves. However, B at its higher level i.e. 20 kg borax ha^{-1} decreased the N-content in leaves. The application of B @ 15 kg borax ha^{-1} gave the highest P-content in leaves. Francois (1986) studied the effect of excess B on cauliflower and reported that Ca, P and K concentrations in the leaves were not significantly affected as B-concentration in the soil water increased. However, K and P concentration in the leaves increased and Ca remained unchanged with increasing levels of B. In contrast to this, under same study with radish he reported that Ca and P concentration in the leaves decreased significantly with increasing B, while, K remained unchanged.

Kotur and Kumar (1989) recorded leaf tissue accumulation of Ca and K both due to deficiency as well as toxicity of B. At optimum level of B, the lower content of these bases may be attributed to dilution effect. They reported that Ca:B ratio of leaf tissue decreased from 1147 to 187 on B application. Vinay Singh *et al.* (1994) found that application of both P and B in a sandy loam soil showed a synergistic effect on the content and uptake of P by cauliflower curd.

Kotur (1997) reported that B application significantly increased Ca-content of leaf tissue, however, the effect of B on leaf-N composition was found to be insignificant. Again, Kotur (1998) reported that foliar and soil application of B significantly increased Ca-content of leaf and reduced Ca:B ratio of leaf tissue compared to control.

2.7.3 Plant and soil critical levels of boron for cauliflower

There is perhaps a great volume of literature on B in plants and soils, however, there is little information on the plant and soil critical levels of B for crops particularly cauliflower. The critical levels are useful for delineating B-deficiency. Berger (1949) said that probable available-B content of soils required for optimum growth of cauliflower is > 0.50 mg kg^{-1}. Wallace (1951) reported 36 mg kg^{-1} B in healthy leaves of cauliflower and 23 mg kg^{-1} B was reported to be associated with B-deficiency.

Raychaudhuri and Datta Biswas (1964) reported 0.10 to 0.50 mg kg^{-1} water soluble B as critical limit in soils in relation to various botanical species grown. Gupta (1971) reported that for cauliflower, less than 3 mg kg^{-1} B in tissue (above ground portion harvested before the appearance of the curd) was in the deficiency range. Boron content in excess of 12 mg kg^{-1}, however, was appeared to be optimum. Similarly, Gupta and Cutcliffe (1977) reported that B-concentration of 8 to 9 mg kg^{-1} in cauliflower leaf tissue was associated with B-deficiency and reduced yields. Tissue B levels of greater than 15 mg kg^{-1} are considered to be in the optimum range to prevent any B-deficiency in cauliflower. According to Chapman (1975), the B levels of cauliflower leaves upto 23 mg kg^{-1} was rated as deficient, 23 to 36 mg kg^{-1} as intermediate and > 36 mg kg^{-1} as high.

Gupta and Cutcliffe (1973) recorded that hot water soluble-B content of 0.34 to 0.49 mg kg^{-1} in sandy loam soils was sufficient for optimum growth of cauliflower. Kotur and Kumar (1989) reported that critical levels of deficiency and toxicity were 0.17 and 0.63 mg kg^{-1} of hws-B in sandy loam soil, 11 and 37 mg kg^{-1} of B in leaf tissue and Ca:B ratio of 900 and 280 in the leaf tissue, respectively. Malewar *et al.* (1999b) reported that the critical soil B concentration established by graphical and statistical procedures were 0.52 and 0.51 mg kg^{-1}, respectively. Malewar *et al.* (1999a) conducted an experiment to establish the critical concentration of plant B (harvested at mid bloom stage/65 days) in cauliflower by graphical and statistical methods, and was found to be 21.0 and 20.4 mg kg^{-1}, respectively and thus closer to each other. Sakal (1985) also reported more or less similar values of available-B in black gram established by both the approaches.

2.7.4 Boron mobility/distribution in different plant parts of cauliflower

Boron-deficiency in crops is more widespread than deficiency of any other micronutrient. The occurrence of B-deficiency disorders even when B is in ample supply in the soil, suggests that B-deficiency in plants is physiological in nature and related to B mobility within the plant (Shelp *et al.*, 1995). Boron is unique among the essential plant nutrients in that it has restricted mobility in many plant species and is freely mobile in others (Brown and Shelp, 1997). Evidence of B mobility can be found in the distribution of B within different parts of a species.

Shelp and Shattuck (1987) reported that at 1.0 mg B litre^{-1}, B levels in the head, old and young leaves of cauliflower were 41, 543 and 145 m μg g^{-1} dry matter, respectively. In the absence of added B, the B levels were 21, 35 and 48 m μg g^{-1} dry matter, respectively, in the head, old and young leaves. Comparison of the relative element composition of young tissue to old leaves indicate that the former, particularly the head, were supplied with nutrients principally by the phloem and that B was relatively phloem immobile. However, indirect assessment of element retranslocation, based on the ratio of its concentration in young leaves or head : old leaves, showed that B is remobilized under B-deficiency. They further reported that the B-concentration of the nutrient solution also caused changes in the retranslocation of other elements, particularly the largely phloem immobile elements, to young leaves.

Gupta (1991) studied B status in different plant parts in vegetable crops viz., broccoli, brussels sprouts and cauliflower and reported that B was consistently higher in the leaves and lowest in the stems. The lower halves of the vegetable crops usually contained close to the highest amounts of B. Similarly, Liu *et al.* (1993) investigated the B distribution in two broccoli cultivars, grown under irrigation with and without supplemental-B at three locations which differed in extractable-B. A decreasing tissue B gradient up the shoot is only found in plants supplied with supplemental-B. Furthermore, floret B concentration and content are rarely affected by the B treatments. Thus, in spite of the accumulation of B in transpiring organs, these studies provide circumstantial evidence for B retranslocation under conditions of low B supply (i.e. conditional mobility). In lines with previous studies Singh *et al.* (2002) reported that the highest B-content in cauliflower leaf tissue (23.77 mg kg^{-1}) and curds (19.31 mg kg^{-1}) was recorded upon treatment with 2.0 kg B ha^{-1} compared to lower B levels. Boron-concentration in the leaf tissue was higher than that in the marketable curds.

MATERIAL AND METHODS

MATERIAL AND METHODS

The study entitled, "Boron status and transformation in relation to cauliflower (*Brassica oleracea* L. var. *botrytis*) growth and yield in some soils of Himachal Pradesh", was carried out with a view to screen out the representative soils of cauliflower growing belt in zone-II and zone-III of Himachal Pradesh with respect to their available-B content, to study the transformation of B as influenced by organic matter in laboratory-incubation and to study the concentration and uptake of B by cauliflower in greenhouse experiment. The materials used and methods followed for fulfilment of above mentioned objectives are presented in this chapter under the following heads.

3.1 Soil sampling

3.2 Laboratory-incubation study

3.3 Greenhouse study

3.4 Methods used for soil and plant analysis

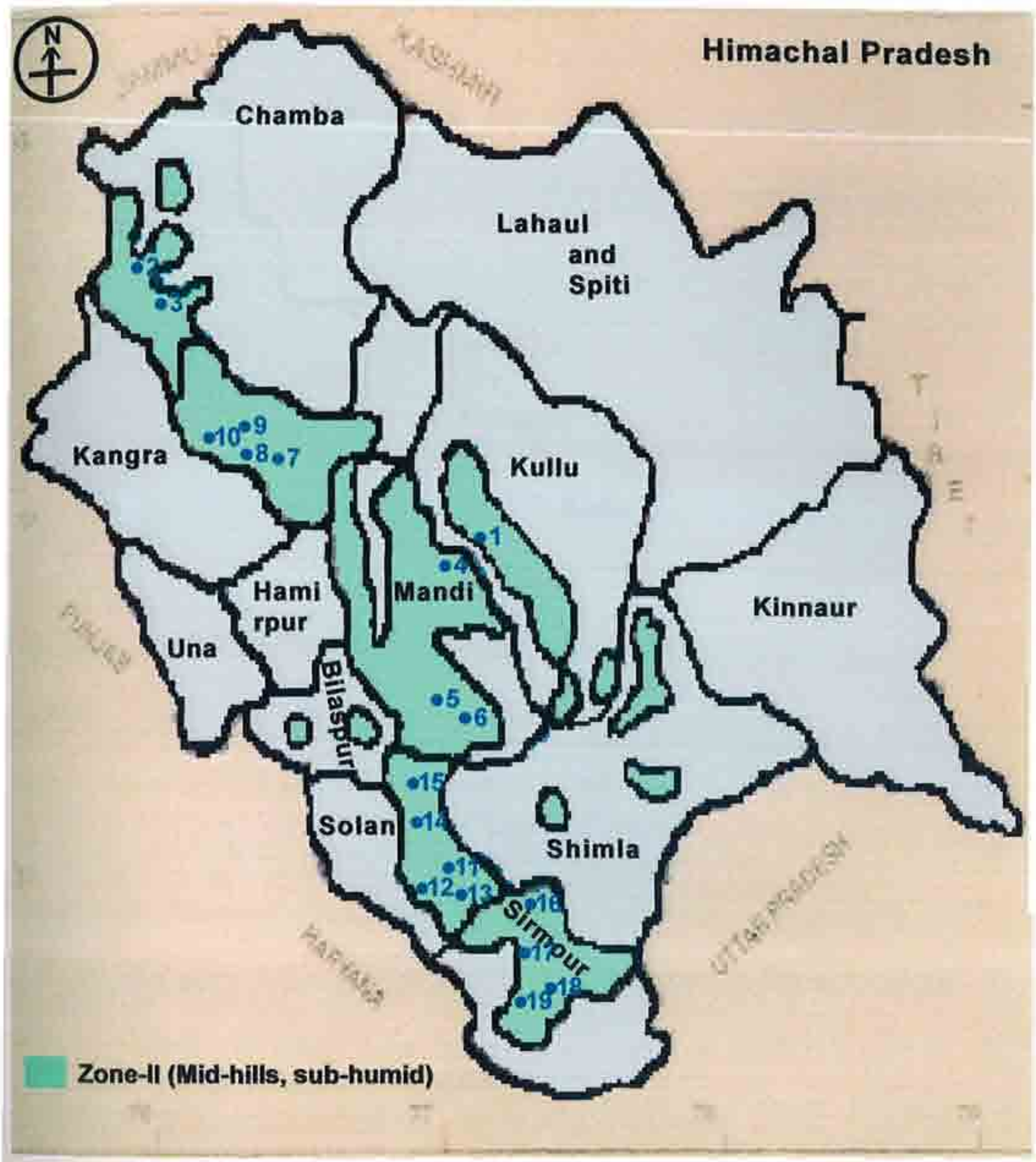
3.5 Statistical analysis

3.1 Soil sampling

The composite soil samples (0 to 0.15m) were collected from undisturbed soils adjacent to cauliflower growing fields in zone-II (Mid-hills, sub-humid) and zone-III (High-hills, wet-temperate) of Himachal Pradesh during months of January-February, 2002. The undisturbed soils were used for this purpose with a view to avoid any effect of cauliflower cultivation and fertilization, if any. In all, nineteen soil samples from zone-II and sixteen from zone-III were collected to screen out the representative soils of cauliflower growing belt of Himachal Pradesh with respect to their available-B content. The location and name of places of soil sample sampling for zone-II and zone-III are given in Fig. 3.1 and 3.2, respectively.

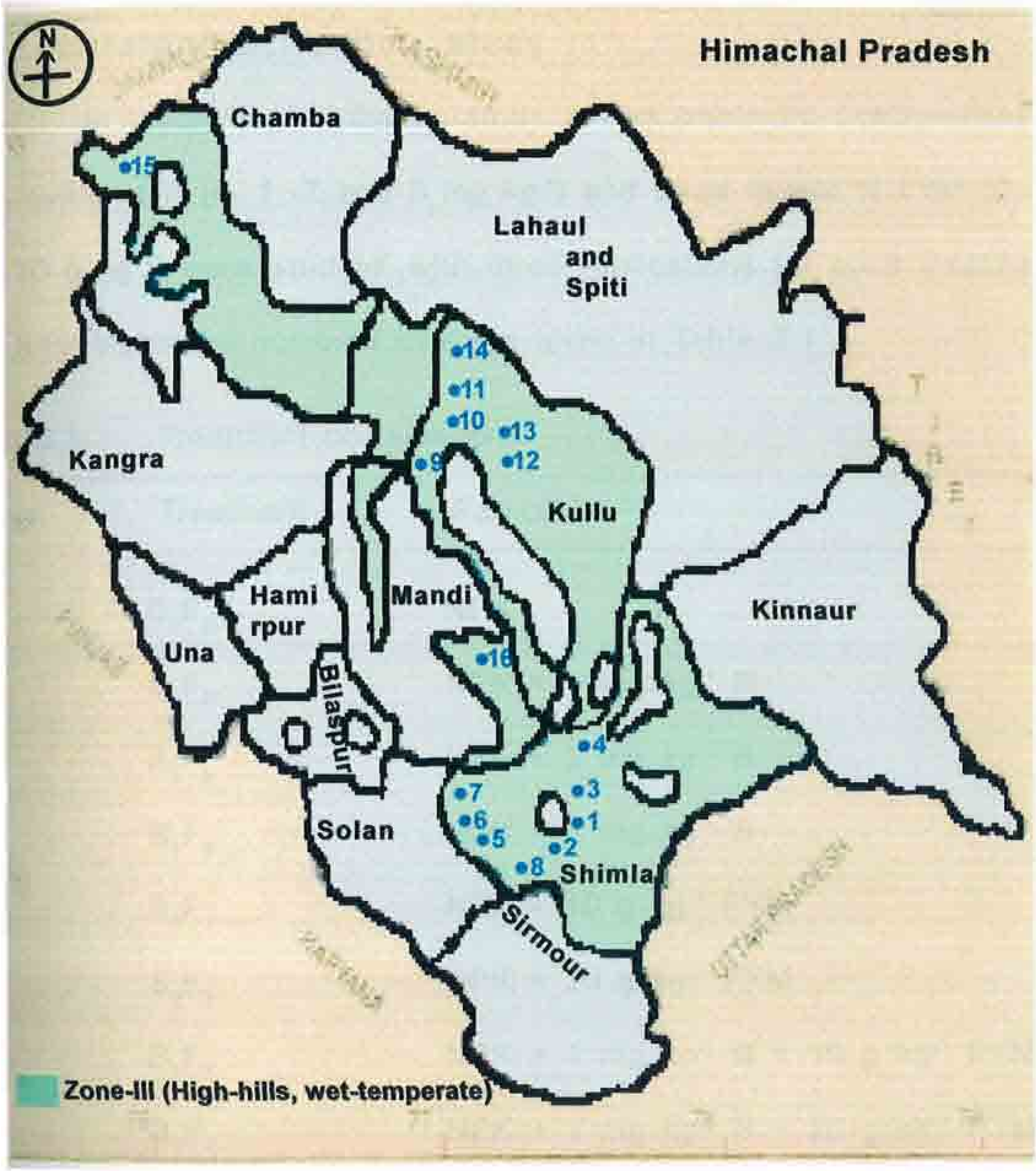
The soil samples so collected were air-dried, ground with the help of wooden pestle and mortar and sieved through 2 mm sieve. The processed soil samples were analysed for available-B (hot water soluble), mechanical separates (per cent sand, silt and clay), organic-carbon, soil reaction (pH), and available-N, P, K and Ca.

The detailed soil analyses are given for each location in zone-II and III in Appendix-I and II, respectively. The soils were screened on the basis of their available-B content and most B-deficient soils in each zone were identified. These were Bajaura in zone-II and Junga in zone-III. The bulk surface soil samples from these two locations were collected and brought to the Department of Soil Science, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur for laboratory-incubation and greenhouse experimentation.



S.No	Location	District	S.No.	Location	District
1.	Bajaura	Kullu	11.	Kandaghat	Solan
2.	Rajpura	Chamba	12.	Sproon	Solan
3.	Mehla	Chamba	13.	Basaal	Solan
4.	Nagwain	Mandi	14.	Kyar	Solan
5.	Kao	Mandi	15.	Darlaghat	Solan
6.	Nihara	Mandi	16.	Rajgarh	Sirmour
7.	Sunehar	Kangra	17.	Dhornibar	Sirmour
8.	Mundla	Kangra	18.	Nehar-Sawaar	Sirmour
9.	Thanpuri	Kangra	19.	Dheera	Sirmour
10.	Nandehar	Kangra			

Fig. 3.1. Soil sampling locations in zone-II of Himachal Pradesh



S.No	Location	District	S.No.	Location	District
1.	Theog	Shimla	9.	Seobag	Kullu
2.	Fagu	Shimla	10.	Katrain	Kullu
3.	Matiana	Shimla	11.	Bari	Kullu
4.	Doja	Shimla	12.	Nashala	kullu
5.	Jalel	Shimla	13.	Naggar	Kullu
6.	Panesh	Shimla	14.	Aleo	Kullu
7.	Rampuri	Shimla	15.	Salooni	Chamba
8.	Junga	Shimla	16.	Janjehli	Mandi

Fig. 3.2. Soil sampling locations in zone-III of Himachal Pradesh

3.2 Laboratory-incubation study

In laboratory-incubation study, twelve treatment combinations of four levels of B (0, 1, 2 and 3 mg kg^{-1}) and three levels of FYM (0, 10 and 20 g kg^{-1}) were studied, with three replications for each treatment. The total treatment combinations are given in Table 3.1.

Table 3.1. Treatment combinations

Sr. No.	Treatment	Particulars
1.	B_0F_0	NPK
2.	B_1F_0	NPK + 1 mg kg^{-1} B
3.	B_2F_0	NPK + 2 mg kg^{-1} B
4.	B_3F_0	NPK + 3 mg kg^{-1} B
5.	B_0F_1	NPK + 10 g kg^{-1} FYM
6.	B_0F_2	NPK + 20 g kg^{-1} FYM
7.	B_1F_1	NPK + 1 mg kg^{-1} B + 10 g kg^{-1} FYM
8.	B_1F_2	NPK + 1 mg kg^{-1} B + 20 g kg^{-1} FYM
9.	B_2F_1	NPK + 2 mg kg^{-1} B + 10 g kg^{-1} FYM
10.	B_2F_2	NPK + 2 mg kg^{-1} B + 20 g kg^{-1} FYM
11.	B_3F_1	NPK + 3 mg kg^{-1} B + 10 g kg^{-1} FYM
12.	B_3F_2	NPK + 3 mg kg^{-1} B + 20 g kg^{-1} FYM

These treatments were tested on two most B-deficient soils of Bajaura (zone-II; Mid-hills, sub-humid) and Junga (zone-III; High-hills, wet-temperate). The incubation study was conducted in two sets of polyethylene bags containing 100g soil. The required levels of B and FYM were applied by mixing them thoroughly with entire amount of soil.

Besides B and FYM levels, recommended doses of N, P and K @ 62.5, 25.0 and 15.0 mg kg^{-1}, respectively, were also applied. The half dose of recommended N and full dose of P and K were applied as basal dose and mixed thoroughly with entire amount of soil. The remaining amount of N was applied in two equal splits at 30 and 60 days after the start of the experiment. The sources of N, P, K and B used were urea, single super phosphate, muriate of potash and borax, respectively.

The moisture content of the soil samples was maintained at 100 per cent of the field capacity. After adjusting the proper moisture level, the soil samples were incubated at 25°C in the incubator (Incubator selecta-6, Sew India). The amount of moisture lost was adjusted at weekly interval on weight basis.

The soil samples from each treatment and replication were drawn after 24, 48, 72 and 96 days of incubation. The soil samples so drawn were analysed for available B, N, P, K and Ca. The concentration of the respective extracting solution was suitably adjusted taking into account the amount of water present in the incubated soil.

3.3 Greenhouse study

Under greenhouse studies, two experiments were conducted, one each with soils from Bajaura (zone-II; Mid-hills, sub-humid) and Junga (zone-III; High hills, wet-temperate). These soils were selected on the basis of their lowest hot water soluble-B content. In each experiment, same set of twelve treatment combinations were tested which were used for laboratory-incubation studies. These experiments were conducted in plastic pots (24cm top diameter x 18cm bottom diameter x 26 cm height). In each pot 10 kg of air dried soil was used.

Under all the treatments, the recommended levels of N, P and K @ 62.5, 25.0 and 15.0 mg kg^{-1}, respectively, were used. The sources of N, P, K and B used for the study were urea, single super phosphate, muriate of potash and borax, respectively. The single super phosphate was applied as solid, whereas, N, K and B were applied in solution form. Whole quantity of P, K and B were applied as basal and N was applied in 3 splits viz., 50 per cent at the time of transplanting and remaining half in two equal splits at one month interval after transplanting of cauliflower. The 10 kg of soil for each treatment in each experiment were weighed separately and spread over a plastic sheet and required amount of FYM as well as P was mixed thoroughly with whole of the soil. After mixing, the soil was put in the pot. The required amount of N, K and B were applied in required pots in solution form and mixed with the help of plastic rod with upper 10 cm of soil.

Two healthy cauliflower seedlings were transplanted in each pot which were thinned to one after 10 days of their establishment. The variety of cauliflower used was Palam-uphaar. The moisture content was adjusted to 100 per cent of the field capacity with deionised water and periodic irrigations were applied to maintain this water content throughout the growth period of the experiment.

To find out the changes in available-B, N, P, K and Ca at different intervals, the soil samples (0 to 0.15 m) from each pot were withdrawn with the help of screw auger at 48 days after transplanting and at maturity of cauliflower.

One day before the harvest of cauliflower, each pot was filled with tap water and left as such overnight. The next day each pot was tilted and the whole of the loose mass of soil was decanted. This process was repeated for two more days after which the remaining soil alongwith plant was removed from each pot and placed in sieve. The soil adhering to plant roots was washed repeatedly and gently with tap water, then with dilute HCl and finally with glass distilled water. The plant materials were separated into leaves + stalks, curd and roots. All these plant parts were dried in an oven at 65±5°C to a constant weight. Each separate part of the plant was ground with the help of stainless steel grinder. All these plant materials were subjected to chemical analysis for B, N, P, K and Ca contents.

In addition to above, some additional parameters of the crop were also recorded which are described below:

3.3.1 Days to curd maturity

The number of days taken from the date of transplanting to the day curd obtained marketable maturity. At this stage, the younger inner leaves covering the curd just begin to separate.

3.3.2 Plant weight

Plant weight was recorded at the time of maturity and it included the weight of curd, leaves, stalks and roots i.e. plant as a whole.

3.3.3 Marketable curd yield

Marketable curd yield refers to the curd weight excluding stalk upto first leaf and leaves upto curd level when harvested at marketable maturity.

3.3.4 Curd weight

At marketable maturity, curd (white portion only) weight was recorded.

3.3.5 Curd depth

Curd depth refers to the length from the point of attachment of curd from stalk upto the top point of curd. It was measured with the help of vernier calipers.

3.3.6 Curd compactness

Compactness of the curd was judged from the ratio of curd weight to curd depth.

3.3.7 Curd diameter

Curd diameter is the mean of the diameters recorded with the help of vernier calipers at right angle to each other.

3.3.8 Stalk length

Length of the stalk was measured from the uppermost secondary root to the position of first leaf.

3.3.9 Number of leaves at maturity

At the time of marketable maturity, fully grown leaves per plant were counted.

