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SULPHUR AND BORON APPLICATION TO FRENCH BEAN (*Phaseolus vulgaris* L.) UNDER INCEPTISOLS OF KASHMIR – ECONOMIC FEASIBILITY AND IMPACT ON SOIL NUTRIENT STATUS

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ABSTRACT

An experiment was conducted at SKAUST-K, Wadura (Kashmir) during *kharif* (summer) 2011 to study the response of French bean (*Phaseoulus vulgaris*) to various levels of sulphur and boron, applied in the form of gypsum and boric acid, respectively. The treatment combination 45 kg S + 1.0 kg B ha^{-1} gave significantly higher seed and stover yield showing 27.1 and 40.8% increase, respectively, over control. This treatment also gave maximum gross and net returns while treatment combination of 30 kg S and 1.0 kg B ha^{-1} gave maximum returns per rupee. The soil pH was significantly reduced with the application of 45 kg S ha^{-1}, however sulphur and boron had no effect on soil electrical conductivity and organic carbon. Significantly higher total-, organic-, SO_4- and adsorbed- sulphur was in soils where S @ 45 kg ha^{-1} was applied. The non-sulphate S was significantly reduced with increasing S level. Boron had no effect on the forms of S, except SO_4-S which showed significant increase with 1.5 kg B. Also, 1.5 kg B had significantly higher total boron content. The treatment combination 45 kg S and 1.5 kg B showed higher available soil nutrients *viz.*, nitrogen, phosphorus, potassium, sulphur and boron.

Key words: Boron forms, economics, *Phaseolus vulgaris*, suphur forms, yield

INTRODUCTION

French bean (*Phaseolus vulgaris* L.) belongs to the family Leguminosae and occupies a premier place among grain legumes in the world, including India (Sharma *et al*., 1994). Sulphur is 4th major element, essential for plant growth and development. Its requirement is high in oilseed and legume crops, but is mostly considered as a forgotten secondary nutrient in crop production (Bharathi and Poongothai, 2008). Among the families of crop plants, the sulphur requirement decreases in the order: cruciferaceae > leguminaceae > graminaceae with sulphur content in their seeds varying from 1.10 to 1.70, 0.24 to 0.32 and 0.12 to 0.20%, respectively (Singh, 2001). Shrivastava *et al*. (2000) reported sulphur deficiency in Inceptisols of Kashmir valley and attributed it to be the main limiting factor in pulse and oilseed crops production.

Sulphur is found in various amino acids (Cys and Met), oligopeptides (glutathione and phytochelatins), vitamins and cofactors (biotin, thiamine, CoA and S-adenosyl-Met), and a variety of secondary products (Leustek, 2000). Further, it helps in many metabolic and enzymatic processes like photosynthesis, respiration and symbiotic nitrogen fixation (Rao *et al*., 2001). Sulfur can be used as a nutrient and an acidifier (Lindemann *et al*., 1991). The acidity produced during sulphur oxidation enhances the availability of other macronutrients like P, Mn, Ca and SO_4 in soils (Lindermann *et al*., 1991), which, in turn, improves soil physico-chemical characteristics (Wainwright, 1984). Sulfur fertilization is relatively inexpensive and its use substantially enhances crop yield and quality. Little is known about the uptake pattern and metabolism of sulfur fertilizers applied to soil as well as metabolic needs for plant growth in relation to nutrient uptake. The nutrient interaction is of great importance because decline in sulfur supply from the atmosphere has already caused substantial losses of nitrogen from agro-ecosystems to the environment (Motior *et al*., 2011).

Most fine and coarse textured soils are considered to be low in available boron and reportedly a boron level of <1 mg kg^{-1} is insufficient for optimum plant growth (Reisenaure *et al*., 1973). Boron plays a key role in reproductive processes affecting anther development, pollen germination and pollen tube growth (Loomis and Durst, 1992). Boron application increases uptake of primary nutrients (Ganie *et al*., 2014), available soil nitrogen in pulse crops as well as nodulation activity (Yakuba *et al*., 2010). Keeping in view the importance of sulphur and boron in pulse crops and their limited availability in inceptisols, the present study was aimed to assess the effect of sulphur and boron on residual soil nutrient availability and their economic impact on French bean production.

