Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur

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GOVIND KUMAR NAGAR

Thesis

Master of Science in Agriculture

(Agronomy)

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DEPARTMENT OF AGRONOMY
RAJASTHAN COLLEGE OF AGRICULTURE
Maharana Pratap University of Agriculture and Technology
Udaipur-313001(Raj.)

Maharana Pratap University of Agriculture and Technology
Rajasthan College of Agriculture, Udaipur

CERTIFICATE-I

Dated: /   /2016

This is to certify that **Mr. Govind kumar Nagar** has successfully completed the Comprehensive Examination held on 03/05/2016 as required under the regulation for degree of **Master of Science in Agriculture.**

(Dr. V. Nepalia)
Professor & Head
Department of Agronomy
Rajasthan College of Agriculture
Udaipur-313001 (Raj.)

Maharana Pratap University of Agriculture and Technology
Rajasthan College of Agriculture, Udaipur

CERTIFICATE-II

Dated: /   /2016

This is to certify that the thesis entitled **"Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur"** submitted for the degree of **Master of Science** in Agriculture in the subject of **Agronomy,** embodies bonafide research work carried out by **Mr. Govind Kumar Nagar** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of this thesis was also approved by the advisory committee on   /   /2016.

(Dr. V. Nepalia)
Professor & Head
Department of Agronomy

(Dr. L.N. Dashora)
Major Advisor
Department of Agronomy

(Dr. Anila Doshi)
Dean
Rajasthan College of Agriculture,
MPUAT, Udaipur-313001 (Raj.)

Maharana Pratap University of Agriculture and Technology
Rajasthan College of Agriculture, Udaipur

CERTIFICATE –III

Dated: /   /2016

This is to certify that the thesis entitled **“Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur”** submitted by **Mr. Govind Kumar Nagar** to the Maharana Pratap University of Agriculture and Technology, Udaipur in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture** in the subject of **Agronomy** after recommendation by the external examiner was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination on his thesis has been found satisfactory we therefore, recommended that the thesis be approved.

(Dr. L.N. Dashora)
Major Advisor

(Dr. N.S. Solanki)
Advisor

(Dr. B. Upadhyay)
Advisor

(Dr. N.L. Meena)
DRI, Nominee

(Dr. V. Nepalia)
Professor & Head
Department of Agronomy

Approved

(Dr. R.A. Kaushik)
Director Resident Instructions
Maharana Pratap University of Agriculture and Technology,
Udaipur-313001(Raj.)

Maharana Pratap University of Agriculture and Technology

Rajasthan College of Agriculture, Udaipur

CERTIFICATE-IV

Dated: / /2016

This is to certify that **Mr. Govind Kumar Nagar** student of M.Sc. (Ag.), **Department of Agronomy,** Rajasthan College of Agriculture, Udaipur has made all corrections/ modifications in the thesis entitled **"Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur"** which were suggested by the external examiner and the advisory committee in the oral examination held on / /2016. The final copies of the thesis duly bound and corrected were submitted on / /2016 are enclosed herewith for approval.

(Dr. L.N. Dashora)
Major Advisor

(Dr. V. Nepalia)
Professor & Head
Department of Agronomy
RCA, Udaipur-313001(Raj.)

(Dr. Anila Doshi)
Dean
Rajasthan College of Agriculture
Udaipur-313001 (Raj.)

RESPONSE OF SOYBEAN [*Glycine max* (L.) Merrill] TO MICROBIAL INOCULATION AND SULPHUR

Govind Kumar Nagar*
Research Scholar

Dr. L.N.Dashora**
Major Advisor

ABSTRACT

A field experiment entitled **"Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur"** was conducted during *Kharif* 2015 at Instructional Farm, Department of Agronomy, Rajasthan College of Agriculture, Udaipur. The objectives were, to assess the effect of microbial inoculants on yield and quality, to study the effect of sulphur levels on yield and quality and to work out the economics of the treatments. The treatments consisted of four microbial inoculation (Control, *Rhizobium,* PSB and *Rhizobium* + PSB) and four sulphur levels (0, 20, 40 and 60 kg S ha^{-1}). These sixteen treatments were replicated three times in Factorial Randomized Block Design. The crop was sown on 16th July and harvested on 14th October, 2015.

The results revealed that inoculation of seeds with *Rhizobium,* PSB and *Rhizobium* + PSB, significantly improved growth parameters i.e. plant height at all stage, dry matter accumulation at all stage (30, 60 DAS and at harvest), LAI at 50 DAS, chlorophyll content and primary branches $plant^{-1}$ at harvest. However, the increase in LAI and chlorophyll content with inoculation of *Rhizobium* was found at par with PSB and yield parameters (number of pods $plant^{-1}$, number of seeds pod^{-1}, seed yield g $plant^{-1}$ and seed index) of soybean crop. Consequently inoculating seeds with *Rhizobium* + PSB recorded higher productivity. However, the highest seed, haulm and biological yield (1442.79, 3409.65 and 4852.62 kg ha^{-1}) were obtained with dual inoculation of *Rhizobium* + PSB, representing increase of 577.43, 1288.82 and 1866.68 kg ha^{-1} over no inoculation.

Inoculation of *Rhizobium* + PSB significantly increased N content in seed and haulm. However, PSB and *Rhizobium* + PSB significantly increased P content in seed and haulm. S content in seed and haulm significantly increased with inoculation of *Rhizobium* + PSB over control. All the inoculants significantly increased N, P and S

* Research Scholar, Department of Agronomy, RCA, Udaipur.

** Professor, Department of Agronomy, RCA, Udaipur.

uptake by seed and haulm over no inoculation. Seed inoculation with *Rhizobium* + PSB significantly improved protein content in seed and yield. However, oil content of seeds was reduced significantly with *Rhizobium* + PSB but oil yield significantly improved over control. The highest net return ((₹ 35182 ha^{-1}) with BC ratio (1.71) were realized under dual inoculation.

Application of 40 kg S ha^{-1} significantly increased plant height and dry matter accumulation at all stage (30, 60 DAS and at harvest) which was found at par with 60 kg S ha^{-1}. Leaf area index failed to show significant variation whereas application of 60 kg S ha^{-1} significantly increased the chlorophyll content and primary branches $plant^{-1}$ over control. Application of 60 kg S ha^{-1} significantly increased the yield and yield attributes of the crop in terms of number of pods $plant^{-1}$, number of seeds pod^{-1}, seed yield g $plant^{-1}$, seed index, seed yield (279.10 kg ha^{-1}), haulm yield (385.10 kg ha^{-1}), biological yield (684.90 kg ha^{-1}) and harvest index (7.09 per cent) over control (1051.60, 2691.50, 3720.30 kg ha^{-1} and 28.20 per cent) respectively. The nutrient N and P content in seed and haulm were highest recorded up to application of 60 kg S ha^{-1} and S content in seed and haulm significantly improved over control. N, P and S nutrient uptake by seed, haulm and total by crop were significantly increased with application of 60 kg S ha^{-1} over control. The quality of seed estimated in terms of protein content and yield, oil yield were also improved significantly up to application of 60 kg S ha^{-1}. The economic analysis indicate that application of 60 kg S ha^{-1} was optimum dose as it fetched highest net returns of (₹ 30375 ha^{-1}) and BC ratio (1.50) compared to least net returns of (₹ 21071 ha^{-1}) and BC ratio (1.00) in control.

The combined effect showed that seed inoculation with *Rhizobium* + PSB and application of 60 kg S ha^{-1} recorded highest seed and haulm yield of 1533.33 and 3530.0 kg ha^{-1} with highest net returns and BC ratio of (₹ 37993 ha^{-1} and 1.82).

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1. INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is an important protein and oil seed crop belongs to family Leguminosae. It contains 40-42 per cent high quality protein, 18-20% oil and several other nutrients like calcium, iron etc. It is also rich in polyunsaturated fatty acids like linoleic and oleic. Soybean is preferable for human nutrition due to its high protein content. It is a good source of isoflavones and therefore it helps in preventing heart diseases, cancer and HIVs (Kumar, 2007). Soybean oil is the leading vegetable oil in the world and is used in many industrial applications including biodiesel. Because of its high nutritional value, it is recognized as ‘Golden Bean’.

Soybean can be utilized for food as well as for non food purposes. Food products like oil, soy flour, soymilk, soy paneer, soy nuts, candy sauce, extruded products, fortified traditional products etc. are made from it. Further, it is utilized for manufacturing of ink, cosmetics, bio-diesel, textiles, fibre glass etc. One kg of soybean may yield five to six kg soymilk. Approximate 85 per cent soybean is utilized for oil extraction, 10 per cent for seed and 5 per cent for food purposes.

The annual soybean production in India is 11.64 mt (Government of India 2014) with its area 10.02 m ha and productivity 1062 kg ha^{-1}. Madhya Pradesh is known as the soybean bowl of India, contributing 59 per cent of the country’s soybean production, followed by Maharashtra with 29 per cent contribution and Rajasthan with a 6 per cent contribution. Rajasthan stands third position in terms of area, production and productivity. Area, production and productivity of soybean in Rajasthan 0.92 m ha, 0.95 mt and 1036 kg ha^{-1} (Government of Rajasthan 2014).

In the recent years, continous hike in prices and scarcity of chemical fertilizers had led to search alternative sources for chemical fertilizers. Microbial fertilization like *Rhizobium* and phosphate solubilizers have shown tremendous potentials as these are eco-friendly, low cost, non bulky bio-fertilizers. Use of bio-fertilizers as a source of N and P can minimize dependence on chemical fertilizers. Rhizobium have an enormous potential to fix atmospheric N_2 while, PSB have capacity to solubilize and mobilize P and micro nutrients present in the soil under soybean cultivation.

Biofertilizers are organic sources containing a specific micro-organism which is derived either from the nodules of plant or from soil around root zone. They possess unique ability to fix atmospheric nitrogen either by living symbiotically or non-symbiotically or to transform native soil nutrients such as phosphorus from the unavailable to available form through biological processes. *Rhizobium* plays an important role in increasing availability of nitrogen to the plants and helps in boosting the production through nitrogen fixation. Similarly, inoculation with PSB plays a pivotal role in supplementary phosphorus requirement of crop. Phosphate Solublizing Bacteria (PSB) brings out more amount of fixed or unavailable native phosphorus into soluble and available form to the plants.

Sulphur fertilization in legume and oilseed is of prime importance in exploiting genetic potential of these crops. It is fourth major plant nutrient among the seventeen essential element needed for normal growth and developments of the plants. Continuous use of sulphur free fertilizers, intensification of agriculture with high yielding varieties and use of scarce amount of organics have resulted in sulphur deficiency all over the country. In Rajasthan, Jaipur, Jodhpur and Udaipur districts have been identified as having deficiency of sulphur (Tondon, 1991).

The deficiency of sulphur in soils and crops mainly arise due to intensive cultivation with high yielding varieties, scarce use of organic manures. The rate of depletion of S from soil is faster and heigher when the cropping system includes legumes or oilseed crops. The sulphur requirement per tone production can be taken as 3 to 4 kg for cereals, 8 kg for legumes and 12 kg for oilseed. The sulphur deficiency caused 12-15% reduction in seed yield of soybean as reported by Chandel *et al*. (1989).

Sulphur is essential for chlorophyll formation and plays an important role in the formation of sulphur containing essential amino acids (cysteine, methionine and cystine), biosynthesis of protein and oil, formation of nodulation in legumes and synthesis of several enzymes that regulate the growth of plants. Studies carried out on sulphur nutrition in mustard indicated a considerable increase in yield and quality of oilseeds (Chauhan *et. al*. 2002).

Keeping in view these facts, a field experiment entitled **Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur** was conducted *kharif* 2015 at the Instructional Farm of RCA, Udaipur with the following objectives.

(i) To assess the effect of microbial inoculants on yield and quality.

(ii) To study the effect of sulphur levels on yield and quality.

(iii) To work out the economics of the treatments.

2. REVIEW OF LITERATURE

A review pertaining to research findings on **"Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur**" is presented in this chapter. Since the work done on microbial inoculation and sulphur levels on soybean crop is meagre therefore, the reference on other field crops have also been carefully included to elucidate the point related to present investigation.

2.1 EFFECT OF MICROBIAL INOCULATION

2.1.1 Effect of *Rhizobium*

2.1.1.1 Growth parameters

Malik *et al.* (2006) in a field experiment conducted at the University of Agriculture, Faisalabad, Pakistan found that *rhizobium* inoculants in soybean significantly increased plant height (56.2 cm) and leaf area index (5.95) over control. Shahid *et. al*. (2009) in a field experiment conducted to evaluate the effect of different phosphorus levels and inoculation with *Rhizobium japonicum* in soybean significantly increased plant height (49.26 cm) and number of pod bearing branches plant^{-1} (4.23) over control. Tahir *et. al.* (2009) in a field experiment, to study the effect of *Rhizobium* inoculation and P fertilization on nodulation, growth characteristics of soybean, significantly increased number of nodules plant^{-1} (152), nodules dry weight plant^{-1} (1.52 g), plant height (94.05 cm), shoot dry weight plant^{-1} (48.84 g), root dry weight plant^{-1} (4.44 g) and root length (38.86 cm) over control. Sajid *et al.* (2011) in a experiment conducted to study the influence of *rhizobium* inoculation on growth and yield of groundnut significantly increased plant height (88.0 cm) and shoots plant^{-1} (16.07) over control.

Lamptey *et al*. (2014) in a field experiment conducted during rainy season in 2012 under rainfed conditions in Guinea Savanna zone of Northern Ghana to investigate influence of phosphorus at different source, rates and *rhizobium* inoculants show significantly increased plant height (35.12 cm) and leaf area (22.38 cm^2) over control. Sultana *et al*. (2014) in a pot experiment conducted in net house to study the effect of different *rhizobial* strains and N fertilizer on growth of soybean significantly increased plant height (86.58 cm) and number of branches plant^{-1} (12.09) over control. Sancholi *et al.* (2015) in a field experiment conducted at Zahedan, Iran recorded that soybean inoculants with *rhizobium* significantly increased plant height (59.08 cm) over control.

2.1.1.2 Yield attributes and yield

Albayrak *et al*. (2006) investigated the effect of inoculation with *Rhizobium leguminoserum* on seed yield and yield components of common vetch and observed that inoculation increased the pod length (25.5%), number of seed pod^{-1} (16.2%), number of pods (28.4%), thousand seed weight (5.5%), biological yield (8.5%), seed yield (7.6%) and straw yield (10.4%) over control. Malik *et al.* (2006) in a field experiment found that *Rhizobium* inoculants in soybean significantly increased number of pods plant^{-1} (35.53), number of seed pods^{-1} (2.73), 1000 seed weight (139.0 g) and grain yield (4785.19 kg ha^{-1}) over control. Shahid *et. al.* (2009) in a field experiment conducted to evaluate the effect of different phosphorus levels and inoculation with *Rhizobium japonicum* in soybean significantly increased number of pods plant^{-1} (40.83), pod length (3.71 cm), number of seed pod^{-1} (2.54) and 1000 seed weight (138.80 g) over control. Dejong **(**2011**)** in a experiment conducted at ISU Western Research and Demonstration Farm revealed that soybean inoculanted with *rhizobium* significantly increased harvested soybean yield (59.2 bushels acre^{-1}) over control.

Patra *et al.* (2012) in a field experiment conducted at Pantnagar, Uttarakhand to study the effect of *rhizobium* in soybean showed significantly increased number of pods (116.03 plant^{-1}), pod dry weight (33.87 g plant^{-1}), number of grain (1.73 pod^{-1}), 100 grain weight (10.01 g), grain yield (23.00 q ha^{-1}) and stover yield (22.20 g plant^{-1}) over no inoculation. Akpalu *et* al. (2014) in a experiment conducted in the major and minor cropping seasons of 2012 and 2013 under field conditions, to study the effect of phosphorus fertilizer and *Rhizobia* inoculation on yield of soybean found significantly increased number of seed pod^{-1} (1.96), 100 seed weight (10.97 g), grain yield (7.6 t ha^{-1}), shelling percentage (67 %) and harvest index (0.52) over control.

Sultana *et. al.* (2014) in a pot experiment conducted in net house to study the effect of different *rhizobial* strains and N fertilizer on yield attributes of soybean significantly increased number of branches plant^{-1} (12.09), number of pods (43.58) and seed plant^{-1} (75.66) over control. Mehta *et al.* (2015) in a experiment conducted during rabi season in medium black soil at College of Agriculture, Rajendranagar, Hyderabad, Andhra Pradesh to study the influence of biofertilizers, vermicompost and chemical fertilizers in black gram and found that application of 50 % RDF + Vermicompost + *Rhizobium* + Pseudomonas significantly increased the seed yield (707 kg ha^{-1}) and haulm yield (7067 kg ha^{-1}) over control.

