

**Effect of Different Levels of Sulphur and Boron on Yield
and Quality of French bean (*Phaseolus vulgaris* L.) Var.
Contendor in Eutrochrepts**

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(2010-A-860-M)



Division of Soil Science

Faculty of Postgraduate Studies

Sher-e-Kashmir

University of Agricultural Sciences & Technology of

Kashmir

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Thesis

Submitted to

The Faculty of Postgraduate Studies

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in partial fulfillment of requirement for the award of the degree of

Master of Science in Agriculture

(Soil Science)

2012

Dedicated

to

my Parents

Sher-e-Kashmir
University of Agricultural Sciences & Technology of Kashmir
Division of Soil Science,
Shalimar Campus Srinagar– 191 121
-::o::-

Certificate – I

This is to certify that the thesis entitled, “**Effect of Different Levels of Sulphur and Boron on Yield and Quality of French bean (*Phaseolus vulgaris* L.) Var. Contendor in Eutrochrepts**” submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science in Agriculture (Soil Science)** to the **Faculty of Postgraduate Studies, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Mr. Mumtaz Ahmad Ganie (Regd. No. 2010-A-860-M)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that information received during the course of investigation has duly been acknowledged.

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We, the members of the Advisory Committee of **Mr. Mumtaz Ahmad Ganie (Regd. No. 2010-A-860-M)**, a candidate for the degree of **Master of Science in Agriculture (Soil Science)** have gone through the manuscript of the thesis entitled, **“Effect of Different Levels of Sulphur and Boron on Yield and Quality of French bean (*Phaseolus vulgaris* L.) Var. Contendor in Eutrochrepts”** and recommend that it may be submitted by the student in partial fulfillment of the requirements for the award of the degree.

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ABSTRACT

A field experiment was conducted at Research Farm, FOA Wadura, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir during *Kharif* 2011 to study the response of french bean to different levels of sulphur and boron. The soil under study was clay loam, low in available sulphur and boron, medium in available nitrogen, phosphorus and potassium with neutral pH. The experiment was laid out in randomized block design with four levels of sulphur (S_0 -0 Kg ha⁻¹, S_{15} -15 Kg ha⁻¹, S_{30} -30 Kg ha⁻¹ and S_{45} -45 Kg ha⁻¹) and four levels of boron (B_0 -0 Kg ha⁻¹, $B_{0.5}$ -0.5 Kg ha⁻¹, $B_{1.0}$ -1.0 Kg ha⁻¹ and $B_{1.5}$ -1.5 Kg ha⁻¹) and replicated thrice. The plots were given uniform recommended dose of nitrogen, phosphorus and potassium of 30, 60 and 60 Kg N, P₂O₅ and K₂O ha⁻¹ respectively along with farm yard manure of 20 ton ha⁻¹. The observations were recorded on various aspects like yield and quality attributes of french bean, nutrient uptake, concentration of nutrients at different stages of growth and chemical properties of soil. The treatment combination of S_{45} $B_{1.0}$ recorded significantly higher values of number of nodules, fresh and dry weight of nodules plant⁻¹, pod yield, dry matter production at flowering, pod picking and harvesting stages, number of pods plant⁻¹, number of seeds pod⁻¹, 100 seed weight, seed yield, stover yield, protein content of pods at pod picking stage, protein content of seeds at

harvesting stage, nutrient content in french bean pods and stover at pod picking stage and seeds and stover at harvesting stage, uptake of nitrogen, phosphorus, potassium, sulphur and boron at pod picking and harvesting stage. Soil pH was significantly reduced with S₄₅ level, however, the application of sulphur and boron had no effect on electrical conductivity and organic carbon. S₄₅ level registered significantly higher values of total, organic, sulphate and adsorbed sulphur while as non sulphate sulphur was significantly reduced with the increasing levels of sulphur. Application of boron had no effect on the forms of sulphur except sulphate sulphur which was increased significantly with B_{1.5} level. B_{1.5} level registered significantly higher levels of total boron. The treatment combination S₄₅B_{1.5} recorded higher values for hot water soluble boron. For seed production, S₄₅B_{1.0} recorded maximum gross and net returns but returns Re⁻¹ was maximum in S₃₀B_{1.0}. The present study revealed that S₄₅B_{1.0} combination exhibited superiority over all other treatment combinations with respect to almost all the characters of French bean. Thus, the results of the study lead to conclusion that for realizing higher yield and quality of french bean on inceptisols under temperate conditions of Kashmir valley the nutrient management must centre around 45 Kg sulphur and 1.0 Kg boron along with the recommended dose of 30 Kg nitrogen, 60 Kg phosphorus, 60 Kg potassium and 20 ton farm yard manure per hectare.

Key words Boron, forms of boron, forms of sulphur, nodulation, *Phaseolus vulgaris* L., quality, sulphur and yield.

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Mumtaz Ahmad Ganie

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Chapter – 1

INTRODUCTION

French bean (*Phaseolus vulgaris* L.) which is known by various names viz; rajma, rajmash, haricot bean, kindey bean, snap bean, navy bean, field bean, dry bean, pole bean etc. in different parts of the world was domesticated in Central and South America more than 6000 years ago. Wild forms of small black seeds found in Tropical America were introduced to West Africa and later to India. Common bean was spread to Europe, Africa and Asia by Spanish and Portuguese and at present it is grown throughout the cooler tropics but not in the hot semi-arid or wet-humid regions (Chatterjee and Bhattacharyya, 1986). Common bean (*Phaseolus vulgaris* L.) belongs to family leguminosae and occupies a premier place among grain legumes in the world including India, where it is locally called as *Rajmash* (Sharma *et al.*, 1994). It is a native of Central and South America and is morphologically highly variable. Common bean is adapted to a wide range of environments under diverse agro-ecosystems (Popelka *et al.*, 2004).

Nutritional value: French bean is quite nutritious and potential source of protein carbohydrates and minerals. The mineral matter, crude fibre and ether extract are concentrated in seed while crude protein and energy are stored in the cotyledons (Singh *et al.* 1997). It contains about 17.5-28.7 percent protein in the dry seeds and about 1.0-2.5 percent protein in the green pods, 3.2-5.0 percent mineral matter, 4.2-6.3 percent crude fibre, 1.2-2.0 percent crude fat and 340-450 kcal energy (Singh *et al.*, 1997) in addition to 61.4 per cent carbohydrates, 3.8 g ash, 425 mg phosphorus, 13.7 mg calcium, 16.7 mg iron per 100 g of edible parts and about 11 percent water (Aykroyd and Doughty, 1973). It is an excellent vegetable crop for pods as well as for seed and is of worldwide significance for direct human consumption and a dietary supplement rich in proteins, vitamins and minerals such as calcium, phosphorus, iron and zinc (Broughton *et al.*, 2003). On fresh weight basis quantitatively 100 g of the

green pod contains: moisture (91.4 percent), carbohydrates (4.5 percent), proteins (1.7 percent), fat (0.1 percent), calories (25), vitamin A (321 IU), thymine (0.08 mg), riboflavin (0.06 mg), vitamin C (16 mg), calcium (50 mg), iron (1.7 mg) and phosphorus (28 mg) (Hazra and Som, 2005).

Uses: French bean is grown in different parts of the world for its mature dry seeds, immature/tender green or yellow pods (snap bean) and for its leaves (in Africa and Asia) to be used as vegetable. In Northern India, dry pods of french bean fetch higher price to that of other pulse crops as its vegetable preparation is considered to be one of the most nutritious and delicious dish for the 'Sunday special'. The dry seeds can also be canned and exported. Tender pods of french bean for vegetable purpose can be harvested at about 55-60 days after sowing (Sardana *et al.*, 2000).

Growing areas: French bean is traditionally a crop of temperate region. It is cultivated in hilly tract of Jammu & Kashmir, Himachal Pradesh (Kullu, Barot, Chamba and Shimla valley) and Uttar Pradesh. Though its cultivation is mainly restricted to hilly region of north India, its consumption is more in the plains of north and central India, where its demand is not fully met. In Jammu & Kashmir, Himachal Pradesh, Hills of Uttar Pradesh and in some parts of Maharashtra (Mahabaleshwar and Ratnagiri region) it is grown as a *kharif* crop and in some other parts of Maharashtra, Andhra Pradesh, western and eastern Ghats and north-east plains as a winter crop because the winters are mild and frost free. Recently its cultivation has been extended to northern plain zone also and the introduction of this non-traditional crop to north eastern plains of India as a winter crop has generated lot of interest in the farming community due to its higher productivity, responsiveness to inputs and remunerative price.

Globally french bean is cultivated over an area of 29.92 million hectares with an annual production of 23.23 million tons while in India it is cultivated over an area of about 10.80 million hectares with an annual production of 4.87 million tons

(Anonymous, 2010). In Jammu and Kashmir, cultivation of beans is confined mainly to rainfed karewa areas extending over an area of about 26.75 thousand hectares with an annual production of 14.2 thousand tons (Anonymous, 2008). As a vegetable crop, french bean is cultivated globally over an area of 1.47 million hectares with an annual production of 17.65 million tons while in India it is cultivated over an area of about 0.20 million hectares with an annual production of 0.58 million tons (Anonymous, 2010) and in Jammu and Kashmir over an area of 2000 hectares with an annual production of 400 tons (Masoodi and Masoodi, 2003).

Botany: It has chromosome number of $2n = 22$, germination is epigeal having adventitious root system. The stem is slender, twisted, angled and ribbed, more or less square in section. The flowers are white, pink or purple with reflexed standard and diadelphous stamens and are self-pollinated. Pods are borne mostly on axillary racemes and are slender, straight or curved and terminated by a prominent beak and usually contain 4-6 seeds. Seeds are non-endospermic and vary greatly in size and colour. It does not nodulate with native *rhizobia* or commercially produced cultures (Sardana *et al.*, 2000).

Climatic requirements: The optimum temperature required for the growth of french bean is about 16-24⁰C (Sardana *et al.*, 2000). It is more prone to frost than other winter pulse crops and is not fit for areas having high temperature or year round humidity and heavy rainfall because of high susceptibility to drought and damping off.

Sulphur is considered to be fourth major element essential for plant growth and development because of its requirement for crop production comparable to phosphorus and its requirement being high in oilseeds and legumes but it is sometimes considered as forgotten secondary nutrient in crop production (Bharathi and Poongothai, 2008). Among the families of crop plants, the requirement decreases in the order: cruciferaceae > leguminaceae > gramineae and the sulphur content in

seeds of these crops varies from 1.10 to 1.70, 0.24 to 0.32 and 0.12 to 0.20 percent respectively (Singh, 2001). Sulphur has been found to be an indispensable element for higher pulse production and it is an integral part of proteins, sulpholipids, enzymes etc (Das and Misra, 1991), besides it is involved in various metabolic and enzymatic processes including photosynthesis, respiration and legume-rhizobium symbiotic nitrogen fixation (Rao *et al.*, 2001). Legume crops are more susceptible to sulphur deficiency (Kaisher *et al.*, 2010) and french bean being a legume crop is quite likely to respond sulphur application. The real importance of sulphur has been marked in the recent past due to intensive cultivation with high yielding varieties and the use of complex fertilizers, which led to its deficiency in many farm soils (Islam *et al.*, 1997).

Boron ranks third in place among micronutrients in its concentration in seed and stem as well as in its total amount after zinc (Robinson, 1973). Boron is very important in cell division and in pod and seed formation. Among various micronutrients, boron is unique because of its marked toxicity to plants even when present in relatively small amounts. The range of its sufficiency and deficiency is very narrow and its application in the form of fertilizer is still not in vogue. The critical level of boron with reference to crops in general is reported to be 0.15 to 0.20 ppm depending on soil types (BARC, 2005). But most of the soils are considered to be low in available boron as it has been reported that $< 1 \text{ mg Kg}^{-1} \text{ B}$ is not generally high enough for optimum plant growth (Reisenaure *et al.*, 1973).

Boron deficiency is found to affect plant growth and reduce yields (Carpena *et al.*, 2000; Shaaban *et al.*, 2004) and is one of the major constraints limiting the production of pulse crops (Mani and Haldar, 1996). Recent studies have shown that sulphur deficiency not only decreases the yield but also reduces the quality in grain legumes by changing the gene expression of storage proteins (Bhat, 2006). Parthasharathy (1993) reported that boron and sulphur deficiency can be controlled

with soil application of 1 Kg B ha⁻¹ and 25 Kg ZnSO₄ ha⁻¹. Since deficiency of sulphur (Irwin *et al.*, 2002; Scherer, 2001) and boron (Shorrocks, 1997) occurs worldwide and while scanning the available literature and information with respect to sulphur and boron and their requirements for french bean under temperate conditions of Kashmir valley have not been documented so far and therefore in view of the above considerations and importance of sulphur and boron in pulse production, the present study entitled, *Effect of Different Levels of Sulphur and Boron on Yield and Quality of French bean Var. Contendor in Eutrochrepts* shall be undertaken with following objectives:

1. To study the effect of different levels of sulphur and boron on yield and quality of the crop.
2. To work out a suitable combination of sulphur and boron for optimum yield of the crop.
3. To study the effect on the different forms of sulphur and boron after harvesting the crop.

Chapter – 2

REVIEW OF LITERATURE

The global scenario of the effect of sulphur and boron on crop production and quality vis-à-vis soil fertility has been reviewed and presented in this chapter under various heads:

2.1 Effect of Sulphur on growth, yield and quality parameters

Sulphur has long been recognized as an essential nutrient element for plant and it ranks in importance with nitrogen and phosphorus (Kaisher *et al.*, 2010) but this element received little attention for many years, because fertilizers and atmospheric inputs supplied the soils with adequate amounts. But now the areas of sulphur deficiency are becoming widespread throughout the world due to the use of high analysis low sulphur fertilizers, low sulphur returns with farmyard manure, high yielding varieties and intensive agriculture and reduced atmospheric inputs caused by stricter emission regulations (Scherer, 2001). Sulphur is very essential for the synthesis of amino acids and activity of proteolytic enzymes (Bharathi and Poongothai, 2008). As opined by Khan and Mazid (2011), it has long been known that in regions where sulphur deficient soil occur, legumes specially pulses are particularly responsive to sulphur containing fertilizers and that elementary sulphur or sulphates increase the percentage nitrogen as well as yield on such deficient soils. Understanding the role of sulphur in pulses, growth is important from the point of view that the deficiency of the sulphur containing amino acids cysteine, cystine and methionine may limit the nutritional value of food and feed (Sexton *et al.*, 1998). Studies with *Medicago sativa* indicate that with suboptimum sulphur supply, the mole percent of both cysteine and methionine significantly decreased (Deboer and Duke, 1982), resulting in lower protein concentration (Rendig *et al.*, 1976), while non-protein N is accumulated. Also in *Pisum sativum*, sulphur deficiency resulted in a

decreased synthesis of sulphur containing storage protein albumin and legumin. However, according to Sexton *et al.* (1998) the protein quality of *Glycine max* can be enhanced by increasing the concentration of sulphur containing amino acids. Sulphur is found in amino acids (Cysteine, Cystine and Methionine), oligopeptides (glutathione and phytochelatins), vitamins and cofactors (biotin, thiamine, CoA and S-adenosyl-Met), and a variety of secondary products (Leustek, 2000). French bean can absorb sulphur in great quantities and it is necessary to maintain the relation of nitrogen and sulphur in the plant to produce protein (Hendrix, 1967) and application of Sulphur between 10-20 Kg ha⁻¹ can control sulphur deficiency (Van Schoonhoven and Voysests, 1991).

Juszczuk and Ostaszewska (2011) observed that the leaves of sulphur deficient bean plants had significantly low concentration of chlorophyll a, chlorophyll b and carotenoids. Application of 40 Kg S ha⁻¹ significantly increased the chlorophyll “a” content by 43.9 percent, 25.7 percent and 21.2 percent over the control at branching, flowering, and maturity respectively. A similar trend was also noticed in the synthesis of chlorophyll “b” and total chlorophyll under this treatment throughout the crop growth (Kumawat *et al.*, 2006). Moreover, the improvement in crop growth and yield attributes with sulphur application could be attributed to its pivotal role in regulating the metabolic and enzymatic processes including photosynthesis (Blake-Kalff *et al.*, 1998) and respiration that ultimately results in an increase in yield which is the ultimate test of the performance and efficiency of any crop growth factor (Singh *et al.* 2006).

2.1.1 Effect of sulphur on Growth

Singh *et al.* (1998) reported that application of 90 Kg S ha⁻¹ along with 120 Kg ha⁻¹N, 60 Kg ha⁻¹ P₂O₅ and 10 Kg ha⁻¹Zn to mustard on sandy clay loam soil in Gwalior increased plant height significantly up to 172 cm and number of branches per plant up to 41.4. Kasturikrishna and Ahlawat (1999) reported that the application

of 40 Kg S ha⁻¹ increased plant height in pea over the control. Chaubey *et al.* (2002) reported that number of primary branches and plant height in groundnut were significantly increased by sulphur application. Increase in pea plant height has been observed by Khanna and Gupta (2005) due to application of 30 Kg S ha⁻¹. Application of 40 Kg S ha⁻¹ markedly increased plant height, shoots plant⁻¹ and green forage of sorghum (Jeevan and Singh, 2009). The plant height was significantly influenced by sulphur application in mungbean, the tallest plant (59.39 cm) was found with 30 Kg S ha⁻¹ and further increase in sulphur content decreased the plant height (Kaisher *et al.*, 2010). Similar results were observed earlier by Singh and Yadav (1997) in green gram. In contrary to the above findings Moniruzzaman *et al.* (2008) reported no significant influence on plant height of french bean due to application of sulphur to sand clay loam soil for two years besides, sulphur application at higher dose (30 Kg ha⁻¹) in the 2nd year, decreased plant height significantly.

Dubey *et al.* (1997) reported that application of sulphur to lentil enhanced number of branches plant⁻¹ and number of capsules plant⁻¹. Singh and Yadav (1997) reported that application of 30 Kg S ha⁻¹ was optimum for number of branches per plant in green gram. Similar results were found by Kaisher *et al.* (2010) in mungbean. Increase in number of branches per plant has also been reported due to application of 30 Kg S ha⁻¹ in pea (Khanna and Gupta, 2005). Successive increase in sulphur levels up to 20 Kg ha⁻¹ significantly increased plant height and number of leaves plant⁻¹ in black gram (Khatkar *et al.*, 2007). Application of 10 Kg S ha⁻¹ in french bean significantly influenced number of branches plant⁻¹ (6.20) in first year, but no significant influence was observed in respect of branches plant⁻¹ due to sulphur application in second year (Moniruzzaman *et al.*, 2008). Deficiency of sulphur during the early stages of plant growth resulted in reduced growth of peanut in the later stages (Jamal *et al.*, 2010). Patel *et al.* (2010) revealed that application of sulphur

significantly influenced growth attributes like plant height at 40 days after sowing and at harvest and branches plant⁻¹ green gram.

Juszczuk and Ostaszewska (2011) reported that depression in the growth of sulphur deficient bean plants became apparent after 15 days of initiating the starvation. Generally the growth of the shoots was more affected than roots. The leaf size was reduced and the lamina of the leaves showed wrinkles and curling of the margins forming the characteristic structures. Moreover, youngest leaves became pale and presented loss of the green pigmentation and turned completely yellow. The chlorotic and necrotic spots became visible on the leaf surface. Juszczuk and Ostaszewska (2011) further found that the fresh and dry weights of the bean leaves decreased by about 48 percent in sulphur deficient bean plants. Moreover, growth of the whole shoot was affected by sulphur deprivation.

Singh *et al.* (1988) reported that application of 30-75 Kg S ha⁻¹ increased nodulation in pea. Application of 15 Kg S ha⁻¹ increased nodule number plant⁻¹ in urd bean (Ghosh, 1994). Application of 30 Kg S ha⁻¹ in lentil significantly increased the plant height and number of nodules plant⁻¹ (Singh and Kumar, 1996).

Vishwa *et al.* (1998) reported that the nodule number and weight (Fresh and dry) of nodules plant⁻¹ of soybean increased significantly with 20 Kg S ha⁻¹ application. Growth attributes viz. plant height, number of nodules plant⁻¹ and dry weight of nodules significantly increased with the increasing levels of sulphur up to 40 Kg ha⁻¹ in Chick pea (Singh *et al.*, 2004a). Increased root nodulation and number of nodules plant⁻¹ was observed due application of 15 Kg S ha⁻¹ in garden pea (Khanna and Gupta, 2005). The application of sulphur in the form of pressmud enhanced the yield and nodulation of pea (Singh *et al.*, 2005). Application of 20 Kg S ha⁻¹ increased number of nodules plant⁻¹, their fresh and dry weight significantly over lower doses. The increase in number of nodules was 16.6 percent over control and 9.6 percent over 10 Kg S ha⁻¹ (Yadav, 2011).

Number, fresh and dry weight of nodules increased significantly with successive increase in application of sulphur up to 30Kg ha⁻¹ in Soyabean, beyond which plateau reached (Najar *et al.*, 2011), however, the author ascribe this fact to sulphur being the integral component of nitrogenase enzyme which may have improved the nodulation and fixation of N₂ in legume-*Rhizobium* symbiosis. Not only in nitrogenase but also in ferredoxin, which play vital roles in N₂ fixation, are rich in sulphur and contain Fe-S clusters (Duke and Reisenauer, 1986; Ali *et al.*, 2004). Similar findings have been reported earlier by Ganeshamurthy and Reddy (2000) in Soyabean. Besides the above role of sulphur in nodulation, Jamal *et al.* (2010) confirmed that the activities of nitrate reductase and ATP sulphurylase were maximum during different growth stages of the crop in the presence of sulphur glass fritz as a source of sulphur, these reports were in consistent with the findings of Jamal *et al.* (2006) in groundnut and Ahmad *et al.* (2007) in *Psoralea corylifolia* when applied with calcium sulphate (gypsum) as a source of Sulphur. On the other hand, it reflects that sulphur deficiency results in a reduction of nitrate reductase activity which in turn leads to accumulation of amino acids in a variety of plants (Reuveny *et al.*, 1980; Hue *et al.*, 1991; Migge *et al.*, 2000; Prosser *et al.*, 2001). This could be due to the feedback repression of nitrogen fixation (Janssen and Vitosh, 1974). Meanwhile, Lang (1998) also suggested that sulphur affects leguminous species through its influence on N fixation by *Rhizobium* species. Similar observations of Jamal *et al.* (2010) strongly support the view that biological N₂ fixation, nodulation and yield of peanut are reduced with sulphur deficiency.

2.1.2 Effect of sulphur on yield

It is well known fact that reproduction is the premier process which has a direct bearing on yield of the crop. Sulphur has a definite role in reproduction process which may be perceived from the finding of Fismes *et al.* (2000) who reported that the Plants grown on sulphur deficient soils have suppressed development of

reproductive organs in rapeseed which may even lead to pod abortion. Reproductive growth and the proportion of the reproductive tissues in total dry matter are significantly increased with the application of sulphur during pod development (MacGrath and Zhao, 1996). The deficiency of sulphur at the early vegetative growth stage causes severe reduction in biomass production, while its deficiency at the reproductive stage drastically reduces flowering, prevents anthesis, and reduces pod settings, seed numbers, and test weights, thereby reducing yield and quality of crops (Singh, 2001). Kasturikrishna and Ahlawat (1999) observed that the application of 40 Kg S ha⁻¹ increased number of pods plant⁻¹ in pea over the control. One of the important yield attributing character of legumes is number of pods per plant and sulphur exerts a significant effect on the number of pods per plant as was seen in mungbean by Krishna (1995). Singh (1995) reported that yield and yield attributing characters of pea were increased with increasing rate of sulphur application. Mandal *et al.* (2003) reported that application of sulphur significantly increased number of seeds per pod in Green gram. Biswas *et al.* (2004) reported 44 percent yield improvement in pea with the application of 30-45 Kg S ha⁻¹ over control. Increases in growth and yield related attributes of pea was observed with increasing levels of sulphur and highest yield was achieved with 30 Kg S ha⁻¹ (Chaubey and Singh 2004). Sasode (2008) observed that application of sulphur significantly increased yield of Green gram. Kaisher *et al.* (2010) found similar results by the application of 30 Kg S ha⁻¹ in mungbean. Patel *et al.* (2010) revealed that application of 30 Kg ha⁻¹ gypsum significantly influenced both seed and straw yield of green gram. Singh and Yadav (1997) observed that the seed weight of the summer mungbean was significantly improved by sulphur application. Similar results were observed by Kaisher *et al.* (2010) in mungbean. The presence of sulphur maximizes the seed and oil content of oilseed crops (Ahmad *et al.*, 2007; Fazli *et al.*, 2008).

