CRITICAL LEVEL OF AVAILABLE BORON FOR SOYBEAN IN INCEPTISOL

By

Amol Gulabrao Ghorpade
(Reg. No.0146)

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI - 413 722, DIST.AHMEDNAGAR,
MAHARASHTRA, INDIA

in partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

SOIL SCIENCE

DEPARTMENT OF AGRICULTURAL CHEMISTRY AND
SOIL SCIENCE

POST GRADUATE INSTITUTE
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DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

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2003

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted by me or other person to any other University or Institute for a Degree or Diploma

Place : MPKV, Rahuri

(A.G. Ghorpade)

Dated : 23/06/2003.

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CERTIFICATE

This is to certify that the thesis entitled, "**CRITICAL LEVEL OF AVAILABLE BORON FOR SOYBEAN IN INCEPTISOL**", submitted to the Mahatma Phule Krishi Vidyapeeth, Rahuri for the award of the degree of **MASTER OF SCIENCE** (AGRICULTURE) in **SOIL SCIENCE**, embodies the results of a *bona fide* research carried out by **Mr. AMOL GULABRAO GHORPADE**, under my guidance and supervision and that no part of the thesis has been submitted for any other Degree or Diploma.

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

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Dated : 23 / 06 /2003. — Research Guide

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Dated : 24/06/2003.

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Place : M.P.K.V., Rahuri (A. G. Ghorpade)

Date : 23/04 2003.

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LIST OF ABBREVIATIONS

@	:	At the rate of
^0C	:	Degree celsius
B	:	Boron
CD	:	Critical difference
cm	:	Centimetre
Cu	:	Copper
cv.	:	Cultivar
DAS	:	Days after sowing
EC	:	Electrical conductivity
et al.	:	And others (et alli)
Fe	:	Iron
Fig.	:	Figure
g	:	Gram
ha	:	Hectare
i.e.	:	That is
K	:	Potassium
kg ha^{-1}	:	kilogram per hectare
kg	:	Kilogram (s)
m	:	Meter (s)
mg kg^{-1}	:	Milligram per kilogram
mg	:	Milligram (s)
ml	:	Milliliters
Mn	:	Manganese
N	:	Nitrogen
N.S.	:	Non-significant
P	:	Phosphorus
ppm	:	Parts per million
q	:	Quintal
S.E.	:	Standard error
t	:	Tonne (s)
viz.,	:	Videlicent (namely)
Zn	:	Zinc
%	:	Per cent

ABSTRACT

CRITICAL LEVEL OF AVAILABLE BORON FOR SOYBEAN IN INCEPTISOL

By

AMOL GULABRAO GHORPADE
A candidate for the degree
of
MASTER OF SCIENCE (AGRICULTURE)
Mahatma Phule Krishi Vidyapeeth,
Rahuri - 413 722
2003

Research Guide	:	**Dr. V.K. Kharche**
Department	:	**Agricultural Chemistry and Soil Science**

A pot culture experiment was conducted at Department of Agricultural Chemistry and Soil Science, M.P.K.V., Rahuri during *kharif* 2002 with a view to evaluate the critical level of boron in soil and soybean plant grown on low (< 0.50 mg kg^{-1}), medium (0.50 to 1.00 mg kg^{-1}) and high (> 1.0 mg kg^{-1}) boron content of soils (Inceptisol) with boron levels of 0, 0.25, 0.50, 0.75 and 1.00 mg kg^{-1}.

The results indicated that on three sets of soils having varying boron content, the application of boron showed significant influence on the dry matter production of soybean. The dry matter production at 0.5 mg kg^{-1} boron level was significantly higher in comparison with low levels of boron indicating that application of boron upto 0.50 mg kg^{-1} was beneficial in increasing dry matter significantly.

Effect of boron levels on the concentration and uptake of boron by soybean crop revealed that application of boron improved the concentration of boron in soybean plant and in turn reflected in high uptake of boron. The concentration and uptake of boron by soybean was found to significantly increase upto 0.75 mg B kg^{-1} in low and medium boron status soils while in high boron status soils it was significantly increased upto 0.5 mg B kg^{-1} indicating that high boron status soils responded better to lower doses of boron in respect of concentration and uptake of boron by soybean.

Application of boron had significantly influenced the concentration and uptake of nutrients by soybean. The concentration and uptake of nitrogen, phosphorus, potassium, calcium, magnesium, zinc, copper and manganese by soybean was significantly increased due to application of higher levels of boron (0.75 to 1.00 mg kg^{-1}) on low boron content soils. As regards medium boron status soils concentration and uptake of these nutrients was significantly increased upto 0.5 to 0.75 mg kg^{-1}. However, on high boron status soils the concentration and uptake of these nutrients increased significantly upto 0.5 mg B kg^{-1} indicating antagonistic effect of boron on concentration and uptake of nutrients by soybean at higher doses. The concentration of magnesium, iron and copper was significantly reduced at higher level of application of boron showing antagonistic effects of these nutrients with boron at higher doses.

The study revealed that the critical level of boron obtained by graphical method was 0.32 mg kg^{-1} for soil and 18.5 mg kg^{-1} for soybean plant. By statistical approach, however, the critical level of boron was 0.36 mg kg^{-1} for soil and 18.0 mg kg^{-1} for soybean plant.

It is thus indicated that below this critical level in soil or in plant, the soybean grown on black alkaline calcareous soils (Inceptisol) need boron fertilization to meet the boron requirement of soybean crop.

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INTRODUCTION

1. INTRODUCTION

One of the most important soil fertility constraints endangering the sustainability of high production agriculture is the emergence of secondary and micronutrient deficiencies. The plant requires 16 essential nutrient elements that are classified as macro, secondary and micronutrients. With increasing use of high purity NPK fertilizers, introduction of high yielding and new genotypes, extension of agriculture to marginal lands, the micronutrient deficiencies are coming up. Todays agriculture characterised by multiple cropping, use of improved crop varieties, high response to added fertilizers and intensive cropping with an objective of getting maximised yield per unit piece of land per unit time leads to nutritional imbalance more particularly in case of micronutrients. Nutritional management strategies depended mainly on NPK fertilizer and largely ignored the replenishment of other micronutrients.

Although most of the dominantly black clayey soils derived from basalt in the semiarid agroecological zones have sufficient amount of boron, the associated relatively coarse textured soils that are alkaline and calcareous in nature pose the problem of boron deficiency (Nayyar, 1999). The availability of boron in soils is conditioned by soil texture, pH, free $CaCO_3$, organic matter and other macro and micro nutrient elements in the soil. Thus, it is likely that the available boron in soil is variable under varied agroclimatic zones and with divergent soils. Thus, the boron deficiency is mainly attributed to unfavourable soil conditions rather than total boron reserves (Kanwar and Randhawa, 1974).

The cultivation of soybean in India has been a success story of the yellow revolution in India. Soybean is the most important oilseed as well as pulse crop. In India, the area under this crop increased considerably during recent years due to its high yielding potential and multifold industrial uses.

In Maharashtra, the area under soybean is about 10.55 lakh ha with total production of 14.71 lakh tonnes (Anonymous, 1999). It contains about 19 per cent oil and 43 per cent proteins (Halwankar *et al.*, 1992). Being leguminous crop, it fixes atmospheric nitrogen to the tune of 60-100 kg ha^{-1}. Though, the area under oilseed crops is increasing day by day, more than seventy per cent of area under oilseed production depends mainly on the vagaries of monsoon. The main reasons for decline in the yield are unscheduled sowing date, inadequate and imbalanced nutrition and moisture stress at critical stages. Among these factors mineral nutrition plays an important role.

Boron has its own contribution in plant growth. Boron plays important role in plant system *viz.*, cell division, N metabolism, carbohydrate transformation, synthesis of sugar and biosynthesis of protein (Takkar and Randhawa, 1978). Boron deficiency typically affects the young growing parts. The young growing parts of the plant including the vegetative and reproductive growth are impaired without any adverse effects being seen on the vegetative growth. A common result of boron deficiency in all crops is an interruption in flowering and fruiting.

Spectacular response to the application of boron in black calcareous soils of Maharashtra through soil or foliar spray to different crops have been observed by several workers (Dongale and Zende, 1976, Patil *et al.*, 1981, Kadlag, 1982, Wani *et al.*, 1988). Patil *et al.* (1981) observed significant increase in oil and protein content of groundnut along with increase in yield in sandy loam and sandy clay loam soils due to the application of 5 kg borax ha^{-1}. Singh (1999) reported that spectacular responses of boron application have been recorded in cereals, oilseeds and pulses and optimum dose of boron in calcareous and heavy textured soils ranged between 1.5 to 2 kg B ha^{-1} while dose for light textured soil reported is from 1 to 1.5 kg B ha^{-1}. The use of boronated superphosphate was significantly superior to single super phosphate for groundnut on medium black soils of Rahuri in Western Maharashtra (Patil *et al.*, 1987, Wani *et al.*, 1988).

The availability of a nutrient in soil is governed by a number of factors and at times its content in plants provides better index of its availability. Therefore, it is desirable to have information on the threshold values of micronutrients in the most important high yielding varieties of crops. The plant and soil analysis are used either individually or in combination to diagnose micronutrient deficiencies. Their value is enhanced and their defects marked if used together. Before soil and plant analysis can be employed as diagnostic tool, it is essential to fix the critical limits for predicting the possibility of deficiency of a nutrient or profitable response to its application.

In soil and plant nutrition studies, a concept of critical level of nutrient was introduced by Ulrich (1959) and Smith (1962). However, the graphical method (Cate and Nelson, 1965) and later the statistical approach given by Cate and Nelson (1971) are being widely used for establishment of critical level of a nutrient. Critical limit is the level of soil available nutrient above which that nutrient is no longer a primary limiting factor. The critical level varies depending on the soil types, crops and varieties, soil test methods and seasonal variations. This concept has been found to be more suitable for micronutrient fertilizer recommendations.

The importance of plant analysis is evident from the fact that concentration of nutrient within the plant directly reflects the ability of the plant to absorb nutrient from soil in its own environment and to grow. This ability can not be inferred from soil test alone since notably climatic conditions and plant type and its inherent ability are very important factors affecting the plant growth. Thus soil and plant analysis are complementary to each other and hence there should be broad adjustment with reasonable variations when a large number of plants grown in the divergent group of soils. Thus, two way analysis i.e. soil and plant appeared to be the most precise approach which can help in balanced, efficient and controlled feeding of crops.

The boron research in soils and plants carried out in the state is fragmentary, inadequate and could not give the clear picture on boron nutrition in major crops and soils of the state. Isolated attempts are made to work out a critical level of boron in soil and plant. very little attention has been paid to the boron nutrition of crops in Maharashtra and information especially on the critical level of boron for crops grown on black alkaline calcareous soils is rather very meagre. With this view in mind and soybean being important pulse and oil seed crop, it was felt necessary to undertake the study with following objectives.

i. To determine soil critical level of available boron in Inceptisol for soybean

ii. To estimate plant critical level of boron for soybean in Inceptisol and

iii. To study the response of soybean to application of boron.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Among the micronutrients boron has its own contribution in plant growth. Boron deficiency is observed at young leaf tip or at growing bud. Stunted growth resulting in decreased crop yield has been observed by long term and extensive use of high analysis boron free fertilizers. Besides NPK there is an increasing concern regarding boron nutrition of crops particularly for oilseeds and legumes. The available literature on availability of boron in soils in relation to soil properties, crop growth, yield and uptake of nutrients as influenced by boron nutrition and the critical level of boron in soils and plants has been reviewed and presented under the appropriate heads in this chapter.

2.1 Boron status of soils

Boron belongs to the third periodic group and the most common geologic forms of boron in soils are boric acid (H_3BO_3) and borate ions (H_2BO_3). Tourmaline and flourine borosilicate is the best known boron containing soil minerals (Katyal and Sharma, 1979).

The total boron content in Indian soils varies between 7 to 630 mg kg^{-1} (Kanwar and Randhawa, 1974). However, the available boron in Indian soils ranged from 0.03 to 3.82 mg kg^{-1} (Katyal and Sharma, 1979). Bokde (1963) reported that less than 5 per cent of the total soil boron is usually available for crop use.

In the lateritic soils of very high rainfall zone of Konkan region of Maharashtra, 57 per cent soils contain available B in sufficient range while remaining 43 per cent area is likely to pose problem of B deficiency (Pererira *et al.,* 1986). Kharche and Patil (2002) studied available boron status of dominant soil series of Western Maharashtra and revealed that the Entisol soil series with alkaline calcareous soils of coarse texture and shallow depth were deficient in 0.01 M $CaCl_2$ extractable boron. The acid red soils of high rainfall areas *viz.,* Amba and Wadkudi soil series were also found to be deficient in available boron.

According to Singh (2001) total stock of boron in most of the Indian soils varies between 3 to 630 mg B kg^{-1} but amount of plant usable boron pools is rather low to moderate depending upon soil properties, cropping pattern being followed and environmental conditions. It is further reported that boron deficiency was widespread in soils of several states of the country leading to low crop yields. Among 36825 surface samples analysed 33 per cent soils were found to be deficient in available boron. Deficiency of boron was found most widespread (39 to 68 %) in red and lateritic soils of West Bengal, Orissa and Maharashtra and highly calcareous and old alluvium of Bihar.

Deficiency of boron in soils of Maharashtra has been reported by Malewar (1989). Boron deficiency on non-calcareous soils (Haplustalf) was 22 to 40 per cent compared to 33 to 45 per cent in calciorthents and 56 per cent in acidic red and lateritic soils of Bihar (Sakal *et al.*, 1996).