Rechiatu *et. al.* (2015) in a field experiment conducted at Savannah Agricultural Research Institute of Ghana, three separate on-station trials (Manga, Kpongu and Nyankpala) to ascertain the effectiveness of some commercial microbial inoculant and micronutrient fertilizer for improvement of soybean productivity, it was noticed that Teprosyn Mo+Legumefix, Legumefix treatments increased soybean grain yield by 205.62%, 135.54% and 110.24% respectively over the control in Manga. In Nyankpala, the application of Legumefix and Teprosyn Mo+Legumefix increased soybean grain yield significantly by 22.43% and 42.10%, respectively relative to the control while no significant response was observed in grain yield among treatments at Kpongu. Sancholi *et al.* (2015) in a field experiment conducted at Zahedan, Iran show that soybean inoculants with *rhizobium* significantly increased number of pods plant^{1} (53.83), and number of seed pod^{-1} (4) over control.

2.1.1.3 Nutrient content and uptake

Fatima *et al.* (2007) undertaken a pot studies (under natural conditions) to determine the effect of various exotic *Bradyrhizobium japonicum* strains viz., TAL 377, 379, 102 used mixture with phosphorus on soybean growth, yield and nitrogen fixation parameters. The result showed significantly increased NPK uptake by plant (2.86 %, 0.23 % and 2.50 %), N nutrient level in soil (0.07 mg kg^{-1}) and organic matter (1.53 %) over control. Sultana *et. al.* (2014) in a pot experiment conducted in net house to study the effect of different *rhizobial* strains and N fertilizer on N content and its uptake by soybean significantly increased grain N content (7.05 %), straw N content (6.61 %), grain N uptake (103.48 kg ha^{-1}) and straw N uptake (159.12 kg ha^{-1}) over control.

Mehta *et. al.* (2015) in a experiment conducted during *rabi* season in medium black soil at College of Agriculture, Rajendranagar, Hyderabad, Andhra Pradesh to study the influence of biofertilizers, vermicompost and chemical fertilizers in black gram and found that application of 50 % RDF + Vermicompost + *Rhizobium* + Pseudomonas significantly increased total NPK nutrient uptake (114.51, 17.83 and 101.43 kg ha^{-1}), over control.

2.1.1.4 Seed quality

Shahid *et al*. (2009) in a field experiment conducted to evaluate the effect of different phosphorus levels and inoculation with *Rhizobium japonicum* in soybean significantly increased oil content (19.27 %), oil yield (331.0 kg ha^{-1}) and protein content (41.42 %) over control.Tahir *et. al.* (2009) in a field experiment, to study the effect of *Rhizobium* inoculation and P fertilization on quality of soybean significantly increased protein content (39.7 %) and oil content (18 %) over control.

Kravchenko *et al.* (2013) in a field experiment, to study the effect of bacterial inoculation on soybean seeds revealed that binary application of *Bradyrhizobium* and Bacillus significantly increased protein content (369 mg g^{-1}) and protein yield (830 kg ha^{-1}) over control. Sultana *et al.* (2014) in a pot experiment conducted in net house to study the effect of different *rhizobial* strains and N fertilizer on quality of soybean significantly increased protein content in grain and straw (44.06 % and 41.37 %) over control.

2.1.2 Effect of Phosphate Solubilizing Bacteria (PSB)

2.1.2.1 Growth parameters

Sandeep *et al.* (2008) in a pot experiment conducted using Phosphate Solubilizing Microorganisms (PSM) isolated from the *rhizosphere* soil to study the improving growth parameters of soybean significantly increased plant height (32.5 cm) over control. Kumawat *et al.* (2009) conducted a field experiment during *kharif* season 2005 and 2006 to study the effects of organic manures, PSB and phosphorus fertilization on growth of mungbean significantly increased plant height (37.63cm), number of branches $plant^{-1}$ (4.24), dry matter accumulation (36.71g) and chlorophyll content (3.44 mg) over control. Ramana *et al.* (2011) conducted a field experiment on frenchbean at Tirupati campus of Acharya N.G. Ranga Agriculture University during *rabi* season 2006 on sandy loam soil reported that application of 75 per cent RDF + VAM@ 2 kg ha^{-1} + PSB @ 2.5 kg ha^{-1} significantly increased plant height (46.11 cm), number of branches per plant (9.72) and leaf area (968.33 cm^2) over control.

Airsing *et al.* (2014) in a field experiment, to study the effect of PSB and AM fungus inoculation on growth in soybean significantly increased plant height (49.1 cm), shoot dry weight (14.8 g) and number of nodules plant^{-1} (11.3) over control. Yadav and Aggarwal (2014) in a pot experiment, to study the effect of inoculation of two arbuscular mycorrhizal species viz *Glomus mosseae* and *Acaulospora laevis* alone and in combination Phosphate solubilizing bacteria Pseudomonas fluorescens with different superphosphate levels were used on soybean. The results showed significant increase in plant height (137 cm), dry shoot biomass (2.34 g), dry root biomass (0.98 g), root length (36.28 cm), leaf area (26.10 m^2) and chlorophyll content (0.824 mg g^{-1} fresh weight) over control.

2.1.2.2 Yield attributes and yield

Sandeep *et al.* (2008) in a pot experiment conducted using Phosphate Solubilizing Microorganisms (PSM) isolated from the *rhizosphere* soil to study the effect on releasing unavailable 'P' and improving growth parameters on soybean significantly increased pods weight (32.29 g pot^{-1}), straw weight (39.51 g pot^{-1}) and seed weight (18.18 g pot^{-1}) over control. Vikram *et al.* (2008) in a field experiment on green gram conducted at the Main Research Station, University of Agricultural sciences, Dharwad, India, found that PSB inoculation significantly increased grain yield (10.07 q ha^{-1}) and straw yield (32.55 q ha^{-1}) over control.

Koushal and Singh (2011) conducted a field experiment to study the impact of integrated nutrient management on soybean found that 50 per cent recommended N applied through urea + 50 per cent N through FYM +PSB in soybean. significantly increased weight of pods plant^{-1} (48.50 g), seed yield plant^{-1} (22.00 g), number of pods plant^{-1} (80.40), number of seed pod^{-1} (2.46), test weight (17.02 g) and seed yield (1149.00 kg ha^{-1}) over control. Ramana *et al.* (2011) conducted a field experiment on frenchbean at Tirupati campus of Acharya N.G. Ranga Agriculture University during *rabi* season 2006 on sandy loam soil reported that application of 75 per cent RDF + VAM@ 2 kg ha^{-1} + PSB @ 2.5 kg ha^{-1} significantly increased pod length (15.28 cm), 100 seed weight (32.809), pod yield per plant (74.93 g) and pod yield per hectare (6.66 t ha^{-1}) than other treatments.

Devi *et al.* (2012) in a field experiment conducted during *kharif* season to study the effect of different sources and levels of phosphorus and PSB on soybean revealed that soybean significantly increased number of pods plant^{-1} (52.75), number of seeds of pod^{-1} (2.84), 100 seed weight (13.27 g), grain yield (1529 kg ha^{-1}) and stover yield (2394 kg ha^{-1}) over control. Mir *et al.* (2013) in a field experiment conducted at Allahabad, to study the effect of levels of phosphorus, sulphur and Phosphorus Solubilizing Bacteria on yield of blackgram for consecutive two years 2004 and 2005. The result show significantly increase in haulm yield (27.43 q ha^{-1}) and grain yield (7.49 q ha^{-1}) over control. Patel *et al.* (2013) conducted a field experiment to study the response of *kharif* greengram to sulphur and phosphorus fertilization with or without PSB inoculation. The results show significant increase in number of pods plant^{-1} (16.34), number of seed pod^{-1} (10.35), seed yield plant^{-1} (6.66 g) and seed yield (1790.00 kg ha^{-1}) than other treatments under study.

2.1.2.3 Nutrient content and uptake

Sandeep *et al.* (2008) in a pot experiment conducted using Phosphate Solubilizing Microorganisms (PSM) isolated from the *rhizosphere* soil to study the effect on releasing unavailable 'P' and improving growth parameters on soybean significantly increased P uptake by straw and seed (66.04 mg pot^{-1} and 113.91 mg pot^{-1}) over control.Vikram *et al.* (2008) in a field experiment on green gram conducted at the Main Research Station, University of Agricultural Sciences, Dharwad, India, and found that PSB inoculation significantly increased P content in shoot, root and grain (29-45 %, 17-30 % and 12-17 %) over control.

Devi *et al.* (2012) in a field experiment conducted during *kharif* season to study the effect of different sources and levels of phosphorus and PSB on soybean revealed that soybean significantly increased P uptake by seed (6.28 kg ha^{-1}) and by stover (7.52 kg ha^{-1}) over control. Mir *et al*. (2013) in a field experiment conducted at Allahabad, to study the effect of levels of phosphorus, sulphur and Phosphorus Solubilizing Bacteria on nutrient content of blackgram for consecutive two years 2004 and 2005. The result showed significant increase in phosphorus content of grain (0.30 %) and available P in soil (28.66 kg ha^{-1}) over control.

Airsing *et al.* (2014) in a field experiment, to study the effect of PSB and AM fungus inoculation on nutrient uptake in soybean significantly increased P uptake in shoot (109 ppm), N uptake in shoot (134 ppm) and K uptake in shoot (157 ppm) over control. Yadav and Aggarwal (2014) in a pot experiment, to study the effect of inoculation of two arbuscular mycorrhizal species viz *Glomus mosseae* and *Acaulospora laevis* alone and in combination, Phosphate solubilizing bacteria Pseudomonas fluorescens with different superphosphate levels were used on soybean. The results showed significant increase in P content in root and shoot (0.22 % and 0.28 %) over control.

2.1.3 Effect of Rhizobium + PSB

2.1.3.1 Growth parameters

Afzal *et al.* (2009) in a field experiment conducted at Islamabad, Pakistan to study the effect of *rhizobium* and PSB in soybean, showed that *rhizobium* + PSB significantly increased plant height (57.59 cm) over no inoculation. Ahsan *et al*. (2012) in a field experiment, to study the integrated use of PSB, *Bradyrhizobium* and P in soybean, revealed that there were significant increase in plant height (26.52 cm) at 115 DAS and chlorophyll content (2.03 mg g^{-1}) over control. Farnia and Gudiny (2014) in a field experiment conducted at Islamic Azad University, Iran, to study the effect of changes in yield and yield components of soybean (*Glycine max* L.) under application of Phosphate and Nitrogen bio-fertilizers, revealed that there were significant increase in plant height (112 cm) over control.

Janagard *et al.* (2013) in a field experiment conducted at Tabriz, Iran to investigate the effects of biological and chemical fertilizers on soybean, noticed significantly increased plant height (73.0 cm) and chlorophyll index (36.96) over control. Rana *et al*. (2014) in a field experiment conducted at CSKHPKV, Palampur during Kharif 2011 to study the effect of PSB, *rhizobium* and phosphorus levels on growth parameters of soybean. The results revealed that plant height (80.2 cm) of soybean increased over control. Vasumathi and Jayanthi (2014) in a field experiment, to study the Co-Inoculation of salt tolerant *Bradyrhizobium japonicum* and phosphate solubilizing bacteria for the maximization of growth of soybean, noticed that there were significantly increased plant height (62.99 cm) and dry matter production (40.80 g $plant^{-1}$) over control. Jaga and Sharma (2015) in a field experiment conducted at farmer's field at village Nandupura (Vidisha) during *kharif* season of 2012 and 2013 to study the effect of bio-fertilizers and fertilizers on growth of soybean show that there were significant increase in plant height at different growth stages (38.0, 66.0 and 76.2 cm) and leaf area index (14.20) over control.

2.1.3.2 Yield attributes and yield

Son *et al.* (2006) in a field experiment, to study the effect of *Bradyrhizobia* and phosphate solubilizing bacteria application on soybean in rotational system, showed that *rhizobium* + PSB significantly increased number of pods plant^{-1} (35.80), 100 grain weight (16.42 g) and grain yield (2223 kg ha^{-1}) over control. Afzal *et al.* (2009) in a field experiment conducted at Islamabad, Pakistan to study the effect of *rhizobium* and PSB in soybean, showed that *rhizobium* + PSB significantly increased number of pods (47.5), 100 grain weight (11.4 g) and yield (2453 kg ha^{-1}) over no inoculation. Bansal (2009) in a field experiment conducted at Agricultural Research Station, Durgapura, Jaipur, to study the synergistic effect of *Rhizobium*, PSB and PGPR on nodulation and grain yield of mungbean, revealed that there was significantly increased grain yield (12.94 q ha^{-1}) over control.

Ahsan *et al.* (2012) in a field experiment, to study the integrated use of PSB, *Bradyrhizobium* and P in soybean, revealed that there were significant increased grain yield plant^{-1} (9.68 g) and stover yield plant^{-1} (19.37 g) over no inoculation. Argaw (2012) in a field experiment conducted at Assossa Agricultural Research Center (AARC) during 2008 in soybean revealed that *rhizobium* + PSB significantly increased number of seeds plant^{-1} (106.2), number of seed pods^{-1} (2), 300 seed weight (48.3 g) and seed yield (2226.7 kg ha^{-1}) over control.

Sheikh *et al.* (2012) in a field experiment , to study the effect of *rhizobium* culture and phosphate solubilizing bacteria with nitrogen and phosphorus applications on the performance of black gram, significantly increased number of pod plant^{-1} (37.17), number of seed pod^{-1} (6.17), test weight (34.60 g) and grain yield (10.31 q ha^{-1}) over control. Meena *et al.* (2014) in a field experiment conducted during *kharif* season 2013 at Jobner (Raj.) to study the effect of fertility levels and bio-fertilizers on cowpea, recorded significantly higher number of pods plant^{-1} (9.51), number of seeds pod^{-1}(9.21), test weight (76.92 g), seed yield (16.09 q ha^{-1}) and straw yield (24.40 q ha^{-1}) over control. Singh *et al.* (2014) in a field experiment conducted during the rainy season 2008 at Jobner, Rajasthan, to study the effect of fertility and bioinoculants on productivity of clusterbean, noticed significantly increased seed yield (1.10 t ha^{-1}), stover yield (2.99 t ha^{-1}) and gum content (29.20%) over control.

Vasumathi and Jayanthi (2014) in a field experiment, to study the Co-Inoculation of salt tolerant *Bradyrhizobium japonicum* and phosphate solubilizing bacteria for the maximization of growth and yield of soybean, noticed that there was significant increase in grain yield (1340.00 kg ha^{-1}) over control. Jaga and Sharma (2015) in a field experiment conducted at farmer's field at village Nandupura (Vidisha) during *kharif* season of 2012 and 2013 to study the effect of bio-fertilizers and fertilizers on yield of soybean showed that there were significant increase in pods $plant^{-1}$ (94.8), seed yield (26.8q ha^{-1}) and test weight (17.99 g) compared to control.

2.1.3.3 Nutrient content and uptake

Son *et al.* (2006) in a field experiment, to study the effect of *Bradyrhizobia* and phosphate solubilizing bacteria applied biofertilizers on soybean in rotational system, found that *rhizobium* + PSB significantly increased N available in soil (892 ppm), P available in soil (920 ppm), total N and P uptake (150 kg ha^{-1}) and (13.30 kg ha^{-1}), respectively over control.

Singh *et al.* (2009) conducted a field experiment during *kharif* seasons of 2004 and 2005 to evaluate the effects of bioinoculants and farmyard manure on performance of rainfed soybean. It was observed that sole or dual inoculation of biofertilizers, application of FYM with or without biofertilizers and recommended dose of fertilizers significantly increased total NPK uptake (256.5 kg ha^{-1}) over control. Argaw (2012) in a field experiment conducted at Assossa Agricultural Research Center (AARC) during 2008 to study the effects of co-inoculation of *Bradyrhizobium japonicum* and phosphate-solubilizing bacteria in soybean revealed that *rhizobium* + PSB significantly increased plant total nitrogen (3.863 %) and plant P (2760 kg ha^{-1}) over control.

2.1.3.4 Seed quality

Afzal *et al.* (2009) in a field experiment conducted at Islamabad, Pakistan to study the effect of *rhizobium* and PSB in soybean, showed that *rhizobium* + PSB significantly increased protein content (34.7 per cent) over no inoculation. Singh *et al.* (2009) in a field experiment conducted during *kharif* seasons of 2004 and 2005 to evaluate the effects of bioinoculants and farmyard manure on performance of rainfed soybean significantly increased oil content (18.25 per cent) and protein content (40.98 per cent) over no inoculation. Ahsan *et al*. (2012) in a field experiment, to study the integrated use of PSB, *Bradyrhizobium* and P in soybean revealed that there were significant increase in oil content (20.25%) and protein content (38.75%) over control.