MATERIALS AND METHODS

A field experiment was conducted in *kharif* (summer) season 2011 at the Regional Research Station, SKUAST-Kashmir, Wadura on a clay loam soil belonging to the taxonomic class *Eutrochrepts*. The soil at the experimental site was neutral in reaction and high in organic carbon content (1.3%). The NPK content in soil was medium but sulphur and boron content was low. Besides, the CEC of soil was 15 cmol kg^{-1}. The climate of experimental site is temperate with mild summers and cold winters with wide variation in mean maximum and minimum temperatures. The experiment was laid out in a factorial randomized block design with each treatment replicated three times. The treatments comprised of four levels of sulphur (0, 15, 30 and 45 kg ha^{-1}) and four levels of boron (0, 0.5, 1.0 and 1.5 kg ha^{-1}). The experimental field was divided into 48 plots of size 3.0 m × 3.0 m. The sulphur and boron fertilizers were applied in the form of gypsum and boric acid, respectively, at sowing time as per treatment. Half the recommended dose of nitrogen (30 kg ha^{-1}) and full dose of phosphorus (60 kg ha^{-1}) and potassium (60 kg ha^{-1}) were applied as basal dose through urea, di-ammonium phosphate and muriate of potash, respectively. Remaining nitrogen was top-dressed when true leaves emerged (25 days after sowing). French bean var. 'Contendor' seeds were sown on 8th June 2011 and all other cultural practices were followed as per the recommended package of practices. Crop was harvested on 5th September 2011. The seed was harvested from 16 undisturbed plants (net area = 0.5 m^2) from each plot and the seed and stover was weighed after proper drying. Gross returns, net returns and benefit-cost ratio were calculated on the basis of the cost of cultivation *viz.*, land preparation, seed, fertilizer, labour and market value of harvested seed.

Composite soil samples were taken from the experimental field prior to the start of experiment and after crop harvest as per the treatment. The soils were dried in shade, ground in a mortar and pestle, sieved through 2 mm sieve and stored in plastic bottles for physico-chemical analysis. The soil pH was determined in 1:2.5 soil: water suspension as per Jackson (1973), electrical conductivity as per Jackson (1973) and organic carbon as per Walkley and Black (1934). The available nitrogen was estimated by alkaline potassium permanganate method (Subbiah and

Asija, 1956), phosphorus by extraction with 0.5 M $NaHCO_3$ as per Olsen *et al*. (1954) and potassium by extraction with neutral normal ammonium acetate method (Jackson, 1973). The various forms of sulphur *viz.*, total-, organic-, SO_4-, adsorbed- and non- SO_4-sulphur and hot water soluble boron and total boron were determined. The total sulphur was estimated by the method of Bardsley and Lancaster (1960) wherein soil samples were fused with Na_2CO_3 and $NaNO_3$ in a platinum crucible at 950°C in a muffle furnace till complete ashing. The samples were shaken with distilled water and specific volumes made. The soil extract (25 mL) was brought to near dryness, taken up in 5 mL 6N HCl treated with 1 mL 1% $FeCl_3$ and 1 mL 40% NaOH solution to precipitate out interfering soil colloids (Hesse, 1957) and acidified by 1 mL glacial acetic acid and sulphur determined after developing turbidity with $BaCl_2$ crystals on a spectrophotometer at a wavelength of 420 nm (Chesnin and Yein, 1951). For organic sulphur determination, the soil samples were digested as per Williams and Steinbergs (1959), leached with distilled water and then with 10% HCl to remove SO_4-sulphur and finally washed with distilled water to remove excessive HCl until no chlorides were present. The soil was evaporated to dryness after adding H_2O_2 and 1% NaOH solution to cooled mixture and shaken for 30 min. The organic sulphur was determined in the same way as total sulphur. SO_4-sulphur was extracted (Williams and Steinberg, 1959) and determined turbidimetrically (Chesnin and Yien, 1951). Adsorbed-sulphur was determined by shaking the soil with 500 ppm potassium dihydrogen phosphate (Ensminger, 1954). The non-SO_4-sulphur was estimated by subtracting organic-, SO_4- and adsorbed-sulphur from the total sulphur. Hot water soluble boron was determined as per Berger and Truog (1940). The total boron was extracted by fusing 1 g soil with Na_2CO_3 through heating on a Bunsen burner in a platinum crucible and the contents extracted with 4N H_2SO_4 (Tan, 2005). The data was statistically analyzed as per the standard methods (Panse and Sukhatme, 1978). The significance of 'F' test was tested at 5% level of significance (Fisher, 1970) and OPSTAT software was used for data analysis.