Sulphur application in legumes has invariably resulted in increased pod production (Jain *et al.*, 1984). Sulphur fertilization improves both yield and quality of crops if adequate supply in the field is ensured (Hocking *et al.*, 1987). Marked increase in seed yield in pea was observed due to sulphur applications (Singh and Singh, 1992). Application of 40 Kg S ha⁻¹ increased seed yield in green gram (Sharma and Shrivastava, 1993). Mishra *et al.* (1995) while studying the effect of sulphur (0, 30, 40 and 60 Kg ha⁻¹) through elemental sulphur, pyrite and gypsum on straw and grain yield of chickpea reported that application of 60 Kg S ha⁻¹ increased grain yield of chickpea. Ghosh *et al.* (1996) reported that application of 20 Kg S ha⁻¹ in black gram increased seed yield. The number of pods plant⁻¹, test weight, seed yield and straw yield of lentil increased significantly with the increasing levels of sulphur up to 30 Kg S ha⁻¹ over control (Singh and Kumar 1996). Dubey *et al.* (1997) reported that sulphur application enhanced the seeds capsule⁻¹, and 1000-grain weight of lentil. Increased dose of sulphur application enhanced yield related components in mustard (Patil and Sheike 1998). Singh *et al.*, (1998) reported that application of 90 Kg S ha⁻¹ along with 120 Kg N + 60 Kg P₂O₅ and 10 Kg Zn ha⁻¹ significantly increased number of seeds pod⁻¹, test weight of grains, seed and stover yield in mustard. Kasturikrishna and Ahlawat (1999) found that the application of 40 Kg S ha⁻¹ significantly increased dry matter, number of grains pod⁻¹ and test weight of seeds in pea. Increase in number of pods plant⁻¹, seed yield and shoot dry weight in pea was reported by Zhao *et al.* (1999) with sulphur application. Shivran *et al.* (2000) observed that application of 30 Kg S ha⁻¹ exhibited favourable response on growth and yield of pigeon pea. Tondon and Mersick (2001) reported that there was 5.3 percent increase in yield of chick pea by applying sulphur in sulphur deficient areas. Budhar and Tamilselvan (2001) while studying the effect of different levels of sulphur (10, 20, 40 and 50 Kg S ha⁻¹) on yield components of rainfed green gram, reported that 40 Kg S ha⁻¹ prominently increased the pods plant⁻¹, number of grains

pod⁻¹ and test weight of grains. Chaubey *et al.* (2002) concluded that number of pods plant⁻¹ and kernel weight of ground nut were significantly increased with the application of sulphur to the crop. Shankaralingappa *et al.* (2002) reported that application of 40 Kg S ha⁻¹ increased number of pods per plant, grain yield and seed weight in pigeon pea. Increased rate of sulphur application exhibited an increase in the number of pods plant⁻¹, number of seeds pod⁻¹, test weight of seeds and grain yield in pea (Malik and Abraham, 2003). Prasad and Prasad (2003) while studying the effect of sulphur (0,10,20, 30 ad 40 Kg S ha⁻¹) on the dwarf and tall cultivars of field pea reported that grain yield, number of pods plant⁻¹ number of grains pod⁻¹ and grain weight plant⁻¹ exhibited an increase with the increase in sulphur levels up to 30 Kg ha⁻¹. Singh *et al.* (2004a) reported that number of pods plant⁻¹, 1000-grain weight, seed and straw yield increased significantly with the increasing levels of sulphur up to 40 Kg ha⁻¹ in chick pea. Singh and Singh (2004) observed that the dose of sulphur significantly increased the grain, straw and total produce of black gram. Yield and yield attributes of pea increased with increasing rates of sulphur fertilizer (Ramesh *et al.*, 2004). Increase in number of branches, fresh and dry weight of plant, pod size, seed number per pod, fresh pod yield, pod dry weight and seed weight has also been reported with the application of 30 Kg S ha⁻¹ in pea (Khanna and Gupta, 2005). The pod yield of groundnut responded significantly to different levels of sulphur application (Jena *et al.*, 2006). Jena *et al.* (2006) reported that the yield response in groundnut ranged from 13.8 to 20 Kg Kg⁻¹ sulphur and decreased with increasing levels of sulphur application. Zizala *et al.* (2008) reported that application of 45 Kg S ha⁻¹ increased the yield and yield attributing characters of mustard. Application of 40 Kg S ha⁻¹ markedly increased dry matter yield of sorghum (Jeevan and Singh, 2009). The yield and bio-chemical composition of seeds in black gram improved favourably with increasing levels of sulphur (Kumar and Singh, 2009).

2.1.3 Effect of sulphur on quality

Besides quantitative effects, sulphur influences the qualitative parameters in legumes of which the effect on the protein content is explicit and worth mention. Application of sulphur increased protein content in pea (Gupta and Gupta, 1972). Aulakh *et al.* (1980) and Singh *et al.* (2000) reported an increase of protein content in grains of oilseeds and pulses due to increase in sulphur content. Kamat *et al.* (1981) observed that application of 30 Kg S ha⁻¹ increased the protein content of grains in green gram. Application of sulphur increased the starch content of potato (Ramamurthy and Susheela, 1981). The seed protein content was increased due to application of 45 Kg S ha⁻¹ in pea (Singh *et al.*, 1988). Application of 40 Kg S ha⁻¹ in chick-pea improved the protein content (Singh and Ram 1989). Aulakh and Pasricha (1997) reported that application of sulphur increased the protein content of mungbean. Singh and Yadav (1997) reported 30 Kg S ha⁻¹ as appropriate for seed protein. Application of sulphur improved protein and vitamin content in various vegetable crops including pea (Dhar *et al.*, 1999). Improvement in protein quality of pulses due to sulphur application was observed by Shahi *et al.* (2002). Improvement in protein content was observed with the application of 30 Kg S ha⁻¹ in groundnut (Venkatesh *et al.*, 2002). Singh and Singh (2004) observed that as the levels of sulphur increased from 0 to 30 Kg ha⁻¹ in black gram, there was a significant effect on protein content in grain and after that the content decreased. Khanna and Gupta (2005) reported that application of 30 Kg S ha⁻¹ increased protein content, carbohydrates and vitamin C content in green pea seeds. Increasing level of sulphur up to 60 Kg ha⁻¹ significantly increased the protein content (37.26 percent) in soyabean seed (Singh *et al.*, 2006). Sasode (2008) reported that application of sulphur significantly increased protein content of green gram. Application of 45 Kg S ha⁻¹ increased the protein content in mustard (Zizala *et al.*, 2008). Kumar and Singh (2009) reported that increased rate of sulphur application markedly increased the

protein, Cytine, Cystein, methionine and carbohydrate content of seeds in black gram. Application of 40 Kg S ha⁻¹ increased crude protein content in Sorghum (Jeevan and Singh, 2009). Deshbhratar *et al.* (2010) reported that application of 20 Kg S ha⁻¹ increased protein content of pigeon pea. Kaisher *et al.* (2010) also found the highest protein content in mungbean with the application of 30 Kg S ha⁻¹ which was attributed to the enhanced synthesis of sulphur containing amino acids (cystine, cysteine and methionine). Patel *et al.* (2010) revealed that application of sulphur significantly influenced quality of green gram in terms of protein content. Bharose *et al.*, 2011 reported that application of 40 Kg S ha⁻¹ significantly increased protein and oil content in toria.

2.1.4 Effect of sulphur on nutrient content and uptake of nutrients by crop

Application of sulphur as elemental sulphur and nitrogen to calcareous soils resulted in a pH drop from an initial value of 9.08 to 7.68 (Motior *et al.*, 2011) which is due to the oxidation of elemental sulfur and subsequent production of acid resulted in a reduction in the pH in all the soils relative to the original soil. Moreover reduction in soil pH significantly increased the availability of micronutrients as well as plant dry matter yield (Motior *et al.*, 2011). Thus in addition to supplying sulphur as a nutrient, sulphur compounds are also used as soil amendments. These compounds act as soil acidifiers which neutralize CaCO₃ resulting in lowering of soil pH and improved nutrient availability in the soil (Motior *et al.*, 2011). Sulphur deficiency decreased the concentration of N in the shoots of many legumes (Andrew, 1977). Tiwari *et al.* (1985) reported that application of 60 Kg S ha⁻¹ increased yield, uptake and concentration of sulphur in lentil. Aulakh and Pasricha (1979) observed that fertilization with sulphur increased the sulphur content of pulses. Significant increase in sulphur uptake was observed due to application of 90 Kg S ha⁻¹ in pea (sharma and Kamath, 1991). Singh and Ram (1989) found that sulphur application increased nutrient content and uptake in chick pea significantly up to 120 Kg S ha⁻¹

both in grain and straw. Singh and Singh (1992) reported that increasing rate of sulphur application markedly influenced the nutrient content and uptake of N, P, K and S in pea. Increasing rate of sulphur application in groundnut increased uptake of N, P, K and S whereas P uptake was decreased at higher levels (Jena *et al.*, 2006). Hoffmann *et al.* (2004) concluded that neither the concentration of sulphur in the leaves nor the sulphur uptake of beet or tops increased with sulphur application. In contrast, field grown oil seed rape responded to sulphur application with increasing sulphur concentration in the leaves. This might be due to the higher sulphur demand of oil seed rape compared to that of sugar beet, which could not entirely be met by soil sulphur supply.

Kasturikrishana and Ahlawat (1999) reported that application of 40 Kg S ha⁻¹ in pea markedly increased the available sulphur in soils, N and S contents in pea grains and uptake of N, P, K, S and Zn. Application of sulphur increased the concentration of nitrogen in the shoots of pea (Zhao *et al.*, 1999). Application of 120 Kg S ha⁻¹ as elemental sulphur in groundnut significantly increased uptake of N, P, K, Ca and Mg (Tathe, 2008).

Venkatesh *et al.*, (2002) reported that application of 30 Kg S ha⁻¹ increased S uptake in groundnut. The uptake of N, K and S increased with increasing levels of sulphur application, whereas, P uptake was decreased at highest level (Marok and Dev, 1980). The available sulphur in the soil increased with sulphur level (Jena *et al.*, 2006). Jeevan and Singh (2009) reported that application of 40 Kg S ha⁻¹ in sorghum increased uptake of N and S. Increasing rate of sulphur application increased S-content and uptake in rye and wheat (Sharma *et al.*, 2009). B harose *et al.*, 2011 reported that application of 40 Kg S ha⁻¹ increased the nitrogen phosphorus and potassium concentration in toria.

Bharathi and Poongothai (2008) reported that application of 45 Kg S ha⁻¹ in maize increased the uptake of N, P, K and nutrient contents and available sulphur in

post-harvest soil. Application of sulphur increased the utilization of soil sulphur when the sulphur levels were low and at higher levels the uptake from soil sulphur was reduced and obviously more and more fertilizer sulphur was taken up. The percentage of S and P in plants varied significantly with the application of sulphur (Acharya, 1973). Zizala *et al.* (2008) reported that sulphur content (seeds and straw) and total sulphur uptake (seeds and straw) increased with the increasing sulphur levels up to 45 Kg ha⁻¹ in mustard.

Tripathi and Sharma (1993) observed that there was a slight decrease in pH with the increasing doses of sulphur. The decrease in soil pH and increased available sulphur was observed with sulphur application (Kher and Singh, 1993). Aulakh and Chibba (1992) observed that there is a significant negative relationship between the soil pH and the available sulphur content in the soil. Soil pH drops with the addition of elemental sulphur (Motior *et al.*, 2011). Similar results were also observed by Lopez-Aguirre *et al.* (1999) who found that addition of varying levels of sulphur (0, 0.5, 1.0 and 2.0 mg Sg⁻¹ of soil) in alkaline tropical soil, lowered the pH from 8.5 to 7.2 at 45 days after incubation.

Tripathi and Sharma (1993) observed a slight decrease in EC with the increasing levels of sulphur. A highly significant and positive correlation between electrical conductivity and sulphur was observed. (Ram *et al.*, 1993). Electrical conductivity (EC) was significantly and positively correlated with sulphur (Ghai, 1980).

Singh *et al.*, (1991) reported that organic carbon showed significant positive correlation with sulphur. Application of sulphur increased the organic carbon (Kher and Singh 1993). Ram *et al.* (1993) observed significant and positive relationship of organic carbon and different forms of sulphur.

The application of sulphur significantly affects various nutrient ratios in stover and seed of legume plants. Najjar *et al.* (2011) observed that N:S and P:S ratio

was maximum in seed than stover of soybean, whereas K:S, Ca:S and Mg:S ratio were maximum in stover with different treatments. Increasing levels of sulphur significantly decreased the entire ratio except P:S ratio which increased with increasing levels of sulphur up to 20 Kg S ha⁻¹ and thereafter decreased. The maximum N:S, K:S, Ca:S and Mg:S ratio were recorded under control whereas minimum with the application of 40 Kg S ha⁻¹ in stover and seed. However, P:S ratio in stover recorded maximum under 20 Kg S ha⁻¹. Decreasing various nutrient ratios in stover and seeds of soybean with increasing levels of sulphur may indicate the sulphur requirement for higher productivity of soybean in sulphur deficient soil. Moreover, adequate availability of sulphur may also help in mineralization of nutrients, as sulphur is the integral part of sulphur containing amino acids which is essential for growth and development of microorganisms that may lead to an increase in the concentration and uptake of macro and secondary nutrients by soybean (Saini *et al.* 2005).

Najar *et al.* (2011) reported that the uptake of N, P, K, S, Ca and Mg by soybean was recorded maximum with the application of 40 Kg S ha⁻¹ over rest of the treatments but at par with 30 Kg S ha⁻¹, although the increasing levels of sulphur increased the uptake of these elements significantly when compared to control. The author owes it to high production of stover and seed yield and increase in the content of these elements in stover and seed due to S application at 40 Kg ha⁻¹. These results corroborate the findings of Shrivastava *et al.* (2000) and Nasreen and Farid (2006).

Regarding nutrient uptake pattern as conditioned by the application of sulphur the findings of Motior *et al.* (2011) revealed that uptake of N, P and S increased which corroborate the findings observed time and again by the scientific community.

2.2 Effect of boron on Growth, yield and quality parameters

Essentiality of boron was established by Warington (1923) who showed not only that field bean (*Vicia faba*) died when boron was not supplied in the nutrient solution but that boron was needed for revival. Boron deficiency is particularly prevalent in light textured soils, where water-soluble boron readily leaches down the soil profile and becomes unavailable for plants (Walsh and Golden, 1953). Boron deficiency may also occur on a soil with adequate boron level if its uptake is impeded by over liming, dry or wet soil conditions, and a low level of soil oxygen (Goldberg, 1997; Wojcik, 2003). Adequate boron nutrition is critical not only for high yields but also for high quality of crops. Boron deficiency causes many anatomical, physiological, and biochemical changes, most of which represent secondary effects (Blevins and Lukaszewski, 1998). Boron is an essential nutrient required for higher plants (Marschner, 1995). Boron has been found to play a key role in reproductive processes affecting anther development, pollen germination, and pollen tube growth (Loomis and Durst, 1992; Robbertse et al., 1990). For this reason, in boron-sensitive crops abortion of flower initials and poor set of fruit or seeds are observed under conditions of boron deficiency (Goldbach, 1997; Mozafar, 1993). The primary effect of boron deficiency appears to be the disruption of the normal functioning of the apical meristems with changes in membrane structure, cell wall synthesis, metabolism of auxin, carbohydrate, ascorbate, and RNA, and lignifications, phenol accumulation and sucrose transport being secondary effects (Parr and Loughman, 1983; Blevins and Lukaszewski, 1998; Brown et al., 2002).

2.2.1 Effect of boron on growth

Application of boron in cow pea significantly increased growth parameters (Hassanein *et al.*, 1999). Bonilla *et al.* (2004) observed that application of boron increased seed germination, root elongation, plant development and mineral composition of pea in saline soils. Yang *et al.* (1998) observed that addition of boron

increased mungbean seedling height. Kaisher *et al.* (2010) reported similar effect on plant height of mungbean and the tallest plant was found with a dosage of 5 Kg B ha⁻¹ beyond which the plant height decreased. Besides plant height, boron affects number of branches per plant in legumes. Kaisher *et al.* (2010) reported highest number of branches per plant in mungbean by applying 5 Kg B ha⁻¹.

Bolanos *et al.* (1996) observed that in boron-deficient pea nodules, the number of infected host cells was much lower than in sufficient controls. Host cells in boron-deficient plants developed enlarged and abnormally shaped infection threads, which frequently burst. Binding of the plant matrix glycoprotein to the cell surface of *Rhizobium leguminosarum* was inhibited by the presence of borate in the incubation buffer. The authors proposed that binding of matrix glycoprotein in the absence of boron may block the interaction between bacterial cell surface and the plant membrane glycocalyx. Developing soybean root nodules were more sensitive to low boron nutrition than large fully developed nodules (Yamagishi and Yamamoto, 1994). Bolanos *et al.* (1994) reported that boron application increased the number, size and weight of nodules in pea. Garate *et al.* (1993) reported that the application of boron increased plant weight and number of nodules in pea. Deficiencies of soil nutrients such as N, P, B and Mo may limit the development of population of free living rhizobia in the rhizosphere, reduce nodule formation, nitrogenase activity and growth of many legumes (Sanginga *et al.*, 2001). Application of boron enhanced nodule development in pea (Azevedo *et al.* 2002). The nodule development in pea was promoted with the boron application under salt conditions (Hamdaoui *et al.*, 2003). Field studies revealed that deficiency of boron cause considerable reduction of growth, nodulation and yield of mungbean (Howeler *et al.*, 1978). The deficiency of these nutrients has been very pronounced under multiple cropping systems due to excess removal by high yielding varieties of crops and hence their exogenous supplies are indispensable (Shil *et al.*, 2007). Yakuba *et al.* (2010) concluded that

application of 0.5 Kg B ha⁻¹ significantly increase nitrogen fixation in cowpea, groundnut and bambara groundnut. Based on all the morphological attributes of pea measured by Mehmood *et al.* (2011), it is concluded that boron plays significant positive role in nodule development up to a certain threshold value, above and below that value it has negative impact on all the parameters of nodulation.

2.2.2 Effect of boron on yield

Micronutrients play an important role in increasing yield of pulses and oilseed legumes through their effects on the plant itself and on the nitrogen fixing symbiotic process (Shil *et al.*, 2007). Singh *et al.* (1992) reported that application of 10 Kg B ha⁻¹ increased yield of vegetable pea. Increase in grain (8.76 q ha⁻¹) of gram was observed with application of 1Kg B ha⁻¹ to sandy loam soil (Singh *et al.*, 2004b). Application of boron increased pod yield in pea (Jana and Paria 1996). Application of boron in cow pea significantly increased yield components (Hassanein *et al.*, 1999). Prasad *et al.*, (1998) reported that foliar application of 2.5 Kg borax ha⁻¹ increased yield of pea. Highest yield of pea was observed with 1.5 Kg B ha⁻¹ along with 3.0 tons lime stone ha⁻¹ (Dwivedi *et al.* 1992). Singh *et al.* (2002) reported that increasing levels of boron application as borax up to 4 Kg ha⁻¹ in pea and black gram increased the grain yield.

Boron has a marked effect on the number of grains per pod as seen by the application of borax in green gram (Rerkasem and Jamjod, 1997). Similarly, the work of Kaisher *et al.* (2010) revealed that the highest number of grains per pod in mungbean was obtained with 5 Kg B ha⁻¹. Test weight in pulses is also affected by the application of boron as observed in mungbean by Zaman *et al.* (1996). Kaisher *et al.* (2010) obtained the maximum test weight of summer mungbean by the application of 5 Kg B ha⁻¹. In french bean, boron application increased pod weight per plant (109.1 g) significantly up to 1.5 Kg B ha⁻¹ in first year but in second year pod weight increased up to 1.0 Kg B ha⁻¹ beyond which it declined (Moniruzzaman *et al.*, 2008).

Bharti *et al.* (2002) reported that mean seed yield of chickpea increased with the application of 2.5 Kg B ha⁻¹. Islam (2005) observed that seed yield of Chickpea (cv. BARI chola 5) increased significantly due to application of 1 to 1.5 Kg B ha⁻¹. With the application of boron and molybdenum in Chickpea, boron principally contributed to yield and the crop performed better with subsequent higher doses up to 2.5Kg B ha⁻¹ (Shil *et al.*, 2007).

2.2.3 Effect of boron on quality

Pratima *et al.* (1999) reported that the lower levels of boron application increased the concentration of sugars, starch, and proteins in pea seeds. The application of lower concentration of boron increased the reducing sugars, sucrose polysaccharides and total carbohydrates in cow pea (Zaky *et al.*, 1999). Increasing levels of boron application significantly improved the protein content in lentil (Kushwaha *et al.*, 2009). Among the qualitative parameters, boron influences the protein content of the pulses. The maximum protein content (37.79 percent) in seed was recorded in soyabean with the application of 40 Kg S ha⁻¹ in combination with 0.5 Kg B ha⁻¹ (Singh *et al.*, 2006). Kaisher *et al.* (2010) reported significant influence on the protein content of mungbean and highest protein content was associated with 5 Kg B ha⁻¹.

2.2.4 Effect of boron on nutrient content and uptake of nutrients by crop

Singh *et al.* (2004c) reported that application of boron (1Kg ha⁻¹) increased the boron content, boron uptake and soil available boron in groundnut and pigeon pea. Application of 2 Kg B ha⁻¹ in soyabean grown on coarse textured soil of Jharkhand significantly enhanced uptake of boron up to 198.72 g ha⁻¹ (Singh *et al.*, 2006).

Hassanein *et al.* (1999) reported that application of boron increased the contents of P, K, Na, Ca, Fe, Mn, Zn, Cu and B in cowpea seeds. Boron content in different parts of pea plants increased with increasing boron concentration. (Zhang *et*

al., 1997). Application of boron enhanced the N content in roots and shoots of pea plant under salinity conditions (Bonilla *et al.*, 2004).

Patel and Golakiya (1986) reported that boron application up to $2\mu\text{g g}^{-1}$ soil increased the uptake of N, P, K, Fe, Cu and B. Application of 1.0 Kg B ha^{-1} in gram grown on sandy loam soil increased B uptake (34.05 g ha^{-1}) in grain while as 2.0 Kg B ha^{-1} markedly enhanced the availability of boron in soil at harvest (Singh *et al.*, 2004b). Increasing levels of boron application in lentil significantly increased B uptake and improved available nutrients – N, P, S and B (Kushwaha *et al.*, 2009). Jena *et al.* (2009) reported that application of boron decreased the pH of soil.

2.3 Suitable combination of S and B for optimum crop performance

Nasreen and Farid (2003) reported that combined application of sulphur and boron markedly improved the growth and yield related attributes of pea. Application of 60 Kg S ha^{-1} along with 1 Kg B ha^{-1} significantly increased seed yield (1.83 t ha^{-1}) and stover yield (3.0 t ha^{-1}) of soyabean (Singh *et al.*, 2006). Increase in yield due to S and B application has also been reported in legume and oilseed crops by several workers (Misra 2001 and Sakal *et al.*, 1988).

Kaisher *et al.* (2010) reported that combined application of 30 Kg sulphur and 5Kg boron ha^{-1} significantly increased plant height, number of branches plant^{-1} , number of pods plant^{-1} , number of seeds pod^{-1} , 1000-seed weight and seed yield of mungbean. Yang *et al.*, (1998) reported that combined application of sulphur and boron markedly increased growth and yield related attributes of mungbean. Sarker *et al.* (2002) reported that combined application of 30 Kg S ha^{-1} and 1Kg B ha^{-1} to silty loam soil increased seed yield up to 23.01 q ha^{-1} and straw yield up to 31.10 q ha^{-1} in soybean significantly. The increase in yield and yield related attributes of french bean was reported due to combined application of N, P, K, S, Zn and B in the ratio of 120 : 120 : 60 : 20 : 4 : 1 (Moniruzzaman *et al.*, 2008).

Karthikeyan and Shukla (2008) reported that application of 60 mg Kg^{-1}

sulphur along with 2 mg Kg⁻¹ boron significantly increased dry matter and seed yield of mustard and sunflower grown on Typic Haplustalfs of India. Combined application of 80 Kg S ha⁻¹ and 2.5 Kg B ha⁻¹ significantly increased dry matter, grain yield, oil and protein content of canola (Nadian *et al.*, 2010).

Singh *et al.* (2006) reported that application of 40 Kg S ha⁻¹ in combination with 0.5 Kg B ha⁻¹ significantly increased the protein content in soybean. An increase of protein content in grains pulses was observed due to application of sulphur and boron (Singh *et al.*, 2000). The oil and protein contents of sun-flower and mustard were significantly improved by the application of sulphur and boron (Karthikeyan and Shukla 2008).

Kaisher *et al.* (2010) reported that application of 30 Kg S ha⁻¹ along with 5 Kg B ha⁻¹ significantly increased the protein content of mungbean. Combined application of 50 Kg S ha⁻¹ and 1 Kg B ha⁻¹ increased the protein up to 43.5 percent in soyabean (Sarker *et al.*, 2002). Chakraborty and Das (2000) reported that the protein content in mustard seeds was significantly influenced by the combined application of 3 Kg B ha⁻¹ and 60 Kg S ha⁻¹. Chakarboty and Das (2000) reported that sole as well as combined application of sulphur and boron increased the S and B content in mustard seeds. Combined application of sulphur (40 Kg ha⁻¹) and boron (2 Kg ha⁻¹) increased the uptake of sulphur (18.10 Kg ha⁻¹) and boron (224.19 g ha⁻¹) in soyabean grown on coarse textured soil of Jharkhand (Singh *et al.*, 2006). The combined effect of boron and sulphur significantly increased the concentration of sulphur in the seeds of sun-flower and mustard (Karthikeyan and Shukla, 2008).

The combined application of S and B in rape seed increased the nutrient content (S and B) and improved nutrient uptake at pod formation stage. A positive and significant relationship of organic carbon and sulphur and boron was observed (Bandyopadhyay and Chattopadhyay 2000). The highest boron uptake (116 g ha⁻¹) was achieved by the combined application of 20 Kg S ha⁻¹ and 4 Kg B ha⁻¹ while as

highest sulphur uptake (9.89 Kg ha^{-1}) was achieved by the combined application of 10 Kg S ha^{-1} and 1 Kg B ha^{-1} in Soyabean (Sarker *et al.*, 2002).

Prasad *et al.*, (1998) reported that the net returns were higher with the foliar application of $2.5 \text{ Kg borax ha}^{-1}$ in pea crop. The maximum net profit was achieved with the application of $10 \text{ Kg tetraborate ha}^{-1}$ in vegetable pea (Singh *et al.*, 1992). Singh *et al.*, (2004c) reported that application of 2.5 mg B Kg^{-1} in pigeon pea significantly increased the gross income and net profit.

Biswas *et al.* (2004) reported that the economic returns from sulphur fertilizer use were very attractive and benefits were much more when the residual effect on succeeding crops were also taken into account. Application of 30 Kg S ha^{-1} in pea significantly increased the gross income and net profit (Prasad and Prasad, 2003).

On the basis of results drawn under the agro-climatic conditions of Varanasi (Uttar Pradesh) by Kumar *et al.* (2009) it may be recommended that in addition to N, P and K, sulphur at 20 Kg ha^{-1} along with vermicompost at 1850 Kg ha^{-1} should be added to the crop to get economically better results from french bean.

2.4 Effect of sulphur fertilization on nutrient content and forms of sulphur in soil.

Knowledge of different forms of sulphur throughout root zone is essential for improving sulphur nutrition of crops. Sulphur status varies with depth depending upon particle size distribution, soil reaction, redox potential, free iron and aluminium oxides, moisture regime, biomass content *etc.* In addition, physiography through its influence on drainage, leaching, type of vegetation and profile development play an important role towards sulphur availability. Sulphur in soils is present in both inorganic and organic forms and the proportion of inorganic to organic sulphur varies widely depending upon the nature of soil, its depth and management factors to which the soil is subjected. The common forms of inorganic sulphur in soils are (1) water soluble sulphur (2) adsorbed sulphate (3) insoluble sulphates and (4) sulphides or

other reduced forms of sulphur. Distribution of different forms of sulphur and their interrelationship with some important soil characteristics decide the sulphur supplying power of a soil by influencing its release and dynamics in soils. Several other soil factors also influence the availability of sulphur and hence the status of different forms of sulphur in soils varies widely with soil type.