2.2 Availability of boron in soils

The kinetics of sorption and desorption of elements from the exchange complex and factors governing their availability, are important from soils fertility and chemistry point of view. Mitchel (1964) reviewed the work on chemistry of micronutrients in soils and recognized various soil properties which are controlling the availability of micronutrients. Factors affecting the amount of boron adsorbed by soils and the availability of boron in soils include pH, soil texture, soil moisture, temperature and management practices (Evans and Sparks, 1983).

2.2.1 Influence of soil pH on the availability of boron

Soil pH which is one of the main factors influencing the availability of boron has been studied by several workers.

Bhattacharjee (1956) reported that availability of boron was comparatively more between pH 6 to 8 and it decreased below or above this range.

Soil pH affects boron availability more by sorption reactions than by formation of less soluble compound. Availability of B is highest in the pH range of 5.5 to 7.5. Boron is sorbed to Fe and Al oxides in soils and is lowest in the pH range of 6 to 9 (Mortvedt *et al.*, 1999).

The availability of boron increased with increase in pH (Kanwar and Singh, 1961). There was no correlation of soil pH and water soluble boron observed in Maharashtra (Mahabari, 1970), Gujrat (Gandhi and Mehta, 1958) and Punjab, Hariyana and Himachal Pradesh (Grewal *et al.*, 1969). A positive relationship was observed between soil pH and available boron (Lodha and Baser, 1971), (Singh and Randhawa, 1977a). The availability of boron increased with increase in soil pH (Mathur *et al.*, 1964, Paliwal and Mehta, 1973, Singh and Singh, 1967, Singh and Randhwa, 1977a, Talati, 1974).

2.2.2 Influence of organic matter on the availability of boron

Available boron significantly increased with increase in organic matter content of soils in Western Rajasthan and Bhana soils in Haryana (Satyanarayan, 1958, Lodha and Baser, 1971 and Sharma and Shukla, 1972) where as such relationships were either non-significant in Mewar region soils (Baser and Saxena, 1967) or did not exist for soils from Rajasthan (Nathani *et al.*, 1969) and Tamilnadu regions (Balsundaram *et al.*, 1972). A negative relationship between organic matter and available boron was observed in saline alkali soils in Punjab and Uttar Pradesh region (Singh and Singh, 1967; Singh and Randhawa, 1977b).

Gandhi and Mehta (1958) found no relationship between available boron and organic matter content in Gujarat.

Lombin (1985) reported that the organic matter content was positively related to B availability. Low B availability to plant was attributed to low organic matter in coarse textured soils of Nigeria.

2.3.3 Influence of clay content on the availability of boron

A rise in clay content also increases the fixation of applied boron. Fine textured soils generally have more water soluble boron than coarse textured soils (Baser and Saxena, 1967) (Singh and Sinha, 1976). On the contrary some workers reported that there was no relationship between the water soluble boron and clay content (Gandhi and Mehta, 1958, Nathani *et al.*, 1969).

Ullaha and Jabbar (1981) reported that the boron adsorption increased with fineness of soil texture.

In general, more micronutrients are removed from the fine textured soils than from the coarse textured one because of the greater capacity of the former group of soil to renew the depleted micronutrient pools.

2.2.4 Influence of irrigation water on the availability of boron

Irrigation water may contain boron and their continuous use may not only cause soil salinization, but also build up the boron level (Singh and Singh, 1972).

A boron content in soil increased as the concentration of boron in irrigation water increases (Chauhan and Powar, 1978, Verma, 1983).

2.2.5 Influence of $CaCO_3$ on the availability of boron

Studies conducted by Bhattacharjee (1956), Gandhi and Mehta (1958), Singh and Singh (1967) revealed that the availability of native and applied boron was not significantly affected by $CaCO_3$ content of the soils. On the contrary in the study of Baser and Saxena (1967) there was a significant adverse effect of $CaCO_3$ on boron availability. A positive significant relationship between water soluble boron and $CaCO_3$ content of soils was demonstrated by Singh and Randhawa (1977b). While negative relationship between water soluble boron and $CaCO_3$ content of the soils was observed by Talati and Agarwal (1974) and Takkar and Randhawa (1978).

Nathani *et al.* (1969) working with Punjab soils did not found statistically significant relationship between $CaCO_3$ and water soluble boron content of soil.

Besides soil properties crops and management practices play an important role in influencing the build up and depletion of micronutrients in soils.

2.3 Crop response to application of boron

Among the micronutrients boron plays important role in increasing the yield as well as oil and protein content in oilseed as well as legume crops.

A deficiency of boron shown by a positive response to boron application has been reported in more than 80 countries and for 132 crops over the last 60 years (Shorrocks, 1997). Loomis and

Durst (1992) published a detailed review of the probable role of boron in higher plants.

There is a long list of possible roles of boron (Parr and Longhman, 1983) including sugar transport, cell wall synthesis, lignification, cell wall structure integrity, carbohydrate metabolism, RNA metabolism, respiration, indole acetic acid metabolism, phenol metabolism and as part of the cell membranes indicating that boron is involved in a number of metabolic pathways. Overall the published literature indicates that in higher plants, boron exerts its primary influence in the cell wall and at the plasma membrane-cell wall interface. The higher boron requirements of dicotyledonous species, compared to graminaceous species is presumably related to the higher proportions of compounds with the cis-diol configuration in the cell walls such as pectic substances (Loomis and Durst, 1992).

Many researchers reported that application of boron either through soil or foliar spray to different crops was found to be beneficial in increasing crop yield. Application of boron either alone or in combination with FYM and sulphur helped in improving the quality of groundnut (Dongale and Zende, 1976, Patil *et al.*, 1981).

Balusamy *et al.*, (1998) reported that application of boron @ 0.5 kg ha^{-1} along with 10 t FYM ha^{-1} to neutral clay loam soil resulted into increase in yield of soybean.

Reinbott and Blevins (1995) reported that foliar application of boron and magnesium increased soybean yield. The yield increased from foliar boron and magnesium treatment resulted from an increased number of pods on the main stem and branches. Four foliar B applications totalling 1.12 kg ha^{-1} increased seed weight per plant on main stems by 13 per cent over control.

Dandagi *et al.* (1971) reported that application of boron @ 1 kg ha^{-1} in acid sedentary soils deficient in boron was found to be optimum for soybean.

Sakal *et al.* (1988) studied nutrition of boron for blackgram and chickpea on coarse textured highly calcareous soil and concluded that application of boron upto 2 kg ha^{-1} significantly increased the grain yield.

Patil *et al.* (1981) studied the effect of application of boron on yield and quality of groundnut and reported significant increase in oil and protein content of groundnut alongwith increase in yield.

Kadlag (1982) studied the effect of application of borax at different levels and reported that borax @ 5 kg ha^{-1} was beneficial for dry matter production of groundnut.

Lal *et al.* (1979) recorded that grain and stover yield of pearlmillet increased significantly with the decrease in Ca/B ratio in soil.

Mehta *et al.* (1964) reported that boron deficiency symptoms appeared when the ratio of Ca/B above 338 in Indian bean. It is further reported that deficiency symptoms of boron were intervenal chlorosis, water soaked areas in leaves, delayed flowering and formation of seedless pods. Boron toxicity symptoms were appeared when the ratio of Ca/B was at 16. Excess supply of boron resulted into decrease in chlorophyll and iron content but increase in boron content in the leaves of groundnut (Harigopal and Rao, 1968).

Sarkar and Ghosh (1992) studied response of sunflower to boron on alluvial soils and reported that application of boron @ 0.5 kg ha^{-1} improved plant productivity in terms of head size, seeds ha^{-1} and 1000 seed weight.

Wani *et al.* (1988) studied the effect of levels of boronated superphosphate on yield and quality of groundnut grown on medium black soil. Application of 100 kg P_2O_5 through boronated superphosphate has shown significant effect on yield of dry pods, shelling percentage, protein content and oil content in comparison to single super phosphate.

Patil *et al.* (1999) studied response of sunflower, mustard and cowpea to boronated superphosphate in lateritic soils and reported that grain yield was significantly increased over the application of single super phosphate alone.

Sakal *et al.* (1988a) found that increasing levels of boron progressively increased the grain and straw yield of chickpea. Application of 2 kg B ha^{-1} increased yield of chickpea from 12.5 to 21.0 q ha^{-1}.

Sakal and Singh (2001) reported that the response of different crops to boron application in calcareous soils which revealed that the optimum level of B for most of the field crops appeared to be 1.5 kg B ha^{-1}.

Although application of 2 kg B ha^{-1} initially gave higher response but indiscriminate use of B fertilizer more than 2 kg ha^{-1} annually leads to B toxicity in plants. Deleterious effect of 2 kg B ha^{-1} in several crops like rice, wheat, mustard and maize have been reported (Sakal *et al.*, 1996). Application of 16 kg boron ha^{-1} at two crops interval in sesame-chickpea cropping system was found to be an ideal dose and frequency of B application on calcareous soil (Sakal and Singh, 1995).

Sankaran et al (1977) studied effect of levels of boron on uptake of nutrient and quality of groundnut. It was observed that increasing levels of boron application significantly enhanced the boron content in haulms over control. Sakal *et al.* (1988b) noticed that increasing levels of B application resulted into increasing uptake of B by grain and straw in lentil.

Kadlag (1982) conducted pot culture experiment for establishment of critical level of boron for groundnut and reported that as levels of application of boron increased there was increase in uptake of B in groundnut plant. Tripathi and Singh (1968) studied boron toxicity in gram and groundnut and found that upto 2 ppm of boron in soil solution and 213 mg kg^{-1} and 218.33 mg kg^{-1} in plant tissue of gram and groundnut, respectively were safe. Sakal *et al.* (1988a) conducted field experiment in sandy loam to silt loam calcareous soil to study effect of boron application on blackgram and chickpea and reported that concentration of boron in grain and straw significantly increased with increasing levels of B application. Boron concentration in grain ranged from 20.56 to 53.77 and while in straw it ranged from 14.93 to 43.47 mg kg^{-1}.

Singh *et al.* (1991) conducted field experiment on chickpea on calcareous soil to study response of different cultivar. Application of boron increased the average B uptake in chickpea, grain and straw from 44 to 69.5 g ha^{-1} and 44.5 to 68.4 g ha^{-1}, respectively. Yadav and Manchanda (1982) conducted field experiment in green house by using sierozem sandy soil to study effect of B application on mustard and noticed that root, shoot, grain B was significantly increased with increase in B content of soil. At crop maturity plant in control and the 6 mg B treatment tested 25 and 558 mg B in their tissue, respectively.

2.4 Critical level of boron

The concept of critical level of an element is useful tool for the controlled feeding of crops with efficient utilization. The critical level of boron for various crops in different soils have been reported by number of workers.

The critical value of B by pertinent method differed markedly in soils for the same crop and was also different for crops grown on same soil.

2.4.1 Critical level of boron in soil

Singh and Sinha (1987) in a pot culture experiment on acid red loam soil evaluated a critical level of 0.47 mg kg^{-1} soil boron for soybean. Datta *et al.* (1994) in a pot culture experiment on acid sedentary soils evaluated critical level of soil available B extractable with hot water and $CaCl_2$ solution as 0.46 and 0.65 mg kg^{-1} soil, respectively below which soybean responded positively to B application.

Kadlag (1982) conducted a pot culture experiment for establishment of critical level of boron for groundnut and reported 0.275 mg kg^{-1} as critical level of boron for soil.

Sakal *et al.* (1985) studied critical level of boron in soil for black gram in calcareous soil and reported that critical limit value of boron was 0.53 mg kg^{-1} below which response to B application can be expected.

2.4.2 Critical level of boron for plant

Datta *et al.* (1994) conducted a pot culture experiment with acid sedentary soils and evaluated critical level of B for soybean plants as 21.5 mg kg^{-1}.

The plant species differ considerably in their B requirement. The critical deficiency concentration (CDC) of boron in monocotydons is from 5 to 10 mg kg^{-1} while for dicotyledons it is 20 to 70 mg kg^{-1}. In species such as soybean, the CDC of B for young leaflet is about 3 to 4 times higher than for mature leaves (Kirk and

Loneragan, 1988) reflecting the main function of B in cell growth and differentiation. Boron deficiency occurs in many plants when the concentration in fully mature leaves is less than 15 mg kg^{-1} and the B sufficiency range is between 20 to 100 mg kg^{-1} (Gupta, 1979).

Singh and Sinha (1987) conducted a pot culture experiment on acid red loam soil in which the critical concentration of boron in soybean plant was found to be 15 mg kg^{-1}.

Woodruff (1979) studied leaf boron content of soybean and reported that plant tissue analysis would be the best mean for evaluation of the need of boron fertilization with 9 to 10 mg kg^{-1} as critical level for deficiency and 50 to 60 mg kg^{-1} as critical level for toxicity in soybean.

Kadlag (1982) conducted a pot culture experiment for establishment of critical level of boron for groundnut and reported 135 mg kg^{-1} as plant critical level for groundnut.

2.5 Concentration and uptake of nutrients as influenced by application of boron

Mehta *et al.* (1964) reported that concentration of boron in leaves of different plants were legumes 54 mg kg^{-1}, cereals 51 mg kg^{-1}, fodder crops 12 mg kg^{-1} and fruit trees 85 mg kg^{-1}. A positive relationship between uptake of boron by plants and water soluble boron of soils was demonstrated by Singh and Randhawa (1977a).

Kadlag (1982) conducted a pot culture experiment for establishment of critical level of boron for groundnut and reported that as levels of B increases the uptake of nitrogen, phosphorus and potassium significantly increased upto 5 kg Borax ha^{-1} which was further decreased.

Yadav and Manchanda (1982) conducted experiment in greenhouse using surface sandy soil to study effect of boron application in mustard and reported that concentration of N as well as uptake was considerably increased with each increase in B content of soil. Karim and Deraz (1961) observed that when boron was applied to mustard it stimulated the absorption of N, P and K in mustard Surinder Kumar (1978) reported that increasing levels of boron in soil significantly increased N, P and K content of barely.

