

**Impact of Biofertilizers and Phosphorus Levels
on Biological Activity of Rhizosphere, Yield and
Nutrient Uptake by Chickpea (*Cicer arietinum* L.)**

**जैव उर्वरक एवं फॉस्फोरस स्तर का जड़ मण्डल की जैविक
क्रिया और चने (*साईसर अराईटिनम* एल.) की उपज
एवं पोषक तत्व उद्ग्रहण पर प्रभाव**

Neha Bharti

Thesis

Master of Science in Agriculture
(Soil Science and Agricultural Chemistry)



2014

**Department of Soil Science and Agricultural Chemistry
COLLEGE OF AGRICULTURE
SWAMI KESHWANAND
RAJASTHAN AGRICULTURAL UNIVERSITY,
BIKANER**

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Thesis

Submitted to the
Swami Keshwanand
Rajasthan Agricultural University, Bikaner
in partial fulfillment of the requirement for
the degree of

Master of Science in Agriculture
(Soil Science and Agricultural Chemistry)

BY

Neha Bharti
2014

**Swami Keshwanand Rajasthan Agricultural University, Bikaner
College of Agriculture, Bikaner**

CERTIFICATE – I

Dated: _____

This is to certify that **Miss Neha Bharti** has successfully completed the Comprehensive Examination held on as required under the regulation for Master's degree.

(I.J. Gulati)

Head

Department of Soil Science and
Agricultural Chemistry,
College of Agriculture,
SKRAU, Bikaner.

Swami Keshwanand Rajasthan Agricultural University, Bikaner
College of Agriculture, Bikaner

CERTIFICATE – II

Date : _____

This is to certify that the thesis entitled “**Impact of Biofertilizers and Phosphorus Levels on Biological Activity of Rhizosphere, Yield and Nutrient Uptake by Chickpea (*Cicer arietinum* L.)**” submitted for the degree of **Master of Science in Agriculture** in the subject **Soil Science and Agricultural Chemistry** embodies bonafide research work carried out by **Miss Neha Bharti** 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 the thesis was also approved by the advisory committee on

(Yogesh Sharma)
Major Advisor

(I.J. Gulati)
HEAD
Department of Soil Science and
Agricultural Chemistry

(I.J. Gulati)
DEAN
College of Agriculture
SKRAU, Bikaner

Swami Keshwanand Rajasthan Agricultural University, Bikaner
College of Agriculture, Bikaner

CERTIFICATE – III

Date : _____

This is to certify that the thesis entitled “**Impact of Biofertilizers and Phosphorus Levels on Biological Activity of Rhizosphere, Yield and Nutrient Uptake by Chickpea (*Cicer arietinum* L.)**” submitted by **Miss Neha Bharti** to the Swami Keshwanand Rajasthan Agricultural University, Bikaner in partial fulfillment of the requirements for the degree of **Master of Science in Agriculture** in the subject of **Soil Science and Agricultural Chemistry**, after recommendation by the external examiner was defended by the candidate before the following members of the advisory committee. The performance of the candidate in the oral examination on her thesis has been found satisfactory. We therefore, recommend that the thesis be approved.

(Yogesh Sharma)
Major Advisor

(I.J. Gulati)
(Advisor)

(S.L. Godara)
(Advisor)

(S.R. Bhunia)
(Dean PGS Nominee)

(I.J. Gulati)
HEAD
Department of Soil Science and
Agricultural Chemistry

(I.J. Gulati)
DEAN
College of Agriculture
SKRAU, Bikaner

Approved

DEAN
POST GRADUATE STUDIES

Swami Keshwanand Rajasthan Agricultural University, Bikaner
College of Agriculture, Bikaner

CERTIFICATE – IV

Date : _____

This is to certify that **Miss Neha Bharti** of the **Department of Soil Science and Agricultural Chemistry, College of Agriculture, Bikaner** has made all corrections/modifications in the thesis entitled **“Impact of Biofertilizers and Phosphorus Levels on Biological Activity of Rhizosphere, Yield and Nutrient Uptake by Chickpea (*Cicer arietinum* L.)”** which were suggested by the external examiner and the advisory committee in the oral examination held on ____/____/2014. The final copies of the thesis duly bound and corrected were submitted on ____/____/2014 are enclosed herewith for approval.

(Yogesh Sharma)
Major Advisor

(I.J. Gulati)
HEAD
Department of Soil Science and
Agricultural Chemistry

(I.J. Gulati)
DEAN
College of Agriculture
SKRAU, Bikaner

Approved

DEAN, PGS
SKRAU, Bikaner

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Place: Bikaner

Date:/....../2014

(Neha Bharti)

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ACRONYMS

@	= At the rate	mt	= Million ton
A.O.A.C.	= Association of Official Agricultural Chemist	Max.	= Maximum
cm	= Centimeters	Min.	= Minimum
cmol kg ⁻¹	= Centimol per kilogram	µg	= Micro gram
CD	= Critical difference	Mg	= Mega gram
DAS	= Days after sowing	MSS	= Mean sum square
°C	= Degree Celsius	N	= Nitrogen
d.f.	= Degree of freedom	p	= Page
dS m ⁻¹	= Deci Simon per meter	pp	= Pages
EC	= Electrical conductivity	/	= Per
<i>et al.</i>	= (et alibi) and else where	P/P ₂ O ₅	= Phosphorus
Fig.	= Figure	q	= Quintals
g	= Gram	RH	= Relative humidity
ha	= Hectare	Rs	= Rupees
kg	= Kilogram	cm ²	= Square centimeter
K	= Potassium	SEm	= Standard error of means
mg	= Milligram	t	= tonne
m	= Meter	Var.	= Variety
m ha	= Million hectare	Viz.,	= (videlicet) namely
₹	= Rupee		

INTRODUCTION

Chickpea (*Cicer arietinum* L.) belongs to the family *Leguminosae*. It is also known as Gram, Bengal gram and king of pulses but its vernacular name is “Channa” which is an important pulse crop grown in northern India during rabi season. In India, chickpea is grown as a winter season crop. It has white flowers with blue, violet or pink veins. Chickpea need a subtropical or tropical climate with more than 400 millimeters of annual rain. In India it is grown in 9.01 mha area with 7.58 mtonnes production and 841 kg/ha productivity (Anonymous 2012). Rajasthan is one of the important chickpea growing states and rank second in respect of area as well as in production after Madhya Pradesh. In Rajasthan it is grown in 12.60 lakh ha area with 16.19 lakh tonnes production and 1284.92 kg/ha productivity. It is used for human consumption as well as feeding to animals. It is eaten both whole fried or boiled and salted, or more generally in the form of the split pulse which is cooked and eaten. Fresh green leaves are used as vegetable (Sag). Straw of chickpea is an excellent fodder for cattle. The grains are also used as vegetable (Chhole). Chickpea flour (Besan) is used in the preparation of various types of sweets. Chickpea is considered to have medicinal effect. Its leaves contain mainly malic acid and oxalic acid which is very useful for stomach ailments and blood purification. It contains 21.1% protein, 61.5% carbohydrate, 4.5% fat. It is also rich in calcium, iron and niacin. The per capita availability of protein (pulse) dwindling fast as 35 gm per capita per day in 2005 against the minimum requirement of 84 gm per capita per day as prescribed by ICMR, thus, causing malnutrition among the growing people (Anonymous, 2006).

Rhizobium is unique in that they are the only nitrogen-fixing bacteria living in a symbiotic relationship with legumes. The symbiotic relationship implies a signal exchange between both partners that

leads to mutual recognition and development of symbiotic structures. *Rhizobium* lives in the soil where they are able to sense flavonoides secreted by the roots of their host legume plant increases yield by 25-30% and 40-80 kg N is left over in field. Increasing the moisture content from 15-35% doubled the frequency of nodulation. The frequency of nodulation increased from 6.5 nodules in winter to 15.3 nodules in summer. Absolutely no nodules were produced by any plant in acidic soil (Osman and ElAtt, 1995). Yield of fresh and dry fodder were significantly higher in inoculated plants as compared to uninoculated control plants (Mohamed and Osman, 1996). The productivity of leguminous crops in dry land could be improved by *Rhizobium* inoculation (Abdelgani *et al.* 2003b). *Rhizobium* multi strain inoculation significantly increased dry weight of shoots, roots and nodules and number of nodules of chickpea. *Rhizobium* *sp.* to control the chickpea diseases has also been reported (Arfaoui *et al.* 2006). Chickpea is a major pulse crop in India. There is a good possibility to increase its production by exploiting better colonization of the roots and rhizospheres through application of effective nitrogen fixing bacteria to the seed or to the soil. This can minimize uses of nitrogenous fertilizer, which is very costly in this country. Using high yielding varieties of chickpea along with use of effective rhizobial strains can enhance the yield (Bhuiyan *et al.* 2008).

PSB have the capability to change the insoluble form of phosphorus into soluble form. It plays an important role in supplying phosphate to plants, in environment friendly and sustainable manner. They colonize the plant roots and promote growth to the plants. It promotes the plant growth, reduce diseases or insect damages. Phosphate solubilizing bacteria are also known to increase phosphorus uptake resulting in better growth and higher yield of crop plants. Soil microorganisms have enormous potential in providing soil phosphates for plant growth. Bareth (1998) observed significantly higher growth

parameters of cowpea due to seed inoculation with PSB culture. Phosphorus biofertilizers in the form of microorganisms can help in increasing the availability of accumulated phosphates for plant growth by solubilisation (Goldstein, 1986; Gyaneshwar *et al.* 2002). In addition, the microorganisms involved in P solubilisation as well as better scavenging of soluble P can enhance plant growth by increasing the efficiency of biological nitrogen fixation, enhancing the availability of other trace elements and by production of plant growth promoting substances (Gyaneshwar *et al.* 2002). They are also successfully applied in the cultivation of barley and chick pea plants (Rodriguez-Barraeco, 2002).

The combined inoculation of *Rhizobium* and phosphate solubilizing bacteria has increased nodulation, growth and yield parameters in chickpea. Inoculation with the PSB *Bacillus megatherium* var. *phosphaticum* (Osman *et al.* 2007) increased nodulation, nodule dry weight, nitrogen and phosphorus content in shoot and fresh and dry fodder. Co-inoculation with *Rhizobium* and PSB had a synergetic effect manifested in increased nodulation, nodule dry weight, shoot dry weight and shoot nitrogen and phosphorus content, compared to uninoculated control (Hassan and Abdelgani, 2009).

Adequate supply of phosphorus has been reported by various workers for vigorous growth, bumper yield, better quality and enormous nodule formation in legumes. It acts as a structural component of membrane system of cell chloroplasts and mitochondria. It is a constituent of energy phosphates like, ADP, ATP, nucleic acid, nucleoprotein, purines, pyrimidines, nucleotides and several coenzymes. It plays an important role in cell division, carbohydrate break down for energy release and hastening the maturity of plants. In areas where legumes are traditionally grown without phosphorus poor nodulation was observed with low yield (Sundra Rao, 1973). Phosphorus application and bacterial inoculation affect yield of

soybean through their effects on phosphorus use efficiency (Shah, 2001). Shivakumar *et al.* (2004) reported that the increasing levels of phosphorus in the form of rock phosphate inoculation with phosphate solubilizing bacteria (PSB) and *Rhizobium* seed treatment significantly increased the plant height, number of branches per plant, grain and stover yield during both the years indicating that application of higher levels of phosphorus under low moisture condition is necessary for getting higher yields of chick pea.

Looking to the medicinal importance and enormous uses of chickpea, the present investigation was planned and carried out during rabi 2013-2014 with the following objectives.

1. To study the effect of phosphorus, *Rhizobium* and PSB on growth, yield, nutrient content and uptake of chickpea.
2. To find out the optimum dose of phosphorus in effect of *Rhizobium* and PSB.
3. To study the effect of inoculation of *Rhizobium*, PSB and phosphorus levels on biological activity of rhizosphere.
4. To work out the economics of various feasibilities.

REVIEW OF LITERATURE

The available literature relating to the “Impact of Biofertilizers and Phosphorus levels on Biological activity of Rhizosphere, Yield and Nutrient uptake by Chickpea (*Cicer arietinum* L.)” has been reviewed in this chapter. Since very limited work has been reported on these aspects in chickpea, therefore, in the review presented here, pertinent literature on the effects of such factors has also been drawn from researches reported on some other legume crops to supplement the literature on chickpea.

2.1 Effect of phosphorus

2.1.1 Growth attributes

Kumar (2000) conducted an experiment in loamy sand soil and revealed that number of nodules per plant and plant height significantly increased with increasing levels of phosphorus. While at Jobner, the application of 30 kg P_2O_5 ha⁻¹ significantly improved plant height, dry matter accumulation and branches per plant over control, 10 and 20 kg P_2O_5 ha⁻¹ in clusterbean crop (Dadhich *et al.*, 2001). Bahadur *et al.* (2002) carried out a field experiment with chickpea crop and revealed that P application significantly improved the vegetative components at 0, 60 and 80 kg ha⁻¹.

Sharma *et al.* (2002) reported that application of P significantly enhanced growth determinants. Application of 60 kg P_2O_5 ha⁻¹ significantly improved plant height, branches per plant, nodules per plant, nodule weight per plant, dry matter accumulation per plant and seed yield over 30 kg P_2O_5 ha⁻¹. Khoja *et al.* (2002) conducted a field experiment at Jobner with chickpea crop and reported that the fertility level (20 kg N + 20 kg P_2O_5 ha⁻¹) significantly increased the plant height over control and 10 kg N + 20 kg P_2O_5 ha⁻¹, whereas, number of branches per plant and dry matter accumulation per plant were significantly enhanced due to 10 kg N + 40 kg P_2O_5 ha⁻¹ over control

and 10 kg N + 20 kg P₂O₅ ha⁻¹. Arya *et al.* (2002) reported that application of 60 kg P₂O₅ ha⁻¹ significantly increased the plant height and dry matter accumulation per plant of chickpea over control.

Jat and Ahalawat (2004) reported that dry matter accumulation per plant and LAI was significantly increased with the application of 26.4 kg P₂O₅ ha⁻¹ over 0 and 13.4 kg P₂O₅ ha⁻¹. Meena *et al.* (2004) reported that growth characters of chickpea as plant height, number of nodules per plant and dry matter accumulation were linearly increased upto 30 kg P₂O₅ ha⁻¹. However, the plant growth from 0 – 30 kg P₂O₅ ha⁻¹ was considerably more than 30 - 60 kg P₂O₅ ha⁻¹. Shivakumar *et al.* (2004) reported that plant height, branches per plant and dry matter accumulation of chickpea significantly increase with each level of phosphorus upto 80 kg P₂O₅ ha⁻¹.

Dass *et al.* (2005) reported that growth characters of pea as plant height and dry root weight consistently and significantly increased with the application of phosphorus upto 75 kg P₂O₅ ha⁻¹. Meena *et al.* (2005) reported that increasing levels of phosphorus up to 60 kg ha⁻¹ resulted in significant increase in dry matter accumulation of chickpea over 0 and 30 kg P₂O₅ ha⁻¹. Singh *et al.* (2005) reported that phosphorus application upto 120 kg P₂O₅ ha⁻¹ significantly increased the plant height, branches per plant, leaves per plant and nodules per plant over control and preceding levels of phosphorus.

Nosheen *et al.* (2006) reported that different doses of phosphorus were supplied in inoculated chickpea. 30 DAS all growth parameters like plant height, no. of nodules, fresh and oven dry weight of root and shoot showed a significant linear increase.