RESULTS AND DISCUSSION

Effect on seed and stover yield

The yield is ultimate test to judge the performance of a particular treatment. In present study, the interaction between sulphur and boron showed a synergistic effect on yield which was highest in treatment combination 45 kg S and 1.0 kg B ha^{-1}. The highest level of boron (1.5 kg ha^{-1}) showed antagonistic effect on seed and stover yield with 30 and 45 kg S ha^{-1} (Table 1). The significant increase in yield due to sulphur reflects its possible role in the synthesis of S-containing amino acids, proteins and enhanced photosynthetic activity of plant with increased chlorophyll synthesis (Juszczuk and Ostaszewska, 2011). Sulphur is also involved in energy transformation, activation of enzymes and carbohydrate metabolism (Davidian and Kopriva, 2010; Juszczuk and Ostaszewska, 2011). Boron application increased both seed and stover yield which may be attributed partly to the low status of boron in soil under study and partly to the greater requirement of nutrients by crop. Moreover, boron regulates carbohydrate metabolism and its transport within the plant besides the synthesis of amino acids and proteins and fruit and seed setting (Ganie *et al*., 2013). The treatment combination 45 kg S + 1.0 kg B gave maximum seed (25.25 q ha^{-1}) and stover yield (41.12 q ha^{-1}). The higher levels of B (1.5 kg ha^{-1}) showed antagonistic effect on seed and stover yield with 30 and 45 kg S ha^{-1}. The findings are in line with Nasreen and Farid (2003) and Kumar and Singh (2009).

The efficiency of a treatment is finally decided in terms of economics (returns and benefit-cost ratio) of that particular treatment. The study revealed highest gross and net returns of ₹ 2,52,500 and 1,52,037, respectively, in treatment combination of 45 kg S + 1.0 kg B ha^{-1}. However, maximum benefit: cost ratio of 1.54 was recorded with treatment combination of 30 kg S and 1.0 kg B ha^{-1} followed by the combination of 45 kg S and 1.0 kg B ha^{-1} (Table 1).

Table 1: Effect of sulphur and boron use on yield and economics of French bean

Treatment	Seed yield (q ha^{-1})	Stover yield (q ha^{-1})	Cost of cultivation (₹)	Gross returns (₹)	Net returns (₹)	B:C ratio
S_0B_0	19.86	29.20	84750.75	198600	113849.25	1.34
$S_0B_{0.5}$	20.75	33.44	89456.55	207500	118043.45	1.32
$S_0B_{1.0}$	23.03	35.24	93922.35	230300	136377.65	1.45
$S_0B_{1.5}$	23.30	35.70	98388.15	233000	134611.85	1.37
$S_{15}B_0$	20.34	30.88	87090.75	203400	116309.25	1.34
$S_{15}B_{0.5}$	21.47	35.69	91796.55	214700	122903.45	1.34
$S_{15}B_{1.0}$	23.39	39.28	96262.35	233900	137637.65	1.43
$S_{15}B_{1.5}$	23.80	39.77	100728.20	238000	137271.80	1.36
$S_{30}B_0$	21.30	35.57	89190.75	213000	123809.25	1.39
$S_{30}B_{0.5}$	23.08	37.37	93896.55	230800	136903.45	1.46
$S_{30}B_{1.0}$	24.96	40.69	98362.35	249600	151237.65	1.54
$S_{30}B_{1.5}$	24.71	40.28	102828.20	247100	144271.80	1.40
$S_{45}B_0$	21.64	35.86	91290.75	216400	125109.25	1.37
$S_{45}B_{0.5}$	23.27	37.48	95996.55	232700	136703.45	1.42
$S_{45}B_{1.0}$	25.25	41.12	100462.40	252500	152037.60	1.51
$S_{45}B_{1.5}$	24.88	40.84	104928.20	248800	143871.80	1.37
$CD_{0.05}$	1.09	1.27	-	-	-	0.04