Gopal (1975) found that the application of 10 ppm boron to groundnut plant in sand culture experiment increased the phosphorus content of root and middle leaves by 10 and 5 per cent, respectively.

Advayi (1978) observed increased leaf K concentration in tomato plant grown in soil culture treated with boron in concentration of 2 to 4 mg kg^{-1}.

Leveque and Beley (1959) observed that the uptake of K increased due to high concentration of B in sand culture experiment in which nutrient solution contained 0.15 to 9 mg kg^{-1} Boron.

Stoyanov (1975) found a significant interaction between potassium and boron on yield. Sakal *et al.* (1988) noticed K an dB has synergetic effect.

Hill and Morill (1975) found significant interaction between potassium and boron on growth and quality of spinach peanut under green house study. They also found a significant interaction between the effect of B and Ca on growth and quality of Spanish peanut under green house condition.

Laughlin (1988) noticed that increasing level of boron in soil significantly increased Ca content in barley.

Advayi (1978) observed the increase in leaf Ca, Mg concentration in tomato plant grown in soil culture treatment with boron application @ 2 and 4 mg kg^{-1}. Netsangtip et al. (1985) reported that a critical concentration of boron in peanut kernels was found to be 13 mg kg^{-1} below which the hollow heart was observed in peanut kernels.

MATERIAL AND METHODS

3. MATERIALS AND METHODS

A pot culture experiment was conducted in the Department of Agricultural Chemistry and Soil Science, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri during *kharif* 2002 to study the critical level of available boron for soybean in Inceptisol. The details of the materials used and methods adopted in the present investigation are given in this chapter.

3.1 Materials

3.1.1 Soil

The soils were selected so as to have wide variation in the available boron status. The soybean crop being mainly grown on Inceptisol. The dominant soil series of this soil order namely Pather (Sawargaon) (Vertic Haplustepts) and Sonawadi (Dholwad) (Vertic Haplustept) have been selected. The surface soil (0-15 cm) samples in bulk were collected from 15 different locations representing these two soil series of Inceptisol. The soil samples were air dried and processed for determination of available boron. On the basis of available boron status the soils were categorised into low, medium and high in respect of its available B content. Out of fifteen locations, soil samples from seven locations were in the category of low boron content (< 0.5 mg kg^{-1}), four were of medium boron content (0.5 to 1.0 mg kg^{-1}) and four were of high boron content (> 1.0 mg kg^{-1}). All the soil samples collected were also analysed for initial soil physical and chemical properties *viz.*, pH, EC, organic carbon, calcium carbonate, texture, available Fe, Mn, Cu, Zn and available NPK status.

3.1.2 Seeds

Healthy soybean seeds (JS-335) obtained from the Central Store, Director of Farm, M.P.K.V., Rahuri were used for the experiment of this investigation.

3.1.3 Fertilizers

The nitrogen, phosphorus and potassium were applied through urea, ammonium dihydrogen phosphate, potassium chloride, respectively using the fertilizer prescription equations for 25 q ha^{-1} yield target of soybean.

3.1.4 Pots

Earthen pots of 5 kg capacity with 21 cm height having inner diameter of 9 cm at bottom and 13 cm at top were used. Black polythene sheet having 0.5 mm thickness was cut into appropriate size and placed inside the earthen pot for lining purpose and to avoid contamination.

3.1.5 Pesticides

All the necessary plant protection measure were undertaken. Actra 25 WG (Thiamethoxam) was used for control of leaf minor.

3.1.6 Irrigation

Deionised water was used for giving irrigation to the pots. The quantity of water was applied considering the field capacity of soils. Irrigation was given to the pots considering the crop coefficient and crop evapotranspiration demand.

3.1.7 Screen house

The screen house for pot culture study is available in the Department of Agricultural Chemistry and Soil Science, M.P.K.V., Rahuri. The earthen pots were kept on the concrete platforms in the screen house.

3.1.8 Glass ware

The glass ware used for analytical work were of corning. The borosilicate glass wares were avoided and the reagent were stored in the plastic bottles during estimation of boron.

3.1.9 Chemicals

The chemicals used for analysis were of high purity (analytical/guaranteed reagent grades). They were obtained from M/s Sd Fine Chemicals, Mumbai.

3.2 Methods

3.2.1 Preparation of soil samples

The collected surface soil samples were air dried. Out of the bulk samples collected, representative sample of 1 kg each was obtained by quartering technique. Each sample was processed with the help of a wooden mortar and pestle, sieved and stored. The remaining bulk samples were also processed, passed through 2 mm sieve and used for filling the pots for conducting the pot culture experiment.

3.2.2 Analysis of soil

The soil samples were analysed for physical and chemical properties by using standard methods as given in Table 1.

Table 1. Methods used for soil analysis

Sr. No.	Particulars	Methods	Reference
1.	Particle size analysis	Bouyoucos hydrometer	Gee and Bauder (1986)
2.	pH	Potentiometric	Jackson (1973)
3.	EC	Conductometric	Jackson (1973)
4.	Available N	Alkaline permanganate	Subbiah and Asija (1956)
5.	Available P	0.5 M $NaHCO_3$ at pH 8.5	Olsen *et al.* (1954)
6.	Available K	Extraction with neutral Ammonium acetate	Jackson (1973)
7.	Available B	$CaCl_2$ extractable (Azomethine)	Bingham (1982)
8.	$CaCO_3$ equivalent	Rapid titration	Piper (1966)
9.	Organic carbon	Walkley and Black wet digestion	Nelson and Sommer (1982)
10.	DTPA Fe, Mn, Cu, Zn	Atomic absorption spectrophotometry	Lindsay and Norvell (1978)

3.2.3 Filling of pots

The polythene lined earthen pots were filled with 5 kg soil samples in each pot. There were in all 15 soils, 5 treatments and 2 replications. Total 150 pots were filled with soil. The complete randomized design was used. for statistical analysis.

3.2.4 Application of fertilizer

Boron was applied through Borax (11.3 % B) as per the treatments in the present pot culture study.

Sr. No.	Treatment	Quantity of Borax applied g/pot
1.	T_1 Control	0
2.	T_2 0.25 mg B kg^{-1} soil	0.011
3.	T_3 0.50 mg B kg^{-1} soil	0.022
4.	T_4 0.75 mg B kg^{-1} soil	0.033
5.	T_5 1.00 mg B kg^{-1} soil	0.044

Since the soils were deficient in zinc 5 mg Zn kg^{-1} soil was applied to all the soils. The quantity of nitrogen, phosphorus and potassium was applied through reagent grade chemicals *viz.,* urea, ammonium dihydrogen phosphate and potassium chloride. The quantity was calculated as per fertilizer prescription equation for 25 q ha^{-1} target for soybean as below.

$FN = 4.30\ T - 0.34\ SN$

$FP_2O_5 = 9.36\ T - 8.17\ SP$

$FK_2O = 2.80\ T - 0.06\ SK$

Where,

T = Targeted yield (q ha^{-1})

SN = Available soil nitrogen (kg ha^{-1})

SP = Available soil phosphorus (kg ha^{-1})

SK = Available soil potassium (kg ha^{-1})

FN = Fertilizer nitrogen (kg ha^{-1})

FP_2O_5 = Fertilizer phosphorus (kg ha^{-1})

FK_2O = Fertilizer potassium (kg ha^{-1})

The available NPK status of soils was used to work out the quantity of NPK to be added based on the fertilizer prescription equation.

Table 2. Quantity of fertilizer application

Soil No.	Quantity of fertilizer (g/pot)		
	Urea	ADP	KCl
1.	0.2326	1.4218	0.3053
2.	0.2582	1.3624	0.4712
3.	0.3552	1.4519	0.2588
4.	0.2534	1.4990	0.3393
5.	0.2426	1.4218	0.2187
6.	0.2176	1.3218	0.2760
7.	0.2845	1.326	0.2474
8.	0.5958	0.1938	0.1099
9.	0.5297	0.1407	0.1040
10.	0.6106	0.1882	0.2992
11.	0.2939	0.9160	0.3107
12.	0.4739	0.2302	0.2533
13.	0.4163	0.1407	0.1959
14.	0.3647	0.7248	0.2533
15.	0.3010	1.5410	0.2246

3.2.5 Sowing

The sowing of soybean (JS-335) seed was carried out on 20th June, 2002. Initially, eight seeds were sown in each pot at equal spacing and upto 1-2 cm depth and immediately watered with deionized water.

3.2.6 Growing of plant

3.2.6.1 Watering

Deionized water was given at an interval of four to six days starting with 2 to 3 days before sowing and was continued upto the flowering stage. The quantity of water required per pot was determined based on the field capacity of different soils. The quantity of water was given as per the crop coefficient and crop evaporation demand.

3.2.6.2 Thinning

Eight days after sowing i.e. 28th June 2002 thinning was carried out and only four healthy plants were kept in each pot.

3.2.6.3 Plant protection

Spraying of Actara 25 WG (Thiamethoxam) was undertaken on 8th July 2002 to control the leaf minor.

3.2.7 Harvesting

The soybean plants were harvested at 45 days after sowing (50 % flowering stage) i.e. on 5th August, 2002. The plants were uprooted carefully without disturbing the roots.

3.2.8 Cleaning and drying of plant samples

The plant samples alongwith the roots were washed first in deionized water and then in distilled water to remove the soil from the samples. The roots were removed by cutting. The samples were air dried under shade and then dried in oven by putting them in paper bags at 55 °C temperature till they showed constant weight. After oven drying the dry matter weights of samples were recorded.

3.2.9 Preparation of plant samples for analysis

The oven dried samples were cut into pieces and powdered in Willey grinding mill. The powdered samples were stored in air light plastic bottles for further analysis.

3.2.10 Plant analysis

The analysis of plant samples was carried out by using standard (Table 3).

Table 3. Methods used for plant analysis

Sr. No.	Particulars	Method	Reference
1.	Total N	Micro-kjeldahl	Parkinson and Allen (1975)
2.	Total P	Vandomolybdate yellow colour	Jackson (1973)
3.	Total K	Flame-photometry	Chapman and Pratt (1961)
4.	Boron	Azomethine	John *et al.* (1975)
5.	Ca	Versenate	Page (1982)
6.	Mg	Versenate	Page (1982)
7.	Fe, Mn, Cu, Zn	Atomic absorption spectrophotometry	Lindsay and Novell (1978)

An acid extract was prepared by binary mixture method. Plant samples, weighing 0.2 g were taken in a digestion tubes. The samples were digested in concentrated H_2SO_4 and H_2O_2 mixture in equal proportion (1 : 1).

3.3 Determination of critical level

The critical level of boron for soybean crop and for soil was determined by using standard procedure as suggested by Cate and Nelson (1965; 1971).

3.3.1 Graphical method

1. The scatter diagram of percentage yield (Y axis) Vs soil test value (X-axis) is plotted on arithmetic paper. The range in values on the Y-axis will always be 0 to about 100 per cent, whereas the range for value on the X-axis will vary with the soil test procedure, the particular soils studied and the nutrient involved.
2. A piece of clear plastic having roughly one and one-half the dimensions of the graph is cut out for use as an overlay. A pair of intersecting perpendicular lines is drawn on the overlay with black India ink in such a way that it is divided into four sectors having area of roughly the same relative size. The signs of these quadrants are then labelled with black India ink.
3. The overlay is moved about horizontally and vertically on the graph always with the two lines parallel to the two axes on the

graph, until the number of points in the negative quadrants is at a minimum.

4. The positions of the lines on the overlay with respect to the axes of the graph are transferred to the graph by making marks on the edges of the graph. The two intersecting lines are then drawn lightly on the graph with pencil. The point where the vertical line crosses the X-axis was defined as the critical soil test level.

3.3.2 Statistical method

The steps followed for calculation of critical level of boron by statistical approach as suggested by Cate and Nelson (1971) were as follows.

1. The initial soil test values of boron were arranged in ascending order.
2. The per cent dry matter yield was written against each soil test boron value.
3. The correction factor (C.F.) and total corrected sum of square (T.C.S.S.) was calculated from per cent dry matter yield by using following formulae.

i. $$\text{C.F.} = \frac{(\Sigma Y)^2}{n} = \frac{\Sigma [Y_1 + Y_2 + Y_3 + \dots\dots\dots Y_n)^2}{n}$$

ii. $$\text{T.C. S.S.} = \sum_{i=1}^{n} Y_i^2 - \text{C.F.}$$

$$= \Sigma [Y_1^2 + Y_2^2 + Y_3^2 + \dots\dots\dots Y_n^2) - \text{C.F.}$$

Where,

Y = Per cent dry matter yield

n = Total number of observations

4. The data were grouped into two groups i.e. if the total number of observations are 'n' then data is grouped as (P, n-P), (P + 1, n-P+1) e.g. If n = 15 then the data is grouped as (2,13) (3,12) .... (13,2).

5. A table with following columns were prepared

   i. Last value of soil available nutrient

   ii. Plant available B included in population I[st]

$$\text{i.e.} = \frac{P_1 + P_2 \ldots\ldots\ldots + P_n}{P}$$

   iii. Combine sum of square of deviation from mean of population I[st] i.e. C.S.S.I.