Das (2008) reported that, in different varieties of chick pea nodulation, growth and yield varied significantly due to the variation in the phosphorus levels. Irrespective of varieties total dry matter accumulation and total nodulation increased with increasing rate of applied phosphorus and then decreased with further increase of

phosphorus fertilizer dose. Nodules and dry weight/plant were correlated positively, but this correlation was statistically insignificant.

Singh and Prasad (2008) observed that dry matter accumulation and dry weight of nodules of chickpea were found to increase with increase in levels of DAP up to 120 kg ha⁻¹, thereafter increase was not significant. Deo and Khaldelwal (2009) reported that application of 60 kg P₂O₅ ha⁻¹ increased the number of nodules per plant by 8.31, 25.5 and 31.3% over 40, 20 and control.

Thenua *et al.* (2010) reported that application of P as SSP recorded significantly higher plant height, branches per plant and dry matter accumulation of chickpea.

Patil (2011) revealed that in chick pea, combination of compost @ 5 t/ ha with 150 kg rock phosphate resulted in higher B:C ratio.

Pandy *et al.* (2012) reported that effect of phosphorus and zinc on growth yield and quality of chickpea (*Cicer arietinum* L.) cv. 'KWR-108'. Growth attributes in chickpea was influenced by P and Zn application and 60 kg P and 10 kg Zn ha⁻¹ gave highest seed yield resulting in 46 and 18% higher over respective control.

Bhanuprakash *et al.* (2013) reported that in rice crop highest values of growth parameters viz., plant height, leaf area index, grain and straw yield and total tillers/m² were with application of 80 kg P₂O₅/ha and lowest were with control. Highest gross returns were with application of 80 kg P₂O₅/ha and lowest were with application of control.

Mohammadi *et al.* (2013) reported that in flowering and podding stages of chickpea B₄ (25 kg/ha phosphorus fertilizer + mycorrhiza biological fertilizer) and B₅ (50 kg/ha phosphorus fertilizer) treatments significantly increased leaf area index, leaf area duration and total dry matter compared with B₁ (control) and B₂ (mycorrhiza). The maximum and minimum total dry matter obtained at 111 days after planting in B₆

(50 kg/ha phosphorus fertilizer + MBF) and B₁ (control) with 10289.07 and 4906.37 kg/ha respectively. B₄ (25 kg/ha phosphorus fertilizer + MBF) treatment increased total dry matter 42.37 percent compared with control. The results of this experiment speculated that application of biological fertilizer can lead to decrease 50 percent application of chemical fertilizer in chickpea production. These results are important in sustainable management of agro-ecosystems.

2.1.2 Yield and yield attributes

Kumar (2000) conducted an experiment on loamy sand soil at Jobner and revealed that increasing level of P₂O₅ ha⁻¹ gave increased yield, both grain and straw of chickpea. Vimla and Natarajan (2000) found significant increase in the pod length, pod width, pod weight, pod yield and shelling percentage of pea with the application of 80 kg P₂O₅ ha⁻¹ along with 120 kg N and biofertilizer. In a field experiment Patra and Bhattacharya (2000) observed highest pod yield of pea due to application of 30 kg P₂O₅ ha⁻¹. Significant increase in yield and parameters such as pod length, number of grains per pod and pod weight was observed by increasing levels of phosphorus (Gupta *et al.* 2000).

Dadhich *et al.* (2001) also conducted a field experiment at Jobner and applied varying levels of P (10, 20, 30 kg P₂O₅ha⁻¹) and revealed that application of 30 kg P₂O₅ ha⁻¹ significantly improved seed yield per plant over control, 10 and 20 kg P₂O₅ ha⁻¹ in clusterbean. Uddin *et al.* (2001) reported that P levels had significant impact on the number of pods per plant, 100 seed weight, total dry matter production, pod yield and seed yield of garden pea.

Meena *et al.* (2001) in a field experiment on chickpea reported that application of 40 kg P₂O₅ ha⁻¹ significantly increased number of pods per plant, number of seeds per pod, test weight, grain and straw yield over control and 20 kg P₂O₅ ha⁻¹. However, application of 60 kg P₂O₅ ha⁻¹ remained at par with 40 kg P₂O₅ ha⁻¹. Singh and Vaishya

(2001) reported that application of 60 kg P_2O_5 ha⁻¹ significantly increased the grain yield of chickpea over control. Tiwari *et al.* (2001) in a field experiment on chickpea reported that application of 60 kg P_2O_5 ha⁻¹ significantly increased the grain yield over control.

Arya *et al.* (2002) revealed that application of 60 kg P_2O_5 ha⁻¹ significantly increased number of pods per plant, number of seeds per pod, test weight, grain and straw yield over control and 30 kg P_2O_5 ha⁻¹ of chickpea. Bahadur *et al.* (2002) carried out an experiment during rabi 1998-99 in Bangladesh and concluded that P application at 60 and 80 kg P_2O_5 ha⁻¹ significantly increased the growth, yield and yield attributes of chickpea. Yakadri *et al.* (2002) revealed that application of 20 kg N ha⁻¹ and 60 kg P_2O_5 ha⁻¹ caused significant differences in leaf area ratios indicating better partitioning of dry matter, increased number of pods and seed yield of greengram.

Lakpale *et al.* (2003) reported that application of 25.8 kg P_2O_5 ha⁻¹ significantly increased number of pods per plant, seed yield of chickpea over control. Application of 25.8 kg P_2O_5 ha⁻¹ significantly increased the seed yield over control, but remains at par with 12.9 kg P_2O_5 ha⁻¹. Nadeem *et al.* (2003) observed that vine length, pod length, number of grains per pod, number of pods per plant and green pod yield of pea were increased by increasing levels of phosphorus. The number of grains per pod and green pod yield were found maximum with the application of 60 kg P_2O_5 ha⁻¹.

Pramanik and Singh (2003) reported that application of 60 kg P_2O_5 ha⁻¹ significantly increased number of pods per plant, number of seeds per pod, test weight and grain yield of chickpea over control and 30 kg P_2O_5 ha⁻¹. Singh *et al.* (2003) reported that application of 40 kg P_2O_5 ha⁻¹ significantly increased number of pods per plant, number of seeds per pod, test weight, grain and straw yield of lentil over control and 20 kg P_2O_5 ha⁻¹.

Jat and Ahalawat (2004) reported that pods per plant, seed and straw yield of chickpea significantly increased with the application of 26.4 kg P₂O₅ ha⁻¹ over 0 and 13.2 kg P₂O₅ ha⁻¹. Kumar and Singh (2004) reported that application of 30 kg P₂O₅ ha⁻¹ significantly increased yield attributes i. e., number of pods per plant, number of grains per pod, grain and straw yield of chickpea. Meena *et al.* (2004) reported that number of grains per pod, grain weight per plant, test weight and straw yield of chickpea increased significantly up to 60 kg P₂O₅ ha⁻¹ over control and 30 kg P₂O₅ ha⁻¹. However, application of 60 kg P₂O₅ ha⁻¹ significantly increased the seed yield over control, but remain at par with 30 kg P₂O₅ ha⁻¹. Shivakumar *et al.* (2004) reported that number of grains per pod, grain weight per plant, test weight, grain and straw yield of chickpea significantly increased with each level of phosphorus upto 80 kg P₂O₅ ha⁻¹

Das *et al.* (2005) observed that application of 75 kg P₂O₅ ha⁻¹ significantly increased the pods per plant, shelling percent and green pod yield of pea over the lower levels (0, 25 and 50 kg P₂O₅ ha⁻¹). Kumar and Sharma (2005) reported that each successive increasing level of P upto 40 kg P₂O₅ ha⁻¹ significantly increased the number of pods per plant, number of seeds per pod, test weight, seed and straw yield of chickpea and found statistically at par with 60 kg P₂O₅ ha⁻¹.

Singh *et al.* (2005) revealed that phosphorus application upto 120 kg P₂O₅ ha⁻¹ significantly increased pods per plant, grains per pod and test weight. Application of 30, 60, 90 and 120 kg P₂O₅ ha⁻¹ increased pod yield of pea by 8.06, 17.81, 30.57 and 35.32 per cent over control, respectively. Tiwari *et al.* (2005) reported that yield attributes of chickpea viz., number of pods per plant, test weight, grain and straw yield and harvest index augmented significantly with application of phosphorus upto 50 kg P₂O₅ ha⁻¹ over 0 and 25 kg P₂O₅ ha⁻¹. Tripathi *et al.* (2005) reported that yield attributes of chickpea like

number of pods per plant, test weight and grain yield recorded markedly increased upto 60 kg P₂O₅ ha⁻¹.

Sharma and Abrol (2007) reported that application of 60 kg P₂O₅ ha⁻¹ resulted maximum grain yield of 2.28 t ha⁻¹ of chickpea though the increase was not significant over the one with 40 kg P₂O₅ ha⁻¹.

Singh and Prasad (2008) revealed that the number of pods per plant, total seed weight per plant, grain yield and straw yield of chickpea increased with increasing levels of DAP, but significant increase was recorded only upto 120 kg DAP ha⁻¹.

Kumar *et al.* (2009) reported that the application of 50 kg P₂O₅ ha⁻¹ significantly increased branches per plant, number of pods per plant, number of grains per pod, test weight, grain and straw yield of chick pea over control. Deo and Khaldelwal (2009) reported that the grain and straw yield increased significantly with increasing levels of phosphorus upto 60 kg P₂O₅ ha⁻¹ in chickpea.

Thenua *et al.* (2010) reported that application of P as SSP showed better result in terms of number of pods per plant, pod yield, number of grains per pod, test weight and grain yield of chickpea.

Nawange *et al.* (2011) reported that application of phosphorus from 0 to 60 kg/ha and sulphur up to 40 kg/ha resulted in linear increase in various yield attributing traits, seed and stalk yield of chickpea. The application of 60 kg P₂O₅/ha produced the highest mean seed yield of 1761 (kg/ha) and stalk yield of 2754 (kg/ha). The application of 40 kg sulphur/ha produced the highest mean seed yield of 1665 (kg/ha) and stalk yield of 2665 (kg/ha).

Madzivhandila *et al.* (2012) reported that the effects of P fertilizer rates (0, 45 and 90 kg P₂O₅ ha⁻¹) on the yield of four chickpea cultivars, two kabuli and two desi types in winter and summer seasons. Grain yield increased with P fertilizer rates only in the summer sowing. The increase in grain yield with P fertilizer application was associated

with greater crop biomass and 100-SW at 45 and 90 kg P ha⁻¹ compared with the control. In contrast, the effect of cultivar on grain yield was significant in both the winter and summer sowings. The variation in grain yield with cultivar was attributed to a similar variation in number of pods per plant (winter sowing) and 100-SW (summer sowing). The lack of response of grain yield to P fertilizer application in the winter sowing was attributed to inadequate moisture received during the crop growth period. Thus, application of P fertilizer may increase grain yield and hence productivity of chickpea at the site of the current study if water is not limiting.

Pandy *et al.* (2012) reported the effect of phosphorus and zinc on yield of chickpea (*Cicer arietinum* L.) cv. 'KWR-108'. Yield attributes in chickpea was influenced by P and Zn application and 60 kg P₂O₅ and 10 kg Zn ha⁻¹ gave highest seed yield resulting in 46 and 18% higher over respective control.

Patel *et al.* (2013) revealed that sulphur application significantly influenced yield attributing characters over control treatment. While, maximum improvement in yield attributes was achieved upto application of 20 kg S ha⁻¹. Phosphorus management treatment either through application of 25 kg P₂O₅ ha⁻¹ or combine application of 25 kg P₂O₅ ha⁻¹ + PSB gave significant results on yield attributes. Application of 20 kg S ha⁻¹ and 25 kg P₂O₅ ha⁻¹ + PSB to chickpea recorded maximum grain yield.

Pattar *et al.* (2013) reported that application of phosphorus through FYM cured DAP (P₅) recorded significantly higher grain yield than other sources of phosphorus, while the lowest grain yield was recorded with application of recommended phosphorus in the form of FYM. Seed priming with 2% SSP (S₃), 2% CaCl₂ (S₂) and 5% cow urine (S₆) recorded significantly higher grain yield which were at par with each other. Interaction of recommended dose of phosphorus through FYM cured DAP and seed priming with 2% SSP (P₅S₃)

recorded higher grain yield of chickpea which was significantly superior over other interactions.

Shukla *et al.* (2013) reported that DAP (2%) and $N_{20} P_{50} K_{20} S_{20}$ as basal, when applied separately or in combination, resulted in highest grain yield and net income from the rainfed chickpea cv. JG 315. Thus, the combined input of DAP (2%) $\times N_{20} P_{50} K_{20} S_{20}$ gave maximum grain yield of 17.23 q/ha and net income up to Rs. 51,201/ha. The net income was higher by Rs. 32457/ha over the absolute control.

Neenu *et al.* (2014) reported that four phosphorus levels viz., 0, 30, 60 and 90 kg P_2O_5 ha⁻¹ and four varieties of chickpea viz., JG 16, JG 11, JG 315 and JG 218. Barring JG 11, application of phosphorus from 0 to 60 kg ha⁻¹ resulted in a linear increase in yield and yield attributing characters in rest of the varieties. Although there was no significant difference in seed yield among the varieties, application of either 60 or 90 kg P_2O_5 ha⁻¹ produced significantly higher seed yield over other doses of P. The application of phosphorus above 60 kg ha⁻¹ has significantly increased the grain phosphorus content in all the four varieties but the interaction effect was not significant. A significant increase of grain phosphorus uptake with phosphorus nutrition was also observed in all the varieties.

2.1.3 Content, uptake of nutrients and quality.

Patel *et al.* (2001) observed that the application of 40 kg P_2O_5 ha⁻¹ gave the maximum grain protein and nutrient uptake were also enhanced significantly due to P levels upto 60 kg P_2O_5 ha⁻¹ in black gram. Dadheech (2001) reported that application of P at 60 kg P_2O_5 ha⁻¹ significantly increased the N and P contents, N and P uptake and protein content in grain and straw over lower doses in blackgram crop. Meena *et al.* (2001) in a field experiment on chickpea found that application of P upto 60 kg P_2O_5 ha⁻¹ significantly increased the protein content in seed. Tiwari *et al.* (2001) in a field experiment on chickpea

found that application of P upto 60 kg P_2O_5 ha⁻¹ significantly increased the uptake of N, P and K over control. Sharma and Rana (2001) observed that the application of 60 kg P_2O_5 ha⁻¹ showed significant and consistent increase in nutrient uptake by Rajma.

Yadav *et al.* (2002) conducted a field experiment during kharif 1997 with mungbean crop and concluded that P content and uptake of seed and stover increased significantly with increasing levels of P.

Singh *et al.* (2003) found that application of P upto 40 kg P_2O_5 ha⁻¹ in chickpea significantly increased the uptake of N and P in grain and straw both over control and 20 kg P_2O_5 ha⁻¹. Pramanik and Singh (2003) found that application of P upto 60 kg P_2O_5 ha⁻¹ significantly increased the uptake of P by chickpea over control and 13.2 kg P_2O_5 ha⁻¹.

Jat and Ahalawat (2004) reported that application of P upto 26.4 kg P_2O_5 ha⁻¹ in chickpea significantly increased the total uptake of N and P over control. Meena *et al.* (2004) found that application of P upto 60 kg P_2O_5 ha⁻¹ significantly increased the uptake of N, P and K and protein contents of chickpea over control and 30 kg P_2O_5 ha⁻¹. Shivakumar *et al.* (2004) reported that the uptake of phosphorus in grain and stover was significantly higher with each successive level of P upto 80 kg P_2O_5 ha⁻¹ in chickpea.