2.4.1 Inorganic sulphur

Sulphate present in soil is either water soluble or in adsorbed form, the latter depends on soil characteristics such as content of iron oxide/hydroxide and pH. The sulphate fraction generally accounts for less than 5 per cent of the total sulphur in soil. Various methods have been proposed to evaluate the amounts of soil sulphur available for plant uptake. Most of the methods for soil sulphur testing involve extraction of soil with a weak salt solution, e.g. CaCl_2 , KCl , $\text{Ca}(\text{H}_2\text{PO}_4)_2$ or KH_2PO_4 . Phosphate containing extractants are used to extract both water-soluble and adsorbed sulphate, whereas, Cl-based extractants mainly for water-soluble sulphate. In calcareous soils, sulphate may also be present in insoluble form due to co-precipitation with CaCO_3 .

Lande *et al.* (1977) while working on sulphate sulphur content in soils of Marathwada region reported that sulphate sulphur varied from 8.4 to 42.0 ppm with an average of 15.9 ppm in normal soils and 117.6 to 144.0 ppm with a mean of 132.5 ppm in saline soils. The amount of sulphate sulphur contributed very small fraction (0.92 percent) to total sulphur. Dolui and Nayek (1981) found that the amount of sulphate sulphur ranged from 0.4 to 28 ppm with an average value of 7.22 ppm in some soils of West Bengal. Its content had no regular trend in its distribution throughout the individual profiles as percentages of total sulphur. Dolui and Saha (1983) reported that sulphate sulphur in soils collected from different agro-climatic regions of West Bengal, ranged from 0.5 to 130.0 ppm with an average value of 19.0 ppm and it accounted for 0.1 to 14.4 per cent of total sulphur. The lowest values of

sulphate sulphur in Jhargram and Bankura soils was accounted for their location at the tropical region where temperature and moisture conditions could possibly lead to higher mineralization as well as initial formation of sulphides and subsequently oxidized to sulphate form which get lost either due to volatilization or leaching.

Arora *et al.* (1988) reported that the CaCl₂ extractable sulphate sulphur ranged from 5.1 to 46.0 ppm in some Benchmark soils of Panjab. On the basis of 9 ppm as critical limit, 40, 21 and 39 per cent of soils were deficient, marginal and adequate in available sulphur, respectively. Padmaja *et al.* (1993) reported that in some pedons of Vertisols of Andhra Pradesh, inorganic sulphate sulphur content ranged from 8 to 19 ppm. The available sulphur contents in these soils were marginal indicating that there is a need to apply sulphur in near future to meet the sulphur requirement of crops, particularly oilseeds. Available sulphur contents (0.15 percent CaCl₂ extractable) in rice growing Alfisols and Inceptisols of the high rainfall zone of Tamil Nadu ranged from 1.9 to 159.6 ppm with a mean of 25.0 ppm (Joseph *et al.*, 1999). Basumatari *et al.* (2010) reported that sulphate sulphur accounts to about 4.1 percent of total sulphur while working with soils of Assam.

2.4.2 Organic sulphur

The nature and properties of organic sulphur fraction in soils are important since they govern the release of plant available sulphur. Much of the organic sulphur in soils remains uncharacterized and three broad groups of sulphur compounds are recognized viz. HI-reducible sulphur, C-bonded sulphur and residual or inert sulphur. Organic sulphur is a reserve source of sulphur for plants and must undergo mineralization before it becomes available to plants. As sulphur immobilization is a microbial process, it depends on factors like moisture, aeration, temperature soil reaction *etc.* Organic sulphur has been designated as indicator of reserve sulphur status of soil (Kumar and Singh, 1974). An increase in content of organic sulphur with increase in altitude has been reported by Dolui and Bandyopadhyay (1983).

Singh *et al.* (1990) reported that organic sulphur content varied from 5.0 to 168.2 ppm in soils under different agro-climatic regions of Haryana and constituted 5 to 39 per cent of total sulphur in different horizons with an average of 15.9 per cent. The range of organic sulphur content in some soils of Varanasi region of Uttar Pradesh was between 21.45 to 70.00 ppm (Tiwari and Pandey, 1990). Tripathi *et al.* (1997) observed that organic sulphur content varied from 1.2 to 65.0 mg Kg⁻¹ with an average of 14.6 mg Kg⁻¹ while the percent contribution of organic sulphur to total sulphur ranged from 3.1 to 15.5. In a study on vertical distribution of sulphur fractions in two soils series belonging to Alfisols and Entisols of Jharkhand, Kumar *et al.* (2002) noticed that organic sulphur content ranged from 221 to 446 and 76 to 665 mg Kg⁻¹ with mean values of 331 and 425 mg Kg⁻¹ in Entisols and Alfisols respectively. Jat and Yadav (2006) noticed that organic sulphur content in mustard growing Entisols of Jaipur district in Rajasthan ranged from 20.50 to 76.40 mg Kg⁻¹ with a mean value of 154.28 mg Kg⁻¹ accounting about 23.66 percent to the total sulphur content. Basumatari *et al.* (2010) reported that organic sulphur constitutes about 70.3 to 76.3 percent of total sulphur while working with soils of Assam of Sibsagar district.

2.4.3 Total sulphur

The amount of total sulphur present in soils vary depending upon its content in the primary material, organic compounds and sulphate ions adsorbed and present in the soil solution. It occurs largely in organic form in humid and sub-humid soils and in inorganic forms in arid and semi-arid regions with low rainfall where salt accumulation is high. Since India is a sub-continent with a wide variety of tropical climate, soils and different agro-ecosystems, the sulphur contents among and within soil types as well as regions vary to a great extent.

Venkateswarlu *et al.* (1969) studied the vertical distribution of different sulphur fractions in fifteen rice growing soils collected from different Model

Agronomic Experimental Centres. Total sulphur content varied from 112.5 ppm in Nasirpur soil to 275 ppm in Titabar soil in the surface (0-15 cm) samples. Balasubramaniam and Kothandaraman (1985) revealed that total sulphur content in soils of Coimbatore district of Tamil Nadu, ranged from 190 to 5700 ppm. It was observed that soils of Dasarapatti series (black calcareous soils) recorded highest amount of total sulphur and was observed to be due to its gypsiferous nature. Very high values of total sulphur in excess of 1000 ppm (0.1 percent) are generally encountered in problem soils such as saline and acid sulphate soils (Ganeshamurthy *et al.*, 1989). Total sulphur is generally higher in fine textured soils than in coarse textured soils. Generally, soil sulphur content is highest in the top soil and decreases with depth following the distribution of organic matter. However, this pattern does not occur where sulphates and carbonates get accumulated in lower layers.

Ram *et al.* (1993) found that the total sulphur content in rice growing soils collected from 22 fields in districts of Kanpur, Aligarh and Mathura of Uttar Pradesh ranged from 100 to 179 mg Kg⁻¹ with mean values of 153 and 148 mg Kg⁻¹ for surface and subsurface respectively. In a study on vertical distribution of sulphur fractions in two soils series belonging to Alfisols and Entisols of Jharkhand, Kumar *et al.* (2002) noticed that total sulphur content ranged from 282 to 470 mg Kg⁻¹ with a mean value of 370 mg Kg⁻¹ in Entisols while it varied from 141 to 723 mg Kg⁻¹ with an average of 489 mg Kg⁻¹ in soils belonging to Alfisols.

Nega *et al.* (2001) reported that the total sulphur content in a laterite soil of sandy clay loam decreased in long-term fertilizer experiment plots with soil depth and varied from 233.4 to 704.1 ppm at surface and from 203.3 to 386.8 ppm at subsurface soil. Hu *et al.* (2005) reported that 64 soils collected from ten provinces in China varied widely in the amount of total sulphur ranging from 64 to 831 mg Kg⁻¹. Jat and Yadav (2006) noticed that the total sulphur content in mustard growing Entisols of Jaipur district in Rajasthan ranged from 101.30 to 302.40 mg Kg⁻¹ with a mean value

of 154.28 mg Kg⁻¹. The mean content of total sulphur varied from 352 mg Kg⁻¹ soil to 585 mg Kg⁻¹ in Sibsagar district of Assam (Basumatari *et al.*, 2010). Total sulphur in the soils of Assam was positively correlated with organic carbon and clay content which has been reported earlier by Sharma and Jaggi, 2001 and Borkotoki and Das, 2008.

The content of total sulphur increases with increase in organic carbon and finer fractions of the soils (Basumatari *et al.*, 2011). Similar correlation of total sulphur with organic carbon and finer fractions of soil have been reported earlier by Aggarwal and Nayyar (1998), Trivedi *et al.* (1998), Jat and Yadav (2006) and Basumatari *et al.* (2008). When a single rate of sulphate sulphur was applied, the concentration of available phosphorus in soil increased versus the NPK fertilized object. The application of 120 Kg S ha⁻¹ caused a significant decline in the amount of available phosphorus in soil relative all the remaining fertilization objects (Skwierawska and Zawartka, 2009). This decrease in phosphorus content could be due to several factors, viz. transfer of phosphorus to the deeper soil layer 40-80 cm. Meanwhile, in the same experiment the authors observed that in the 40-80 cm soil horizon, the other sulphur rates had little effect on the dynamics of available phosphorus. Besides when the sulphate sulphur was applied as a fertilizer dose, a tendency towards decreasing concentration of available phosphorus in soil appeared.

2.5 Effect of boron fertilization on nutrient content and forms of boron in soil.

Knowledge of different forms of boron throughout root zone is essential for improving its nutrition to crops. Boron status varies with depth depending upon particle size distribution, soil reaction, moisture regime, biomass content *etc.* In addition, physiography through its influence on drainage, leaching, type of vegetation and profile development play an important role towards boron availability. Boron can be considered as existing in five categories in the soil viz. primary minerals such as

tourmaline and B rich micas; Secondary minerals, particularly within the clay mineral lattice; Adsorbed on clays, hydrous oxide surfaces and organic matter; Solution usually as boric acid but also as borate anions and Organic matter and the microbial biomass. Parent material, soil texture, pH, liming and leaching can be viewed as variously influencing B in one or more of these categories.

2.2.1. Total Boron

Total boron content of most agricultural soils ranges from 1 to 467 mg kg⁻¹, with an average content of 9 to 85 mg kg⁻¹. Total boron in major soil orders, Inceptisol and Alfisol, in India ranged from 8 to 18 mg kg⁻¹ (Borkakati and Takkar, 1996). Such wide variations among soils in the total boron content are mainly ascribed to the parent rock types and soil types falling under divergent geographical and climatic zones. Boron is generally high in soils derived from marine sediments. The Indian soils have been reported to contain 3.8-630 mg Kg⁻¹ total boron moreover; Raina *et al.* (2006) found a significant positive correlation between available boron and total boron with a correlation coefficient of 0.87. Similar findings have been reported by Hadwani *et al.* (1989). Kher *et al.* (2006) reported that total boron content of citrus orchard soils of Jammu region range from 5.75-34.60 mg Kg⁻¹ with an average value of 18.30 mg Kg⁻¹.

2.2.2. Available Boron

Available boron, measured by various extraction methods, in agricultural soils varies from 0.5 to 5 mg kg⁻¹. Most of the available boron in soil is believed to be derived from sediments and plant material. Few studies have been conducted to identify solid-phase controls on boron solubility in soils. Most of the common boron minerals are too much soluble for such purposes (Lindsay, 1991).

Hot water soluble boron in benchmark surface soils of India range from 0.07 to 3.62 mg Kg⁻¹ soil with a mean value of 0.70 mg Kg⁻¹ (Sharma and Katyal, 2006). Further Sharma and Katyal (2006) reported that soils with aquatic moisture regime had

the lowest hot water soluble boron with a mean value of 0.56 mg Kg^{-1} . Contrary to this boron may accumulate to toxic levels in the upper soil layer of arid regions (Kanwar and Singh, 1961).

Soil texture shows very little effect on available boron status. However fine textured vertisols and coarse textured entisols contained marginally lower levels of hot water soluble boron compared with the medium textured inceptisols (Sharma and Katyal, 2006) which may be due to pronounced leaching in sandy soils and strong adsorption on fine textured soils.

Chapter – 3

MATERIALS AND METHODS

A field experiment entitled *Effect of different levels of Sulphur and boron on yield and quality of French bean (Phaseolus vulgaris L.) var. Contendor in eutrochrepts* was conducted during *kharif* 2011 at the Research Field of Regional Research Station Wadura Sopore. The details of materials used and methods adopted for experiment are presented as under:

3.1 Location

The field investigation was carried out at the experimental field of Regional Research Station Wadura Sopore which is situated between 34⁰.20' North latitude and 74⁰.24' East latitude at an elevation of 1585.26 meters above mean sea level.

3.2 Climate

The climate of the experimental site is of temperate type with mean rainfall, maximum day temperature and relative humidity during *kharif* 2011 was 14.92 mm, 21.71 °C and 76.65 % respectively. The mean monthly meteorological data pertaining to period of experimentation was taken from agro-meteorological observatory of RRS and FOA Wadura, Sopore and is given in fig 1.

3.3 Soil of the experimental site

The composite soil sample taken at a depth of 0-15 cm before the start of experiment was subjected to mechanical and chemical analysis. The results obtained at the beginning of experiment revealed that soil was clay loam in texture, medium in available nitrogen, phosphorus and potassium and deficit in sulphur and boron with neutral pH and is given in table below.

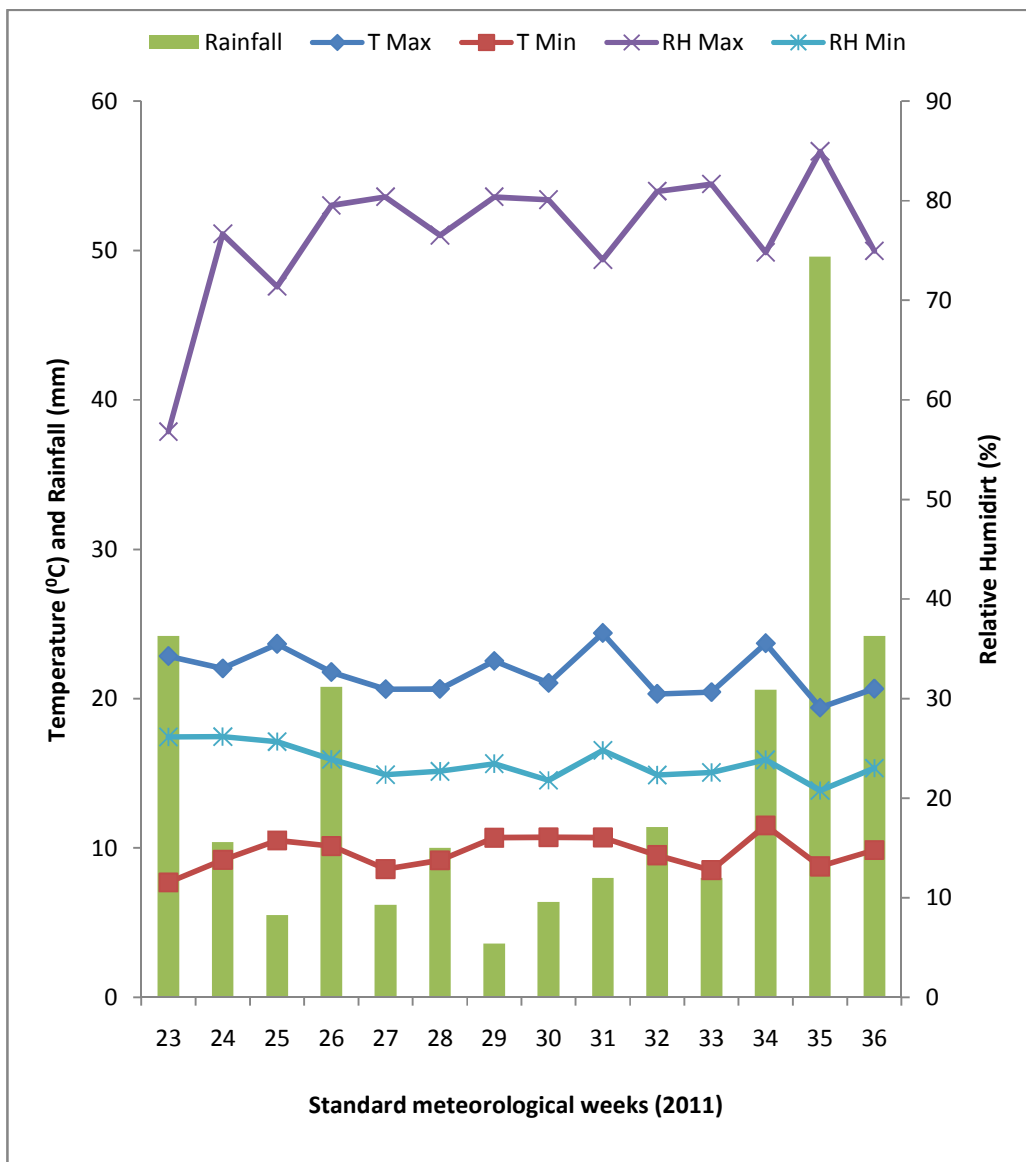


Fig. 1: Mean weekly meteorological data during crop growth period of *kharif* 2011

Table: Physico-chemical properties of soil of the experimental field before sowing.

Particulars	Value	Method employed
Mechanical Characteristics		
Sand (percent)	42.50	International Pipette Method (Piper, 1966)
Silt (percent)	25.25	
Clay (percent)	32.25	
Textural Class	Clay loam	
Chemical Characteristics		
pH	7.02	1:2.5 soil water suspension with Beckman's Glass Electrode pH Meter (Jackson, 1967).
EC (dsm ⁻¹)	0.14	Solubridge Conductivity Meter (Chopra, 1976).
Organic carbon (percent)	1.30	Walkley and Black Rapid Titration Method (Jackson, 1973).
Available N (kg ha ⁻¹)	310.38	Alkaline potassium permanganate method (Subbiah and Asija, 1956).
Available P (kg ha ⁻¹)	21.92	Extraction with 0.5 M NaHCO ₃ (Olsen <i>et al.</i> 1956).
Available K (kg ha ⁻¹)	155.0	Extraction with Neutral Normal Ammonium Acetate (Jackson, 1967).
Available S (ppm)	8.92	Extraction by (Williams and Steinberg, 1959) method and determination by turbidimetric (Chesnin and Yien, 1951) method.
Available B (ppm)	0.56	Azomethine -H method John <i>et al.</i> (1975).
CEC (cmolKg ⁻¹)	15.0	Ammonium acetate method Peech <i>et al.</i> (1947).
CaCO ₃ (percent)	0.22	Rapid titration method (Puri, 1930).

3.4 Experimental material

The seed of French bean cv. Contendor was provided by Department of Plant Breeding and Genetics while as chemical fertilizers, sulphur and boron were provided by Department of Soil Science Regional Research Station and Faculty Agriculture Wadura Sopore.

3.5. Brief description of cultivar used

The cultivar Contendor takes 50-55 days for first picking. Pods are round, green, 13-14cm long, stringless, meaty and slightly curved, seeds light brown. Pod yield is 80-95 q ha⁻¹.

3.6. Experimental methods

3.6.1 Experimental details

Table: The details of the experiment are summarised below:

a)	Design	RBD
b)	Treatments	16
c)	Replications	03
d)	Total number of plots	48
e)	Plot size	3.0 m × 3.0 m = 9.0 m ²
f)	Spacing	30cm × 10cm
g)	No. of rows plot ⁻¹	10
h)	Number of plants plot ⁻¹	300
i)	Crop	French bean
j)	Cultivar	Contendor
k)	No. of observational plants	10

3.6.2 Treatments Details

a)	Sulphur	(Source : Gypsum)
	Levels of sulphur	
	S ₀ : No sulphur	0 kg ha ⁻¹
	S ₁₅ : 15 kg ha ⁻¹	100 kg ha ⁻¹
	S ₃₀ : 30 kg ha ⁻¹	200 kg ha ⁻¹
	S ₄₅ : 45 kg ha ⁻¹	300 kg ha ⁻¹
b)	Boron	(Source : Boric acid)
	Levels of boron	
	B ₀ : No boron	0 kg ha ⁻¹
	B _{0.5} : 0.5 kg ha ⁻¹	2.94 kg ha ⁻¹
	B _{1.0} : 1.0 kg ha ⁻¹	5.88 kg ha ⁻¹
	B _{1.5} : 1.5 kg ha ⁻¹	8.82 kg ha ⁻¹
c)	Treatment combinations	
	Notation	Treatment combination
		Treatments
	T ₁	S ₀ B ₀ (RFD) 30:60:60 N: P ₂ O ₃ : K ₂ O kg ha ⁻¹ + FYM 20 tha ⁻¹
	T ₂	S ₀ B _{0.5} RFD + 0 kg S ha ⁻¹ + 0.5 kg B ha ⁻¹
	T ₃	S ₀ B _{1.0} RFD + 0 kg S ha ⁻¹ + 1 kg B ha ⁻¹
	T ₄	S ₀ B _{1.5} RFD + 0 kg S ha ⁻¹ + 1.5 kg B ha ⁻¹
	T ₅	S ₁₅ B ₀ RFD + 15 kg S ha ⁻¹ + 0 kg B ha ⁻¹
	T ₆	S ₁₅ B _{0.5} RFD + 15 kg S + 0.5 kg B ha ⁻¹
	T ₇	S ₁₅ B _{1.0} RFD + 15 kg S + 1 kg B ha ⁻¹
	T ₈	S ₁₅ B _{1.5} RFD + 15 kg S ha ⁻¹ + 1.5 kg B ha ⁻¹
	T ₉	S ₃₀ B ₀ RFD + 30 kg S ha ⁻¹ + 0 kg B ha ⁻¹
	T ₁₀	S ₃₀ B _{0.5} RFD + 30 kg S + 0.5 kg B ha ⁻¹
	T ₁₁	S ₃₀ B _{1.0} RFD + 30 kg S + 1 kg B ha ⁻¹

T ₁₂	S ₃₀ B _{1.5}	RFD + 30 kg S + 1.5 kg B ha ⁻¹
T ₁₃	S ₄₅ B ₀	RFD + 45 kg S ha ⁻¹ + 0 kg B ha ⁻¹
T ₁₄	S ₄₅ B _{0.5}	RFD + 45 kg S + 0.5 kg B ha ⁻¹
T ₁₅	S ₄₅ B _{1.0}	RFD + 45 kg S + 1 kg B ha ⁻¹
T ₁₆	S ₄₅ B _{1.5}	RFD + 45 kg S + 1.5 kg B ha ⁻¹

3.7 Details of field operations

The details of field operations performed during the experimentation are given in Table below.

3.7.1 Experimental site and preparatory tillage

The site selected for the experiment was well levelled with medium fertility status and good drainage. Land was prepared by ploughing, clods were broken and layout was done after removing weeds and trashes. The field was divided into 48 plots of size 3.0 m × 3.0 m, separating each plot from the adjoining plots by 15 cm wide small bunds, moreover, two blocks were separated by 50 cm wide path.

3.7.2 Application of manures and fertilizers

The entire dose of FYM was applied as basal dose and thoroughly incorporated in the soil. The entire dose of phosphorus and potassium along with half dose of nitrogen was given as basal and thoroughly mixed with the soil. Moreover, sulphur and boron was also applied to soil as per the treatments at the time of sowing. The remaining half dose of nitrogen was given 30 days after germination. The sources of N, P and K were urea (46 percent N), DAP (46 percent P₂O₅ and 18 percent N) and MOP (60 percent K₂O) respectively. The sources of B and S were Gypsum (15 percent S) and boric acid (17 percent B) respectively. The plan of the layout is given in fig. 2.

Fig. 2: Layout plan of experimental field

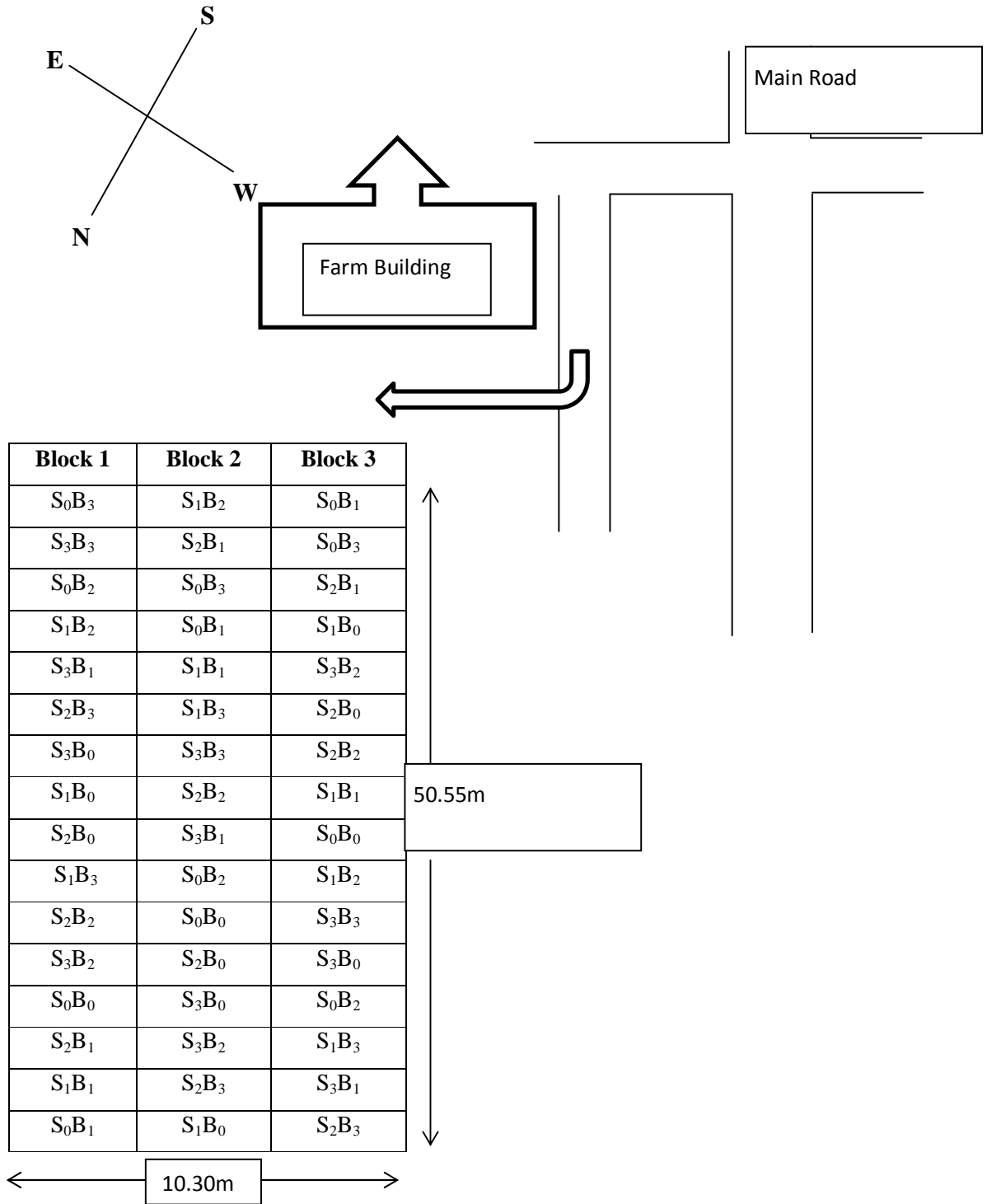


Table: Calendar of operations followed during the season.