   Here total of all values of population I[st] was made

$$\text{C.S.S.I.} = \sum P_1^2 + P_2^2 \ldots\ldots\ldots + P_n^2 - \frac{\sum (P_1 + \ldots\ldots P_n)^2}{n}$$

   iv. If K_n is the number of observations in population II[nd], then mean relative yield in population II[nd]

$$= \frac{K_1 + K_2 + \ldots\ldots\ldots + K_n}{n}$$

v. Combined sum of square of deviation from mean of population II[nd] (CSSII). Here total of all values of population II[nd] was made i.e. $(K_1 + K_2 + \ldots\ldots\ldots + K_n)$

$$CSSII = \sum K_1^2 + K_2^2 + \ldots\ldots\ldots + K_n^2 - \frac{\sum (K_1 + \ldots\ldots + K_n)^2}{n}$$

vi. Postulated critical level (split between the two population) i.e. P.C.L. was calculated as

$$P.C.L. = \frac{\text{Last value in I}^{st}\text{ population} + \text{I}^{st}\text{ value in II}^{nd}\text{ population}}{2}$$

vii. $$R^2 = \frac{TCSS - CSSI - CSSII}{TCSS}$$

The concentration having highest R^2 is the critical concentration .

The data obtained were statistically analysed according to the procedure given by Panse and Sukhatme (1967).

The critical level of boron in soil and plant was determined by following statistical approach as suggested by Cate and Nelson (1971).

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

Micronutrients are being continuously removed in high yields of harvested produce, without being replaced. In order to maximise the crop yield all the essential nutrients must be optimised. Despite the fact that micronutrients are required by plants in small quantity, nutrition of boron for the crops grown on alkaline calcareous soils needs attention. The indiscriminate use of boron sources may not be helpful in view of the narrower gap between deficiency and toxicity level of boron for plant growth. Critical level of micronutrients which are sufficient to allow good growth of plant tissues vary, but are generally small. However, a lack of this very small amount of boron in the crop is likely to cause serious physiological damage thus retarding plant growth and reducing crop yield substantially. The critical levels of nutrients were found to differ markedly in soils for the same crop and were also different for crops grown on same soil. In view of the increasing area under soybean on dominantly calcareous alkaline soils of Maharashtra, the present investigation was carried out to study the boron nutrition for soybean on these soils. Considering the main objectives to study the response of soybean to boron and to evaluate the critical concentration of boron in soil and plant, the experimental results are presented and discussed under the appropriate headings.

4.1 Physical and chemical properties of soil

4.2 Effect of boron application on the dry matter yield of soybean

4.3 Effect of boron application on the concentration and uptake of nutrients in soybean

4.4 Establishment of critical level of boron by graphical method

4.5 Establishment of critical level of boron by statistical method

4.1 Physical and chemical properties of soils

The soil samples from 15 different locations were analysed for the soil properties such as pH, EC, organic carbon, particle size analysis, calcium carbonate, available boron, available nitrogen, phosphorus and potassium and DTPA extractable zinc, iron, manganese and copper and the data are presented in Table 4.

These results revealed that pH of the soils ranged from 7.1 to 8.4. Electrical conductivity ranged from 0.31 to 1.87 dSm^{-1}. Organic carbon content varied from 3.5 to 8.9 g kg^{-1}. The calcium carbonate of the soils varied from 53.5 to 180.0 g kg^{-1}. The available nitrogen varied from 90.9 to 178.7 kg ha^{-1}. The available phosphorus in soils varied from 4.0 to 27.5 kg ha^{-1}. The available potassium ranged from 246.4 to 963.2 kg ha^{-1}. The sand content ranged from 8.9 to 21.5, silt from 31.8 to 44.6 and clay from 32.9 to 58.7 per cent with textural class from clay to clay loam. The DTPA extractable iron, manganese, zinc and copper varied from 2.62 to 7.32 mg kg^{-1}, 7.16 to 24.76 mg kg^{-1}, 0.28 to 0.54 mg kg^{-1} and 1.68 to 2.88 mg kg^{-1}, respectively. The available boron in soils varied from 0.19 to 1.47 mg

Table 4. Physical and chemical properties of soils

Sr. No.	pH (1 : 2.5)	Electrical conductivity (dSm⁻¹)	organic carbon (g kg⁻¹)	$CaCO_3$ equivalent g kg⁻¹)	Available nutrient (kg ha⁻¹)			Particle size analysis (%)			Texture class	Micronutrients (mg kg⁻¹)				Available Boron mg kg⁻¹)
					N	P	K	Sand	Silt	Clay		Fe	Mn	Cu	Zn	
1.	7.10	1.87	3.5	53.5	131.7	6.0	448.0	11.6	36.3	52.1	Clay	6.92	26.76	2.02	0.54	0.41
2.	7.40	1.31	4.1	75.0	129.6	7.0	246.4	13.3	32.1	54.6	Clay	2.62	11.16	2.60	0.28	0.30
3.	7.2	1.43	4.7	130.0	90.9	5.5	660.8	9.5	31.8	58.7	Clay	4.34	13.10	1.68	0.38	0.19
4.	8.1	0.37	4.9	173.0	119.2	4.7	504.0	8.9	36.4	54.7	Clay	4..42	8.50	2.02	0.32	0.23
5.	8.3	0.31	5.4	160.0	128.6	6.0	739.2	12.1	36.5	51.4	Clay	4.28	9.28	2.16	0.36	0.49
6.	8.3	0.51	5.7	160.0	144.3	7.7	627.2	11.3	36.3	52.4	Clay	3.26	16.68	1.94	0.36	0.50
7.	7.7	0.92	6.1	180.0	123.4	8.0	683.2	9.4	32.8	57.8	Clay	3.04	18.66	2.12	0.38	0.46
8.	8.1	1.78	6.3	135.0	119.2	27.0	952.0	13.6	39.5	46.9	Clay	4.18	7.16	1.94	0.30	0.93
9.	8.3	0.46	6.1	140.0	144.3	27.5	963.2	19.3	41.5	39.2	Clay loam	3.98	10.34	2.88	0.30	0.68
10.	7.4	0.80	7.1	90.0	116.0	26.7	582.4	20.6	40.0	39.4	Clay loam	3.78	14.78	2.80	0.40	0.99
11.	8.2	0.34	7.3	160.0	153.7	14.7	560.0	12.6	37.6	49.8	Clay	7.32	10.0	2.20	0.36	0.54
12.	7.6	0.80	7.8	110.0	133.7	26.0	672.0	20.7	42.6	36.6	Clay loam	5.30	14.10	2.44	0.52	1.46
13.	8.4	0.36	8.2	85.0	178.7	27.5	784.0	20.6	40.6	38.8	Clay loam	4.02	11.48	2.00	0.44	1.18
14.	8.4	0.37	8.6	80.0	147.4	17.7	672.8	20.1	40.5	39.3	Clay loam	4.84	9.82	2.40	0.40	1.47
15.	8.2	0.42	8.9	75.0	100.4	4.0	728.0	21.5	44.6	32.9	Clay loam	4.72	10.66	1.74	0.34	1.24

kg^{-1}. The seven soils were in low available boron (< 0.50 mg kg^{-1}) four in medium (0.50 to 1.00 mg kg^{-1}) and four in high available boron (> 1.00 mg kg^{-1}). Therefore these soils varying widely in available boron were selected for the study. Thus from the above results it is clear that the soils were slight to moderately alkaline in reaction, low in organic carbon, calcareous in nature deficient in Zn and sufficient in Cu, Mn and Fe, low in available nitrogen, low to moderately high phosphorus and high in available potassium.

4.2 Effect of application of boron on dry matter yield

The dry matter yield of soybean grown on low, medium and high boron status soils as influenced by various levels of boron application are reported in Table 5.

Table 5. Effect of application of boron on dry matter yield of soybean

Treatments	Dry matter yield (g plant^{-1})		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	4.83	4.84	4.89
T_2 : 0.25 mg B kg^{-1} soil	5.38	5.41	5.43
T_3 : 0.50 mg B kg^{-1} soil	6.94	7.11	7.28
T_4 : 0.75 mg B kg^{-1} soil	6.97	7.16	7.29
T_5 : 1.00 mg B kg^{-1} soil	7.05	7.17	7.34
Mean	6.23	6.34	6.44
S.E. $\pm$	0.040	0.0461	0.057
C.D. at 5 %	0.115	0.135	0.168

The application of boron to soybean grown on low, medium and high boron status soils significantly influenced the dry matter production of soybean. The average dry matter yield of soybean was more in high boron status soils (6.44 g $plant^{-1}$) followed by medium (6.34 g $plant^{-1}$) and low (6.23 g $plant^{-1}$) boron status soil.

The increasing levels of boron application significantly increased the dry matter yield of soybean up to 0.5 mg kg^{-1} in all soils. Application of boron @ 0.50 mg kg^{-1} (T_3) showed significant increase in dry matter yield of soybean (6.94 g $plant^{-1}$) over control (T_1) (4.83 g $plant^{-1}$) and application of boron @ 0.25 mg kg^{-1} (T_2) (5.38 g $plant^{-1}$) in low boron status soils. However, the treatments comprising application of boron @ 0.75 (T_4) and 1.00 mg kg^{-1} (T_5) were on par with 0.50 mg kg^{-1} treatment (T_3).

The increase in dry matter production of soybean with application of boron can be attributed to the role of boron in cell wall synthesis, cell wall structure and integrity of plasma membrane consequently, regulating cell growth and differentiation (Kirk and Loneragan, 1988).

In the medium boron status soils application of boron @ 0.5 mg kg^{-1} (T_3) was also found superior over control (T_1) and application of boron @ 0.25 mg kg^{-1} (T_2) in respect of dry matter yield. Similarly in the high boron status soils, the application of boron upto

0.5 mg kg^{-1} has shown significant increase in dry matter yield of soybean.

The results indicated that the application of higher levels of boron (> 0.5 mg kg^{-1} soil) did not show significant effect on the dry matter yield of soybean grown in soil with low, medium and high boron content. Increase in dry matter production with application of boron in soybean crop was also reported by Singh and Sinha (1987) and Datta *et al.* (1994). Significant increase in dry matter production of soybean due to application of boron upto 1 mg kg^{-1} soil was observed by Datta *et al.* (1994) in acid sedentary soils. In the black alkaline calcareous soils (Kadlag, 1982) significant increase in the dry matter production of groundnut due to application of boron as borax upto 5 kg ha^{-1} has been reported.

Thus, it is observed that application of boron @ 0.50 mg kg^{-1} resulted into significant increase in dry matter yield of soybean indicating that response of soybean was optimum at 0.50 mg kg^{-1} soil boron application and hence this level of boron was used for estimation of Brays per cent yield and subsequently for determination of critical level.

4.3 Effect of application of boron on the concentration and uptake of nutrients in soybean plant

The concentration of various nutrients like N, P, K, Ca, Mg including B, Zn, Mn, Fe and Cu as well as the uptake of these nutrients by soybean crop was studied under different levels of boron application on soils with low, medium and high available boron. Several workers have reported the antagonistic or synergistic relationship between boron and other macro as well as micronutrients. The results of present study are discussed here under appropriate headings.

4.3.1 Effect of application of boron on the concentration of nitrogen in soybean

The nitrogen concentration of soybean as influenced by the graded levels of boron application in low, medium and high boron status soils are reported in Table 6.

Table 6. Effect of application of boron on concentration of nitrogen in soybean

Treatments	Nitrogen concentration (%)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	2.21	2.53	2.76
T_2 : 0.25 mg B kg^{-1} soil	3.09	3.10	3.24
T_3 : 0.50 mg B kg^{-1} soil	3.57	3.55	3.77
T_4 : 0.75 mg B kg^{-1} soil	3.74	3.67	3.81
T_5 : 1.00 mg B kg^{-1} soil	3.77	3.78	3.82
Mean	3.276	3.320	3.481
S.E. $\pm$	0.020	0.038	0.029
C.D. at 5 %	0.057	0.112	0.086

The data revealed that the application of boron to soybean grown on low, medium and high boron containing soils showed significant effect on nitrogen concentration in soybean. The average nitrogen concentration in soybean was higher in high boron status soil (3.48 %) followed by medium (3.32 %) and low (3.27 %) boron status soils. The increasing levels of boron application significantly increased the nitrogen concentration in soybean over control.

The application of boron resulted in significant increase in N content (3.74 %) of soybean plant upto 0.75 mg B kg^{-1} (T_4) in low boron status soils. However, application of 1.00 mg B kg^{-1} (T_5) was found on par in respect of N with 0.75 mg B kg^{-1} application. In soils having medium available boron, similar trend was observed in respect of nitrogen concentration which was significantly increased upto 0.75 mg kg^{-1}. However, in case of soil having high boron status the application of 0.5 mg kg^{-1} (T_3) recorded significantly higher N concentration (3.77 %) which is on par with 0.75 and 1.00 mg B kg^{-1}.

The results indicated that the application of higher levels of boron was found effective in increasing the N content of soybean in soils with low to medium available B. However, application of higher levels of boron ($>$ 0.5 mg kg^{-1}) was less effective in increasing the nitrogen content of soybean particularly in soils with high available boron. Similar results were reported by Karim and Deraz (1961) and Kadlag (1982). It has been reported that application of boron stimulated absorption of nitrogen in mustard (Karim and Deraz, 1961) and in groundnut (Kadlag, 1982). Surinder Kumar (1978) reported significant increase in N concentration in barley with increasing levels of boron.

4.3.2 Effect of application of boron on the concentration of phosphorus in soybean

The concentration of phosphorus in soybean plant as influenced by various levels of boron application in soils of varying available boron content is presented in Table 7.

Table 7. Effect of application of boron on concentration of phosphorus in soybean

Treatments	Phosphorus concentration (%)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	0.33	0.35	0.38
T_2 : 0.25 mg B kg^{-1} soil	0.35	0.37	0.42
T_3 : 0.50 mg B kg^{-1} soil	0.38	0.41	0.44
T_4 : 0.75 mg B kg^{-1} soil	0.42	0.43	0.44
T_5 : 1.00 mg B kg^{-1} soil	0.42	0.41	0.44
Mean	0.381	0.392	0.422
S.E. $\pm$	0.0019	0.0059	0.0018
C.D. at 5 %	0.0056	0.0173	0.0054

The graded levels of boron application in low, medium and high boron content soils were found significant for phosphorus concentration in soybean. The average P concentration in soybean crop was highest in high boron status soils (0.42 %) followed by medium (0.39 %) and low (0.38 %) boron status soils.