Marco *et al*. (2013) in a field experiment conducted during rainy seasons of 2010 and 2011 to study the effect of sulphur and biofertilizers on quality of blackgram showed that *rhizobium* + PSB recorded significant increase in protein content (22.91) over control. Meena *et al*. (2014) in a field experiment conducted during *kharif* season 2013 at Jobner (Raj.) to study the effect of fertility levels and bio-fertilizers on cowpea, revealed significant increase in protein content (26.31 per cent) over control. Vasumathi and Jayanthi (2014) in a field experiment of soybean, revealed that there was significant increase in protein content (41.80 %) over control.

2.1.3.5 Economics

Bansal (2009) in a field experiment conducted at Agricultural Research Station, Durgapura, Jaipur, on mungbean, revealed that there was significant increase in BC ratio (4.37) over control. Marco *et al*. (2013) in a field experiment conducted during rainy seasons of 2010 and 2011 to study the effect of sulphur and biofertilizers on economics of blackgram showed that *rhizobium* + PSB significantly increased BC ratio (2.35) over control. Rana *et al*. (2014) in a field experiment conducted at CSKHPKV, Palampur during *Kharif* 2011 on soybean revealed increase in BC ratio (1.39) over control.

2.2 EFFECT OF SULPHUR

2.2.1 Growth parameters

Sarker *et al*. (2002) reported that application of sulphur 30 kg and boron 1.0 kg ha^{-1} in soybean significantly increased plant height (66.7 cm) and branches $plant^{-1}$ (3.94) over control. Sharma and Singh (2005) in a study found that application of 25 and 50 kg S ha^{-1} in clusterbean significantly increased dry matter accumulation and branches $plant^{-1}$ as compared to control. Khatkar *et al*. (2007) in a field experiment observed that application of sulphur at 20 kg ha^{-1} in black gram significantly increased plant height (25.78 cm) 30 DAS over control.

Farhad *et al*. (2010) in a field experiment conducted at the Sher-e-Bangla Agricultural University Farm, Dhaka, during December 2008 to April 2009 reported that the application of sulphur 20 kg ha^{-1} in soybean resulted the highest plant height (69.72 cm) over control. Hussain *et al.* (2011) in a field experiment carried out on soybean at the Research Farm of Arid Agriculture University Rawalpindi (Pakistan) during summer 2009 revealed that the application of inoculation and sulphur (30 kg ha-1) resulted in significantly increased plant height and dry matter yield up to 14 and 26% as compared to control, respectively.

Bhattacharjee *et al.* (2013) in a field experiment reported that application of 60 kg P_2O_5 ha^{-1} along with 15 kg S and 1 kg Co is advisable for optimum growth of soybean on acid alfisols of northeast India. Choudhary *et al.* (2014) in a pot experiment obsereved that application of sulphur and Zn at 40 ppm and 5 ppm in soybean, significantly increased plant height (43. 5 cm) and branches $plant^{-1}$ (6.7) over control. Lakshman *et al.* (2015) in a field experiment to study the performance of soybean as influenced by different levels and time of sulphur application during 2009 and 2010 at IARI, New Delhi found that application of 45 kg sulphur as 50% basal and 50% at flowering recorded highest number of branches plant $^{-1}$ (3.9), leaf area index (3.85), nodules $plant^{-1}$ (47.4) over control. Jawahar *et al.* (2016) in a field experiment on rice fallow blackgram conducted at Annamalai University Experimental Farm, Annamalai Nagar found that application of 40 kg S ha^{-1} recorded highest plant height (42.49 cm), leaf area index (2.33), chlorophyll content (2.42 mg g^{-1}), dry matter production (3095 kg h^{-1}) and branches $plant^{-1}$ (8.91) over control.

2.2.2 Yield attributes and yield

Dayanand and Meena (2002) in a field experiment at Jobner found that application of sulphur 40 kg ha^{-1} in groundnut significantly increased pods $plant^{-1}$ (28.68), kernel pod^{-1} (1.64), and test weight (398.2 g), pod yield (17.34 q ha^{-1}), kernel yield (11.38 q ha^{-1}) and biological yield (57.30 q ha^{-1}) over control. Sarker *et al.* (2002) reported that application of sulphur 30 kg and boron 1.0 kg ha^{-1} in soybean significantly increased pod $plant^{-1}$ (46.2), seed $plant^{-1}$ (95.3), 100 seed weight (12.6 g), grain yield (2301 kg ha^{-1}), stover yield (3010 kg ha^{-1}) and harvest index (43.3 %) over control. Wastmatkar *et al.* (2002) in a study at Akola (Maharastra) found that application of 30 kg S ha^{-1} resulted higher grain yield (1962 kg ha $^{-1}$) and straw yield (2642 kg ha^{-1}) of soybean compared to control.

Maity and Giri (2003) in a field experiment at IARI, New Delhi observed that application of sulphur 30 kg ha^{-1} in groundnut significantly increased pods $plant^{-1}$ (42.7), pod weight $plant^{-1}$ (24.4 g) and 100 kernel weight (40.1 g) over control. Jamal *et al.* (2005) in a field experiment conducted to asses the seed yield of two cultivars of soybean PK-416 and PK-1024 in relation to sulphur and nitrogen nutrition. Maximum response was recorded with treatment having 40 kg S and 43.5 kg N ha^{-1}. Seed yield increased 90 % in PK-416 and 104 % in PK-1024, respectively as compared to the control. Singh (2006) reported that application of sulphur 30 kg ha^{-1} in mungbean through ammonium sulphate gave significantly higher seed and straw yields by 11.18 and 33.26 q ha^{-1}, respectively over control.

Singh *et al.* (2006) in an experiment on soybean found that application of S at 60 kg ha^{-1} significantly increased seed and straw yield compared to control. Khatkar *et al.* (2007) in a field experiment observed that application of sulphur at 20 kg ha^{-1} in black gram significantly increased grain yield (7.23 q ha^{-1}) and straw yield (24.40 q ha^{-1}) over control. Shinde *et al.* (2007) in a field experiment reported that application of sulphur at 60 kg ha^{-1} in soybean significantly increased grain yield (4.78 q ha^{-1}) and straw yield (11.03 q ha^{-1}) over control.

Ghosh and Joseph (2008) in a study found that application of sulphur 30 kg ha^{-1} in green gram through gypsum significantly increased number of pods $plant^{-1}$ (21.27), test weight (31.67 g), seed yield (8.91 q ha^{-1}) and stover yield (17,67 q ha^{-1}) over control. Farhad *et al.* (2010) in a field experiment conducted at the Sher-e-Bangla Agricultural University Farm, Dhaka, during December 2008 to April 2009 and reported that the application of sulphur 20 kg ha^{-1} in soybean resulted the highest 1000-seed weight (82.86 g) over control. Choudhary *et al.* (2014) in a pot experiment obsereved that application of sulphur and Zn at 40 ppm and 5 ppm in soybean, significantly increased pods $plant^{-1}$ (13.0), grain $pods^{-1}$ (3.2), seed index (9.96 g) and grain yield (15.30 g pot^{-1}), over control.

Dhage *et al.* (2014) in a field experiment to study the effect of phosphorus and sulphur levels on soybean during 2009-10 and 2010-11 at Research Farm Department of Soil Science and Agril. Chemistry, MKV, Parbhani (MS) on Vertisol found that the yield of soybean (seed and straw) increased significantly due to application of 60 kg S ha^{-1} by 14.01% and 15.90%, respectively over control. Thenua *et al.* (2014) in a field experiment conducted during *kharif* season of 2009 and 2010 at Agronomy Research

Farm at Meerut, to study the sulphur and zinc requirement of soybean and its effect on yield and their availability status in the soil. The highest yield 1983 kg h^{-1} during 2009 and 1872 kg h^{-1} during 2010 of soybean was recorded under 40 kg S ha^{-1}, it was closely followed by 30 kg S ha^{-1} compared to its lower levels.

Lakshman *et al.* (2015) in a field experiment to study the performance of soybean as influenced by different level and time of sulphur application during 2009 and 2010 at IARI, New Delhi reported that application of 45 kg sulphur as 50% basal and 50% at flowering recorded highest values of pods $plant^{-1}$ (42.64), seed pod^{-1} (2.97) and seed index (10.49 g) over lower doses. Jawahar *et al.* (2016) in a field experiment conducted at Annamalai University Experimental Farm, Annamalai Nagar found that application of 40 kg S ha^{-1} recorded highest branches $plant^{-1}$ (8.91), pods $plant^{-1}$ (19.68), seeds pod^{-1} (5.95), grain yield (1037 kg ha^{-1}) and haulm yield (2261.95 kg ha^{-1}) over control in rice fallow blackgram.

2.2.3 Nutrient content and uptake

Sangale and Sonar (2004) in a study at Maharastra observed that application of sulphur in soybean at increasing level from 0 to 30 kg ha^{-1} significantly increased seed yield and nutrient uptake over control. Ganie *et al.* (2014) conducted experiment during kharif 2011, to study the effect of sulphur and boron application on nutrient content and uptake in frenchbean. The result showed that N content in stover and seed (0.67% and 3.37%), P content in stover and seed (0.043% and 0.437%), S content in stover and seed (0.11% and 0.34%) and NPK uptake (90.58, 10.38, 10.50 kg ha^{-1}) increased significantly over control.

Sharma *et al.* (2014) in pot experiment of soybean grown under different treatments viz. control, recommended dose of nitrogen as urea 31.25 kg N ha^{-1}, sulphur as gypsum 20 kg S ha^{-1} or in combination, increased nutrient uptake in all the treatments as compared to control.

2.2.4 Seed quality

Singh *et al.* (2001) in a field experiment at Udaipur found that application of sulphur 60 kg ha^{-1} in soybean significantly increased oil yield (378.80 kg ha^{-1}), and protein yield (736.37 q ha^{-1}) over control. Sonune *et al.* (2001) in a field experiment at Akola observed that application of sulphur in soybean at increasing levels from 0 to 40 Kg ha^{-1} significantly increased the protein and oil contents of soybean over control.

Sarker *et al.* (2002) reported that application of sulphur 30 kg and boron 1.0 kg ha^{-1} in soybean significantly increased protein content (43.3) and oil content (21.6) over control. Maity and Giri (2003) in a field experiment at IARI, New Delhi observed that application of sulphur 30 kg ha^{-1} in groundnut significantly increased oil content (54.3 percent) over control. Shinde *et al.* (2007) in a field experiment reported that application of sulphur at 60 kg ha^{-1} in soybean significantly increased oil content (22.34 %) and protein content (41.54 %) over control. Dhanashree and Patil (2011) in a field experiment at the Agriculture Research Station,Washim (Akola) revealed that the oil and protein content in soybean grain were significantly higher due to application of 30 kg S ha^{-1} through gypsum and 2.5 kg Zn ha^{-1} through $ZnSO_4$, whereas oil and protein content were recorded as 20.01 and 39.92 per cent, respectively.

Chauhan *et al.* (2013) in a field experiment conducted on vertisols (black cotton soil) during 2009-10 and 2010-11, to study the effect of Potassium, Sulphur and Zinc on oil content in soybean variety JS-9560 at Ujjain, M.P. found that application of K 20kg h^{-1}, S 20 kg h^{-1} and Zn 5kg h^{-1} in combination dose increased oil percentage by 1.3% and 1.1% in both the years, respectively. Tiwari *et al.* (2014) in a field experiment conducted on medium black soil at the Agricultural University, Junagadh (Gujarat) during the summer season of 2012 reported that application of 40 kg S ha^{-1} significantly increased the protein content (27.27 %) and protein yield (97 %) of clusterbean over control. Lakshman *et al.* (2015) in a field experiment to study the performance of soybean as influenced by different level of sulphur application during 2009 and 2010 at IARI, New Delhi and found that application of 45 kg sulphur as 50% basal and 50% at flowering recorded highest oil content (20.48) and protein content (40.65) over other treatments.

3. MATERIALS AND METHODS

A field experiment entitled **"Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur"** was conducted during *Kharif* season of 2015, at Instructional Farm, Rajasthan College of Agriculture, Udaipur. The details of materials used, procedures followed and criteria adopted for evaluation of treatments during the course of investigation are presented in this chapter.

3.1 EXPERIMENTAL SITE

The experiment was conducted at the Instructional Farm, Rajasthan College of Agriculture, Udaipur. The site situated at South-Eastern part of Rajasthan at an altitude of 582.5 meter above mean sea level with 24˚35' N latitude and 73˚42' E longitude. The region falls under agro-climatic zone IVa (Sub - Humid Southern Plain and Aravali Hills) of Rajasthan.

3.2 CLIMATE AND WEATHER CONDITIONS

This zone possesses typical sub-tropical climatic conditions characterized by mild winters and moderate summers associated with high relative humidity during the months of July to September. The mean annual rainfall of the region is 637 mm, most of which is contributed by south west monsoon from July to September.

The mean weekly meteorological parameters recorded during cropping period are presented in Table 3.1 and depicted in Fig. 3.1. These observations reveal that maximum and minimum temperatures ranged between 27.8° - 35.9°C and 16.6° - 26.2°C, respectively during *kharif,* 2015. The total amount of rainfall received during the crop growth period in 2015 was 636 mm and this was well distributed in crop growing period.

Table 3.1 Mean weekly meteorological observations during crop period (*Kharif*, 2015).

Standard Week No.	Date	Temperature (°C)		RH (%)		Wind velocity (km hr^{-1})	Sunshine (hrs)	Rainfall (mm)	Evaporation (mm day^{-1})
		Maximum	Minimum	Maximum	Minimum				
28	9 July - 15 July	34.4	26.2	69.7	44.4	9.3	5.0	0.0	9.2
29	16 July - 22July	32.7	24.9	79.3	61.1	6.6	2.4	45.2	5.2
30	23 July - 29 July	27.8	23.0	92.1	88.1	7.0	0.2	217.8	2.8
31	30 July -5Aug	28.5	23.3	80.3	69.7	7.6	2.4	29.2	4.1
32	6 Aug-12 Aug	31.6	24.3	84.0	68.6	4.3	4.0	43.4	4.3
33	13 Aug-19 Aug	29.8	23.6	89.1	73.9	3.1	2.0	62.0	2.9
34	20 Aug-26 Aug	30.3	23.8	79.4	61.3	6.0	6.5	0.0	4.7
35	27 Aug-2 Sept	31.6	22.8	82.9	57.0	3.8	7.7	0.0	4.9
36	3 Sept -9 Sept	32.0	20.6	76.3	48.6	2.6	8.3	0.0	5.0
37	10 Sept-16 Sept	34.8	22.5	70.1	41.9	2.8	7.7	0.0	5.4
38	17 Sept - 23 Sept	30.5	23.5	86.1	72.1	5.7	3.2	41.6	3.5
39	24 Sept- 30 Sept	31.9	19.3	77.6	41.3	3.1	8.9	0.0	4.9
40	1 Oct – 7 Oct	35.4	17.7	62.6	24.0	1.9	8.3	0.0	5.1
41	8 Oct – 14 Oct	35.1	17.4	64.7	27.0	2.2	9.1	0.0	5.0
42	15 Oct – 21 Oct	35.9	18.9	63.0	24.4	1.3	7.9	0.0	4.6
43	22 Oct- 28 Oct	34.3	16.6	64.7	24.7	1.5	8.1	0.0	4.7

3.3 PHYSICO CHEMICAL PROPERTIES OF EXPERIMENTAL SOIL

In order to assess the physico-chemical properties of soil, random samples were drawn from experimental site up to 15 cm depth before commencement of the experiment and a composite sample was prepared. It was then subjected to mechanical, physical and chemical analysis to ascertain the physico-chemical properties of the experimental soils. The result of the analysis is presented in Table 3.2. A perusal of data presented in Table 3.2 shows that the soil of experimental field was clay loam in texture and having alkaline reaction (pH 8.1).The soil was medium in available nitrogen (276.3 kg ha^{-1}) and available phosphorus (19.41kg ha^{-1}) but high in available potassium (378.6 kg ha^{-1}).

Table 3.2 Physico-chemical properties of the experimental soil

Characteristics	Content	References
A. Mechanical		
Sand (%)	37.78	International pipette method (Piper, 1950) (Jena, *et al.*, 2013)
Silt (%)	27.76	
Clay (%)	34.46	
Textural class	Clay loam	Triangular diagram (Brady and Weil,2002)
B. Physical		
Bulk density (Mg m^{-3})	1.26	Core sampler method (Piper, 1950)
Particle density (Mg m^{-3})	2.76	(Black, 1965)
Porosity (%)	49.15	(Black, 1965)
C. Chemical		
pH (1:2 soil : water)	8.1	(Richard, 1968)
EC (1:2) (dS m^{-1} at 25ºC)	0.89	(Richard, 1968)
Organic Carbon (%)	0.84	(Walkley and Black, 1947)
Available Nitrogen (kg ha^{-1})	276.3	(Subbiah and Asija, 1956)
Available Phosphorus (kg ha^{-1})	19.41	(Olsen *et al.*, 1954)
Available Potassium (kg ha^{-1})	378.6	(Jackson, 1973)
Available S (ppm)	8.7	(Chesnin and Yien, 1950)

3.4 CROPPING HISTORY

On the experimental site, in previous season wheat crop was taken and during summer, field was kept fallow before the present experiment. During the course of investigation, the test crop was soybean, variety JS-9560.