3.3.10 Leaf size

Leaf size was calculated as an average of the leaf area determined of fully grown leaves with the help of leaf area meter.

3.4 Methods used for soil and plant analysis

3.4.1 Soil

The methods used for a particular parameter in soil analysis are described below in Table 3.2.

Table 3.2. The methods used for determination of various parameters in soil analysis

Sr.No.	Parameter	Method followed
1.	pH	1:2.5::Soil:water suspension with pH meter
2.	Oxidisable organic-carbon	Rapid titration method of Walkley and Black (1934) as described by Jackson (1973).
3.	Mechanical analysis	International pipette method (Piper, 1966).
4.	Hot water soluble-B	Extraction by boiling soil:water::1:2 suspension for five minutes and determination by Carmine method (Hatcher and Witcox, 1950)
5.	Available-nitrogen	Alkaline permanganate method (Subbiah and Asija, 1956).
6.	Available-phosphorus	Extraction by Olsen method (Olsen *et al.*, 1954) and estimation colorimetrically by Dickman and Bray's (1940) chloromolybdic acid stannous chloride method in HCl system as described by Jackson (1973).
7.	Available-potassium	Extraction with 1 N ammonium acetate solution (Marwin and Peach, 1951) and determination with the help of flame photometer (Black, 1965).
8.	Available-calcium	Extraction with 1 N ammonium acetate solution and determination with the help of AA-175 atomic absorption spectrophotometer.
9.	Available micronutrient cations viz., zinc, copper, iron and manganese	Extraction with DTPA method (Lindsay and Norvell, 1969) and analysis on AA-175 atomic absorption spectrophotometer.

3.5.2 Plant

The methods used for determination of various nutrient elements in plant samples are described below in Table 3.3

Table 3.3 The methods used for determination of various nutrient elements in plant samples

Sr. No.	Nutrient element	Method followed
1.	Boron	Digestion by dry ashing at 550°C for 6 hours and ash digested with 6.0 N HCl. Boron determination with the help of carmine method (Hatcher and Wilcox, 1950).
2.	Nitrogen	Digestion with concentrated H_2SO_4 in the presence of digestion mixture (K_2SO_4:$CuSO_4$:Se powder::10:1:0.1). Determination by microKjeldahl method (Jackson, 1973).
3.	Phosphorus	Digestion in diacid mixture (HNO_3:$HClO_4$::9:4) and determination following vanadomolybdate acid yellow colour method (Jackson, 1973).
4.	Potassium	Digestion in diacid mixture (HNO_3:$HClO_4$::9:4) and estimation by flame photometric method (Black, 1965).
5.	Calcium	Digestion in diacid mixture (HNO_3:$HClO_4$::9:4) and determination with the help AA-175 atomic absorption spectrophotometer.

3.5 Statistical analysis

Simple correlation of various soil properties with hot water soluble-B in soil samples collected from various locations in zone-II and zone-III of Himachal Pradesh were worked out as per detailed procedure described by Snedecor and Cochran (1994).

The data generated from experiments was also analysed statistically by standard procedure by Gomez and Gomez (1984).

RESULTS

Chapter-IV

RESULTS

The results emanating from the undertaken investigation entitled, "Boron status and transformation in relation to cauliflower (*Brassica oleracea* L. var. *botrytis*) growth and yield in some soils of Himachal Pradesh" have been described in this chapter under the following main heads:

4.1 General physical and chemical properties of the soils

4.2 Relationship between available (hot water soluble)-boron and soil properties

4.3 Laboratory-incubation study

4.4 Greenhouse study

4.1 General physical and chemical properties of the soils

Detailed physical and chemical properties of the surface (0 to 0.15 m) soils from zone-II (mid hills, sub-humid) and zone-III (High-hills, wet-temperate) are given in Appendix-I and II, respectively. However, the ranges and mean values of different soil properties are given in Table 4.1.

The per cent clay, silt and sand varied from 8.90 to 38.6 (average 19.6), 12.3 to 46.5 (average 28.1) and 22.4 to 78.8 (average 52.3) in zone-II and from 10.7 to 34.8 (average 17.7), 10.7 to 53.1 (average 28.4) and 12.1 to 77.0 (average 53.9) in zone-III, respectively.

Table 4.1. Physical and chemical properties of the soils in different agroclimatic zones of Himachal Pradesh

Soil property	Zone-II (Mid-hills, sub-humid)		Zone-III (High-hills, wet temperate)	
	Range	Mean	Range	Mean
Soil separates (%)				
Clay	8.9- 38.6	19.6	10.0-34.8	17.7
Silt	12.3-46.5	28.1	10.7-53.1	28.4
Sand	22.4-78.8	52.3	12.1-77.0	53.9
Organic-C (g kg^{-1})	8.6-27.5	15.5	9.5-22.7	16.4
pH	5.9-7.2	6.5	5.2-6.8	6.1
Available nutrients (kg ha^{-1})				
N	282.3-439.1	346.6	282.3-501.8	363.6
P	2.3-37.0	16.8	2.3-37.0	9.0
K	39.2-560.0	208.9	67.2-504.0	196.0
Exch.-Ca (mg kg^{-1})	276.3-2195.0	1286.7	761.3-1743.8	1178.5
Hws-B (mg kg^{-1})	0.30-2.13	1.10	0.30-1.75	0.92
DTPA extractable micronutrients (mg kg^{-1})				
Zn	1.00-11.02	3.36	0.44-2.06	0.94
Cu	0.14-2.80	1.07	0.02-3.60	1.01
Fe	10.6-70.8	35.3	22.8-96.6	46.4
Mn	2.1-34.9	17.5	5.7-40.0	21.2

The general range in soil texture was from sandy loam to clay loam, however, sandy loam and loam textured were the dominated soils in both the zones.

In general, the organic-carbon content varied from 8.6 to 27.5 g kg^{-1} irrespective of agroclimatic zone. However, the soils of zone-III contained higher amount of organic-carbon when compared with the soils of zone-II. In general, 10.5 and 89.5 per cent soils from zone-II and 12.5 and 87.5 per cent from zone-III fell in medium and high organic-carbon content classes, respectively.

The soils from zone-III were more acidic when compared with the soils of zone-II. The general range of the soil pH was 5.9 to 7.2 in zone-II and 5.2 to 6.8 in zone-III with average values of 6.5 and 6.1, respectively.

The available-B (hot water soluble) content in zone-II varied from 0.30 to 2.13 mg kg^{-1} with an average value of 1.10 mg kg^{-1}. The range of variation in available-B content was from 0.30 to 1.75 mg kg^{-1} with an average value of 0.92 mg kg^{-1} in zone-III. Considering 0.50 mg kg^{-1} as the critical limit of available-B in soil (Takkar and Randhawa, 1968-76 and Malewar *et al.*, 1999b), about 16 per cent soils in zone-II and 19 per cent in zone-III were below this level. The B-deficient areas in these two zones were found to be sporadic. Therefore, no contiguous area could be indentified for B-deficiency. A study of available-B content of individual soil samples from the two agroclimatic zones revealed that soils from Bajaura (0.30 mg kg^{-1} available-B) location in zone-II and from

Junga (0.30 mg kg^{-1} available-B) location in zone-III contained the minimum content of available-B which was far below the critical value. Therefore, these soils were collected in bulk for further laboratory-incubation and greenhouse studies.

Like B content, the soils from zone-II, were also found to have higher amount of exchangeable-Ca (1287 mg kg^{-1}) in comparison to soils from zone-III (1179 mg kg^{-1}). The exchangeable-Ca content in general varied from 276 to 2195 mg kg^{-1} in zone-II and from 761 to 1744 mg kg^{-1} in zone-III.

The available-N, P and K content ranged form 282.3 to 439.1 (average 346.6 kg ha^{-1}), 2.3 to 37.0 (average 16.8 kg ha^{-1}) and 39.2 to 560.0 (average 208.9 kg ha^{-1}) kg ha^{-1}, respectively in zone-II. The variation in these nutrients in zone-III were from 282.3 to 501.8 (average 363.6 kg ha^{-1}), 2.3 to 37.0 (average 9.0 kg ha^{-1}) and 67.2 to 504.0 (average 196.0 kg ha^{-1}) kg ha^{-1}, respectively. Considering the N, P, K content of individual soil samples in each zone, it was observed that all the soil samples in each zone were medium in available-N content. However, 47, 32 and 21 per cent soils in zone-II and 63, 31 and 6 per cent in zone-III were found to be in low, medium and high fertility P classes, respectively, indicating thereby that majority of the soils of these two zones were low to medium in available-P content. As against this, 21, 58 and 21 per cent soils from zone-II and 31, 56 and 13 per cent soils from zone-III were in low, medium and high fertility K classes.

respectively, showing clearly that majority of the soils of two zones were medium to high in available-K content.

DTPA extractable Zn, Cu, Fe and Mn ranged from 1.00 to 11.02; 0.14 to 2.80; 10.6 to 70.8 and 2.1 to 34.9 mg kg^{-1}, respectively, in zone-II soils. Similarly, the range of variation in DTPA extractable Zn, Cu, Fe and Mn in zone-III were from 0.44 to 2.06, 0.02 to 3.60, 22.8 to 96.6 and 5.7 to 40.0 mg kg^{-1}, respectively. The average values for DTPA extractable Zn, Cu, Fe and Mn were 3.36, 1.07, 35.3 and 17.5 mg kg^{-1} in zone-II, and 0.94, 1.01, 46.4 and 21.2 mg kg^{-1} in zone-III, respectively. Considering the critical limits of 0.5, 0.2, 4.5 and 2.0 mg kg^{-1} for available Zn, Cu, Fe and Mn, respectively (Follet and Lindsay, 1970), zone-II soils were sufficient in available Zn, Fe and Mn, while, zone-III soils in available-Fe and Mn only. Sixteen per cent soils in zone-II and 13 per cent in zone-III were found to be deficient in available-Cu. Contrary to zone-II soils, 19 per cent soils in zone-III, were also deficient in available-Zn.

4.2 Relationship between available (hot water soluble)-boron and soil properties

The simple correlation coefficients were worked out between available-B content with different soil properties. Among different studied soil properties, the hot water-soluble-B was observed to be correlated positively and significantly with clay content, available-P and available-K

(Table 4.2). The other properties such as silt and sand content, organic-carbon, soil pH, exchangeable-Ca, available-N, and DTPA extractable micronutrients (Zn, Cu, Fe, Mn) were not found to be correlated with hot water soluble-B content in the soils under study.

Table 4.2. Relationship between soil characteristics and hot water soluble-B in soils

Soil character	Correlation-coefficient (*r*)
Clay	0.4747**
Silt	0.0523
Sand	-0.2696
Organic-C	0.2193
pH	0.1305
Exchangeable-Calcium	0.3190
Available-Nitrogen	-0.0075
Available-Phosphorus	0.3784*
Available-Potassium	0.3734*
DTPA extractable-Zn	0.2298
DTPA extractable-Cu	0.1199
DTPA extractable-Fe	-0.0595
DTPA extractable-Mn	0.0482

* Significant at 5 per cent level

** Significant at 1 per cent level

4.3 Laboratory-incubation study

4.3.1 Hot water soluble (available)-Boron

4.3.1.1 Bajaura soil

The results on the changes in availability of B in Bajaura soil as influenced by the application of B and FYM are presented in Table 4.3. In general, the incorporation of FYM has resulted into significant build up of hot water soluble (hws)-B at 24, 48, 72 and 96 days of incubation. However, significant and consistent increase was observed only at later stages of incubation viz., 72 and 96 days. By contrast, at 24 days of incubation, only higher level of FYM at the rate of 20 g kg^{-1} resulted into significant increase in hws-B over the control. At 48 days of incubation both the levels of FYM increased the hws-B over the control, but remained at par among themselves. In general, the significant increase in hot water soluble-B from 24 to 96 days of incubation period varied from 1.16 to 1.37 times at 10 g FYM kg^{-1} soil and from 1.15 to 1.43 times at 20 g FYM kg^{-1} soil.

Like FYM incorporation, the application of B from 1 to 3 mg kg^{-1} also resulted into significant and consistent increase in hws-B in the present study. In general, the increase in hws-B content from 24 to 96 days of incubation period varied from 1.19 to 1.41 times at 1 mg kg^{-1} B application, from 1.54 to 1.85 times at 2 mg kg^{-1} B and 1.75 to 2.30 times at 3 mg kg^{-1} B application. Like increasing levels of B application,

Table 4.3 Effect of Boron and FYM application on the changes in availability of Boron (mg kg^{-1}) in Bajaura soil

Treatment	Days of incubation															
	24				48				72				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	0.50	0.60	0.62	0.57	0.44	0.48	0.50	0.47	0.40	0.45	0.48	0.44	0.25	0.27	0.29	0.27
B_1	0.63	0.68	0.72	0.68	0.55	0.68	0.69	0.64	0.50	0.62	0.64	0.59	0.31	0.41	0.42	0.38
B_2	0.78	0.91	0.96	0.88	0.66	0.87	0.91	0.81	0.63	0.71	0.73	0.69	0.38	0.55	0.58	0.50
B_3	1.00	0.95	1.06	1.00	0.88	0.97	1.00	0.95	0.73	0.86	0.90	0.83	0.47	0.68	0.70	0.62
Mean	0.73	0.79	0.84		0.63	0.75	0.78		0.57	0.66	0.69		0.35	0.48	0.50	

CD (5%)	24	48	72	96
B	*0.09*	*0.06*	*0.04*	*0.02*
F	0.07	0.05	0.03	0.02
B x F	NS	NS	NS	0.04

the advancement in incubation period also resulted in higher increase in hws-B content over the control. Further, throughout the incubation study, comparatively smaller fraction of the applied-B (6 to 20%)was found to be present in the extractable form in soil, while, major portion got transformed into some non-extractable form.

A further insight into this table indicates that the interaction between FYM incorporation and B application during the incubation study was not found significant at any stage of sampling except at 96 days of incubation. At this stage, FYM incorporation only at 20 g kg^{-1} soil increased hws-B in the absence of B application. However, in the presence of B application from 1 to 3 mg kg^{-1} both the levels of FYM resulted into significant build-up in hws-B over the control without any significant difference among themselves. By contrast, B application from 1 to 3 mg kg^{-1} soil increased hws-B content significantly and consistently both with and without FYM application.

The trend of changes in hws-B content in soil was found to record a slow and gradual decrease with the advancement of incubation period (Fig. 4.1 and 4.2). A study of Fig. 4.1 and 4.2 further revealed that at later stages of incubation viz. 72 to 96 days, greater amounts of hws-B content seems to be transformed into some non-extractable forms as compared to .early periods of the incubation.

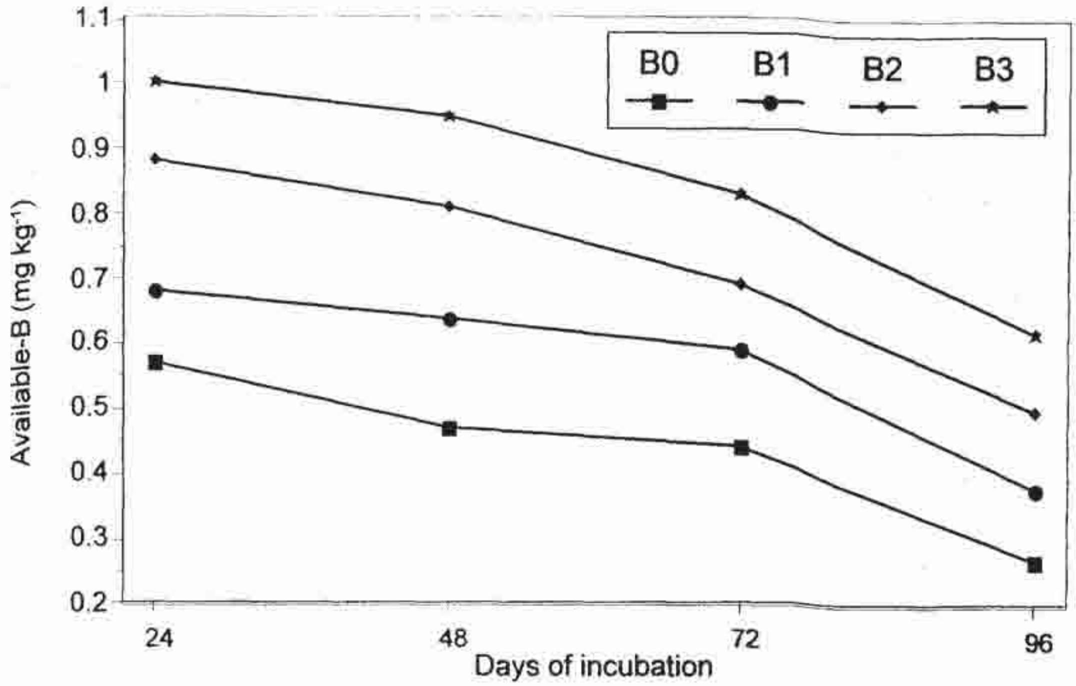


Fig. 4.1. Effect of Boron application on the changes in availability of Boron (mg kg^{-1}) in Bajaura soil.

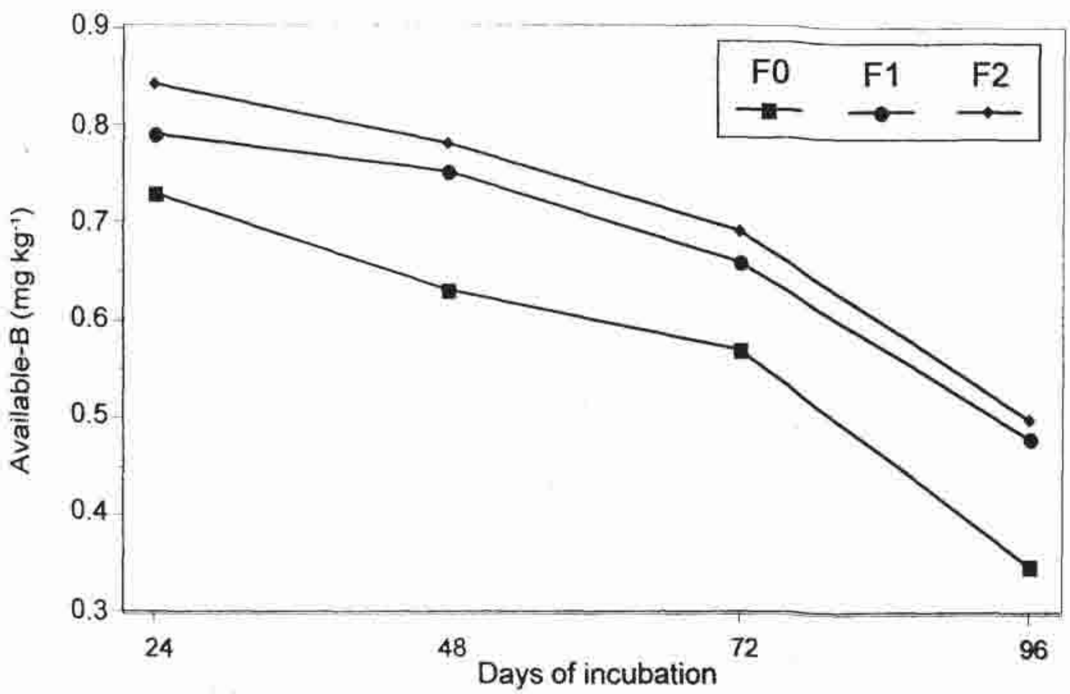


Fig. 4.2. Effect of FYM application on the changes in availability of Boron (mg kg^{-1}) in Bajaura soil.

4.3.1.2 Junga soil

A reference to data in Table 4.4 regarding similar study in Junga soil revealed more or less similar results as observed in Bajaura soil. In Junga soil, the availability of B was found to be more as compared to Bajaura soil.

During 24 and 48 days of sampling, irrespective of B application, FYM incorporation at higher level of 20 g kg^{-1} only could cause significant increase in hws-B content in soil over the control, the extent of increase being 1.05 and 1.11 times, at 24 and 48 days of incubation, respectively. But at 72 and 96 days of incubation, incorporation of FYM at both the levels recorded a significant and consistent increase in hws-B content in soil over the control. Expressed quantitatively, FYM incorporation of 10 and 20 g kg^{-1} increased hws-B in soil amounting to 1.20 and 1.29 times at 72 days, and 1.13 and 1.19 times at 96 days of incubation over no-FYM incorporation in soil, respectively.

Similarly, irrespective of FYM incorporation, B application from 1 to 3 mg kg^{-1}, maintained a significant and consistent increase in hws-B throughout the incubation study. During this study, the increase in hws-B content in soil ranged from 1.19 to 1.29 times at 1 mg kg^{-1} B, from 1.39 to 1.76 times at 2 mg kg^{-1} and from 1.69 to 2.24 times at 3 mg kg^{-1} B application. Like Bajaura soil, in Junga soil also, the increase in hws-B was found to be higher as a result of B application with an

Table 4.4 Effect of Boron and FYM application on the changes in availability of Boron (mg kg^{-1}) in Junga soil

Treatment	Days of incubation															
	24				48				72				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	0.60	0.63	0.68	0.64	0.51	0.59	0.63	0.58	0.41	0.45	0.50	0.45	0.28	0.34	0.38	0.33
B_1	0.74	0.73	0.80	0.76	0.63	0.71	0.73	0.69	0.52	0.58	0.63	0.58	0.39	0.41	0.46	0.42
B_2	0.90	0.88	0.90	0.89	0.84	0.88	0.92	0.88	0.65	0.83	0.88	0.79	0.53	0.60	0.59	0.57
B_3	1.10	1.02	1.12	1.08	1.06	1.00	1.09	1.05	0.76	0.96	1.02	0.91	0.68	0.75	0.79	0.74
Mean	0.84	0.82	0.88		0.76	0.80	0.84		0.59	0.71	0.76		0.47	0.53	0.56	
CD (5%)																
B	0.04				0.06				0.05				0.03			
F	0.03				0.05				0.04				0.02			
B x F	NS				NS				NS				NS			

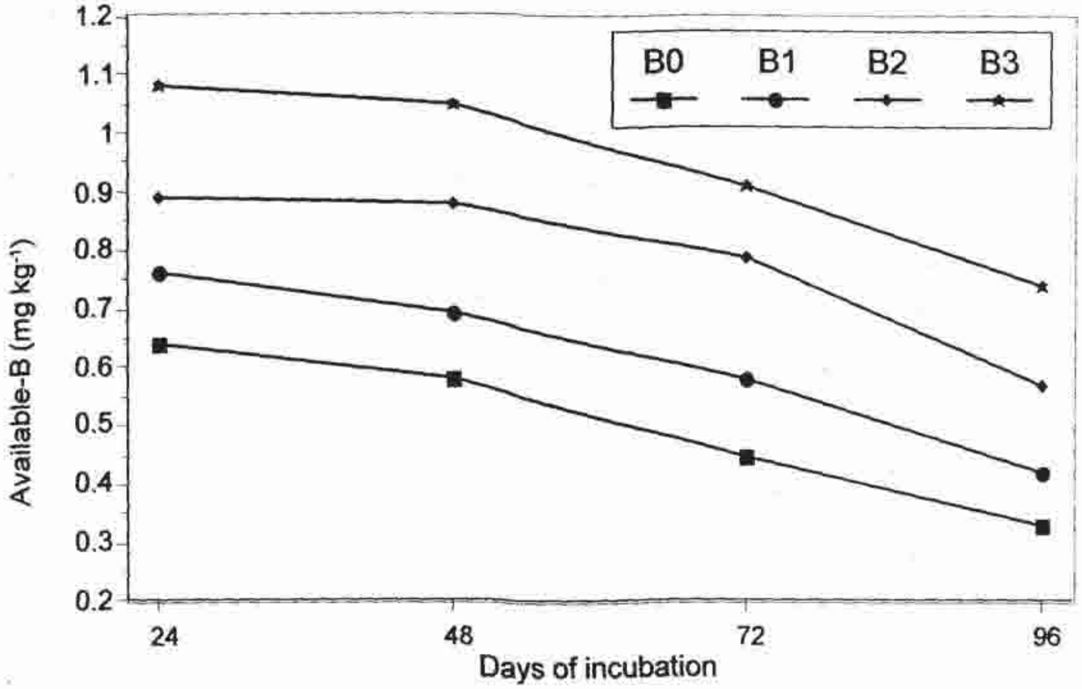


Fig. 4.3. Effect of Boron application on the changes in availability of Boron (mg kg^{-1}) in Junga soil.