Input cost: Cost of seed =: ₹ 100 kg^{-1}; cost of MOP = ₹ 13.0 kg^{-1}; cost of FYM = ₹ 500 ton^{-1} ; cost of urea = ₹ 5.80 kg^{-1} ; cost of boric acid = ₹ 375.0 kg^{-1}; cost of labour = ₹ 120 day^{-1}; cost of DAP = ₹ 19.0 kg^{-1}; cost of gypsum = ₹ 8.0 kg^{-1}; tractorization = ₹ 3000 ha^{-1}

Output cost: Selling price of harvested seeds = ₹ 1000 q^{-1}

Effect on some soil chemical properties

The increasing sulphur levels significantly decreased soil pH in comparison to control, however all S treatments, except control, were at par (Fig. 1). There was a slight insignificant increase in both electrical conductivity and soil organic carbon with increase in sulphur application. Further, the increasing levels of boron non-significantly decreased soil pH (Fig. 1). Boron application negligibly affected soil electrical conductivity and organic carbon after crop harvest. The interaction of

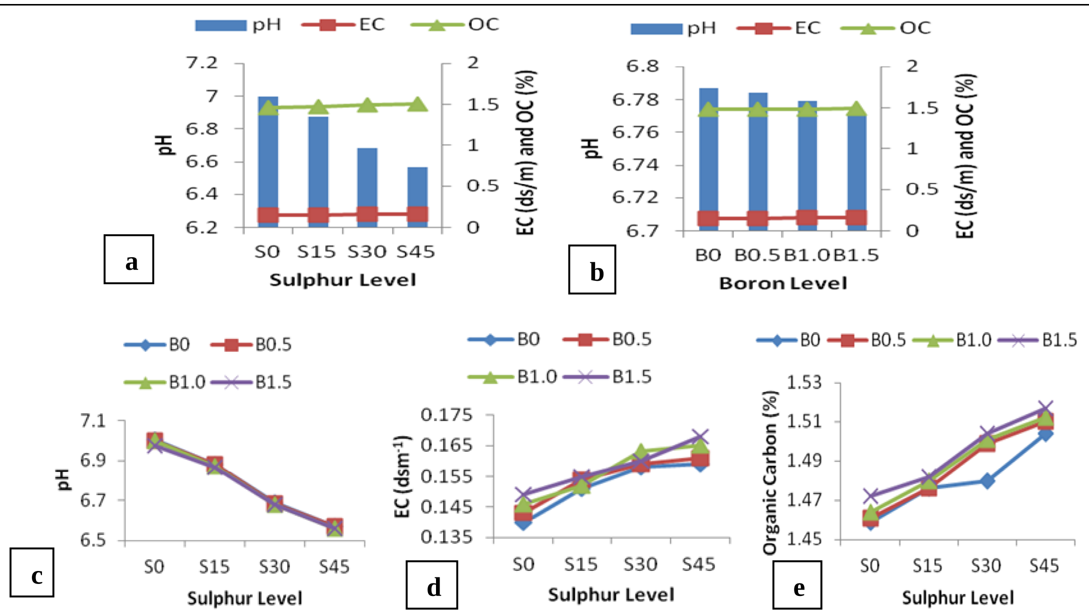

Fig. 1: Effect of a) sulphur, b) boron, and c, d & e) sulphur x boron interaction on physico-chemical properties of soil after crop harvest