3.5 EXPERIMENTAL DETAILS:

3.5.1 Detail of Treatments:

(A)	Microbial inoculation	Symbol
(i)	Control (without inoculation)	I_0
(ii)	*Rhizobium*	I_1
(iii)	Phosphate solubilizing bacteria	I_2
(iv)	*Rhizobium* + Phosphate solubilizing bacteria	I_3

(B)	Sulphur levels [kg ha^{-1}] (through gypsum)	Symbol
(i)	0	S_0
(ii)	20	S_1
(iii)	40	S_2
(iv)	60	S_3

3.5.2 Experimental details:

i. Test crop : Soybean

ii. Date of sowing : 16-07-2015

iii. Number of treatments combinations : 16

iv. Replications : 3

v. Total number of plot : 48

vi. Design : Factorial RBD

vii. Plot size

a. Gross : 5.0 m x 3.6 m = 18 m^2

b. Net : 4.0 m x 3.0 m = 12 m^2

viii. Spacing : 30 cm x 10 cm

ix. Seed rate : 80 kg ha^{-1}

x. Variety : JS-9560

xi. Seed treatment : Thiram @ 2 g kg^{-1} of seed

xii. Fertilizer application : 20 kg N and 40 kg P_2O_5 ha^{-1}

xiii. Weed control : As per recommendation

xiv. Irrigation : Rainfed

xv. Season : *Kharif,* 2015

3.5.3 Sources of nutrients

The sources used for applying N and P were di-ammonium phosphate (adjusted for its N content) urea and Sulphur applied through gypsum.

3.6 CHARACTERISTICS OF VARIETY

The variety JS-9560 is extra early (82-89 days) with four seeded pods, having yield potential of about 20 q ha^{-1}, excellent germination, high crop growth rates, resistance to lodging, shattering, root rot, important soybean diseases and insect-pest. It is most suitable for increasing cropping intensity, intercropping, low rain fall and upland situation.

3.7 DETAILS OF CROP RAISING

Details of cultural operations carried out for soybean crop are given in Table 3.3.

Table 3.3 Schedule of operations during crop period

S. N	Operations	Date
1.	Field preparation	12.07.2015
2.	Layout, bunding and leveling	14.07.2015

3.	Furrows opening	15.07.2015
4.	Fertilizer placement and sowing	16.07.2015
5.	Irrigation	16.07.2015
6.	Herbicide spray (pre-emergence)	18.07.2015
7.	Thinning	30.07.2015
8.	Insecticide spray	10.08.2015
9.	Hoeing and weeding	15.08.2015
10.	Harvesting	14.10.2015
11,	Threshing and winnowing	24.10.2015

3.7.1 Field preparation

The field was ploughed down with tractor drawn disc plough followed by cross harrowing and planking. The plots were demarcated as per plan of layout (Fig.3.2) and bunds were prepared to separate out each experimental unit.

3.7.2 Seed inoculation

Seeds were treated with Thiram @ 2 g kg^{-1} seed to prevent seed borne diseases. Then the seeds were inoculated with efficient *Rhizobium* and PSB strains procured from Department of Agricultural Chemistry and Soil Science (Microbiology unit) Rajasthan College of Agriculture, Udaipur as per recommended procedure.

3.7.3 Fertilizer application

A uniform dose of 20 kg N and 40 kg P_2O_5 ha^{-1} was given through urea and DAP, after adjusting the quantity of nitrogen supplied through DAP. Sulphur was applied as per treatments through mineral gypsum. Full dose of N, P_2O_5 and S were given as basal application.

3.7.4 Seed and sowing

Sowing was done manually at the depth of 2.0 – 3.0 cm using 80 kg seed rate per hectare. Soybean cultivar JS-9560 was sown keeping inter row distance of 30 cm.

3.7.5 Thinning

To maintain plant to plant distance of about 10 cm, within rows extra and weak plants were uprooted at 15 days after sowing.

3.7.6 Weed management and hoeing

To keep the field weed free at initial stage pre-emergence spray of Pendimethalin @ 0.75 kg a.i. ha^{-1} in 600 liter of water was done immediately after sowing. Further, to minimize weed competition at later stage and to keep soil well aerated one weeding-cum hoeing operation was carried out at 30 DAS.

3.7.7 Plant protection measures

Mild infestation of girdle beetle and leaf minors were noticed in soybean at 25 days after sowing and it was controlled by spraying of insecticide (*i.e.* thiamethoxam /rynaxypyr) immediately.

3.7.8 Harvesting

The crop was harvested at physiological maturity when leaves turned yellow and start falling. The plants from border areas were harvested first (14.10.2015) and collected thereafter and removed from each plot. After this, crop was harvested from net plot area, bundled and tagged separately.

3.7.9 Threshing and winnowing

These bundles were brought to the threshing floor and left for sun drying for a period of 10 days. The dried bundles were weighed to record biological yield. After threshing, winnowing and cleaning was done and seeds were weighed separately to record seed yield. The composite seed and haulm samples from each experimental unit were collected for laboratory studies.

3.8 TREATMENT EVALUATION

In order to evaluate effect of the treatments on growth, yield attributes, yield, nutrient uptake, quality of crop and other aspects of soybean crop, observations were recorded for each parameter as per the procedure mentioned below.

3.8.1 Crop studies

(A) Plant population

The number of plants were counted in five randomly selected (one meter) row length in each experimental plot after 30, 60 DAS and at harvest. These were averaged and number of plant ha^{-1} were worked out.

(B) Growth characters

(i) Plant height at 30, 60 DAS and at harvest (cm)

Height of five randomly selected plants from each plot was measured from the base of the plant to fully open leaf tip at 30, 60 DAS and at harvest. The average plant height was worked out and was expressed in cm.

(ii) Dry matter at 30, 60 DAS and at harvest (g plant^{-1})

The periodic changes in dry matter accumulation plant^{-1} were recorded at 30, 60 DAS and at harvest by uprooting five randomly selected plants from each plot. These samples were placed in perforated paper bags followed by sun drying for two days and finally kept in oven at 65 ^{0}C for 48 hours till a constant weight was noted. Dry matter accumulation plant^{-1} was computed for each treatment at each stage and expressed as g plant^{-1}.

(iii) Leaf area index at 50 DAS

Leaf area was calculated by randomly selecting five plants, detaching leaves and categorizing them according to their size i.e.length and width (small, medium and large). The number of leaves in each category was counted. The average area of three representative leaves was estimated through planimeter from each category. This average leaf area was used to compute total leaf area in each category by multiplying area of representative leaf and number of leaves in same category. The leaf area of all three categories was summed up to find out the leaf area of five plants and then average leaf area plant^{-1} was obtained dividing it with five. Leaf area (m^{-2}) was calculated using formula: Plant population running m^{-1} x 3.33 x leaf area plant^{-1} (m^{2}).

Leaf area index: Mean leaf area plant^{-1} was used to work out leaf area index using equation given by (Watson, 1947) as under.

$$\textbf{Leaf area index (LAI)} = \frac{\text{Leaf area plant}^{-1}\ (\text{m}^2)}{\text{Ground area occupied by plant}^{-1}\ (\text{m}^2)}$$

(iv) Primary branches plant^{-1} at harvest

The number of primary branches from the five randomly selected plants from each plot was recorded at harvest and average worked out.

(C) Yield attributes

(i) Pods plant^{-1}

. Fully matured and developed pods from randomly selected five plants from each plot were plucked and counted. The average pods plant^{-1} were worked out.

(ii) Seeds pod^{-1}

Pods collected from randomly selected five plants were threshed, cleaned and total number of seeds were counted and the average number of seed pod^{-1} were estimated.

(iii) Seed index

Seed sample was drawn after weighing to produce from each net plot yield and 100 seeds were counted and weighed and expressed in gram.

(D) Yield

(i) Seed yield $plant^{-1}$

Randomly selected five plants from each plot and were threshed, cleaned and weighed then recorded average seed yield $plant^{-1}$ and expressed in g $plant^{-1}$.

(ii) Seed yield

After threshing and winnowing seed yield of net plot was recorded and used to compute seed yield kg ha^{-1}.

(iii) Haulm yield

The haulm yield was computed by subtracting the corresponding seed yield from biological yield and expressed in kg ha^{-1}.

(iv) Biological yield

The plants from net plot were harvested and sun dried for 10 days and weighed for recording biological yield and expressed as kg ha^{-1}.

(v) Harvest index

It is ratio of economic yield (seed yield) to the biological yield and worked out by following formula (Donald and Hamblin, 1976). This is expressed in per cent.

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

(E) Biochemical studies

(i) Oil content and oil yield

Oil percentage in seed from each net plot sample was determined by Soxhlet Ether Extraction method (A.O.A.C., 1965) and expressed as per cent oil content in seed.

Oil yield was worked out by multiplying the seed yield with oil content for each corresponding treatment.

$$\text{Oil yield (kg ha}^{-1}\text{)} = \frac{\text{Oil content in seed (\%) x seed yield (kg ha}^{-1}\text{)}}{100}$$

(ii) Protein content and protein yield

The protein content in seed was obtained by multiplying per cent nitrogen of the seed by the factor 6.25 (Simson *et al.*, 1965) and expressed as per cent protein content.

Protein yield was worked out by formula;

$$\text{Protein yield (kg ha}^{-1}\text{)} = \frac{\text{Protein content in seed (\%) x seed yield (kg ha}^{-1}\text{)}}{100}$$

(iii) Chlorophyll content (mg g^{-1})

Chlorophyll content (total) of fresh leaf samples from each experimental plot was estimated at 50 DAS following the procedure laid down by Arnon (1949) using 80% acetone. Total chlorophyll was computed using following formula.

$$\text{Total chlorophyll content (mg g}^{-1}\text{)} = \frac{20.2\ A_{645} + 8.02\ A_{663}}{a \times 1000 \times W} \times V$$

Where,

A = Absorbance specific wave lengths

a = Length of light path in the cell (usually 1 cm)

W = Fresh weight of the sample (g)

V = Volume of extract (ml)

(F) Chemical analysis

(i) Nutrient content

Seed and haulm samples collected at harvest from each experimental unit were oven dried at 65^0 C to a constant weight and grounded in laboratory mill. These samples were subjected to chemical analysis for determining N, P and S content as per the following standard methods.

Table 3.4: Method of plant analysis

$_4$ and H_2O_2 for determination of nitrogen

content.

fter development of colour with
Nesseler's reagent.

O$_4$ (10:4).

d yellow colour method

3.8.2 Nutrient uptake

Uptake of nutrients N, P and S by seed and haulm were estimated by using following formula.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content in seed/haulm x Seed/haulm yield (kg ha}^{-1}\text{)}}{100}$$

The total uptake of nutrients was computed by summing up the uptake by seed and haulm.

3.9 ECONOMICS OF TREATMENTS

3.9.1 Net returns (₹ ha^{-1})

To find out the most profitable treatment, economics of different treatments were worked out in terms of net monetary returns (₹ ha^{-1}) by subtracting the cost of treatment and the cost of cultivation from gross income obtained. Cost of cultivation and net profit were calculated on the basis of prevailing prices of produce and inputs.

3.9.2 Benefit - Cost ratio

This was calculated by dividing gross returns with cost of cultivation for each treatment to see the economic viability of treatments. The computation details of economics for each treatment are given in Appendix (XIII).

Benefit cost ratio was also calculated by using the following formula:

$$\text{Benefit: Cost} = \frac{\text{Net returns (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation}}$$

3.10 STATISTICAL ANALYSIS

3.10.1 Analysis of variance and test of significance

The data recorded for evaluation of treatment were subjected to statistical analysis by applying technique of analysis of variances for" Factorial RBD" in order to test the significance of the experimental results. Wherever, the "F" test was found significant at 5 per cent level of significance, the critical differences (CD) for the treatment means was worked out.

3.10.2 Correlation and regression studies:

Correlation studies were carried out with a view to determine interrelationship between various characters as described by Panse and Sukhatme (1985). Regression equation for the characters indicating significant correlation were also worked out and presented at appropriate places.

4. EXPERIMENTAL RESULTS

The result of the experiment entitled **"Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur"** conducted at Instructional Farm, Rajasthan College of Agriculture, Udaipur, during *kharif*, 2015 are being presented in this chapter.

Data pertaining to effect of treatment on various aspects of growth, yield components, yield, nutrient content and their uptake as well as other aspects of soybean were statistically analyzed and analysis of variance for these data has been given in Appendices (I to XIII), wherein significant at 5 per cent level of probability have been indicated by asterisks.

4.1 EFFECT OF MICROBIAL INOCULATION AND SULPHUR LEVELS ON PLANT STAND

A perusal of data (Table 4.1 and Appendix I) reveal that varying microbial inoculation and sulphur levels didn't influence number of plants ha^{-1} recorded 30, 60 DAS and at harvest of the crop.

4.2 EFFECT OF MICROBIAL INOCULATION AND SULPHUR LEVELS ON GROWTH PARAMETERS

Data on various growth parameters of soybean under the influence of treatments are presented in Table 4.2 to 4.4 and respective analysis of variance have been furnished in Appendix II to IV.

4.2.1 Plant height

Microbial inoculation : It is evident form data Table 4.1 that inoculation with single strain *Rhizobium*, PSB and combined application of *Rhizobium* + PSB significantly improved the plant height over no inoculation at all the stages of crop growth (30, 60 DAS and at harvest). The improvement in mean plant height was by 11.26, 7.25 and 20.95 per cent at 30 DAS, 6.01, 2.63 and 9.42 per cent at 60 DAS and 7.22, 4.76, 10.61 per cent at harvest with the application of *Rhizobium* , PSB and *Rhizobium* + PSB over no inoculation, respectively. Among the microbial inoculation *Rhizobium* +PSB recorded heighest plant height, which was significantly superior over rest of inoculation.

Sulphur levels: An examination of data (Table 4.2) reveals that there was significant increase in plant height with the increasing levels of sulphur up to 40 kg S ha^{-1} at all the stages. However, maximum plant height (23.57, 37.65 and 46.31 cm) at 30, 60 DAS and at harvest was recorded with the application of 40 kg S ha^{-1} which was found at par with 60 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} increased the plant height to the tune of 6.60, 12.72 and 9.90 per cent at 30 DAS, 3.31, 7.51 and 6.11 per cent at 60 DAS and 3.41, 7.52 and 5.94 per cent at harvest, respectively, over control.

4.2.2 Dry matter accumulation

Microbial inoculation : It is evident form data Table 4.3 that inoculation with single strain *Rhizobium*, PSB and combined application of *Rhizobium* + PSB significantly improved the dry matter accumulation over no inoculation at all the stages of crop growth (30, 60 DAS and at harvest). The improvement in mean dry matter accumulation were by 6.81, 3.57 and 19.80 per cent at 30 DAS, 8.41, 4.47 and 12.65 per cent at 60 DAS and 5.41, 2.53, 8.15 per cent at harvest with the application of *Rhizobium* , PSB and *Rhizobium* + PSB, respectively over no inoculation. Among the microbial inoculation *Rhizobium* +PSB recorded heighest dry matter accumulation, which was significantly superior over rest of inoculation.

Sulphur levels : An examination of data (Table 4.3) reveals that there was significant increase in dry matter accumulation with the increasing levels of sulphur up to 40 kg S ha^{-1} at all the stages. However, maximum dry matter accumulation (3.39, 14.31 and 29.53 cm) at 30, 60 DAS and at harvest was recorded with the application of 40 kg S ha^{-1} which was found at par with 60 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} increased the dry matter accumulation to the tune of 3.13, 6.26 and 5.95 per cent at 30 DAS, 5.67, 9.74 and 7.43 per cent at 60 DAS and 2.57, 5.77 and 4.54 per cent at harvest, respectively, over control.

4.2.3 Leaf area index at 50 DAS

Microbial inoculation: It is evident from the data reported in Table 4.4 that due to inoculation of seed with *Rhizobium*, PSB and *Rhizobium* + PSB, the leaf area index at 50 DAS significantly improved in comparison to control. The improvement in leaf area index with *Rhizobium* + PSB was significant over *Rhizobium* as well as PSB inoculations. However, the increase in leaf area index with inoculation of *Rhizobium* was found at par with PSB. The improvement in leaf area index with *Rhizobium*, PSB and *Rhizobium* + PSB inoculations was to the extent of 3.14, 2.61 and 15.70 per cent, respectively over control.

Sulphur levels: It is clear from Table 4.4 that the increasing levels of sulphur improved leaf area index but the effect was not found significant. The maximum leaf area index was recorded 4.12 at 50 DAS with the application of 60 kg S ha^{-1}.