Meena *et al.* (2005) reported that application of P upto 60 kg P_2O_5 ha⁻¹ in chickpea significantly increased the P content and uptake over control. Tiwari *et al.* (2005) reported that application of P upto 26.4 kg P_2O_5 ha⁻¹ in chickpea significantly increased the uptake of N, P and K in grain and straw over control and 25 kg P_2O_5 ha⁻¹. Singh *et al.* (2005) in a field experiment on pea revealed that N and P uptake were enhanced significantly with increasing dose of P from 0-120 kg P_2O_5 ha⁻¹.

Sharma and Abrol (2007) revealed that concentration of P increased significantly upto the application of 40 kg P₂O₅ ha⁻¹ both in seed and straw of chickpea. Singh and Prasad (2008) in a field experiment on chickpea found that application of higher dose of DAP (180 kg ha⁻¹) numerically increased the N and P uptake, however it was statistically at par with 120 kg ha⁻¹.

Kumar *et al.* (2009) reported that the uptake of P by grain and straw of chickpea increased significantly with the application of varying levels of P upto 50 kg P₂O₅ ha⁻¹. Deo and Khaldelwal (2009) reported that S, P content and P uptake in grain and straw of chickpea were found to increased significantly due to application of P upto 60 kg P₂O₅ ha⁻¹, but the N and protein contents were found significantly increase with application of P upto 40 kg P₂O₅ ha⁻¹.

Shukla *et al.* (2010) reported that reducing, non reducing and total sugar content of *Hordeum vulgare* L. were influenced by changes in the phosphorous doses. Further, maximum protein, lysine, tryptophan, methionine and total mineral content of grains of plant were found maximum by the application of P₂O₅.

Ghaemmaghami *et al.* (2012) reported that after 12 and 24 soaking hours, calcium content of peas and after 8, 12 and 24 h soaking time, magnesium and phosphorus content of samples were decreased and also in soaking water samples, comparing the tap water used for soaking, after 24 h of soaking calcium content was increased and after 8 and 12 h, phosphorus content was decreased. Also, magnesium content of soaking water samples was increased and Na content was decreased. It appears that the soaking as an effective method of reducing flatulent materials and anti-nutrients, causing the reduction of minerals by leaching into the water does not have a significant effect on bioavailability of minerals.

Pandy *et al.* (2012) reported that effect of phosphorus and zinc on quality of chickpea (*Cicer arietinum* L.) cv. 'KWR-108'. Protein content in chickpea was influenced by P and Zn application.

Lai *et al.* (2013) found that application of increasing levels of phosphorus and sulphur increased the protein content, nutrient content and nutrient uptake of chickpea. But increase in protein content, nutrient content and uptake were found to be significantly up to 40 kg P₂O₅/ha and 30 kg S/ha only.

Shukla *et al.* (2013) reported that DAP (2%) and N₂₀ P₅₀ K₂₀ S₂₀ as basal, when applied separately or in combination, resulted in highest chlorophyll content, grain protein and net income from the rainfed chickpea cv. JG 315. Thus, the combined input of DAP (2%) × N₂₀ P₅₀ K₂₀ S₂₀ gave maximum grain protein 23.13% and net income up to Rs. 51,201/ha.

Singh *et al.* (2014) reported that application of phosphorus increased the N and P uptake up to 60 kg P₂O₅/ha. Peat based biofertilizers inoculation (PSB+*Rhizobium*) at the rate 1.60 kg/ha was used for seed inoculation which gave significantly higher nutrient uptake compared to uninoculation and PSB or *Rhizobium* inoculation alone.

2.2 EFFECT OF BIOFERTILIZERS

2.2.1 Effect of *Rhizobium*

2.2.1.1 Growth attributes

Khurana and Sharma (2002) reported that the nodule number, nodule biomass were recorded at 55 DAS, while grain yield was recorded at harvesting of chickpea crop. Effect of fungicide on legume - *Rhizobium* symbiosis revealed that yield and yield attributing characters were not affected by its application.

Kantar *et al.* (2003) reported that in the growth room trial, bacterial inoculations significantly increased shoot dry weight, N %, total N, N fixed and efficiency of symbiosis compared with the uninoculated control treatment depending on the strains. In the field trial, inoculations with HF 274 and HF 177 increased nodule dry weight, N %, chlorophyll, seed yield and total biomass yield depending on the strains, the lowest values being recorded in uninoculated plots. In conclusion, rhizobial inoculation of chickpea with HF 274 and HF 177 strains isolated from wild chickpeas (*C. anatolicum*) of high altitudes may substitute costly N fertilizers in chickpea production even in cold highland areas.

Nosheen and Shafique (2006) reported that inoculated chickpea v. CMC-77S was supplied with different doses of phosphorous 0, 15, 30 and 45 ppm. After germination data were recorded after every 15 days in respect of different parameters i.e. number of nodules, plant height, fresh and oven-dry weight of root and shoot. Up to 30 days, nodulation showed a significant decline, but after that rhizobial activity recovered and showed non-significant difference in T₁ and T₃ However, all other growth parameters plant height, fresh and oven-dry weight of root and shoot showed a significant linear increase.

Miller *et al.* (2007) reported that the strains of *R. leguminosarum* bv. *trifolii* formed effective nodules on *T. ambiguum* i.e., Caucasian clover and ineffective nodules on *T. repensi* i.e., white clover.

Huang and Erickson (2007) tested the effectiveness of *R. leguminosarum* for improving growth of pea and lentil. They found improved seedling growth, nodule biomass and shoot and root biomass in peas. In case of lentil, seed treatment with *R. leguminosarum* exhibited increase in seedling height, shoot and nodule biomass.

Giri and Joshi (2010) revealed that in chickpea bacterized seeds showed, increase of 14.06% in total length, 10.83% in total weight and

9.0% in germination over control in pot experiment. The results indicate that *Rhizobium* inoculation is a promising fertilizer because it is cheap, easy to handle and improves plant growth and seed quality.

Erman *et al.* (2011) reported that in chickpea arbuscular mycorrhizal fungus (AMF) inoculation, alone or in combination with other treatments, was very effective under rainfed conditions, resulting in large increases in root colonization. On the other hand, rhizobial inoculation increased significantly all traits examined, particularly root nodulation under irrigated conditions and combined with AMF significantly increased root colonization while its combination with *Rhizobium* increased the number of nodules. Combinations of two or three treatments were more effective than individual applications. The greatest yield, root colonization and nodulation were obtained from the combination of all three treatments under irrigation.

Abbasdokht *et al.* (2012) reported that hydropriming and *Rhizobium* bacteria inoculation treatments significantly increased plant height. Cattle manure significantly affected all of traits except number of seed per pod. The interaction effect of hydroprimed and *Rhizobium* bacteria inoculation was significant for all traits except number of seed per pod and the interaction effect of hydroprimed and cattle manure was significant only for plant height and number of pod per plant.

Abbasi *et al.* (2013) reported that in chickpea increasing of nitrogen rates up 50 kg/ha increased number and weight of nodules per plant but it decreased in application of 75 kg N/ha. Minimum of these traits was obtained in without seed inoculation and nitrogen application. Seed inoculation with *Rhizobium* and PGPR increased number and weight of nodules per plant. Maximum of these traits was obtained in seed inoculation with *Rhizobium leguminosarum* and *Azospirillum + Pseudomonas*.

Deshwal *et al.* (2013) observed that *Rhizobia* have some unique quality to fix nitrogen, produce plant growth hormones, Siderophore production, HCN production and good colonizer. Co-inoculation of *Rhizobia* with other microorganism can improve the plant growth and productivity in chickpea. Few *Rhizobia* can tolerate few extent of salt, acidic environment, and low water content in soil. All above activity clearly indicate that *Rhizobia* are unique plant growth promoting rhizobacteria.

Moradi *et al.* (2013) reported that mycorrhizal treatments significantly increased the shoot and root lengths. All of morphological properties (fresh and dry weights of shoot and root, shoot and root lengths) significantly increased in rhizobial treatment. Co-inoculation treatments of plant with AM fungi and *Rhizobium* significantly increased fresh and dry weights of shoot and root. Generally, in chickpea inoculation with AM fungi and/or *Mesorhizobium ciceri* can increase plant growth, synergistically, in the soil of low nutrient content.

Kumari *et al.* (2013) reported that *Rhizobium* isolates showed characteristics pattern of reactions in respect of growth rate, colony characteristics and acid/alkali production on different growth media. The effect of inoculations of *Rhizobium* isolates on nodulation and growth of chickpea were assessed by Leonard Jar experiment. Among the *Rhizobium* isolates BRC₄ and BRC₅ had significant positive effect on nodulation.

Singh *et al.* (2014) reported that a high increase in growth of *C. arietinum* was observed when inoculated with PSB in tricalcium phosphate amended soils. This study demonstrated the ability of novel PSB *P. cypripedii* along with *E. aerogenes* and *R. ciceri* to promote chickpea growth.

2.2.1.2 Yield and yield attributes

Barhate *et al.* (2004) reported that the inoculation of *Rhizobium* significantly enhanced grain yield and nodulation in chickpea. MPKV, a local strain, resulted in the highest mean grain yield (26.24 quintal/ha) and number of nodules per plant (53.00). Under this treatment, the grain yield and number of nodules increased by 17.24 and 36.31% over the control.

Solaiman *et al.* (2005) reported that dual inoculation of *Rhizobium* and arbuscular mycorrhiza in presence of poultry litter performed best in recording number of pods/plant, number of seeds/pod, and seed yields of chickpea. From the view point of yield attributes and yields of chickpea, dual inoculation of *Rhizobium* inoculants and arbuscular mycorrhiza along with poultry litter was considered to be the balanced combination of nutrients for achieving the maximum output from cultivation of chickpea.

Solaiman *et al.* (2006) reported that *Rhizobium* inoculant alone was superior to the control for all parameters studied. Dual inoculation with *Rhizobium* and AM (arbuscular mycorrhiza) in the presence of P performed the best in recording number of spore 100 g^{-1} rhizosphere soil and root colonization, number of pod plant⁻¹, number of seed pod⁻¹, seed and stover yields of chickpea. The maximum seed yield of 3.33 g plant^{-1} was obtained by inoculating chickpea plants with *Rhizobium* and AM in association with P. From the view point of yield attributes and yield of chickpea, dual inoculation with *Rhizobium* and AM along with P was considered to be the balanced combination of nutrients for achieving the highest output from cultivation of chickpea.

Suryawanshi *et al.* (2007) reported that in chickpea *Rhizobium* strains significantly influenced the grain yield. The seed inoculation with G-567-SMR *Rhizobium* strain recorded the maximum grain yield (23.47 q/ha). The grain yield increased by 25% due to seed treatment with G-

567-SMR strain over the uninoculated control. The grain yield obtained due to seed inoculation with various *Rhizobium* strains were more or less equal and were at par with each other.

Ahmed (2008) observed that *Rhizobium* inoculated plants gave significantly higher nodule number, nodule weight, stover and seed yield in chickpea compared to uninoculated plants.

Karasu and Dogan (2009) reported that three genotypes; Local population, Cantez 87 cultivar and ILC-114 Line were used as the crop material. Five different N doses (0, 30, 60, 90 and 120 kg ha⁻¹) as ammonium nitrate and bacterial isolate with *Rhizobium ciceri*. Inoculation of seed did a significant effect on yield and some yield components of chickpea. But, nitrogen doses had no significant effect on yield and yield components. According to two years results, Local population gave the highest yield (2149.1 kg ha⁻¹) among chickpea used.

Khodarahmi *et al.* (2013) reported that shortest days to maturity was observed for chickpea cv. Arman inoculated with *Mesorhizobium* of SWRI-3. The highest seed yield was obtained for chickpea cv. Azad inoculated with *Mesorhizobium* of SWRI-15 which produced 151% higher than check (no inoculation). Therefore, considering the environmental friendly effect of *Mesorhizobium* symbiosis and its effect on seed yield and yield components, it is recommended that *Mesorhizobium* inoculation is used as an alternative of urea fertilizer.

Maleki *et al.* (2014) reported that in chickpea crop effects of irrigation, nitrogen fertilizer levels and bacterial inoculation were significant on number of pods per plant, number grains per plant, grain weight, grain yield, biological yield and harvest index at 1% probability level. Also Results showed that the grain yield in full irrigation treatment and inoculated with *Rhizobium* bacteria was significantly higher than the other treatments. By applying irrigation at flowering, grain filling and

normal irrigation, highest N uptake was obtained with the use of 75 kg/ha N. In general, normal irrigation and use of nitrogen fertilizer and inoculation with bacteria, improves the value of seed element absorption.

Singh *et al.* (2014) reported that application of 60 kg P₂O₅ ha⁻¹ significantly increased the number of nodules/plant, yield attributes and seed, straw and biological yields of chickpea. Peat based biofertilizer inoculation (PSB+Rhizo) at 1.60 kg/ha was used for seed inoculation which gave significantly higher seed, straw and biological yields compared to uninoculation and PSB or *Rhizobium* inoculation alone.

2.2.1.3 Content, uptake of nutrients and quality

Khurana (2002) reported that the nodulation, leghaemoglobin content, nitrate reductase activity (NRA) and nitrogen content was assessed at 55 days after sowing (DAS) and during the flower initiation stage of chickpea. Strain SG387 increased the leghaemoglobin content, nodule number and NRA of cv. GF89133 at 55 DAS, the nitrogen content at both developmental stages, and grain yield at maturity. Strain SG387 also increased the nodule number of BG256 at flower initiation.

Hua (2003) found that the biofertilizers play positive effect on product quality improvement. Generally, biofertilizers application resulted in increase in sugar and vitamin C for vegetable and fruit, increase in length and intensity of cotton fiber, adding the proportion of first class ratio in tobacco.

Ahmad *et al.* (2008) reported the effect of different methods of rhizobial inoculation on seed protein contents of two lentil varieties (Masoor-93 and Massor-2002). The variables such as seed protein contents, root nodulation, N-contents of root and shoot of lentil, N-contents of soil were significantly affected by inoculation with *Rhizobium*.

Tavasolee *et al.* (2011) reported that chickpea plants were inoculated with six strains of *Mesorhizobium ciceri* and three Arbuscular mycorrhizal fungi (AMF) species, *Glomus intraradices* (GI), *G. mosseae* (GM) and *G. etunicatum* (GE). The plants inoculated with a number of AMF species and bacterial strains increased overall plant dry mass compared to non-inoculated plants. The results revealed that dual inoculation with AMF and *Rhizobium* enhanced nitrogen, phosphorus, zinc, iron and copper content in plants but these increasing effects was different between fungal and bacterial treatments.

Jain *et al.* (2012) reported that *Rhizobium sp.* fixes sufficient quantity of atmospheric nitrogen which range up to 25% of the requirement of the chickpea crops. It has also been reported that indigenous *Rhizobium* not only protect seeds from root rots causing fungal plant pathogens but also produces plant growth promoting substances.

Abdalla *et al.* (2013) reported that *Rhizobium* inoculation significantly ($p \leq 0.05$) increased fiber, tannin and protein content of chickpea seeds. *Bacillus megatherium* var. *Phosphaticum* (BMP) inoculation significantly ($p \leq 0.05$) increased fiber, protein content and cook ability. *Rhizobium* and BMP co-inoculation significantly ($p \leq 0.05$) increased fat, protein content and cook ability. Application of chemical fertilizers significantly ($p \leq 0.05$) increased fat and protein content.