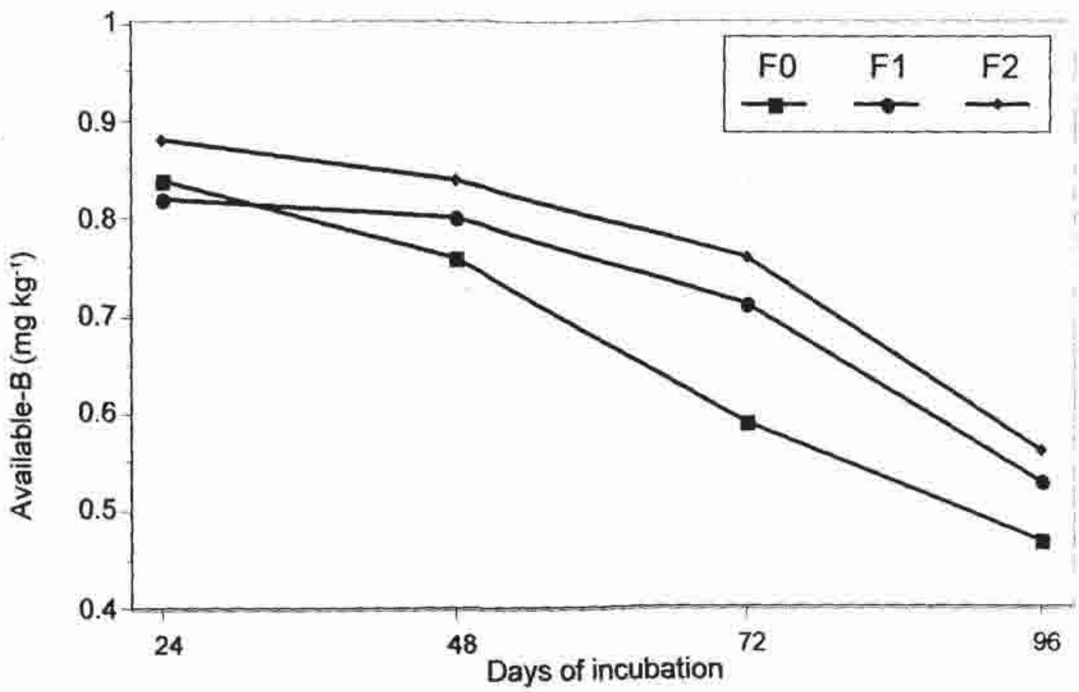


Fig. 4.4 Effect of FYM application on the changes in availability of Boron (mg kg^{-1}) in Junga soil.

advancement of incubation period. The interaction between B application and FYM incorporation on hws-B content was not found significant at any stage of incubation in Junga soil. Similar to the observation made in Bajaura soil, in Junga soil also, greater amounts of B were fixed at later stages of incubation (Fig. 4.3 and 4.4).

4.3.2 Exchangeable-Calcium

4.3.2.1 Bajaura soil

A perusal of the data presented in Table 4.5 revealed that irrespective of B application, FYM incorporation recorded a significant and consistent increase in exchangeable-Ca over the control throughout the incubation study. The increase in exchangeable-Ca over no-FYM ranged from 1.31 to 2.31 per cent at 10 g kg^{-1} and from 2.22 to 4.38 per cent at 20 g kg^{-1} FYM incorporation. The per cent increase in exchangeable-Ca with FYM incorporation consistently increased with the advancement of incubation period.

The effect of B application in general as well as its interaction with FYM incorporation was not found significant. A further reference to the data in above mentioned Table indicates that the exchangeable-Ca continued to increase with the progress of incubation time.

4.3.2.2 Junga soil

The results on the changes in exchangeable-Ca in Junga soil (Table 4.6) were exactly similar to that observed in Bajaura soil. In Junga

Table 4.5 Effect of Boron and FYM application on the changes in availability of Calcium (mg kg^{-1}) in Bajaura soil

Treatment	Days of incubation															
	24				48				72				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	1562.3	1580.0	1596.2	1579.5	1602.8	1630.3	1652.0	1628.4	1665.1	1703.4	1736.1	1701.5	1792.1	1834.3	1872.1	1832.8
B_1	1559.9	1580.6	1594.0	1578.2	1601.7	1631.9	1650.8	1628.1	1663.9	1700.2	1734.1	1699.4	1790.2	1833.0	1867.9	1830.4
B_2	1556.3	1578.9	1592.0	1575.7	1598.1	1628.5	1649.0	1625.2	1665.4	1696.3	1735.4	1699.0	1789.0	1830.0	1867.2	1828.7
B_3	1555.3	1576.0	1590.0	1573.8	1598.9	1627.0	1647.0	1624.3	1663.2	1700.7	1731.0	1698.3	1787.3	1827.2	1864.9	1826.5
Mean	1558.5	1578.9	1593.1		1600.4	1629.4	1649.7		1664.4	1700.2	1734.2		1789.7	1831.1	1868.0	
CD (5%)																
B		NS				NS				NS				NS		
F		12.3				15.8				16.5				16.5		
B x F		NS				NS				NS				NS		

Table 4.6 Effect of Boron and FYM application on the changes in availability of Calcium (mg kg^{-1}) in Junga soil

Treatment	Days of incubation															
	24				48				72				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	658.1	682.0	704.0	681.4	684.0	719.1	744.2	715.8	718.0	766.9	803.3	762.7	778.2	832.5	873.8	828.2
B_1	655.8	679.1	701.1	678.7	681.4	717.9	742.6	714.0	718.3	764.2	802.4	761.6	776.1	828.4	872.5	825.7
B_2	654.8	675.3	698.3	676.1	682.5	712.8	744.0	713.1	716.1	761.3	799.4	758.9	774.5	826.4	871.3	724.1
B_3	652.1	676.4	696.1	674.9	677.9	710.0	742.3	710.1	712.3	762.7	797.5	757.5	771.6	825.1	868.5	821.7
Mean	655.2	678.2	699.9		681.5	715.0	743.3		716.2	763.8	800.7		775.1	828.1	871.5	
CD (5%)																
B		NS				NS				NS				NS		
F		15.9				16.3				16.5				16.4		
B x F		NS				NS				NS				NS		

soil, FYM incorporation, however, resulted into more per cent increase in exchangeable-Ca as compared to that in Bajaura soil. During the incubation study, the increase in exchangeable-Ca over the control varied from 3.51 to 6.84 per cent and 6.82 to 12.4 per cent at 10 and 20 g kg^{-1} soil FYM incorporation, respectively.

4.3.3 Available-Nitrogen

4.3.3.1 Bajaura soil

The data with respect to changes in available-N in Bajaura soil as influenced by the application of B and FYM is presented in Table 4.7. A critical examination of the data revealed that irrespective of B application, FYM incorporation at the rate of 10 and 20 g kg^{-1} significantly and consistently increased available-N during all the stages of incubation. In general, the per cent increase varied from 1.48 to 4.57 at 10 g kg^{-1} and 3.25 to 5.78 at 20 g kg^{-1} FYM incorporation, respectively.

The individual effect of B application as well as its interaction with FYM incorporation was not observed to be significant at any stage of the incubation period.

4.3.3.2 Junga soil

The changes in available-N content in soil during the incubation period from 24 to 96 days as influenced by FYM incorporation and B

Table 4.7 Effect of Boron and FYM application on the changes in availability of Nitrogen (kg ha^{-1}) in Bajaura soil

Treatment	Days of incubation															
	24				48				72				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	392.0	397.3	402.5	397.3	431.2	444.3	451.5	442.3	331.9	332.9	347.6	337.5	326.7	324.1	328.5	326.4
B_1	384.2	394.6	397.3	392.0	415.5	444.3	448.9	436.2	334.5	338.1	345.0	339.2	313.6	321.5	328.5	321.2
B_2	389.4	386.8	397.3	391.2	433.8	452.1	459.3	448.4	329.3	338.1	345.0	337.5	318.9	321.5	325.9	322.1
B_3	391.6	399.9	410.3	397.3	436.5	454.7	456.7	449.3	329.3	335.5	339.7	334.8	308.4	324.1	325.9	319.5
Mean	386.8	394.7	401.9		429.3	448.9	454.1		331.3	336.2	344.3		316.9	322.8	327.2	
CD (5%)																
B		NS				NS				NS				NS		
F		4.3				4.8				4.3				4.0		
B x F		NS				NS				NS				NS		

Table 4.8 Effect of Boron and FYM application on the changes in availability of Nitrogen (kg ha^{-1}) in Junga soil

Treatment	Days of incubation															
	24				48				72				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	402.5	415.5	423.4	413.8	410.3	423.4	434.2	422.6	321.5	327.5	331.9	327.0	295.3	301.9	305.8	301.0
B_1	392.0	407.7	415.5	405.1	420.8	431.2	436.8	429.6	316.2	139.6	334.5	323.4	290.1	294.1	295.3	293.2
B_2	399.9	410.3	418.1	409.4	415.5	428.6	431.6	425.2	313.6	139.6	326.7	320.0	282.3	288.9	297.9	289.7
B_3	394.6	418.1	420.8	411.2	420.8	431.2	435.8	429.6	308.4	317.0	318.8	314.7	287.5	291.5	300.5	293.2
Mean	397.3	412.9	419.5		416.9	428.6	434.6		314.9	320.9	328.0		288.8	294.1	299.9	
CD (5%)																
B		NS				NS				NS				NS		
F		4.7				4.8				4.3				4.7		
B x F		NS				NS				NS				NS		

application almost followed the same trend as was observed in Bajaura soil (Table 4.8). The incorporation of FYM at 10 and 20 g kg^{-1} soil increased the available-N consistently and significantly at all the periods of incubation. The general per cent increase being 1.84 to 3.93 at 10 g kg^{-1} and 3.84 to 5.59 at 20 g kg^{-1} FYM incorporation. The general effect of B as well as its interaction with FYM was not found significant in this soil also.

The trend of change in available-N content in this soil was almost the same as observed in Bajaura soil where upto 48 day of incubation, there was an increase in available-N and after that there was a decreasing trend.

4.3.4 Available-Phosphorus

4.3.4.1 Bajaura soil

A study of the data in Table 4.9 makes it clear that individually the FYM incorporation as well as B application increased available P-content in soil consistently and significantly at all the stages of incubation period. The per cent increase ranged from 11.1 to 22.2, 8.72 to 18.8, 11.7 to 20.4 and 10.9 to 18.8 with FYM incorporation at 24, 48, 72 and 96 days of incubation, respectively. Similarly, the corresponding values for available-P ranged from 1.82 to 6.06, 1.90 to 5.70, 2.03 to 4.73 and 2.21 to 6.62 per cent with B application at 24, 48, 72 and 96 days of incubation period, respectively.

Table 4.9 Effect of Boron and FYM application on the changes in availability of Phosphorus (kg ha^{-1}) in Bajaura soil

Treatment	Days of incubation															
	24				48				72				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	14.6	16.7	18.2	16.5	14.2	16.0	17.1	15.8	13.2	15.0	16.1	14.8	12.3	13.8	14.8	13.6
B_1	15.0	16.8	18.6	16.8	14.6	16.1	17.7	16.1	13.6	15.2	16.4	15.1	12.7	13.9	15.1	13.9
B_2	15.5	17.1	18.8	17.1	15.1	16.3	17.9	16.4	13.7	15.5	16.6	15.3	12.9	14.3	15.3	14.2
B_3	16.1	17.3	19.1	17.5	15.5	16.5	18.2	16.7	14.1	15.6	16.9	15.5	13.3	14.7	15.5	14.5
Mean	15.3	17.0	18.7		14.9	16.2	17.7		13.7	15.3	16.5		12.8	14.2	15.2	
CD (5%)																
B		0.25				0.26				0.20				0.24		
F		0.22				0.23				0.18				0.21		
B x F		NS				NS				NS				NS		

Table 4.10 Effect of Boron and FYM application on the changes in availability of Phosphorus (kg ha^{-1}) in Junga soil

Treatment	Days of incubation															
	24				48				72				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	7.9	10.3	11.7	10.0	7.4	9.6	10.8	9.3	6.2	8.4	9.3	8.0	5.4	7.4	8.5	7.1
B_1	8.5	10.6	11.9	10.3	7.9	10.0	11.0	9.6	6.7	8.6	9.7	8.3	5.6	7.6	8.8	7.3
B_2	9.0	11.0	12.1	10.7	8.3	10.1	11.2	9.2	7.2	8.7	9.9	8.6	5.8	7.9	9.0	7.6
B_3	9.6	11.3	12.3	11.1	8.8	10.3	11.5	10.2	7.5	9.1	10.2	8.9	6.1	8.4	9.1	7.9
Mean	8.8	10.8	12.0		8.1	10.0	11.1		6.9	8.7	9.8		5.7	7.8	8.9	
CD (5%)																
B		0.21				0.19				0.21				0.19		
F		0.18				0.16				0.18				0.17		
B x F		NS				NS				NS				NS		

The interaction between FYM incorporation and B application on available-P was not found significant at any period of incubation.

4.3.4.2 Junga soil

Similar to the observation recorded in Bajaura soil, the data presented in Table 4.10 reveals that individually the FYM incorporation as well as B application increased available-P content in Junga soil also consistently and significantly at all the stages of incubation period. The per cent increase recorded with FYM incorporation varied from 22.7 to 36.4, 23.5 to 37.0, 26.1 to 42.0 and 36.8 to 56.1 at 24, 48, 72 and 96 days of incubation, respectively. Similarly, the increase in available-P ranged from 3.00 to 11.0, 3.23 to 9.68, 3.75 to 11.3 and 2.82 to 11.3 per cent with B application at 24, 48, 72 and 96 days of incubation period, respectively.

The interaction between B and FYM application was also not found significant at any period of incubation.

4.3.5 Available-Potassium

4.3.5.1 Bajaura soil

The data pertaining to the content of available-K in soil as influenced by B application and FYM incorporation was presented in Table 4.11. A study of this Table indicates that like available-P, the content of available-K was also increased consistently and significantly

Table 4.11 Effect of Boron and FYM application on the changes in availability of Potassium (kg ha^{-1}) in Bajaura soil

Treatment	Days of incubation															
	24				48				72				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	184.8	190.4	197.9	191.0	209.1	212.8	218.4	213.4	229.6	235.2	240.8	235.2	243.6	250.1	256.7	250.1
B_1	182.0	188.5	196.0	188.8	206.1	209.9	217.4	211.1	228.6	232.3	237.9	232.9	242.1	247.2	254.2	248.0
B_2	179.2	188.5	196.0	187.9	207.2	210.0	215.6	210.9	226.8	232.4	238.0	232.4	240.7	246.3	253.7	246.9
B_3	177.3	188.5	193.2	186.3	204.4	207.2	215.6	209.1	225.8	230.5	234.2	230.2	238.7	246.2	251.8	245.6
Mean	180.8	189.0	195.8		206.7	210.0	216.8		227.7	232.6	237.7		241.3	247.6	254.1	
CD (5%)																
B		NS				NS				NS				NS		
F		1.6				1.8				1.8				1.8		
B x F		NS				NS				NS				NS		

with an incorporation of FYM at all the stages of incubation period. The increase in available-K, in general, varied from 4.54 to 8.30, 1.60 to 4.89, 2.15 to 4.39 and 2.61 to 5.30 per cent with application of FYM at 10 and 20 g kg^{-1} soil at 24, 48, 72 and 96 days of incubation, respectively. Like exchangeable-Ca and available-N, the individual effect of B application as well as its interaction with FYM incorporation was not observed to be significant at any stage of the incubation period. A further examination of the above mentioned data revealed that available-K continued to increase with the progress of incubation period.

4.3.5.2 Junga soil

The results presented in Table 4.12 revealed exactly similar trend in changes in available-K in Junga soil as influenced by B and FYM application as was observed in Bajaura soil. In this soil, the increase in available-K varied from 8.97 to 16.1, 11.2 to 16.3, 6.65 to 13.9 and 8.35 to 15.3 per cent with application of FYM at 10 and 20 g kg^{-1} soil at 24, 48, 72 and 96 days of incubation, respectively. The individual effect of B application and its interaction with FYM incorporation on available-K was not found significant in Junga soil also.

Table 4.12 Effect of Boron and FYM application on the changes in availability of Potassium (kg ha^{-1}) in Junga soil

Treatment	Days of incubation															
	24				48				72				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	84.0	89.6	98.0	90.5	98.9	108.3	113.9	107.0	112.0	117.6	128.8	119.5	123.2	134.4	142.8	133.5
B_1	81.6	88.2	94.7	88.2	95.2	106.4	112.0	104.5	109.2	114.8	123.2	115.7	120.8	131.1	139.5	130.5
B_2	81.2	89.6	93.3	88.0	95.2	106.4	110.1	103.9	106.4	116.7	122.3	115.1	120.3	130.6	139.0	130.0
B_3	78.8	87.2	91.9	86.0	93.3	104.5	109.2	102.3	105.4	112.9	119.4	112.6	119.4	127.8	136.2	127.8
Mean	81.4	88.7	94.5		95.7	106.4	111.3		108.3	115.5	123.4		120.9	131.0	139.4	
CD (5%)																
B		NS				NS				NS				NS		
F		1.8				1.7				2.5				2.3		
B x F		NS				NS				NS				NS		

4.4 Greenhouse study

4.4.1 Soil study

4.4.1.1 Hot water soluble (hws)-Boron

4.4.1.1.1 Bajaura soil

The data with respect to changes in available-B content in Bajaura soil under cauliflower cultivation as influenced by B and FYM application is presented in Table 4.13. Like incubation study, the incorporation of FYM as well as B application individually maintained significantly and consistently higher amounts of hws-B content in soil both at 48 days after transplanting and at harvest of the crop (96 days). The increase in hws-B content in soil with the incorporation of FYM at the rate of 10 and 20 g kg^{-1} over no-FYM was 1.21 and 1.33 times at 48 days after transplanting and 1.12 and 1.37 times at harvest of the crop, respectively. Similarly, the application of B at the rate of 1, 2 and 3 mg kg^{-1} recorded an increase in hws-B to the extent of 1.60, 2.02 and 2.40 times at 48 days after transplanting, and 1.61, 1.92 and 2.27 times at harvest of the crop, respectively.

The interaction between B application and FYM incorporation was not found significant either at 48 or 96 days of study (at harvest).

A further study of the data points out that under all treatments, higher contents of hws-B in soil were observed in greenhouse study in contrast to laboratory-incubation study.

Table 4.13 Effect of Boron and FYM application on the changes in availability of Boron (mg kg^{-1}) in Bajaura soil

Treatments	Days after transplanting							
	48				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	0.58	0.62	0.70	0.63	0.42	0.45	0.67	0.51
B_1	0.75	1.06	1.23	1.01	0.63	0.89	0.95	0.82
B_2	1.03	1.34	1.44	1.27	0.89	0.92	1.14	0.98
B_3	1.38	1.52	1.64	1.51	1.04	1.09	1.35	1.16
Mean	0.94	1.14	1.25		0.75	0.84	1.03	
CD (5%)								
B		0.04				0.05		
F		0.03				0.04		
B x F		NS				NS		

4.4.1.1.2 Junga soil

An examination of the data in Table 4.14 revealed exactly the similar trends in Junga soil as also observed in Bajaura soil. However, the incorporation of FYM at the rate of 10 and 20 g kg^{-1} have resulted comparatively higher increase in hws-B. The increase being about 1.93 and 2.34 times at 48 days after transplanting, and 1.57 and 1.75 times at harvest of the crop, respectively. Similarly, the increase in hws-B was

Table 4.14 Effect of Boron and FYM application on the changes in availability of Boron (mg kg^{-1}) in Junga soil

Treatments	Days after transplanting							
	48				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	0.51	0.74	1.10	0.78	0.38	0.63	0.79	0.60
B_1	0.68	1.56	1.97	1.40	0.47	0.83	0.88	0.73
B_2	1.06	2.01	2.52	1.86	0.60	0.90	0.99	0.83
B_3	1.35	2.64	2.83	2.27	0.68	0.97	1.05	0.90
Mean	0.90	1.74	2.11		0.53	0.83	0.93	
CD (5%)								
B		0.05				0.04		
F		0.04				0.04		
B x F		NS				NS		

of the order of 1.79, 2.38 and 2.91 times at 48 days after transplanting, and 1.22, 1.38 and 1.50 times at harvest of the crop with the application of B at the rate of 1, 2 and 3 mg kg^{-1}, respectively.

4.4.1.2 Exchangeable-Calcium

4.4.1.2.1 Bajaura soil

From Table 4.15, it is evident that similar to incubation study, the incorporation of FYM, irrespective of B application, maintained a significant and consistent increase in exchangeable-Ca over the control in Bajaura soil throughout the growth period of cauliflower. FYM incorporation at the rate of 10 and 20 g kg^{-1} resulted in 3.53 and 7.13 per cent increase in exchangeable-Ca at 48 days after transplanting, and 2.84 and 6.06 at harvest of the crop, respectively.

Table 4.15 Effect of Boron and FYM application on the changes in availability of exchangeable-Calcium (mg kg^{-1}) in Bajaura soil

Treatments	Days after transplanting							
	48				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	1897.4	1962.1	2030.1	1963.2	1751.9	1805.3	1858.0	1805.1
B_1	1892.8	1960.1	2027.1	1960.0	1746.8	1798.3	1854.2	1799.8
B_2	1893.3	1957.1	2025.2	1958.5	1742.9	1790.1	1848.1	1793.7
B_3	1883.7	1955.0	2024.0	1954.2	1739.9	1786.3	1844.2	1790.1
Mean	1891.8	1958.6	2026.6		1745.4	1795.0	1851.1	
CD (5%)								
B		NS				NS		
F		16.7				16.6		
B x F		NS				NS		

The application of B, as in laboratory-incubation, could not record a significant effect on the exchangeable-Ca content in soil under cauliflower cultivation in the greenhouse study. Further, the interaction between B application and FYM incorporation was not found significant at any stage.