4.2.4 Chlorophyll content at 50 DAS

Microbial inoculation: It is evident from the data (Table 4.4) that due to inoculation with *Rhizobium*, PSB and *Rhizobium* + PSB, the chlorophyll content at 50 DAS significantly increased in comparison to control. The increase in chlorophyll content with *Rhizobium* + PSB was significant over *Rhizobium* as well as PSB inoculations. However, the increase in chlorophyll content with inoculation of *Rhizobium* was found at par with PSB. The increase in chlorophyll content of soybean with *Rhizobium,* PSB and *Rhizobium* + PSB inoculations were to the extent of 4.72, 4.00 and 11.27 per cent, respectively over control (2.75 mg g^{-1}).

Sulphur levels: It is evident from data presented in Table 4.4 that application of 60 kg S ha^{-1} gave significantly higher chlorophyll content at 50 DAS over control. The per cent increase in chlorophyll content in plants due to 20, 40 and 60 kg S ha^{-1} were 1.78, 3.93 and 6.78 respectively, compared to control (2.80 mg g^{-1}).

4.2.5 Primary branches $plant^{-1}$

Microbial inoculation: A perusal of data (Table 4.4) indicates that crop inoculated with single strain *Rhizobium,* PSB and with combined application of *Rhizobium* + PSB significantly improved the primary branches $plant^{-1}$ over no inoculation at harvest. Data further indicate that improvement in primary branches $plant^{-1}$ was by 52.10, 40.72 and 80.54 per cent at harvest with the application of *Rhizobium*, PSB and *Rhizobium* + PSB over control, respectively. Among the microbial inoculation, *Rhizobium* + PSB recorded maximum primary branches $plant^{-1}$ (6.03) and significantly superior over rest of inoculations.

Sulphur levels: An examination of data (Table 4.4) reveals that there was significant improvement in the number of primary branches $plant^{-1}$ with increasing levels of sulphur up to 60 kg S ha^{-1} over control at harvest stage. The improvement in primary branches $plant^{-1}$ were 14.32, 16.47 and 26.25 per cent at harvest with the application of 20, 40 and 60 kg S ha^{-1} over control, respectively. Among the sulphur levels 60 kg

S ha^{-1} recorded maximum primary branches plant^{-1} (5.29), which was significantly superior over 20 and 40 kg S ha^{-1}. Both the lower levels were at par in this regard.

Interaction effect : It is evident from data presented in Table 4.4.1 that interaction effect of microbial inoculation and sulphur on primary branches plant^{-1} was recorded significantly maximum primary branches plant^{-1} (20.10) under the treatment combination I_3S_3 over rest of the treatments combination. Minimum primary branches plant^{-1} (9.07) was recorded under treatment combination I_0S_0.

Table: 4.4.1: Interaction effect of microbial inoculation and sulphur levels on primary branches plant^{-1}

Treatments	**Microbial inoculation**			
Sulphur levels	**I_0**	**I_1**	**I_2**	**I_3**
S_0	9.07	10.60	15.58	15.10
S_1	9.37	16.22	13.72	18.18
S_2	10.36	16.53	12.67	18.98
S_3	11.33	17.65	14.47	20.10
SEm$\pm$	0.039			
CD (P= 0.05)	0.111			

4.3 EFFECT OF MICROBIAL INOCULATION AND SULPHUR LEVELS ON YIELD AND YIELD ATTRIBUTES

4.3.1 Number of pods plant^{-1}

Microbial inoculation: It is evident from the data reported in Table 4.5 that due to inoculation with *Rhizobium*, PSB, and *Rhizobium* + PSB the number of pods plant^{-1} significantly increased in comparison to control. The increase in number of pods plant $^{-1}$ with *Rhizobium* + PSB was significant over *Rhizobium* as well as PSB inoculations. The increase in number of pods plant^{-1} with *Rhizobium*, PSB, and *Rhizobium* + PSB inoculations were to the extent of 9.28, 5.70 and 13.26 per cent, respectively over control (25.10).

Sulphur levels: A perusal of data presented in Table 4.5 reveals that the pods plant^{-1} were significantly increased with 60 kg S ha^{-1}. Maximum pods plant^{-1} (28.02) were observed with the application of 60 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} increased pods plant^{-1} by 3.91, 6.52 and 9.45 per cent over control (25.60).

4.3.2 Number of seeds pod^{-1}

Microbial inoculation: Results presented in Table 4.5 reveal that due to inoculation with *Rhizobium*, PSB and *Rhizobium* + PSB, the significantly increased number of seeds pod^{-1} in comparison to control. The increase in number of seeds pod^{-1} with *Rhizobium*, PSB and *Rhizobium* + PSB were to the tune of 7.58, 2.88 and 19.13 per cent, respectively over control (2.77).

Sulphur levels: An examination of data (Table 4.5) reveals that the there were significant increase in seeds pod^{-1} with the increasing levels of sulphur upto 40 kg S ha^{-1}. However, highest seeds pod^{-1} (3.10) were observed at 60 kg S ha^{-1}, which was at par with 40 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} increased the seeds pod^{-1} to the tune of 8.00, 11.64 and 12.72 per cent, respectively, over control (2.75).

4.3.3 Seed yield plant^{-1}

Microbial inoculations: It is evident from the data depicted in Table 4.5 that due to inoculation of seed with *Rhizobium,* PSB and *Rhizobium* + PSB, the seed yield plant^{-1} significantly increased in comparison to control. The increase in seed yield plant^{-1} with *Rhizobium* + PSB was significant over *Rhizobium* as well as PSB inoculations. The increase in seed yield plant^{-1} of soybean with *Rhizobium*, PSB, and *Rhizobium* + PSB inoculations were to the extent of 21.66, 10.96 and 32.62 per cent, respectively over control (7.48 g plant^{-1}).

Sulphur levels: A perusal of data presented in Table 4.5 reveals that the seed yield plant^{-1} was significantly increased with 60 kg S ha^{-1}. Maximum seed yield plant^{-1} (9.13 g plnat^{-1}) was observed with the application of 60 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} increased seed yield plant^{-1} by 5.26, 8.31 and 11.61 per cent, respectively, over control (8.18 g plant^{-1}).

4.3.4 Seed index

Microbial inoculation: It is evident from the data in Table 4.5 that due to inoculation of seed with *Rhizobium*, PSB and *Rhizobium* + PSB, the seed index significantly increased in comparison to control. The increase in seed index with *Rhizobium* + PSB was significant over *Rhizobium* as well as PSB inoculations. The increase in seed index of soybean with *Rhizobium*, PSB, and *Rhizobium* + PSB inoculations were to the extent of 15.56, 7.69 and 26.51 per cent, respectively, over control (10.79).

Sulphur levels: A perusal of data presented in Table 4.5 indicates that the there were significant increase in seed index with the increasing levels of sulphur upto 40 kg S ha^{-1}. However, maximum seed index (12.47) was observed with the application of 60 kg S ha^{-1} but it was at par with 40 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} increased seed index by 3.35, 6.18 and 7.04 per cent over control (11.65), respectively.

4.3.5 Seed yield (kg ha^{-1})

Microbial inoculation: Further analysis of data presented in Table 4.6 reveal that due to inoculation of seeds with *Rhizobium*, PSB and *Rhizobium* + PSB, the seed yield significantly increased as compared to control. Maximum seed yield kg ha^{-1} (1442.79 kg ha^{-1}) was observed with the inoculation of *Rhizobium* + PSB. The increase in seed yield with *Rhizobium* + PSB was found to be significant over *Rhizobium* as well as PSB inoculations. The increase in seed yield with *Rhizobium*, PSB and *Rhizobium* + PSB were to the extent of 517.22, 284.33 and 577.43 kg ha^{-1} respectively, over control (865.36 kg ha^{-1}).

Sulphur levels: A perusal of data presented in Table 4.6 reveals that the seed yield plant^{-1} was significantly increased with 60 kg S ha^{-1}. Maximum seed yield kg ha^{-1} (1330.70 kg ha^{-1}) was observed with the application of 60 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} increased seed yield by 139.6, 216 and 279.1 kg ha^{-1} respectively, over control (1051. 60 kg ha^{-1}).

4.3.6 Haulm yield (kg ha^{-1})

Microbial inoculation: It is evident from the data in Table 4.6 that due to inoculation of seed with *Rhizobium*, PSB and *Rhizobium* + PSB, the haulm yield significantly increased in comparison to control. Maximum haulm yield kg ha^{-1} (3409.65 kg ha^{-1}) was recorded with the inoculation of *Rhizobium* + PSB. The increase in haulm yield with *Rhizobium* + PSB was significant over *Rhizobium* as well as PSB inoculations. The increase in haulm yield with *Rhizobium*, PSB and *Rhizobium* + PSB inoculations were to the extent of 1162.0, 618.75, and 1288.82 kg ha^{-1} respectively over control (2120.83 kg ha^{-1}).

Sulphur levels: An examination of data (Table 4.6) reveals that there was significant increase in haulm yield with the increasing levels of sulphur upto 40 kg S ha^{-1}. However, highest haulm yield (3076.60 kg ha^{-1}) were observed at 60 kg S ha^{-1} which was at par with 40 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} increased the haulm yield to the 75.40, 326.40 and 385.10 kg ha-^{1}, respectively, over control (2691.50 kg ha^{-1}).

4.3.7 Biological yield (kg ha^{-1})

Microbial inoculation: Data presented in Table 4.6 reveal that due to inoculation of seeds with *Rhizobium*, PSB and *Rhizobium* + PSB the biological yield of soybean was significantly increased as compared to control. Maximum biological yield kg ha^{-1} (4852.62 kg ha^{-1}) was recorded with the inoculation of *Rhizobium* + PSB. The increase in biological yield with *Rhizobium* + PSB was found to be significant over *Rhizobium* as well as PSB inoculations. The increase in biological yield of soybean with *Rhizobium,* PSB and *Rhizobium* + PSB were to the extent of 1678.05, 879.98 and 1866.68 kg ha^{-1} respectively, over control (2985.94 kg ha^{-1}).

Sulphur levels: It is apparent from data presented in Table 4.6 that there was significant increase in biological yield with the increasing levels of sulphur upto 60 kg S ha^{-1}. Maximum biological yield (4405.20 kg ha^{-1}) was noticed with the application of 60 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} increased biological yield by 237.10, 562.2 and 684.9 kg ha^{-1} respectively, over control (3720.30 kg ha^{-1}).

4.3.8 Harvest index

Microbial inoculation: A perusal of data (Table 4.6) indicates that inoculation with single strain *Rhizobium*, PSB and combined application of *Rhizobium* + PSB significantly increased the harvest index over control. The increase in harvest index was by 29.80, 29.48 and 30.10 per cent with the application of *Rhizobium* PSB and *Rhizobium* + PSB over control (28.94 %), respectively. While, combined inoculation recorded maximum harvest index (30.10 %) and which was found at par with *Rhizobium* inoculation. Both the alone inoculants of *Rhizobium* and PSB were at par with each other.

Sulphur levels: It is explicit from the data presented in Table 4.6 that there was significant increase in harvest index with the increasing levels of sulphur upto 60 kg S ha^{-1}. Maximum harvest index (30.50 %) was noticed with the application of 20 kg S ha^{-1} which was found at par with 60 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} increased harvest index by 8.15, 4.25 and 7.09 per cent respectively, over control (28.20%).

4.4 EFFECT OF MICROBIAL INOCULATION AND SULPHUR LEVELS ON NUTRIENT CONTENT OF SEED AND HAULM

4.4.1 N Content

4.4.1.1 Seed

Microbial inoculation: A perusal of data (Table 4.6) indicates that crop inoculated with *Rhizobium* + PSB recorded highest N content in seed (6.58 per cent) which was significantly enhanced the N content over *Rhizobium* as well as PSB alone and control. Further, *Rhizobium* and PSB inoculation though significantly improved N content of seed over control but were at par with each other and the improved in N content was by 5.05, 3.87 and 10.77 per cent with the application of *Rhizobium*, PSB and *Rhizobium* + PSB over control (5.94 per cent), respectively.

Sulphur levels: The result presented in (Table 4.7) show that there was significant improvement in N content in seed with increasing levels of sulphur up to 40 kg S ha^{-1}. However, maximum N content in seed (6.38 per cent) was recorded with the application of 60 kg S ha^{-1}, which was at par with 40 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} improved N content in seed to the tune of 2.99, 5.15 and 6.15 per cent over control (6.01 per cent), respectively.

4.4.1.2 Haulm

Microbial inoculation: Data Table 4.7 show that crop inoculation with *Rhizobium* + PSB, recorded highest N content in haulm (1.69 per cent) which was significantly higher over *Rhizobium* as well as PSB alone and control. Further, *Rhizobium* and PSB inoculation though significantly improved N content of haulm over control. The improvement in N content was by 9.50, 5.83 and 23.36 per cent with the application of *Rhizobium*, PSB and *Rhizobium* + PSB over control (1.37per cent), respectively.

Sulphur levels: An examination of data presented in Table 4.7 show that there was significant improvement N content in haulm with increasing levels of sulphur up to 40 kg S ha^{-1}. However, maximum N content in haulm (1.54 per cent) recorded with the application of 60 kg S ha^{-1}, which was at par 40 kg S ha^{-1}. the application of 20, 40 and 60 kg S ha^{-1} improved N content to the tune of 3.47, 5.55 and 6.95 per cent over control (1.44 per cent), respectively.

4.4.2 P Content

4.4.2.1 Seed

Microbial inoculation: A perusal of data (Table 4.7) indicates that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB, significantly improved P content of seed by 4.46, 12.40 and 21.31 per cent over control (0.516 per cent), respectively. Further, seed inoculation with *Rhizobium* + PSB recorded highest P content in seed (0.626 per cent) and it was significantly superior over *Rhizobium* and PSB alone. PSB alone was also superior over *Rhizobium* and control.

Sulphur levels: An examination of data (Table 4.7) reveals that there was significant improvement in P content with increasing levels of sulphur up to 60 kg S ha^{-1} over control and the improvement in P content in seed were by 2.49, 3.65 and 6.39 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (0.548 per cent), respectively. Among the sulphur levels 60 kg S ha^{-1} recorded maximum P content in seed (0.583), which was significantly superior over 20 and 40 kg S ha^{-1}. Both the lower levels were at par in this regard.

4.4.2.2 Haulm

Microbial inoculation: It is evident from the data in Table 4.7 that due to inoculation with *Rhizobium*, PSB and *Rhizobium* + PSB significant improvement in P content of haulm. The extent of increase were by 2.64, 8.46 and 17.99 per cent over the control (0.189 per cent), respectively. Further, seed inoculation with *Rhizobium* + PSB recorded highest P content in haulm (0.223 per cent) and it was significantly superior over *Rhizobium* and PSB alone. PSB alone was also superior over *Rhizobium.*

Sulphur levels: It is apparent from data presented in Table 4.7 that there was significant improvement in P content in haulm due to increasing levels of sulphur up to 40 kg S ha^{-1}. However, highest haulm yield (0.207 per cent) was noticed with 60 kg S ha^{-1}, which was at par with 40 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} improved P content in haulm which were by 3.04, 4.57 and 5.08 per cent over control (0.197 per cent), respectively.

4.4.3 S Content

4.4.3.1 Seed

Microbial inoculation: Data Table 4.8 indicate that crop inoculated with *Rhizobium* + PSB significant improvement in S content of seed over control. The extent of increase were by 1.24 per cent over control (.322), respectively. Further, seed inoculation with *Rhizobium* + PSB recorded highest S content in seed (0.326 per cent) and it was significantly superior over control and *Rhizobium* was found at par with *Rhizobium* + PSB. PSB failed to bring about significant improvement in S content of seed over control.

Sulphur levels: It is evident from data in Table 4.8 that there was significant improvement in S content in seed with increasing levels of sulphur up to 60 kg S ha^{-1}. The improvement in S content in seed were by 1.24, 3.83 and 6.07 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (.313 per cent), respectively. Among the sulphur levels 60 kg S ha^{-1} recorded maximum S content in seed (.332 per cent), which was significantly superior over 20 and 40 kg S ha^{-1}. 40 kg S ha^{-1} was also superior of 20 kg S ha^{-1} and control and 20 kg S ha^{-1} was superior over control, respectively.

4.4.3.2 Haulm

Microbial inoculation: It is explicit from data (Table 4.8) that due to inoculation of seed with *Rhizobium*, PSB and *Rhizobium* + PSB, significant improvement in S content of haulm was noticed. The extent of increase was by 6.84, 6.31 and 9.47 per cent by these treatments over the control (0.190 per cent), respectively. Further, seed inoculation with *Rhizobium* + PSB recorded highest S content in haulm (0.208 per cent) and it was significantly superior over *Rhizobium* and PSB alone. *Rhizobium* was at par with PSB in this respect.