Operations	Date	Remarks
Discing	04-06-2011	-
Tractorization with cultivator and harrow	06-06-2011	Two turns with cultivator and one turn with harrow was done.
Layout	07-06-2011	-
Application of inorganic fertilizers	08-06-2011	Half dose of nitrogen, full dose P and K and full dose of S and B as per the treatment were applied basally before sowing to each plot.
Sowing of seed	08-06-2011	Pre-soaked seeds were sown at a row spacing of 30cm in each plot @ 80Kg ha ⁻¹ .
Irrigation 1 st 2 nd	13-07-2011 23-07-2011	1 st Irrigation was given one week prior to flowering and 2 nd at pod setting stage of the crop.
Top dressing of nitrogen	29-06-2011	Remaining half dose of nitrogen was top dressed when true leaves emerged
Pod Picking 1 st 2 nd 3 rd	30-07-2011 09-08-2011 20-08-2011	Pod picking was done when pods were tender, stringless and green.
Harvesting	05-09-2011	Crop was harvested when pods were yellow to brown in colour

3.7.3 Sowing of seed

Seed sowing of French bean cv. Contendor in kharif 2011 was carried out on 08-06-2010. The seeds were sown by dropping them manually in furrows at a spacing of 30 × 10 cm. The seeds were covered with 2-3 cm soil cover. The plant population was maintained by gap filling (re-sowing).

3.7.4 Cultural practices

Cultural practices like weeding, hoeing was practised when required. Irrigations were given just one week before flowering and at pod setting stages.

3.7.5 Pod Picking

The picking of pods was done 50 days after sowing for vegetable purpose. First picking was done when pods were green, tender and stringless and pods were not filled with grains on 28th of July 2011. For picking operation ten plants were randomly selected in each plot and were tagged. Further two pickings were performed after 10 days intervals from the tagged plants. After 3rd picking almost 16 plants over an area of 0.5m² were left undisturbed in each plot for recording observations on seed related attributes of the crop.

Finally the undisturbed portion of the crop in each plot was harvested by uprooting the whole plant when the pods were yellow to brown in colour and the seeds were relatively firm. The crop was then sun dried and seeds were recovered by beating the crop with sticks.

3.8 Details of observations recorded

During the course of investigation, observations were recorded on various aspects of growth and yield attributes of French bean plants.

Observation on growth related attributes of French bean.

3.8.1 Number of nodules plant⁻¹, their fresh and dry weight at flowering stage

Ten plants from each treatment were randomly uprooted at flowering and the soil adhered to the roots was removed by washing under tap water. Then the healthy

nodules which were pinkish in colour (effective nodules) were carefully counted and average number of nodules plant^{-1} was determined. After taking fresh weight the nodules were dried in oven at 60-65 $^{\circ}\text{C}$ for 48 hours. Then dry weight of randomly selected samples was recorded.

3.8.2 Dry weight (q ha^{-1})

10 plants were uprooted from each treatment and dried in an oven at 60-65 $^{\circ}\text{C}$ for 48 hours and the weight of randomly selected plants was recorded in grams and finally converted in to quintals per hectare.

Observation on yield related characters of French bean

3.8.3 Green pod yield (q ha^{-1})

Fresh weight of total green pods harvested from 10 random plants in three pickings was recorded to work out the average pod yield plant^{-1} in grams and was converted in to green pod yield per hectare in quintals.

Observation on seed yield related attributes of French bean

3.8.4 Number of seeded pods plant^{-1}

Number of seeded pods from 10 random plants were counted to work out the average number of seeded pods plant^{-1} .

3.8.5 Number of seeds pod^{-1}

The number of seeds in randomly selected 10 pods from each treatment was counted and their average was worked out.

3.8.6 Seed yield (q ha^{-1})

Seed yield was taken from 16 undisturbed plants (0.5 m^2 area) of each plot and was converted into seed yield plot^{-1} (Kg) and further into seed yield ha^{-1} (q).

3.8.7 100 Seed weight (g)

A random sample of 100 seeds from each treatment was taken and weighed to work out 100 seed weight in grams.

3.8.8 Stover yield ($q\ ha^{-1}$)

Stover yield was also taken from the undisturbed plants ($0.5\ m^2$ area) after harvesting the crop which was then converted into quintals per hectare from each treatment.

3.9 Observation on quality related characters of French bean

For quality aspects of French bean, pod and seed protein content was recorded in laboratory. Protein content in French bean pods and grains at pod picking and harvesting from each treatment was worked out by estimating the percentage of N in pods and seeds by Kjeldhals method - Tandon (1993). The percent N was multiplied by factor 6.25 to estimate the protein content of pods and seeds.

3.10 Chemical studies of French bean pods, grains and stover for nutrient contents (N, P, K, S and B) at pod picking and harvesting

Five plants out of ten observational plants were selected randomly from each treatment at both pod picking and harvesting stages to serve as a substrate for analysis of concentration of nutrient contents in French bean pods and stover at pod picking stage and seed and stover at harvesting stage. The selected samples were cleaned with tap water, dilute HCl ($5\ ml\ litre^{-1}$ of water) and distilled water. The cleaned seed was finally subject to oven drying at $65\ ^\circ C$, till the material exhibited a constant weight. The dried material was ground to powder in Wiley grinding mill.

For estimating N concentration, the powdered material ($0.5g$) was digested in concentrated H_2SO_4 in presence of digestion mixture K_2SO_4 , $Fe\ SO_4$ and $CuSO_4$ in the ration of 10:1:0.5 with $1g$ Selenium powder. The digest was cooled and diluted to $100\ ml$ with distilled water. $20\ ml$ of the digest was taken for N estimation. For estimation of P, K, and S the powdered material ($0.5\ g$) was digested in di-acid (HNO_3 and $HClO_4$) in the ratio of 9:4. The digested material was filtered and volume made up to $100\ ml$ with distilled water and $5\ ml$ of the digest was used for P, K and S estimation respectively. For estimation of boron concentration the powdered material

(0.5 g) was digested by dry ashing technique. The digested material was treated with 20 percent HCl to dissolve it, filtered and volume made up to 25 ml with distilled water. 1 ml of aliquot was used for B estimation.

Method used for estimation of concentration of nutrients at pod picking and harvesting stages.

3.10.1 Nitrogen (percent)

Nitrogen concentration in plant samples was determined by Kjeldhal method as outlined by Tandon (1993).

3.10.2 Phosphorus (percent)

Phosphorus concentration in plant samples was estimated by vanadomolybdo phosphoric acid yellow colour method (Jackson, 1973).

3.10.3 Potassium (percent)

Potassium concentration in plant samples was estimated by Flame photometer as per the procedure outlined by Jackson (1973).

3.10.4 Sulphur (percent)

Sulphur concentration in plant samples was estimated by turbidimetric method (Chesnin and Yien, 1951).

3.10.5 Boron (ppm)

Boron concentration in plant samples was estimated by Azomethine –H method (John *et al.*, 1975).

3.11 Soil analysis

Before the start of the experiment composite soil sample was taken from the experimental field and after harvest of the crop, the soil samples were also taken as per the treatment and analysed for various soil properties viz., pH, electrical conductivity, organic carbon and available plant nutrients like nitrogen, phosphorus, potassium, sulphur, boron and forms of sulphur and boron using standard procedures.

The initial status of experimental site with respect to above characteristics is given in the table 3.1.

3.11.1 pH

The pH of the soil sample was determined by digital pH meter in 1:2.5 ratio of soil water suspension Jackson (1973).

3.11.2 Organic carbon (percent)

The organic carbon content was estimated by Walkley and Black method (1934).

3.11.3 Electrical conductivity (ds m^{-1})

Electrical conductivity was estimated by solubridge conductivity meter-Jackson (1973).

3.11.4 Available sulphur (kg ha^{-1})

Available sulphur was determined by turbidimetric method (Chesnin and Yien, 1951).

3.11.5 Available boron (ppm)

Available boron was estimated by azomethine-H method (John *et al.*, 1975).

3.11.6 Forms of sulphur

3.11.6.1 Total Sulphur (mg Kg^{-1} Soil)

Total sulphur in soil samples was estimated by method of Bardsley and Lancaster (1960), briefly described as under:

3.11.6.1.1 Fusion

Soil was fused with Na_2CO_3 and NaNO_3 in platinum crucible at 950°C in an electric furnace till ashing was complete.

3.11.6.1.2 Dissolution

After ashing the sample was shaken with distilled water and was made to specified volume.

3.11.6.1.3 Development of turbidity

The extract (25 ml) was brought to near dryness, taken up in 5 ml of 6N HCl treated with 1 ml of 1 percent FeCl_3 and 1 ml of 40 percent NaOH solution to precipitate out interfering soil colloids (Hesse, 1957) and acidified by 1ml of glacial acetic acid and determined after developing the turbidity with BaCl_2 crystals on spectrophotometer at wavelength of 420 nm as per method proposed by Chesnin and Yein (1951).

3.11.6.2 Organic sulphur

Digestion was carried out as per the method proposed by Williams and Steinbergs (1959) whose brief detail is given as under:

3.11.6.2.1 Leaching

The soil was leached with distilled water and then with 10 percent HCl to remove sulphate sulphur and finally washed with distilled water to remove excess of HCl until no chloride was present and then soil was evaporated to dryness after adding hydrogen peroxide.

3.11.6.2.2 Shaking

After cooling 1 percent NaOH solution was added and shaken for half an hour.

3.11.6.2.3 Determination

Organic sulphur was determined from the filtrate by the Hesse (1957) and Chesnin and Yein (1951) method.

3.11.6.3 Sulphate sulphur

Sulphate sulphur was estimated by Chesnin and Yein method (1951).

3.11.6.4 Adsorbed sulphur

Adsorbed sulphur was determined by shaking the soil with 500 ppm potassium dihydrogen phosphate as outlined by Ensminger (1954).

3.11.6.5 Non sulphate sulphur

Non sulphate sulphur was estimated by subtracting organic, sulphate and adsorbed sulphur from total sulphur.

3.11.7 Total Boron (mg Kg⁻¹ Soil)

Total boron was extracted by fusing 1g of soil with Na₂CO₃ by heating on a Bunsen burner in a platinum crucible. The content was extracted with 4N H₂SO₄ as per the procedure of Tan (2005).

3.11.8 Economics of production

Economics of all treatment combinations was worked on the basis of seed and stover yield. The cost of input and output was estimated as per prevailing market rates at the time of experimentation. The benefit cost ratio was determined as:

$$\text{Benefit Cost Ratio} = \frac{\text{Net returns}}{\text{Total cost of cultivation}}$$

3.11.9 Statistical analysis

In order to test the significance of results, the experimental data were subjected to statistical analysis as per the method described by Panse and Sukhatme (1978). The significance of “F” test was tested at 5 percent level of significance as given by Fisher (1970). The software used for the analysis of data was OPSTAT.

Chapter – 4

EXPERIMENTAL FINDINGS

The results obtained from the present study entitled “Effect of different levels of sulphur and boron on yield and quality of french bean (*Phaseolus vulgaris* L.) var. contendor in eutrochrepts” conducted during *Kharif* 2011 are presented in this chapter under relevant headings through data tables and graphs wherever necessary.

4.1 Observations recorded in french bean at flowering stage

4.1.1 Number of nodules plant⁻¹, their fresh and dry weight at flowering stage

The data on the number, fresh weight and dry weight of nodules is presented in Table 1 and illustrated in fig 3. The results indicate that the number, fresh weight and dry weight of nodules increased with the increasing levels of sulphur and boron. The number of nodules, fresh weight and dry weight of nodules increased from 9.42 to 14.44 plant⁻¹, 86.33 to 119.88 mg plant⁻¹ and 15.68 to 21.48 mg plant⁻¹ respectively with increase in sulphur application. The maximum number of nodules plant⁻¹ (14.44), fresh weight (119.88 mg plant⁻¹) and dry weight (21.48 mg plant⁻¹) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, the number, fresh and dry weight of nodules increased significantly with the increasing levels of boron. The maximum number of nodules plant⁻¹ (15.07), fresh weight (125.42 mg plant⁻¹) and dry weight (22.78 mg plant⁻¹) was recorded at 1.5 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the number, fresh weight and dry weight of french bean nodules plant⁻¹. The maximum number (17.10), fresh weight (140.09 mg plant⁻¹) and dry weight (24.82 mg plant⁻¹) of nodules was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ but higher levels of sulphur and boron showed antagonistic effect on these parameters.

Table – 1 Effect of sulphur and boron application on nodulation in French bean at flowering stage

Sulphur levels (Kg ha ⁻¹)	Number of nodules plant ⁻¹					Fresh weight of nodules (mg Plant ⁻¹)					Dry weight of nodules (mg Plant ⁻¹)				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	5.50	7.13	12.26	12.80	9.42	56.01	71.66	107.00	110.66	86.33	9.37	12.63	20.29	20.42	15.68
S₁₅	6.90	11.20	13.26	13.73	11.27	60.66	91.66	110.33	112.34	93.75	10.70	15.65	21.02	21.16	17.13
S₃₀	8.26	14.86	16.95	16.40	14.12	75.66	117.00	138.92	136.66	117.06	14.44	21.70	24.77	24.70	21.40
S₄₅	8.96	14.90	17.10	16.80	14.44	78.00	121.66	140.09	139.75	119.88	14.48	21.87	24.82	24.75	21.48
Mean	7.41	12.02	14.76	15.07		67.58	100.50	123.52	125.42		12.25	17.96	22.71	22.78	
C.D (p≤0.05)	Sulphur (S) = 0.95					Sulphur (S) = 9.87					Sulphur (S) = 0.20				
	Boron (B) = 0.95					Boron (B) = 9.87					Boron (B) = 0.20				
	S × B = 1.90					S × B = 19.75					S × B = 0.40				

4.1.2 Dry matter accumulation at flowering

The data on dry matter accumulation at flowering presented in Table 2 and illustrated in fig 3 revealed that sulphur and boron enhanced dry matter accumulation at flowering stage. Results indicate that dry matter accumulation increased from 11.36 in control to 14.77 q ha⁻¹ at 45 Kg S ha⁻¹ which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, dry matter accumulation increased significantly with the increasing levels of boron. The maximum accumulation of dry matter (14.99 q ha⁻¹) was recorded at 1.5 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased dry matter accumulation of french bean at flowering stage. Though maximum accumulation of dry matter (17.08 q ha⁻¹) was observed to be highest at 1 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ yet, higher levels of sulphur and boron showed antagonistic effect on dry matter accumulation.

4.2 Observations recorded in french bean at pod picking stage

4.2.1 Dry matter accumulation at pod picking

The data on the dry matter accumulation of french bean at pod picking stage has been presented in Table 3 and illustrated in fig 3. Dry matter accumulation in pods, stover and in total by plant was significantly influenced by the application of sulphur and boron. The dry matter accumulation in pods, stover and in total by plant significantly increased from 1.89, 15.20 and 17.09 q ha⁻¹ in control to 2.65, 19.74 and 22.39 q ha⁻¹ respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg S ha⁻¹. Similarly, dry matter accumulation in pods, stover and total plant significantly increased from 1.82, 15.43 and 17.25 q ha⁻¹ in control to 2.61, 20.49 and 23.10 q ha⁻¹ with increasing level of boron application up to 1.5 Kg ha⁻¹. The dry matter accumulation at 1.5 Kg B ha⁻¹ was significantly superior to lower levels but was at par to 1.5 Kg B ha⁻¹.

Table – 2 Effect of sulphur and boron application on dry matter accumulation ($q\ ha^{-1}$) in French bean at flowering stage

Sulphur levels ($Kg\ ha^{-1}$)	Boron levels ($Kg\ ha^{-1}$)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S ₀	9.29	10.22	12.73	13.19	11.36
S ₁₅	9.67	10.55	13.03	13.53	11.70
S ₃₀	10.90	13.81	16.75	16.41	14.47
S ₄₅	11.17	13.98	17.08	16.83	14.77
Mean	10.26	12.14	14.90	14.99	

C.D_(p≤0.05) Sulphur (S) = 0.65

Boron (B) = 0.65

S × B = 1.30

Table – 3 Effect of sulphur and boron application on dry matter ($q\ ha^{-1}$) accumulation in French bean at pod picking stage

Sulphur levels ($Kg\ ha^{-1}$)	Pods					Stover					Total dry matter				
	Boron levels ($Kg\ ha^{-1}$)				Mean	Boron levels ($Kg\ ha^{-1}$)				Mean	Boron levels ($Kg\ ha^{-1}$)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S ₀	1.58	1.65	2.09	2.24	1.89	14.52	14.53	15.80	15.93	15.20	16.10	16.18	17.89	18.17	17.09
S ₁₅	1.79	2.03	2.34	2.39	2.14	14.57	14.60	20.34	20.66	17.54	16.36	16.63	22.68	23.05	19.68
S ₃₀	1.92	2.55	2.97	2.89	2.58	16.23	16.48	22.73	22.51	19.49	18.15	19.03	25.70	25.40	22.07
S ₄₅	1.99	2.68	2.99	2.93	2.65	16.39	16.72	23.02	22.84	19.74	18.38	19.40	26.01	25.77	22.39
Mean	1.82	2.23	2.60	2.61		15.43	15.58	20.47	20.49		17.25	17.81	23.07	23.10	
c.D ($p \leq 0.05$)	Sulphur (S) = 0.15					Sulphur (S) = 0.45					Sulphur (S) = 0.52				
	Boron (B) = 0.15					Boron (B) = 0.45					Boron (B) = 0.52				
	S × B = 0.30					S × B = 0.90					S × B = 1.04				

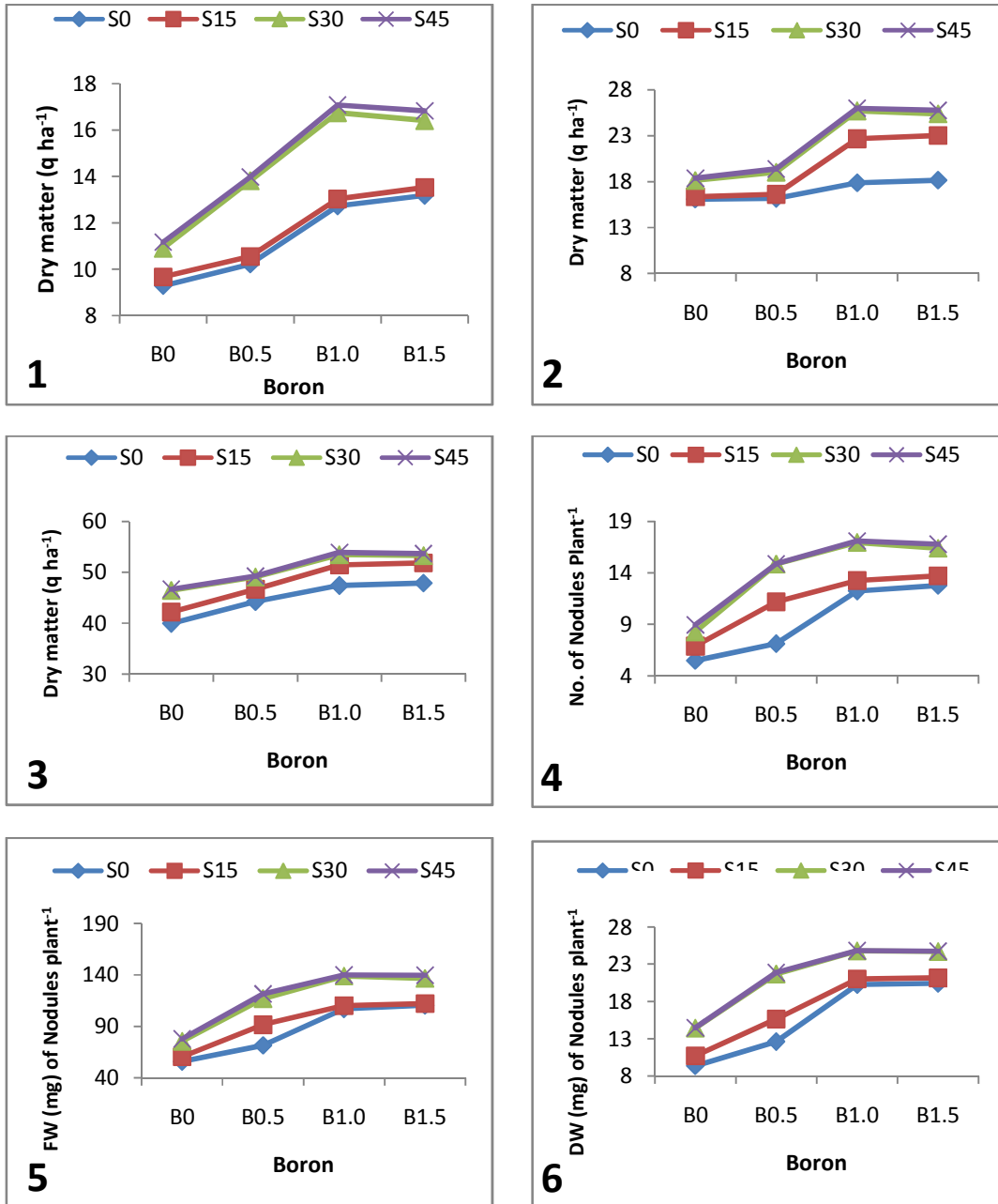


Fig. 3: Dry matter accumulation at flowering (1), pod picking (2) and harvesting (3) and number (4), fresh weight (5) and dry weight (6) of nodules as affected by sulphur and boron application.

The interaction effect of sulphur and boron was synergistic on dry matter accumulation in pods, stover as well as in whole plant and the maximum was observed to be 2.99, 23.02 and 26.01 q ha⁻¹ respectively at 45 Kg S ha⁻¹ in combination with 1 Kg B ha⁻¹. Higher levels of sulphur and boron showed antagonistic effect on dry matter accumulation at pod picking stage.

4.2.2 Pod yield of french bean (q ha⁻¹)

The data on pod yield presented in Table 4 and illustrated in fig 4 revealed that sulphur and boron enhanced pod yield of french bean significantly. The data indicates that the pod yield increased from 76.52 q ha⁻¹ in control to 93.70 q ha⁻¹ at 45 Kg S ha⁻¹ which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, pod yield increased significantly with the increasing levels of boron and the maximum pod yield (94.63 q ha⁻¹) was recorded at 1.5 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.5 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased pod yield of french bean. The maximum pod yield (101.23 q ha⁻¹) was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹. However, higher levels of sulphur and boron showed antagonistic effect on pod yield of french bean.

4.2.3 Nitrogen content of french bean at pod picking stage

The data on the nitrogen content in pods and stover is presented in Table 5. The results indicate that the nitrogen content increased with the increasing levels of sulphur and boron. The nitrogen content in pods and stover increased from 0.264 to 0.283 percent and 0.109 to 0.427 respectively with increase in sulphur application. The maximum nitrogen content in pods (0.283 percent) and stover (0.427 percent) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, the

Table – 4 Effect of sulphur and boron application on pod yield (q ha⁻¹) of French bean at picking stage

Sulphur levels (Kg ha ⁻¹)	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S ₀	71.12	73.46	78.06	83.45	76.52
S ₁₅	73.37	83.02	96.57	97.23	87.55
S ₃₀	82.62	89.21	99.54	98.36	92.43
S ₄₅	83.25	90.82	101.23	99.48	93.70
Mean	77.59	84.13	93.85	94.63	

C.D_(p≤0.05)

Sulphur (S) = 1.69

Boron (B) = 1.69

S × B = 3.38

Table – 5 Effect of sulphur and boron application on nitrogen content (percent) of French bean at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Pods					Stover				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S ₀	0.257 (1.121)	0.263 (1.124)	0.268 (1.126)	0.269 (1.126)	0.264 (1.124)	0.052 (1.026)	0.093 (1.042)	0.130 (1.063)	0.162 (1.079)	0.109 (1.047)
S ₁₅	0.260 (1.122)	0.264 (1.124)	0.269 (1.126)	0.280 (1.129)	0.268 (1.126)	0.163 (1.079)	0.204 (1.096)	0.311 (1.146)	0.324 (1.150)	0.251 (1.117)
S ₃₀	0.276 (1.129)	0.278 (1.130)	0.285 (1.133)	0.284 (1.133)	0.281 (1.131)	0.361 (1.165)	0.402 (1.184)	0.464 (1.209)	0.455 (1.209)	0.421 (1.188)
S ₄₅	0.278 (1.130)	0.280 (1.131)	0.287 (1.134)	0.285 (1.133)	0.283 (1.132)	0.372 (1.169)	0.402 (1.184)	0.471 (1.213)	0.463 (1.213)	0.427 (1.189)
Mean	0.268 (1.126)	0.271 (1.127)	0.277 (1.129)	0.280 (1.129)		0.237 (1.110)	0.275 (1.122)	0.344 (1.157)	0.351 (1.161)	
C.D (p ≤ 0.05)	Sulphur (S) = 0.0011					Sulphur (S) = 0.0041				
	Boron (B) = 0.0011					Boron (B) = 0.0041				
	S × B = 0.0022					S × B = 0.0082				

Figures in parentheses are square root transformed values.

nitrogen content in pods and stover increased significantly with the increasing levels of boron. The maximum nitrogen content in pods (0.280 percent) and stover (0.351 percent) was recorded at 1.5 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹ level.

The interaction effect between sulphur and boron significantly and synergistically increased the nitrogen content in pods and stover of french bean at pod picking stage. The maximum nitrogen content in pods (0.287 percent) and stover (0.471 percent) was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ and higher levels of sulphur and boron showed antagonistic effect on nitrogen content of pods and stover of french bean at pod picking stage.