4.4.1.2.2 Junga soil

The results on the changes in exchangeable-Ca in Junga soil under cauliflower cultivation as affected by B and FYM are presented in Table 4.16.

Table 4.16 Effect of Boron and FYM application on the changes in availability of exchangeable-Calcium (mg kg^{-1}) in Junga soil

Treatments	Days after transplanting							
	48				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	907.9	987.3	1086.4	993.9	894.2	944.2	990.2	942.9
B_1	903.2	980.3	1080.4	988.0	889.9	936.8	984.0	936.9
B_2	900.4	972.2	1073.2	981.9	886.1	934.7	979.1	933.3
B_3	898.4	967.7	1070.7	978.9	882.1	930.2	978.2	930.2
Mean	902.5	976.9	1077.7		888.1	936.5	982.9	
CD (5%)								
B		NS				NS		
F		16.3				16.4		
B x F		NS				NS		

A critical examination of the data makes it clear that exactly similar results, as observed in Bajaura soil, were recorded in Junga soil. In this soil, the increase in exchangeable-Ca content over the control with the incorporation of FYM at the rate of 10 and 20 g kg^{-1} was of the order of 8.24 and 19.4 per cent at 48 days after transplanting, and 5.45 and 10.7 per cent at harvest of the crop, respectively. Thus, increase in exchangeable-Ca content with FYM incorporation was more in Junga soil as compared to that in Bajaura soil.

4.4.1.3 Available-Nitrogen

4.4.1.3.1 Bajaura soil

A reference to data in Table 4.17 shows that FYM incorporation maintained consistently and significantly higher amounts of available-N over no-FYM both during the mid of the crop growth as well as at the harvest of the crop. FYM incorporation at the rate of 10 and 20 g kg^{-1} increased available-N to the extent of 9.35 and 19.8 per cent at 48 days after transplanting, and 2.61 and 7.03 per cent at harvest of the crop, respectively.

Unlike incubation study where B application had no significant effect on available-N, its application during greenhouse study significantly reduced available-N content in soil over no-B application at both the stages. However, the higher levels of B (2 and 3 mg kg^{-1} soil) remained at par among themselves. The per cent decrease in available-N was of the order of 4.03, 6.60 and 7.57 at 48 days after transplanting, and 3.23, 5.09 and 5.54 at harvest of the crop with B application at the rate of 1, 2 ad 3 mg kg^{-1}, respectively.

Table 4.17 Effect of Boron and FYM application on the changes in availability of Nitrogen (kg ha^{-1}) in Bajaura soil

Treatments	Days after transplanting							
	48				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	376.3	407.7	444.3	409.4	363.3	376.3	392.0	377.2
B_1	360.7	389.4	428.6	392.9	352.8	363.3	378.9	365.0
B_2	345.0	384.2	418.1	382.4	347.6	355.4	371.1	358.0
B_3	342.7	376.7	415.9	378.4	347.6	352.8	368.5	356.3
Mean	356.2	389.5	426.7		352.8	362.0	377.6	
CD (5%)								
B		5.1				4.6		
F		4.4				4.0		
B x F		NS				NS		

Similar to the observation in laboratory-incubation, the interaction effect was not found significant in greenhouse study also.

4.4.1.3.2 Junga soil

The effects of B and FYM application on available-N content in Junga soil (Table 4.18) were almost similar to that recorded in Bajaura soil. In Junga soil also, the FYM incorporation at the rate of 10 and 20 g kg^{-1} increased available-N consistently and significantly. The increase being 1.38 and 3.51 per cent at 48 days after transplanting, and 2.94 and 5.71 per cent at the harvest of the crop, respectively.

Table 4.18 Effect of Boron and FYM application on the changes in availability of Nitrogen (kg ha^{-1}) in Junga soil

Treatments	Days after transplanting							
	48				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	449.5	439.1	465.2	451.3	376.3	363.3	389.4	376.3
B_1	418.1	431.2	446.9	432.1	355.4	358.1	376.3	363.3
B_2	431.2	423.4	431.2	428.6	360.7	350.2	368.5	359.8
B_3	433.8	415.5	426.0	425.1	363.7	342.7	361.1	355.8
Mean	433.2	427.3	442.3		364.0	353.6	373.8	
CD (5%)								
B		4.6				5.7		
F		4.0				4.9		
B x F		NS				NS		

As in Bajaura soil, the application of B resulted in a decrease in available-N over the control in Junga soil also. However, higher levels of B were at par with each other. The decrease recorded was of the order of 4.25, 5.03 and 5.81 per cent at 48 days after transplanting, and 3.45, 4.38 and 5.45 per cent at harvest of the crop, respectively.

4.4.1.4 Available-Phosphorus

4.4.1.4.1 Bajaura soil

The results on changes in available-P content in Bajaura soil in greenhouse study as affected by B application and FYM incorporation are presented in Table 4.19. Similar to laboratory study, FYM incorporation significantly and consistently maintained higher available-P content over no-FYM throughout the growing period of cauliflower. The increase recorded with 10 and 20 g kg^{-1} FYM over no-FYM was 16.7 and 26.9 per cent at 48 days after transplanting, and 31.0 and 40.2 per cent at harvest of the crop, respectively.

Similarly, at 48 days after transplanting, the application of B from 1 to 3 mg kg^{-1} recorded a significant and consistent increase in available-P content in soil over the control. Quantitatively, B applied at the rate of 1, 2 and 3 mg kg^{-1} enhanced available-P to the tune of 1.66, 3.73 and 5.39 per cent, respectively, over no-B application. However, at harvest of the crop, a reverse trend was observed with B application from 1 to 3 mg kg^{-1} which reduced the available-P content significantly

Table 4.19 Effect of Boron and FYM application on the changes in availability of Phosphorus (kg ha^{-1}) in Bajaura soil

Treatments	Days after transplanting							
	48				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	20.9	24.8	26.5	24.1	8.5	11.7	12.9	11.0
B_1	21.3	25.0	27.3	24.5	8.6	11.3	12.1	10.7
B_2	21.9	25.4	27.8	25.0	8.9	11.3	11.9	10.7
B_3	22.4	25.7	28.1	25.4	8.9	11.1	11.8	10.6
Mean	21.6	25.2	27.4		8.7	11.4	12.2	
CD (5%)								
B		0.26				0.22		
F		0.23				0.19		
B x F		NS				NS		

over the control without any significant effect among higher levels of B. Similar to the laboratory study, the interaction between B application and FYM incorporation on available-P in soil was not found significant at any of the stage.

4.4.1.4.2 Junga soil

The results related to changes in available-P content in Junga soil under greenhouse study (Table 4.20) also revealed significant and consistent increase in available-P with incorporation of FYM over the control throughout the growth period of cauliflower. The increase in available-P was 35.8 and 45.0 per cent at 48 days after transplanting, and 20.0 and 32.0 per cent at harvest of the crop, with the application of 10 and 20 g kg^{-1} FYM over no-FYM, respectively.

Table 4.20 Effect of Boron and FYM application on the changes in availability of Phosphorus (kg ha^{-1}) in Junga soil

Treatments	Days after transplanting							
	48				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	11.4	15.9	17.0	14.8	4.9	6.3	6.9	6.0
B_1	11.7	16.1	17.3	15.0	4.7	6.0	6.7	5.8
B_2	12.2	16.4	17.5	15.4	5.1	5.8	6.4	5.8
B_3	12.6	16.6	17.7	15.6	5.3	5.8	6.3	5.8
Mean	12.0	16.3	17.4		5.0	6.0	6.6	
CD (5%)								
B		0.20				0.19		
F		0.18				0.17		
B x F		NS				NS		

Similar to Bajaura soil, the application of B, consistently and significantly maintained higher available-P over the control at 48 days after transplanting and decreased it significantly at harvest of the crop. However, higher levels of B were again found at par among themselves. The application of B at the rate of 1, 2 and 3 mg kg^{-1} increased available-P to the tune of 1.35, 4.05 and 5.41 per cent at 48 days after transplanting, respectively, but, decreased to the extent of 3.33 per cent at harvest under each level of B application. The interaction between FYM incorporation and B application was not found significant on available-P content.

4.4.1.5 Available-Potassium

4.4.1.5.1 Bajaura soil

In conformity with the incubation study, a consistent and significant increase in available-K with FYM incorporation was observed at both the stages during greenhouse study (Table 4.21). The incorporation of FYM at the rate of 10 and 20 g kg^{-1} recorded 1.82 and 5.61 per cent increase at 48 days after transplanting, and 13.7 and 25.7 per cent at harvest of the crop.

Unlike laboratory-incubation where the application of B did not affect available-K significantly, its application during greenhouse study significantly reduced available-K content in soil over the control at both the stages of observation. The application of B at the rate of 1, 2 and

3 mg kg^{-1}, decreased the available-K to the extent of 6.90, 10.0 and 12.9 per cent at 48 days after transplanting, and 10.2 , 15.1 and 17.0 per cent at harvest of the crop, respectively. Like laboratory-incubation study, the interaction between B application and FYM incorporation on available-K content in Bajaura soil was not found significant at any of the stage.

Table 4.21 Effect of Boron and FYM application on the changes in availability of Potassium (kg ha^{-1}) in Bajaura soil

Treatments	Days after transplanting							
	48				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	199.7	203.6	218.4	207.2	162.4	197.9	216.5	192.3
B_1	194.1	190.5	194.1	192.9	154.0	173.6	190.4	172.7
B_2	182.0	186.8	190.4	186.4	147.5	162.4	180.1	163.3
B_3	172.7	181.2	187.6	180.5	143.7	156.8	178.3	159.6
Mean	187.1	190.5	197.6		151.9	172.7	191.3	
CD (5%)								
B		2.0				3.1		
F		1.8				2.7		
B x F		NS				NS		

4.4.1.5.2 Junga soil

The effect of B and FYM application on the changes in availability of K in Junga soil (Table 4.22) recorded exactly similar trend as was observed in Bajaura soil.

Table 4.22 Effect of Boron and FYM application on the changes in availability of Potassium (kg ha⁻¹) in Junga soil

Treatments	Days after transplanting							
	48				96			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	98.9	112.9	121.3	111.0	89.6	83.6	98.0	93.7
B_1	81.2	106.4	112.0	99.9	72.8	84.3	89.6	82.2
B_2	84.9	100.8	104.5	96.7	75.6	79.5	81.2	78.8
B_3	90.5	94.2	97.0	93.9	78.4	71.2	75.6	75.1
Mean	88.9	103.6	108.7		79.1	82.2	86.1	
CD (5%)								
B		2.1				2.7		
F		1.8				2.3		
B x F		NS				NS		

The incorporation of FYM at the rate of 10 and 20 g kg^{-1} recorded a significant and consistent increase in available-K over the control to the tune of 16.5 and 22.3 per cent at 48 days after transplanting, and 3.92 and 8.85 per cent at harvest of the crop, respectively. Similarly, the B application at 1, 2 and 3 mg kg^{-1} decreased the available-K to the extent of 11.0, 12.9 and 15.4 per cent at 48 days after transplanting, and 12.3, 15.9 and 19.9 per cent at harvest of the crop, respectively. The interaction between B and FYM application on available-K status in Junga soil was also not found significant at any of the stage.

4.4.2 Plant study

4.4.2.1 Physiological and morphological characteristics

4.4.2.1.1 Bajaura soil

The results regarding effects of B and FYM application on various physiological and morphological characteristics of cauliflower grown in Bajaura soil in a greenhouse experiment are presented in Table 4.23. The interaction effect between B application and FYM incorporation was not found significant on any of the studied characteristic. The results are described here character-wise.

4.4.2.1.1.1 Days to curd maturity

The incorporation of FYM, irrespective of B application, resulted in significant and consistent earliness in curd maturity over the control. Similarly, the application of B also recorded a significant earliness in curd maturity, but, only at B application of 2 and 3 mg kg^{-1}

over the control, whereas, its application at 1 mg kg^{-1} had no significant effect on days to curd maturity.

Table 4.23 Effect of Boron and FYM application on various growth characteristics (Physiological and morphological) of cauliflower in Bajaura soil

Treatments	Days to curd maturity	Curd compa-ctness	Curd depth (cm)	Curd diameter (cm)	Stalk length (cm)	Number of mature leaves at harvest	Leaf size (cm^2)
Boron levels							
B_0	93.6	11.9	4.37	6.36	5.81	9.78	142.0
B_1	93.3	12.8	4.88	6.70	5.12	10.56	153.9
B_2	91.0	13.5	5.19	7.01	6.73	10.78	167.9
B_3	89.4	13.9	5.32	7.09	6.68	10.44	170.7
CD (5%)	1.4	0.6	0.44	0.37	NS	NS	9.6
FYM levels							
F_0	94.1	11.5	4.09	5.90	5.93	9.50	147.7
F_1	91.4	12.6	4.89	6.46	6.19	10.50	156.2
F_2	90.0	14.9	5.84	8.02	6.13	11.17	174.2
CD (5%)	1.2	0.53	0.38	0.32	NS	0.63	8.3

4.4.2.1.1.2 Curd compactness

The FYM incorporation as well as B application significantly enhanced curd compactness over the control. In case of FYM incorporation, each successive increment was found significant over the preceding one. However, in case of B, its application only upto 2 mg kg^{-1} resulted in significant increase in curd compactness, whereas, further increase in B application was not found significant over 2 mg kg^{-1} B application.

4.4.2.1.1.3 Curd depth

Curd depth was also observed to increase significantly both with B and FYM application over the control. The successive increment in FYM incorporation was also found significant in increasing curd depth over the preceding one. In case of B application, it was found that only its application at the rate of 1 mg kg^{-1} was helpful in increasing curd depth significantly. The further increase in its application were found at par with 1 mg kg^{-1} B application.

4.4.2.1.1.4 Curd diameter

Irrespective of B application, FYM incorporation recorded a significant and consistent increase in curd diameter over the control. However, irrespective of FYM incorporation, B application at the rate of 1 mg kg^{-1} was not found significant in increasing curd diameter, but, its application at 2 and 3 mg kg^{-1} increased the curd diameter significantly over the control without any significant difference among these two levels of B application.

4.4.2.1.1.5 Stalk length

A reference to Table 4.23 reveals that the effect of FYM incorporation at the rate of 10 and 20 g kg^{-1} as well as that of the effect of B application from 1 to 3 mg kg^{-1} was not found significant on stalk length.

4.4.2.1.1.6 Number of mature leaves at harvest

The FYM incorporation significantly and consistently increased number of mature leaves at harvest over the control. However, the application of B had no significant effect on number of mature leaves.

4.4.2.1.1.7 Leaf size

The FYM incorporation consistently and significantly increased the leaf size of cauliflower. Similarly, the application of B from 1 to 3 mg kg^{-1} soil also increased the leaf size of cauliflower over the control. But there was no significant difference among 2 and 3 mg kg^{-1} B, indicating thereby the usefulness of B only upto 2 mg kg^{-1} soil as far as its effect on leaf size of cauliflower is concerned.

4.4.2.1.2 Junga soil

The results on the effect of B and FYM application on physiological and morphological characteristics of cauliflower grown in Junga soil in a greenhouse study are shown in Table 4.24. Like Bajaura soil, the interaction between B and FYM application was not found significant on any of the characteristic in Junga soil also. The character-wise description is presented as under:

Table 4.24 Effect of Boron and FYM application on various growth characteristics (Physiological and morphological) of cauliflower in Junga soil

Treatments	Days to curd maturity	Curd compa-ctness	Curd depth (cm)	Curd diameter (cm)	Stalk length (cm)	Number of mature leaves at harvest	Leaf size (cm^2)
Boron levels							
B_0	92.3	9.3	4.42	5.77	7.23	10.45	133.8
B_1	91.4	11.2	5.50	6.79	6.58	11.11	144.3
B_2	90.4	11.7	5.46	6.84	6.93	11.00	144.9
B_3	89.0	11.6	5.43	6.82	7.11	10.44	143.1
CD (5%)	1.5	0.6	0.37	0.41	NS	NS	6.8
FYM levels							
F_0	93.0	7.5	4.87	5.34	7.09	9.75	113.9
F_1	90.9	11.5	5.24	6.53	6.90	10.88	148.8
F_2	88.5	12.9	5.90	7.80	6.90	11.42	161.9
CD (5%)	1.3	0.5	0.32	0.35	NS	0.47	5.9

4.4.2.1.2.1 Days to curd maturity

Like observation recorded in Bajaura soil, the incorporation of FYM resulted in a significant and consistent earliness in curd maturity in

Junga soil also. The application of B only at higher levels (2 and 3 mg kg^{-1}) also recorded a significant earliness in curd maturity. However, the application of B at 1 mg kg^{-1} could not record a significant effect on maturity of the crop.

4.4.2.1.2.2 Curd compactness

In conformity with the trend in Bajaura soil, the curd compactness was observed to be increased significantly and consistently with FYM incorporation. By contrast, the application of B only upto 1 mg kg^{-1} was found useful in increasing curd compactness of cauliflower. A further increase in B application was not found significant over 1 mg kg^{-1} B application.

4.4.2.1.2.3 Curd depth

Similar to curd compactness, the curd depth increased significantly and consistently with FYM incorporation. The application of B only upto 1 mg kg^{-1} resulted in significant increase in curd depth and further increase in B application was not found significant over 1 mg kg^{-1} B application.

4.4.2.1.2.4 Curd diameter

The curd diameter was also found to increase significantly and consistently with FYM incorporation. In case of B application, it was again found that its application only upto 1 mg kg^{-1} was helpful in increasing curd diameter significantly. However, a further increase in B application to 2 and 3 mg kg^{-1} was found at par with 1 mg kg^{-1} B application.

4.4.2.1.2.5 Stalk length

Similar to the observation recorded in Bajaura soil, the effect of the application of B as well as FYM incorporation on stalk length was not found significant in Junga soil also.

4.4.2.1.2.6 Number of mature leaves at harvest

The number of mature leaves increased significantly and consistently with FYM incorporation, however, the application of B could not record a significant effect on number of mature leaves. Exactly similar results were also recorded in Bajaura soil.

4.4.2.1.2.7 Leaf size

In conformity with the trends in other growth characteristics viz. curd compactness, curd depth and curd diameter, the leaf size was found to increase significantly and consistently with FYM incorporation. Similarly, the application of B only upto 1 mg kg^{-1} was found effective in significantly increasing the leaf size. The application of B at 2 and 3 mg kg^{-1} were found at par with 1 mg kg^{-1} B application in influencing the size of the leaf.

4.4.2.2 Fresh and dry matter yield

4.4.2.2.1 Bajaura soil

The data presented in Table 4.25 shows the effects of B and FYM application on fresh and dry matter yield of cauliflower grown in Bajaura soil in a greenhouse study. Similar to various physiological and morphological characters of cauliflower, the interaction between B and FYM application was not found significant on fresh as well as dry matter yield of cauliflower. The detailed effects of B and FYM application are described below:

4.4.2.2.1.1 Fresh matter yield

The fresh matter yield expressed in different forms viz., total plant weight (root + shoot), marketable curd yield and net curd weight was found to increase significantly and consistently with the incorporation of FYM. The FYM incorporation at the rate of 10 and 20 g kg^{-1} recorded an increase of 11.4 and 20.0 per cent in total plant weight, 6.43 and 21.8 per cent in marketable curd yield, and 31.2 and 85.4 per cent in net curd weight, respectively, over the control.

The application of B upto the rate of 2 mg kg^{-1} also increased fresh matter yield significantly and consistently. However, the application of B at 3 mg kg^{-1} was found at par with 2 mg kg^{-1} B application. The increase recorded was 10.7, 15.2 and 16.9 per cent in total plant weight, 12.4, 19.3 and 24.9 per cent in marketable curd yield, and 19.9, 34.7

and 41.6 per cent in net curd weight with the application of B at the rate of 1, 2 and 3 mg kg^{-1}, respectively, over the control.

Table 4.25 Effect of Boron and FYM application on fresh and dry matter yield of cauliflower in Bajaura soil

Treatments	Fresh matter yield (g pot^{-1})			Dry matter yield (g pot^{-1})		
	Total plant weight	Marketable curd yield	Net curd weight	Leaves+stalks	Curd	Root
Boron levels						
B_0	255.1	143.2	52.7	24.9	5.86	3.57
B_1	282.3	160.9	63.2	26.7	6.44	4.02
B_2	294.0	170.8	71.0	27.5	6.94	4.41
B_3	298.2	178.8	74.6	27.8	7.02	4.51
CD (5%)	8.6	8.5	5.0	0.8	0.50	0.39
FYM levels						
F_0	255.7	149.4	47.1	24.9	5.39	3.37
F_1	284.8	159.0	61.8	26.4	6.60	4.21
F_2	306.8	181.9	87.3	27.7	7.55	4.75
CD (5%)	7.5	7.3	4.3	0.7	0.43	0.34

4.4.2.2.1.2 Dry matter yield

The individual effects of B as well as FYM application were exactly similar to those recorded under fresh matter yield. The FYM

Plate 1. Response of cauliflower to B and FYM application in Bajaura soil

incorporation at 10 and 20 g kg^{-1} recorded an increase over the control to the tune of 6.02 and 11.2 per cent in leaves + stalks, 22.4 and 40.1 per cent in curd, and 24.9 and 40.9 per cent in roots, respectively. Similarly, the application of B at the rate of 1, 2 and 3 mg kg^{-1} increased dry matter yield over the control to the extent of 7.23, 10.4 and 11.6 per cent in leaves + stalks, 9.90, 18.4 and 19.8 per cent in curd, and 12.6, 23.5 and 26.3 per cent in roots, respectively.

4.4.2.2.2 Junga soil

The data pertaining to fresh and dry matter yield of cauliflower grown in Junga soil (Table 4.26) revealed exactly the similar effects of FYM incorporation as were observed in Bajaura soil. The application of B also increased fresh as well as dry matter yield significantly over the control. However, unlike Bajaura soil where B application upto 2 mg kg^{-1} responded significantly, in Junga soil its application only upto 1 mg kg^{-1} soil was found significant in increasing fresh and dry matter yields of cauliflower.

4.4.2.2.2.1 Fresh matter yield

Expressed quantitatively, the incorporation of FYM at the rate of 10 and 20 g kg^{-1} resulted an increase to the extent of 27.3 and 41.4 per cent in total plant weight, 33.7 and 56.8 per cent in marketable curd yield, and 60.8 and 103.5 per cent in net curd weight, respectively (Table 4.26). Similarly, the application of B at the rate of 1, 2 and 3 mg kg^{-1}

recorded an increase to the tune of 15.2, 20.2 and 15.5 per cent in total plant weight, 25.0, 29.9 and 21.9 per cent in marketable curd yield and 41.5, 49.4 and 47.6 per cent in net curd weight, respectively.