The application of boron @ 0.75 mg kg^{-1} soil to soybean grown on low boron content soils showed significantly higher phosphorus concentration (0.42 %) which was found superior over the treatments comprising levels of boron *viz.*, 0, 0.25 and 0.50 mg kg^{-1}. However, it was found on par with higher level i.e. 1 mg B kg^{-1}. Similarly in medium boron status soils also significant increase in P concentration (0.43 %) was observed upto 0.75 mg B kg^{-1} which was on par with 1 mg B kg^{-1}. In case of soils having high available B, application of B @ 0.5 mg kg^{-1} (T_3) was found to show significantly higher P concentration (0.44 %) in comparison with control and 0.25 mg B kg^{-1}. It was however on par with 0.75 and 1.00 mg kg^{-1}.

The results indicated that the application of higher levels of B (> 0.75 mg kg^{-1} soil) was less effective in increasing phosphorus content of soybean in low boron content soils and application of more than 0.5 mg kg^{-1} soil was less effective in increasing phosphorus content of soybean in medium and high boron status soils. Similar results were reported by in groundnut (Kadlag, 1982) and in barley (Surinder Kumar, 1978).

4.3.3 Effect of application of boron on the concentration of potassium in soybean

The data regarding the potassium concentration in soybean as influenced by the graded levels of boron in various boron status soils are presented in Table 8.

Table 8. Effect of application of boron on concentration of potassium in soybean

Treatments	Potassium concentration (%)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	1.62	1.68	1.70
T_2 : 0.25 mg B kg^{-1} soil	1.80	1.86	1.90
T_3 : 0.50 mg B kg^{-1} soil	2.12	2.24	2.28
T_4 : 0.75 mg B kg^{-1} soil	2.33	2.27	2.30
T_5 : 1.00 mg B kg^{-1} soil	2.31	2.30	2.33
Mean	2.015	2.069	0.103
S.E. $\pm$	0.017	0.013	0.010
C.D. at 5 %	0.050	0.038	0.030

The increasing levels of boron application significantly increased the potassium concentration in soybean grown on low, medium and high boron content of soils.

In low available boron content soils, highest potassium concentration was recorded (2.33 %) at 0.75 mg kg^{-1} soil available boron (T_4) which was significantly higher than that of at 0, 0.25 and

0.50 mg B kg^{-1} and at par with 1 mg kg^{-1} soil (2.31 %). In medium and high boron status soils, application of boron @ 0.5 mg kg^{-1} (T_3) showed significant increase in potassium concentration in soybean as compared with control (T_1) and 0.25 mg kg^{-1} (T_2). The higher level of boron application i.e. 0.75 (T_4) and 1.00 (T_5) mg kg^{-1} were however found to be on par with 0.5 mg kg^{-1} (T_3).

Thus, the application of boron upto 0.75 mg kg^{-1} soil (T_4) in low boron status soils was found useful for increasing potassium concentration in soybean while application of boron upto 0.5 mg kg^{-1} soil (T_3) was beneficial for increasing potassium concentration significantly in soybean plant in case of medium and high boron status soils. These observations are in close accordance with Advayi (1978), Leveque and Beley (1959) and Stoyanov (1975).

4.3.4 Effect of application of boron on concentration of boron in soybean

The concentration of boron in soybean as influenced by graded levels of boron in low, medium and high boron content soils are depicted in Table 9.

The results indicate that the differences in the boron concentration in soybean due to different levels of boron were significant. All the levels of boron application significantly increased the boron concentration in soybean over the control. The mean boron concentration ranged from 18.23 to 44.0 mg kg^{-1} under different levels of boron application i.e. from 0 to 1.0 mg kg^{-1} levels. On low boron status soils, application of 1 mg kg^{-1} (T_5) recorded highest B concentration (40.28 mg kg^{-1}) which was found significant over control (T_1) 0.25 mg (T_2) and 0.5 mg B kg^{-1} (T_3) and was on par with 0.75 mg kg^{-1} (T_4). However, on medium and high boron status soils 0.5 mg B kg^{-1} (T_3) was found superior over control (T_1) and 0.25 mg kg^{-1} (T_2) which was on par with the higher levels of boron.

Table 9. Effect of application of boron on concentration of boron in soybean

Treatments	Concentration of boron (mg kg^{-1})		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	18.23	21.93	25.50
T_2 : 0.25 mg B kg^{-1} soil	26.23	29.21	31.30
T_3 : 0.50 mg B kg^{-1} soil	34.19	37.49	39.31
T_4 : 0.75 mg B kg^{-1} soil	37.27	39.33	42.41
T_5 : 1.00 mg B kg^{-1} soil	40.28	41.05	44.01
Mean	31.24	33.80	36.64
S.E. ±	1.21	1.52	1.61
C.D. at 5 %	3.64	4.48	4.76

The results thus indicated that the application of boron upto 1 mg kg^{-1} on low boron status soils and 0.5 mg kg^{-1} on medium and high boron status soils increased the concentration of boron in soybean significantly. Similar results were also reported by Kadlag (1982) in groundnut and Datta *et al.* (1993) in soybean.

4.3.5 Effect of application of boron on the concentration of calcium in soybean

The concentration of calcium in soybean as influenced by graded levels of boron in low, medium and high boron content soils are depicted in Table 10.

Table 10. Effect of application of boron on concentration of calcium in soybean

Treatments	Concentration of calcium (%)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	0.79	0.88	0.94
T_2 : 0.25 mg B kg^{-1} soil	0.94	1.05	1.16
T_3 : 0.50 mg B kg^{-1} soil	1.04	1.13	1.23
T_4 : 0.75 mg B kg^{-1} soil	1.13	1.17	1.21
T_5 : 1.00 mg B kg^{-1} soil	1.09	1.20	0.97
Mean	0.999	1.085	1.105
S.E. $\pm$	0.045	0.020	0.022
C.D. at 5 %	0.131	0.061	0.065

The application of boron to soybean grown on various boron status soils showed the significant effect on calcium concentration in soybean. The mean calcium concentration in soybean was highest in high boron status soils (1.11 %) followed by medium (1.09 %) and low boron status soils (0.99 %).

The calcium concentration in low boron status soils was highest (1.13 %) due to application of boron @ of 0.75 mg kg^{-1} (T_4)

which was on par with 1.00 mg B kg^{-1} soil (1.09 %) (T_5). In medium and high boron status soils 0.5 mg B kg^{-1} soil (T_3) recorded significantly higher calcium concentration in soybean plant (1.13 to 1.23 %) which was on par with higher levels of boron. Kadlag (1982) also observed significant increase in the calcium concentration in groundnut due to application of boron.

4.3.6 Effect of application of boron on the concentration of magnesium in soybean

The concentration of magnesium in soybean plant as influenced by various levels of boron application in soils of varying available boron content is presented in Table 11.

Table 11. Effect of application of boron on concentration of magnesium in soybean

Treatments	Concentration of magnesium (%)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	0.68	0.74	0.75
T_2 : 0.25 mg B kg^{-1} soil	0.75	0.95	0.86
T_3 : 0.50 mg B kg^{-1} soil	0.91	0.95	0.92
T_4 : 0.75 mg B kg^{-1} soil	0.97	0.86	0.75
T_5 : 1.00 mg B kg^{-1} soil	0.95	0.72	0.57
Mean	0.85	0.84	0.77
S.E. ±	0.018	0.056	0.045
C.D. at 5 %	0.052	0.164	0.134

The graded levels of boron application in low, medium and high boron status soils to soybean were found significant for magnesium concentration in soybean.

The magnesium concentration in soybean grown in low B status soil was highest (0.97 %) at 0.75 mg B kg^{-1} soil (T_4) which was significant over application of boron @ 0, 0.25 and 0.50 mg kg^{-1}. However, application of boron @ 1 mg kg^{-1} was found on par with 0.75 mg kg^{-1} soil. In case of medium boron status soils concentration of magnesium was found to increase only upto 0.25 mg kg^{-1} B. In case of soil having high B content concentration of magnesium was significantly increased due to 0.5 mg kg^{-1} soil.

Thus, it is observed that no definite trend has been seen in the concentration of magnesium due to application of various levels of boron on different soils, however, better response to application of boron (0.75 mg kg^{-1}) has been shown by low boron status soils in increasing the concentration of magnesium.

4.3.7 Effect of application of boron on concentration of iron in soybean plant

Application of boron @ 0.25 mg kg^{-1} (T_2) to low boron status soils was found to increase the concentration of iron in soybean (366.92 mg kg^{-1}) significantly over control (T_1) which was on par with higher levels of boron. In medium boron status soils application of boron upto 0.75 mg kg^{-1} significantly increased the iron concentration. However, in high boron status soils application of boron @ 0.25 mg kg^{-1} was found on par with control. Application of boron @ 0.50 mg kg^{-1} recorded highest Fe concentration (441.42 mg kg^{-1}) which was significant over control. Thus, no definite trend was observed in iron concentration due to levels of boron. However, the concentration of iron in soybean was significantly decreased at the higher level of boron (> 0.75 mg B kg^{-1}). The concentration of iron at 1 mg B kg^{-1} (347.10 mg kg^{-1}) was drastically reduced which was significantly lower as compared with iron concentration in control (394.25 mg kg^{-1}).

Table 12. Effect of application of boron on concentration of iron in soybean

Treatments	Concentration of iron (mg kg^{-1})		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg.B kg^{-1} soil	311.78	303.75	394.25
T_2 : 0.25 mg B kg^{-1} soil	366.92	364.12	418.25
T_3 : 0.50 mg B kg^{-1} soil	398.35	414.37	441.62
T_4 : 0.75 mg B kg^{-1} soil	389.78	463.87	390.12
T_5 : 1.00 mg B kg^{-1} soil	378.35	395.00	347.00
Mean	369.04	388.22	398.25
S.E. $\pm$	12.38	6.55	12.59
C.D. at 5 %	35.54	19.28	37.06

4.3.8 Effect of application of boron on the concentration of manganese in soybean

Table 13. Effect of application of boron on concentration of manganese in soybean

Treatments	Concentration of manganese (mg kg^{-1})		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	38.06	37.40	38.63
T_2 : 0.25 mg B kg^{-1} soil	39.40	38.52	41.29
T_3 : 0.50 mg B kg^{-1} soil	41.37	42.28	41.63
T_4 : 0.75 mg B kg^{-1} soil	43.30	42.81	41.40
T_5 : 1.00 mg B kg^{-1} soil	42.19	42.76	40.11
Mean	40.86	40.75	40.61
S.E. $\pm$	0.283	0.212	0.159
C.D. at 5 %	0.813	0.625	0.468

The increasing levels of application of boron in low boron status soils were found to increase the manganese concentration in soybean upto 0.75 mg B kg^{-1} (T_4) which was on par with 1 mg B kg^{-1} (T_5). In medium boron status soils, concentration of manganese was found to significantly increase upto 0.5 mg B kg^{-1} while on high boron status soils it was significantly more upto 0.25 mg B kg^{-1}.

This indicates that higher levels of application of boron were not useful in increasing manganese concentration in soybean, however in low boron status soils application of boron upto 0.75 mg kg^{-1} significantly increased the concentration of manganese.

4.3.9 Effect of application of boron on the concentration of zinc in soybean

Table 14. Effect of application of boron on concentration of zinc in soybean

Treatments	Concentration of zinc (mg kg^{-1})		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	18.31	20.72	21.97
T_2 : 0.25 mg B kg^{-1} soil	20.06	21.83	23.67
T_3 : 0.50 mg B kg^{-1} soil	21.54	25.29	26.04
T_4 : 0.75 mg B kg^{-1} soil	24.27	26.48	25.25
T_5 : 1.00 mg B kg^{-1} soil	25.65	27.35	24.38
Mean	21.97	24.33	24.26
S.E. $\pm$	0.204	0.172	0.62
C.D. at 5 %	0.586	0.507	1.84

Effect of application of graded levels of boron on the zinc concentration in soybean was studied and it was observed that the difference in zinc concentration in soybean due to various levels of boron were significant. It was interesting to note that the increasing level of application of boron upto 1 mg kg^{-1} in low and medium boron status soils were found to significantly increase the concentration of zinc in soybean (25.65 mg kg^{-1} and 27.35 mg kg^{-1}, respectively). However, in high boron status soils zinc concentration was significantly increased only upto 0.5 mg kg^{-1} (26.04 mg kg^{-1}) which was on par with the higher levels of boron.

4.3.10 Effect of application of boron on the concentration of copper in soybean

Table 15. Effect of application of boron on the concentration of copper in soybean

Treatments	Concentration of copper (mg kg^{-1})		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	15.02	15.50	15.00
T_2 : 0.25 mg B kg^{-1} soil	16.23	16.35	18.41
T_3 : 0.50 mg B kg^{-1} soil	17.48	17.22	17.85
T_4 : 0.75 mg B kg^{-1} soil	18.27	18.05	17.56
T_5 : 1.00 mg B kg^{-1} soil	18.00	17.89	15.75
Mean	19.99	17.00	16.91
S.E. $\pm$	0.201	0.327	0.233
C.D. at 5 %	0.579	0.962	0.687

Application of boron @ 0.75 mg kg^{-1} (T_4) recorded highest concentration of copper (18.27 mg kg^{-1}) in low boron status soils which is significant over 0, 0.25 and 0.50 mg kg^{-1} boron application and was on par with 1.00 mg B kg^{-1}. However, in medium boron status soils 0.50 mg B kg^{-1} (T_3) recorded 17.22 mg kg^{-1} copper in soybean which is significant over control and on par with higher levels of boron. In high boron status soils significant increase in copper concentration was found only upto 0.25 mg B kg^{-1} and thereafter the concentration of copper was decreased at higher levels of boron application. The copper concentration in soybean was drastically reduced (15.75 mg kg^{-1}) at higher level of boron application *viz.,* 1.00 mg B kg^{-1} which is significantly lower as compared with that of in the lower levels of boron. Similar results were also reported by Gopal (1975) where the adverse effect of higher levels of boron on concentration of copper in groundnut was observed.