Vishwakarma *et al.* (2013) revealed that seed yield, test weight and dal husk ratio of chickpea seeds were significantly increased with *Rhizobium* treatment. Protein content significantly increased at 2-4%. Essential amino acid tryptophan was slightly decreased but not the significantly, nitrate-reductase enzyme activity (1-6%) significantly increased with *Rhizobium* inoculation. Hence, it may be concluded that *Rhizobium* inoculation improved the quality and quantity of chickpea.

Singh *et al.* (2014) reported that application of phosphorus increased the N and P uptake by chickpea up to 60 kg P₂O₅ha⁻¹. Peat based biofertilizer inoculation (PSB+Rhizo) at 1.60 kg/ha was used for seed inoculation which gave significantly higher nutrient uptake compared to uninoculation and PSB or *Rhizobium* inoculation alone.

2.2.2 EFFECT OF PHOSPHATE SOLUBILIZING BACTERIA (PSB)

In most neutral and alkaline calcareous soils (pH above 7.5) phosphates are found in insoluble inorganic fixed forms. Several soil bacteria particularly those belonging to genera *Pseudomonas* and *Bacillus* and fungi belonging to genera *Penicillium* and *Aspergillus* possess the ability to bring insoluble phosphates into soluble forms by secreting organic acids. These acids lower the soil pH and bring about the dissolution of bound forms of phosphates.

2.2.2.1 Growth attributes

Dadhich *et al.* (2001) revealed that seed inoculation with PSB (500 g ha⁻¹) significantly increased the dry matter accumulation in clusterbean over control.

Chatterjee and Bhattacharjee (2002) found that mungbean seeds inoculated with PSB showed significantly higher rate of nodulation over no inoculation.

Gull *et al.* (2004) revealed that the plant growth, shoot phosphorus and nitrogen concentrations, nodulation efficiency and nitrogenase activity were significantly enhanced, showing the positive effect of phosphate solubilising bacterial strains had also the maximum positive effect on shoot length, shoot dry weight and nodulation of chickpea plants.

Afzal & Bano (2008) studied the effects of a rhizobial strain (Thal 8) and a P solubilizer strain (54RB) in single and dual combination with and without P₂O₅ on wheat in a P deficient natural non-sterilized sandy loam soil. The results of experiment revealed that single and dual

inoculation with fertilizer significantly increased root and shoot weight, plant height, spike length of the test crop.

Vikram and Hamzehzarghani (2008) indicated that inoculation of green gram seeds with PSB (PSB-14) recorded the highest nodule number, nodule dry weight, shoot dry matter and total plant dry matter at 45 DAS.

Demissie *et al.* (2013) reported that two isolates of PSB (JURB48+JURMB69) were co-inoculated, increased the percentage of seed germination (21.4%), vigor index (46.2%), radicle (25.3%) and plumule (50%) lengths of germinated seeds of Faba bean over non-inoculated. Faba bean shoot fresh weight, root weight, leaf number, flower number, root dry weight and total dry matter were significantly increased compared to non-inoculated. Plant height, root length, nodule number and weight were enhanced due to inoculation with PSB isolates.

Singh *et al.* (2014) reported that a high increase in growth of *C. arietinum* was observed when inoculated with PSB in tricalcium phosphate amended soils. A higher uptake in total P (53%) of plants was observed when inoculated with mixture of *P. cypripedii* and *E. aerogenes* along with *Rhizobium ciceri* as compared to respective control plants which significantly increased the seed number (98.3%) and seed weight (46.1%).

2.3.2 Yield attributes and yield

Mukherjee and Rai (2000) reported that application of phosphorus exhibited perceptible influence on yield of the crops. Biofertilizer and phosphorus nutrition interaction showed significant influence on growth and phosphorus uptake by wheat and chickpea compared with either of the components applied separately. Among the biofertilizers, *P. striata* registered the highest grain yield in both crops at both levels of phosphorus, closely followed by *G. fasciculatum*.

Among the VAM fungi, *G. fasciculatum* had positive effects on yield and phosphorus uptake, unlike *G. macrocarpum*.

Jat and Shaktawat (2001) observed that pods/plant, seeds/pod and test weight of fenugreek significantly increased with increasing dose of P up to 80 kg P₂O₅ ha⁻¹. Dual inoculation with *Rhizobium* +PSB significantly increased the seed and biological yields during both the years and straw yield during first year.

Chattopadhyay and Dutta (2003) conducted two years field study in West Bengal to investigate the effects of bio fertilizers (PSB and *Rhizobium*) on vegetable cowpea in alluvial soil, and found that single or combined application of bio fertilizers increased the pod yield in cowpea.

Pramanik and Singh (2003) reported that inoculation of biofertilizers significantly increased yield attributes of pods/plant and yield of chickpea. Among biofertilizers, dual inoculation of PSB + VAM markedly enhanced these yield attributes and yield compared with PSB or VAM alone. Application of phosphorus from 0 to 60 kg P₂O₅ ha⁻¹ resulted in linear increase in yield attributes and yield. Aqua placement of phosphorus significantly increased grain yield in first year only.

Singh *et al.* (2004) revealed that application of P along with PSM showed additive effect on yield attributes and yield of mungbean. Under all phosphorus x PSM (phosphorus solubilising microorganisms) treatments the yield are higher with 60 kg P₂O₅ ha⁻¹ than with the lower and higher levels of P. The highest yield of grain (8.81 q ha⁻¹) and straw yield (8.63 q ha⁻¹) was obtained with PSM inoculation.

Shrinivasa (2005) reported that seed treatment with phosphate solubilising bacteria (500 g ha⁻¹) is more effective in increasing yield potential and quality in fenugreek through their influence on physiological parameters.

Mian *et al.* (2005) in a field experiment conducted at Bangladesh Agricultural University, to compare the effects of different nitrogenous fertilizer and bio-fertilizers on the yield of mungbean (*Vigna radiate* L.) showed that the seed inoculation with bio fertilizers significantly increased grain, straw and biological yield.

Lanje *et al.* (2005) conducted an experiment in kharif 2001 for determining the effect of *Rhizobium* and Phosphorus Solubilizing microorganism (PSM) with recommended dose of fertilizer on seed oil, seed protein and seed yield in which *Rhizobium* + PSM treatment showed the highest nodules number i.e. 67.00 of soybean. Recommended dose of fertilizers + *Rhizobium* + PSM showed maximum seed oil content (19.95) and seed yield (10.78 q/ ha) of soybean. It was followed by *Rhizobium* + PSM, RDF+ *Rhizobium* + PSM, full or half P₂O₅ + *Rhizobium* + PSM without exhibiting any significant differences.

Sarwagi and Rajput (2005) conduct an experiment to study the effect of phosphorus, zinc, and phosphorus solubilizing microbes on yield of soybean in vertisols. Grain and straw yield and yield attributes of soybean increased with increasing levels of phosphorus. All these characters were further increased with the inoculation of PSM over their respective levels of phosphorus.

Jat *et al.* (2006) reported that in seed treatment in fenugreek with PSB, *Rhizobium* sp. and their combination increased the mean dry matter accumulation by 2.84, 1.62 and 1.03% over the control at 60 DAS, and by 4.72, 3.30 and 1.89% at 90 DAS. The maximum yield was obtained with the treatments P at 80 kg/ha, S at 100 kg/ha and *Rhizobium* + PSB.

Gupta and Sharma (2006) observed that seed inoculation of urdbean with phosphorus solubilizing bacteria resulted in significant increase in yield attributes and yield. Response of crop to phosphorus

fertilization was significant upto 60 kg P_2O_5 ha⁻¹ for seed and straw yields.

Kumar and Singh (2007) found that application of PSB recorded the maximum seeds per pod, 1000-seed weight and nodules per plant and the seed yield @ 50 kg P_2O_5 ha⁻¹.

Kumari *et al.* (2009) concluded that with inoculation of phosphate solubilising bacteria number of branches per plant, number of flowers per plant, number of pods per plant and dry weight/plant of urdbean increased significantly.

Veluchamy *et al.* (2010) indicated that application of phosphate solubilising bacteria (*Bacillus megatherium*) increased yield characteristics such as number of pods per plant, fresh pod weight, dry pod weight, pod yield, haulm yield, shelling percentage and hundred kernel weight in groundnut.

Abraham and Abraham (2011) revealed that in chickpea band placement recorded significantly higher pods plant⁻¹(47.95), pod yield (12.01 g plant⁻¹), seed weight plant⁻¹(13.09 g) and seed yield (35.03 q ha⁻¹). Among the bio-inoculants, the performance of dual inoculation of *Trichoderma* + PSB was the best having recorded significantly superior growth, yield attributes and yield. Increase in grain yield in *Trichoderma* + PSB was 10.75% and 12.79% over single inoculation of *Trichoderma* and PSB. Application of molybdenum + boron also significantly influenced yield attributes and yield (32.72 q ha⁻¹).

Patel *et al.* (2013) revealed that sulphur application significantly influenced yield attributing characters over control treatments. While, maximum improvement in yield attributes was achieved upto application of 20 kg S ha⁻¹. Phosphorus management treatment either through application of 25 kg P_2O_5 ha⁻¹ or combine application of 25 kg P_2O_5 ha⁻¹ + PSB gave significant results on yield attributes. Application

of 20 kg S ha⁻¹ and 25 kg P₂O₅ ha⁻¹ + PSB to chickpea recorded maximum grain yield.

Tagore *et al.* (2013) reported that in five elite genotypes of chickpea, IG-593 performed better in respect of symbiotic parameters including yield attributes and yield. Leghaemoglobin content (2.55 mg g⁻¹ of fresh nodule) was also higher under IG-593. Among microbial inoculants, the *Rhizobium* + PSB was found most effective in terms of shoot dry weight (11.76 g plant⁻¹), and leghaemoglobin content (2.29 mg g⁻¹ of fresh nodule) and also showed its positive effect in enhancing all the yield attributing parameters, grain and straw yields.

Singh *et al.* (2014) reported that Application of 60 kg P₂O₅/ha significantly increased the yield attributes and seed, straw and biological yields of chickpea. Peat based biofertilizer inoculation (PSB+Rhizo) at 1.60 kg/ha was used for seed inoculation which gave significantly higher seed, straw and biological yields compared to uninoculation and PSB or *Rhizobium* inoculation alone.

Moinuddin *et al.* (2014) reported that in chickpea P₆₀ (60 kg P₂O₅/ha) proved superior or equivalent to P₃₀ (30 kg P₂O₅/ha) while among the biofertilizer treatments, BNF+BPF gave the greatest values for yield and quality parameters. 30 kg P₂O₅ ha⁻¹ applied with N and P biofertilizers (P₃₀ × BNF+BPF) was the most profitable interaction for yield and quality characteristics. Furthermore, P₃₀ × BNF+BPF was statistically equal to P₆₀ × BNF+BPF with regard to seed yield and for most yield components. Thus, P₃₀ × BNF+BPF saved 30 kg P₂O₅ha⁻¹ of the costly inorganic P fertilizer to achieve the greatest crop yield and quality.

2.3.3 Nutrient content, uptake and quality

Dadhich *et al.* (2001) observed that seed inoculation with PSB improved the N, P and gum content in seed of clusterbean over no inoculation.

Igual *et al.* (2001) observed that the use of phosphate-solubilizing bacteria (PSB) in chickpea as inoculants simultaneously increases P uptake by the plant. A method to isolate efficient strains, an overview of some updated molecular techniques useful in their characterization (16S rRNA sequencing, LMW RNA profiles, TP-RADP and rep-PCR fingerprinting) and a method for obtaining strain-specific DNA probes was briefly explained. These methodologies are not time-consuming and, in general, do not require sophisticated equipment.

Singh and Pareek (2003) concluded that seed inoculation with PSB significantly increased N (59.7 kg ha^{-1}) and P (7.4 kg ha^{-1}) uptake of mungbean.

Tanwar *et al.* (2003) found that dual inoculation of seed with PSB (*Bacillus megatherium* var. *phosphaticum*) and *Rhizobium* caused a significant increase in N and P content in seed and straw and their uptake by blackgram over single inoculation and control.

Naagar and Meena (2004) also revealed that seed inoculation with PSB significantly increased the protein content in seed and straw, gum content and total uptake of N, P and S by clusterbean over no inoculation.

Gupta and Sharma (2006) reported that seed inoculation of urdbean with phosphorus solubilizing bacteria resulted in significant increase in protein content and nutrient (N and P) uptake. Response of crop to phosphorus fertilization was significant upto $60 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ for seed and straw yields. Phosphorus application also resulted in significant increase in protein content of seed and N and P uptake in seed and straw.

Zaidi *et al.* (2009) observed that phosphate solubilizing bacteria providing P to plants also facilitate plant growth by other mechanisms. Despite their different ecological niches and multiple functional properties, P-solubilizing bacteria have yet to fulfil their promise as

commercial bio-inoculants. Current developments in our understanding of the functional diversity, rhizosphere colonizing ability, mode of actions and judicious application are likely to facilitate their use as reliable components in the management of sustainable agricultural systems.

Khan (2009) observed utilization of PSB for direct application in agriculture under a wide range of agro-ecological conditions with a view to fostering sustainable agricultural intensification in developing countries of the tropics and subtropics.

Kundu *et al.* (2009) recorded the highest PSB number and greatest variability in the rhizosphere of chickpea, followed by wheat and then mustard.

Singh *et al.* (2014) reported that application of phosphorus increased the N and P uptake up to 60 kg P_2O_5 /ha. Peat based biofertilizer inoculation (PSB+Rhizo) used for seed inoculation gave significantly higher nutrient uptake compared to uninoculation and PSB or *Rhizobium* inoculation alone.

Moinuddin *et al.* (2014) reported that in chickpea P_{60} (60 kg P_2O_5 /ha) proved superior or equivalent to P_{30} (30 kg P_2O_5 /ha) while among the biofertilizer treatments, BNF+BPF gave the greatest values for nutrient uptake as well as for protein content.

2.4 INTERACTION BETWEEN PHOSPHORUS, RHIZOBIUM AND PSB

Sarawgi *et al.* (2000) reported that Grain and straw yield and yield attributes of chickpea increased with increasing levels of phosphorus (0-60 kg P_2O_5 /ha). Growth and nodulation were further increased with the inoculation of PSB compared with P application alone. Inoculation of *Rhizobium* culture further enhanced the yield. The greatest yield was given by 60 kg P_2O_5 + PSB + *Rhizobium* + seed treatment with Mo and Fe followed by this treatment without trace

elements (1.35 t). The maximum proportional impact of PSB and rhizobium (34.1%) was observed with the application of 30 kg P₂O₅.

Meena *et al.* (2001) reported that the application of 40 kg P₂O₅ increased the number of pods per plant and seeds per pod, test weight, and seed and straw yields of chickpea. *Rhizobium*+PSB inoculation significantly increased the number of seeds per pod and pods per plant as well as the seed and straw yields. The yield obtained with this treatment was higher with that produced by Rhizobium inoculation, but was at par with the yield obtained with PSB inoculation.

Jain and Singh (2003) reported that in chickpea field seed treatment with Rizo + PSB showed 8.33, 24.75 and 13.07% higher plant height, dry matter accumulation and number of branches per plant, respectively, compared to the control. P at 50 kg/ha showed 9.99, 34.33 and 16.46% higher values for these growth parameters, respectively, compared to the control. Rizo + PSB and P at 50 kg/ha also increased nutrient content and uptake. Rizo + PSB increased the soil N availability after harvest, but the P fertilizer did not improve soil N status. Rizo + PSB application and graded application of P significantly increased P availability in the soil after harvest.