Table 2: Effect of sulphur and boron on forms of sulphur in soil after crop harvest

Sulphur levels (kg ha^{-1})	Total S (ppm)	Organic-S (ppm)	SO_4-S (ppm)	Adsorbed-S (ppm)	Non-sulphate-S (ppm)
S_0	141.12	121.64	4.96	4.08	10.44
S_{15}	144.22	124.98	9.04	4.42	8.77
S_{30}	148.36	125.60	9.60	4.43	8.73
S_{45}	153.18	130.21	11.19	4.59	7.20
$CD_{0.05}$	7.04	6.58	0.70	0.49	2.84
B_0	146.05	124.91	8.37	9.59	9.59
$B_{0.5}$	146.45	125.44	8.54	8.99	8.99
$B_{1.0}$	146.80	125.68	8.78	8.60	8.60
$B_{1.5}$	147.58	126.40	9.09	7.97	7.97
$CD_{0.05}$	Ns	ns	0.70	ns	ns
S_0 B_0	140.76	120.98	4.36	3.96	11.46
S_0 $B_{0.5}$	140.98	121.43	4.53	4.02	11.00
S_0 $B_{1.0}$	141.18	121.86	5.12	4.13	10.07
S_0 $B_{1.5}$	141.56	122.29	5.83	4.21	9.23
$S_{15}B_0$	143.13	124.43	8.89	4.19	9.54
S_{15} $B_{0.5}$	144.00	124.73	9.00	4.31	9.14
S_{15} $B_{1.0}$	144.54	125.05	9.11	4.58	8.62
S_{15} $B_{1.5}$	145.21	125.69	9.14	4.60	7.78
S_{30} B_0	147.72	125.06	9.42	4.13	9.11
S_{30} $B_{0.5}$	147.96	125.42	9.57	4.33	8.64
S_{30} $B_{1.0}$	148.33	125.60	9.66	4.47	8.60
S_{30} $B_{1.5}$	149.43	126.32	9.75	4.79	8.57
S_{45} B_0	152.59	129.18	10.82	4.36	8.23
S_{45} $B_{0.5}$	152.87	130.16	11.07	4.46	7.18
S_{45} $B_{1.0}$	153.15	130.20	11.22	4.63	7.10
S_{45} $B_{1.5}$	154.11	131.28	11.63	4.91	6.29
$CD_{0.05}$	ns	ns	1.45	ns	ns

sulphur and boron synergistically decreased soil pH with minimum value in treatment combination of 45 kg S + 1.5 kg B ha^{-1} (Fig. 1). The sulphur and boron interaction non-significantly increased both the soil electrical conductivity and organic carbon with maximum increase in treatment combination of 45 kg S + 1.5 kg B ha^{-1} (Fig. 1). Erdal *et al.* (2000) reported a similar decrease in soil pH by 0.11 to 0.37 units due to sulphur application. The decrease in soil pH due to sulphur-use may be attributed to the oxidation of applied sulphur and subsequent production of acid which reduced soil pH (Motior *et al.*, 2011). Neilsen *et al.* (1993) opined that sulfur can be used not only as a nutrient but also as an acidifier. Application of boron as boric acid insignificantly decreased soil pH, perhaps because boric acid is a weak acid. However, boric acid in combination with sulphur significantly reduced soil pH by complementing the effect of sulphur on soil pH.