4.2.4 Phosphorus content of french bean at pod picking stage

The data on the phosphorus content of french bean at pod picking stage has been presented in Table 6. Phosphorus content in pods and stover was significantly influenced by the application of sulphur and boron. The content of phosphorus in pods and stover significantly increased from 0.027 and 0.011 percent in control to 0.033 and 0.017 percent respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg S ha⁻¹. Similarly, phosphorus content in pods and stover significantly increased from 0.029 and 0.011 percent in control to 0.031 and 0.017 percent respectively with increasing level of boron application to 1.5 Kg ha⁻¹. The phosphorus content both in pods and stover at 1.5 Kg B ha⁻¹ was significantly superior to lower levels but was at par to 1.0 Kg B ha⁻¹.

The interaction effect of sulphur and boron was synergistic on phosphorus content in pods and stover, the maximum (0.035 and 0.021 percent respectively) was recorded at 45 Kg S ha⁻¹ in combination with 1 Kg B ha⁻¹ and higher levels of sulphur and boron showed antagonistic effect on phosphorus content at pod picking stage.

Table – 6 Effect of sulphur and boron application on phosphorus content (percent) of French bean at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Pods					Stover				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S ₀	0.025 (1.013)	0.026 (1.013)	0.027 (1.014)	0.029 (1.014)	0.027 (1.013)	0.009 (1.004)	0.010 (1.005)	0.013 (1.006)	0.012 (1.006)	0.011 (1.005)
S ₁₅	0.026 (1.013)	0.028 (1.014)	0.029 (1.014)	0.029 (1.014)	0.028 (1.014)	0.011 (1.006)	0.012 (1.006)	0.014 (1.007)	0.015 (1.007)	0.013 (1.006)
S ₃₀	0.031 (1.016)	0.032 (1.016)	0.034 (1.017)	0.033 (1.016)	0.033 (1.016)	0.012 (1.006)	0.016 (1.008)	0.019 (1.009)	0.019 (1.009)	0.017 (1.008)
S ₄₅	0.032 (1.016)	0.033 (1.016)	0.035 (1.017)	0.033 (1.016)	0.033 (1.016)	0.012 (1.006)	0.016 (1.008)	0.021 (1.010)	0.020 (1.010)	0.017 (1.008)
Mean	0.029 (1.014)	0.030 (1.015)	0.031 (1.016)	0.031 (1.016)		0.011 (1.006)	0.014 (1.007)	0.017 (1.008)	0.017 (1.008)	
C.D _(p≤0.05)	Sulphur (S) = 0.0002					Sulphur (S) = 0.0003				
	Boron (B) = 0.0002					Boron (B) = 0.0003				
	S × B = 0.0004					S × B = 0.0010				

Figures in parentheses are square root transformed values.

4.2.5 Potassium content of french bean at pod picking stage

The data on the potassium content in pods and stover is presented in Table 7. The data revealed that potassium content increased with the increasing levels of sulphur and boron. The potassium content in pods and stover increased from 0.26 to 0.33 percent and 0.38 to 0.50 percent respectively with increasing levels of sulphur application. The maximum potassium content in pods (0.33 percent) and stover (0.50 percent) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, the potassium content in pods and stover increased significantly with the increasing levels of boron. The maximum potassium content in pods (0.32 percent) and stover (0.49 percent) was recorded at 1.5 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the potassium content in pods and stover of french bean at pod picking stage. The maximum potassium content in pods (0.35 percent) and stover (0.54 percent) was observed at 1 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹, however, higher levels of sulphur and boron showed antagonistic effect on potassium content of pods and stover of french bean at pod picking stage.

4.2.6 Sulphur content of french bean at pod picking stage

The data on the sulphur content of french bean at pod picking stage has been presented in Table 8. Sulphur content in pods and stover was significantly influenced by the application of sulphur and boron. The content of sulphur in pods and stover significantly increased from 0.071 and 0.033 percent in control to 0.086 and 0.060 percent respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg ha⁻¹ of sulphur application. Similarly, sulphur content in pods and stover significantly increased from 0.074 and 0.040 percent in control to 0.085 and 0.054 percent respectively with increasing level of boron applic-

Table – 7 Effect of sulphur and boron application on potassium content (percent) of French bean at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Pods					Stover				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	0.19 (1.089)	0.24 (1.114)	0.28 (1.129)	0.30 (1.139)	0.26 (1.123)	0.28 (1.132)	0.36 (1.168)	0.42 (1.188)	0.44 (1.201)	0.38 (1.176)
S₁₅	0.26 (1.123)	0.29 (1.138)	0.30 (1.139)	0.31 (1.142)	0.29 (1.138)	0.39 (1.180)	0.44 (1.201)	0.46 (1.209)	0.46 (1.209)	0.44 (1.201)
S₃₀	0.30 (1.139)	0.33 (1.151)	0.34 (1.159)	0.33 (1.151)	0.33 (1.151)	0.44 (1.201)	0.48 (1.215)	0.53 (1.237)	0.52 (1.232)	0.49 (1.220)
S₄₅	0.30 (1.139)	0.33 (1.151)	0.35 (1.178)	0.32 (1.146)	0.33 (1.151)	0.44 (1.201)	0.49 (1.220)	0.54 (1.242)	0.52 (1.232)	0.50 (1.224)
Mean	0.26 (1.116)	0.30 (1.139)	0.32 (1.146)	0.32 (1.146)		0.39 (1.180)	0.44 (1.201)	0.49 (1.220)	0.49 (1.220)	
C.D _(p≤0.05)		Sulphur (S) = 0.0011				Sulphur (S) = 0.0050				
		Boron (B) = 0.0011				Boron (B) = 0.0050				
		S × B = 0.0022				S × B = 0.0010				

Figures in parentheses are square root transformed values.

Table – 8 Effect of sulphur and boron application on sulphur content (percent) of French bean at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Pods					Stover				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	0.067 (1.033)	0.069 (1.034)	0.071 (1.035)	0.076 (1.035)	0.071 (1.035)	0.022 (1.011)	0.033 (1.016)	0.036 (1.018)	0.041 (1.018)	0.033 (1.016)
S₁₅	0.071 (1.035)	0.072 (1.035)	0.080 (1.039)	0.085 (1.040)	0.077 (1.037)	0.035 (1.017)	0.038 (1.019)	0.041 (1.020)	0.046 (1.021)	0.040 (1.020)
S₃₀	0.076 (1.037)	0.080 (1.039)	0.090 (1.044)	0.089 (1.043)	0.084 (1.041)	0.050 (1.025)	0.054 (1.026)	0.064 (1.031)	0.063 (1.031)	0.058 (1.028)
S₄₅	0.080 (1.037)	0.080 (1.039)	0.093 (1.045)	0.090 (1.044)	0.086 (1.042)	0.052 (1.025)	0.055 (1.026)	0.066 (1.032)	0.065 (1.032)	0.060 (1.029)
Mean	0.074 (1.036)	0.075 (1.037)	0.084 (1.040)	0.085 (1.040)		0.040 (1.020)	0.045 (1.022)	0.052 (1.025)	0.054 (1.026)	
C.D (p≤0.05)	Sulphur (S) = 0.003					Sulphur (S) = 0.002				
	Boron (B) = 0.003					Boron (B) = 0.002				
	S × B = 0.006					S × B = 0.004				

Figures in parentheses are square root transformed values.

-ion to 1.5 Kg ha⁻¹. The sulphur content in both pods and stover at 1.5 Kg B ha⁻¹ was significantly superior to lower levels but was at par to 1.0 Kg B ha⁻¹.

The interaction effect of sulphur and boron was synergistic on sulphur content in pods and stover and the maximum was observed to be 0.093 and 0.066 percent respectively at 45 Kg S ha⁻¹ in combination with 1 Kg B ha⁻¹. However, higher levels of sulphur and boron showed antagonistic effect on sulphur content at pod picking stage.

4.2.7 Boron content of french bean at pod picking stage

The data presented in Table 9 revealed that boron content increased with the increasing levels of sulphur and boron. The boron content in pods and stover increased from 26.99 to 39.68 ppm and 8.03 to 12.48 ppm respectively with increasing level of sulphur application. The maximum boron content in pods (39.68 ppm) and stover (12.48 ppm) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, the boron content in pods and stover increased significantly with the increasing levels of boron. The maximum boron content in pods (38.63 ppm) and stover (11.89 ppm) was recorded at 1.5 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the boron content in pods and stover of french bean at pod picking stage. The maximum boron content in pods (43.26 ppm) and stover (13.51 ppm) was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ but higher levels of sulphur and boron showed antagonistic effect on boron content of pods and stover of french bean at pod picking stage.

4.2.8 Nitrogen uptake (Kg ha⁻¹) in french bean at pod picking stage

The data on the nitrogen uptake in pods, stover and total uptake by plant is presented in Table 10. The results revealed that the nitrogen uptake increased with the

Table – 9 Effect of sulphur and boron application on boron content (ppm) of French bean at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Pods					Stover				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	18.43	25.65	30.82	33.07	26.99	5.81	7.00	9.38	9.93	8.03
S₁₅	22.45	29.58	32.27	36.75	30.26	7.92	8.54	10.12	11.68	9.57
S₃₀	33.36	39.10	43.17	42.58	39.55	10.82	11.93	13.29	12.73	12.19
S₄₅	34.11	39.21	43.26	42.12	39.68	10.98	12.22	13.51	13.21	12.48
Mean	27.09	33.39	37.38	38.63		8.88	9.92	11.58	11.89	
C.D _(p≤0.05)	Sulphur (S) = 1.91					Sulphur (S) = 0.42				
	Boron (B) = 1.91					Boron (B) = 0.42				
	S × B = 3.82					S × B = 0.84				

Table – 10 Effect of sulphur and boron application on nitrogen uptake (Kg ha⁻¹) in French bean at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Pods					Stover					Total uptake				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	0.41	0.43	0.56	0.60	0.50	0.76	1.35	2.05	2.58	1.69	1.16	1.79	2.61	3.18	2.19
S₁₅	0.47	0.54	0.63	0.67	0.57	2.37	2.98	6.33	6.69	4.59	2.84	3.51	6.96	7.36	5.17
S₃₀	0.53	0.71	0.85	0.82	0.73	5.86	6.62	10.55	10.24	8.32	6.39	7.33	11.39	11.06	9.04
S₄₅	0.55	0.75	0.86	0.84	0.75	6.10	6.72	10.84	10.57	8.56	6.65	7.47	11.70	11.41	9.31
Mean	0.49	0.61	0.72	0.73		3.77	4.42	7.44	7.52		4.26	5.03	8.17	8.25	
C.D _(p≤0.05)	Sulphur (S) = 0.031					Sulphur (S) = 0.330					Sulphur (S) = 0.298				
	Boron (B) = 0.031					Boron (B) = 0.330					Boron (B) = 0.298				
	S × B = 0.062					S × B = 0.660					S × B = 0.597				

increasing levels of sulphur and boron. The nitrogen uptake in pods, stover, and total uptake by plant increased from 0.50 to 0.75 Kg ha⁻¹, 1.69 to 8.56 Kg ha⁻¹ and 2.19 to 9.31 Kg ha⁻¹ respectively with increasing level of sulphur application. The maximum nitrogen uptake in pods (0.75 Kg ha⁻¹), stover (8.56 Kg ha⁻¹) and total by plant (9.31 Kg ha⁻¹) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, nitrogen uptake in pods, stover and total uptake by plant increased significantly with the increasing levels of boron. The maximum nitrogen uptake in pods (0.73 Kg ha⁻¹), stover (7.52 Kg ha⁻¹) and total uptake (8.25 Kg ha⁻¹) was recorded at 1.5 Kg B ha⁻¹ level which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the nitrogen uptake in pods, stover and total uptake by french bean plant at pod picking stage. The maximum nitrogen uptake in pods (0.86 Kg ha⁻¹), stover (10.84 Kg ha⁻¹) and total uptake (11.70 Kg ha⁻¹) was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹. However, higher levels of sulphur and boron showed antagonistic effect on nitrogen uptake in pods, stover and total uptake by french bean plant at pod picking stage.

4.2.9 Phosphorus uptake (Kg ha⁻¹) in french bean at pod picking stage

The data on the phosphorus uptake of french bean at pod picking stage has been presented in Table 11. Phosphorus uptake in pods, stover and total uptake by plant was significantly influenced by the application of sulphur and boron. The uptake of phosphorus in pods, stover and total uptake by plant significantly increased from 0.051, 0.168 and 0.219 Kg ha⁻¹ in control to 0.088, 0.351 and 0.439 Kg ha⁻¹ respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg ha⁻¹ of sulphur application. Similarly phosphorus uptake in pods, stover and total uptake by plant significantly increased from 0.052, 0.171 and

Table – 11 Effect of sulphur and boron application on phosphorus uptake (Kg ha⁻¹) in French bean at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Pods					Stover					Total uptake				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	0.040	0.043	0.056	0.065	0.051	0.131	0.145	0.205	0.191	0.168	0.170	0.188	0.262	0.256	0.219
S₁₅	0.047	0.057	0.068	0.069	0.060	0.160	0.175	0.285	0.310	0.233	0.207	0.232	0.353	0.379	0.293
S₃₀	0.060	0.082	0.101	0.095	0.084	0.195	0.264	0.432	0.428	0.330	0.254	0.345	0.533	0.523	0.414
S₄₅	0.064	0.088	0.105	0.097	0.088	0.197	0.268	0.483	0.457	0.351	0.260	0.356	0.588	0.553	0.439
Mean	0.052	0.067	0.082	0.082		0.171	0.213	0.351	0.346		0.223	0.280	0.434	0.428	
C.D _(p≤0.05)	Sulphur (S) = 0.005					Sulphur (S) = 0.031					Sulphur (S) = 0.035				
	Boron (B) = 0.005					Boron (B) = 0.031					Boron (B) = 0.035				
	S × B = 0.010					S × B = 0.062					S × B = 0.070				

0.223 Kg ha⁻¹ in control to 0.082, 0.346 and 0.428 Kg ha⁻¹ respectively with increasing level of boron application to 1.5 Kg ha⁻¹. The phosphorus uptake in pods, stover and total uptake by plant at 1.5 Kg B ha⁻¹ was significantly superior to lower levels but was at par to 1.0 Kg B ha⁻¹.

The interaction effect of sulphur and boron was synergistic on phosphorus uptake in pods, stover and total uptake by plant, the maximum of which was observed to be 0.105, 0.483 and 0.588 Kg ha⁻¹ respectively at 45 Kg S ha⁻¹ in combination with 1 Kg B ha⁻¹ and higher levels of sulphur and boron showed antagonistic effect on phosphorus uptake at pod picking stage.

4.2.10 Potassium uptake (Kg ha⁻¹) in french bean at pod picking stage

The data on the potassium uptake in pods, stover and total uptake by plant is presented in Table 12. The results revealed that the potassium uptake increased with the increasing levels of sulphur and boron. The potassium uptake in pods, stover, and total uptake by plant at pod picking stage increased from 0.49 to 0.87 Kg ha⁻¹, 5.74 to 9.93 Kg ha⁻¹ and 6.62 to 10.79 Kg ha⁻¹ respectively with increasing levels of sulphur application. The maximum potassium uptake in pods (0.87 Kg ha⁻¹), stover (9.93 Kg ha⁻¹) and total by plant (10.79 Kg ha⁻¹) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ level of sulphur application. Similarly, potassium uptake in pods, stover and total uptake by plant increased significantly with the increasing levels of boron. The maximum potassium uptake in pods (0.84 Kg ha⁻¹), stover (10.12 Kg ha⁻¹) and total uptake (10.95 Kg ha⁻¹) was recorded at 1.0 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the potassium uptake in pods, stover and total uptake by french bean plant at pod picking stage. The maximum potassium uptake in pods (1.05 Kg ha⁻¹), stover (12.43 Kg ha⁻¹) and total uptake (13.48 Kg ha⁻¹) was observed at 1.0

Table – 12 Effect of sulphur and boron application on potassium uptake (Kg ha⁻¹) in French bean at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Pods					Stover					Total uptake				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	0.30	0.40	0.59	0.67	0.49	4.07	5.23	6.64	7.01	5.74	4.37	5.63	7.22	7.68	6.22
S₁₅	0.47	0.59	0.70	0.74	0.62	5.68	6.42	9.36	9.50	7.74	6.15	7.01	10.06	10.24	8.37
S₃₀	0.58	0.84	1.01	0.95	0.85	7.14	7.91	12.05	11.71	9.70	7.72	8.75	13.06	12.66	10.55
S₄₅	0.60	0.88	1.05	0.94	0.87	7.21	8.19	12.43	11.88	9.93	7.81	9.08	13.48	12.81	10.79
Mean	0.48	0.68	0.84	0.83		6.03	6.94	10.12	10.02		6.51	7.62	10.95	10.85	
C.D _(p≤0.05)	Sulphur (S) = 0.049					Sulphur (S) = 0.281					Sulphur (S) = 0.330				
	Boron (B) = 0.049					Boron (B) = 0.281					Boron (B) = 0.330				
	S × B = 0.098					S × B = 0.562					S × B = 0.660				

Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹, however, higher levels of sulphur and boron showed antagonistic effect on potassium uptake in pods, stover and total uptake by french bean plant at pod picking stage.

4.2.11 Sulphur uptake (Kg ha⁻¹) in french bean at pod picking stage

The data on the sulphur uptake of french bean at pod picking stage has been presented in Table 13. Sulphur uptake in pods, stover and total uptake by plant was significantly influenced by the application of sulphur and boron. The uptake of sulphur in pods, stover and total uptake by plant significantly increased from 0.13, 0.51 and 0.64 Kg ha⁻¹ in control to 0.23, 1.19 and 1.42 Kg ha⁻¹ respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg ha⁻¹ of sulphur application. Similarly, sulphur uptake in pods, stover and total uptake by plant significantly increased from 0.13, 0.62 and 0.76 Kg ha⁻¹ in control to 0.22, 1.13 and 1.35 Kg ha⁻¹ respectively with increasing level of boron application to 1.5 Kg ha⁻¹. The sulphur uptake in pods, stover and total uptake by plant at 1.5 Kg B ha⁻¹ was significantly superior to lower levels but was at par to 1.0 Kg B ha⁻¹.

The interaction effect of sulphur and boron was synergistic on sulphur uptake in pods, stover and total uptake by plant, the maximum was observed to be 0.28, 1.52 and 1.80 Kg ha⁻¹ respectively at 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹ however, higher levels of sulphur and boron showed antagonistic effect on sulphur uptake at pod picking stage.

4.2.12 Boron uptake (Kg ha⁻¹) in french bean at pod picking stage

The data on the boron uptake in pods, stover and total uptake by plant is presented in Table 14. The results revealed that the boron uptake increased with the increasing levels of sulphur and boron. The boron uptake in pods, stover, and total uptake by plant at pod picking stage increased from 5.25 to 10.64 g ha⁻¹, 12.31 to 24.92 g ha⁻¹ and 17.56 to 35.57 g ha⁻¹ respectively with increasing level of sulphur application. The maximum boron uptake in pods (10.64 g ha⁻¹), stover (24.92 g ha⁻¹)

Table – 13 Effect of sulphur and boron application on sulphur uptake (Kg ha⁻¹) in French bean at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Pods					Stover					Total uptake				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	0.11	0.11	0.15	0.17	0.13	0.32	0.48	0.57	0.65	0.51	0.43	0.59	0.72	0.82	0.64
S₁₅	0.13	0.15	0.19	0.20	0.17	0.51	0.55	0.83	0.95	0.71	0.64	0.70	1.02	1.15	0.88
S₃₀	0.15	0.20	0.27	0.26	0.22	0.81	0.89	1.45	1.42	1.14	0.96	1.09	1.72	1.68	1.36
S₄₅	0.16	0.21	0.28	0.26	0.23	0.85	0.92	1.52	1.48	1.19	1.01	1.13	1.80	1.75	1.42
Mean	0.13	0.17	0.22	0.22		0.62	0.71	1.09	1.13		0.76	0.88	1.31	1.35	
C.D _(p≤0.05)	Sulphur (S) = 0.014					Sulphur (S) = 0.061					Sulphur (S) = 0.081				
	Boron (B) = 0.014					Boron (B) = 0.061					Boron (B) = 0.081				
	S × B = 0.029					S × B = 0.122					S × B = 0.162				

Table – 14 Effect of sulphur and boron application on boron uptake (g ha⁻¹) in French bean at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Pods					Stover					Total uptake				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	2.91	4.23	6.44	7.41	5.25	8.44	10.17	14.82	15.82	12.31	11.35	14.40	21.26	23.23	17.56
S₁₅	4.02	6.00	7.55	8.78	6.59	11.54	12.47	20.58	24.13	17.18	15.56	18.47	28.14	32.91	23.77
S₃₀	6.41	9.97	12.82	12.31	10.38	17.56	19.66	30.21	28.66	24.02	23.97	29.63	43.03	40.96	34.40
S₄₅	6.79	10.51	12.93	12.34	10.64	18.00	20.43	31.10	30.17	24.92	24.78	30.94	44.03	42.51	35.57
Mean	5.03	7.68	9.94	10.21		13.88	15.68	24.18	24.69		18.91	23.36	34.12	34.90	
C.D _(p≤0.05)	Sulphur (S) = 0.405					Sulphur (S) = 1.338					Sulphur (S) = 1.503				
	Boron (B) = 0.405					Boron (B) = 1.338					Boron (B) = 1.503				
	S × B = 0.811					S × B = 2.677					S × B = 3.007				

and total by plant (35.57 g ha^{-1}) was recorded at 45 Kg ha^{-1} of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha^{-1} of sulphur application. Similarly, boron uptake in pods, stover and total uptake by plant increased significantly with the increasing levels of boron. The maximum boron uptake in pods (10.21 g ha^{-1}), stover (24.69 g ha^{-1}) and total uptake (34.90 g ha^{-1}) was recorded at 1.5 Kg B ha^{-1} which was significantly superior to other levels but at par with 1.0 Kg B ha^{-1} .

The interaction effect between sulphur and boron significantly and synergistically increased the boron uptake in pods, stover and total uptake by french bean plant at pod picking stage. The maximum boron uptake in pods (12.93 g ha^{-1}), stover (31.10 g ha^{-1}) and total uptake (44.03 g ha^{-1}) was observed to be highest at 1.0 Kg B ha^{-1} in combination with 45 Kg S ha^{-1} but higher levels of sulphur and boron showed antagonistic effect on boron uptake in pods, stover and total uptake by french bean plant at pod picking stage.

4.2.13 Crude protein content (percent) in french bean at pod picking stage

The data on crude protein content in pods at pod picking stage presented in Table 15 revealed that sulphur and boron enhanced crude protein content at pod picking stage. Results indicate that crude protein content increased from 1.65 in control to 1.77 percent at 45 Kg S ha^{-1} which was significantly superior to other levels but was at par with 30 Kg ha^{-1} of sulphur application. Similarly, crude protein content increased significantly with the increasing levels of boron. The maximum protein content (1.75 percent) was recorded at 1.5 Kg B ha^{-1} which was significantly superior to other levels but at par with 1.0 Kg B ha^{-1} .

The interaction effect between sulphur and boron significantly and synergistically increased protein content of french bean pods at pod picking stage. The maximum protein content (1.79 percent) was observed at 1.0 Kg B ha^{-1} in combi-

Table – 15 Effect of sulphur and boron application on crude protein content (percent) of French bean pods at pod picking stage

Sulphur levels (Kg ha ⁻¹)	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S ₀	1.61 (1.616)	1.64 (1.627)	1.68 (1.637)	1.68 (1.637)	1.65 (1.628)
S ₁₅	1.63 (1.622)	1.65 (1.628)	1.68 (1.637)	1.75 (1.657)	1.68 (1.637)
S ₃₀	1.73 (1.654)	1.74 (1.655)	1.78 (1.667)	1.78 (1.667)	1.75 (1.657)
S ₄₅	1.74 (1.655)	1.75 (1.657)	1.79 (1.669)	1.78 (1.667)	1.77 (1.665)
Mean	1.67 (1.635)	1.70 (1.643)	1.73 (1.654)	1.75 (1.657)	

Figures in parentheses are square root transformed values.

C.D._(p≤0.05) Sulphur (S) = 0.0096
 Boron (B) = 0.0096
 S × B = 0.0192

-nation with 45 Kg S ha⁻¹ however, higher levels of sulphur and boron showed antagonistic effect on crude protein content.

4.3 Observations recorded in french bean at harvesting stage

4.3.1 Yield attributes of french bean at harvesting stage

The data presented in Table 16 and illustrated in fig 4 indicated that the number of pods plant⁻¹, number of seeds pod⁻¹ and 100 seed weight increased with the increasing levels of sulphur and boron. The number of pods plant⁻¹, number of seeds pod⁻¹ and 100 seed weight increased from 6.50 to 9.07, 5.32 to 6.03 and 27.43 to 28.78 g respectively with increasing level of sulphur application. The maximum number of pods plant⁻¹ (9.07), seeds pod⁻¹ (6.03) and 100 seed weight (28.78 g) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, the number of pods plant⁻¹, number of seeds pod⁻¹ and 100 seed weight increased significantly with the increasing levels of boron. The maximum number of pods plant⁻¹ (8.61), number of seeds pod⁻¹ (6.02) and 100 seed weight (28.95 g) was recorded at 1.5 Kg B ha⁻¹ level which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the number of pods plant⁻¹, number of seeds pod⁻¹ and 100 seed weight of french bean. The maximum number of pods plant⁻¹ (9.85), number of seeds pod⁻¹ (6.37) and 100 seed weight (29.83 g) was observed to be highest at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ but higher levels of sulphur and boron showed antagonistic effect on yield attributing characters.