Tyagi *et al.* (2003) revealed that interaction effect between phosphorus and biofertilizers was found significant in terms of dry matter yield.

Jat and Ahlawat (2004) reported that seed inoculation with *Rhizobium* and phosphate-solubilizing bacteria enhance growth and yield attributes of chickpea.

Singh *et al.* (2004) revealed that application of P along with PSB showed additive effect on growth, yield attributes and yield of mungbean. Under all phosphorus x PSM treatments the growth and yield were higher with 60 kg P₂O₅ ha⁻¹ than with the lower and higher

levels of P. The highest yield of grain (8.81 q ha^{-1}) and straw yield (8.63 q ha^{-1}) was obtained with PSM inoculation.

Gupta and Sharma (2006) indicated that crop responded favourably to seed inoculation with PSB and phosphorus fertilization ($60 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$) in influencing seed yield of urdbean.

Shaharoona *et al.* (2006) observed that co-inoculation with *Pseudomonas* and *Bradyrhizobium* species significantly improved root length, total biomass and nodulation in mung bean. Co-inoculation showed the most promising increases in case of number of nodules and fresh and dry nodule weight comparison with sole inoculation with *Bradyrhizobium*.

Valverde *et al.* (2006) observed that the co-inoculation treatment resulted in highest in seed yield (52% greater than the uninoculated control treatment) and nodule fresh weight and suggested that *P. jessenii* PS06 (PSB) can act synergistically with *M. ciceri* C-2/2 (*Rhizobium*) in promoting chickpea growth.

Rosas *et al.* (2006) studied the promising action of two phosphate solubilizing *Pseudomonas* strains on the symbiosis of rhizobial strains (*S. meliloti* and *B. japonicum*) with alfalfa and soybean. A greater number of nodules and dry weight was recorded in soybean when the co-inoculation with *B. Japonicum* and *Pseudomonas* was done. They found that *Pseudomonas* supplied phosphorous when growing with *B. Japonicum*.

Vishramram *et al.* (2007) reported that three biofertilizers viz., PSB, *Rhizobium* and VAM were tested in five doses of phosphorus viz., 0, 20, 40, 60 and 80 kg/ha. Result showed that VAM produced significantly better growth attributes, yield attributes and yield over rest of the biofertilizers. In terms of margin, VAM gave 7.32 g and 3.58 g more dry matter, 5.70 and 4.43 higher seeds per plant and 1.64 q/ha (9.58%) and 1.42 q/ha (8.19%) higher grain yield than PSB and

Rhizobium, respectively. The application of 60 kg P₂O₅/ha produced significantly better growth and yield attributes and yield. The use of 60 kg P₂O₅/ha enhanced the grain yield by a margin of 9.94 q (92.8%), 4.34 q (36.53%) and 1.77 q/ha (9.93%) over control and use of 20 and 40 kg P₂O₅/ha, respectively in chickpea.

Elkoca *et al.* (2007) observed that in the controlled environment and in the field trials, single, dual, and triple inoculations with *Rhizobium*, N₂-fixing *Bacillus subtilis* (OSU-142) and P-solubilizing *Bacillus megatherium* (M-3) in chickpea significantly increased plant height, shoot, root and nodule dry weight, N%, chlorophyll content, pod number, seed yield, total biomass yield, and seed protein content compared with the control treatment.

Mehta *et al.* (2010) found that application of 40 kg P₂O₅ ha⁻¹ with seed inoculation by *Rhizobium sp.* and phosphorus solublizing bacteria is better for higher growth and yield of fenugreek.

Qureshi *et al.* (2011) revealed that co-inoculation of *R. phaseoli* and *B. megatherium* enhanced the mungbean growth, nodulation and yield and also produced higher root mass, root length, nodule number and nodular mass as compared to control. Co-inoculations also improved the nutrient concentration in mung plant and grains. Study suggested that co-inoculation with *R. phaseoli* and *Bacillus sp.* employed assending effect on yield components and could be a useful approach than their sole application.

Singh and Sharma (2011) reported that the application of P through organic manures (P-enriched vermicompost and compost) and fertilizer alone or in combination with *Rhizobium* and phosphorus-solubilizing microorganisms (PSM) inoculation significantly improved the growth, yield, crude protein content, N, P, K and S uptake by chickpea. Maximum grain (2 639 kg/ha) and stover yield (2 978 kg/ha) of chickpea was recorded with addition of recommended dose of P through P-enriched vermicompost along with *Rhizobium* and PSM

inoculation. Maximum gain was 97 kg available N/ha and 0.69 kg available P/ha over initial (152 kg/ha available N and 9.73 kg/ha available P) with application of P through P-enriched vermicompost along with *Rhizobium* and PSM inoculation.

Roopa *et al.* (2012) observed that inoculation with *Rhizobia* or PGPR alone improved nodulation/growth of chickpea over uninoculated control under natural conditions. Moreover, co-inoculation with *Rhizobia* and PGPR further improved nodulation and growth of chickpea when compared to single-strain-inoculation.

Das *et al.* (2013) reported that application of 30 kg P₂O₅ ha⁻¹ significantly enhanced plant height, number of branches per plant, number of nodules per plant, pods per plant, seeds per pod, test weight, seed yield (1263 kg ha⁻¹) straw yield (3336 kg ha⁻¹), biological yield (4734 kg ha⁻¹), harvest index, N and P content in seed and straw and uptake and total uptake of N and protein content in seed over control and 15 kg P₂O₅ ha⁻¹ respectively. The combined inoculation of *Rhizobium* and PSB significantly enhanced growth, yield attributes, yield, nutrient content and their uptake in seed and straw of chickpea.

Tagore *et al.* (2013) studied that the effect of *Rhizobium* and phosphate solubilizing bacterial (PSB) inoculants on symbiotic traits, nodule leghaemoglobin, and yield of five elite genotypes of chickpea. Among microbial inoculants, the *Rhizobium* + PSB was found most effective in terms of nodule number, nodule fresh weight, nodule dry weight, shoot dry weight, and leghaemoglobin content and also showed its positive effect in enhancing all the yield attributing parameters, grain and straw yield.

Singh *et al.* (2014) reported that application of 60 kg P₂O₅/ha significantly increased the number of nodules/plant, fresh and dry weight of nodules/plant, yield attributes and seed, straw and biological yields of chickpea. Application of phosphorus increased the N and P uptake up to 60 kg P₂O₅/ha. Peat based biofertilizer inoculation

(PSB+Rhizo) at 1.60 kg/ha was used for seed inoculation which gave significantly higher number of nodules, fresh and dry weight of nodules, seed, straw and biological yields and nutrient uptake compared to uninoculation and PSB or *Rhizobium* inoculation alone.

MATERIALS AND METHODS

A field experiment entitled, “Impact of Biofertilizers and Phosphorus Levels on Biological Activity of Rhizosphere, Yield and Nutrient Uptake by Chickpea (*Cicer arietinum* L.)” was conducted during rabi season, 20013-14 at Agronomy Farm, College of Agriculture, Bikaner. The details of experimental techniques followed and materials used during the course of the investigation are being described in this chapter under the following heads:

3.1 EXPERIMENTAL SITE AND LOCATION

The experimental site is located in north direction at 28.01°N latitude and 73.22 °E longitude with an altitude of 234.70 meters above sea level. This region falls under agroclimatic zone I-C [Hyper Arid Partially Irrigated Western Plain Zone] of Rajasthan and agroclimatic zone XIV [Western Dry Region] of India.

3.2 CLIMATE AND WEATHER CONDITIONS

Bikaner has arid climate and average annual rainfall is ranging between 200 to 300 mm. More than 80 per cent rainfall is received in the Kharif season (July-September) by the south-west monsoon. During summers, the maximum temperature may go as high as 48°C while in the winters it may fall as low as 0°C. This region is prone to high wind velocity and soil erosion due to dusty winds in summers.

The periodical mean weekly weather parameters for the period of the experimentation recorded from the meteorological observatory of Agriculture Research Station, Swami Keshwanand Rajasthan Agricultural University Bikaner, are presented in Table 3.1 and depicted in fig. 3.1 shows that lowest and highest maximum value of temperature of 18.7 and 34.6°C were recorded in the 2nd and 43th standard metrological week, respectively. Likewise, the extreme values of minimum temperature (3.5 & 18.1°C) were recorder in the 2nd and

Table 3.1 : Mean weekly meteorological data during crop season (*Rabi*, 2013-14)

Standard Week	Duration		Temperature (°C)		Relative Humidity (%)		Total Rainfall (mm)	Rainy days	Wind velocity (km/hr)	Evaporation (mm/day)	BSSH
	From	To	Max.	Min.	Max.	Min.					
43	22/10/13	28/10/13	34.6	15.1	57.5	24.7	0.0	0	4.0	7.7	9.1
44	29/10/13	04/11/13	33.3	13.1	61.8	17.2	0.0	0	5.1	6.8	8.7
45	05/11/13	11/11/13	27.1	10.8	75.5	34.5	0.0	0	4.0	6.0	6.0
46	12/11/13	18/11/13	26.7	9.3	59.8	21.1	0.0	0	3.2	5.7	9.5
47	19/11/13	25/11/13	29.5	9.5	53.8	26.8	0.0	0	3.7	5.1	9.2
48	26/11/13	02/12/13	30.1	11.3	57.4	20.2	0.0	0	3.3	5.0	9.0
49	03/12/13	09/12/13	27.8	12.4	64.5	25.8	0.0	0	2.9	3.4	8.9
50	10/12/13	16/12/13	27.8	11.0	60.0	28.4	0.0	0	4.0	2.1	8.3
51	17/12/13	23/12/13	20.5	8.4	75.4	43.8	0.0	0	3.2	2.5	3.0
52	24/12/13	30/12/13	20.1	10.6	61.0	25.7	0.0	0	3.5	1.4	9.6
1	01/12/13	07/01/14	19.7	3.9	66.0	25.0	0.0	0	2.9	1.3	7.7
2	08/01/14	14/01/14	18.7	3.5	70.0	38.0	0.0	0	4.3	1.1	6.3
3	15/01/14	21/01/14	18.8	4.0	69.7	45.5	0.0	0	5.8	1.0	3.5
4	22/01/14	28/01/14	20.6	5.8	77.5	48.5	0.0	0	3.9	1.6	4.5
5	29/01/14	04/02/14	26.1	8.6	71.5	25.8	0.0	0	5.2	2.8	6.9
6	05/02/14	11/02/14	23.0	9.2	69.2	25.4	0.0	0	5.6	3.7	6.5
7	12/02/14	18/02/14	23.2	8.4	64.0	35.5	0.0	0	5.5	3.2	8.7
8	19/02/14	25/02/14	26.0	9.1	58.2	35.7	0.0	0	6.0	5.2	8.6
9	26/02/14	04/03/14	25.9	11.3	53.8	38.2	0.0	0	6.4	5.8	7.8
10	05/03/14	11/03/14	27.8	14.6	55.8	33.4	0.0	0	7.4	6.7	8.4
11	12/03/14	18/03/14	30.1	11.4	68.7	40.0	0.0	0	6.7	7.1	8.8
12	19/03/14	25/03/14	32.7	16.4	78.7	42.0	0.0	0	6.5	6.7	8.6
13	26/03/14	01/03/14	31.8	18.1	72.1	43.3	0.0	0	6.8	6.3	7.9

* 2.5 mm or more rainfall is considered as a rainy day.

Data taken from Agro-meteorology observatory, A.R.S., (Beechwal), Rajasthan Agricultural University, Bikaner

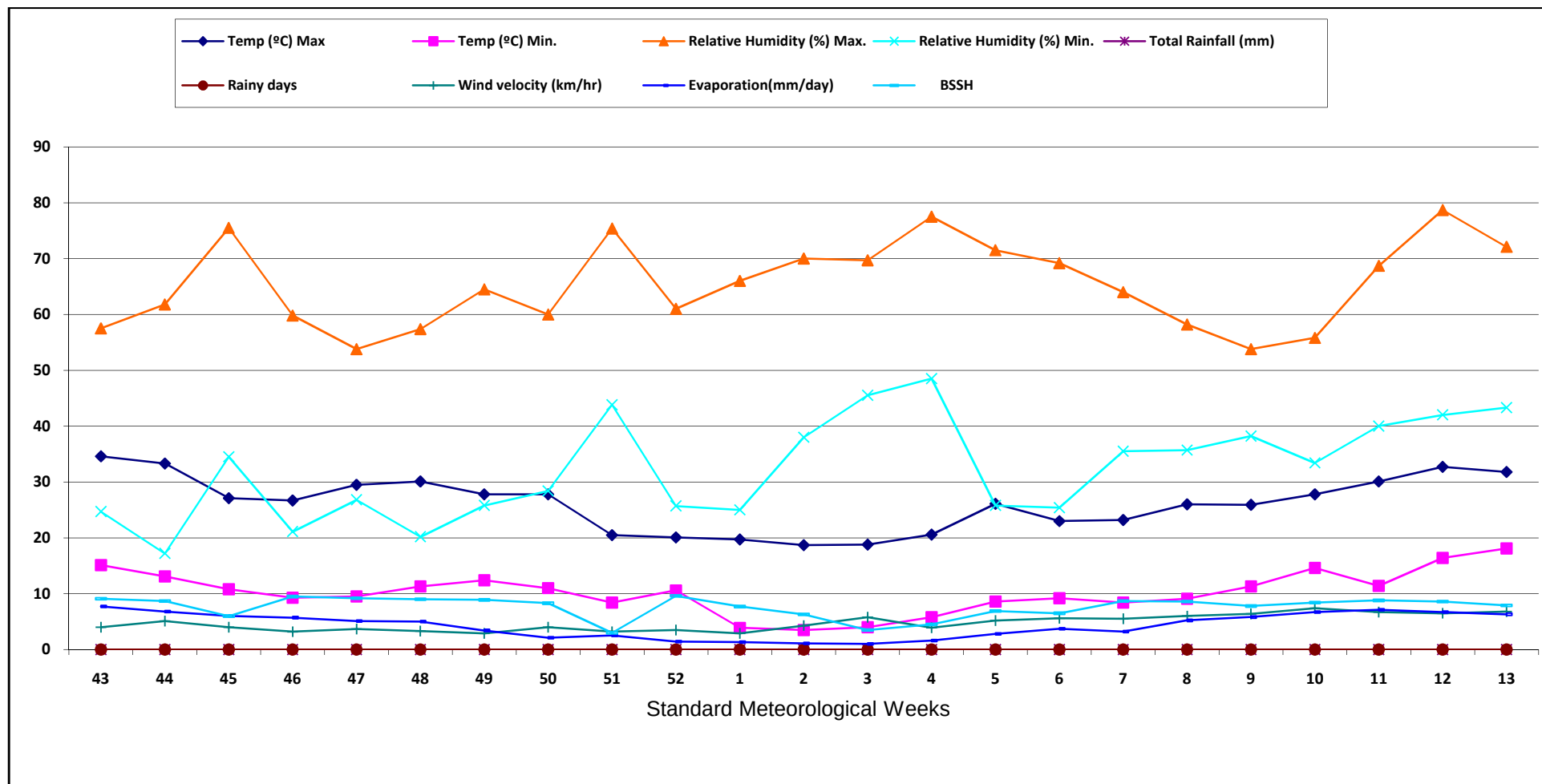


Fig. 3.1: Mean weekly meteorological data during crop season (*Rabi*, 2013-14)

13th standard metrological weeks, respectively. Crop received no rainfall in the growing season. Evaporation ranged from 1.0 to 7.7 mm per day during the crop growing period. The average relative humidity during experimentation fluctuated in the range of 17.2 to 78.7% (in standard week no. 44 and 12 respectively). The wind velocity ranged from 2.9 to 7.4 km/hr.