Table 4.26 Effect of Boron and FYM application on fresh and dry matter yield of cauliflower in Junga soil

Treatments	Fresh matter yield (g pot^{-1})			Dry matter yield (g pot^{-1})		
	Total plant weight	Marketable curd yield	Net curd weight	Leaves+stalks	Curd	Root
Boron levels						
B_0	220.4	116.2	43.1	22.1	4.32	2.82
B_1	254.0	146.4	61.0	23.7	6.13	3.53
B_2	264.9	150.9	64.4	22.5	6.31	3.60
B_3	254.6	141.6	63.6	21.8	6.13	3.22
CD (5%)	10.3	7.0	5.8	0.8	0.53	0.37
FYM levels						
F_0	202.2	106.6	37.5	19.1	3.83	2.63
F_1	257.3	142.5	60.3	23.7	6.26	3.38
F_2	285.9	167.2	76.3	24.9	7.09	3.78
CD (5%)	9.0	6.1	5.0	0.7	0.46	0.32

4.4.2.2.2.2 Dry matter yield

The incorporation of FYM at the rate of 10 and 20 g kg^{-1} recorded a significant and consistent increase over the control to the

Plate 2. Response of cauliflower to B and FYM application in Junga soil

Plate 3a. Toxicity symptoms of B in Junga soil at B level of 2 mg kg^{-1}.

Plate 3b. Toxicity symptoms of B in Junga soil at B level of 3 mg kg^{-1}.

tune of 24.1 and 30.4 per cent in leaves + stalks, 63.4 and 85.1 per cent in curd, and 28.5 and 43.7 per cent in roots, respectively. Similarly, the application of B at 1, 2 and 3 mg kg^{-1} resulted 41.9, 46.1 and 41.9 per cent increase in curd, and 25.2, 27.7 and 14.2 per cent increase in root, respectively, over the control. In case of leaves + stalk, the application of B only at the rate of 1 mg kg^{-1} could increase their dry matter yield to the extent of 7.24 per cent over the control.

4.4.2.3 Nutrient contents

4.4.2.3.1 Boron

The data regarding the effect of B and FYM application on B-content in different parts of cauliflower is presented in Table 4.27 for Bajaura soil and in Table 4.28 for Junga soil. In general, the B-content was higher in leaves + stalks, curd and roots of cauliflower in Junga soil in comparison to Bajaura soil. The average B-content in leaves + stalks, curd and roots were 35.5, 5.23 and 7.25 mg kg^{-1} in Bajaura soil, and 64.9, 7.49 and 9.68 mg kg^{-1} in Junga soil, respectively. As far as B-content in different parts of cauliflower is concerned, it was observed that, in general, highest B-content was found in leaves + stalks, followed by roots and lowest in curd.

4.4.2.3.1.1 Bajaura soil

The application of B, in general, increased the B-content consistently and significantly in leaves + stalks, curd and root parts of

Table 4.27 Effect of Boron and FYM application on Boron content (mg kg^{-1}) in different parts of cauliflower in Bajaura soil

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	12.33	19.33	20.17	17.28	2.67	3.83	3.83	3.44	4.00	5.50	5.67	5.06
B_1	29.67	29.17	31.87	30.24	4.33	5.33	5.50	5.05	6.00	6.67	6.83	6.50
B_2	40.50	40.17	40.83	40.50	4.83	6.00	5.83	5.55	7.83	8.00	8.00	7.94
B_3	58.17	52.67	51.67	54.17	6.50	7.17	7.00	6.89	9.67	9.50	9.33	9.50
Mean	35.17	35.34	36.14		4.58	5.58	5.54		6.88	7.42	7.46	
CD (5%)												
B		2.65				0.62				0.77		
F		NS				0.54				NS		
B x F		NS				NS				NS		

cauliflower in Bajaura soil (Table 4.27). The effect of FYM incorporation was found significant only in curd and not in leaves + stalks and roots of cauliflower. In curd, the application of FYM at the rate of 10 g kg^{-1} increased B-content significantly while, at 20 g kg^{-1} did not influence B-content over 10 g kg^{-1} FYM incorporation. The interaction effect of B application and FYM incorporation was not found significant on B-content in any part of cauliflower.

4.4.2.3.1.2 Junga soil

Similar to Bajaura soil, in Junga soil also, the application of B increased the B-content significantly and consistently in all the parts of cauliflower (Table 4.28). The increase in B-content at 1, 2 and 3 mg kg^{-1} B were 1.85, 2.89 and 3.69 times in leaves + stalks, 1.37, 1.75 and 2.00 times in curd, and 1.32, 1.64 and 2.10 times in roots, respectively. The FYM incorporation only upto 10 g kg^{-1} increased the B-content significantly over the control in all parts of the cauliflower, whereas, its incorporation at the rate of 20 g kg^{-1} did not influence B-content over its lower rate. The interaction between FYM and B was found significant on B-content in leaves + stalks and root parts of cauliflower. In these parts, B application was observed to increase B-content significantly and consistently both with and without FYM application. The FYM incorporation only at the rate of 10 g kg^{-1} increased B-content significantly in the absence of B as well as upto 2 mg kg^{-1} B application

Table 4.28 *Effect of Boron and FYM application on Boron content (mg kg^{-1}) in different parts of cauliflower in Junga soil*

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	17.67	31.83	33.17	27.56	3.50	5.50	5.67	4.89	4.83	7.00	7.33	6.39
B_1	31.83	60.50	60.67	51.00	5.33	7.33	7.50	6.72	6.50	9.33	9.50	8.44
B_2	75.40	82.33	81.50	79.74	8.50	8.67	8.50	8.56	9.50	11.17	10.83	10.50
B_3	110.67	96.50	96.83	101.33	9.33	10.00	10.00	9.78	13.83	13.00	13.33	13.39
Mean	58.89	67.79	68.04		6.67	7.88	7.92		8.67	10.13	10.25	
CD (5%)												
B		3.44				0.84				0.82		
F		*2.98*				*0.73*				*0.71*		
B x F		5.96				NS				1.43		

in leaves + stalks and in roots. At 3 mg kg^{-1} B application, while, FYM did not influence B-content significantly in roots, it decreased them significantly in leaves + stalks.

4.4.2.3.2 Calcium

From the data presented in Table 4.29 and 4.30 for Bajaura and Junga soils, respectively, it was concluded that in contrast to B-content, the Ca-content was higher in leaves + stalks, curd and roots of cauliflower in Bajaura soil in comparison to Junga soil. The average Ca-content in leaves + stalks, curd and roots were 2.42, 0.20 and 0.59 per cent in Bajaura soil, and 1.84, 0.17 and 0.26 per cent in Junga soil, respectively. Regarding Ca-content in different parts of cauliflower, similar to B-content, the highest Ca-content was observed in leaves + stalks followed by roots and lowest in curd.

4.4.2.3.2.1 Bajaura soil

Like B-content, the Ca-content was also found to increase significantly and consistently in leaves + stalks, curd and root parts of cauliflower over the control with B application (Table 4.29). Similarly, the incorporation of FYM also increased Ca-content in cauliflower parts significantly over the control. The increase was consistent in curd and roots, while, in leaves + stalks, the FYM incorporation at 20 g kg^{-1} could not record a significant increase in Ca-content over 10 g kg^{-1} FYM level.

Table 4.29. Effect of Boron and FYM application on Calcium content (%) in different parts of cauliflower in Bajaura soil

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	1.90	2.20	2.22	2.11	0.16	0.17	0.19	0.17	0.47	0.48	0.52	0.49
B_1	2.19	2.26	2.40	2.28	0.17	0.19	0.20	0.19	0.51	0.59	0.60	0.57
B_2	2.39	2.48	2.56	2.48	0.19	0.21	0.22	0.21	0.56	0.59	0.69	0.61
B_3	2.77	2.78	2.86	2.80	0.21	0.23	0.24	0.23	0.66	0.62	0.76	0.68
Mean	2.31	2.43	2.51		0.18	0.20	0.21		0.55	0.57	0.64	
CD (5%)												
B		0.13				0.01				0.03		
F		0.11				0.01				0.02		
B x F		NS				NS				NS		

Table 4.30 Effect of Boron and FYM application on Calcium content (%) in different parts of cauliflower in Junga soil

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	0.98	1.52	1.56	1.35	0.10	0.14	0.15	0.13	0.15	0.24	0.27	0.22
B_1	1.15	2.04	2.02	1.74	0.11	0.18	0.19	0.16	0.18	0.26	0.28	0.24
B_2	1.46	2.32	2.38	2.05	0.13	0.20	0.21	0.18	0.21	0.27	0.33	0.27
B_3	1.69	2.47	2.50	2.22	0.16	0.22	0.22	0.20	0.26	0.33	0.37	0.32
Mean	1.32	2.09	2.12		0.13	0.19	0.19		0.20	0.28	0.31	
CD (5%)												
B		0.11				0.01				0.02		
F		*0.10*				*0.01*				*0.02*		
B × F		*NS*				*NS*				*NS*		

The interaction between B and FYM application was not found significant on Ca-content in any part of cauliflower.

4.4.2.3.2.2 Junga soil

Like Bajaura soil, the application of B increased the Ca-content significantly and consistently in all the cauliflower parts (Table 4.30). The FYM incorporation also increased Ca-content significantly and consistently in roots, while, in leaves + stalks and curd, two levels of FYM incorporation remained at par. The interaction between B and FYM application on Ca-content was not found significant in Junga soil.

4.4.2.3.3 Nitrogen

In contrast to B and Ca contents in cauliflower parts, a perusal of data in Table 4.31 and 4.32 for Bajaura and Junga soils, respectively, revealed higher N-content in curd, followed by leaves + stalks and lowest in roots. The average N-content in leaves + stalks, curd and roots were 2.81, 5.30 and 1.86 per cent in Bajaura soil, and 2.83, 4.33 and 1.83 per cent in Junga soil, respectively.

4.4.2.3.3.1 Bajaura soil

Like Ca-content, the application of B, in general, increased N content in cauliflower parts significantly and consistently over the control (Table 4.31). The FYM incorporation was also found to increase N-

Table 4.31 Effect of Boron and FYM application on Nitrogen content (%) in different parts of cauliflower in Bajaura soil

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	2.55	2.58	2.75	2.63	4.73	4.93	5.60	5.09	1.45	1.76	2.01	1.74
B_1	2.70	2.67	2.83	2.73	5.13	5.21	5.63	5.32	1.51	1.82	2.08	1.80
B_2	3.11	2.75	2.87	2.91	5.36	4.97	5.71	5.35	1.82	1.82	2.11	1.92
B_3	3.14	2.76	2.96	2.95	5.37	5.22	5.72	5.44	1.88	1.85	2.22	1.98
Mean	2.88	2.69	2.85		5.15	5.08	5.67		1.67	1.81	2.11	
CD (5%)												
B		*0.05*				*0.04*				*0.04*		
F		*0.04*				*0.04*				*0.03*		
B x F		NS				NS				NS		

Table 4.32 *Effect of Boron and FYM application on Nitrogen content (%) in different parts of cauliflower in Junga soil*

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	2.55	2.61	2.71	2.62	3.64	3.96	4.08	3.89	1.49	1.83	1.90	1.74
B_1	2.81	2.65	2.76	2.74	4.17	4.13	4.36	4.22	1.60	1.85	1.93	1.79
B_2	2.97	2.68	2.83	2.83	4.37	4.62	4.75	4.58	1.70	1.93	1.94	1.86
B_3	3.19	3.06	3.08	3.11	4.42	4.70	4.77	4.63	1.74	1.99	2.00	1.91
Mean	2.88	2.75	2.85		4.15	4.35	4.49		1.63	1.90	1.94	
CD (5%)												
B		0.03				0.06				0.03		
F		0.03				0.05				0.03		
B x F		NS				NS				NS		

content significantly and consistently in roots. However, in case of leaves + stalks and curd, the incorporation of FYM at 10 g kg^{-1} significantly decreased N-content over the control, whereas, at higher level of 20 g kg^{-1}, FYM did not influenced N-content in leaves + stalks, but, increased significantly in curd. The interaction between B and FYM application on N-content was not found significant in any part of cauliflower.

4.4.2.3.3.2 Junga soil

As in Bajaura soil, the application of B, in general, increased N-content in cauliflower parts significantly and consistently over the control (Table 4.32). The incorporation of FYM decreased N-content significantly over the control in leaves + stalks but, increased it significantly and consistently in curd and roots of cauliflower. The interaction between B application and FYM incorporation was not found significant on N-content in any part of cauliflower in Junga soil also.

4.4.2.3.4 Phosphorus

A study of the results presented in Table 4.33 and 4.34 for Bajaura and Junga soils, respectively, revealed that like N-content, the highest P-content was also found in curd followed by leaves + stalks and lowest in roots. The average P-content in leaves + stalks, curd and roots were 745.0, 1333.0 and 634.6 mg kg^{-1} in Bajaura soil, and 1326.6, 1353.2 and 674.8 mg kg^{-1} in Junga soil, respectively. A further study

Table 4.33 Effect of Boron and FYM application on Phosphorus content (mg kg^{-1}) in different parts of cauliflower in Bajaura soil

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	604.0	671.0	793.3	689.4	1235.0	1338.3	1368.3	1313.9	496.3	615.0	678.7	596.7
B_1	651.3	736.0	816.7	734.7	1254.0	1348.3	1378.0	1326.8	545.7	633.3	663.7	614.2
B_2	676.7	795.0	819.3	763.7	1257.3	1358.3	1396.0	1337.2	562.3	635.7	692.3	630.1
B_3	681.7	843.3	851.7	792.2	1286.7	1377.7	1398.0	1354.1	615.0	735.0	741.7	697.2
Mean	653.4	761.3	820.3		1258.3	1355.7	1385.1		554.8	654.8	694.1	
CD (5%)												
B		38.6				NS				32.8		
F		33.5				26.0				28.4		
B x F		NS				NS				NS		

revealed that in general, the P-content was higher in leaves + stalks, curd and roots of cauliflower in Junga soil in comparison to Bajaura soil, inspite of higher soil available-P in Bajaura soil in contrast to Junga soil throughout the laboratory-incubation and greenhouse soil study.

4.4.2.3.4.1 Bajaura soil

A reference to Table 4.33 revealed a significant increase in P-content in leaves + stalks with B application over the control. However, the succeeding increment in B was at par with the preceding one. The B application did not affect P-content in curd significantly. In case of roots, the application of B at 2 and 3 mg kg^{-1} increased P-content significantly and consistently over the control, while its application at 1 mg kg^{-1} was found at par with the control. The incorporation of FYM, however, increased P-content in cauliflower parts significantly and consistently over the control. The interaction effect of B and FYM on P-content was not found significant in any part of cauliflower.

4.4.2.3.4.2 Junga soil

An examination of the data presented in Table 4.34 showed that individually the application of B as well as FYM incorporation increased P-content significantly and consistently in cauliflower parts over the control. However, in case of curd, the incorporation of FYM could not record significant effect on P-content. The interaction between B and

Table 4.34 Effect of Boron and FYM application on Phosphorus content (mg kg^{-1}) in different parts of cauliflower in Junga soil

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	1003.3	1136.7	1334.0	1158.0	1261.3	1283.0	1301.7	1282.0	484.0	660.0	703.0	615.7
B_1	1096.7	1235.0	1402.3	1244.7	1324.0	1338.3	1337.3	1333.2	576.7	682.3	726.7	661.9
B_2	1217.3	1486.3	1510.0	1404.5	1340.7	1348.3	1386.0	1358.3	598.3	692.3	750.0	680.2
B_3	1245.7	1625.7	1625.7	1499.0	1430.0	1420.7	1467.3	1739.3	681.0	748.0	794.7	741.2
Mean	1140.8	1370.9	1468.0		1339.0	1347.6	1373.1	585.0	695.7	743.6		
CD (5%)												
B		36.9				33.5				32.7		
F		32.0				NS				28.3		
B x F		NS				NS				NS		

FYM application on P-content in different parts of cauliflower grown in Junga soil was not found significant.

4.4.2.3.5 Potassium

The results on K-content in cauliflower parts as influenced by B and FYM application are presented in Table 4.35 for Bajaura soil and Table 4.36 for Junga soil. In conformity with higher available-K observed in Bajaura soil than in Junga soil both in laboratory-incubation and greenhouse study, the K-content in cauliflower parts, in general, were also higher in Bajaura soil in comparison to Junga soil. The average K-content in leaves + stalks, curd and roots were 1.86, 3.65 and 1.28 per cent in Bajaura soil, and 1.39, 3.31 and 0.97 per cent in Junga soil, respectively. Like N and P content, in general, the highest K-content was also found in curd followed by leaves + stalks and lowest in roots.

4.4.2.3.5.1 Bajaura soil

In general, the application of B from 1 to 3 mg kg^{-1} recorded a significant and consistent increase in K-content in curd and roots of cauliflower over the control (Table 4.35). However, in case of leaves + stalks, the B application only upto 2 mg kg^{-1} recorded a significant and consistent increase while, further increase in its level to 3 mg kg^{-1} did not influence K-content over its 2 mg kg^{-1} level. The FYM incorporation recorded a significant and consistent increase in K-content in curd and

Table 4.35 Effect of Boron and FYM application on Potassium content (%) in different parts of cauliflower in Bajaura soil

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	1.50	1.56	1.75	1.60	1.96	3.50	3.59	3.02	0.96	1.09	1.13	1.06
B_1	1.80	1.84	2.00	1.88	2.21	4.00	4.46	3.56	1.21	1.25	1.29	1.25
B_2	2.00	1.85	2.04	1.96	2.38	4.46	4.92	3.92	1.29	1.29	1.38	1.32
B_3	2.04	1.89	2.09	2.01	2.96	4.42	4.96	4.11	1.50	1.42	1.54	1.49
Mean	1.84	1.79	1.97		2.38	4.10	4.48		1.24	1.26	1.34	
CD (5%)												
B		0.08				0.18				0.10		
F		0.07				0.15				NS		
B x F		*NS*				*NS*				*NS*		

Table 4.36 Effect of Boron and FYM application on Potassium content (%) in different parts of cauliflower in Junga soil

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	1.04	1.13	1.29	1.15	2.00	3.46	4.00	3.15	0.71	0.79	1.00	0.83
B_1	1.25	1.29	1.46	1.33	2.25	3.50	3.54	3.10	0.79	0.79	1.13	0.90
B_2	1.38	1.42	1.54	1.45	2.96	3.50	3.79	3.42	0.96	0.88	1.25	1.03
B_3	1.50	1.59	1.79	1.63	3.00	3.71	3.96	3.56	1.00	1.00	1.29	1.10
Mean	1.29	1.36	1.52		2.55	3.54	3.82		0.87	0.87	1.17	
CD (5%)												
B		0.08				0.17				0.08		
F		*0.07*				*0.15*				*0.07*		
B x F		*NS*				*NS*				*NS*		

no significant effect in root part of cauliflower. In case of leaves + stalks, the FYM incorporation only at 20 g kg^{-1} recorded a significant increase over the control while FYM incorporation at 10 g kg^{-1} remained at par with the control. The interaction between B and FYM on K-content was not found significant in any part of cauliflower.

4.4.2.3.5.2 Junga soil

The application of B increased K-content significantly and consistently in leaves + stalks over the control. However, in curd and roots of cauliflower, the application of B at 1 mg kg^{-1}, while, did not influence K-content significantly, its application at 2 and 3 mg kg^{-1} increased the K-content significantly over the control. The incorporation of FYM, however, increased K-content significantly and consistently in curd and leaves + stalks, while in root, only higher level of FYM at 20 g kg^{-1} could record significant increase in K-content over the control. The interaction between B and FYM application on K-content in different parts of cauliflower was not found significant in Junga soil also.

4.4.2.4 Nutrient uptake

4.4.2.4.1 Boron

4.4.2.4.1.1 Bajaura soil

A study of the data presented in Table 4.37 revealed a significant and consistent increase in B-uptake by cauliflower over the control with the incorporation of FYM. The increase recorded was 8.51

Table 4.37 Effect of Boron and FYM application on Boron uptake ($\mu g\ pot^{-1}$) by cauliflower in Bajaura soil

Treatments	Total B uptake in Bajaura soil			
	F_0	F_1	F_2	Mean
B_0	311.2	515.7	593.0	473.3
B_1	795.8	846.3	959.5	867.2
B_2	1084.4	1170.8	1234.8	1163.3
B_3	1545.8	1522.5	1532.8	1533.7
Mean	934.3	1013.8	1080.0	
CD (5%)				
B	73.1			
F	63.3			
B x F	NS			

and 15.6 per cent with the incorporation of FYM at the rate of 10 and 20 g kg^{-1}. Similarly, the application of B resulted in a significant and consistent increase in B-uptake. The application of B at the rate of 1, 2 and 3 mg kg^{-1} recorded 1.83, 2.46 and 3.24 times increase over the control, respectively. The interaction between B and FYM application was not found significant.

4.4.2.4.1.2 Junga soil

The data with respect to B-uptake by cauliflower grown in Junga soil (Table 4.38) revealed more B-uptake as compared to Bajaura soil, inspite of higher yields in Bajaura soil. Similar to the observation made in Bajaura soil, the incorporation of FYM at the rate of 10 and 20 g kg^{-1} resulted in a significant and consistent increase in B-uptake over the control to the tune of 53.0 and 62.1 per cent, respectively. Similarly, the application of B at the rate of 1, 2, 3 mg kg^{-1} recorded a significant and consistent increase in B-uptake over the control to the extent of 1.95, 2.85 and 3.44 times, respectively.

Table 4.38 Effect of Boron and FYM application on Boron uptake (µg pot^{-1}) by cauliflower in Junga soil

Treatments	Total B uptake in Junga soil			
	F_0	F_1	F_2	Mean
B_0	356.1	785.4	854.1	665.2
B_1	757.9	1519.5	1608.7	1295.4
B_2	1426.8	2080.2	2175.8	1894.3
B_3	1897.3	2403.9	2556.3	2285.8
Mean	1109.5	1697.3	1798.7	
CD (5%)				
B	89.4			
F	77.4			
B x F	154.8			

The interaction between B application and FYM incorporation was found significant on B-uptake in Junga soil. The FYM incorporation only upto 10 g kg^{-1} increased B-uptake significantly both with and without B application. However, B application from 1 to 3 mg kg^{-1} increased B-uptake significantly and consistently both with and without FYM incorporation.

4.4.2.4.2 Calcium

4.4.2.4.2.1 Bajaura soil

The results with respect to Ca-uptake by cauliflower grown in Bajaura soil are presented in 4.39.

Table 4.39 Effect of Boron and FYM application on Calcium uptake (mg pot^{-1}) by cauliflower in Bajaura soil

Treatments	Total Ca uptake in Bajaura soil			
	F_0	F_1	F_2	Mean
B_0	463.2	566.2	633.1	554.2
B_1	582.4	644.8	710.6	645.9
B_2	638.3	716.9	773.6	709.6
B_3	735.6	797.2	849.4	794.1
Mean	604.9	681.3	741.7	
CD (5%)				
B	43.4			
F	37.6			
B x F	NS			

A reference to data in Table 4.39 revealed that individually, the incorporation of FYM as well as B application resulted into a significant and consistent increase in Ca-uptake over the control. The increase recorded was 12.6 and 22.6 per cent with the incorporation of FYM at the rate of 10 and 20 g kg^{-1}, respectively. Similarly, the application of B at 1, 2 and 3 mg kg^{-1} resulted into 16.5, 28.0 and 43.3 per cent increase in Ca-uptake, respectively. The interaction between B and FYM application was not found significant.