4.3.11 Effect of application of boron on the uptake of nitrogen in soybean plant

The uptake of nitrogen by soybean due to different levels of boron grown on varying boron content soils are presented in Table 16.

Table 16. Effect of application of boron on uptake of nitrogen by soybean

Treatments	Nitrogen uptake (mg $plant^{-1}$)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	110.25	121.97	134.92
T_2 : 0.25 mg B kg^{-1} soil	165.64	167.85	175.56
T_3 : 0.50 mg B kg^{-1} soil	247.45	252.71	275.45
T_4 : 0.75 mg B kg^{-1} soil	260.63	261.40	274.68
T_5 : 1.00 mg B kg^{-1} soil	266.23	271.29	277.48
Mean	210.04	215.04	227.62
S.E. $\pm$	2.397	3.336	2.130
C.D. at 5 %	6.881	9.911	6.267

The data presented in Table 16 revealed that the uptake of nitrogen by soybean was increased significantly with the increasing level of boron application to soybean grown on low, medium and high boron content soils. The magnitude of nitrogen uptake by soybean due to different levels of boron application grown on varying boron content soils was in the order of high boron content soil (227.6 mg $plant^{-1}$) > medium boron content soils (215.0 mg $plant^{-1}$) > low boron content soils (210.0 mg $plant^{-1}$).

The nitrogen uptake by soybean on low boron status soils was significantly increased with increasing level of boron and the application of boron @ 0.75 mg B kg^{-1} recorded N uptake of 260.63 mg kg^{-1} which is significantly higher over that of in the control (T_1), 0.25 mg B kg^{-1} (T_2) and 0.50 mg B kg^{-1} (T_3) treatments. However, it is on par with 1.00 mg B kg^{-1} (T_5) (266.23 mg $plant^{-1}$). In medium boron status soils similar trend was observed. In high boron status soils the N uptake in soybean was found to increase with boron application upto 0.50 mg B kg^{-1}. This treatment (T_3) was found on par with higher levels of boron (T_4 and T_5) in respect of N uptake in high boron status soils. This indicates that, application of boron has significantly increased N uptake in soybean. However, boron application upto 0.75 mg B kg^{-1} in low and medium B status soil and 0.5 mg B kg^{-1} in high B status soil was found beneficial in increasing the uptake of nitrogen. It has been reported that application of boron improved the utilization of applied nitrogen by cotton plants by increasing the translocation of N compounds into the boll (Miley, 1969). The significant increase in N uptake due to application of boron was also reported by Surinder Kumar (1979), Karim and Deraz (1961) and Kadlag (1982).

4.3.12 Effect of application of boron on the uptake of phosphorus in soybean

The effect of boron application on phosphorus uptake by soybean due to different levels of boron grown on low, medium and high boron content soils are recorded in Table 17.

Table 17. Effect of application of boron on uptake of phosphorus by soybean

Treatments	Phosphorus uptake (mg plant^{-1})		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	15.93	18.17	16.91
T_2 : 0.25 mg B kg^{-1} soil	18.60	22.73	19.66
T_3 : 0.50 mg B kg^{-1} soil	26.57	30.97	29.61
T_4 : 0.75 mg B kg^{-1} soil	28.86	31.56	30.00
T_5 : 1.00 mg B kg^{-1} soil	29.67	31.46	30.11
Mean	23.93	26.98	25.54
S.E. $\pm$	0.213	0.251	0.454
C.D. at 5 %	0.612	0.743	1.336

The phosphorus uptake by soybean grown on soils with varying boron status significantly influenced due to different levels of boron application. The uptake of phosphorus by soybean grown on soil with low available B status was significantly increased upto 1 mg kg^{-1} B. However on medium and high B status soils application of boron @ 0.5 mg kg^{-1} (T_3) recorded significant increase in P uptake over control (T_1) and 0.25 mg B kg^{-1} (T_2) and it was on par with the higher levels of boron.

These results indicate that application of boron upto 1 mg kg^{-1} (T_5) was beneficial on low boron status soils, however, 0.5 mg B kg^{-1} (T_3) was sufficient on medium and high boron status soils for increasing P uptake by soybean. Similar results were also reported by Advayi (1978). It has been reported that at higher level of boron application the uptake of phosphorus was reduced.

The studies by Karim and Deraz (1961), Yadav and Manchanda (1982) and Kadlag (1982) indicated that boron application was increased the P uptake only at lower level of its application in groundnut and mustard.

4.3.13 Effect of application of boron on the uptake of potassium in soybean

The uptake of potassium by soybean grown on soils having low, medium and high B status significantly influenced due to varying levels of B in Table 18.

The application of B in low B status soil significantly increased K uptake upto 1 mg kg^{-1}. The application of B in medium B status soil significantly increased uptake of K upto 0.75 mg B kg^{-1} soil

(T_4). Application of B in high B status soil significantly increased K uptake upto 0.5 mg kg^{-1} soil B (T_3).

Table 18. Effect of application of boron on uptake of potassium by soybean

Treatments	Potassium uptake (mg $plant^{-1}$)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	78.11	81.13	83.02
T_2 : 0.25 mg B kg^{-1} soil	95.87	100.80	103.07
T_3 : 0.50 mg B kg^{-1} soil	146.58	158.92	165.86
T_4 : 0.75 mg B kg^{-1} soil	156.02	162.53	167.86
T_5 : 1.00 mg B kg^{-1} soil	163.07	164.78	170.90
Mean	127.93	133.63	138.14
S.E. $\pm$	1.504	0.856	1.407
C.D. at 5 %	4.318	2.520	4.140

Application of boron @ 1 mg B kg^{-1} recorded higher K uptake (163.07 mg $plant^{-1}$) which is significant over all the other levels in low B status soils. Among medium B status soils 0.75 mg B kg^{-1} has shown significant increase in K uptake while in high B status 0.5 mg kg^{-1} recorded significantly higher uptake of potassium.

4.3.14 Effect of application of boron on boron uptake by soybean plant

The data on effect of different levels of boron application on its uptake by soybean are reported in Table 19.

Table 19. Effect of application of boron on uptake of boron by soybean

Treatments	Boron uptake (mg $plant^{-1}$)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	0.08	0.11	0.12
T_2 : 0.25 mg B kg^{-1} soil	0.14	0.16	0.17
T_3 : 0.50 mg B kg^{-1} soil	0.23	0.26	0.28
T_4 : 0.75 mg B kg^{-1} soil	0.27	0.28	0.31
T_5 : 1.00 mg B kg^{-1} soil	0.28	0.29	0.33
Mean	0.198	0.220	0.242
S.E. $\pm$	0.0162	0.0097	0.0136
C.D. at 5 %	0.0487	0.0288	0.0409

The uptake of boron was found to be highest in the high boron status soils (0.24 mg $plant^{-1}$) followed by medium (0.22 mg $plant^{-1}$) and low boron status soils (0.19 mg $plant^{-1}$). The increasing levels of application of boron were found to increase the uptake of boron by soybean upto 0.75 mg B kg^{-1} (T_4) in low and medium boron status soils, which is significant over control (T_1), 0.25 mg B kg^{-1} (T_2) and 0.50 mg B kg^{-1} (T_3) and on par with 1.00 mg B kg^{-1} (T_5). However on high boron status soils 0.5 mg B kg^{-1} (T_3) was found superior over control (T_1) and 0.25 mg B kg^{-1} which was on par with the higher levels of boron. The results indicated that the application of boron upto 0.75 mg kg^{-1} on low and medium boron status soils and 0.5 mg

kg^{-1} on high boron status soils increased the boron uptake in soybean significantly. Similar results were also reported by Kadlag (1982) in groundnut.

4.3.15 Effect of application of boron on the uptake of calcium in soybean

The uptake of calcium by soybean grown on soils having low, medium and high B status was significantly influenced due to varying levels of B (Table 20).

Table 20. Effect of application of boron on uptake of calcium by soybean

Treatments	Calcium uptake (mg $plant^{-1}$)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	38.29	42.38	45.85
T_2 : 0.25 mg B kg^{-1} soil	50.50	56.90	63.06
T_3 : 0.50 mg B kg^{-1} soil	72.34	80.05	90.01
T_4 : 0.75 mg B kg^{-1} soil	78.66	84.18	88.13
T_5 : 1.00 mg B kg^{-1} soil	82.68	86.02	71.55
Mean	64.49	69.91	71.72
S.E. $\pm$	1.275	1.42	1.77
C.D. at 5 %	3.662	4.17	5.22

The increasing levels of application of boron upto 1 mg kg^{-1} soil were found to significantly increase the Ca uptake in low B content soils. On the medium boron status soils application of boron

@ 1 mg kg^{-1} recorded highest calcium uptake (86.02 mg $plant^{-1}$) which was found significant over control (T_1), 0.25 mg B kg^{-1} (T_2) and 0.50 mg B kg^{-1} (T_3) and on par with 0.75 mg B kg^{-1} (T_4). On the high boron status soils Ca uptake was increased significantly upto 0.5 mg B kg^{-1} and thereafter decreased. Surinder Kumar (1978) made similar observation that increasing levels of B in soil significantly increased Ca content in barely. Similar observations were also reported by Leveque and Beley (1966) for groundnut.

4.3.16 Effect of application of boron on the uptake of magnesium in soybean

The uptake of magnesium by soybean as influenced by different levels of B on various B status soils are presented in Table 21.

Table 21. Effect of application of boron on uptake of magnesium by soybean

Treatments	Magnesium uptake (mg $plant^{-1}$)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	32.97	35.71	36.77
T_2 : 0.25 mg B kg^{-1} soil	40.18	51.42	46.78
T_3 : 0.50 mg B kg^{-1} soil	62.95	67.58	67.31
T_4 : 0.75 mg B kg^{-1} soil	67.75	61.81	54.65
T_5 : 1.00 mg B kg^{-1} soil	67.06	60.10	50.48
Mean	54.18	55.52	51.20
S.E. ±	1.255	1.568	1.196
C.D. at 5 %	3.605	4.614	5.768

The application of B @ 0.75 mg kg^{-1} (T_4) registered highest magnesium uptake (67.75 mg $plant^{-1}$) in low B content soil which was significant over 0, 0.25 and 0.50 mg B kg^{-1} treatments and on par with 1 mg B kg^{-1}. In case of medium and high B status soils uptake of magnesium was increased upto 0.5 mg B kg^{-1} (T_3) and thereafter decreased significantly. Similar results were shown by Kadlag (1982) in groundnut.

4.3.17 Effect of application of boron on the uptake of iron in soybean

Table 22. Effect of application of boron on the uptake of iron by soybean

Treatments	Uptake of iron (mg $plant^{-1}$)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	1.544	1.483	1.925
T_2 : 0.25 mg B kg^{-1} soil	1.966	1.968	2.260
T_3 : 0.50 mg B kg^{-1} soil	2.769	2.943	3.209
T_4 : 0.75 mg B kg^{-1} soil	2.727	3.235	2.831
T_5 : 1.00 mg B kg^{-1} soil	2.665	2.829	2.461
Mean	2.334	2.491	2.537
S.E. ±	0.088	0.069	0.084
C.D. at 5 %	0.254	0.175	0.251

The application of boron upto 0.5 mg kg^{-1} (T_3) was found to increase the uptake of iron in soybean significantly over control and 0.25 mg B kg^{-1} in all the soils except medium boron status soils where it showed increase in iron uptake upto 0.75 mg B kg^{-1} (Table 22). However, the uptake of iron was significantly reduced at higher level of boron application (T_5). The adverse effect of higher boron levels on uptake of iron in groundnut was also reported by Gopal (1975).

4.3.18 Effect of application of boron on the uptake of manganese in soybean

Table 23. Effect of application of boron on the uptake of manganese by soybean

Treatments	Uptake of manganese (mg $plant^{-1}$)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	0.183	0.181	0.189
T_2 : 0.25 mg B kg^{-1} soil	0.211	0.208	0.224
T_3 : 0.50 mg B kg^{-1} soil	0.286	0.300	0.303
T_4 : 0.75 mg B kg^{-1} soil	0.295	0.306	0.301
T_5 : 1.00 mg B kg^{-1} soil	0.297	0.305	0.294
Mean	0.254	0.260	0.262
S.E. $\pm$	0.0019	0.0021	0.002
C.D. at 5 %	0.0056	0.0063	0.006

The uptake of manganese in soybean was observed to be significantly influenced due to various levels of application of boron (Table 23). Application of boron upto 0.75 mg kg^{-1} (T_4) recorded significant increase in manganese uptake (0.295 mg $plant^{-1}$) over lower levels of boron in low boron status soils. However, the uptake of manganese was increased upto 0.5 mg B kg^{-1} in medium and high boron status soils. The results thus indicated that application of boron @ 0.75 mg kg^{-1} in low boron status soils and 0.5 mg kg^{-1} in medium and high boron status soils were found beneficial in increasing the uptake of manganese by soybean.