3.3 CROPPING HISTORY OF EXPERIMENTAL FIELD

The previous cropping history of the experimental field has been given in the table 3.2.

Table 3.2 Cropping history of the experimental field

Crop year	Season	
	Kharif	Rabi
2011-12	Guar	Mustard
2012-13	Bajra	Wheat
2013-14	Guar	Chickpea*

* Experimental crop

3.4 SOIL OF EXPERIMENTAL FIELD

In order to know the physical and chemical properties of soil, samples were taken randomly from 0-30 cm depth from different spots of the experimental field and a representative composite sample was prepared by mixing all these samples together. This composite sample was analyzed to determine the mechanical composition, physico-chemical properties, organic carbon and available N, P and K of the soil. The results of the analysis along with methods used are presented in table 3.3.

Results of the physical and chemical analysis revealed that the soil of the experimental field was loamy sand in texture and slightly alkaline in reaction. The status of soil was poor in organic carbon, low in available nitrogen, phosphorus and potassium.

Table 3.3 Physico-chemical characteristics of the experimental soil

Soil properties	Value at 0-30cm soil depth	Methods of analysis with reference
A. Mechanical Composition		
Sand (%)	84.25	Hydrometer method (Bouyoucos, 1962)
Silt (%)	7.70	
Clay (%)	7.84	
Texture	Loamy sand	Triangular method (Brady, 1983)
B. Physical properties		
Bulk density (Mg m^{-3})	1.58	Method No. 38, USDA Hand Book No. 60 (Richards, 1954)
Particle density (Mg m^{-3})	2.65	Method No. 39, USDA Hand Book No. 60 (Richards, 1954)
Field Capacity (%)	7.92	Method No. 30, USDA Hand Book No. 60 (Richards, 1954)
Porosity (%)	37.30	Method No. 40, USDA Hand book No. 60 (Richards, 1954)
C. Chemical properties		
Organic carbon (%)	0.08	Walkley and Black's wet digestion method (Walkley and Black's, 1934)
Available nitrogen (kg ha^{-1})	87.72	Alkaline KMnO_4 method (Subbiah and Asija, 1956)
Available P_2O_5 (kg ha^{-1})	20.72	Olsen method (Olsen <i>et al.</i> , 1954)
Available K_2O (kg ha^{-1})	164.14	Flame photometric method (Metson <i>et al.</i> , 1956)
EC (dS m^{-1}) (1:2 soil water suspension at 25°C)	0.15	Method No. 4 USDA Handbook No.60 (Richards, 1954)
Soil pH (1:2 soil water suspension)	8.15	Method No. 21 b, USDA Handbook No. 60 (Richards, 1954)

3.5 EXPERIMENTAL DETAILS

3.5.1 Experimental design and layout

The experiment was laid out in a Split Plot design and replicated thrice. The treatments were allotted to various plots with the help of random table as advocated by Fisher (1950). The gross plot size 3.0 m x 3.0 m was used for yield and other related studies. The plan of layout of experiment is given in figure 3.2 and other details are given below:

Season	:	Rabi, 2013-14
Total number of treatments	:	3 x 4 =12
Number of replications	:	3
Total number of plots	:	12 x 3=36
Experimental design	:	SPD
Plot size		
(a) Gross	:	3.0 m x 3.0 m= 9 m ²
(b) Net	:	2.9 m x 2.7 m = 7.83 m ²
Test crop	:	Chickpea
Variety	:	RSG-945
Crop geometry	:	30 cm x 10 cm
Seed rate	:	80 kg ha ⁻¹
Fertilizers		
Nitrogen	:	20 kg N ha ⁻¹ through urea
Phosphorus	:	Phosphorus as per treatment through SSP

3.5.2 Treatments

The treatments comprised of four levels of Culture and three levels of Phosphorus thereby making twelve treatment combinations. The detail of treatments along with the symbols used have been given in table 3.4.

Table 3.4 Detail of treatments with symbols

Treatments		Symbols
A. Cultures		
(i)	Control	C ₀
(ii)	<i>Rhizobium</i>	C ₁
(iii)	PSB	C ₂
(iv)	<i>Rhizobium</i> and PSB	C ₃
B. Phosphorus levels (kg P₂O₅ ha⁻¹)		
(i)	0	P ₀
(ii)	60	P ₁
(iii)	80	P ₂

3.6 CHARACTERISTICS OF CROP VARIETY

RSG-945: Area of adoption of this variety is Rajasthan. It is also known as 'Asha' and released in year 2005. It is suitable for late sown irrigated conditions. Growth habit is semi erect with profuse branching. Leaf colour has green, stem has also green and shape of pinnate is ovate. Flowers are medium and purple in colour. Pod and seed size is medium bold, seed has reddish brown colour and shape is obviate. It matures in 125-130 days. It is moderately resistant to dry root rot and wilt.

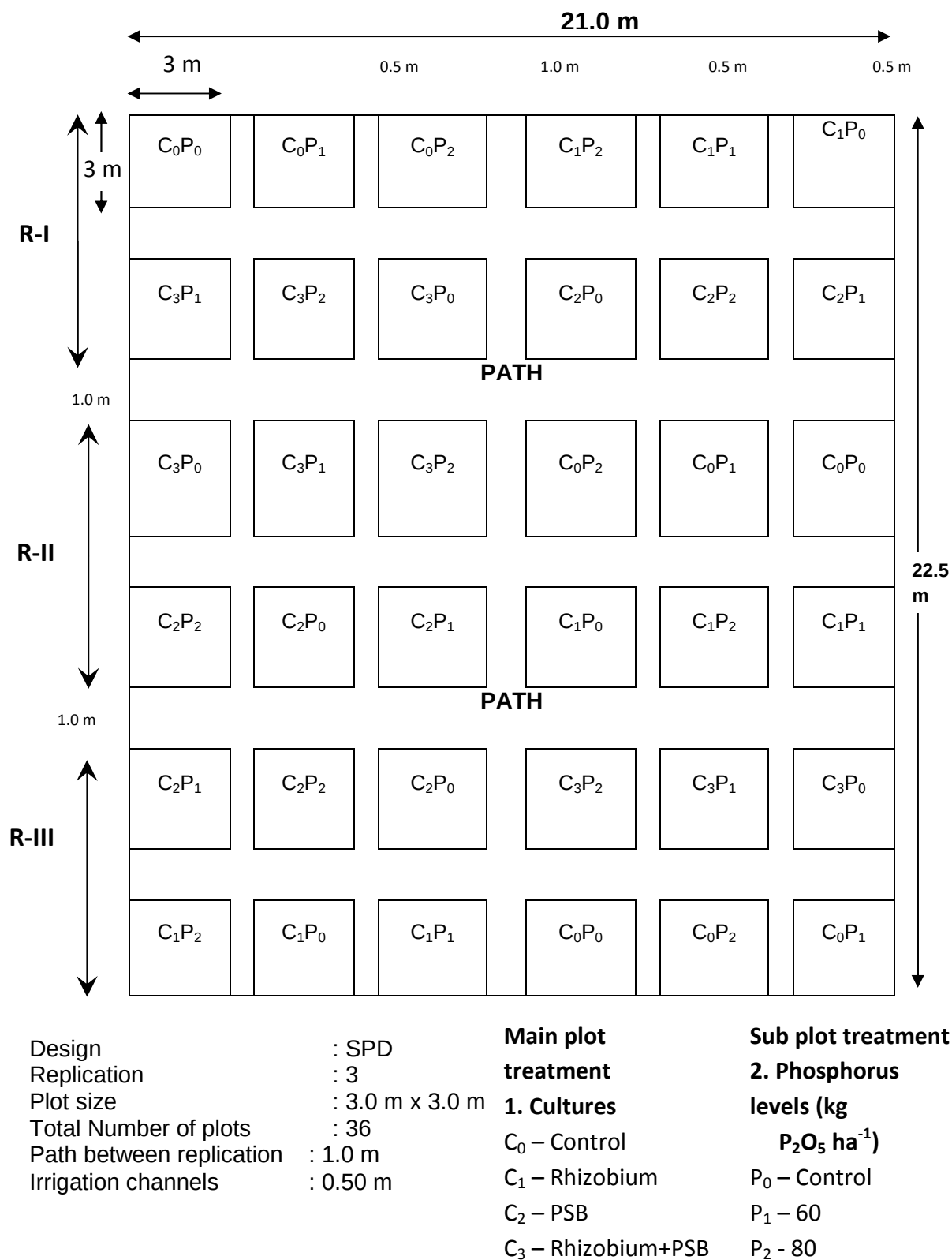


Fig. 3.2 Layout of plan

3.7 DETAILS OF CROP RAISING

3.7.1 Field preparation

The field was cross ploughed by tractor drawn disc harrow and finally planked with the help of planker. Treatment plots of 3.0 x 3.0 meter size were prepared as shown in layout plan.

3.7.2 Fertilizer application

- a. Nitrogen @ 20 kg ha⁻¹ through urea as basal
- b. Phosphorus was applied as per treatment through single super phosphate (SSP).

3.7.3 Seed rate and sowing

The seeds of the variety RSG-945 were sown @ 80 kg ha⁻¹ in the rows spaced at 30 cm and depth of 5 cm on Oct. 26, 2013 by “Kera” method in open furrows along with the fertilizers.

3.7.4 Thinning

One thinning was done at 20 DAS to maintain optimum plant population by keeping intra row spacing of 10 cm.

3.7.5 Weeding and hoeing

Hoeing and weeding was done manually at 30 and 45 days after sowing with the help of hand hoe. The field was kept practically weed free by hand pulling of subsequent emerging weeds.

3.7.6 Irrigation

A pre sowing irrigation was given before sowing. Later three irrigations were applied to the crops as per requirement through sprinkler system. The dates of irrigation given to crop are presented in Table 3.5

3.7.7 Harvesting

To assess the biological, seed and straw yields, net area of 2.9 m x 2.7 m was harvested separately from each plot by sickles, tied in bundles and tagged. These tagged bundles were left for sun drying in the plots. After complete drying the bundles were weighed using the physical balance and the weight of each bundle was recorded in kilograms as biological yield.

3.7.8 Threshing and winnowing

After recording the biological yield, the bundles of each plot were threshed [by beating with wooden sticks] and winnowed separately. The weight of clean seed obtained was recorded as seed yield and converted into kg ha⁻¹. The straw yield was computed by deducing the weight of seed yield from total biological yield.

3.8 CHRONOLOGICAL RECORD

The chronological record of crop raising is given in table 3.5

Table 3.5: Chronological record of crop raising

S. No.	Particulars	Date	Remarks
1.	Pre- sowing irrigation	24.10.13	Sprinkler for 5 hours
2.	Ploughing and planking	25.10.13	Tractor drawn disc harrow and planker
3.	Layout of experimental field	26.10.13	Manually
4.	Fertilizers application	26.10.13	Basal application manually by “Kera method”
5.	Seed treatment and inoculation	26.10.13	Manually
6.	Sowing of seeds	26.10.13	Manually by “Kera” method
7.	Thinning and gap filling	16.11.13	Manually

8.	Hoeing and weeding		
	1 st	28.11.13	Manually
	2 nd	11.12.13	
9.	Irrigation		
	1 st irrigation	16.12.13	
	2 nd irrigation	23.01.14	Sprinkler 3 hours
	3 rd irrigation	19.02.14	
10.	Harvesting	22.03.14	Manually
11.	Threshing and Winnowing	02.04.10	Manually

3.9 TREATMENT EVALUATION OF CHICKPEA

The methodologies used for evaluating different treatments in terms of growth, yield and quality of the crop are given as below:

3.9.1 Growth parameters

For evaluating growth characters, five plants were randomly selected from each plot and tagged.

3.9.1.1 Plant stand

The number of plants per meter row length was recorded at harvest and their average was worked out.

3.9.1.2 Plant height

The height of five permanently tagged plants from each plot was measured from the cotyledonary node to the apex of the main shoot with the help of meter scale at harvest. The average of five plants was recorded as mean plant height (cm).

3.9.1.3 Number of branches

Number of branches per plant was counted at harvest from the same five tagged plants and their average was worked out.

3.9.1.4 Viable root nodules per plant

The nodules of five plants were uprooted randomly from the outer rows of each plot without disturbing roots and their nodules. After thorough washing the roots along with nodules were dried in shade. Thereafter, nodules were separated from roots of each plant separately with the help of forceps and counted them at flowering stage. The average numbers of root nodules per plant was recorded.

3.9.2 Yield attributes and Yield

3.9.2.1 Number of pods per plant

Pods of the five tagged plants were collected at harvest from each plot and average number of pods per plant was calculated.

3.9.2.2 Number of pods per branch

Five branches were randomly selected from each five tagged plants and numbers of pods per branch were counted and mean value for number of pods per branch were calculated.

3.9.2.3 Number of seeds per pod

Five pods were randomly selected from each five tagged pants and numbers of seeds per pod were counted and mean value for number of seeds per pod was calculated.

3.9.2.4 Seed index

One hundred seeds were counted from each sample drawn from the produce of each plot and weighed. The weight was recorded as test weight in gram.

3.9.2.5 Seed yield

After threshing, winnowing and cleaning, seed yield from each net plot was weighed and converted into kg ha⁻¹.

3.9.2.6 Straw yield

Straw yield was calculated by deducting the seed yield from biological yield and expressed in kg ha⁻¹.

3.9.2.7 Biological yield

After complete sun drying of harvested material from each net plot, weight was taken for biological yield and then converted into kg ha⁻¹.

3.9.2.8 Harvest index

The Harvest index was worked out by dividing the grain yield (economic yield) by grain + straw yield (biological yield) obtained from plot area and multiplies by 100 to express it in percent (Singh and Stoskopf 1971).

$$\text{Harvest Index (\%)} = \text{Economic yield} / \text{Biological yield} \times 100$$

3.10 CHEMICAL ANALYSIS

3.10.1 Plant analysis

For estimation of nitrogen, phosphorus and protein content representative samples of seed and straw were taken at the time of harvest. Each dried straw sample was ground in Willey mill. For estimating nutrient content in seed, each sample was ground by an electric grinder. Nutrient content in seed and straw were determined using standard method as given below:

Table 3.6 Methods of plant analysis

S.No	Determination	Methods	References
1.	Nitrogen content	Digestion of plant samples with sulphuric acid and development of colour with Neseller's reagents for colorimetric method	Snell and Snell (1949)

2.	Phosphorus content	Digestion of plant samples with di-acid and developed colour with Vanado-molybdate for colorimetric estimation	Jackson (1973)
3.	Protein content	Protein in seeds was calculated by multiplying the nitrogen percentage with 6.25	A.O.A.C. (1970)

3.10.2 Nutrient uptake

The uptake of nitrogen and phosphorus in seed and straw was estimated by using the following formula.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\left(\frac{\text{Per cent nutrient content in seed} \times \text{Seed yield (kg ha}^{-1}\text{)}}{100} \right) + \left(\frac{\text{Per cent nutrient content in straw} \times \text{Straw yield (kg ha}^{-1}\text{)}}{100} \right)}{100}$$

3.11 BIOLOGICAL ACTIVITIES

Table 3.7 Methods of soil analysis for biological activities

S.No	Determination	Methods	References
1.	Total bacteria count	Serial dilution method	Blodgett (2005a)
2.	Dehydrogenase activity ($\mu\text{g TPF g}^{-1} \text{ soil h}^{-1}$)	TTC substrate method	Casida <i>et al.</i> (1964)
3.	Alkaline phosphatase activity ($\mu\text{g PNP g}^{-1} \text{ soil h}^{-1}$)	p- nitrophenol estimation method	Tabatabai and Bremner (1969)

3.11 ECONOMICS OF TREATMENTS

The economics of different treatments were worked out in terms of net return (Rs ha⁻¹) and B:C ratio as, these are the most important for making any recommendation for its adoption. The cost of cultivation for each treatment was subtracted from the gross returns received from the respective treatments and a net return was obtained. For this, prevailing market price for inputs and outputs were used. The computation details of economics for each treatment are given in appendices at the end.