Residual soil nutrient availability

The application of sulphur and boron increased available soil nutrients like N, P, K, S and B (Fig. 2 & 3). Increase in soil nitrogen may be attributed to the concomitant increase in nodulation activity perhaps due to the improvement in ferridoxin content. Ferridoxins are rich in sulphur and contain Fe-S clusters which play vital role in N_2 fixation (Ali *et al.*, 2004). Boron application also increased soil available nitrogen apparently due to the increase in nodulation activity through high nitrogenase enzyme production. Boron plays an essential role in bacterial differentiation by stabilizing the conjugate components of 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 enhanced the nodulation activity. Sulphur application increases available phosphorus in soil more than that of boron. This could be attributed to the favourable effect of sulphur fertilizers in mobilizing soil phosphorus in available form for plant use due to the action of acids produced by the added sulphur (Singh *et al.*, 2006). The use of both sulphur and boron insignificantly increased available potassium in soil after crop harvest. The increase in available sulphur with sulphur application and available boron with boron application is inevitable. However, the influence of sulphur on available soil boron and vice versa was non-significant. Boron and sulphur interaction depicted positive and synergistic effect on available N, P, K, S and B (Fig. 4) in soil after crop harvest with highest contents observed in treatment combination 45 kg S and 1.5 kg B ha^{-1}.

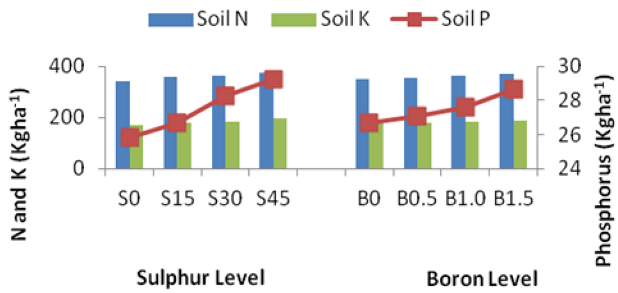

Fig. 2: Individual effects of sulphur and boron fertilization on available N, P and K content in soil after crop harvest

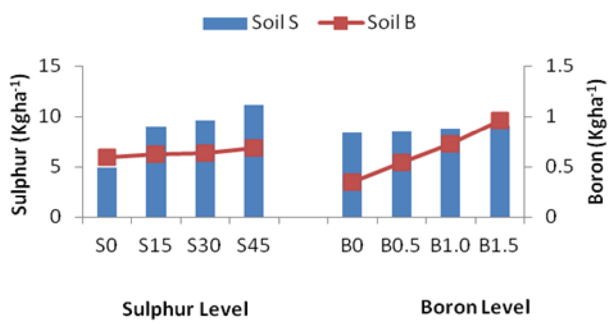

Fig. 3: Individual effects of sulphur and boron fertilization on available S and B content in soil after crop harvest