Sulphur levels: The results presented in Table 4.8 indicate that there was significant improvement in S content in haulm by increasing levels of sulphur up to 60 kg S ha^{-1} over control. The improvement in S content in haulm was by 1.53, 3.57 and 5.10 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (0.196 per cent), respectively. Among the sulphur levels 60 kg S ha^{-1} recorded maximum S content in seed (0.206 per cent), which was significantly superior over 20 and 40 kg S ha^{-1}. 40 kg S ha^{-1} was also superior of 20 kg S ha^{-1} and control and 20 kg S ha^{-1} was superior over control.

4.5 EFFECT OF MICROBIAL INOCULATION AND SULPHUR LEVELS ON NUTRIENT CONTENT OF SEED AND HAULM

4.5.1 N Uptake

4.5.1.1 Seed

Microbial inoculation : A perusal of data (Table 4.9) indicates that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB significantly increased N uptake by seed and the extent of increase were by 66.97, 37.79 and 84.23 per cent over the control (51.57 kg ha^{-1}), respectively . Among the inoculations *Rhizobium* + PSB recorded the highest N uptake by seed (95.01 kg ha^{-1}) and it was significantly superior over other treatments.

Sulphur levels: It is evident from data in Table 4.9 that there was significant improvement in N uptake by seed with increasing levels of sulphur up to 60 kg S ha^{-1} over control and the improvement in N uptake by seed were by 15.75, 24.96 and 33.22 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (64.10 kg ha^{-1}), respectively. Application of 60 kg S ha^{-1} recorded maximum N uptake by seed (85.40 kg ha^{-1}), which was significantly superior over control and other lower levels.

4.5.1.2 Haulm

Microbial inoculation: Data presented in Table 4.9 indicate that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB, significantly increased N uptake by haulm and the extent of increase was by 70.20, 37.06 and 98.27 per cent over the control (29.00 kg ha^{-1}), respectively . Inoculations with *Rhizobium* + PSB recorded the highest N uptake by haulm (57.50 kg ha^{-1}) and it was significantly superior over other treatments.

Sulphur levels: It is apparent from data in Table 4.9 that there was significant improvement in N uptake by haulm with increasing levels of sulphur up to 60 kg S ha^{-1}. The improvement in N uptake by haulm were by 6.34, 18.02 and 21.57 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (39.40 kg ha^{-1}), respectively. Sulphur levels 60 kg S ha^{-1} recorded maximum N uptake by haulm (47.90 kg ha^{-1}), which was 3.01 and 14.31 per cent higher by 40 and 20 kg S ha^{-1}.

4.5.1.3 Total uptake:

Microbial inoculation: An examination of data (Table 4.9) reveals that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB significantly increased total N uptake by crop and the extent of increase was by 68.13, 37.53 and 89.30 per cent over the control (80.57 kg ha^{-1}), respectively . *Rhizobium* + PSB recorded the highest total N uptake by crop (152.52 kg ha^{-1}) and it was significantly superior by 12.58 and 37.64 per cent higher with *Rhizobium* and PSB inoculation, respectively.

Sulphur levels: It is explicit from data (Table 4.9) that there was significant improvement in total N uptake by crop with increasing levels of sulphur up to 60 kg S ha^{-1}. The improvement in total N uptake by crop was by 8.00, 17.67 and 24.00 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (107.50 kg ha^{-1}), respectively. Sulphur level 60 kg S ha^{-1} recorded maximum total N uptake by crop (133.3 kg ha^{-1}), which was significantly superior over 40, 20 and no sulphur application.

4.5.2 P Uptake

4.5.2.1 Seed

Microbial inoculation : A perusal of data (Table 4.10) indicates that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB significantly improved P uptake by seed and it was obtained that the extent of increase was by 67.11, 49.66 and 80.31 per cent over the control (4.47 kg ha^{-1}), respectively. Further, seed inoculation with *Rhizobium* + PSB recorded highest P uptake by seed (8.06 kg ha^{-1}) and it was 7.89 and 20.47 per cent higher over *Rhizobium* and PSB inoculation.

Sulphur levels: An examination of data (Table 4.10) reveals that there was significant improvement in P uptake by seed with increasing levels of sulphur up to 60 kg S ha^{-1}. The improvement in P uptake by seed was by 17.24, 25.86 and 34.48 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (5.80 kg ha^{-1}), respectively. Sulphur level 60 kg S ha^{-1} recorded maximum P uptake by seed (7.80 kg ha^{-1}), which was 6.84 and 14.70 per cent higher over 40 and 20 kg S ha^{-1}, respectively.

4.5.2.2 Haulm

Microbial inoculation: Data presented in Table 4.9 indicate that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB significantly improved P uptake of haulm and the extent of increase was by 59.95, 39.80 and 89.80 per cent over control (4.02 kg ha^{-1}), respectively. Further, seed inoculation with *Rhizobium* + PSB recorded highest P uptake by haulm (7.63 kg ha^{-1}), which was 18.66 and 35.76 per cent higher over *Rhizobium* and PSB inoculation.

Sulphur levels: An examination of data (Table 4.10) reveals that there was significantly improved P uptake by haulm with increasing levels of sulphur up to 40 kg S ha^{-1} over control and the improvement in P uptake by haulm was by 7.55, 18.86 and 20.75 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (5.30 kg ha^{-1}), respectively. Sulphur level 60 kg S ha^{-1} recorded maximum P uptake by haulm (6.40 kg ha^{-1}), which was found at par with 40 kg S ha^{-1}.

4.5.2.3 Total uptake

Microbial inoculation: Data presented in Table 4.10 indicate that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB, significantly improved total P uptake of crop and the extent of increase was by 63.72, 44.99 and 84.80 per cent over the control (8.49 kg ha^{-1}), respectively. Further, seed inoculation with *Rhizobium* + PSB recorded highest P uptake by crop (15.69 kg ha^{-1}), which was 12.87 and 27.45 per cent superior over *Rhizobium* and PSB.

Sulphur levels: An examination of data (Table 4.10) reveals that there was significantly improved total P uptake with increasing levels of sulphur up to 60 kg S ha^{-1} over control and the improvement in total P uptake of crop was by 11.71, 21.62 and 28.82 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (11.10 kg ha^{-1}), respectively. Among the sulphur levels 60 kg S ha^{-1} recorded maximum P uptake by seed (14.30 kg ha^{-1}), which was significantly superior over other treatments, 40 and 20 kg S ha^{-1} and sulphur levels were at the tune of 5.92 and 15.32 per cent, respectively.

4.5.3 S Uptake

4.5.3.1 Seed

Microbial inoculation: A perusal of data (Table 4.11) that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB, significantly increased S uptake by seed and the extent of increase were by 60.21, 29.74 and 69.17 per cent over the control (2.79 kg ha^{-1}), respectively. *Rhizobium* + PSB recorded the highest S uptake by seed (4.72 kg ha^{-1}) and it was 5.59 and 30.38 per cent higher over *Rhizobium* and PSB inoculation. *Rhizobium* recorded 23.48 per cent higher S uptake over PSB.

Sulphur levels: It is evident from data in Table 4.11 indicates that there was significantly improved S uptake with increasing levels of sulphur up to 60 kg S ha^{-1} over control and the improvement in S uptake by seed were by 15.15, 24.24 and 33.33 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (3.30 kg ha^{-1}), respectively. Application of 60 kg S ha^{-1} recorded maximum S uptake by seed (4.40 kg ha^{-1}), which was 7.31 and 15.78 per cent higher over 40 and 20 kg S ha^{-1}, respectively.

4.5.3.2 Haulm

Microbial inoculation: Data presented in Table 4.11 indicate that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB, significantly increased S uptake by haulm and the extent of increase was by 65.59, 37.37 and 76.48 per cent over control (4.04 kg ha^{-1}), respectively. *Rhizobium* + PSB recorded the highest S uptake by haulm (7.13 kg ha^{-1}) and it was 6.57 and 28.46 per cent higher over *Rhizobium* and PSB inoculation, respectively.

Sulphur levels: It is apparent from data depicted in Table 4.11 that there was significantly improved S uptake with increasing levels of sulphur up to 60 kg S ha^{-1} over control and the improvement in S uptake by haulm was by 3.77, 16.98 and 20.75 per cent with the application of 20, 40 and 60 kg S ha^{-1} over control (5.30 kg ha^{-1}), respectively. Application of 60 kg S ha^{-1} recorded maximum S uptake by haulm (6.40 kg ha^{-1}), which was 16.36 per cent superior over 20 kg S ha^{-1}.

4.5.3.3 Total uptake

Microbial inoculation: An examination of data (Table 4.11) reveals that crop inoculated with *Rhizobium* ,PSB and *Rhizobium* + PSB, significantly increased total S uptake by crop and the extent of increase was by 63.40, 34.26 and 73.64 per cent over the control (6.83 kg ha^{-1}), respectively. *Rhizobium* + PSB recorded the highest total S uptake by crop (11.86 kg ha^{-1}) and it was significantly superior by 6.27 and 29.33 per cent over *Rhizobium* and PSB inoculation.

Sulphur levels: It is explicit from data (Table 4.11) that there was significantly improved total S uptake with increasing levels of sulphur up to 60 kg S ha^{-1} over control and the improvement in total S uptake was by 8.13, 19.76 and 25.58 per cent with the application of 20, 40 and 60 kg S ha^{-1} over control (8.60 kg ha^{-1}), respectively. Application of 60 kg S ha^{-1} recorded maximum total S uptake (10.80 kg ha^{-1}), which was 16.12 and 4.85 per cent higher over by 20 and 40 kg S ha^{-1}.

4.6 EFFECT OF MICROBIAL INOCULATION AND SULPHUR LEVELS ON QUALITY PARAMETERS OF SOYBEAN

4.6.1 Protein content

Microbial inoculation: A perusal of data (Table 4.12) indicates that crop inoculated with *Rhizobium* + PSB recorded highest protein content in seed (40.34 per cent) which was significantly higher over *Rhizobium* as well as PSB and control. The improvement in protein content in seed were by 4.90, 2.38 and 7.34 per cent with the application of *Rhizobium*, PSB and *Rhizobium* + PSB over control (37.58 per cent), respectively.

Sulphur levels: Analysis of data in Table 4.12 show that there was significant improved in protein content in seed with the increasing level of sulphur upto 40 kg S ha^{-1}. However, maximum protein content (39.27 per cent) was recorded with the application of 60 kg S ha^{-1} but it was at par with 40 kg S ha^{-1}. The application of 20, 40 and 60 kg S ha^{-1} improved protein content by 0.49, 1.66 and 1.84 per cent over control, respectively.

4.6.1 Protein yield

Microbial inoculation: A perusal of data (Table 4.12) indicates that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB significantly increased protein yield and the extent of increase were by 67.34, 35.89 and 78.81 per cent over the control (325.60 kg ha^{-1}), respectively. Further, seed inoculation with *Rhizobium* + PSB recorded highest protein yield (582.23 kg ha^{-1}), which was 6.85 and 31.57 per cent higher over *Rhizobium* and PSB.

Sulphur levels: An examination of data (Table 4.12) reveals that there was significantly increased protein yield with increasing levels of sulphur up to 60 kg S ha^{-1}. The increase in protein yield were by 13.62, 22.32 and 28.52 per cent with the application of 20, 40 and 60 kg S ha^{-1} over control (408.00 kg ha^{-1}), respectively. Application of 60 kg S ha^{-1} recorded maximum protein yield (524.40 kg ha^{-1}), which was significantly superior over other treatments viz 40 and 20 kg S ha^{-1} sulphur by 5.06 and 13.11 per cent, respectively.

4.6.3 Oil content in seed

Microbial inoculation: Data presented in Table 4.12 indicate that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB negatively influenced on oil content of seeds. The lowest oil content was recorded with *Rhizobium* + PSB inoculation (20.89 per cent) and the reduction was significantly inferior over the control.

Sulphur levels: An examination of data (Table 4.12) reveals that there was significant improvement in oil content with increasing levels of sulphur up to 60 kg S ha^{-1}. The data reveal that improvement in oil content in seed was by 0.52, 2.40 and 5.76 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (20.80 per cent), respectively. Application of 60 kg S ha^{-1} recorded maximum oil content (22.0 per cent), which was significantly superior by 5.21 and 3.29 per cent over 40 and 20 kg S ha^{-1}.

Interaction effect: It is evident from data presented in Table 4.12.1 that interaction effect of microbial inoculation and sulphur on oil content was recorded significantly maximum oil content (68.52 per cent) under the treatment combination I_1S_3 over rest of the treatments combination. Minimum oil content (60.36 per cent) was recorded under treatment combination I_1S_0.

Table: 4.12.1: Interaction effect of microbial inoculation and sulphur levels on oil content

Treatments	Microbial inoculation			
Sulphur levels	**I_0**	**I_1**	**I_2**	**I_3**
S_0	63.34	60.36	63.13	62.33
S_1	64.74	60.70	64.30	61.26
S_2	65.81	61.70	65.57	62.23
S_3	66.49	68.52	66.34	62.70
SEm$\pm$	0.019			
CD (P= 0.05)	0.055			

4.6.4 Oil yield

Microbial inoculation: A perusal of data (Table 4.12) indicates that crop inoculated with *Rhizobium*, PSB and *Rhizobium* + PSB significantly increased oil yield and the extent of increase was by 54.12, 32.42 and 58.72 per cent over the control (188.16 kg ha^{-1}), respectively. *Rhizobium* + PSB recorded the highest oil yield (298.66 kg ha^{-1}) and it was significantly superior over other treatments.

Sulphur levels: It is evident from data in Table 4.12 that there was significant increase in oil yield with increasing levels of sulphur up to 60 kg S ha^{-1} over control and the increase was by 13.98, 23.50 and 34.49 per cent with the application 20, 40 and 60 kg S ha^{-1} over control (217.40 kg ha^{-1}), respectively. Application of 60 kg S ha^{-1} recorded maximum oil yield (292.40 kg ha^{-1}), which was significantly superior over control.

4.6 EFFECT OF MICROBIAL INOCULATION AND SULPHUR LEVELS ON NET RETURN AND BC RATIO

4.6.1 Net returns

Microbial inoculation : A critical examination of data presented in Table 4.13 reveal that crop inoculation with *Rhizobium*, PSB and *Rhizobium* + PSB, the net returns significantly increased in comparison to control. The maximum net returns (₹ 35182 ha^{-1}) was recorded with under the *Rhizobium* + PSB and minimum (₹ 13220 ha^{-1}) was under control, respectively

Sulphur levels : It is clear from in Table 4.13 that net returns increased significantly with successive increase in varying level of sulphur in soybean. Further, the increase in net returns with 60 kg S ha^{-1} was found to bi significant over 20 as well as 40 kg S ha^{-1}. The maximum net returns (₹ 30375 ha^{-1}) was obtained under the 60 kg S ha^{-1} and minimum net returns (₹ 21071 ha^{-1}) was under control, respectively.

4.6.1 BC ratio

Microbial inoculation: A critical examination of data depicted in Table 4.13 reveal that the highest BC ratio (1.71) was obtained under the *Rhizobium* +PSB and minimum (0.65) was under control, respectively

Sulphur levels: It is clear from data (Table 4.13) that BC ratio increased significantly with successive increase in varying level of sulphur in soybean. Further, the increase in BC ratio with 60 kg S ha^{-1} was found to be significant over 20 as well as 40 kg S ha^{-1}. The maximum BC ratio (1.50) was obtained under the 60 kg S ha^{-1} and minimum BC ratio (1.00) was under control, respectively.