4.3.2 Seed and stover yield (q ha⁻¹) of french bean at harvesting stage

The data on yield (seed + stover) of french bean is presented in Table 17 and illustrated in fig 4. Seed and stover yield was significantly influenced by the application of sulphur and boron. Seed and stover yield significantly increased from

Table – 16 Effect of sulphur and boron application on yield attributes of French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Number of pods plant ⁻¹					Number of seeds pod ⁻¹					100 seed weight (g)				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	5.10	6.20	7.21	7.49	6.50	4.87	5.17	5.53	5.72	5.32	26.60	26.90	27.93	28.28	27.43
S₁₅	6.20	6.36	7.33	7.48	6.84	4.97	5.20	5.70	5.90	5.44	26.74	27.06	28.33	28.66	27.70
S₃₀	8.06	8.50	9.80	9.70	9.02	5.43	5.90	6.28	6.20	5.95	27.07	28.48	29.58	29.37	28.63
S₄₅	8.13	8.56	9.85	9.75	9.07	5.50	5.97	6.37	6.27	6.03	27.10	28.71	29.83	29.47	28.78
Mean	6.87	7.41	8.55	8.61		5.19	5.56	5.97	6.02		26.88	27.79	28.92	28.95	
C.D _(p≤0.05)	Sulphur (S) = 0.11					Sulphur (S) = 0.09					Sulphur (S) = 0.46				
	Boron (B) = 0.11					Boron (B) = 0.09					Boron (B) = 0.46				
	S × B = 0.23					S × B = 0.18					S × B = 0.92				

Table – 17 Effect of sulphur and boron application on yield (q ha⁻¹) of French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seed yield					Stover yield				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	19.86	20.75	23.03	23.30	21.74	29.20	33.44	35.24	35.70	33.40
S₁₅	20.34	21.47	23.39	23.80	22.25	30.88	35.69	39.28	39.77	36.41
S₃₀	21.30	23.08	24.96	24.71	23.51	35.57	37.37	40.69	40.28	38.48
S₄₅	21.64	23.27	25.25	24.88	23.76	35.86	37.48	41.12	40.84	38.83
Mean	20.79	22.14	24.16	24.17		32.88	36.00	39.08	39.15	
C.D (p ≤ 0.05)		Sulphur (S) = 0.54				Sulphur (S) = 0.63				
		Boron (B) = 0.54				Boron (B) = 0.63				
		S × B = 1.09				S × B = 1.27				

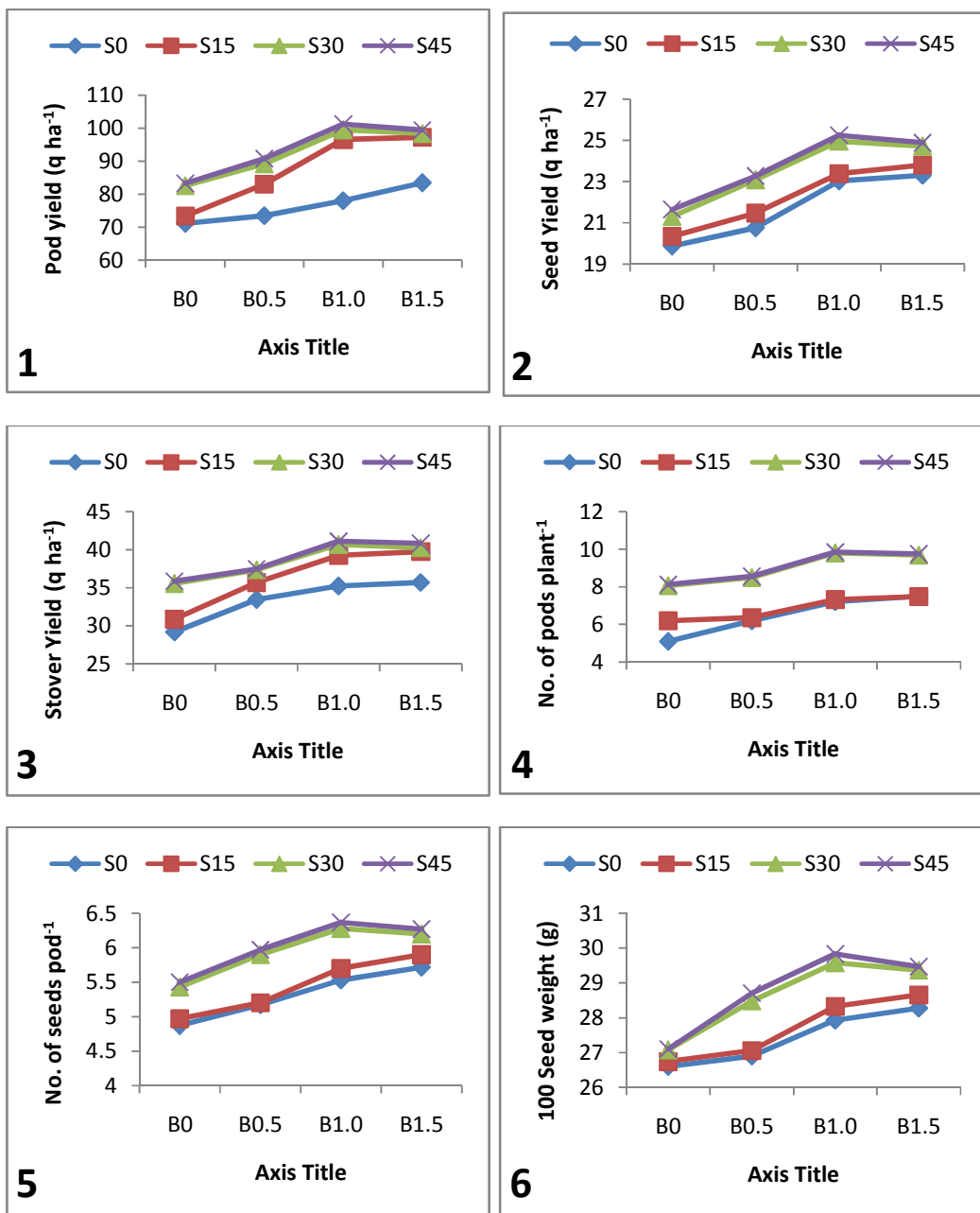


Fig. 4: Yield (1, 2 and 3) and yield attributes (4, 5 and 6) of french bean as affected by sulphur and boron application.

21.74 and 33.40 q ha⁻¹ in control to 23.76 and 38.83 q ha⁻¹ respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg ha⁻¹ of sulphur application. Similarly, seed and stover yield significantly increased from 20.79 and 32.88 q ha⁻¹ in control to 24.17 and 39.15 q ha⁻¹ respectively at 1.5 Kg B ha⁻¹. Both seed and stover yield at 1.5 Kg B ha⁻¹ level was significantly superior to lower levels but was at par to 1.0 Kg B ha⁻¹.

The interaction effect of sulphur and boron was synergistic on seed and stover yield, the maximum was observed to be 25.25 and 41.12 q ha⁻¹ respectively at 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹ and higher levels of sulphur and boron showed antagonistic effect on sulphur content at pod picking stage.

4.3.3 Dry matter accumulation at harvesting stage

The data on the dry matter accumulation of french bean at harvesting stage has been presented in Table 18 and illustrated in fig 3. Dry matter accumulation in seeds, stover and in total by plant was significantly influenced by the application of sulphur and boron. The dry matter accumulation in seeds, stover and in total by plant significantly increased from 19.16, 25.71 and 44.87 q ha⁻¹ in control to 20.80, 30.10 and 50.89 q ha⁻¹ respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg ha⁻¹ of sulphur application. Similarly dry matter accumulation in seeds, stover and total plant significantly increased from 18.51, 25.31 and 43.82 q ha⁻¹ in control to 21.33, 30.35 and 51.68 q ha⁻¹ with increasing level of boron application to 1.5 Kg ha⁻¹. The dry matter accumulation at 1.5 Kg B ha⁻¹ level was significantly superior to lower levels but was at par to 1.0 Kg B ha⁻¹ level.

The interaction effect of sulphur and boron was synergistic on dry matter accumulation in seeds, stover as well as in whole plant, the maximum of which was observed to be 22.19, 31.72 and 53.91 q ha⁻¹ respectively at 45 Kg S ha⁻¹ in combinat-

Table – 18 Effect of sulphur and boron application on dry matter ($q\ ha^{-1}$) accumulation in French bean at harvesting stage

Sulphur levels ($Kg\ ha^{-1}$)	Seeds					Stover					Total dry matter				
	Boron levels ($Kg\ ha^{-1}$)				Mean	Boron levels ($Kg\ ha^{-1}$)				Mean	Boron levels ($Kg\ ha^{-1}$)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S ₀	17.48	18.28	20.33	20.55	19.16	22.45	25.99	27.08	27.33	25.71	39.93	44.27	47.41	47.88	44.87
S ₁₅	18.78	18.93	20.63	20.87	19.80	23.42	27.76	30.82	30.99	28.25	42.20	46.69	51.45	51.86	48.05
S ₃₀	18.82	19.88	21.92	21.83	20.61	27.65	29.20	31.52	31.44	29.95	46.47	49.08	53.44	53.27	50.57
S ₄₅	18.95	19.96	22.19	22.08	20.80	27.72	29.32	31.72	31.63	30.10	46.67	49.28	53.91	53.71	50.89
Mean	18.51	19.26	21.27	21.33		25.31	28.07	30.29	30.35		43.82	47.33	51.55	51.68	
	Sulphur (S) = 0.32					Sulphur (S) = 0.27					Sulphur (S) = 0.42				
	Boron (B) = 0.32					Boron (B) = 0.27					Boron (B) = 0.42				
	S × B = 0.64					S × B = 0.55					S × B = 0.84				

-ion with 1.0 Kg B ha⁻¹ but higher levels of sulphur and boron showed antagonistic effect on dry matter accumulation at harvesting stage.

4.3.4 Nitrogen content of french bean at harvesting stage

The data on the nitrogen content in seeds and stover is presented in Table 19. The data indicates that the nitrogen content increased with the increasing levels of sulphur and boron. The nitrogen content in seeds and stover increased from 2.91 to 3.37 percent and 0.16 to 0.67 percent respectively with increasing level of sulphur application. The maximum nitrogen content in seeds (3.37 percent) and stover (0.67 percent) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, the nitrogen content in seeds and stover increased significantly with the increasing levels of boron. The maximum nitrogen content in seeds (3.33 percent) and stover (0.54 percent) was recorded at which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the nitrogen content in seeds and stover of french bean at harvesting stage. The maximum nitrogen content in seeds (3.50 percent) and stover (0.73 percent) was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ however, higher levels of sulphur and boron showed antagonistic effect on nitrogen content of seeds and stover of french bean at harvesting stage.

4.3.5 Phosphorus content of french bean at harvesting stage

The data on the phosphorus content of french bean at harvesting stage has been presented in Table 20. Phosphorus content in seeds and stover was significantly influenced by the application of sulphur and boron. The content of phosphorus in seeds and stover significantly increased from 0.417 and 0.039 percent in control to 0.437 and 0.043 percent respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg ha⁻¹ of sulphur application.

Table – 19 Effect of sulphur and boron application on nitrogen content (percent) of French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seeds					Stover				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	2.72 (1.92)	2.82 (1.95)	3.03 (2.00)	3.05 (2.00)	2.91 (1.96)	0.08 (1.043)	0.13 (1.067)	0.21 (1.101)	0.21 (1.101)	0.16 (1.095)
S₁₅	3.09 (2.02)	3.16 (2.03)	3.27 (2.06)	3.30 (2.06)	3.21 (2.04)	0.25 (1.119)	0.32 (1.152)	0.51 (1.230)	0.52 (1.236)	0.40 (1.185)
S₃₀	3.16 (2.03)	3.33 (2.08)	3.50 (2.11)	3.48 (2.11)	3.37 (2.09)	0.58 (1.259)	0.63 (1.277)	0.72 (1.314)	0.72 (1.314)	0.66 (1.289)
S₄₅	3.16 (2.03)	3.34 (2.08)	3.50 (2.11)	3.49 (2.11)	3.37 (2.09)	0.60 (1.267)	0.63 (1.277)	0.73 (1.323)	0.72 (1.314)	0.67 (1.293)
Mean	3.03 (2.00)	3.16 (2.03)	3.33 (2.07)	3.33 (2.07)		0.38 (1.177)	0.43 (1.197)	0.54 (1.243)	0.54 (1.243)	
C.D _(p≤0.05)		Sulphur (S) = 0.01				Sulphur (S) = 0.011				
		Boron (B) = 0.01				Boron (B) = 0.011				
		S × B = 0.02				S × B = 0.022				

Figures in parentheses are square root transformed values.

Table – 20 Effect of sulphur and boron application on phosphorus content (percent) of French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seeds					Stover				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S ₀	0.412 (1.188)	0.415 (1.189)	0.419 (1.191)	0.421 (1.192)	0.417 (1.191)	0.038 (1.019)	0.038 (1.019)	0.039 (1.019)	0.042 (1.021)	0.039 (1.020)
S ₁₅	0.415 (1.190)	0.417 (1.191)	0.421 (1.192)	0.422 (1.193)	0.419 (1.191)	0.040 (1.020)	0.041 (1.020)	0.041 (1.020)	0.042 (1.021)	0.041 (1.020)
S ₃₀	0.428 (1.195)	0.431 (1.196)	0.444 (1.202)	0.443 (1.201)	0.437 (1.199)	0.040 (1.021)	0.042 (1.021)	0.043 (1.021)	0.043 (1.021)	0.042 (1.021)
S ₄₅	0.429 (1.195)	0.431 (1.196)	0.444 (1.202)	0.443 (1.201)	0.437 (1.199)	0.042 (1.021)	0.043 (1.021)	0.044 (1.022)	0.042 (1.021)	0.043 (1.021)
Mean	0.421 (1.192)	0.424 (1.194)	0.432 (1.197)	0.432 (1.197)		0.040 (1.020)	0.041 (1.020)	0.042 (1.021)	0.042 (1.021)	
C.D (p ≤ 0.05)	Sulphur (S) = 0.0003					Sulphur (S) = 0.0001				
	Boron (B) = 0.0003					Boron (B) = 0.0001				
	S × B = 0.0010					S × B = 0.0002				

Figures in parentheses are square root transformed values.

Similarly phosphorus content in seeds and stover significantly increased from 0.421 and 0.040 percent in control to 0.432 and 0.042 percent respectively at 1.5 Kg B ha⁻¹. The phosphorus content both in seeds and stover at 1.5 Kg B ha⁻¹ level was significantly superior to lower levels but was at par to 1.5 Kg B ha⁻¹.

The interaction effect of sulphur and boron was synergistic on phosphorus content in seeds and stover, the maximum of which was observed to be 0.444 and 0.044 percent respectively at 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹ but higher levels of sulphur and boron showed antagonistic effect on phosphorus content at harvesting stage.

4.3.6 Potassium content of french bean at harvesting stage

The data on the potassium content in seeds and stover presented in Table 21 revealed that potassium content increased with the increasing levels of sulphur and boron. The potassium content in seeds and stover increased from 1.50 to 1.54 percent and 1.81 to 1.89 percent respectively with increasing level of sulphur. The maximum potassium content in seeds (1.54 percent) and stover (1.89 percent) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ level of sulphur application. Similarly, the potassium content in seeds and stover increased significantly with the increasing levels of boron. The maximum potassium content in seeds (1.53 percent) and stover (1.87 percent) was recorded at 1.5 Kg B ha⁻¹ level which was significantly superior to other levels but at par with 1.5 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the potassium content in seeds and stover of french bean at harvesting stage. The maximum potassium content in seeds (1.57 percent) and stover (1.91 percent) was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ and higher levels of sulphur and boron showed antagonistic effect on potassium content of seeds and stover of french bean at harvesting stage.

Table – 21 Effect of sulphur and boron application on potassium content (percent) of French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seeds					Stover				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	1.47 (1.572)	1.49 (1.578)	1.50 (1.581)	1.52 (1.587)	1.50 (1.580)	1.79 (1.671)	1.80 (1.674)	1.82 (1.680)	1.85 (1.689)	1.81 (1.680)
S₁₅	1.48 (1.575)	1.49 (1.578)	1.51 (1.584)	1.53 (1.591)	1.50 (1.582)	1.85 (1.689)	1.87 (1.695)	1.87 (1.695)	1.86 (1.692)	1.86 (1.692)
S₃₀	1.52 (1.587)	1.54 (1.594)	1.55 (1.597)	1.54 (1.594)	1.54 (1.594)	1.87 (1.695)	1.88 (1.698)	1.89 (1.701)	1.90 (1.704)	1.89 (1.701)
S₄₅	1.53 (1.591)	1.55 (1.597)	1.57 (1.603)	1.52 (1.587)	1.54 (1.594)	1.89 (1.701)	1.90 (1.704)	1.91 (1.706)	1.87 (1.693)	1.89 (1.701)
Mean	1.50 (1.581)	1.52 (1.587)	1.53 (1.591)	1.53 (1.591)		1.85 (1.689)	1.86 (1.692)	1.87 (1.695)	1.87 (1.695)	
C.D (p ≤ 0.05)	Sulphur (S) = NS					Sulphur (S) = 0.0005				
	Boron (B) = NS					Boron (B) = 0.0005				
	S × B = NS					S × B = 0.0010				

Figures in parentheses are square root transformed values.

4.3.7 Sulphur content of french bean at harvesting stage

The data on the sulphur content of french bean at harvesting stage has been presented in Table 22. The data indicates that the content of sulphur in seeds and stover significantly increased from 0.25 and 0.07 percent in control to 0.34 and 0.11 percent respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg ha⁻¹ of sulphur application. Similarly, increasing levels of boron significantly increased sulphur content in seeds and stover from 0.27 and 0.07 percent in control to 0.32 and 0.11 percent respectively at 1.5 Kg B ha⁻¹. The sulphur content in both seeds and stover at was significantly superior to lower levels but was at par to 1.0 Kg B ha⁻¹.

The interaction effect of sulphur and boron was synergistic on sulphur content in seeds and stover, the maximum of which was observed to be 0.36 and 0.13 percent respectively at 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹ however, higher levels of sulphur and boron showed antagonistic effect on sulphur content at harvesting stage.

4.3.8 Boron content of french bean at harvesting stage

The data on the boron content in seeds and stover is presented in Table 23. The results revealed that boron content increased with the increasing levels of sulphur and boron. The boron content in seeds and stover increased from 30.38 to 51.90 ppm and 12.55 to 18.98 ppm respectively with increasing level of sulphur application. The maximum boron content in seeds (51.90 ppm) and stover (18.98 ppm) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, the boron content in seeds and stover increased significantly with the increasing levels of boron. The maximum boron content in seeds (48.41 ppm) and stover (18.04 ppm) was recorded at 1.5 Kg B ha⁻¹ level which was significantly superior to other levels but at par with 1.5 Kg B ha⁻¹.

Table – 22 Effect of sulphur and boron application on sulphur content (percent) of French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seeds					Stover				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	0.21 (1.098)	0.23 (1.108)	0.28 (1.130)	0.29 (1.134)	0.25 (1.118)	0.05 (1.026)	0.06 (1.028)	0.08 (1.038)	0.08 (1.038)	0.07 (1.034)
S₁₅	0.24 (1.112)	0.26 (1.121)	0.29 (1.134)	0.30 (1.143)	0.27 (1.127)	0.06 (1.031)	0.07 (1.033)	0.09 (1.042)	0.10 (1.050)	0.08 (1.040)
S₃₀	0.31 (1.143)	0.33 (1.155)	0.35 (1.163)	0.35 (1.163)	0.34 (1.159)	0.07 (1.033)	0.09 (1.046)	0.11 (1.055)	0.11 (1.055)	0.10 (1.050)
S₄₅	0.31 (1.143)	0.34 (1.159)	0.36 (1.167)	0.35 (1.163)	0.34 (1.159)	0.09 (1.046)	0.11 (1.055)	0.13 (1.064)	0.12 (1.060)	0.11 (1.055)
Mean	0.27 (1.127)	0.29 (1.134)	0.32 (1.147)	0.32 (1.147)		0.07 (1.035)	0.08 (1.038)	0.10 (1.050)	0.11 (1.055)	
C.D (p≤0.05)	Sulphur (S) = 0.007					Sulphur (S) = 0.006				
	Boron (B) = 0.007					Boron (B) = 0.006				
	S × B = 0.014					S × B = 0.012				

Figures in parentheses are square root transformed values.

Table – 23 Effect of sulphur and boron application on boron content (ppm) of French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seeds					Stover				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	22.72	27.66	34.75	36.40	30.38	8.58	11.78	14.15	15.67	12.55
S₁₅	24.46	28.52	36.49	39.41	32.22	10.36	15.28	16.37	16.69	14.68
S₃₀	41.02	45.96	59.30	58.70	51.25	16.40	18.65	20.10	19.83	18.75
S₄₅	41.83	46.56	60.08	59.12	51.90	16.64	18.97	20.34	19.96	18.98
Mean	32.51	37.18	47.66	48.41		13.00	16.17	17.74	18.04	
C.D (p≤0.05)	Sulphur (S) = 1.042					Sulphur (S) = 0.407				
	Boron (B) = 1.042					Boron (B) = 0.407				
	S × B = 2.084					S × B = 0.814				

The interaction effect between sulphur and boron revealed significant and synergistic increase in boron content in seeds and stover of french bean at harvesting stage. The maximum boron content in pods (60.08 ppm) and stover (20.34 ppm) was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ and higher levels of sulphur and boron showed antagonistic effect on boron content of seeds and stover of french bean at harvesting stage.

4.3.9 Nitrogen uptake (Kg ha⁻¹) in french bean at harvesting stage

The data on the nitrogen uptake in seeds, stover and total uptake by plant presented in Table 24 revealed that the nitrogen uptake increased with the increasing levels of sulphur and boron. The nitrogen uptake in seeds, stover, and total uptake by plant increased from 55.84 to 70.32 Kg ha⁻¹, 4.15 to 20.26 Kg ha⁻¹ and 59.99 to 90.58 Kg ha⁻¹ respectively with increasing levels of sulphur. The maximum nitrogen uptake in seeds (70.32 Kg ha⁻¹), stover (20.26 Kg ha⁻¹) and total by plant (90.58 Kg ha⁻¹) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, nitrogen uptake in seeds, stover and total uptake by plant increased significantly with the increasing levels of boron. The maximum nitrogen uptake in seeds (71.14 Kg ha⁻¹), stover (16.82 Kg ha⁻¹) and total uptake (87.96 Kg ha⁻¹) was recorded at 1.5 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the nitrogen uptake in seeds, stover and total uptake by french bean plant at harvesting stage. The maximum nitrogen uptake in seeds (77.67 Kg ha⁻¹), stover (23.16 Kg ha⁻¹) and total uptake (100.82 Kg ha⁻¹) was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ however, higher levels of sulphur and boron showed antagonistic effect on nitrogen uptake in seeds, stover and total uptake by french bean plant at harvesting stage.

Table – 24 Effect of sulphur and boron application on nitrogen uptake (Kg ha⁻¹) in French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seeds					Stover					Total uptake				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	47.55	51.55	61.60	62.68	55.84	1.80	3.38	5.69	5.74	4.15	49.34	54.93	67.29	68.42	59.99
S₁₅	58.03	59.82	67.46	68.87	63.55	5.86	8.88	15.72	16.11	11.64	63.89	68.70	83.18	84.99	75.19
S₃₀	59.47	66.20	76.72	75.97	69.59	16.04	18.40	22.69	22.64	19.94	75.51	84.60	99.41	98.61	89.53
S₄₅	59.88	66.67	77.67	77.06	70.32	16.63	18.47	23.16	22.77	20.26	76.51	85.14	100.82	99.83	90.58
Mean	56.23	61.06	70.86	71.14		10.08	12.28	16.81	16.82		66.31	73.34	87.68	87.96	
C.D (p≤0.05)	Sulphur (S) = 0.921					Sulphur (S) = 0.351					Sulphur (S) = 1.202				
	Boron (B) = 0.921					Boron (B) = 0.351					Boron (B) = 1.202				
	S × B = 1.842					S × B = 0.702					S × B = 2.404				

4.3.10 Phosphorus uptake (Kg ha⁻¹) in french bean at harvesting stage

The data on the phosphorus uptake of french bean at harvesting stage has been presented in Table 25. Phosphorus uptake in seeds, stover and total uptake by plant was significantly influenced by the application of sulphur and boron. The uptake of phosphorus in seeds, stover and total uptake by plant significantly increased from 7.99, 1.01 and 9.0 Kg ha⁻¹ in control to 9.09, 1.29 and 10.38 Kg ha⁻¹ respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg ha⁻¹ of sulphur application. Similarly, phosphorus uptake in seeds, stover and total uptake by plant significantly increased from 7.79, 1.02 and 8.81 Kg ha⁻¹ in control to 9.23, 1.28 and 10.51 Kg ha⁻¹ respectively with increasing level of boron application to 1.5 Kg B ha⁻¹. The phosphorus uptake in seeds, stover and total uptake by plant at 1.5 Kg B ha⁻¹ was significantly superior to lower levels but was at par to 1.0 Kg B ha⁻¹.

The interaction effect of sulphur and boron was synergistic on phosphorus uptake in seeds, stover and total uptake by plant, the maximum was observed to be 9.85, 1.40 and 11.25 Kg ha⁻¹ respectively at 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹ but higher levels of sulphur and boron showed antagonistic effect on phosphorus uptake at harvesting stage.

4.3.11 Potassium uptake (Kg ha⁻¹) in french bean at harvesting stage

The data on the potassium uptake in seeds, stover and total uptake by plant is presented in Table 26. The results revealed that the potassium uptake increased with the increasing levels of sulphur and boron. The potassium uptake in seeds, stover, and total uptake by plant increased from 28.67 to 32.08 Kg ha⁻¹, 46.70 to 56.96 Kg ha⁻¹ and 75.37 to 89.04 Kg ha⁻¹ respectively with increasing sulphur level. The maximum potassium uptake in seeds (32.08 Kg ha⁻¹), stover (56.96 Kg ha⁻¹) and total by plant (89.04 Kg ha⁻¹) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur applic-

Table – 25 Effect of sulphur and boron application on phosphorus uptake (Kg ha⁻¹) in French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seeds					Stover					Total uptake				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	7.20	7.59	8.52	8.65	7.99	0.85	0.99	1.06	1.15	1.01	8.05	8.57	9.57	9.80	9.00
S₁₅	7.79	7.89	8.69	8.81	8.29	0.94	1.14	1.26	1.30	1.16	8.73	9.03	9.95	10.11	9.46
S₃₀	8.05	8.57	9.73	9.67	9.01	1.11	1.23	1.36	1.35	1.26	9.16	9.79	11.09	11.02	10.27
S₄₅	8.13	8.60	9.85	9.78	9.09	1.16	1.26	1.40	1.33	1.29	9.29	9.86	11.25	11.11	10.38
Mean	7.79	8.16	9.20	9.23		1.02	1.15	1.27	1.28		8.81	9.32	10.46	10.51	
C.D (p≤0.05)	Sulphur (S) = 0.099					Sulphur (S) = 0.052					Sulphur (S) = 0.061				
	Boron (B) = 0.099					Boron (B) = 0.052					Boron (B) = 0.061				
	S × B = 0.199					S × B = 0.104					S × B = 0.122				

Table – 26 Effect of sulphur and boron application on potassium uptake (Kg ha⁻¹) in French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seeds					Stover					Total uptake				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	25.70	27.24	30.50	31.24	28.67	40.19	46.78	49.29	50.56	46.70	65.88	74.02	79.78	81.80	75.37
S₁₅	27.79	28.21	31.15	31.93	29.77	43.33	51.91	57.63	57.64	52.63	71.12	80.12	88.78	89.57	82.40
S₃₀	28.61	30.62	33.98	33.62	31.70	51.71	54.90	59.57	59.74	56.48	80.31	85.51	93.55	93.35	88.18
S₄₅	28.99	30.94	34.84	33.56	32.08	52.39	55.71	60.59	59.15	56.96	81.38	86.65	95.42	92.71	89.04
Mean	27.77	29.25	32.62	32.59		46.90	52.32	56.77	56.77		74.67	81.57	89.38	89.36	
C.D (p≤0.05)	Sulphur (S) = 0.730					Sulphur (S) = 0.697					Sulphur (S) = 1.065				
	Boron (B) = 0.730					Boron (B) = 0.697					Boron (B) = 1.065				
	S × B = 1.460					S × B = 1.394					S × B = 2.130				

-ation. Similarly, potassium uptake in seeds, stover and total uptake increased significantly with the increasing levels of boron. The maximum potassium uptake in seeds (32.62 Kg ha⁻¹), stover (56.77 Kg ha⁻¹) and total uptake (89.38 Kg ha⁻¹) was recorded at 1.0 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.5 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the potassium uptake in seeds, stover and total uptake by french bean plant at harvesting stage. The maximum potassium uptake in seeds (34.84 Kg ha⁻¹), stover (60.59 Kg ha⁻¹) and total uptake (95.42Kg ha⁻¹) was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ and higher levels of sulphur and boron showed antagonistic effect on potassium uptake in seeds, stover and total uptake by french bean plant at harvesting stage.