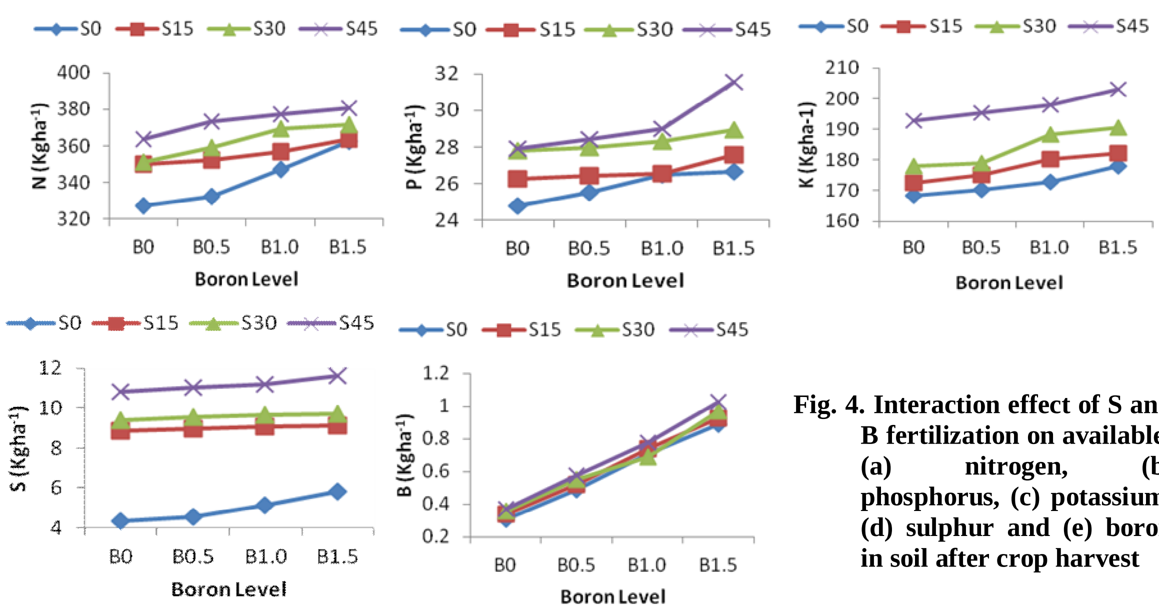

Fig. 4. Interaction effect of S and B fertilization on available: (a) nitrogen, (b) phosphorus, (c) potassium, (d) sulphur and (e) boron in soil after crop harvest

Effect on the forms of sulphur and boron in soil after crop harvest

Increasing levels of sulphur from 0 to 45 kg ha^{-1} significantly influenced all the forms of sulphur in soil (Table 2). The total sulphur increased from 141.12 to 153.18 ppm, organic sulphur from 121.64 to 130.21 ppm, SO_4-sulphur from 4.96 to 11.19 ppm, adsorbed sulphur from 4.08 to 4.59 ppm but significantly decreased non- SO_4 sulphur from 10.44 to 7.20 ppm. The boron application had no effect on total sulphur, organic sulphur, adsorbed sulphur and non- SO_4 sulphur. Contrary to this,

Table 3: Effect of sulphur and boron application on the forms of boron (ppm) in soil after crop harvest

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	$B_{0.5}$	$B_{1.0}$	$B_{1.5}$	
S_0	0.31	0.49	0.71	0.89	0.60	24.06	24.32	24.67	25.31	24.59
S_{15}	0.34	0.52	0.74	0.93	0.63	24.19	24.53	24.90	25.63	24.81
S_{30}	0.36	0.55	0.69	0.97	0.64	24.43	24.71	25.18	25.84	25.04
S_{45}	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	
$CD_{0.05}$	Sulphur (S) = 0.022 Boron (B) = 0.022 S × B = 0.045					Sulphur (S) = ns Boron (B) = 1.22 S × B = ns				

SO_4-sulphur increased significantly from 8.37 ppm in control to 9.09 ppm at 1.5 kg ha^{-1} of boron. Interaction between sulphur and boron exhibited significant influence on SO_4 sulphur only and 45 kg S in combination with 1.5 kg B ha^{-1} registered maximum SO_4 sulphur content (11.63 ppm). 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. The change in various forms of soil sulphur after crop harvest may be attributed to the fact that applied sulphur undergoes microbial transformation into various forms, hence increasing their residual status.

Increasing levels of sulphur from 0 to 45 kg ha^{-1} significantly increased the hot water soluble boron in soil from 0.60 to 0.69 ppm (Table 3). However, the increasing levels of boron significantly improved hot water soluble boron and total boron in soil (Table 3). The hot water soluble and total boron 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. The increase in total boron was significantly superior to 0 kg B ha^{-1} but at par with 0.5 kg B ha^{-1} and 1.0 kg B ha^{-1}. The interaction of sulphur and boron significantly and synergistically increased hot water soluble boron in soil. The maximum hot water soluble boron (1.03 ppm) was observed with a treatment combination of 1.5 kg B ha^{-1} and 45 kg S ha^{-1}.

Conclusion: For realizing economically higher French bean yield on inceptisols under temperate conditions of Kashmir, the nutrient management may 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 t ha^{-1}). But for increasing soil fertility status with respect to the above nutrients sulphur and boron should be applied @ 45 and 1.5 kg ha^{-1}, respectively.

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