Table 4.1: Effect of microbial inoculation and sulphur levels on the plant population of soybean

Treatments	Plant population (lac ha^{-1})		
	30 DAS	60 DAS	At harvest
Inoculation			
Control	3.12	2.98	2.90
Rhizobium	3.07	3.05	2.91
PSB	3.08	3.02	2.87
Rhizobium + PSB	3.10	3.09	2.91
SEm ±	0.02	0.03	0.02
CD (P = 0.05)	NS	NS	NS
Sulphur levels (kg ha^{-1})			
0	3.11	3.05	2.87
20	3.12	3.01	2.90
40	3.06	3.02	2.92
60	3.00	3.04	2.89
SEm ±	0.02	0.03	0.02
CD (P = 0.05)	NS	NS	NS

Table 4.2: Effect of microbial inoculation and sulphur level on the plant height of soybean

Treatments	Plant height (cm)		
	30 DAS	60 DAS	At harvest
Inoculation			
Control	20.42	34.93	41.57
Rhizobium	22.72	37.03	44.57
PSB	21.91	35.85	43.55
Rhizobium + PSB	24.70	38.33	45.98
SEm ±	0.22	0.30	0.27
CD (P = 0.05)	0.65	0.86	0.78
Sulphur levels (kg ha^{-1})			
0	20.91	35.02	42.62
20	22.29	36.18	43.46
40	23.57	37.65	44.88
60	22.98	37.16	44.70
SEm ±	0.22	0.30	0.27
CD (P = 0.05)	0.65	0.86	0.78

Table 4.3: Effect of microbial inoculation and sulphur levels on the dry matter accumulation

Treatments	Dry matter accumulation (g plant^{-1})		
	30 DAS	**60 DAS**	**At harvest**
Inoculation			
Control	3.08	12.96	27.71
Rhizobium	3.29	14.05	29.21
PSB	3.19	13.54	28.41
Rhizobium + PSB	3.69	14..60	29.97
SEm ±	0.03	0.12	0.24
CD (P = 0.05)	0.087	0.34	0.696
Sulphur levels (kg ha^{-1})			
0	3.19	13.04	27.92
20	3.29	13.78	28.64
40	3.39	14.31	29.53
60	3.38	14.01	29.19
SEm ±	0.03	0.12	0.24
CD (P = 0.05)	0.087	0.34	0.696

Table 4.4: Effect of microbial inoculation and sulphur levels on LAI, chlorophyll content and primary branches

Treatments	LAI (50 DAS)	Chlorophyll (50 DAS) (mg g^{-1})	Primary branches plant^{-1} (at harvest)
Inoculation			
Control	3.82	2.75	3.34
Rhizobium	3.94	2.88	5.08
PSB	3.92	2.86	4.70
Rhizobium + PSB	4.42	3.06	6.03
SEm ±	0.03	0.015	0.051
CD (P = 0.05)	0.097	0.042	0.148
Sulphur levels (kg ha^{-1})			
0	3.92	2.80	4.19
20	3.99	2.85	4.79
40	4.06	2.91	4.88
60	4.12	2.99	5.29
SEm ±	0.03	0.015	0.051
CD (P = 0.05)	NS	0.042	0.148

Table 4.5: Effect of microbial inoculation and sulphur levels on yield attributes and yield of soybean

Treatments	No. of pods plant^{-1}	No. of seeds pod^{-1}	Seed yield (g plant^{-1})	Seed index
Inoculation				
Control	25.10	2.77	7.48	10.79
Rhizobium	27.43	2.98	9.10	12.47
PSB	26.53	2.85	8.30	11.62
Rhizobium + PSB	28.43	3.30	9.92	13.65
SEm ±	0.226	0.026	0.077	0.104
CD (P = 0.05)	0.654	0.075	0.224	0.299
Sulphur levels (kg ha^{-1})				
0	25.60	2.75	8.18	11.65
20	26.60	2.97	8.61	12.04
40	27.27	3.07	8.86	12.37
60	28.02	3.10	9.13	12.47
SEm ±	0.226	0.026	0.077	0.104
CD (P = 0.05)	0.654	0.075	0.224	0.299

Table 4.6: Effect of microbial inoculation and sulphur levels on yield attributes and yield of soybean

Treatments	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Inoculation				
Control	865.36	2120.83	2985.94	28.94
Rhizobium	1382.58	3282.83	4663.99	29.80
PSB	1149.69	2739.58	3865.92	29.48
Rhizobium + PSB	1442.79	3409.65	4852.62	30.10
SEm $\pm$	9.86	27.78	35.38	0.16
CD (P = 0.05)	28.46	78.78	102.19	0.48
Sulphur levels (kg ha^{-1})				
0	1051.60	2691.50	3720.30	28.20
20	1190.60	2766.90	3957.40	30.50
40	1267.60	3017.90	4285.50	29.40
60	1330.70	3076.60	4405.20	30.20
SEm $\pm$	9.86	27.78	35.38	0.16
CD (P = 0.05)	28.46	78.78	102.19	0.48

Table 4.7: Effect of microbial inoculation and sulphur levels on nutrient content of soybean at harvest

Treatments	Nutrient (%)			
	N		P	
	Seed	Haulm	Seed	Haulm
Inoculation				
Control	5.94	1.37	0.516	0.189
Rhizobium	6.24	1.50	0.539	0.194
PSB	6.17	1.45	0.580	0.205
Rhizobium + PSB	6.58	1.69	0.626	0.223
SEm ±	0.039	0.009	0.002	0.001
CD (P = 0.05)	0.112	0.027	0.007	0.002
Sulphur levels (kg ha^{-1})				
0	6.01	1.44	0.548	0.197
20	6.19	1.49	0.562	0.203
40	6.32	1.52	0.568	0.206
60	6.38	1.54	0.583	0.207
SEm ±	0.039	0.009	0.002	0.001
CD (P = 0.05)	0.112	0.027	0.007	0.002

Table 4.8: Effect of microbial inoculation and sulphur levels on sulphur content of soybean at harvest

Treatments	S (%)	
	Seed	Haulm
Inoculation		
Control	0.322	0.190
Rhizobium	0.324	0.203
PSB	0.315	0.202
Rhizobium + PSB	0.326	0.208
SEm ±	0.001	0.001
CD (P = 0.05)	0.002	0.002
Sulphur levels (kg ha^{-1})		
0	0.313	0.196
20	0.317	0.199
40	0.325	0.203
60	0.332	0.206
SEm ±	0.001	0.001
CD (P = 0.05)	0.002	0.002

Table 4.9: Effect of microbial inoculation and sulphur levels on N uptake at harvest

Treatments	N (kg ha^{-1})		
	Seed	**Haulm**	**Total**
Inoculation			
Control	51.57	29.00	80.57
Rhizobium	86.11	49.36	135.47
PSB	71.06	39.75	110.81
Rhizobium + PSB	95.01	57.50	152.52
SEm ±	0.68	0.51	1.04
CD (P = 0.05)	1.97	1.47	3.00
Sulphur levels (kg ha^{-1})			
0	64.10	39.40	107.50
20	74.20	41.90	116.10
40	80.10	46.50	126.50
60	85.40	47.90	133.30
SEm ±	0.68	0.51	1.04
CD (P = 0.05)	1.97	1.47	3.00

Table 4.10: Effect of microbial inoculation and sulphur levels on P or P_2O_5 uptake at harvest

Treatments	P (kg ha^{-1})		
	Seed	Haulm	Total
Inoculation			
Control	4.47	4.02	8.49
Rhizobium	7.47	6.43	13.90
PSB	6.69	5.62	12.31
Rhizobium + PSB	8.06	7.63	15.69
SEm ±	0.06	0.05	0.10
CD (P = 0.05)	0.18	0.15	0.29
Sulphur levels (kg ha^{-1})			
0	5.80	5.30	11.10
20	6.80	5.70	12.40
40	7.30	6.30	13.50
60	7.80	6.40	14.30
SEm ±	0.06	0.05	0.10
CD (P = 0.05)	0.18	0.15	0.29

Table 4.11: Effect of microbial inoculation and sulphur levels on S uptake at harvest

Treatments	S (kg ha^{-1})		
	Seed	**Haulm**	**Total**
Inoculation			
Control	2.79	4.04	6.83
Rhizobium	4.47	6.69	11.16
PSB	3.62	5.55	9.17
Rhizobium + PSB	4.72	7.13	11.86
SEm ±	0.03	0.07	0.10
CD (P = 0.05)	0.10	0.19	0.27
Sulphur levels (kg ha^{-1})			
0	3.30	5.30	8.60
20	3.80	5.50	9.30
40	4.10	6.20	10.30
60	4.40	6.40	10.80
SEm ±	0.03	0.07	0.10
CD (P = 0.05)	0.10	0.19	0.27

Table 4.12: Effect of microbial inoculation and sulphur levels on protein content and yield, oil content and yield

Treatments	Protein content (%)	Protein yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
Inoculation				
Control	37.58	325.60	21.70	188.16
Rhizobium	39.42	544.87	20.94	290.01
PSB	38.44	442.46	21.61	249.17
Rhizobium + PSB	40.34	582.23	20.89	298.66
SEm ±	0.06	3.65	0.02	2.11
CD (P = 0.05)	0.16	10.56	0.07	6.18
Sulphur levels (kg ha^{-1})				
0	38.56	408.00	20.80	217.40
20	38.75	463.60	20.91	247.80
40	39.20	499.10	21.30	268.50
60	39.27	524.40	22.00	292.40
SEm ±	0.06	3.65	0.02	2.11
CD (P = 0.05)	0.16	10.56	0.07	6.18

Table 4.13: Effect of microbial inoculation and sulphur levels on net return (₹ ha^{-1}) and BC ratio

Treatments	Net return (₹ ha^{-1})	BC ratio
Inoculation		
Control	13220	0.65
Rhizobium	32949	1.61
PSB	23983	1.17
Rhizobium + PSB	35182	1.71
SEm ±	371.69	0.02
CD (P = 0.05)	1073	0.05
Sulphur levels (kg ha^{-1})		
0	21071	1.00
20	25462	1.30
40	28426	1.40
60	30375	1.50
SEm ±	371.69	0.02
CD (P = 0.05)	1073	0.05

5. DISCUSSION

During the course of presenting the results of field investigation entitled **"Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur"** in preceeding chapter, many significant variations in the criteria used for treatments evaluation were obtained under the influence of different treatments. In the present chapter, efforts have been made to ascertain cause and effect relationship among the various parameters found significant on soybean productivity were studied and the important data pertaining to the effect of different treatments have also been presented in this chapter through suitable graphs, wherever felt necessary. Experimental findings or observations of other workers on the same crop or family irrespective of season have been cited to support the results of present experiment.

5.1 Effect of microbial inoculation

5.1.1 Growth parameters

The results revealed that seed inoculation either with *Rhizobium*, PSB or *Rhizobium* + PSB significantly improved plant growth characters namely, plant height, dry matter accumulation, LAI at 50 DAS of the crop growth (Table 4.2 to 4.4). At harvest, inoculation of seeds with *Rhizobium* + PSB accumulated highest biomass (29.97 g plant^{-1}) which was significantly higher by 6.77 per cent over no inoculation (Table 4.3) However, number of primary branches plant^{-1} significantly increased by all the inoculants at harvest where as *Rhizobium* + PSB proved superior over others (Table 4.4).

It is well documented that inoculation of seeds with specific strain of *Rhizobia* increases number of this organism in the soil *rhizospher*. The greater availability of bacteria near the root zone of the plants maximize infection on developing root system thereby increases nodule formation on the roots and ultimately results in fixation of higher N in nodules from atmosphere.

The addition of PSB culture to soils through seed inoculation, increases solubilization of native and applied phosphorus by producing higher quantum of different organic acids. Hence, increase availability of P to *rhizobia* and plant. Thus, P is essential for growth and development of *Rhizobium* and plant which might be increase nodulation in soybean (Gour, 1985). Further, Subba Rao (1984) reported that

PSB inoculation increased availability of phosphorus to plants by enhancing mineralization rate of organic phosphates. These bacterias were also capable to secrete some biologically active compounds such as auxins, gibberellins, vitamins etc. Which were considered to be important for proper growth and development of plants.

The greater availability of nutrients (N and P) in soils their by in the plants seems to have promoted various physiological activities in plants which are considered to be indispensable for proper growth and development. Thus congenial nutritional environment in plants under microbial inoculation seems to have promoted various growth parameters i.e. plant height, number of primary branches plant^{-1} and LAI. It is well established that dry matter production of plants is dependent on LAI, which helps in better interception of solar radiation as well as chlorophyll content of leaves. Therefore, higher LAI and presumably chlorophyll content under the influence of microbial inoculation seems to have resulted in greater photosynthetic activity thereby production of higher biomass. Further, regression analysis between dry matter and LAI reveal that an unit increase in LAI improved dry matter accumulation by 3.32 times.

Significantly improvement in overall growth of soybean plants due to inoculation particularly with *Rhizobium* + PSB was close agreement with findings of Vasumathi and Jayanthi (2014). Janagard *et al.* (2013), Jaga and Sharma (2015) who reported significant increase in plant height and dry matter accumulation plant^{-1} with *Rhizobium* + PSB inoculation.

5.1.2 Yield attributes and yields

In comparison to no inoculation, seed inoculation with *Rhizobium*, PSB and *Rhizobium* + PSB significantly improved various yield attributes namely, number of pods plant^{-1}, number of seeds pod^{-1}, seed yield plant^{-1} (g plant^{-1}) and seed index (Table 4.5). Though, all the inoculants were recorded significant variation in productivity of crop. However, highest seed yield, haulm yield and biological yield (1715.06, 3740.90 and 5384.29 kg ha^{-1}) were produced under inoculation *Rhizobium* + PSB which was significantly superior. Further inoculation *Rhizobium* + PSB recorded maximum harvest index (31.87 per cent) and significantly superior over rest of the inoculations. Both the alone inoculants of *Rhizobium* and PSB were at par with each other (Table 4.6).

The better availability of metabolites/ nutrients and other growth inputs like vitamins and hormones to the plant under seed inoculation might have promoted various yield attributes. Under the present study, regression analysis also showed dependence of dry matter on plant height, LAI and and chlorophyll content, seed yield on pods plant^{-1}, seeds pod^{-1} and seed yield (g plant^{-1}) (Table 5.1). This also substantiate aforesaid statement.

Since seed yield is the function of various yield components. The increase in each component under the influence of *Rhizobium* + PSB resulted in higher soybean seed yield 1715.06 kg ha^{-1} over control. Positive inter-relationship between seed yield and number of pods plant^{-1} (0.917*), seeds pod^{-1} (0.922*), seed yield (g plant^{-1}) (0.962*), seed index (0.966*), (Table 5.1) also confirm the results. Significant increase in haulm and biological yields with seed inoculation over control seems to be due to improvement in growth and yield parameters of the crop.

The findings of present investigation were in close agreement with results reported by several researchers (Janagard *et al.*, 2013; Farnia and Gudiny, 2014; Vasumathi and Jayanthi, 2014). Jaga and Sharma (2015) reported that inoculation with *Rhizobium* + PSB significantly increased seed yield over control.

5.1.3 Nutrient content and uptake

It was observed that microbial inoculation with *Rhizobium* + PSB significantly improved N and P contents of seed and haulm. However, the aforesaid inoculation failed to increase S content of seed but it is significantly increased in haulm over control (Table 4.7 and 4.8). Further all the inoculation treatments recorded significant increase in nutrients uptakes by seed, haulm and total uptake by the crop over control. Though, seed inoculation with *Rhizobium* + PSB accumulate highest nutrients (136.33 kg N, 14.98 kg P, 12.03 kg S ha^{-1}) compared to least under control (78.18 kg N, 8.25 kg P, 6.83 kg S ha^{-1}) to establish significant superiority over control as well as single inoculation *Rhizobium* and PSB in this respect (Table 4.9 to 4.12).

Significant improvement in nutrient contents and uptake by the crop under the influence of microbial inoculants appears to be on account of improvement in nutrients by various plant parts. Besides this, higher nodulation might have resulted in improving N status of the plant Thus overall improvement in crop growth (dry matter production) and nutrient status of plants ultimately led to accumulation of higher nutrients under the influence of *Rhizobium* + PSB. The regression analysis showed positive inter-relationship between biological yield and N uptake (0.957*), P uptake (0.847*) and S uptake (0.994*) (Table 5.1).

Significant increase in contents and uptake of nutrients under the influence of inoculation particularly with *Rhizobium* + PSB was also reported by Singh *et al.* (2009), Jaga and Sharma (2015) in soybean, Singh *et al.* (2014) in clusterbean, Chatterjee and Bandyopadhyay (2015) in cowpea.

5.1.4 Quality parameters

It was observed from the Table 4.12 that microbial inoculation had negative effect on oil content of soybean seeds. The significant reduction was recorded in *Rhizobium* + PSB inoculation. However, *Rhizobium* and PSB alone failed to attain any significant variation in oil content of seeds. The reduction of oil content might be due to that microbial inoculants increased nodulation and fixation of N by symbiosis and increase availability of N to the plant. Thus increase N content of plant which ultimately increased protein content of seed.

Apart from seed protein content and oil content were also influenced by the nitrogen regime. Protein and oil content are negatively correlated (Burton, 1985) and the protein content shows more variability than oil content (Weilenmann and Luquez, 1999). Seed oil content decreased while seed protein content increased with increased amounts of applied nitrogen thereby supporting previous findings (Blamey and Chapmen, 1981). Further, the inverse relation in oil content and protein content exist, so microbial inoculants decrease oil content of seed of soybean and hence negative inter-relationship between oil content and oil yield (-0.199). The finding of present investigation was close agreement with Ahsan *et al*. (2012) and Jaga and Sharma (2015).

5.2 Effect of sulphur levels

5.2.1 Growth parameters

It is evident from results that application of sulphur 40 kg ha^{-1} significantly improved plant height and dry matter accumulation (Table 4.2 to 4.3) and the application of sulphur 60 kg ha^{-1} significantly improved other morphological components of growth (Table 4.4) and which ultimately reflected in over all improvement of growth.