3.11.1 Net returns (Rs ha⁻¹)

To find out the more profitable treatment, economics of different treatments were worked out in terms of net returns (Rs ha⁻¹) on the basis of the prevailing market rates so that the most remunerative treatment could be recommended.

3.11.2 Benefit : cost ratio

Treatment wise benefit : cost ratio was calculated to ascertain economic viability of the treatment using the following formula:

$$\text{B:C ratio} = \frac{\text{Gross returns}}{\text{Cost of cultivation}}$$

3.12 OPTIMUM DOSE OF PHOSPHORUS

In order to evaluate the economic feasibility of different treatment, the net return (Rs. ha⁻¹), B:C ratio and optimum economic dose of phosphorus was worked out on the basis of prevailing market prices. The quadratic response function ($Y = a + bx + cx^2$) was fitted to seed yield data by the procedure described by Panse and Sukhatme (1985). The economic optimum dose of phosphorus was worked out by the following relationship.

$$\text{Optimum dose of phosphorus (kg ha}^{-1}\text{)} = \frac{P_x - bP_y}{2 \times c \times P_y}$$

Where,

P_x = Price of phosphorus (Rs. kg^{-1})

P_y = Price of seed (Rs. kg^{-1})

b = Regression coefficient of Y on X

c = Coefficient of quadratic component

3.13. STATISTICAL ANALYSIS

3.13.1 Analysis of variance and test of significance

The data of growth, yield and other characters were statistically analyzed with the help of Fisher's analysis of variance technique (Fisher, 1950). The critical difference (CD) for the treatment comparisons were worked out where ever the variance ratio (F test) was found significant at 5% level of probability. To evaluate the nature and magnitude of treatment effect, summary tables along with S.Em. $\pm$ and CD ($P=0.05$) were prepared and are given in the text of the chapter entitled "Experimental Results" and their analysis of variance for mean sum of square (MSS) are given in the appendices at the end.

EXPERIMENTAL RESULTS

Results of field experiment entitled, Impact of biofertilizers and phosphorus levels on biological activity of rhizosphere, yield and nutrient uptake by chickpea (*Cicer arietinum* L.) conducted during rabi 2013-14 at Agronomy Farm, College of Agriculture, SKRAU, Bikaner are presented in this chapter. The data of growth, yield and quality characters obtained during the course of investigation were statistically analyzed and significance of the results verified. The analyses of variance for various components are given in appendices at the end.

4.1 GROWTH ATTRIBUTES

4.1.1 Plant stand

A perusal of data presented in Table 4.1 showed that plant stand of chickpea at harvest was not significantly affected due to application of biofertilizers and phosphorus.

4.1.2 Plant height

Effect of biofertilizers

Data mentioned in Table 4.1 revealed that at harvest, the plant height was significantly higher due to seed inoculation with *Rhizobium* + PSB treatment over control and *Rhizobium* treatments. The per cent increase in plant height was at the tune of 20.51 and 2.47 per cent respectively. Seed inoculation with *Rhizobium* and PSB alone being at par with each other had significant effect on plant height over control. However, PSB and *Rhizobium* + PSB were statistically at par.

Effect of Phosphorus

A perusal of data (Table 4.1) revealed that at harvest stage, the plant height increased significantly due to increasing levels of phosphorus. Application of 60 kg P₂O₅ ha⁻¹ increased plant height

significantly by 18.19 per cent over control. However, the plant height at 60 and 80 kg P₂O₅ ha⁻¹ were statistically at par.

Table 4.1: Effect of biofertilizers and phosphorus levels on plant stands and plant height at harvest of chickpea

Treatments	Plant stand (per meter row length)	Plant height (cm)
Cultures		
C ₀	7.90	39.04
C ₁	8.01	45.91
C ₂	8.02	46.28
C ₃	8.18	47.05
S.Em±	0.10	0.37
CD (P=0.05)	NS	0.92
Phosphorus levels (kg P₂O₅ ha⁻¹)		
P ₀	7.94	39.59
P ₁	8.03	46.79
P ₂	8.11	47.33
S.Em±	0.11	0.35
CD (P=0.05)	NS	0.74

4.1.3 Branches per plant

4.1.3.1 Primary branches

Effect of biofertilizers

An appraisal of data (Table 4.2 and Fig. 4.1) further showed that number of primary branches per plant at harvest stage increased significantly due to seed treatment with biofertilizer over control. Dual inoculation of *Rhizobium* + PSB increased maximum number of branches per plant but statistically at par with *Rhizobium* and PSB alone. The magnitude of increase by dual inoculation (*Rhizobium* + PSB) over control at harvest was 41.75 per cent. Seed inoculation with *Rhizobium* and PSB alone being at par with each other had also significant effect on number of branches per plant over control.

Effect of phosphorus

Data from table 4.2 further showed that all the levels of phosphorus significantly increased number of primary branches per plant over control at harvest. Application of 60 kg P₂O₅ ha⁻¹ produced significantly more branches per plant over control with per cent increase of 33.78, but remained statistically at par with 80 kg P₂O₅ ha⁻¹.

4.1.3.2 Secondary branches

Effect of biofertilizers

An appraisal of data (Table 4.2 and Fig. 4.1) further showed that number of secondary branches per plant at harvest stage increased significantly due to seed treatment with biofertilizers over control. Dual inoculation of *Rhizobium* + PSB increased maximum number of secondary branches per plant over control but remained statistically at par with *Rhizobium* and PSB alone. The magnitude of increase by dual inoculation (*Rhizobium* + PSB) over control at harvest was 50.00 per cent. Seed inoculation with *Rhizobium* and PSB alone being at par with

each other had also significant effect on number of branches per plant over control.

Effect of phosphorus

Data from table 4.2 showed that all the levels of phosphorus significantly increased number of secondary branches per plant over control at harvest. Application of 60 kg P₂O₅ ha⁻¹ produced significantly more branches per plant over control with per cent increase of 37.45, but remained statistically at par with 80 kg P₂O₅ ha⁻¹.

4.1.4 Number of nodules per plant

Effect of biofertilizers

Data presented in table 4.2 and Fig. 4.1 further revealed that number of viable root nodules per plant at flowering stage increased significantly due to seed treatment with biofertilizers over control. Seed inoculation with *Rhizobium* + PSB recorded maximum number of root nodules per plant and produced significantly higher root nodules to the extent of 117.63, 10.57 and 71.93 per cent at flowering stage over control, *Rhizobium* and PSB alone respectively. Seed inoculation with *Rhizobium* alone has significantly increased the number of nodules at the time of flowering by 55.49 per cent over PSB alone.

Effect of phosphorus

Data in table 4.2 indicated that application of varying phosphorus levels significantly enhanced number of root nodules per plant over control at flowering stage. Application of 60 kg P₂O₅ ha⁻¹ produced significantly higher number of root nodules per plant over control by 38.43 per cent at flowering stage, but remained statistically at par with 80 kg P₂O₅ ha⁻¹.

Table 4.2: Effect of biofertilizers and phosphorus levels on no. of branches per plant at harvest and viable root nodules per plant at flowering stage of chickpea

Treatments	Number of branches per plant		Viable root nodules per plant
	Primary branches	Secondary branches	
Cultures			
C ₀	5.75	11.62	27.08
C ₁	7.55	16.18	53.31
C ₂	7.90	16.52	34.28
C ₃	8.16	17.43	58.95
S.Em±	0.27	0.61	0.37
CD (P=0.05)	0.67	1.51	0.92
Phosphorus levels (kg P ₂ O ₅ ha ⁻¹)			
P ₀	5.86	12.38	34.85
P ₁	7.85	16.91	47.14
P ₂	8.31	17.02	48.24
S.Em±	0.22	0.46	0.57
CD (P=0.05)	0.47	0.99	1.22

Interaction effect between biofertilizers and phosphorus levels on no. of viable root nodules per plant of chickpea

Data pertaining to the effect of biofertilizers and phosphorus levels on no. of viable root nodules per plant (Table 4.3) revealed that application of 60 kg P_2O_5 ha⁻¹ + seed inoculation with *Rhizobium* + PSB treatment combination produced significantly highest root nodules per plant and which was at par with treatment combination of 80 kg P_2O_5 ha⁻¹ + seed inoculation with *Rhizobium* + PSB.

Table 4.3: Interaction effect between biofertilizers and phosphorus levels on no. of viable root nodules per plant of chickpea

Phosphorus levels (kg P_2O_5)	Cultures			
	C ₀	C ₁	C ₂	C ₃
P ₀	25.66	40.40	27.13	46.20
P ₁	27.04	59.76	37.15	64.60
P ₂	28.55	59.78	38.58	66.05
S.Em±	1.15			
CD (5%)	2.45			

4.2 YIELD AND YIELD ATTRIBUTES

4.2.1 Number of pods per plant

Effect of biofertilizers

Further reference to data given in table 4.4 indicated that seed treatment with *Rhizobium* + PSB recorded the maximum number of pods per plant and registered significant increase of 47.37, 13.53 and 12.51 per cent over control, *Rhizobium* and PSB alone. Seed

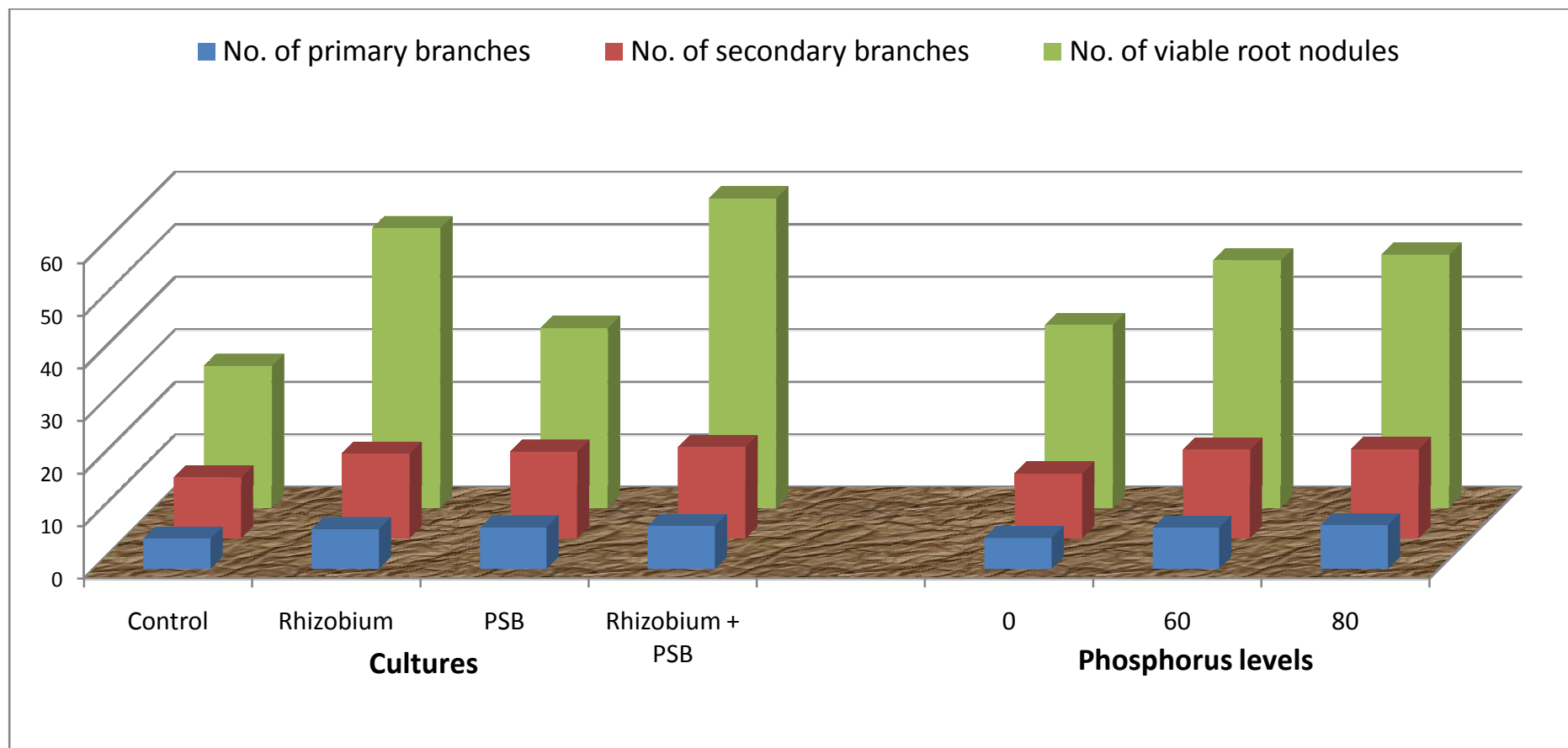


Fig. 4.1 Effect of biofertilizers and phosphorus levels on no. of branches and viable root nodules per plant of chickpea

inoculation with *Rhizobium* and PSB alone being at par with each other had significant effect on number of pods per plant over control.

Effect of phosphorus

It is evident from the data (Table 4.4) that phosphorus levels had significant effect on number of pods per plant. Application of 60 kg P_2O_5 ha⁻¹ produced significantly higher number of pods per plant over control with per cent increase of 31.20 but remained statistically at par with 80 kg P_2O_5 ha⁻¹.

4.2.2 Number of pods per branch

Effect of biofertilizers

Further reference to data given in table 4.4 indicated that seed treatment with *Rhizobium* + PSB recorded the maximum number of pods per branch and registered significant increase of 54.01, 10.05 and 2.49 per cent over control, *Rhizobium* and PSB alone. Seed inoculation with PSB alone has significantly increased the no. of pods at the rate 7.37 per cent over *Rhizobium*.

Effect of phosphorus

It is evident from the data (Table 4.4) that phosphorus levels had significant effect on number of pods per branch. Application of 60 kg P_2O_5 ha⁻¹ produced significantly higher number of pods per branch over control with per cent increase of 38.67 but remained statistically at par with 80 kg P_2O_5 ha⁻¹.

4.2.3 Number of seeds per pod

A perusal of data presented in Table 4.4 showed that plant stand of chickpea at harvest was not significantly affected due to application of biofertilizers and phosphorus.