4.4.2.4.2.2 Junga soil

As in Bajaura soil, the incorporation of FYM significantly and consistently increased Ca-uptake over the control (Table 4.40). The increase recorded was 2.00 and 2.15 times with the incorporation of 10 and 20 g kg^{-1} FYM, respectively. Unlike in Bajaura soil, the application of B increased Ca-uptake but only upto 2 mg kg^{-1} level of its application, whereas, further B application to 3 mg kg^{-1}, could not record a significant increase over 2 mg kg^{-1} B. The B application of 1, 2 and 3 mg kg^{-1} increased Ca-uptake over the control to the extent of 36.9, 56.6 and 64.4 per cent, respectively. The interaction between B and FYM on Ca-uptake was not found significant in Junga soil also.

Table 4.40 Effect of Boron and FYM application on Calcium uptake (mg pot^{-1}) by cauliflower in Junga soil

Treatments	Total Ca uptake in Junga soil			
	F_0	F_1	F_2	Mean
B_0	193.9	365.0	392.4	317.1
B_1	268.2	505.8	528.6	434.2
B_2	276.4	580.6	632.6	496.5
B_3	292.2	613.3	658.1	521.2
Mean	257.7	516.2	552.9	
CD (5%)				
B	26.4			
F	22.9			
B x F	NS			

4.4.2.4.3 Nitrogen

4.4.2.4.3.1 Bajaura soil

A study of the results presented in Table 4.41 revealed that the incorporation of FYM at the rate of 10 and 20 g kg^{-1} increased N-uptake significantly and consistently over the control to the tune of 6.85 and 25.3 per cent, respectively. Similarly, the application of B upto 2 mg kg^{-1} increased N-uptake significantly and consistently, whereas, its application at the rate of 3 mg kg^{-1} did not influence N-uptake in a significant way over its 2 mg kg^{-1} level. Boron applied at 1 and 2 mg

kg^{-1} resulted 12.5 and 20.1 per cent increase in N-uptake, respectively. The interaction effect between B and FYM application was, however, not found significant.

Table 4.41 Effect of Boron and FYM application on Nitrogen uptake (mg pot^{-1}) by cauliflower in Bajaura soil

Treatments	Total N uptake in Bajaura soil			
	F_0	F_1	F_2	Mean
B_0	832.9	1000.7	1229.5	1021.0
B_1	1002.8	1135.0	1309.3	1149.0
B_2	1169.0	1157.3	1351.2	1225.8
B_3	1198.3	1198.0	1377.1	1257.8
Mean	1050.8	1122.8	1316.8	
CD (5%)				
B	38.4			
F	33.2			
B x F	NS			

4.4.2.4.3.2 Junga soil

In Junga soil also, the FYM incorporation at the rate of 10 and 20 g kg^{-1} increased N-uptake significantly and consistently over the control to the extent of 32.0 and 46.9 per cent, respectively (Table 4.42). The application of B was also found to increase N-uptake significantly over the control. However, among B levels from 1 to 3 mg kg^{-1}, the successive increment in B level was found at par with the preceding one. The application of B at the rate of 1, 2 and 3 mg kg^{-1} resulted 21.0, 23.5 and 27.5 per cent increase in N-uptake, respectively, over the control. Like Bajaura soil, the interaction effect between B and FYM was not found significant here too.

Table 4.42 Effect of Boron and FYM application on Nitrogen uptake (mg pot^{-1}) by cauliflower in Junga soil

Treatments	Total N uptake in Junga soil			
	F_0	F_1	F_2	Mean
B_0	598.1	863.5	947.6	803.1
B_1	886.1	954.1	1075.9	972.0
B_2	772.5	1037.0	1166.1	991.9
B_3	745.0	1108.8	1218.9	1024.2
Mean	750.4	990.9	1102.1	
CD (5%)				
B	36.7			
F	31.8			
B x F	NS			

4.4.2.4.4 Phosphorus

4.4.2.4.4.1 Bajaura soil

The data regarding the effect of B and FYM application on P-uptake in cauliflower grown in Bajaura soil is given in Table 4.43. An examination of the results revealed that individually both FYM as well as B application resulted in a significant and consistent increase in uptake of P over the control. The increase was 27.6 and 46.0 per cent with FYM incorporation of 10 and 20 g kg^{-1}, respectively, and 13.6, 19.5 and 24.6 per cent with B application of 1, 2 and 3 mg kg^{-1}, respectively. The interaction between B and FYM application on P-uptake was also not found significant.

Table 4.43 Effect of Boron and FYM application on Phosphorus uptake (mg pot^{-1}) by cauliflower in Bajaura soil

Treatments	Total P uptake in Bajaura soil			Mean
	F_0	F_1	F_2	
B_0	20.6	26.9	34.1	27.2
B_1	25.0	31.4	36.2	30.9
B_2	26.6	33.5	37.3	32.5
B_3	27.6	35.8	38.2	33.9
Mean	25.0	31.9	36.5	
CD (5%)				
B	1.4			
F	1.2			
B x F	NS			

4.4.2.4.4.2 Junga soil

As in Bajaura soil, the FYM incorporation at the rate of 10 and 20 g kg^{-1} increased P-uptake significantly and consistently over the control to the tune of 53.4 and 73.9 per cent, respectively (Table 4.44). However, the application of B only upto 2 mg kg^{-1} could increase P-uptake significantly and consistently over the control, whereas, its application at the rate of 3 mg kg^{-1} did not bring about any significant effect over its 2 mg kg^{-1} level. The B applied at the rate of 1, 2 and 3 mg kg^{-1} recorded 21.4, 29.8 and 34.3 per cent increase in P-uptake over the control, respectively. Like Bajaura soil, the interaction between B and FYM was not found significant.

Table 4.44 Effect of Boron and FYM application on Phosphorus uptake (mg pot^{-1}) by cauliflower in Junga soil

Treatments	Total P uptake in Junga soil			
	F_0	F_1	F_2	Mean
B_0	22.9	34.9	41.9	33.2
B_1	32.9	40.2	47.7	40.3
B_2	29.5	47.6	52.1	43.1
B_3	27.9	50.7	55.2	44.8
Mean	28.3	43.4	49.2	
CD (5%)				
B	1.7			
F	1.4			
B x F	NS			

4.4.2.4.5 Potassium

4.4.2.4.5.1 Bajaura soil

A perusal of data in Table 4.45 revealed a significant and consistent increase in K-uptake over the control with FYM incorporation. An increase of 23.0 and 50.4 per cent was observed with FYM incorporation at 10 and 20 g kg^{-1}, respectively. The application of B also increased K-uptake significantly and consistently, but, only upto 2 mg kg^{-1}.

Table 4.45 Effect of Boron and FYM application on Potassium uptake (mg pot^{-1}) by cauliflower in Bajaura soil

Treatments	Total K uptake in Bajaura soil			
	F_0	F_1	F_2	Mean
B_0	457.7	637.2	778.1	624.3
B_1	613.8	723.6	952.7	763.4
B_2	693.9	856.5	1022.9	857.8
B_3	757.8	885.5	1040.9	894.7
Mean	630.8	775.7	948.7	
CD (5%)				
B	45.8			
F	39.6			
B x F	NS			

A further application of B at 3 mg kg^{-1} did not increase K-uptake significantly over its 2 mg kg^{-1} level. The B applied at 1, 2 and 3 mg kg^{-1} increased K-uptake over the control to the extent of 22.3, 37.4 and 43.3 per cent, respectively. The interaction between B and FYM on K-uptake was not found significant.

4.4.2.4.5.2 Junga soil

The data with respect to K-uptake in cauliflower in Junga soil (Table 4.46) revealed exactly the similar effect of B as well as FYM.

Table 4.46 Effect of Boron and FYM application on Potassium uptake (mg pot^{-1}) by cauliflower in Junga soil

Treatments	Total K uptake in Junga soil			
	F_0	F_1	F_2	Mean
B_0	257.6	463.4	572.3	431.1
B_1	417.0	556.9	662.2	545.4
B_2	403.0	617.7	736.7	585.8
B_3	390.6	658.3	805.9	618.3
Mean	367.1	574.1	694.3	
CD (5%)				
B	33.8			
F	29.2			
B x F	NS			

as was observed in Bajaura soil. The FYM incorporation at 10 and 20 g kg^{-1} recorded an increase in K- uptake over the control to the extent of 56.4 and 89.1 per cent, respectively. Similarly, the application of B at the rate of 1, 2 and 3 mg kg^{-1} recorded 26.5, 35.9 and 43.4 per cent increase in K-uptake over the control, respectively. Here again, the interaction between B and FYM application was not found significant.

4.4.2.5 Relative distribution of nutrients among different parts of cauliflower

An attempt has been made to find out the relative distribution of B, Ca, N, P and K among different parts of cauliflower as influenced by B application and FYM incorporation. For this purpose, the uptake data for individual nutrient has been pooled among two experimental soils.

4.4.2.5.1 Boron

The data in Table 4.47 clearly indicates that out of the total removal of the B by cauliflower, the major portion (about 94 %) was retained by the leaves + stalks and only smaller fraction of it was translocated to curd (about 3 %). Similarly, remaining 3 per cent was retained by the roots of cauliflower. As far as the effect of B application and FYM incorporation was concerned, it was found that increasing

Table 4.47 Per cent distribution of Boron among different parts of cauliflower

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	94.0	92.6	92.3	93.0	2.8	4.1	4.2	3.7	3.2	3.3	3.5	3.3
B_1	94.2	93.7	93.4	93.8	3.1	3.6	3.8	3.5	2.7	2.7	2.8	2.7
B_2	95.1	94.3	94.1	94.5	2.6	3.1	3.3	3.0	2.3	2.6	2.6	2.5
B_3	95.7	94.5	94.2	94.8	2.3	3.1	3.3	2.9	2.0	2.4	2.5	2.3
Mean	94.8	93.8	93.5		2.7	3.5	3.6		2.5	2.7	2.9	

levels of FYM incorporation decreased the distribution of B in leaves + stalks and increased it in curd and roots. By contrast, the application of B from 1 to 3 mg kg^{-1}, while, increased the B distribution in leaves + stalks, it decreased in curd and root.

4.4.2.5.2 Calcium

Like B, the major portion (about 95 %) of the total removal of the Ca by cauliflower was retained by leaves + stalks and a smaller fraction of it (about 2 %) was translocated to curd (Table 4.48). The remaining 3 per cent was retained by the roots of cauliflower. Similarly, the incorporation of FYM tended to decrease relative Ca distribution in leaves + stalks and increased it in curd and root parts of cauliflower. In contrast to relative B distribution, the application of B resulted into a consistent decrease in relative Ca distribution in leaves + stalks and an increase in curd and roots.

4.4.2.5.3 Nitrogen

A study of the data in Table 4.49 points out that in contrast to B and Ca, the relative distribution of N was less in leaves + stalks and more in curd and roots. Still, the major portion (about 66 %) of the total removal by cauliflower remained in leaves + stalks, followed by curd (about 28 %) and lowest in roots (about 6 %). Like Ca, the incorporation of FYM as well as B application, in general, decreased relative

Table 4.48 Per cent distribution of Calcium among different parts of cauliflower

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	96.6	95.5	94.9	95.6	1.2	1.9	2.2	1.8	2.2	2.6	2.9	2.6
B_1	95.6	95.1	94.7	95.1	1.8	2.1	2.3	2.1	2.6	2.8	3.0	2.8
B_2	95.5	95.1	94.4	95.0	1.8	2.2	2.4	2.1	2.7	2.7	3.2	2.9
B_3	95.3	95.1	94.3	94.9	2.0	2.2	2.4	2.2	2.7	2.7	3.3	2.9
Mean	95.8	95.2	94.6		1.7	2.1	2.3		2.5	2.7	3.1	

Table 4.49 Per cent distribution of Nitrogen among different parts of cauliflower

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	76.8	66.5	64.4	69.2	18.2	27.1	28.7	24.7	5.0	6.4	6.9	6.1
B_1	69.5	64.4	62.1	65.3	25.0	28.9	30.6	28.2	5.5	6.7	7.3	6.5
B_2	68.6	63.4	60.7	64.2	25.4	29.5	32.1	29.0	6.0	7.1	7.2	6.8
B_3	68.5	64.0	61.5	64.7	26.0	29.3	31.3	28.9	5.5	6.7	7.2	6.4
Mean	70.9	64.6	62.2		23.6	28.7	30.7		5.5	6.7	7.1	

distribution of N in leaves + stalks and correspondingly increased it in curd and root parts of cauliflower.

4.4.2.5.4 Phosphorus

The data on relative distribution of P in different parts of cauliflower is given in Table 4.50. The relative distribution pattern of P in parts of cauliflower and the effects of B and FYM application on it were almost similar to that observed in N uptake. Out of total P removal, about 69 per cent remained in leaves + stalks, 24 per cent in curd and 7 per cent in roots of cauliflower. The incorporation of FYM as well as B application, decreased the distribution of P in leaves + stalks, while, correspondingly increased it in curd and root parts of cauliflower.

4.4.2.5.5 Potassium

A perusal of data in Table 4.51 revealed exactly similar trends in relative distribution of K in parts of cauliflower as encountered in case of N and P uptake. Out of total K, 61 per cent was retained in leaves + stalks, 33 per cent in curd and 6 per cent in roots. The incorporation of FYM as well as B application, decreased the relative distribution of K in leaves + stalks and increased it in curd and roots of cauliflower.

Table 4.50 Per cent distribution of Phosphorus among different parts of cauliflower

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	76.4	68.1	69.6	71.4	18.2	24.9	23.3	22.1	5.4	7.0	7.1	6.5
B_1	70.4	68.1	68.2	68.9	23.1	24.7	24.4	24.1	6.5	7.2	7.4	7.0
B_2	69.6	69.9	67.7	69.1	23.5	23.1	24.8	23.8	6.9	7.0	7.5	7.1
B_3	68.1	70.0	67.9	68.7	25.0	22.7	24.5	24.1	6.9	7.3	7.6	7.2
Mean	71.1	69.0	68.4		22.5	23.9	24.2		6.4	7.1	7.4	

Table 4.51 Per cent distribution of Potassium among different parts of cauliflower

Treatment	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	77.3	58.0	57.5	64.3	17.0	36.3	36.5	29.9	5.7	5.7	6.0	5.8
B_1	70.7	55.6	56.7	61.0	22.8	38.3	36.7	32.6	6.5	6.1	6.6	6.4
B_2	67.5	57.1	54.7	59.8	25.6	36.8	38.6	33.6	6.9	6.1	6.7	6.6
B_3	65.8	57.5	55.7	59.7	27.7	36.2	37.5	33.8	6.5	6.3	6.8	6.5
Mean	70.3	57.0	56.2		23.3	36.9	37.3		6.4	6.1	6.5	

4.4.2.6 Boron mobility

The B mobility among different parts of cauliflower has also been studied by dividing B-content in curd by B-content in leaves + stalks and the B-content in leaves + stalks divided by B-content in roots. Hence, in this section, the data regarding the ratios between B-content in curd to B-content in leaves + stalks and B-content in leaves + stalks to B-content in roots were discussed.

Table 4.52 Effect of Boron and FYM application on Boron mobility in different parts of cauliflower

Treatments	B in Curd/B in leaves + stalks				B in Leaves + stalks/B in roots			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	0.211	0.221	0.183	0.205	3.40	4.08	4.07	3.85
B_1	0.159	0.154	0.149	0.154	4.98	5.49	5.55	5.34
B_2	0.116	0.127	0.124	0.122	6.58	6.24	6.33	6.38
B_3	0.099	0.120	0.120	0.113	7.06	6.50	6.45	6.67
Mean	0.146	0.156	0.144		5.51	5.58	5.60	
CD (5%)								
B		0.025				0.63		
F		NS				NS		
B x F		NS				NS		

The pooled data for the experimental soils in Table 4.52 clearly indicates that the mobility of B from roots to leaves + stalks increased and from leaves + stalks to curd decreased with increasing levels of B application from 1 to 3 mg kg^{-1}. As far as the effect of FYM on the mobility of B among different parts of cauliflower was concerned, there was no significant effect. Similarly, the interaction between B application and FYM incorporation on B mobility was not found significant.

4.4.2.7 Calcium : Boron ratios in cauliflower parts

In addition to B status in plant tissues, Ca: B ratio is also an important parameter of exhibiting B-deficiency or toxicity symptoms, hence the ratios between Ca and B contents in parts of cauliflower grown in Bajaura and Junga soils were worked out and are presented in Table 4.53 and 4.54, respectively.

4.4.2.7.1 Bajaura soil

A study of data in Table 4.53 pointed out a significant decrease in Ca:B ratio from 1275.7 to 521.4 in leaves + stalks, 520.4 to 328.7 in curd, and 1010.8 to 716.0 in roots of cauliflower on B application. The incorporation of FYM, however, did not record a significant effect on Ca:B ratio in any part of cauliflower. The interaction between B and FYM application on Ca:B ratio in leaves + stalks was also found significant. The application of B was found to decrease Ca:B ratio in leaves + stalks both with and without FYM incorporation. By

Table 4.53 Effect of Boron and FYM application on Ca:B ratio in different parts of cauliflower in Bajaura soil

Treatments	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	1565.3	1142.8	1119.1	1275.7	604.4	459.3	497.6	520.4	1237.0	875.3	920.0	1010.8
B_1	738.6	785.2	753.3	759.0	404.0	371.5	359.0	378.2	865.1	889.9	877.4	877.5
B_2	591.6	618.0	632.2	613.9	391.9	356.9	383.3	377.4	715.0	741.5	870.6	775.7
B_3	477.3	530.5	556.3	521.4	318.8	328.4	338.9	328.7	681.5	649.1	817.5	716.0
Mean	843.2	769.1	765.2		429.8	379.0	394.7		874.7	789.0	871.4	
CD (5%)												
B		107.7				62.0				132.8		
F		NS				NS				NS		
B x F		186.5				NS				NS		

Table 4.54 Effect of Boron and FYM application on Ca:B ratio in different parts of cauliflower in Junga soil

Treatments	Leaves+stalks				Curd				Root			
	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean	F_0	F_1	F_2	Mean
B_0	563.7	479.4	471.3	504.8	291.7	250.4	268.4	270.2	317.0	347.8	370.4	345.1
B_1	363.3	337.6	333.4	344.8	209.2	247.7	248.9	235.3	278.8	279.4	291.2	283.1
B_2	194.4	281.9	292.1	256.1	153.4	232.2	252.6	212.7	225.6	246.5	301.3	257.8
B_3	153.0	256.7	258.2	222.6	174.9	223.3	220.7	206.3	188.7	251.2	275.8	238.6
Mean	318.6	338.9	338.8		207.3	238.4	247.7		252.5	281.2	309.7	
CD (5%)												
B		41.0				38.9				28.4		
F		NS				NS				NS		
B x F		71.1				NS				NS		

contrast, the incorporation of FYM at the rate of 10 and 20 g kg^{-1}, while, did not affect Ca:B ratio in the presence of B from 1 to 3 mg kg^{-1}, it decreased the Ca:B ratio significantly, when incorporated in the absence of B.

4.4.2.7.2 Junga soil

The data with respect to Ca:B ratio in parts of cauliflower grown in Junga soil is presented in Table 4.54. In comparison to Bajaura soil, the Ca:B ratios, in different cauliflower parts in general, were lower in Junga soil. But as in Bajaura soil, the application of B significantly decreased Ca:B ratios in cauliflower parts, from 504.8 to 222.6 in leaves + stalks, 270.2 to 206.3 in curd and 345.1 to 238.6 in roots. Like Bajaura soil, the incorporation of FYM, could not affect Ca:B ratios significantly. The interaction between B and FYM application on Ca:B ratio was again found significant in leaves + stalks only. The application of B significantly decreased Ca:B ratio in leaves + stalks over the control both in presence and absence of FYM. Similar to Bajaura soil, in absence of B application, the incorporation of FYM decreased Ca:B ratio significantly. However, when B was applied from 2 to 3 mg kg^{-1}, FYM incorporation increased the Ca:B ratio, whereas, at 1 mg kg^{-1} B, FYM incorporation did not influence this ratio over the control.

DISCUSSION

Chapter-V

DISCUSSION

The results obtained from the investigation entitled, "Boron status and transformation in relation to cauliflower (*Brassica oleracea* L. var. *botrytis*) growth and yield in some soils of Himachal Pradesh" have been presented in the previous chapter and are discussed in this section under the following heads:

5.1 General physical and chemical properties of the soils

5.2 Relationship between available (hot water soluble)-B and some soil properties

5.3 Effects of B and FYM application on nutrient availability in soils

5.4 Response of cauliflower to B and FYM application

5.4.1 Yield and growth characteristics

5.4.2 Nutrient content and uptake

5.5 Relative distribution of nutrients among different parts of cauliflower

5.6 Boron mobility

5.7 Calcium : Boron ratio in cauliflower parts

5.1 General physical and chemical properties of the soil

In general, the soils varied in texture from sandy loam to clay loam in zone-II (Mid-hills, sub-humid) and zone-III (High-hills, wet-temperate) of Himachal Pradesh. The Himachal soils having developed over a variety of parent material with different weathering rates due to influence of variable climatic conditions (Bhandari, 1973) is probably the reason for varied texture in soils from both the zones. Among soil separates, the per cent clay, silt and sand ranged from 8.9 to 38.6, 12.3 to 46.5 and 22.4 to 78.8 in zone-II, and 10.7 to 34.8, 10.7 to 53.1 and 12.1 to 77.0 in zone-III (Table 4.1). The results are in line with the findings of Kanwar *et al.* (1986), Upadhyay *et al.* (1993), Tripathi *et al.* (1994) and Singh (2002).

The mean organic-carbon content was found to be 15.5 g kg^{-1} in zone-II soils and 16.4 g kg^{-1} in zone-III soils. A higher organic-carbon content in zone-III is obvious due to more precipitation which favours luxurious plant growth and low temperature which slows down the rate of organic matter decomposition resulting higher amounts of organic-carbon at higher altitudes. The results obtained for locations in zone-II and III are in accordance with the findings of Minhas and Bora (1982), Kanwar *et al.* (1983), Kanwar and Tripathi (1984), Bhandari and Randhawa (1985), Kanwar and Tripathi (1985), Kanwar *et al.* (1986), Verma and Tripathi (1987), Upadhyay *et al.* (1993), Sharma and Kanwar (1998), Mahajan (2000) and Singh (2002).

The soils in zone-III, in general, were more acidic (pH 5.2 to 6.8) in contrast to soils in zone-II (pH 5.9 to 7.2). The comparatively low soil pH in zone-III as compared to zone-II soils may be due to the leaching of bases from the surface soil because of high precipitation.

Besides this, the decomposition of organic matter might have resulted into more amount of organic acids which, in turn, is responsible for low pH of the soils of zone-III in comparison to zone-II. The similar results have also been observed by Minhas and Bora (1982), Kanwar *et al.* (1983), Kanwar and Tripathi (1984), Bhandari and Randhawa (1985), Kanwar and Tripathi (1985), Sharma and Sethi (1985), Kanwar *et al.* (1986), Verma and Tripathi (1987), Yashoda Pradhan and Kanwar (1987), Upadhyay *et al.* (1993), Tripathi *et al.* (1994), Sharma and Kanwar (1998), Mahajan (2000) and Singh (2002).