4.3.12 Sulphur uptake (Kg ha⁻¹) in french bean at harvesting stage

The data on the sulphur uptake of french bean at harvesting stage has been presented in Table 27. Sulphur uptake in seeds, stover and total uptake by plant was significantly influenced by the application of sulphur and boron. The uptake of sulphur in seeds, stover and total uptake by plant significantly increased from 4.88, 1.76 and 6.64 Kg ha⁻¹ in control to 7.09, 3.41 and 10.50 Kg ha⁻¹ respectively at 45 Kg S ha⁻¹. The results were significantly superior to other levels but were at par with 30 Kg ha⁻¹ of sulphur application. Similarly sulphur uptake in seeds, stover and total uptake by plant significantly increased from 4.97, 1.74 and 6.71 Kg ha⁻¹ in control to 6.90, 3.13 and 10.03 Kg ha⁻¹ respectively with increasing level of boron application to 1.5 Kg ha⁻¹. The sulphur uptake in seeds, stover and total uptake by plant at 1.5 Kg B ha⁻¹ was significantly superior to lower levels but was at par to 1.0 Kg B ha⁻¹.

The interaction effect of sulphur and boron was synergistic on sulphur uptake in seeds, stover and total uptake by plant, the maximum was observed to be 7.99, 4.12 and 12.11 Kg ha⁻¹ respectively at 45 Kg S ha⁻¹ in combination with 1 Kg B ha⁻¹ but

Table – 27 Effect of sulphur and boron application on sulphur uptake (Kg ha⁻¹) in French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seeds					Stover					Total uptake				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	3.67	4.20	5.69	5.96	4.88	1.12	1.56	2.17	2.19	1.76	4.79	5.76	7.86	8.15	6.64
S₁₅	4.51	4.92	5.98	6.26	5.42	1.41	1.94	2.77	3.10	2.31	5.91	6.87	8.76	9.36	7.72
S₃₀	5.83	6.56	7.67	7.64	6.93	1.94	2.63	3.47	3.46	2.87	7.77	9.19	11.14	11.10	9.80
S₄₅	5.87	6.79	7.99	7.73	7.09	2.49	3.23	4.12	3.80	3.41	8.37	10.01	12.11	11.52	10.50
Mean	4.97	5.62	6.83	6.90		1.74	2.34	3.13	3.13		6.71	7.96	9.97	10.03	
C.D (p ≤ 0.05)	Sulphur (S) = 0.332					Sulphur (S) = 0.562					Sulphur (S) = 0.893				
	Boron (B) = 0.332					Boron (B) = 0.562					Boron (B) = 0.893				
	S × B = 0.665					S × B = 1.125					S × B = 1.786				

higher levels of sulphur and boron showed antagonistic effect on sulphur uptake at harvesting stage.

4.3.13 Boron uptake (Kg ha⁻¹) in french bean at harvesting stage

The data on the boron uptake in seeds, stover and total uptake by plant is presented in Table 28. The results revealed that the boron uptake increased with the increasing levels of sulphur and boron. The boron uptake in seeds, stover, and total uptake by plant increased from 58.93 to 109.01 g ha⁻¹, 32.76 to 57.35 g ha⁻¹ and 91.69 to 166.36 g ha⁻¹ respectively with increasing levels of sulphur. The maximum boron uptake in seeds (109.01 g ha⁻¹), stover (57.35 g ha⁻¹) and total by plant (166.36 g ha⁻¹) was recorded at 45 Kg ha⁻¹ of sulphur application which was significantly superior to other levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, boron uptake in seeds, stover and total uptake by plant increased significantly with the increasing levels of boron. The maximum boron uptake in seeds (103.93 g ha⁻¹), stover (55.01 g ha⁻¹) and total uptake (158.4 g ha⁻¹) was recorded at 1.5 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased the boron uptake in seeds, stover and total uptake by french bean plant at harvesting stage. The maximum boron uptake in seeds (133.32 g ha⁻¹), stover (64.52 g ha⁻¹) and total uptake (197.84 g ha⁻¹) was noticed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹. Higher levels of sulphur and boron showed antagonistic effect on boron uptake in seeds, stover and total uptake by french bean plant at harvesting stage.

4.3.14 Crude protein content (percent) in french bean at harvesting stage

The data on crude protein content in seeds at harvesting stage presented in Table 29 revealed that sulphur and boron enhanced crude protein content at harvesting stage. Results indicate that crude protein content increased from 18.16 in control to 21.08 percent at 45 Kg S ha⁻¹ which was significantly superior to other

Table – 28 Effect of sulphur and boron application on boron uptake (g ha⁻¹) in French bean at harvesting stage

Sulphur levels (Kg ha ⁻¹)	Seeds					Stover					Total uptake				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	39.71	50.56	70.65	74.80	58.93	19.26	30.62	38.32	42.83	32.76	58.98	81.18	108.96	117.63	91.69
S₁₅	45.94	53.99	75.28	82.25	64.36	24.26	42.42	50.45	51.72	42.21	70.20	96.41	125.73	133.97	106.58
S₃₀	77.20	91.37	129.99	128.14	106.67	45.35	54.46	63.36	62.35	56.38	122.55	145.83	193.34	190.49	163.05
S₄₅	79.27	92.93	133.32	130.54	109.01	46.13	55.62	64.52	63.13	57.35	125.39	148.55	197.84	193.67	166.36
Mean	60.53	72.21	102.31	103.93		33.75	45.78	54.16	55.01		94.28	117.99	156.47	158.94	
	Sulphur (S) = 2.612					Sulphur (S) = 1.265					Sulphur (S) = 3.962				
C.D _(p≤0.05)	Boron (B) = 2.612					Boron (B) = 1.265					Boron (B) = 3.962				
	S × B = 5.224					S × B = 2.530					S × B = 7.924				

Table – 29 Effect of sulphur and boron application on crude protein content (percent) of French bean seeds at harvesting stage

Sulphur levels (Kgha ⁻¹)	Boron levels (Kgha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	17.00 (4.240)	17.63 (4.314)	18.94 (4.463)	19.06 (4.475)	18.16 (4.379)
S₁₅	19.31 (4.505)	19.75 (4.547)	20.44 (4.623)	20.63 (4.656)	20.03 (4.583)
S₃₀	19.75 (4.547)	20.81 (4.653)	21.88 (4.768)	21.75 (4.754)	21.05 (4.681)
S₄₅	19.75 (4.537)	20.88 (4.676)	21.88 (4.782)	21.81 (4.774)	21.08 (4.692)
Mean	18.95 (4.457)	19.77 (4.548)	20.78 (4.645)	20.81 (4.653)	

Figures in parentheses are square root transformed values.

C.D_(p≤0.05) Sulphur (S) = 0.024
 Boron (B) = 0.024
 S × B = 0.048

levels but was at par with 30 Kg ha⁻¹ of sulphur application. Similarly, crude protein content increased significantly with the increasing levels of boron. The maximum protein content (20.81 percent) was recorded at 1.5 Kg B ha⁻¹ which was significantly superior to other levels but at par with 1.0 Kg B ha⁻¹.

The interaction effect between sulphur and boron significantly and synergistically increased protein content of french bean at harvesting stage. The maximum protein content (21.88 percent) was observed at 1.0 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹ and higher levels of sulphur and boron showed antagonistic effect on crude protein content.

4.4 Soil analysis after harvest

4.4.1 Soil reaction, electrical conductivity and organic carbon content in soil

The data on the soil pH, electrical conductivity and organic carbon is presented in Table 30. Increasing sulphur levels from 0 to 45 Kg ha⁻¹ decreased soil pH significantly from 6.995 to 6.565. The decrease in pH exhibited significant difference with control but remained at par with all other levels of sulphur. Increasing levels of boron revealed decrease in soil pH slightly and had no statistical significance. Interaction between sulphur and boron exhibited no influence on soil pH.

The data in the table also indicated that the effect of sulphur and boron application had no effect on electrical conductivity and organic carbon content of soil.

4.4.2 Forms of sulphur in soil after harvest

The data on forms of sulphur in soil after harvesting the crop has been presented in Table 31. Increasing levels of sulphur from 0 to 45 Kg ha⁻¹ significantly influenced all the forms of sulphur in soil. The data in the table revealed that total sulphur increased from 141.12 to 153.18 ppm, organic sulphur from 121.64 to 130.21 ppm, sulphate sulphur from 4.96 to 11.19 ppm adsorbed sulphur from 4.08 to 4.59.

Table – 30 Effect of sulphur and boron application on pH, EC and Organic Carbon content of soil after harvesting crop

Sulphur levels (Kg ha ⁻¹)	pH					EC (dsm ⁻¹)					OC (percent)				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S ₀	7.003	7.000	7.000	6.977	6.995	0.140	0.143	0.146	0.149	0.145	1.459	1.461	1.464	1.472	1.464
S ₁₅	6.883	6.880	6.873	6.868	6.876	0.151	0.154	0.152	0.155	0.153	1.476	1.476	1.480	1.482	1.479
S ₃₀	6.690	6.686	6.681	6.678	6.684	0.158	0.159	0.163	0.160	0.160	1.480	1.499	1.501	1.504	1.496
S ₄₅	6.572	6.568	6.561	6.560	6.565	0.159	0.161	0.165	0.168	0.163	1.504	1.510	1.512	1.517	1.511
Mean	6.787	6.784	6.779	6.771		0.152	0.154	0.157	0.158		1.480	1.487	1.489	1.494	
C.D (p≤0.05)	Sulphur (S) = 0.11					Sulphur (S) = NS					Sulphur (S) = NS				
	Boron (B) = NS					Boron (B) = NS					Boron (B) = NS				
	S × B = 0.22					S × B = NS					S × B = NS				

Table – 31 Effect of sulphur and boron application on forms of sulphur (ppm) in soil after harvesting the crop

Sulphur levels (Kg ha ⁻¹)	Total sulphur					Organic sulphur					Sulphate sulphur				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	140.76	140.98	141.18	141.56	141.12	120.98	121.43	121.86	122.29	121.64	4.36	4.53	5.12	5.83	4.96
S₁₅	143.13	144.00	144.54	145.21	144.22	124.43	124.73	125.05	125.69	124.98	8.89	9.00	9.11	9.14	9.04
S₃₀	147.72	147.96	148.33	149.43	148.36	125.06	125.42	125.60	126.32	125.60	9.42	9.57	9.66	9.75	9.60
S₄₅	152.59	152.87	153.15	154.11	153.18	129.18	130.16	130.20	131.28	130.21	10.82	11.07	11.22	11.63	11.19
Mean	146.05	146.45	146.80	147.58		124.91	125.44	125.68	126.40		8.37	8.54	8.78	9.09	
	Sulphur (S) = 7.04					Sulphur (S) = 6.58					Sulphur (S) = 0.70				
C.D _(p≤0.05)	Boron (B) = NS					Boron (B) = NS					Boron (B) = 0.70				
	S × B = NS					S × B = NS					S × B = 1.45				

Cont...

Table 31 continued...

Sulphur levels (Kg ha ⁻¹)	Adsorbed sulphur					Non sulphate sulphur				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	3.96	4.02	4.13	4.21	4.08	11.46	11.00	10.07	9.23	10.44
S₁₅	4.19	4.31	4.58	4.60	4.42	9.54	9.14	8.62	7.78	8.77
S₃₀	4.13	4.33	4.47	4.79	4.43	9.11	8.64	8.60	8.57	8.73
S₄₅	4.36	4.46	4.63	4.91	4.59	8.23	7.18	7.10	6.29	7.20
Mean	4.16	4.28	4.45	4.63		9.59	8.99	8.60	7.97	
C.D _(p≤0.05)		Sulphur (S) = 0.49				Sulphur (S) = 2.84				
		Boron (B) = NS				Boron (B) = NS				
		S × B = NS				S × B = NS				

However, increasing levels of sulphur from 0 to 45 Kg ha⁻¹ significantly decreased non sulphate sulphur from 10.44 to 7.20 ppm. The results further revealed that boron application had no effect on total sulphur, organic sulphur, adsorbed sulphur and non sulphate sulphur. Contrary to this sulphate sulphur increased from 8.37 ppm in control to 9.09 ppm at 1.5 Kg ha⁻¹ of boron application.

Interaction between sulphur and boron exhibited significant influence on sulphate sulphur only and 45 Kg S ha⁻¹ in combination with 1.5 Kg B ha⁻¹ registered maximum content (11.63 ppm) of sulphate sulphur.

4.4.3 Forms of boron in soil after crop harvest

The data on forms of boron in soil after harvesting the crop has been presented in Table 32. Increasing levels of sulphur from 0 to 45 Kg ha⁻¹ increased hot water soluble boron in soil significantly from 0.60 to 0.69 ppm and showed no significance in increasing total boron in soil. However, increasing levels of boron had significant effect on hot water soluble boron as well as total boron in soil and increased from 0.35 and 24.39 ppm in control to 0.96 and 25.71 ppm respectively at 1.5 Kg B ha⁻¹. The increase in hot water soluble boron was significantly superior to all other levels but increase in total boron was significantly superior to 0 Kg B ha⁻¹ and was at par with 0.5 Kg B ha⁻¹ and 1.0 Kg B ha⁻¹ of boron application.

The interaction effect between sulphur and boron significantly and synergistically increased hot water soluble boron in soil. The maximum hot water soluble boron (1.03 ppm) was observed at 1.5 Kg B ha⁻¹ in combination with 45 Kg S ha⁻¹.

4.7 Relative economics

Relative economics with respect to seed yield of french bean was worked out for all treatment combinations of sulphur and boron and presented in Table 33-35. Gross returns, net returns and benefit-cost ratio were calculated on the basis of cost of cultivation viz., land preparation, seed, fertilizer, labour, etc. Highest gross and net

Table – 32 Effect of sulphur and boron application on forms of boron (ppm) in soil after harvesting the crop

Sulphur levels (Kg ha ⁻¹)	Hot water soluble B					Total B				
	Boron levels (Kg ha ⁻¹)				Mean	Boron levels (Kg ha ⁻¹)				Mean
	B ₀	B _{0.5}	B _{1.0}	B _{1.5}		B ₀	B _{0.5}	B _{1.0}	B _{1.5}	
S₀	0.31	0.49	0.71	0.89	0.60	24.06	24.32	24.67	25.31	24.59
S₁₅	0.34	0.52	0.74	0.93	0.63	24.19	24.53	24.90	25.63	24.81
S₃₀	0.36	0.55	0.69	0.97	0.64	24.43	24.71	25.18	25.84	25.04
S₄₅	0.37	0.58	0.78	1.03	0.69	24.88	25.12	25.29	26.06	25.34
Mean	0.35	0.54	0.73	0.96		24.39	24.67	25.01	25.71	
C.D (p ≤ 0.05)		Sulphur (S) = 0.022				Sulphur (S) = NS				
		Boron (B) = 0.022				Boron (B) = 1.22				
		S × B = 0.045				S × B = NS				

Table – 33 Treatment wise costs incurred on fertilizers and their application for cultivation of French bean

Treatment		Cost involved on				Labour days required	Cost of labour @ Rs 120 per labour day	Total cost Rs ha ⁻¹
		Fertilizer (Rs)	Manure (Rs)	Sulphur (Rs)	Boron (Rs)			
S₀ B₀	RDF 100percent 30:60:60 N:P ₂ O ₅ :K ₂ O kg ha ⁻¹ + 20tons FYM ha ⁻¹	3861.45	10000.00	-	-	19	2280.00	33275.05
S₀ B_{0.5}	RDF + 0kg S ha ⁻¹ +0.5 kg B ha ⁻¹	3861.45	10000.00	-	1102.50	20	2400.00	37980.85
S₀ B_{1.0}	RDF + 0 kg S ha ⁻¹ + 1.0 kg B ha ⁻¹	3861.45	10000.00	-	2205.00	20	2400.00	42446.65
S₀ B_{1.5}	RDF + 0kg S ha ⁻¹ +1.5 kg B ha ⁻¹	3861.45	10000.00	-	3307.50	20	2400.00	46912.45
S₁₅ B₀	RDF +15kg S ha ⁻¹ +0 kg B ha ⁻¹	3861.45	10000.00	800.00	-	20	2400.00	35615.05
S₁₅ B_{0.5}	RDF +15kg S ha ⁻¹ +0.5 kg B ha ⁻¹	3861.45	10000.00	800.00	1102.50	21	2520.00	40320.85
S₁₅ B_{1.0}	RDF +15kg S ha ⁻¹ +1.0 kg B ha ⁻¹	3861.45	10000.00	800.00	2205.00	21	2520.00	44786.65
S₁₅ B_{1.5}	RDF +15kg S ha ⁻¹ +1.5 kg B ha ⁻¹	3861.45	10000.00	800.00	3307.50	21	2520.00	49252.45
S₃₀ B₀	RDF +30 kg S ha ⁻¹ +0 kg B ha ⁻¹	3861.45	10000.00	1600.00	-	20	2400.00	37715.05
S₃₀ B_{0.5}	RDF +30 kg S ha ⁻¹ +0.5 kg B ha ⁻¹	3861.45	10000.00	1600.00	1102.50	21	2520.00	42420.85
S₃₀ B_{1.0}	RDF +30 kg S ha ⁻¹ +1.0 kg B ha ⁻¹	3861.45	10000.00	1600.00	2205.00	21	2520.00	46886.65
S₃₀ B_{1.5}	RDF +30 kg S ha ⁻¹ +1.5 kg B ha ⁻¹	3861.45	10000.00	1600.00	3307.50	21	2520.00	51352.45
S₄₅ B₀	RDF +45 kg S ha ⁻¹ +0 kg B ha ⁻¹	3861.45	10000.00	2400.00	-	20	2400.00	39815.05
S₄₅ B_{0.5}	RDF +45 kg S ha ⁻¹ +0.5 kg B ha ⁻¹	3861.45	10000.00	2400.00	1102.50	21	2520.00	44520.85
S₄₅ B_{1.0}	RDF +45 kg S ha ⁻¹ +1.0 kg B ha ⁻¹	3861.45	10000.00	2400.00	2205.00	21	2520.00	48986.65
S₄₅ B_{1.5}	RDF +45 kg S ha ⁻¹ +1.5 kg B ha ⁻¹	3861.45	10000.00	2400.00	3307.50	21	2520.00	53452.45

RDF = Recommended Fertilizer dose, FYM = Farm Yard Manure, B = Boron, S = Sulphur

Table – 34 Treatment wise comparative economics of Cost of cultivation in French bean

Treatment		Fixed cost Rs ha ⁻¹	Variable cost Rs ha ⁻¹	Cost on fertilizers Rs ha ⁻¹	Total variable cost Rs ha ⁻¹	Total cost of cultivation Rs ha ⁻¹
S₀ B₀	RDF 100percent 30:60:60 N:P ₂ O ₅ :K20 kg ha ⁻¹ + 20tons FYM ha ⁻¹	19787.70	31688.00	33275.05	64963.05	84750.75
S₀ B_{0.5}	RDF + 0kg S ha ⁻¹ +0.5 kg B ha ⁻¹	19787.70	31688.00	37980.85	69668.85	89456.55
S₀ B_{1.0}	RDF + 0 kg S ha ⁻¹ + 1.0 kg B ha ⁻¹	19787.70	31688.00	42446.65	74134.65	93922.35
S₀ B_{1.5}	RDF + 0kg S ha ⁻¹ +1.5 kg B ha ⁻¹	19787.70	31688.00	46912.45	78600.45	98388.15
S₁₅ B₀	RDF +15kg S ha ⁻¹ +0 kg B ha ⁻¹	19787.70	31688.00	35615.05	67303.05	87090.75
S₁₅ B_{0.5}	RDF +15kg S ha ⁻¹ +0.5 kg B ha ⁻¹	19787.70	31688.00	40320.85	72008.85	91796.55
S₁₅ B_{1.0}	RDF +15kg S ha ⁻¹ +1.0 kg B ha ⁻¹	19787.70	31688.00	44786.65	76474.65	96262.35
S₁₅ B_{1.5}	RDF +15kg S ha ⁻¹ +1.5 kg B ha ⁻¹	19787.70	31688.00	49252.45	80940.45	100728.20
S₃₀ B₀	RDF +30 kg S ha ⁻¹ +0 kg B ha ⁻¹	19787.70	31688.00	37715.05	69403.05	89190.75
S₃₀ B_{0.5}	RDF +30 kg S ha ⁻¹ +0.5 kg B ha ⁻¹	19787.70	31688.00	42420.85	74108.85	93896.55
S₃₀ B_{1.0}	RDF +30 kg S ha ⁻¹ +1.0 kg B ha ⁻¹	19787.70	31688.00	46886.65	78574.65	98362.35
S₃₀ B_{1.5}	RDF +30 kg S ha ⁻¹ +1.5 kg B ha ⁻¹	19787.70	31688.00	51352.45	83040.45	102828.20
S₄₅ B₀	RDF +45 kg S ha ⁻¹ +0 kg B ha ⁻¹	19787.70	31688.00	39815.05	71503.05	91290.75
S₄₅ B_{0.5}	RDF +45 kg S ha ⁻¹ +0.5 kg B ha ⁻¹	19787.70	31688.00	44520.85	76208.85	95996.55
S₄₅ B_{1.0}	RDF +45 kg S ha ⁻¹ +1.0 kg B ha ⁻¹	19787.70	31688.00	48986.65	80674.65	100462.40
S₄₅ B_{1.5}	RDF +45 kg S ha ⁻¹ +1.5 kg B ha ⁻¹	19787.70	31688.00	53452.45	85140.45	104928.20

RDF = Recommended Fertilizer dose, FYM = Farm Yard Manure, B = Boron, S = Sulphur

Total Variable cost (variable cost + added cost). Total cost of cultivation (Total variable cost + Fixed cost)

Table – 35 Economics of seed production of French bean

Treatment		Total cost of cultivation (Rs. ha ⁻¹)	Yield (q ha ⁻¹)	Gross returns (Rs. ha ⁻¹)	Net returns (Rs. ha ⁻¹)	Returns Re ⁻¹ invested (B:C ratio)
S₀ B₀	RDF 100percent 25:60:60 N:P ₂ O ₅ : K ₂ O kg ha ⁻¹ + 20tons FYM ha ⁻¹	84750.75	19.86	198600	113849.25	1.34
S₀ B_{0.5}	RDF + 0kg S ha ⁻¹ +0.5 kg B ha ⁻¹	89456.55	20.75	207500	118043.45	1.32
S₀ B_{1.0}	RDF + 0 kg S ha ⁻¹ + 1.0 kg B ha ⁻¹	93922.35	23.03	230300	136377.65	1.45
S₀ B_{1.5}	RDF + 0kg S ha ⁻¹ +1.5 kg B ha ⁻¹	98388.15	23.30	233000	134611.85	1.37
S₁₅ B₀	RDF +15kg S ha ⁻¹ +0 kg B ha ⁻¹	87090.75	20.34	203400	116309.25	1.34
S₁₅ B_{0.5}	RDF +15kg S ha ⁻¹ +0.5 kg B ha ⁻¹	91796.55	21.47	214700	122903.45	1.34
S₁₅ B_{1.0}	RDF +15kg S ha ⁻¹ +1.0 kg B ha ⁻¹	96262.35	23.39	233900	137637.65	1.43
S₁₅ B_{1.5}	RDF +15kg S ha ⁻¹ +1.5 kg B ha ⁻¹	100728.20	23.80	238000	137271.80	1.36
S₃₀ B₀	RDF +30 kg S ha ⁻¹ +0 kg B ha ⁻¹	89190.75	21.30	213000	123809.25	1.39
S₃₀ B_{0.5}	RDF +30 kg S ha ⁻¹ +0.5 kg B ha ⁻¹	93896.55	23.08	230800	136903.45	1.46
S₃₀ B_{1.0}	RDF +30 kg S ha ⁻¹ +1.0 kg B ha ⁻¹	98362.35	24.96	249600	151237.65	1.54
S₃₀ B_{1.5}	RDF +30 kg S ha ⁻¹ +1.5 kg B ha ⁻¹	102828.20	24.71	247100	144271.80	1.40
S₄₅ B₀	RDF +45 kg S ha ⁻¹ +0 kg B ha ⁻¹	91290.75	21.64	216400	125109.25	1.37
S₄₅ B_{0.5}	RDF +45 kg S ha ⁻¹ +0.5 kg B ha ⁻¹	95996.55	23.27	232700	136703.45	1.42
S₄₅ B_{1.0}	RDF +45 kg S ha ⁻¹ +1.0 kg B ha ⁻¹	100462.40	25.25	252500	152037.60	1.51
S₄₅ B_{1.5}	RDF +45 kg S ha ⁻¹ +1.5 kg B ha ⁻¹	104928.20	24.88	248800	143871.80	1.37

Input cost

Cost of seed : Rs. 100 kg⁻¹
 10000 q⁻¹
 Cost of Urea : Rs. 5.80 kg⁻¹
 Cost of DAP : Rs. 19.0 kg⁻¹
 Cost of MOP :Rs. 13.0 kg⁻¹
 Cost of Boric acid :Rs. 375.0 kg⁻¹
 Cost of Gypsum :Rs. 8.0 kg⁻¹

Out put cost

Cost of FYM : Rs. 500 ton⁻¹
 Selling price of grains: Rs.
 Cost of labour : Rs. 120 day⁻¹
 Tractorization : Rs. 3000 ha⁻¹

returns of Rs 252500.0 and Rs 152037.60 respectively were recorded with 45 Kg S ha⁻¹ and 1.0 Kg B ha⁻¹ combination. However, maximum benefit cost ratio of 1.54 was recorded with 30 Kg S ha⁻¹ and 1.0 Kg B ha⁻¹ combination.