The role of sulphur can be viewed from its participation in the primary and secondary metabolism as a constituent of various organic compouns that are vital for the functioning of plant processes. Sulphur in the form of sulphate, is the best known for its role in production of protein, primarily because S is a constituent of three S containing amino acids (cysteine, cystine and methionine), which are the building blocks of protein. About 90% of plant sulphur is present in these amino acids. It is also involved in chlorophyll formation, glutathione a compound supposed to play vital role being a constituent of succynyl co-A (Pirson, 1955). It is also a constituent of glutathione, a compound supposed to play a role in plant respiration and synthesis of oil (Jordan and Reisenaur, 1957).

Glutathione (Y- glut amyl cysteinyl glycine) is the most abundant low molecular weight thiol in plant cell. Though, not a primary product of cellular metabolism for life, glutathione plays an important role in detoxification of compounds that are unfavorable for growth (Renmenberg and Lamoureux, 1990). Sulphur deficiency also leads to an impaired synthesis of several co-enzyme and prosthetic groups such as ferrodoxin, biotin and thiamine, wherein S forms as a structural constituent (Tondon, 1991). Reduced ferrodoxin, a protein with iron-sulphur complex acts as transmitter of electron generating energy rich compound, NADPH in light reaction of photosynthesis (Marschner, 1986).

The increasing sulphur levels 20 and 40 kg ha^{-1} significantly improved plant height, dry matter accumulation of soybean (Table 4.2 and 4.3) and primary branches $plant^{-1}$ at harvest highest recorded in application of sulphur 60 kg ha^{-1} (Table 4.4). It is obvious that higher sulphur levels increased S supply in the rhizosphere, which culminated into more absorption and higher uptake of nutrient (Table 4.9 and 4.10) by the crop plants. This could have resulted into better growth i.e. plant height and primary branches $plant^{-1}$. Significant improvement in plant height and primary branches $plant^{-1}$ (Table 4.3 and 4.4) might have resulted into better interception, absorption and utilization of radiant energy leading to higher photosynthetic rate and finally more accumulation of dry matter by plants. Significant positive correlation of dry matter accumulation with plant height at harvest (0.898*) and LAI at 50 DAS (0.734*) (Table 5.1) further substantiate the results. Increase in plant height, primary branches $plant^{-1}$ or dry matter accumulation with increasing doses of sulphur are in close conformity with the findings of several researchers Farhad *et al.* (2010), Hussain *et al.* (2011) Thenua *et al*. (2014) and Lakshman *et al.* (2015).

5.2.2 Yield attributes and yield

It was observed that S application to soybean crop improved various yield components (Table 4.5) with significant increase in crop productivity (Table 4.6) in general. Increase in yield parameters of soybean with S application could be ascribed to its role in improving mineral nutrition of the crop. In preceding section it was emphasized that S fertilization play an important role to alter physic-chemical properties of soil, conductive for growth and development of the crop. Viewing the work done of effect of gypsum (S source) application to various crops, it was inferred that its application promoted root growth and yield of crops (Shainberg *et al*. 1989).

This eventually suggests better availability of nutrients. These nutrients upon translocation towards reproductive structures and also higher photosynthesis activity might have resulted in significant increase in yield attributes and yield. The observed improvement in yield attributes seems to be due to balanced nutritional environment. Another possible reason could be efficient and greater partitioning of metabolites and adequate translocation of nutrients towards reproductive site. Wareing and Patrik (1975) reported that improvement in yield parameters was attributed to diversion of greater proportion of assimilates to the developing pods of groundnut due to increased sink strength reflected through larger demands for photosynthesis.

The net results of increased yield attributes was reflected in increased seed yield of soybean with S application. High yield can be attained by the gross contribution of yield component *viz.* number of pods plant^{-1} (28.02), seed yield g plant^{-1} (9.13 g), seed index (12.47). Positive interrelationship between seed yield and number of pods plant^{-1} (0.917*), seed yield g plant^{-1} (0.962*), and seed index (0.966*) also validates profound effect of these parameters on yield. These results are in agreement with the finding of Serker *et al.* (2002), Dhage *et al.* (2014) and Lakshman *et al.* (2015).

5.2.3 Nutrient content and uptake

A significant increase in N, P and S content over control and uptake in grain, haulm and total by crop were recorded with successive levels of sulphur upto 60 kg S ha^{-1} (Table 4.7 to 4.11). Improvement in nutritional environment of plants in general seems to be due to greater availability of nutrients from the soil and later on their higher extraction by roots and translocation to plant parts. Reviewing the work done on effect of sulphur through gypsum application to various crops, it was inferred that its application promoted root growth. Better root development can therefore, be reasoned for greater extraction of nutrients. It is generally believed that the extracted nutrients are used to maintain their critical concentration in plants and thereby for the use of developing structures. Thus, higher concentration of nutrients under S fertilization suggests adequate supply of nutrients.

N, P and S uptake significantly increased up to 60 kg S ha^{-1}. Application of 60 kg S ha^{-1} was superior over 20 and 40 kg S ha^{-1} in this regard (Table 4.9, 4.10 and 4.11). The trend of nutrient uptake is seemed to similar that of grain, haulm and total yield, which is due to the fact that nutrient uptake, is the function of yield and nutrient content. Therefore, nutrient uptake by crop was also significantly increased up to 60 kg S ha^{-1}. The regression analysis showed positive inter-relationship between seed yield and N uptake (0.976*), P uptake (0.896*) and S uptake (0.994*), (Table 5.1). The result so obtained corroborate with the finding of Serker *et al.* (2002), Nagar and Meena (2004) and Dhage *et al.* (2014).

5.2.4 Quality parameters

Protein content in seed and yield was increased with the increasing levels of sulphur upto 60 kg S ha^{-1}. The role of S can be viewed from its participation in the several biochemical processes for the metabolism of carbohydrates, fat and protein in plant system. Sulphur in the form of sulphate, is best known for its role in synthesis of S containing amino acids, namely methionine, cysteine and cystine and those amino acids are integral part of protein formation in any leguminous crop. Further, regression analysis between seed yield and protein yield (0.923*), (Table 5.1). Similar results have been observed by Serker *et al.* (2002), Dhage et al. (2014)) and Lakshman *et al*. (2015).

Increase in oil content in soybean seed and oil yield with sulphur application can be ascribed to the fact that sulphur deficiency hinders the full utilization of carbohydrates in plant for conversion into oil. Positive inter-relationship between seed yield and oil yield (0.990*), (Table 5.1). Positive role of sulphur as metabolism of carbohydrates into oil has been reported by Serker *et al*. (2002), Dhage et al. (2014) and Lakshman *et al.* (2015).

6. SUMMARY

Results of the field experiment entitled **"Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur"** presented and discussed in preceding chapters are summarized and concluded as follows:

EFFECT OF MICROBIALINOCULATION

- Seed inoculation with *Rhizobium*, PSB and combined application of *Rhizobium* + PSB, significantly improved the plant height over no inoculation at all the stages of crop growth (30, 60 DAS and at harvest). Among the microbial inoculation *Rhizobium* +PSB tended to increase plant height by 20.95, 9.73 and 10.61 percent over control, at 30, 60 DAS and harvest, respectively.
- Seed inoculation with *Rhizobium*, PSB and combined application of *Rhizobium* + PSB, significantly improved the dry matter accumulation over no inoculation at all the stages of crop growth (30, 60 DAS and at harvest). Among the microbial inoculation *Rhizobium* +PSB tended to increase dry matter accumulation by 19.80, 12.65 and 8.15 per cent over no inoculation, at 30, 60 DAS and harvest stages, respectively.
- Seed inoculation with *Rhizobium* + PSB, the leaf area index at 50 DAS significantly improved in comparison to control. However, *Rhizobium* + PSB was significant over *Rhizobium* as well as PSB inoculations but *Rhizobium* was found to be at par with PSB. *Rhizobium* + PSB recorded maximum leaf area index (4.42) over control (3.82).
- Seed inoculation with *Rhizobium* + PSB the chlorophyll content at 50 DAS significantly increased in comparison to control but *Rhizobium* was found at par with PSB. *Rhizobium* + PSB recorded maximum chlorophyll content (3.06 mg g^{-1}) over control (2.75 mg g^{-1}).
- Seed inoculation with *Rhizobium* + PSB recorded maximum primary branch plant^{-1} (6.03) and significantly superior over control (3.34), which was 80.53 per cent higher.
- Seed inoculation with *Rhizobium* + PSB the number of pods plant^{-1}, number seeds pod^{-1}, seed yield (g plant^{-1}) and seed index significantly increased in comparison to control. *Rhizobium* + PSB were found significantly superior rest of treatment, which was increased number of pods plant^{-1} (13.26), number seeds pod^{-1} (19.13), seed yield (g plant^{-1}) (32.65) and seed index (26.50) per cent higher over control.

- Seed inoculation with *Rhizobium* + PSB produced highest seed, haulm and biological yield (1442.79, 3409.65 and 4852.62) which was significantly higher over control. *Rhizobium* + PSB was found significantly superior over rest of the treatments. *Rhizobium* + PSB produced 577.43 kg ha^{-1} seed yield, 1288.82 kg ha^{-1} haulm yield and 1866.68 kg ha^{-1} biological yield higher over no inoculation.

- Seed inoculation with *Rhizobium* + PSB significantly increased harvested index over control but *Rhizobium* was found at par with PSB. *Rhizobium* + PSB recorded maximum harvest index (30.10) over control (28.94).

- Seed inoculation with *Rhizobium* + PSB significantly improved N content in seed and haulm over control, but N content in seed treated with *Rhizobium* was found at par with PSB. Maximum N content in seed (6.58) and haulm (1.69) under *Rhizobium* + PSB.

- Seed inoculation with *Rhizobium* + PSB significantly improved P content in seed and haulm over control, which was found superior over rest of inoculation. Maximum P content in seed (0.626) and haulm (0.223) under *Rhizobium* + PSB.

- Seed inoculation with *Rhizobium* + PSB significantly improved S content in seed and haulm over control, which was found superior over no inoculation. Maximum S content in seed (0.326) and haulm (0.208) under *Rhizobium* + PSB.

- Seed inoculation with *Rhizobium*, PSB and *Rhizobium* + PSB significantly improved nutrient (N, P and S) uptake by seed, haulm and crop. The crop under the influence of *Rhizobium* + PSB recorded highest nutrients uptake (152.52 kg N, 15.69 kg P and 11.86 kg S ha^{-1}) which recorded increase of 89.30, 84.80 and 73.64 per cent over control (80.57 kg N, 8.49 kg P and 6.83 kg S ha^{-1}).

- Seed inoculation with *Rhizobium*, PSB and *Rhizobium* + PSB significantly improved protein content and protein yield. The crop under the influence of *Rhizobium* + PSB recorded highest protein content and protein yield (40.34 per cent and 582.23 kg ha^{-1}) which represented increase of 7.34 and 78.81 per cent over control (37.58 per cent and 325.60 kg ha^{-1}).

- Inoculation with *Rhizobium* ,PSB and *Rhizobium* + PSB negatively influenced the oil content of seeds, while *Rhizobium* + PSB significant increased oil yield over control. However, highest oil yield recorded with *Rhizobium* + PSB (298.66 kg ha^{-2}) over control (188.16 kg ha^{-1}).

- Maximum net returns (₹ 44746 ha^{-1}) and BC ratio (2.09) were obtained with *Rhizobium* + PSB compared to lowest net returns (₹ 13220) and BC ratio (0.66) with no inoculation.

EFFECT OF SULPHUR LEVELS

- Plant height significantly increased with the application of 40 kg S ha^{-1} at all the stages over control, which was found at par with 60 kg S ha^{-1}. It was 12.72, 7.51 and 5.3 per cent higher at 30, 60 DAS and at harvest with the application of 40 kg S ha^{-1} over control (20.91, 35.02 and 42.62 cm), respectively.

- The dry matter accumulation significantly increased with the application 40 kg S ha^{-1} at all the stages over control, which was found at par with 60 kg S ha^{-1} with application of 40 kg S ha^{-1}. The increase in dry matter were to the tune of 6.26, 9.74 and 5.77 per cent at 30, 60 DAS and at harvest over control (3.19, 13.04 and 27.92), respectively.

- The maximum leaf area index was recorded 4.12 at 50 DAS with the application of 60 kg S ha^{-1}. However, it was recorded non-significant among the treatments.

- Chlorophyll content was significantly increased with the application of different levels S at 50 DAS over control. The maximum per cent increase in chlorophyll content with 60 kg S ha^{-1} was 6.78 compared to control.

- Application of 60 kg S ha^{-1} recorded highest primary branches $plant^{-1}$ (5.29) over control (4.19). But application of 40 kg S ha^{-1} at par with 20 kg S ha^{-1}. The per cent increase in primary branches $plant^{-1}$ with 60 kg S ha^{-1} was 26.25 over control.

- Application of 60 kg S ha^{-1} significantly increased number of pods $plant^{-1}$ over control as well as lower levels of sulphur application. The per cent increase in pods $plant^{-1}$ with 60 kg S ha^{-1} was 9.45 compared to control.

- Application of 60 kg S ha^{-1} recorded highest number of seeds pod^{-1} (3.10) over control, which was found at par with application of 40 kg S ha^{-1}. The per cent increase in seeds pod^{-1} with 60 kg S ha^{-1} was 12.72 over to control.

- Application of 60 kg S ha^{-1} significant increase seed yield (g $plant^{-1}$) over control as well as lower levels of sulphur application. The per cent increase in seed yield (g $plant^{-1}$) with 60 kg S ha^{-1} was 11.61 per cent compared to control.

- Application of 60 kg S ha^{-1} recorded highest seed index (12.47) over control, which was found at par with application of 40 kg S ha^{-1}. The per cent increase in seed index with 60 kg S ha^{-1} was 7.03 per cent over control.

- Application of 60 kg S ha^{-1} significant increased seed yield over control, which was recorded highest seed yield (1330.70). The application 60 kg S ha^{-1} increased seed yield by 279.1 kg ha^{-1} over control (1051. 60 kg ha^{-1}).
- Application of 40 kg S ha^{-1} significantly increased haulm yield over control, which was found at par with 60 kg S ha^{-1}. The application of 60 kg S ha^{-1} recorded highest haulm yield (3076.60 kg ha^{-1}), which was increased haulm yield by 385.10 kg ha^{-1} over control (2691.50 kg ha^{-1}).
- Application of 60 kg S ha^{-1} significant increased biological yield over control, which recorded highest biological yield (4405.20 kg ha^{-1}). The application of 60 kg S ha^{-1} increased biological yield by 684.90 kg ha^{-1} over control (3720.30 kg ha^{-1}).
- Application of 60 kg S ha^{-1} significantly increased harvest index over control, which was highest (30.10). The application of 60 kg S ha^{-1} increased harvest index by 4.00 per cent over control (28.94).
- N content in seed and haulm significantly increased with 40 kg S ha^{-1} over control, which was found at par with 60 kg S ha^{-1}. Maximum N content in seed (6.38) and haulm (1.54) under 60 kg S ha^{-1}. While P content in seed (0.583) and haulm (0.207) maximum recorded with 60 kg S ha^{-1} and S content is significant increased with the application of 60 kg S ha^{-1} over control. The maximum S content in seed (0.332 per cent) and (0.206 per cent) recorded with 60 kg S ha^{-1} over control.
- Different levels of sulphur significantly increased N, P and S uptake by seed, haulm and crop. Application of 60 kg S ha^{-1} resulted in significantly highest total uptake of N (133.30 kg ha^{-1}), P (14.30 kg ha^{-1}) and S (10.80 kg ha^{-1}) by the crop compared to control (107.50 N, 11.10 P and 8.60 kg S ha^{-1}).
- Application of 40 kg S ha^{-1} significantly increased the protein content and application 60 kg S ha^{-1} significantly increased the protein yield over control. Maximum protein content (39.27 per cent) and protein yield (524.40) was recorded with 60 kg S ha^{-1} over control.
- Oil content and oil yield was significantly increased with the application of 60 kg S ha^{-1} over control. Maximum oil content (22.0 per cent) and oil yield (292.40 kg ha^{-1}) recorded over control.
- Maximum net returns (₹ 30375 ha^{-1}) and BC ratio (1.50) were obtained with 60 kg S ha^{-1} compared to the lowest net returns of (₹ 21071) and BC ratio of (1.00) with no sulphur application.

CONCLUSION

On the basis of results and economic evaluation of treatments of the field experiment entitled “Response of Soybean [*Glycine max* (L.) Merrill] to Microbial Inoculation and Sulphur” it is concluded that microbial inoculation *Rhizobium* + PSB with 60 kg S ha^{-1} recorded the seed yield of 1533.33 kg ha^{-1}. This treatment also recorded the maximum net return (₹ 37993 as well as BC ratio (1.82) compared to rest of the treatments.

The results are based on one year study, hence it needs to be validated by further experimentation before making final recommendation.

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