4.3.19 Effect of application of boron on the uptake of zinc in soybean

Table 24. Effect of application of boron on the uptake of zinc by soybean

Treatments	Uptake of zinc (mg $plant^{-1}$)		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	0.088	0.100	0.108
T_2 : 0.25 mg B kg^{-1} soil	0.107	0.117	0.128
T_3 : 0.50 mg B kg^{-1} soil	0.147	0.181	0.189
T_4 : 0.75 mg B kg^{-1} soil	0.168	0.189	0.184
T_5 : 1.00 mg B kg^{-1} soil	0.173	0.196	0.183
Mean	0.137	0.157	0.158
S.E. $\pm$	0.0017	0.0012	0.0039
C.D. at 5 %	0.0050	0.0037	0.0115

The effect of application of graded levels of boron on the uptake of zinc by soybean was studied in low, medium and high boron status soils (Table 24). The uptake of zinc by soybean was significantly influenced due to application of boron and the highest zinc uptake (0.158 mg plant^{-1}) was observed in high boron status soils followed by medium (0.157 mg plant^{-1}) and low boron status soils (0.137 mg plant^{-1}). The increasing levels of application of boron upto 1.00 mg B kg^{-1} significantly increased zinc uptake in low (0.173 mg plant^{-1}) and medium (0.196 mg plant^{-1}) boron status soils in comparison with rest of the treatments. Similarly, in high boron status soils the zinc uptake was significantly increased due to application of boron upto 0.5 mg kg^{-1}. The results indicate that the application of boron @ 1.00 mg kg^{-1} in low and medium boron status soils and 0.5 mg kg^{-1} in high boron status soils was beneficial in increasing the uptake of zinc by soybean.

4.3.20 Effect of application of boron on the uptake of copper in soybean

Table 25. Effect of application of boron on the uptake of copper by soybean

Treatments	Uptake of copper (mg plant^{-1})		
	Soil boron status		
	Low	Medium	High
T_1 : 0 mg B kg^{-1} soil	0.071	0.073	0.075
T_2 : 0.25 mg B kg^{-1} soil	0.087	0.100	0.089
T_3 : 0.50 mg B kg^{-1} soil	0.120	0.127	0.122
T_4 : 0.75 mg B kg^{-1} soil	0.127	0.128	0.128
T_5 : 1.00 mg B kg^{-1} soil	0.125	0.118	0.128
Mean	0.106	0.109	0.108
S.E. $\pm$	0.0014	0.0022	0.0020
C.D. at 5 %	0.0040	0.0066	0.0060

The uptake of copper by soybean was found to be significantly increased due to application of boron in low boron status soils upto 0.75 mg kg^{-1} while in medium and high boron status soils upto 0.5 mg kg^{-1}. The higher levels of boron were found to be on par with these levels and were not beneficial for increasing copper uptake in soybean. However, the uptake of copper was significantly reduced at 1.00 mg B kg^{-1} (T_5) in comparison with lower levels of boron. Gopal (1975) observed similar results in groundnut.

4.4 Establishment of critical level of boron by graphical method

The critical limits of micronutrients in soils and plants are useful to isolate the micronutrient deficient soils and plants from the normal soils and plants. Obviously, these can be employed to forecast the need for micronutrient fertilization. In view of the discrepancies in soil test crop response data in calculating the fertilizer requirement, Cate and Nelson (1965) suggested the need for more adequate representation of the relationship between soil test values and Bray's per cent yield which further developed into graphical method for establishment of critical level of nutrients in soil and plant.

4.4.1 Critical level of boron in soil

The data on soil available boron, dry matter yield of soybean at 0 and 0.50 mg kg^{-1} soil boron application, concentration of

Table 26. Effect of application of boron on dry matter yield (Bray's per cent dry matter) and plant boron concentration

Sr. No.	Soil boron (mg kg^{-1})	Dry matter yield (g $plant^{-1}$)		Brays (%) D.M. yield	Plant B (mg kg^{-1})
		0 mg B kg^{-1} soil	0.5 mg B kg^{-1} soil		
1.	0.41	4.55	6.60	68.93	18.72
2.	0.30	4.65	6.95	66.90	17.23
3.	0.19	4.40	7.25	60.68	16.44
4.	0.23	4.70	6.95	67.62	16.56
5.	0.49	5.30	6.70	79.10	20.36
6.	0.50	5.25	6.85	76.64	19.18
7.	0.46	4.95	7.25	68.82	19.12
8.	0.93	4.65	7.00	66.42	21.10
9.	0.68	4.55	6.95	65.46	21.97
10.	0.99	5.05	7.05	71.63	22.53
11.	0.54	5.10	7.45	68.45	22.11
12.	1.46	4.90	7.30	67.12	25.60
13.	1.18	4.95	7.30	67.80	25.09
14.	1.47	4.80	7.25	66.20	26.48
15.	1.24	4.90	7.25	67.67	24.83

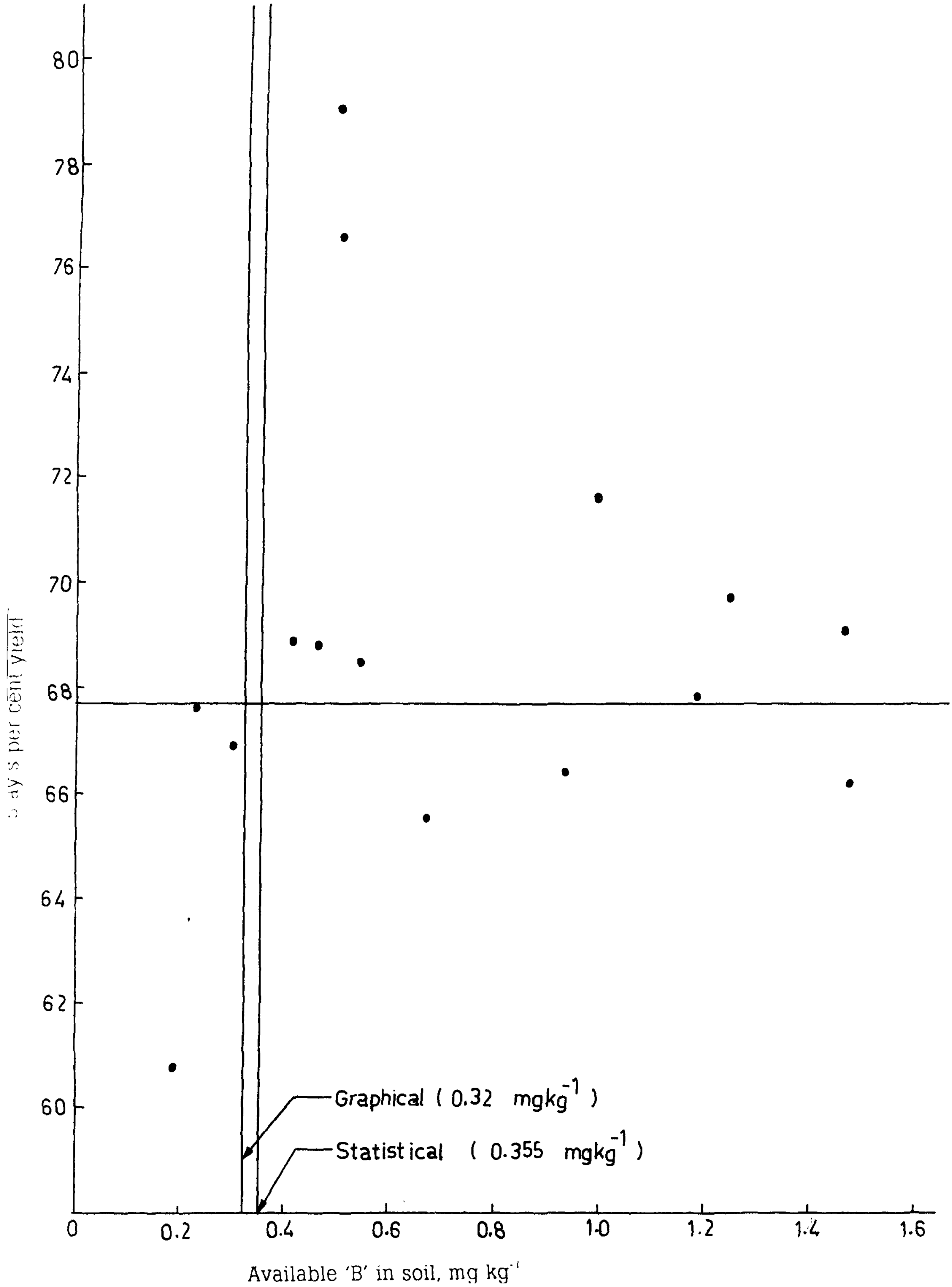

Fig. 1. Scatter diagram for Bray's per cent yield of soybean v/s available 'B' in soil

boron in soybean plant at control condition and Bray's per cent yield are presented in Table 26.

In the graphical method as suggested by Cate and Nelson (1965) yield obtained in the experiment was converted into Bray's per cent yield which was calculated as follows.

$$\text{Bray's per cent yield} = \frac{\text{Yield without boron}}{\text{Yield with optimum boron}} \times 100$$

The soils selected for this study contained available boron in the range of 0.19 to 1.47 mg kg^{-1}. The dry matter yield of soybean with boron and without boron varied from 6.60 to 7.45 g plant^{-1} and 4.40 to 5.30 g plant^{-1}, respectively. The calculated Bray's per cent yield varied from 60.68 to 79.1. After plotting Bray's per cent yield against soil available boron, the critical level was determined. A cross is placed over the data and moved until the upper left and lower right quadrants have a minimum number of points. The critical value is read from the X-axis where the vertical line intercepts it. The established critical level of boron for soybean is presented in Fig. 1. Thus, according to graphical method, scatter diagram indicated 0.32 mg kg^{-1} as critical level of boron in soil, below which response to boron fertilization may be expected in case of soybean. The critical level of boron as reported by Kadlag (1982) for black alkaline calcareous clay loam soils was 0.275 mg kg^{-1} for groundnut. However, slightly higher values have been reported (0.47 and 0.65 mg kg^{-1}) for the acid red loam soils for soybean (Singh and Sinha, 1987; Datta *et al.*, 1994). This variation obviously may be attributed to the variation in soil type comprising variability in physical and chemical properties and to the crop cultivar. The proposed critical level of boron i.e. 0.32 mg kg^{-1} obtained in the present study holds good for the widely distributed predominant black alkaline calcareous clay to clay loam soils of Maharashtra qualifying for inceptisol and for the high yielding crop variety (JS-335) of soybean.

4.4.2 Critical level of boron in soybean plant

Yield data of the experiment was utilized for computing Bray's per cent yield which was used for assessing the critical level of boron in plant. The concentration of boron in soybean plant grown on untreated soils of variable boron status was correlated with Bray's per cent yield and critical level of boron in soybean plant was worked out according to Cate and Nelson (1965) procedure. The boron content in soybean plants at control varied from 16.44 to 26.48 mg kg^{-1} (Table 26). The critical level of boron in soybean plant established is presented in Fig. 2. The scatter diagram indicated 18.5 mg kg^{-1} as the critical level of boron in plant. Below this value the soybean plants could be expected to give the response to added boron. The critical value computed is in accordance with Gupta (1979) who reported that boron deficiency occurs in many plants when the concentration is less than 15 mg kg^{-1} and the B sufficiency range is between 20 and 100 mg kg^{-1}. However, slightly higher value of 21.5 mg kg^{-1} has been reported by Datta *et al.* (1994) for soybean plant on

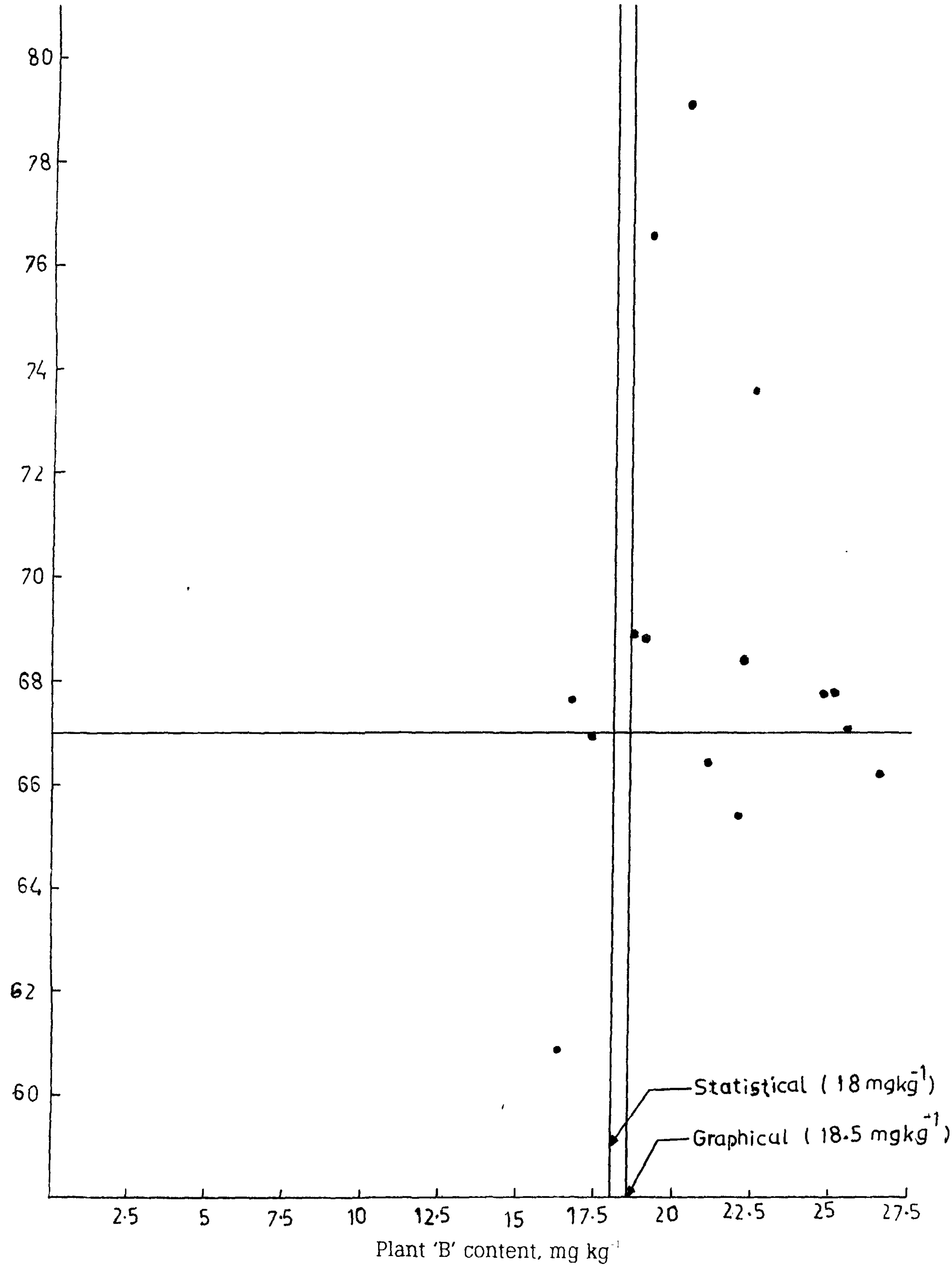

Fig. 2. Scatter diagram for Bray's per cent yield of soybean v/s plant 'B' content