The available-B in zone-II and III varied from 0.30 to 2.13 and 0.30 to 1.75 mg kg^{-1} with an average values of 1.10 and 0.92 mg kg^{-1}, respectively. Boron is present chiefly as non-ionised molecule, $B(OH)_3$, over the pH range suitable for plant growth (Raven, 1980). The comparatively low B-content in zone-III soils might be because of high precipitation in this zone which seems to be responsible for leaching of $B(OH)_3$, non-ionised molecule from the soils. As per the critical level of 0.50 mg kg^{-1} B as reported by Takkar and Randhawa (1968-76) and Malewar *et al.* (1999b), 16 per cent soils in zone-II and 19 per cent soils in zone-III were found to be deficient in available-B in the present study. Grewal *et al.* (1969) have reported that available-B ranged from 0.56 to 0.75 mg kg^{-1} in H.P. soils. For surface apple orchard soils of Kullu district of H.P., Kapur and Dev (1977) have reported that available-B fell in the range of 0.05 to 0.70 mg kg^{-1}. Similarly, for Shimla soils, B-content ranged from 0.10 to 1.00 mg kg^{-1} (Bhandari and Randhawa, 1978, 1985) and in Sproon valley from 0.20 to 0.80 mg kg^{-1} (Thakur and Bhandari, 1986). However, Mahajan (2000) reported available-B from 0.60 to 1.80 mg kg^{-1} in zone-II soils. Similarly, Singh (2002) found available-B in the apple belts of district Shimla, Kullu, Mandi and Chamba in the range of 0.12 to 0.78, 0.16 to 1.09, 0.40 to 0.74 and 0.36 to 1.25 mg kg^{-1}, respectively. In this context, the ranges of available-B observed in the present study in zone-II and III soils of Himachal Pradesh were slightly higher as compared to those already reported. The higher values of available-B in the present study might be because of the fact that soil samples in the present study were collected from undisturbed soils adjacent to cauliflower fields. However, the B-content in the present soils were almost similar as those reported by Rawat and Mathpal (1981) and Datta and Munna Ram (1993) for hill parts of India.

Like available-B, the exchangeable-Ca varied from 276 to 2195 mg kg^{-1} in zone-II and from 761 to 1744 mg kg^{-1} in zone-III soils with average values of 1287 and 1179 mg kg^{-1}, respectively. Here again, the high precipitation in zone-III might have resulted into more leaching of Ca from the soils which ultimately resulted into its lower content in comparison to its content in soils of zone-II. These results are in conformity with those reported by Minhas and Bora (1982), Kanwar *et al.* (1986) and Yashoda Pradhan and Kanwar (1987).

The available-N content in soils ranged from 282.3 to 439.1 kg ha^{-1} in zone-II and from 282.3 to 501.8 kg ha^{-1} in zone-III with mean values of 346.6 and 363.6 kg ha^{-1}, respectively. Like organic-carbon content, the available-N was also high in zone-III in contrast to zone-II. The comparatively higher N-content in zone-III is probably due to higher organic-carbon content in soils of this zone. Similar results have also been reported earlier (Minhas and Bora, 1982). Unlike the N-content, the available-P content was higher in zone-II (16.8 kg ha^{-1}) when compered with zone-III (9.0 kg ha^{-1}). Further, 47, 32 and 21 per cent soils in zone-II and 63, 31 and 6 per cent in zone-III were found to be in low, medium and high fertility classes with respect to available-P, respectively. The soils in zone-III are more acidic in reaction. Under such situations, Fe and Al oxides are very active and result into lot of fixation of P. This might be the reason for comparatively lower available-P content in soils of zone-III as compared with soils of zone-II. Like B, Ca and P, the content of available-K ranged from 39.2 to 560.0 kg ha^{-1} with an average value of 208.9 kg ha^{-1} in zone-II and from 67.2 to 504.0 kg ha^{-1} with an average value of 196.0 kg ha^{-1} in zone-III. In general, 21, 58 and 21 per cent soil in zone-II and 31, 56 and 13 per cent in zone-III were found in low, medium and high fertility K classes, respectively. This clearly shows that majority of the soils in these two agroclimatic zones of Himachal Pradesh were medium to high in available-K content. In case of available-K also, leaching seems to be the dominant factor governing its status in the soils.

Since, zone-III, experiences high precipitation which results into more leaching of K from the soils and ultimately had comparatively low available-K content when compared with the soils of zone-II.

The available micronutrients viz., Zn, Cu, Fe and Mn varied from 1.00 to 11.02, 0.14 to 2.80, 10.6 to 70.8 and 2.1 to 34.9 mg kg^{-1} in zone-II soils, and from 0.44 to 2.06, 0.02 to 3.60, 22.8 to 96.6 and 5.7 to 40.0 mg kg^{-1} in zone-III soils. The average values for available Zn, Cu, Fe and Mn were 3.36, 1.07, 35.3 and 17.5 mg kg^{-1} in zone-II, and 0.94, 1.01, 46.4 and 21.2 mg kg^{-1} in zone-III soils. Almost similar values of DTPA extractable-Zn, Cu, Fe and Mn have also been reported by Kapur and Dev (1977), Kanwar *et al.* (1983), Kanwar and Tripathi (1984), Bhandari and Randhawa (1985), Kanwar *et al. (1986)*, Verma and Tripathi (1987), Tripathi *et al.* (1994) and Mahajan (2000). Further, considering the critical limits of 0.5, 0.2, 4.5 and 2.0 mg kg^{-1} for DTPA extractable-Zn, Cu, Fe and Mn, respectively (Follet and Lindsay, 1970), all the soils in zone-II were sufficient in DTPA extractable-Zn, Fe and Mn, and DTPA extractable-Fe and Mn in soils of zone-III. As far as Cu in zone-II was concerned, about 16 per cent soils were observed to have Cu-content below its critical level. Similarly, in zone-III, about 13 per cent soils with respect to Cu and 19 per cent soils with respect to Zn were deficient. The comparatively higher DTPA content of Fe and Mn in soils from zone-III might be because of more acidic nature of the soils in comparison to those in zone-II.

5.2 Relationship between available (hot water soluble)-B and some soil properties

An attempt has been made to correlate the available-B content with some of the soil properties such as soil separates, organic-carbon and pH as well as with other nutrients such as Ca, N, P, K, Zn, Cu, Fe and Mn. For this purpose the soils from the two agroclimatic zones were pooled. A study of Table 4.2 clearly indicates that available-B content was found to be positively and significantly correlated with clay content of the soils and available content of P and K. The rest of the soil properties as well as available nutrients did not bear any significant relationship with available-B content in the present soils. Among different soil separates, clay content is the finest separate. Its significant and positive relationship with available-B is understandable, because the finer fractions of the soil are known to be the seat of all chemical reactions and also the source of nutrient elements in soil. Nathani *et al.* (1969), Awad and Mikhael (1980) and Saha and Haldar (1996) have also reported positive relationship of clay with available-B. Both P and B are present in soils as anions and had similar adsorption sites and they compete among themselves for adsorption sites in the soils. Therefore, when there is a high concentration of phosphate ions in the soil solution, they compete for adsorption sites already occupied by borate ions. Because of this, the borate ions which had already been adsorbed on the adsorption sites will be replaced by the phosphate present in the soil solution. This results into more and more release of the adsorbed borate ion into the soil solution increasing its available content in the soil. This explains the positive relationship between available-B and available-P content in soils. An almost similar relationship between P and B have been reported in earlier studies (Harda and Tamai, 1968; Haldar and Mondal, 1987; Saha, 1992; Goldberg, 1997; Saha and Haldar, 1998 and Singh *et al.*, 1999). Similarly, there is a formation and adsorption of calcium-borate ion pair in the soils (Mattigod *et al.*, 1985). When K concentration is increased in the soil solution, it reduces the Ca activity (Reeve and Shive, 1944) which in turn is not capable of forming calcium-borate and hence maintained higher concentration of B in the soils. This explains the positive relationship between available-B and available-K in the soils. Similar relationship between K and B have also been reported in earlier studies (Hadwani *et al.*, 1969; Kar and Motiramani, 1976; Moyano *et al.*, 1990 and Mohammadi *et al.*, 1992).

5.3 Effects of B and FYM application on nutrient availability in soils

The data documented in Table 4.3 to 4.12 revealed the effects of B and FYM application on nutrient availability in laboratory-incubation, while, data in Table 4.13 to 4.22 revealed their effects on nutrient availability in greenhouse study.

In general, the application of B maintained a higher available-B in soil throughout the laboratory-incubation as well as greenhouse study. The application of B is obvious to increase the available-B content in soil. These results are in line with the findings of Gupta (1968), Mani and Haldar (1996) and Saha and Haldar (1998). Similarly, the application of B resulted increased content of available-P in soil throughout the incubation study, while, in greenhouse study, the increase was maintained upto 48 days after transplanting followed by a decrease at harvest. An increase in the content of available-P as a result of B application might be attributed to the probable borate-phosphate anion exchange mechanism. A similar increase in available-P with B application has also been reported earlier (Saha and Haldar, 1998). A decrease in available-P in greenhouse study at harvest may be due to increased yield (Table 4.25 and 4.26) and P-uptake (Table 4.43 to 4.44) by cauliflower as a result of B application. The exchangeable-Ca was not affected significantly with B application both in laboratory-incubation as well as in greenhouse study probably due to its very high content in soil. Similarly, the application of B did not affect the available-N and K content significantly in soil during incubation study. However, the contents of N and K decreased significantly both at 48 days after transplanting and at harvest in greenhouse study with the increased levels of B application. A decrease in available-N and K content in greenhouse study might be due to their enhanced uptake (Table 4.41, 4.42, 4.45 and 4.46) as a result of higher yield with B application.

By contrast, the incorporation of FYM maintained significantly higher availability of nutrients viz., B, Ca, N, P and K throughout the laboratory-incubation as well as greenhouse study. A similar increase in available-B content in soil as a result of organic matter application has also been reported earlier by Purves and Mackenzie (1973), Garai and Haldar (1985), Pakrashi and Haldar (1992), Tapan Adhikari *et al.* (1993) and Pleseviciene *et al.* (1997). A significant increase in available-N, P, K and exchangeable-Ca with FYM application was also reported by Sankhayan (1997). The beneficial effect of FYM on nutrient status of soils may be due to the fact that FYM itself contains reasonable amounts of B, Ca, N, P and K (Appendix-III), which might have resulted into their build-up in the soil upon decomposition. The incorporation of FYM also improves all physical and microbiological properties of soils which, in turn, might have resulted into the build-up of these nutrients in soil. Further, FYM also maintained higher available-B in soil through checking its loss by leaching or adsorption in unavailable forms by chemical reaction between native or applied B and favourable diols (di-hydroxy organic compounds) of the organic matter which are broken down by microbial action with subsequent release of B (Parks and White, 1952) and thus making it available to plants throughout the growth period. The build-up of available-N following FYM incorporation could be expected due to increased population of microbes which, in turn, increased net mineralization of organic-N compounds and thus increased available-N content in soil. The improvement of available-P with FYM incorporation may be explained on the basis of solubilization of phosphate by the action of organic acids produced during the decomposition of FYM (Singh and Subbiah, 1969), formation of protective coating on sesquioxides which reduce P-fixation (Singh and Lal, 1976) and complex formation with humic and fuluic acids, thereby replacing phosphate ions by sequioxides (Bhardwaj and Patil, 1982). The improved build-up of K and Ca can be explained due to the solvent action of organic acids produced during the decomposition of FYM (Black, 1973; Brady, 1999 and Tisdale *et al.*, 1995).

With the advancement in incubation study, B and P availability decreased, while that of K and Ca increased. The increase in available-K and exchangeable-Ca occured probably due to the solvent action of organic acids produced with the decomposition of organic matter in soil and release of K and Ca therein because of comparatively higher amounts of organic matter present in experimental soils. The adsorption of B and P on clay minerals and fixation via ligand exchange probably reduced their available contents in soil. Further, increased exchangeable-Ca with the advancement of incubation study was probably one of the reasons in reducing the availability of B and P in soil due to formation of insoluble calcium-borates (Mattigod *et al.*, 1985) and calciumphosphates (Brady, 1990), respectively. The available-N content, in general, increased upto 48 days of incubation and also in greenhouse study and decreased thereafter. An increase in N-content upto 48 days was on expected lines due to its heavy application as basal dose and then first top dressing at 30 days after start of the experiment. By contrast, in greenhouse study, the contents of all the nutrients (B, Ca, N, P, K) in soil decreased at harvest in comparison to their status at 48 days of growth period of the crop. In greenhouse study, the total removal of nutrients at harvest of the crop must be the reason for their decreased amounts in soils.

5.4 Response of cauliflower to B and FYM application

5.4.1 Yield and growth characteristics

With the application of B there was significant earliness to curd maturity in both the experimental soils (Table 4.23 and 4.24). This observation was in accordance with the findings of Thakur *et al. (1991)*. The fresh and dry matter yield (Table 4.25 and 4.26) and growth characteristics of cauliflower viz., curd compactness, curd depth, curd diameter and leaf size increased beneficially upto 2 mg B kg^{-1} in Bajaura soil and upto 1 mg B kg^{-1} in Junga soil (Table 4.25 and 4.26). The probable reason for enhanced yield of cauliflower with better quality as a result of B application may be attributed to the increased availability of nutrients to plants (Singh and Thakur, 1991), thereby manufacturing more carbohydrates and proteins (Takkar and Randhawa, 1978 and Verma, 1983) along with its role in enhancing their translocation from the site of synthesis to the storage organs (Sharma, 2002). Further, B plays a key role in many metabolic processes such as cell differentiation, cell development, N-metabolism, fertilization, fat metabolism, harmone metabolism, active salt absorption and photosynthesis (Nason and McElory, 1963) which all contributed to higher fresh and dry matter yield of cauliflower. Gupta (1971), Mishra (1972), Mehrotra *et al.* (1975), Gupta and Cutcliffe (1975), Lukovnikova and Kuliev (1976), Chakraborty (1976), Prasad and Singh (1988), Kotur and Kumar (1989), Thakur *et al.* (1991), Kotur (1992), Vinay Singh and Dixit (1994), Vinay Singh *et al.* (1994), Ghosh and Hasan (1997), Kotur (1997), Batal *et al.* (1997), Kotur (1998), Malewar *et al.* (1999a) and Singh *et al.* (2002) have also reported a similar promotive effect of B application on cauliflower yield and growth parameters. The effect of B application on stalk length and number of mature leaves at harvest was not found significant.

The incorporation of FYM also recorded a significant and consistent earliness in curd maturity along with a highly significant and consistent increase in yield and growth characteristics of cauliflower, except stalk length, in both the experimental soils. A highly significant response of the cauliflower to FYM can be interpreted in terms of its effect on improvement in soil nutrient reserves, and soil physical conditions. Singh and Sharma (1990) have also observed similar results.

5.4.2 Nutrient content and uptake

A perusal of data (Table 4.27 to 4.46) revealed a significant increase in nutrient (B, Ca, N, P and K) content and uptake in cauliflower parts with B application. These results are in line with the findings of Francois (1986), Kotur and Kumar (1989), Kotur (1992), Vinay Singh and Dixit (1994), Vinay Singh *et al.* (1994) and Kotur (1998). An increase in B-content in plant tissues is obvious, as B application had significantly increased available-B in soil. According to Faust and Shear (1968), B has the property of catalysing the uptake of more Ca. Boron is stated to play an important role in phosphate transport across membranes (Loughman, 1977). Moreover, the application of B was found to enhance P availability in soil. Further, K-uptake by plants does not occur in the absence of B (Schon *et al.*, 1991). Extensive studies have supported the idea that B in plants functions at the membrane level (Shelp *et al.*, 1995). Boron is credited with maintaining membrane integrity (Cakmak *et al.*, 1995) and hence enhanced ability of membranes to transport vital nutrients.

Similarly, FYM incorporation also recorded a significant increase in nutrient contents and uptake in cauliflower parts. This may be due the beneficial effect of FYM on nutrient availability in soil and improvement in soil physical properties. Singh and Sharma (1990) have also observed similar results.

Among parts of cauliflower, the highest content of B and Ca were found in leaves + stalks followed by roots and least in curd. While, the maximum amounts of N, P and K were found in curd followed by leaves + stalks and least in roots. In plants, the translocation of nutrients takes place in the vascular system consisting of the xylem and phloem; water is the translocating agent in these tissues. Upward movement from the roots to the shoot occurs in the non-living cells of the xylem and is driven predominantly by the gradient in water potential resulting from surface water loss (transpiration). Thus, primary xylem translocation is directed mainly to the sites of highest transpiration (the large source leaves), which are not usually the sites of highest demands for nutrients. In contrast, long distance translocation in the phloem with its living cells occurs in both upward and downward direction. Phloem translocation is independent of transpiration and supplies the major proportion of nutrient requirements for actively growing areas such as young leaves, fruits and seeds, and organs that do not lose water readily. During translocation, nutrients are transferred between xylem and phloem by extensive exchange processes. The differential behaviour of nutrient distribution among different parts of cauliflower in the present study may be explained in terms of their retranslocation. In the literature, N, P and K are generally regarded as being retranslocated, whereas, B and Ca are not. Explanations for low retranslocation include low solubility in the phloem exudate and fixation by certain constituents in the tissue, the latter of which may be affected by the nutrient status of the plant.

Further, B-content in parts of cauliflower grown in Junga were more as compared to Bajaura soil. This may be due to higher availability of B in Junga soil due to its coarse textured nature. Wear and Patterson (1962) and Keren *et al.* (1985) also reported highest B-uptake by plants grown on coarse textured soil in contrast to fine textured soil. Further, higher exchangeable-Ca in Bajaura soil might have depressed B-uptake by cauliflower as it has antagonistic effect on B absorption. Reeve and Shive (1944), Patel and Mehta (1966) and Hill and Morril (1975) also observed marked decrease in B-content in plant tissue with increase in the Ca-concentration in the nutrient solution. By contrast, the higher contents of Ca and K in parts of cauliflower grown in Bajaura soil as compared to Junga soil were expected because of their higher available contents in Bajaura soil. The N-content in parts of cauliflower in both the experimental soils were almost equal probably due to their equal initial status and availability during the growth period of cauliflower. However, in spite of higher availability of P in Bajaura soil both during laboratory-incubation and greenhouse study, the P-content in parts of cauliflower grown in Junga soil was higher as compared to Bajaura soil. This could be because of the role of B in increasing P transport across the cell membranes (Loughman, 1977). The available-P content in Bajaura soil was though higher but because of higher B-content in Junga soil, it might have helped in more translocation of P across the cell membranes and hence resulted into higher P-content in cauliflower parts in Junga soils. Moreover, Bajaura soil had comparatively higher amount of exchangeable-Ca which might have depressed P absorption by cauliflower roots.

5.5 Relative distribution of nutrients among different parts of cauliflower

The data regarding the relative distribution of nutrients among different parts of cauliflower have been presented in Tables 4.47 to 4.51. In general, 94 to 95 per cent of B and Ca is retained by leaves + stalks, whereas, only 2 to 3 per cent is retained each by roots and curd of cauliflower. By contrast, about 61 to 69 per cent of N, P, K were remained in leaves + stalks and about 24 to 33 per cent were translocated to curd. As far as the retention of NPK by the roots of cauliflower is concerned, only 6 to 7 per cent were retained by the roots. The application of B increased its relative distribution in leaves + stalks, while, correspondingly decreased it in curd and roots. The relative distribution of other nutrients viz., Ca, N, P and K as affected by B application was, however, found to decrease in leaves + stalks and increase in curd and root parts. Similarly, the incorporation of FYM decreased relative distribution of all nutrients (B, Ca, N, P and K) in leaves + stalks and correspondingly increased it in curd and root parts of cauliflower. Such a pattern of nutrient distribution may be understood from dry matter yields of cauliflower parts (Table 4.25 and 4.26), where, the application of B as well as the incorporation of FYM recorded more per cent increase in dry matter yields of curd and root parts as compared to leaves + stalks. Hence, curd and root parts of cauliflower are expected to get increased share of total distribution of nutrients with successive increments in B or FYM. The exceptional behaviour of B distribution with the application of B levels may be due to its translocation in xylem tissue along transpirational stream and subsequent accumulation in leaves, the sources of transpiration. Further, the reduced mobility of B (Table 4.52) with the application of B resulted in increasing share of B uptake in leaves + stalks and correspondingly decreasing share in curd and root parts.

5.6 Boron mobility

The mobility of B from roots to leaves + stalks increased and from leaves + stalks to curd decreased with increasing levels of B application (Table 4.52). There is little doubt that the distribution of B in plants is related primarily to its translocation in the xylem to sites of greatest water loss i.e. primary translocation (Shelp *et al.*, 1995) and probably due to this reason B mobility from roots to leaves + stalks is increased with external B supply. However, there is considerable controversy regarding the role that the phloem plays in providing B to sites that do not lose water readily i.e. secondary translocation or re-translocation from leaves + stalks to curd. In the present study, the mobility of B from leaves + stalks to curd decreased with increasing levels of B. Furthermore, curd B content was not markedly influenced by external B application (Table 4.27 and 4.28). This clearly provides circumstantial evidence for B retranslocation under conditions of low B supply (i.e. conditional mobility). Shelp and Shattuck (1987) and Liu *et al.* (1993) have also reported similar result on B mobility. The incorporation of FYM as well as its interaction with B application on B mobility was not found significant.

5.7 Calcium : Boron ratio in cauliflower parts

The calcium : Boron ratios in parts of cauliflower decreased with B application in both the experimental soils (Table 4.53 and 4.54). Similar results have also been reported earlier by Kotur and Kumar (1989) and Kotur (1998). The decrease in Ca:B ratio in leaves + stalks was from 1275.7 to 521.4 in Bajaura soil and from 504.8 to 222.6 in Junga soil, in curd, from 520.4 to 328.7 in Bajaura soil and from 270.2 to 206.3 in Junga soil, while, in roots, from 1010.8 to 716.0 in Bajaura soil and from 345.1 to 238.6 in Junga soil. In general, the lower Ca:B ratios in all the parts of cauliflower grown in Junga soil in comparison to Bajaura soil may be due to low exchangeable-Ca and higher available-B in Junga soil. A decrease in Ca:B ratio with the application of B is obvious due to enhanced availability of B in soil and subsequent uptake by the plant. The Ca:B ratio is an important parameter of B status and according to Kotur and Kumar (1989), the Ca:B ratio in leaf tissue above 900 was associated with B-deficiency and below 280 with its toxicity, and the critical levels of 11 and 37 mg kg^{-1} in leaf tissue were reported for its deficiency and toxicity, respectively. Looking into the Ca:B ratio in leaves + stalks of cauliflower grown in Bajaura soil in the absence of B application, it was observed that this ratio was much higher than the reported Ca:B ratio of 900 associated with B-deficiency. However, because of given Ca:B ratio, we could not observe any B-deficiency symptoms in cauliflower. This might be because of higher B-content which was much above the reported critical level of B of 11 mg kg^{-1}. However, with the application of B, the Ca:B ratio in leaves + stalks remained within the critical levels. In Junga soil, the Ca:B ratio remained within permissible limits either in absence of B application or with lower amount of B application (1mg kg^{-1}). However, at higher levels of B application (2 and 3 mg kg^{-1}), the Ca:B ratio reduced much below the critical level reported in leaves + stalks which were observed to be associated with the appearance of B-toxicity symptoms such as poor plant vigour, stunted growth, leaf necrosis at the tip and margins. This might be because of comparatively higher B-content in Junga soil as compared to Bajaura soil. As far as the effect of FYM incorporation on

Ca:B ratio was concerned, it was found that in the absence of B application, the incorporation of FYM has a tendency to decrease Ca:B ratio in leaves + stalks of cauliflower which might be because of higher availability of B under FYM incorporation. However, when FYM was incorporated along with higher levels of B, there was a significant increase in Ca:B ratios. This could probably be because of more retention of B by FYM particularly under coarse textured soils. A similar ameliorating effect of organic matter in modifying the toxic effect of B in problematic soils has been reported earlier by Paliwal and Mehta (1973).