Chapter – 5

DISCUSSION

The experimental results of the present investigation obtained and described in the previous chapter are discussed here under various headings by providing reasoning in the light of available literature.

5.1 Nodulation attributes of french bean at flowering

Data presented in the table 1 revealed that the nodulation activity increased significantly with the increasing levels of sulphur as compared to control. The maximum number (14.44), fresh weight (119.88 mg) and dry weight (21.48 mg) of nodules plant⁻¹ was recorded with the application of 45 Kg S ha⁻¹ but the nodulation activity was at par with 30 Kg S ha⁻¹. This increase in the nodulation activity with the increasing levels of sulphur could be attributed to concomitant increase in ferridoxin content which is responsible for nodulation activity. Ferridoxins are rich in sulphur and contain Fe-S clusters which play vital role in N₂ fixation (Ali *et al.*, 2004; Duke and Reisenauer, 1986). Similarly, increase in boron application resulted in a significant increase in nodulation activity. The maximum number (15.07), fresh weight (125.42 mg) and dry weigh (22.78) of nodules plant⁻¹ was recorded with the application of 1.5 Kg B ha⁻¹ but being at par with the application of 1 Kg B ha⁻¹. The significant increase in nodulation activity with boron application could be due to increased activity of nitrogenase enzyme and nitrogen fixing bacteria as boron play an essential role during bacterial differentiation by stabilizing the conjugate components of the inner face of peribacteroid membrane (Bolanos *et al.*, 1996). Moreover, in nodules boron apparently plays a structural role in maintaining the integrity of cell wall and membranes (Bolanos *et al.*, 1994) which in turn might have resulted in an increased nodulation activity. Boron and sulphur interaction showed positive and synergistic effect on nodulation activity at lower levels of boron application and the maximum number (17.10), fresh weight (140.09 mg) and dry

weight (24.82 mg) of nodules was recorded with 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹. Higher levels of boron (1.5 Kg ha⁻¹) resulted in antagonistic effect on nodulation activity with 30 and 45 Kg S ha⁻¹. The results obtained are in agreement with the findings of Azevedo *et al.*, 2002; Hamdaoui *et al.*, 2003; Singh *et al.*, 2004; Khanna and Gupta 2005; Singh *et al.*, 2005 and Yakuba *et al.*, 2010).

5.2 Dry matter accumulation

Dry matter accumulation was markedly influenced by sulphur and boron fertilization as presented in Table 2, 3 and 18. Discernible gradual improvement at flowering, pod picking and harvesting stage was observed in this important character due to sulphur application up to 45 Kg ha⁻¹. Higher dry matter accumulation was recorded at flowering (14.77 q ha⁻¹), Pod picking (22.39 q ha⁻¹) as well as harvesting stage (50.89 q ha⁻¹) due to application of 45 Kg S ha⁻¹. The increase in dry matter accumulation due to sulphur application could be attributed to low status of sulphur in the studied soil and its subsequent role in increase in chlorophyll contents and photosynthetic rate that paved the way for increased dry matter production (Juszczuk and Ostaszewska, 2011). It was also found that dry matter accumulation recorded significant improvement at flowering (14.99 q ha⁻¹), pod picking (23.10 q ha⁻¹) and harvesting (51.68 q ha⁻¹) up to 1.5 Kg B ha⁻¹. The significant increase in dry matter accumulation may be attributed to low status of boron in the studied soil. Boron and sulphur interaction showed positive and synergistic effect on dry matter accumulation at lower levels of boron application and the maximum dry matter accumulation at flowering (17.08 q ha⁻¹), pod picking (26.01 q ha⁻¹) and harvesting (53.91) was recorded with 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹. Higher levels of boron (1.5 Kg ha⁻¹) showed antagonistic effect on dry matter accumulation with 30 and 45 Kg S ha⁻¹. The results obtained are in tune with the findings of Yang *et al.*, 1998; Singh *et al.*, 2003; Khanna and Gupta 2005.

5.3 Yield and yield attributing characters

The ultimate test to judge the performance or efficiency of a particular treatment is yield. In the present study, it was found that yield and yield attributing characters recorded significant and consistent increase with increase in levels of sulphur and boron (Table 4, 16 and 17). The significant increase in the yield attributing characters like number of pods plant⁻¹ (9.07), number of seeds pod⁻¹ (6.03) and 100 seed weight (28.78) with increasing levels of sulphur to 45 Kg ha⁻¹ could be due its role in synthesis of sulphur containing amino acids, proteins and enhanced photosynthetic activity of plant with increased chlorophyll synthesis (Juszczuk and Ostaszewska, 2011). Similarly, application of sulphur increased pod yield at pod picking stage (93.70 q ha⁻¹) and seed (23.76 q ha⁻¹) and stover yield (38.83 q ha⁻¹) at harvesting stage of the crop significantly up to 45 Kg ha⁻¹, however, the results were at par to 30 Kg ha⁻¹. The improvement in yield due to increase in sulphur levels might be due to its important role in energy transformation, activation of enzymes and carbohydrate metabolism (Davidian and Kopriva, 2010; Juszczuk and Ostaszewska, 2011). Boron application showed significant increase in yield attributes of the crop and the maximum increase was recorded with 1.5 Kg B ha⁻¹ which was at par to 1.0 Kg B ha⁻¹. The significant increase in yield attributes may be attributed partly to the low status of boron in the soil under study and partly to the greater requirement of the nutrient by the crop. Similarly the improvement in pod (94.63 q ha⁻¹), seed (24.17 q ha⁻¹) and stover yield (39.15) with boron application up to 1.5 Kg ha⁻¹ may be due to its role in regulation of carbohydrate metabolism and its transport within the plant besides the synthesis of amino acids and proteins and fruit and seed setting (Debnath and Ghosh, 2011). The interaction between sulphur and boron revealed a synergistic influence on yield attributing characters and yield which were observed to be highest at 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹. Higher levels of boron (1.5 Kg ha⁻¹) showed antagonistic effect on yield attributing characters as well as pod and seed

yield with 30 and 45 Kg S ha⁻¹. The results obtained are in line with the findings of Singh *et al.*, 2002; Prasad and Prasad, 2003; Nasreen and Farid, 2003; Khanna and Gupta, 2005 and Kumar and Singh 2009).

5.4 Crude protein content of french bean

The study revealed a marked increase in the crude protein content of both french bean pods at pod picking stage and seeds at harvesting stage due to sulphur and boron application as presented in Table 15 and 29. The significant increase in the crude protein content in pods (1.77 percent) at pod picking stage and seeds (21.08 percent) at harvesting stage of the crop with application of sulphur up to 45 Kg ha⁻¹ being at par with the application of 30 Kg ha⁻¹ may be ascribed to the fact that it is a constituent of cysteine, methionine and a variety of other metabolites like glutathione, phyto-chelatins, ferredoxin, thioredoxin as well as formation of clusters with iron which plays a role in crucial processes in the plant cell, such as biosynthesis, assembly and activity regulation of proteins (Droux, 2004; Nikiforova *et al.*, 2004; Davidian and Kopriva, 2010). Similarly the crude protein content in pods (1.75 percent) as well as seeds (20.81 percent) of the crop increased significantly with the application of boron up to 1.5 Kg ha⁻¹, being at par to 1.0 Kg ha⁻¹. The significant increase in protein content in pod as well as seed by boron application could be attributed to the vital role of boron in protein and nucleic acid metabolism (Debnath and Ghosh, 2011). The interaction between sulphur and boron revealed a synergistic influence on crude protein content in pods and seeds which was observed to be highest at 45 Kg S ha⁻¹ application in combination with 1.0 Kg B ha⁻¹. Higher levels of boron (1.5 Kg ha⁻¹) showed antagonistic effect on crude protein content with 30 and 45 Kg S ha⁻¹. Current study corroborates the findings of Singh *et al.*, 1988; Singh and Yadav, 1997; Aulakh and Pasricha, 1997; Hussein, 2002; Khanna and Gupta, 2005; Nadian *et al.*, 2010 and Deshbhratar *et al.*, 2010.

5.5 Nitrogen content and uptake

The present study revealed a marked increase in the nitrogen content and uptake of plant at pod picking as well as harvesting stages with the application of sulphur and boron as presented in Table 5, 10, 19 and 24. The significant increase in the nitrogen content at pod picking and harvesting stage of the crop with the application of sulphur up to 45 Kg ha⁻¹ being at par to 30 Kg ha⁻¹ could be attributed to the increase in the number and size of nodules which in turn increase the nitrogen fixation by the plant and also due to utilization of carbohydrates for protein synthesis (Ganeshamurthy and Reddy, 2000). Nitrogen uptake also followed the similar trend as nitrogen content registered marked increase with increase in sulphur level up to 45 Kg ha⁻¹. In fact, uptake at harvest is the product of dry matter yield and respective nutrient content and since both dry matter and nitrogen content showed significant improvement with the increase in levels of sulphur and hence the increase in nitrogen uptake. Similarly, application of boron also improved nitrogen content at pod picking and harvesting stage of the crop up to 1.5 Kg ha⁻¹ level, being at par to 1 Kg ha⁻¹. The increase in the nitrogen content with the increase in boron application could be attributed to increase in nodule activity (Yakuba *et al.*, 2010). Moreover, application of boron in boron deficient soil might have resulted in increased availability of boron which in turn has influenced DNA and protein synthesis leading to increased nitrogen content and uptake (Debnath and Ghosh, 2011). Boron and sulphur interaction showed positive and synergistic effect on nitrogen content and uptake in plant at pod picking and harvesting stage which was observed to be highest at at lower levels of boron application and the maximum was recorded with 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹. Higher levels of boron (1.5 Kg ha⁻¹) resulted in antagonistic effect on nitrogen content and uptake at pod picking and harvesting stage with 30 and 45 Kg S ha⁻¹. The above results are in concurrence with the reports of Zhao *et al.*, 1999; Hussein, 2002; Bonilla *et al.*, 2004 and Najjar *et al.*, 2011.

5.6 Phosphorus content and uptake

The study revealed a marked increase in the phosphorus content and uptake of plant at pod picking as well as at harvesting stage with the application of sulphur and boron as presented in Table 6, 11, 20 and 25. Phosphorus content increased significantly at pod picking and harvesting stages with the application of sulphur up to 45 Kg ha⁻¹, being at par to 30 Kg ha⁻¹. This could be attributed to the favourable effect of sulphur fertilization on phosphorus absorption, as sulphur mobilizes soil phosphorus in available form for plant use due to the action of acid produced by the added sulphur (Singh *et al.*, 2006) and thereby, increased phosphorus content and uptake. Similarly, application of boron also improved phosphorus content at pod picking and harvesting stage up to 1.0 Kg ha⁻¹, being at par with 1.5 Kg ha⁻¹. The increase in the phosphorus content with the increase in boron application could be due to favourable influence of boron on various metabolic processes which augments the production of metabolites and their translocation to different parts including seed which ultimately increases the concentration of nutrients in seed and stover. Uptake of phosphorus at pod picking stage increases up to 1.0 Kg B ha⁻¹ but at harvesting stage uptake of phosphorus increases up to 1.5 Kg B ha⁻¹ which is because of greater increase in dry matter at harvesting stage up to 1.5 Kg B ha⁻¹. The interaction between sulphur and boron revealed a synergistic influence on phosphorus content and uptake by plant at pod picking and harvesting stage which was observed to be highest at 45 Kg ha⁻¹ of sulphur application in combination with 1.0 Kg ha⁻¹ of boron. However, the interaction becomes antagonistic at higher levels of boron (1.5 Kg ha⁻¹) with 30 and 45 Kg S ha⁻¹. The above results are in close conformity with the reports of Jat and Mehra, 2007; Bharathi and Poongothai, 2008; Chander *et al.*, 2010 and Najar *et al.*, 2011.

5.7 Potassium content and uptake

The study revealed a marked increase in the potassium content and uptake by plant at pod picking as well as harvesting stages with the application of sulphur and boron as presented in Table 7, 12, 21 and 26. Potassium content increased at pod picking as well as harvesting stage of the crop with the application of sulphur up to 45 Kg ha⁻¹, being at par to 30 Kg ha⁻¹. But the increase in potassium content of seeds at harvesting stage was non significant. Uptake of potassium increased significantly at pod picking as well as harvesting stage up to 45 Kg S ha⁻¹ and remained at par to 30 Kg S ha⁻¹. The increase in the content and uptake of potassium by sulphur fertilization could be attributed to improved nutritional environment both in the rhizosphere and the plant system. The increased availability of the nutrients in the root zone coupled with increased metabolic activity may have increased their absorption, accumulation and uptake subsequently (Jat and Mehra, 2007). Similarly, potassium content increased at pod picking stage of the crop with the application of boron up to 1.0 Kg ha⁻¹, being at par with 1.5 Kg ha⁻¹. But the increase in potassium content of seeds at harvesting stage was non significant. Uptake of potassium increased significantly at pod picking and harvesting stage up to 1.0 Kg B ha⁻¹ and remained at par to 1.5 Kg B ha⁻¹. The increase in the content and uptake of potassium by boron fertilization could be attributed to better growth of crop resulting in greater absorption of nutrients from soil leading to its higher content and uptake. The interaction between sulphur and boron revealed a synergistic influence on potassium content and uptake in plant at pod picking and harvesting stage. Potassium content and uptake was observed to be highest at 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹. However, the interaction becomes antagonistic at higher levels of boron (1.5 Kg ha⁻¹) with 30 and 45 Kg S ha⁻¹. The above results are in conformity with the reports of Jat and Mehra, 2007; Bharathi and Poongothai, 2008 and Najjar *et al.*, 2011.

5.8 Sulphur content and uptake

The study revealed a marked increase in the sulphur content and uptake by plant at pod picking as well as harvesting stages with the application of sulphur and boron as presented in Table 8, 13, 22 and 27. The significant increase in the sulphur content and uptake at pod picking stage and harvesting stage of the crop with the application of sulphur up to 45 Kg ha⁻¹, being at par to 30 Kg ha⁻¹ could be ascribed to rapid absorption and translocation of sulphur by plant with adequate supply of sulphur from the soil (Shrivastava *et al.*, 2000) leading to improved sulphur content and uptake subsequently by the crop. Similarly, application of boron also improved sulphur content and uptake at pod picking and harvesting stage of the crop up to 1.5 Kg ha⁻¹, being at par to 1.0 Kg ha⁻¹. The increase in the sulphur content with the increase in boron application could be attributed to better growth of crop resulting in greater absorption of nutrients from soil leading to its higher content and uptake. The interaction between sulphur and boron revealed a synergistic influence on sulphur content and uptake in plant at pod picking and harvesting stage. Sulphur content and uptake was observed to be highest at 45 Kg S ha⁻¹ in combination with 1 Kg B ha⁻¹. However, the interaction becomes antagonistic at higher levels of boron (1.5 Kg ha⁻¹) with 30 and 45 Kg S ha⁻¹. The above results are in close conformity with the reports of Jat and Mehra, 2007; Karthikeyan and Shukla, 2008 and Najar *et al.*, 2011.

5.9 Boron content and uptake

Boron content and uptake at pod picking and harvesting stage of the crop showed significant improvement with increase in levels of sulphur and boron as presented in the Table 9, 14, 23 and 28. The significant increase in the boron content and uptake at pod picking and harvesting stage of the crop with the application of sulphur up to 45 Kg ha⁻¹, being at par to 30 Kg ha⁻¹ could be attributed to improved nutritional environment both in the rhizosphere and the plant system. The increased availability of the nutrients in the root zone coupled with increased metabolic activity

may have increased their absorption, accumulation and uptake subsequently (Jat and Mehra, 2007). Similarly, application of boron improved boron content at pod picking and harvesting stage of the crop up to 1.5 Kg ha⁻¹, being at par to 1.0 Kg ha⁻¹. The increase in the boron content with the increase in levels of boron could be attributed to increased concentration of B in soil. The interaction between sulphur and boron revealed a synergistic influence on boron content and uptake in plant at pod picking stage and harvesting stage. Boron content and uptake was observed to be highest at 45 Kg S ha⁻¹ in combination with 1 Kg B ha⁻¹. However, the interaction becomes antagonistic at higher levels of boron (1.5 Kg ha⁻¹) with 30 and 45 Kg S ha⁻¹. The above results are in close conformity with the reports of Singh *et al.*, 2004 and Chander *et al.*, 2010.

5.9 Soil pH, electrical conductivity and organic carbon content of soil

Soil pH was markedly influenced by application of sulphur but was not affected by boron application. Moreover, the effect of sulphur and boron application on electrical conductivity and organic carbon was non-significant (Table 30).

Soil pH dropped significantly and consistently by increasing levels of sulphur to 45 Kg ha⁻¹. The decrease in soil pH due to sulphur application may be attributed to oxidation of applied sulphur and subsequent production of acid, resulting in reduction of soil pH (Motior *et al.*, 2011). Interaction of sulphur and boron presented no effect on soil pH, electrical conductivity as well as organic carbon content.

5.10 Forms of sulphur in soil

The application of sulphur to 45 Kg ha⁻¹ revealed significant effect on the forms of sulphur in soil (Table 31). All the forms of sulphur increased significantly with increasing levels of sulphur except non sulphate sulphur which decreased by the application of sulphur. This could be attributed to the fact that increase in sulphur application may have increased its availability in soil which may have increased the forms of sulphur in soil. Besides, application of sulphur decreased soil pH and the

correlation between soil pH and total, organic, sulphate and adsorbed sulphur is negative but with non-sulphate sulphur the correlation is positive (Akhter, 1997). Hence total, organic, sulphate and adsorbed sulphur increased and non-sulphate sulphur decreased with increase in sulphur application. Among different forms of sulphur in soil, the application of boron increased sulphate sulphur only and had no effect on forms of sulphur in soil and sulphur and boron had no interaction effect on sulphur forms in soil.

5.11 Forms of boron in soil

The application of boron to 1.5 Kg ha⁻¹ revealed significant effect on the forms of boron in soil (Table 32). Both total and hot water soluble boron increased significantly with increasing levels of boron. Hot water soluble boron was significantly affected by increasing levels of sulphur to 45 Kg ha⁻¹. The increase in total boron and hot water soluble boron could be attributed to the basal application of boron. Interaction of sulphur and boron revealed significant effect only on hot water soluble boron and was observed to be highest at 45 Kg S ha⁻¹ in combination with 1.5 Kg B ha⁻¹. Similar findings have been reported by Singh *et al.*, 2004; Singh *et al.*, 2006; Jena *et al.*, 2006; Jat and Mehra, 2007; Bharathi and Poongothai 2008; Kushwaha *et al.*, 2009 and Chander *et al.*, 2010).

5.12 Relative economics

The efficiency of a treatment is finally decided in terms of economics (returns and benefit- cost ratio) of that treatment. The present investigation revealed that the highest gross and net returns were obtained with the application of 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹. However, benefit-cost ratio remained highest with the combination 30 Kg S ha⁻¹ and 1.0 Kg B ha⁻¹ which was followed by the combination of 45 Kg S ha⁻¹ and 1.0 Kg B ha⁻¹ (Table 35).

Chapter – 6

SUMMARY AND CONCLUSION

Field experiment was conducted at Research Field of Regional Research Station Wadura, Sopore during *Kharif* 2011 with following objectives:

- To study the effect of different levels of sulphur and boron on yield and quality of the crop.
- To work out a suitable combination of Sulphur and boron for optimum yield of the crop.
- To study the effect on the different forms of sulphur and boron after harvesting the crop.

The experiment was laid out in Randomized Block Design during *Kharif* 2011 with four sulphur levels (S_0 -0 Kg ha⁻¹, S_{15} -15 Kg ha⁻¹, S_{30} -30 Kg ha⁻¹ and S_{45} -45 Kg ha⁻¹) and four boron levels (B_0 -0 Kg ha⁻¹, $B_{0.5}$ -0.5 Kg ha⁻¹, $B_{1.0}$ -1 Kg ha⁻¹ and $B_{1.5}$ -1.5 Kg ha⁻¹). The plots were given uniform recommended dose of FYM, nitrogen, phosphorus and potassium at the rate of 20 tons ha⁻¹, 30 Kg ha⁻¹, 60 Kg ha⁻¹ and 60 Kg ha⁻¹ respectively.

The soil of the experimental field was clay loam in texture, medium in available nitrogen, phosphorus and potassium and low in available sulphur and boron with neutral pH. The treatment effects on various characters under study have been described in detail in preceding chapters. The important findings are summarized here under:

Effect of sulphur

- Application of 45 Kg S ha⁻¹ significantly increased nodulation attributes at flowering stage, dry matter production at flowering, pod picking and

harvesting stages of french bean over 0 Kg S ha⁻¹ and 15 Kg S ha⁻¹. However, the results were at par with the results obtained at 30 Kg S ha⁻¹ level of sulphur application.

- Pod yield at pod picking stage of the crop and both seed and stover yield at harvesting stage of the crop recorded higher values with the application of sulphur at 45 Kg ha⁻¹ which was significant over 0 Kg S ha⁻¹ and 15 Kg S ha⁻¹. However, the results were at par with the results obtained at 30 Kg S ha⁻¹.
- Nitrogen, Phosphorus, Potassium, Sulphur and boron content and their uptake both at pod picking and harvesting stage registered significantly increasing trend with increasing levels of sulphur from 0 Kg ha⁻¹ to 45 Kg ha⁻¹. However, the results were at par to 30 Kg ha⁻¹ of sulphur application.
- Crude protein content showed significant and consistent increase with increase in the sulphur up to 45 Kg ha⁻¹, which was at par to 30 Kg ha⁻¹ of sulphur application.
- Application of sulphur significantly and consistently reduced pH of soil and increased total, organic, sulphate and adsorbed sulphur up to 45 Kg S ha⁻¹. However non sulphate sulphur was reduced significantly and consistently with sulphur application up to 45 Kg ha⁻¹. Moreover, sulphur application consistently increased hot water soluble boron in soil up to 45 Kg ha⁻¹ but had no effect on total boron in soil.

Effect of boron

- Application of 1.5 Kg B ha⁻¹ significantly increased nodulation attributes at flowering stage, dry matter production at flowering, pod picking and harvesting stages of french bean over 0 Kg B ha⁻¹ and 0.5 Kg B ha⁻¹. However, the results were at par with the results obtained at 1.0 Kg B ha⁻¹

level of boron application.

- Pod yield at pod picking stage of the crop and both seed and stover yield at harvesting stage of the crop recorded higher values with the application of boron at 1.5 Kg B ha⁻¹ which was statistically significant over 0 and 0.5 Kg B ha⁻¹. However, the results were at par with the results obtained at 1. Kg B ha⁻¹.
- Nitrogen, Phosphorus, Potassium, Sulphur and boron content and their uptake both at pod picking and harvesting stage of the crop registered significantly increasing trend with increase in the levels of boron from 0 to 1.5 Kg B ha⁻¹. However, the results were at par to 1.0 Kg ha⁻¹ of boron application.
- Crude protein content showed significant and consistent increase with increase in the boron levels up to 1.5 Kg ha⁻¹, which was at par to 1.0 Kg ha⁻¹ of boron application.
- Application of boron significantly and consistently increased total boron and hot water soluble boron in soil with boron application up to 1.5 Kg ha⁻¹. Moreover, boron application up to 1.5 Kg ha⁻¹ increased sulphate sulphur in soil also but had no effect on other forms of sulphur.

Relative economics

- Gross returns and net returns were highest at 45 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹. However, benefit cost ratio was highest at 30 Kg S ha⁻¹ in combination with 1.0 Kg B ha⁻¹ which was followed by treatment combination of 45 Kg S ha⁻¹ and 1.0 Kg B ha⁻¹.

Conclusion

It was evident from the findings that there was a definite effect of sulphur and boron on yield and quality of french bean. The treatment combination of 45 Kg S ha⁻¹ and 1.0 Kg B ha⁻¹ recorded significantly highest dry matter, crude protein content of

Pods as well as seeds of french bean but remained statistically at par with treatment combination of 30 Kg S ha⁻¹ and 1.0 Kg B ha⁻¹. Highest pod as well as seed and stover yield was obtained with combination of 45 Kg S and 1.0 Kg B ha⁻¹ but was at par with treatment combination of 30 Kg S ha⁻¹ and 1.0 Kg B ha⁻¹. From economic point of view, the treatment combination of 45 Kg S ha⁻¹ and 1.0 Kg B ha⁻¹ gave the highest gross returns and net returns, however, highest benefit cost ratio was obtained at combination of 30 Kg S ha⁻¹ and 1.0 Kg B ha⁻¹. Hence in the light of the experimental findings, it may be concluded that among various treatment combinations, 45 Kg S ha⁻¹ with 1.0 Kg B ha⁻¹ showed better response with respect to pod yield, fresh and dry weight of plant, seed yield, protein content, nutrient concentration of pea grains, nutrient uptake and nodulation of french bean, besides being economic as well. Thus, the results of the study lead to conclusion that for realizing higher yield and quality of french bean on inceptisols under temperate conditions of Kashmir valley, the nutrient management must centre around 45 Kg S and 1.0 Kg B ha⁻¹, along with recommended dose of nitrogen (30 Kg ha⁻¹), phosphorus (60 kg ha⁻¹), potassium (60 kg ha⁻¹) and farm yard manure (20 ton ha⁻¹). All the same the results obtained during the present course of investigation have generated quite useful information which could be exploited advantageously for future detailed investigations to be carried out on field at various locations.

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CERTIFICATE

Certified that all the corrections/amendments as suggested by External Examiner Dr. Anil Sharma, Senior Scientist, Central Institute of temperate Horticulture, Rangreth, Srinagar during Viva-Voce examination held on 19-06-2012 have been incorporated in the manuscript entitled “**Effect of Different Levels of Sulphur and Boron on Yield and Quality of French bean (*Phaseolus vulgaris* L.) Var. Contendor in Eutrochrepts**” submitted by **Mr. Mumtaz Ahmad Ganie (Regd. No. 2010-A-860-M)**.

(Dr. Farida Akhter)
Chairman
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