acid red loam soils. The critical value of boron for cultivar Buchanan of soybean was observed to be 12 mg kg^{-1} by Kirk and Longeragan (1980). The higher value of boron as 18.5 mg kg^{-1} obtained in the present study for the soybean cultivar JS-335 in comparison to this suggests that there is considerable variation in susceptibility of soybean cultivars to boron deficiency. A critical concentration of boron in peanut kernels was found to be 13 mg kg^{-1} below which the hollow heart was observed in peanut kernels (Netsangtip *et al.,* 1985). The results thus indicated that the black alkaline calcareous soils (Inceptisol) of Maharashtra with less than 0.335 mg kg^{-1} available boron and soybean plant (JS-335) with boron concentration below 18.5 mg kg^{-1} may need boron fertilization to meet the boron requirement of soybean crop.

4.5 Establishment of critical level of boron by statistical method

The soil test values are often divided into two or more classes for the purpose of making fertilizer recommendations. However, the basis for defining the different classes such as very low, low, medium etc. is often subjective or arbitrary. In the graphical approach discussed previously the dividing line between two categories is drawn approximately and thus the subjectivity is involved in superimposing the vertical and horizontal lines on a scatter diagram. Therefore in order to overcome this, a statistically sound method for setting class limits is suggested by Cate and

Nelson (1971). A mathematical model has been developed for partitioning soil analysis correlation data into two sets i.e. responsive and non-responsive soils as per method suggested by Cate and Nelson (1971).

4.5.1 Critical level of boron in soil by statistical method

Soil test data obtained from the experiment on soybean was subjected to the statistical method for computing critical level of boron in soil as suggested by Cate and Nelson (1971).

The threshold value for soil available boron can be isolated by considering the highest R^2 value with corresponding X value for soybean which can be identified as 0.355 mg kg^{-1}. Thus, it is likely that soybean grown in soils containing available boron below the defined threshold value may respond to the applied boron on black alkaline calcareous soils (Inceptisol) of semi-arid eco-regions.

4.5.2 Critical level of boron in soybean plant by statistical method

Similar to soil test data, plant test data obtained from the experiment were subjected to the statistical approach for computing the critical level of boron in soybean plant as suggested by Cate and Nelson (1971).

The threshold value of plant boron can be isolated by considering the highest R^2 value with corresponding X value for soybean which was identified as 18 mg kg^{-1}.

Table 27. Soil available boron, corresponding Bray's per cent yield and critical level of boron for Inceptisol

Sr. No.	Soil available 'B' (mg kg^{-1})	Bray's per cent yield	Last value of available B included in population	Mean Relative yield in population I	CSS of deviation from mean of population I CSSI	Mean relative yield in population II	CSS of deviation from mean of population II CSSII	Postulated critical level (split between two population)	R^2 for postulated critical level
1.	0.19	60.68	-	-	-	-	-	-	-
2.	0.23	67.62	0.23	64.84	15.45	69.31	204.49	0.265	0.199
3.	0.30	66.90	0.30	65.52	18.28	69.52	198.16	0.355	0.213
4.	0.41	68.93	0.41	66.37	26.97	69.57	197.78	0.435	0.182
5.	0.46	68.82	0.46	66.86	31.74	69.64	197.15	0.475	0.170
6.	0.49	79.10	0.49	68.90	156.47	68.59	97.91	0.495	0.075
7.	0.50	76.64	0.50	70.01	207.75	67.59	25.17	0.520	0.150
8.	0.54	68.45	0.54	69.81	209.88	67.47	24.33	0.610	0.148
9.	0.68	65.46	0.68	69.33	226.74	67.80	19.61	0.805	0.104
10.	0.93	66.42	0.93	69.04	234.36	68.08	17.30	0.960	0.084
11.	0.99	71.63	0.99	69.27	240.46	67.19	1.58	1.08	0.120
12.	1.18	67.80	1.18	69.15	242.46	66.99	1.10	1.21	0.110
13.	1.24	67.67	1.24	69.04	244.49	66.06	0.42	1.35	0.110
14.	1.46	67.12	1.46						
15.	1.47	66.20	1.47						

Table 28. Plant boron, corresponding Bray's per cent yield and critical level of boron for soybean plant

Sr. No.	Plant boron (mg kg^{-1})	Bray's per cent yield	Last value of plant B included in population	Mean Relative yield in population I	CSS of deviation from means of population I CSSI	Mean relative yield in population II	CSS of deviation from mean of population II CSSII	Postulated critical level (split between two population)	R^2 for postulated critical level
1.	16.44	60.68	-	-	-	-	-	-	-
2.	16.56	67.62	16.56	64.15	24.08	69.31	204.49	16.89	0.168
3.	17.23	66.90	17.23	65.06	29.12	69.52	198.16	17.98	0.173
4.	18.72	68.93	18.72	66.03	40.31	69.57	197.78	18.92	0.134
5.	19.12	68.82	19.12	66.59	46.53	69.64	197.15	19.15	0.113
6.	19.18	76.64	19.18	68.26	130.70	68.87	142.85	19.77	0.005
7.	20.36	79.10	20.36	69.81	231.32	67.59	25.17	20.73	0.067
8.	21.10	66.42	21.10	69.38	241.40	67.76	23.59	21.53	0.036
9.	21.97	65.46	21.97	68.95	255.12	68.14	17.41	22.04	0.008
10.	22.11	68.45	22.11	68.90	255.34	68.08	17.30	22.32	0.008
11.	22.53	71.63	22.53	69.15	262.11	67.19	1.58	23.68	0.041
12.	24.83	67.67	24.83	69.02	264.12	67.04	1.28	24.96	0.034
13.	25.09	67.80	25.09	68.93	265.61	66.66	0.42	25.34	0.032
14.	26.60	67.12	25.60						
15.	26.48	66.20	26.48						

It is thus indicated that below this critical level of boron in soil or in plant response to boron fertilization may be expected in case of soybean (JS-335) grown on black alkaline calcareous clay to clay loam soils.

SUMMARY AND CONCLUSION

5. SUMMARY AND CONCLUSION

5.1 Summary

Present day agriculture is characterised by use of high analysis NPK fertilizers, newly introduced high yielding varieties of crops, extension of agriculture to marginal lands and increasing intensity of cropping which causes accelerated use of micronutrients resulting into their depletion from soil. The black alkaline calcareous soils were observed to pose the problem of boron deficiency. Owing to the narrower gap between the deficiency and toxicity the determination of critical level of boron needs attention especially on the black alkaline calcareous soils of Maharashtra. The information on the critical levels of boron in soil and for the important pulse and oilseed crop like soybean dominantly grown on these soils is rather negligible. Keeping this in view the pot culture experiment was conducted to evaluate the critical level of boron in soil and soybean plant, as also the response of soybean to boron application in completely randomised design with two replications at the Department of Agril. Chemistry and Soil Science, M.P.K.V., Rahuri during *kharif* 2002. The results obtained and the inferences drawn during the course of investigation are summarised briefly in this chapter.

For pot culture study bulk surface soil samples from 15 different locations representing the two predominant inceptisol soil series *viz.*, Pather (Sawargaon, Vertic Haplustepts) and Sonawadi (Dholwad Vertic Haplustepts) were collected from the fields around villages in the Rahuri tahsil of Ahmednagar district. After categorising soils into low, medium and high in available boron, these soils were used for conducting a pot culture experiment on soybean crop with varied levels of boron (0, 0.25, 0.50, 0.75 and 1.00 mg kg^{-1}). The dry matter production, concentration and uptake of nutrients *viz.*, N, P, K, Ca, Mg including B, Fe, Mn, Zn and Cu at various levels of boron were estimated. The available boron in soils, plant boron, dry matter yield and computed Bray's per cent yield emerged out from this experiment were further used for establishing critical level of boron in soil and in plant by both graphical and statistical methods.

The soils used for the experiment were slight to moderately alkaline in reaction, calcareous in nature, deficient in Zn and sufficient in Cu, Fe, Mn, low in organic carbon and nitrogen, very low to moderate in available phosphorus and high in available potassium. The available boron in the soils varied widely *viz.*, 0.19 to 1.47 mg kg^{-1} soil.

The dry matter production of soybean increased significantly due to various levels of boron application. The dry matter production was significantly higher at 0.50 mg kg^{-1} boron level on low (6.94 g $plant^{-1}$), medium (7.11 g $plant^{-1}$) and high (7.28 g $plant^{-1}$) boron status soils in comparison with lower levels of boron.

The dry matter production at 0.50 mg kg^{-1} was found on par with higher levels of boron indicating that application of boron upto 0.5 mg kg^{-1} was beneficial in increasing the dry matter significantly.

The concentration of boron in soybean was significantly increased with the various levels of boron in low, medium and high boron status soils. Application of boron upto 1.00 mg kg^{-1} on low boron status soils and 0.50 mg kg^{-1} on medium and high boron status soils increased the concentration of boron in soybean significantly. The uptake of boron by soybean was found to increase upto 0.75 mg kg^{-1} in low and medium boron status soils while in high boron status soils it was significantly increased upto 0.5 mg B kg^{-1}. It indicated that there was better response in respect of concentration and uptake of boron at higher doses of boron to soils having low and medium boron content. However, high boron status soils responded better to lower doses of boron in respect of concentration and uptake of boron by soybean.

The soils with low boron content showed the higher concentration of nitrogen, phosphorus, potassium, calcium, magnesium, manganese, zinc and copper with application of boron @ 0.75 mg kg^{-1} soil. The uptake of nitrogen, magnesium, manganese and copper were significantly higher with an application of boron @ 0.75 mg kg^{-1} soil. However, the uptake of phosphorus, potassium, calcium and zinc was significantly increased upto 1.00 mg kg^{-1} soil application of boron on low boron status soils. The uptake of iron by soybean was increased only upto application of 0.5 mg kg^{-1} soil suggesting adverse effect of higher levels of boron on the concentration and uptake of iron by soybean.

The soils with medium boron status showed the higher concentration of nitrogen and phosphorus with application of boron @ 0.75 mg kg^{-1} while concentration of potassium, calcium, manganese and copper were increased upto 0.50 mg B kg^{-1}. Similarly the uptake of these nutrients in general was increased upto 0.50 to 0.75 mg B kg^{-1}.

The higher concentration and uptake of nitrogen, phosphorus, potassium, calcium, manganese, zinc and copper in high boron status soils were observed when the rate of application of boron was 0.50 mg kg^{-1} soil indicating antagonistic effect of boron on concentration and uptake of nutrients by soybean at higher doses. The results also revealed that higher dose of boron @ 1.00 mg kg^{-1} soil had an adverse effect on the concentration of magnesium, iron and copper showing antagonistic effects of these nutrients with boron at higher doses.

From the data in respect of initial available boron status of soils, dry matter production and boron concentration in soybean, the critical level of boron in soil and soybean plant was computed by graphical and statistical method. The critical level of boron obtained by graphical method was 0.32 mg kg^{-1} for soil and 18.5 mg kg^{-1} for soybean plant. By statistical approach, however, the critical level of boron was 0.355 mg kg^{-1} for soil and 18.0 mg kg^{-1} for soybean.

Further, it is seen that there is not much variation in critical level of boron in soil and plant computed by graphical and statistical method. It is thus indicated that below this critical level in soil or in plant response to boron fertilization may be expected in case of soybean grown on black alkaline calcareous soils.

5.2 Conclusion

In a pot culture study application of boron upto 0.50 mg kg^{-1} was found beneficial in increasing the dry matter production in soybean (JS-335) grown on black alkaline, clay to clay loam, calcareous soils. The concentration and uptake of major (N, P, K), secondary (Ca, Mg) and micronutrients (B, Fe, Mn, Zn and Cu) were also significantly influenced due to application of boron.

The critical level of boron in soil (Inceptisol) and plant (Soybean JS-335) was 0.32 and 18.5 mg kg^{-1}, respectively as per graphical method. The critical level of boron by statistical method was 0.355 mg kg^{-1} for soil and 18.0 mg kg^{-1} for soybean plant indicating the comparable values of critical level by both the methods. Below these critical values soybean (JS-335) crop grown on black alkaline calcareous clay to clay loam soils may need boron fertilization to meet the boron requirement of soybean crop.

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6. LITERATURE CITED

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