SUMMARY

Chapter-VI

SUMMARY

The present investigation entitled, "Boron status and transformation in relation to cauliflower (*Brassica oleracea* L. var. *botrytis*) growth and yield in some soils of Himachal Pradesh was carried out during the years 2002 and 2003.

The composite surface (0 to 0.15m) soil samples were collected from undisturbed soils adjascent to cauliflower growing fields in zone-II (Mid-hills, sub-humid) and zone-III (High-hills, wet-temperate) of Himachal Pradesh. The soil samples so collected were analysed for available (hot water soluble)-B and some of the physical and chemical properties of the soils. Further, relationship of available-B with soil properties was also worked out. One most B-deficient soil in each zone i.e. Bajaura in zone-II and Junga in zone-III were identified for bulk surface soil sample collection to conduct laboratory-incubation and greenhouse studies. The effects of four levels of B (0, 1, 2, 3 mg kg^{-1} soil) and three levels of FYM (0. 10, 20 g kg^{-1} soil) application were investigated in laboratory and greenhouse studies with two most B-deficient soils of zone-II and zone-III. In laboratory-incubation and greenhouse studies, the effect of different B and FYM levels were studied periodically (at 24, 48, 72 and 96 days in laboratory-incubation and at 48, 96 days/at harvest in greenhouse study) on nutrient (B, Ca, N, P, K) availability. In greenhouse study, the response of different levels of B and FYM were also investigated on cauliflower, besides nutrient availability.

In general, the soils of zone-II and zone-III of Himachal Pradesh were sandy loam to clay loam in texture, with medium to high organic-carbon and moderately acidic to neutral in soil reaction. Among these two zones, the soils of zone-III were slightly lighter in texture, with more organic-carbon and more acidic in reaction in contrast to zone-II. The available-B in these zones varied from 0.30 to 2.13 mg kg^{-1} with an average value of 1.10 mg kg^{-1} in zone-II and 0.92 mg kg^{-1} in zone-III. As per the critical level of 0.50 mg kg^{-1} B, about 16 per cent soils in zone-II and 19 per cent in zone-III were found to be deficient in available-B in the present study. Thus, majority of the soils were sufficient with respect to available-B. Regarding N, P and K content, majority of the soils were medium in available-N (282.3 to 501.8 kg ha^{-1}), low to medium in available-P (2.3 to 37.0 kg ha^{-1}) and medium to high in available-K (39.2 to 560.0 kg ha^{-1}). Comparatively, zone-III soils contained more available-N and lower contents of available-P and K in comparison to those in zone-II. On an average, the contents of exchangeable-Ca were also lower in zone-III soils (average 1179 mg kg^{-1}) in contrast to zone-II soils (average 1287 mg kg^{-1}). As far as the DTPA extractable micronutrients viz., Zn, Cu, Fe, Mn in zone-II and zone-III soils of Himachal Pradesh were concerned, the majority of the soils were sufficient in their contents (Zn 0.44 to 11.02; Cu 0.02 to 3.60; Fe 10.6 to 96.6 and Mn 2.14 to 40.0 mg kg^{-1}). However, 16 per cent soils in zone-II and 13 per cent in zone-III were found to be deficient in DTPA extractable-Cu. In addition to this, about 19 per cent soils in zone-III were also observed to be deficient in DTPA extractable-Zn.

In the present study, the available-B was found to correlate positively and significantly with clay as well as available-P and K contents. The available-B contents were not found to be significantly correlated either with other properties of soils or with their available nutrients.

In laboratory-incubation study, the application of B from 1 to 3 mg kg^{-1} maintained significantly higher amounts of available-B and P in both the soils throughout the study period. The general increase in available-B ranged form 1.19 to 2.30 times over its 0.47 mg kg^{-1} in the control and in available-P from 1.82 to 11.3 per cent over its 11.9 kg ha^{-1} in the control. The contents of exchangeable-Ca and available-N and K were, however, not affected significantly. In contrast, the incorporation of FYM was found to maintain a higher availability of all the nutrients viz., B, Ca, N, P and K throughout the study in both the soils. In general, per cent increase in available B, Ca, N, P and K ranged from 4.76 to

42.9, 1.31 to 12.4, 1.48 to 5.78, 8.72 to 56.1 and 1.60 to 16.3 over their 0.62 mg kg^{-1}, 1180.1 mg kg^{-1}, 360.3 kg ha^{-1}, 10.8 kg ha^{-1} and 157.9 kg ha^{-1} values in the control, respectively.

Irrespective of B application and FYM incorporation, with the advancement of incubation period, the contents of available-B and P decreased, while, that of exchangeable-Ca and available-K increased in both the soils. However, in case of available-N, it was observed that its contents increased only upto 48 days of incubation period, whereas, after that there was a significant decrease in its contents.

In greenhouse study, available-B content increased (1.60 to 2.40 times in Bajaura soil and 1.22 to 2.91 times in Junga soil over their control values of 0.57 and 0.69 mg kg^{-1}), respectively, significantly with 1 to 3 mg kg^{-1} B application throughout the growth period of cauliflower in both the soils. The application of B did not have any significant effect on exchangeable-Ca at any stage of the crop growth. However, the available-P content increased (1.35 to 5.41 %) with the application of B from 1 to 3 mg kg^{-1} over the control (19.5 kg ha^{-1}), but only upto 48 days of cauliflower transplanting, whereas at harvest, its content decreased (2.73 to 3.64 %) significantly over the control (8.5 kg ha^{-1}). Unlike laboratory-incubation study, where application of B had no significant effect on available-N and K, the contents of both these nutrients decreased significantly with the application of B from 1 to 3 mg kg^{-1} soil at 48 days after transplanting as well as at harvest of cauliflower. In general, per cent decrease in available-N and K varied from 3.23 to 7.57 and 6.90 to 19.9 over their 403.6 and 151.1 kg ha^{-1} values in the control, respectively. Like laboratory-incubation study, the incorporation of FYM at 10 and 20 g kg^{-1} soil also increased the contents of available-B (1.12 to 2.34 times), N (1.38 to 19.8 %), P (16.7 to 4.50 %), K (1.82 to 25.9 %) and exchangeable-Ca (2.84 to 19.4 %) with their respective values of 0.78 mg kg^{-1}, 372.5 kg ha^{-1}, 11.8 kg ha^{-1}, 126.8 kg ha^{-1} and 1357.0 mg kg^{-1} under the control (at both the stages of cauliflower growth i.e. 48 days after transplanting and at harvest), respectively. As in laboratory-incubation study, where available B and P decreased with time, in greenhouse study also, their contents decreased at harvest of cauliflower as compare to their respective contents at 48 days after transplanting. However, unlike laboratory-incubation, where available-K and exchangeable-Ca increased with the advancement of incubation period, in greenhouse study, their availability decreased at harvest of the crop as compared to that at 48 days after transplanting. The available-N content, in general, increased upto 48 days and then decreased both in laboratory-incubation and greenhouse studies.

In addition to the effect of different levels of B and FYM on nutrient availability in greenhouse study, their effect was also evaluated in terms of growth characteristics, yield, nutrient content and uptake.

Keeping in view the initial status of available-B as well as exchangeable-Ca content in soil, in general, the application of B upto 2 mg kg^{-1} in Bajaura soil and only upto 1 mg kg^{-1} in Junga soil responded significantly in terms of crop growth parameters such as curd compactness, curd depth, curd diameter and leaf size, and yield. In addition, the B application enhanced nutrient content and uptake by crop in both the soils. By contrast, the incorporation of FYM upto highest level of 20 g kg^{-1} responded beneficially in both the soils with respect to above mentioned crop growth characteristics, yield, nutrient content and their uptake.

On the basis of uptake of nutrients by different parts of cauliflower relative to total uptake, an attempt was made to find out the effect of B and FYM application on the relative distribution of different nutrients among different parts of cauliflower. In general, 94 to 95 per cent of B and Ca was retained by leaves + stalks, whereas, only 2 to 3 per cent was retained each by curd and roots of cauliflower. By contrast, about 61 to 69 per cent of N, P and K were retained in leaves + stalks and about 24 to 33 per cent in curd. As far as the retention of NPK by the roots of cauliflower was concerned, only 6 to 7 per cent were retained by them. The application of B was found to increase the relative distribution of B in leaves + stalks, while decreasing it in curd and root parts of cauliflower. However, the relative distribution of Ca, N, P and K in leaves + stalks decreased and correspondingly increased in curd and root parts with B application. Similarly, the incorporation of FYM, also decreased the relative distribution of all nutrients in leaves + stalks and increased them in curd and roots of cauliflower.

On the basis of ratios of B-content in curd by B-content in leaves + stalks and B-content in leaves + stalks by B-content in roots, an attempt was made to find out the mobility of B from leaves + stalks to curd and from roots to leaves + stalks, respectively, in relation to application of different levels of B and FYM. The application of B from 1 to 3 mg kg^{-1} in the present study was found to decrease B mobility from leaves + stalks to curd accompanied with little fluctuation in curd B content and thus indicating circumstantial evidence for B retranslocation under conditions of low B supply (i.e. conditional mobility). The mobility of B from roots to leaves + stalks, however, increased with increasing levels of B application because of its translocation via non-living cells of xylem along with transpirational stream of water.

The Ca:B ratio in plant tissue is an important parameter in addition to B status from nutrition point of view. A balanced Ca:B ratio in leaf tissue of cauliflower as reported earlier is 280 to 900. A Ca:B ratio above 900 is suspected to produce deficiency of B, while, below 280, a toxicity of B. In the present investigation, in Bajaura soil, a nutritional imbalance towards B-deficiency was observed from the point of view of Ca:B ratio of 1275.7 in leaves + stalks of cauliflower in the absence of B application. In Junga soil, this Ca:B ratio was 504.8 which was well within the critical level. With the application of B from 1 to 3 mg kg^{-1}, the Ca:B ratio in leaves + stalks ranged from 759.0 to 521.4 in Bajaura soil and from 344.8 to 222.6 in Junga soil. The Ca:B ratio of 256.1 and 222.6 at B levels of 2 and 3 mg kg^{-1} in Junga soil were associated with B-toxicity symptoms. Regarding the effects of FYM incorporation, it was found that in the absence of B application, the incorporation of FYM decreased Ca:B ratio in leaves + stalks of cauliflower in both the soils. In Junga soil, when B was applied from 2 to 3 mg kg^{-1}, FYM incorporation increased the Ca:B ratio, whereas, at 1 mg kg^{-1} B, FYM incorporation did not influence this ratio over the control. By contrast, the incorporation of FYM at the rate of 10 and 20 g kg^{-1} in Bajaura soil did not affect Ca:B ratio in the presence of B from 1 to 3 mg kg^{-1}.

Thus, from the results of the present study following conclusions can be made:

i. The soils under study were medium to high in organic-carbon, acidic to neutral in reaction, medium in available-N, low to medium in available-P, medium to high in available-K, sufficient in available-B, exchangeable-Ca and DTPA extractable micronutrients and sandy loam to clay loam in texture.

ii. With the application of B, the availability of B and P is increased without having any effect on Ca, N and K in laboratory-incubation study. However, in greenhouse study, the contents of B and P increased and that of N and K decreased, having no effect on exchangeable-Ca.

iii. Keeping in view the lower amounts of B and higher amounts of exchangeable-Ca in Bajaura soil in comparison to Junga soil, cauliflower responded beneficially upto 2 mg kg^{-1} B application in the former and only upto 1 mg kg^{-1} in the latter in terms of plant growth parameters, yield, nutrient content and uptake.

iv. In general, low contents of exchangeable-Ca were found to be associated with B-toxicity symptoms in cauliflower.

v. The incorporation of FYM proved to be beneficial for improving plant growth parameters, yield, nutrient content and their uptake.

vi. In general, the application of B and FYM increased the translocation of Ca, N, P and K from leaves + stalks to curd.

vii. The mobility of B increased from roots to leaves + stalks and decreased from leaves + stalks to curd with the increasing levels of B application.

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LITERATURE CITED

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*** Original not seen***

APPENDICES

Appendix-I

Physical and chemical properties of the surface soil samples (0 to 0.15m) collected from different locations in zone-II (Mid-hills, sub-humid) of Himachal Pradesh

Location	Mechanical separates (%)			Textural class	Oxid. org.-C ($g\ kg^{-1}$)	pH	Hws-B ($mg\ kg^{-1}$)	Exch. -Ca. ($mg\ kg^{-1}$)	Avail. -N ($kg\ ha^{-1}$)	Avail. -P ($kg\ ha^{-1}$)	Avail. -K ($kg\ ha^{-1}$)	DTPA extractable micronutrients ($mg\ kg^{-1}$)			
	Clay	Silt	Sand									Zn	Cu	Fe	Mn
Bajaura	21.9	30.5	47.6	Loam	11.3	7.1	0.30	1998.8	329.3	6.7	123.2	1.80	1.70	10.8	15.1
Rajpura	8.9	12.3	78.8	Sandy loam	16.7	5.9	1.15	1117.5	345.0	24.9	39.2	11.02	1.30	45.4	14.1
Mehla	18.4	33.8	47.8	Loam	12.6	5.9	0.45	1132.5	376.3	6.7	112.0	1.00	0.50	53.0	7.4
Nagwain	38.6	21.8	39.6	Clay loam	27.5	6.4	1.15	467.5	439.1	6.7	184.0	1.14	2.80	70.8	25.1
Kao	16.6	33.8	49.6	Loam	12.6	6.2	1.20	1502.5	360.7	37.0	179.2	3.92	1.70	49.4	34.2
Nihara	11.5	23.8	64.7	Sandy loam	11.7	5.8	1.08	1007.5	298.0	29.8	134.4	2.46	0.92	69.0	34.9
Sunehar	15.4	21.3	63.3	Sandy loam	9.3	6.3	0.68	1403.8	282.3	4.5	145.6	1.64	0.54	39.8	27.2
Mundla	14.0	23.5	62.5	Sandy loam	13.7	6.3	0.75	1638.8	313.6	29.8	246.4	3.52	1.24	63.0	23.9
Thanpuri	15.6	33.8	50.6	Loam	14.0	6.0	0.35	956.3	392.0	2.3	84.0	0.64	0.14	30.4	26.5
Nandehar	13.8	39.4	46.8	Loam	8.6	6.1	1.15	836.3	407.7	4.5	56.0	1.30	0.30	62.4	19.3
Kandaghat	20.3	25.1	54.6	Sandy clay loam	16.2	6.6	1.53	1595.0	345.0	9.0	162.4	3.28	0.28	27.4	16.3
Sproon	20.3	27.0	52.7	Sandy clay loam	26.7	7.2	1.20	657.5	329.3	22.4	240.8	5.32	1.72	33.4	15.1
Basaal	19.8	23.8	56.4	Sandy loam	14.7	6.8	1.45	1807.5	282.3	24.9	257.6	2.50	0.60	29.0	2.1
Kyar	19.2	12.6	68.2	Sandy loam	15.0	6.7	1.00	1736.3	392.0	9.0	218.4	2.84	0.14	21.0	6.8
Darlaghat	31.1	46.5	22.4	Clay loam	17.6	7.5	1.15	917.5	360.7	24.7	560.0	3.54	0.14	10.6	11.0
Rajgarh	28.2	24.2	47.6	Sandy clay loam	11.6	6.8	2.13	2195.0	313.6	21.3	308.0	2.80	1.54	12.4	21.5
Dhornibar	20.8	34.2	45.0	Loam	15.2	6.2	1.38	1352.5	376.3	4.5	414.4	2.50	1.14	13.8	18.0
Nehar-sawar	18.8	41.9	39.3	Loam	21.3	7.2	1.15	276.3	360.7	25.8	302.4	10.44	2.80	14.4	9.5
Dheera	19.0	25.5	55.5	Sandy loam	17.9	6.5	1.68	1848.8	282.3	24.9	201.6	2.20	0.74	14.8	5.0

Appendix-II

Physical and chemical properties of the surface soil samples (0 to 0.15m) collected from different locations in zone-III (High-hills, wet-temperate) of Himachal Pradesh

Location	Mechanical separates (%)			Textural class	Oxid. org.-C ($g\ kg^{-1}$)	pH	Hws-B ($mg\ kg^{-1}$)	Exch. -Ca. ($mg\ kg^{-1}$)	Avail. -N ($kg\ ha^{-1}$)	Avail. -P ($kg\ ha^{-1}$)	Avail. -K ($kg\ ha^{-1}$)	DTPA extractable micronutrients ($mg\ kg^{-1}$)			
	Clay	Silt	Sand									Zn	Cu	Fe	Mn
Theog	21.9	27.6	50.5	Sandy clay loam	17.3	6.2	1.75	1530.0	360.7	13.5	252.0	1.00	0.80	30.8	34.4
Fagu	29.6	38.9	31.5	Clay loam	22.7	5.8	1.08	1611.3	423.4	37.0	285.6	1.54	0.68	42.8	36.3
Matiana	34.8	53.1	12.1	Silty clay loam	18.2	5.7	1.68	1743.8	360.7	9.0	280.0	0.84	1.48	71.0	40.0
Doja	17.6	31.2	51.2	Sandy loam	20.3	6.0	0.75	1315.0	345.0	10.1	168.0	0.68	0.22	32.4	22.6
Jalel	20.1	17.5	62.4	Sandy clay loam	13.5	6.4	1.15	936.3	345.0	2.3	67.2	0.44	0.04	22.8	18.6
Panesh	12.3	24.0	63.7	Sandy loam	15.0	6.5	0.75	1528.8	282.3	2.3	179.2	2.06	0.52	28.8	9.5
Rampuri	13.2	15.5	71.3	Sandy loam	13.8	6.2	0.75	968.8	329.3	5.6	78.4	1.34	0.02	47.2	9.5
Junga	11.3	36.4	52.3	Sandy loam	12.9	6.1	0.30	932.5	329.3	2.3	72.8	0.60	0.34	31.0	10.7
Seobag	10.0	15.1	74.9	Sandy loam	9.9	6.4	0.90	761.3	329.3	2.3	112.0	1.20	3.60	31.4	17.6
Katrain	12.3	10.7	77.0	Sandy loam	9.5	6.0	0.43	791.3	313.6	7.9	168.0	1.08	1.80	32.4	15.0
Bari	19.0	24.9	56.1	Sandy loam	21.2	5.9	1.15	1170.0	376.3	2.3	201.6	0.44	1.12	65.2	7.7
Nashala	15.2	26.9	57.9	Sandy loam	15.9	6.0	0.83	932.5	439.1	11.2	240.8	0.44	1.44	89.0	2.5
Naggar	17.5	29.3	53.2	Sandy loam	11.9	6.8	0.83	1098.8	345.0	7.9	504.0	1.20	2.00	53.0	38.1
Aleo	20.3	31.8	47.9	Loam	20.6	5.2	1.15	948.8	501.8	11.2	224.0	0.64	1.30	96.6	5.7
Salooni	17.7	41.6	40.7	Loam	21.5	6.3	0.45	1325.0	345.0	6.7	112.0	0.62	0.54	31.4	33.6
Janjehli	10.6	29.7	59.7	Sandy loam	17.7	5.9	0.75	1261.3	392.0	12.3	190.4	0.88	0.24	37.2	36.5

Appendix-III

Chemical composition of FYM used in laboratory-incubation and greenhouse studies

Boron (mg kg^{-1})	21.5
Calcium (%)	1.27
Nitrogen (%)	0.80
Phosphorus (%)	0.09
Potassium (%)	0.40
Moisture (%)	55.2

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Title of the Thesis	:	Boron status and transformation in relation to cauliflower (*Brassica oleracea* L. var. *botrytis*) growth and yield in some soils of Himachal Pradesh
Name of the student	:	Girish Chander
Admission No.	:	A-2000-40-05
Major Subject	:	Soil Science

ABSTRACT

With a view to screen out the B-deficient soils, the composite surface (0 to 0.15m) soil samples ollected from undisturbed soils adjascent to cauliflower growing fields in zone-II (Mid-hills, sub-humid) nd zone-III (High-hills, wet-temperate) of Himachal Pradesh were analysed for available-B and some f the physical and chemical properties of the soils. The soils under study were medium to high in rganic-carbon, acidic to neutral in reaction, medium in available-N, low to medium in available-P, medium o high in available-K, sufficient in available-B, exchangeable-Ca and DTPA extractable micronutrients nd sandy loam to clay loam in texture. In general, 16% soils in zone-II and 14% in zone-III were found o be deficient in available-B. The available-B was found to correlate positively and significantly with clay s well as available-P and K contents.

To find out the effect of B levels and FYM application, laboratory-incubation and greenhouse studies ere conducted with most B-deficient soil from each of the agroclimatic zone. Laboratory incubation tudy was conducted without cauliflower, whereas in greenhouse study, cauliflower was raised as a st crop. Twelve treatment combination of four levels of B (0,1,2 and 3 mg kg^{-1}) and three levels of FYM), 10 and 20 g kg^{-1}) with three replications were studied in two most B-deficient soils of Bajaura in one-II and Junga in zone-III.

In Laboratory-incubation, the application of B increased the availability of B and P without having ny effect on Ca, N and P. The incorporation of FYM maintained a higher availability of all the nutrients roughout the study in both the soils. With the advancement of incubation period, the available-B and P ecreased, available-K and exchangeable-Ca increased while available-N increased upto 48 days and ecreased thereafter.

In greenhouse study also, the available contents of B and P increased with B application, however, at of N and K decreased without having any significant effect on exchangeable-Ca. The incorporation FYM increased the contents of all nutrients. The available nutrients under study were decreased at rvest in contrast to that observed at 48 days after transplanting in both the experimental soils.

Keeping in view the lower amounts of B and higher amounts of exchangeable-Ca in Bajaura soil comparison to Junga soil, cauliflower responded beneficially upto 2 mg kg^{-1} B application in the former d only upto 1 mg kg^{-1} B application in the latter in terms of plant growth parameters such as curd mpactness, curd depth, curd diameter, leaf size, and yield. The incorporation of FYM upto highest vel of 20 g kg^{-1} proved beneficial in both the soils. Both B and FYM application enhanced quality of the oduce in terms of nutrient content and uptake.

Further, the application of B and FYM increased the translocation of Ca, N, P and K from aves+stalks to curd. The mobility of B from leaves+stalks to curd decreased with external B application d thus indicated circumstantial evidence for B retranslocation under conditions of low B supply. The orporation of FYM showed an ameliorating effect on Ca:B ratio of plant tissue, an important parameter exhibiting B-deficiency or toxicity symptoms, in both the experimental soils.

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