Table 4.4: Effect of biofertilizers and phosphorus levels on no. of pods per plant, number of pods per branch and no. of seeds per pod of chickpea

Treatments	No. of pods per plant	No. of pods per branch	No. of seeds per pod
Cultures			
C ₀	67.48	5.73	1.76
C ₁	87.60	8.02	1.77
C ₂	88.39	8.61	1.78
C ₃	99.45	8.83	1.81
S.Em±	0.85	0.07	0.02
CD (P=0.05)	2.09	0.18	NS
Phosphorus levels (kg P₂O₅ ha⁻¹)			
P ₀	70.66	6.17	1.76
P ₁	92.72	8.56	1.78
P ₂	93.81	8.65	1.80
S.Em±	0.57	0.06	0.01
CD (0.05)	1.21	0.13	NS

Interaction effect between biofertilizers and phosphorus levels on no. of pods per plant of chickpea

Data pertaining to the effect of biofertilizers and phosphorus levels on no. of pods per plant of chickpea (Table 4.5) revealed that application of 60 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB treatment combination produced significantly highest pods per plant of chickpea and which was at par with treatment combination of 80 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB.

Table 4.5: Interaction effect between biofertilizers and phosphorus levels on no. of pods per plant of chickpea

Phosphorus levels (kg P ₂ O ₅)	Cultures			
	C ₀	C ₁	C ₂	C ₃
P ₀	61.00	72.72	73.20	75.75
P ₁	69.46	94.85	95.26	111.29
P ₂	72.00	95.23	96.71	111.32
S.Em±	1.14			
CD (5%)	2.42			

4.2.4 Seed yield

Effect of biofertilizers

Inoculation of seed with single or dual biofertilizers brought a significant improvement in seed yield of chickpea over control (Table 4.6 and Fig. 4.2). The maximum seed yield (1770.46 kg ha⁻¹) was obtained when chickpea seeds were inoculated with *Rhizobium* + PSB and produced significantly higher seed yield by 32.81, 11.11 and 8.16 per cent over control, *Rhizobium* and PSB alone, respectively. Inoculation with *Rhizobium* and PSB alone has also increased seed yield over control by 19.53 and 22.79 per cent respectively.

Effect of phosphorus

A perusal of data (Table 4.6) showed that seed yield of chickpea increased significantly over control due to successive increase in varying levels of phosphorus. Application of 60 kg P₂O₅ ha⁻¹ produced seed yield of 1703.13 kg ha⁻¹ which was significantly higher by 27.41 per cent over control, but it remained at par with 80 kg P₂O₅ ha⁻¹.

4.2.5 Straw yield

Effect of biofertilizers

Data in table 4.6 and fig. 4.2 showed that dual inoculation of *Rhizobium* + PSB increased the straw yield significantly by 32.28, 13.63 and 9.38 per cent over control, *Rhizobium* and PSB alone, respectively. Inoculation with *Rhizobium* and PSB alone also recorded significantly higher straw yield over control. The magnitude of increase in straw yield noted due to *Rhizobium* and PSB was 16.41 and 20.92 per cent respectively over control. However, there was no significant difference in straw yield between *Rhizobium* and PSB inoculation.

Effect of phosphorus

A reference to data presented in table 4.6 revealed that application of 60 kg P₂O₅ ha⁻¹ produced significantly higher straw yield over control to the extent of 24.50 per cent, but it remained at par with 80 kg P₂O₅ ha⁻¹.

4.2.6 Biological yield

Effect of biofertilizers

Data in table 4.6 and fig. 4.2 showed that dual inoculation of *Rhizobium* + PSB increased the biological yield significantly by 32.51, 12.53 and 8.85 per cent over control, *Rhizobium* and PSB alone, respectively. Inoculation with *Rhizobium* and PSB alone also recorded significantly higher biological yield over control. The magnitude of

Table 4.6: Effect of biofertilizers and phosphorus levels on seed, straw and biological yields of chickpea

Treatments	Seed yield (kg ha⁻¹)	Straw yield (kg ha⁻¹)	Biological yield (kg ha⁻¹)
Cultures			
C ₀	1333.00	1784.44	3117.44
C ₁	1593.38	2077.30	3670.68
C ₂	1636.86	2157.84	3794.71
C ₃	1770.46	2360.46	4130.92
S.Em±	15.60	43.31	56.57
CD (P=0.05)	38.17	105.98	138.42
Phosphorus levels (kg P₂O₅ ha⁻¹)			
P ₀	1336.67	1787.56	3124.23
P ₁	1703.13	2225.56	3928.70
P ₂	1710.47	2271.91	3982.39
S.Em±	13.20	33.57	42.78
CD (P=0.05)	27.98	71.16	90.69

increase in biological yield noted due to *Rhizobium* and PSB was 17.74 and 21.72 per cent over control. However, there was no significant difference in biological yield between *Rhizobium* and PSB inoculation alone.

Effect of Phosphorus

Data in table 4.6 revealed that all the phosphorus levels recorded significantly higher biological yield of chickpea over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased biological yield over control which was 26.37 per cent higher but remained at par with 80 kg P₂O₅ ha⁻¹.

Interaction effect between biofertilizers and phosphorus levels on seed yield of chickpea

Data pertaining to the effect of biofertilizers and phosphorus levels on seed yield (Table 4.7 and fig. 4.3) revealed that application of 60 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB treatment combination produced significantly highest seed yield and which was at par with treatment combination of 80 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB. The minimum chickpea seed yield was recorded in the treatment combination P₀C₀ when neither phosphorus nor any culture was applied.

Table 4.7: Interaction effect between biofertilizers and phosphorus levels on seed yield of chickpea

Phosphorus levels (kg P ₂ O ₅)	Cultures			
	C ₀	C ₁	C ₂	C ₃
P ₀	1216.00	1350.80	1363.08	1416.80
P ₁	1387.64	1697.06	1783.41	1944.41
P ₂	1395.36	1732.28	1764.10	1950.17
S.Em±	26.40			
CD (5%)	55.97			

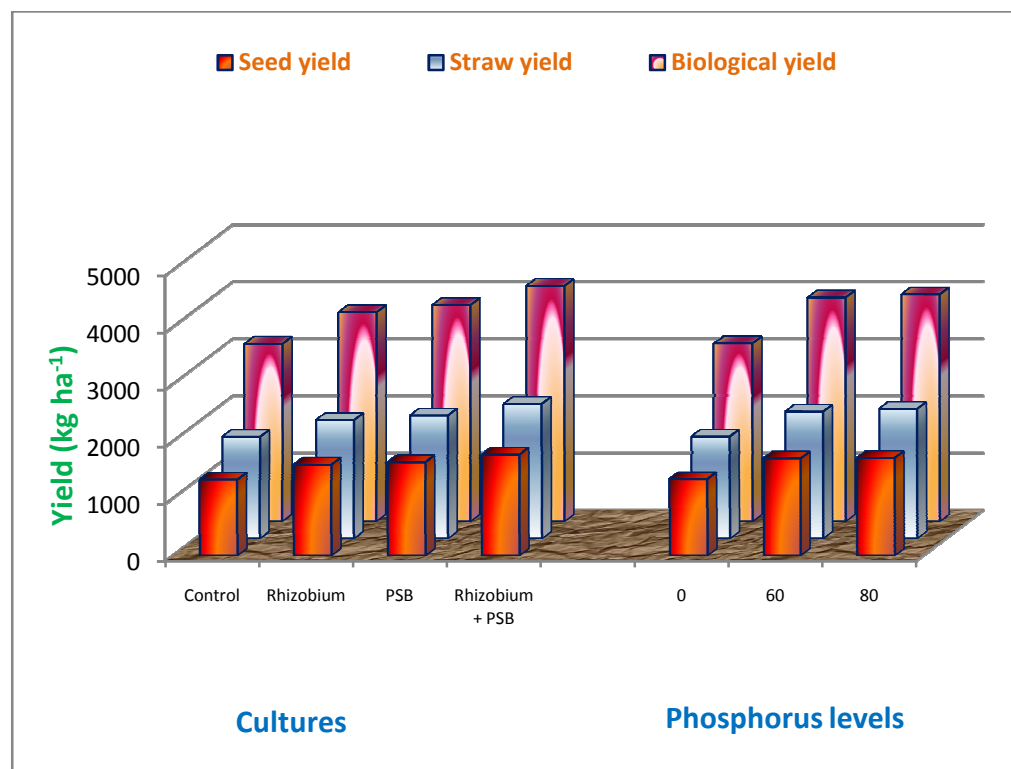


Fig. 4.2 Effect of biofertilizers and phosphorus levels on seed, straw and biological yield of chickpea

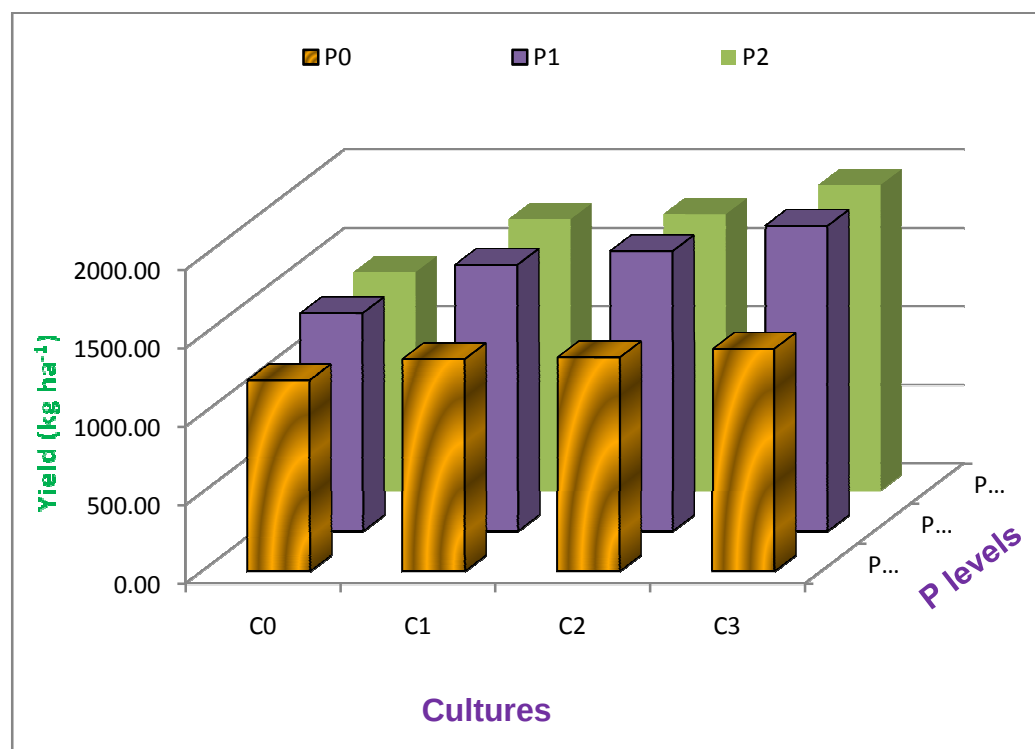


Fig. 4.3 Interaction effect between biofertilizers and phosphorus levels on seed yield of chickpea

Interaction effect between biofertilizers and phosphorus levels on straw yield of chickpea

Data pertaining to the effect of biofertilizers and phosphorus levels on straw yield (Table 4.8) revealed that application of 60 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB treatment combination produced significantly highest straw yield and which was at par with treatment combination of 80 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB.

Table 4.8: Interaction effect between biofertilizers and phosphorus levels on straw yield of chickpea

Phosphorus levels (kg P ₂ O ₅)	Cultures			
	C ₀	C ₁	C ₂	C ₃
P ₀	1642.66	1801.06	1817.44	1889.06
P ₁	1850.18	2157.51	2340.43	2554.14
P ₂	1860.48	2273.33	2315.66	2638.19
S.Em±	67.14			
CD (5%)	142.33			

.2.7 Seed index

Effect of biofertilizers

Data in table 4.9 and showed that dual inoculation of *Rhizobium* + PSB increased the seed index significantly by 38.14, 20.73 and 12.74 per cent over control, *Rhizobium* and PSB alone, respectively. Inoculation with *Rhizobium* and PSB alone also recorded significantly higher seed index over control. The magnitude of increase in seed index noted due to *Rhizobium* and PSB alone was 14.43 and 22.51 per cent over control. However, there was no significant difference between *Rhizobium* and PSB inoculation alone on seed index of chickpea.

Table 4.9: Effect of biofertilizers and phosphorus levels on seed and harvest index of chickpea

Treatments	Seed index (g)	Harvest index (%)
Cultures		
C ₀	13.32	42.75
C ₁	15.24	43.37
C ₂	16.32	43.11
C ₃	18.40	42.89
S.Em±	0.54	0.25
CD (P=0.05)	1.33	NS
Phosphorus levels (kg P₂O₅ ha⁻¹)		
P ₀	13.77	42.77
P ₁	16.48	43.33
P ₂	17.21	42.98
S.Em±	0.43	0.24
CD (P=0.05)	0.92	NS

Effect of phosphorus

Data in table 4.9 and revealed that all the phosphorus levels recorded significantly higher seed index of chickpea over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased seed index over control which was 19.68 per cent higher but remained at par with 80 kg P₂O₅ ha⁻¹.

4.2.8 Harvest index

A perusal of data presented in Table 4.9 showed that harvest index of chickpea was not significantly affected due to application of biofertilizers and phosphorus.

4.3 NUTRIENT CONTENT, UPTAKE AND QUALITY

4.3.1 Nitrogen content in seed

Effect of biofertilizers

Data in table 4.10 and fig. 4.4 showed that dual inoculation of *Rhizobium* + PSB increased the nitrogen content in seed significantly by 38.84 and 22.06 per cent over control and PSB alone, respectively and inoculation of *Rhizobium* alone increased nitrogen content significantly by 37.92 per cent over control. However, nitrogen content in seed of chickpea was at par between *Rhizobium* and *Rhizobium* + PSB inoculation treatments.

Effect of phosphorus

Data in table 4.10 revealed that all the phosphorus levels recorded slightly higher nitrogen content in seed of chickpea over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased nitrogen content in seed over control which was 4.02 per cent higher but remained at par with 80 kg P₂O₅ ha⁻¹.

4.3.2 Nitrogen content in straw

Effect of biofertilizers

Data in table 4.10 and fig. 4.4 showed that dual inoculation of *Rhizobium* + PSB increased the nitrogen content in straw significantly by 42.85 and 25.69 per cent over control and PSB alone, respectively and inoculation of *Rhizobium* alone increased nitrogen content significantly by 42.38 per cent over control. However, nitrogen content in straw of chickpea was at par between *Rhizobium* and *Rhizobium* + PSB inoculation treatments.

Effect of phosphorus

Data in table 4.10 revealed that all the phosphorus levels recorded slightly higher nitrogen content in straw of chickpea over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased nitrogen content in straw over control which was 5.62 per cent higher but remained at par with 80 kg P₂O₅ ha⁻¹.

4.3.3 Protein content in seed

Effect of biofertilizers

Data in table 4.10 and showed that dual inoculation of *Rhizobium* + PSB increased the protein content in seed significantly by 38.84 and 22.08 per cent over control and PSB alone, respectively and inoculation with *Rhizobium* alone increased protein content significantly by 37.90 per cent over control. However, there was no significant difference in protein content between *Rhizobium* and *Rhizobium* + PSB inoculation.

Effect of phosphorus

Data in table 4.10 and further revealed that all the phosphorus levels recorded slightly higher protein content in seed of chickpea over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased protein content over control which was 4.08 per cent higher but remained at par with 80 kg P₂O₅ ha⁻¹.

4.3.4 Nitrogen uptake in seed

Effect of biofertilizers

Data in table 4.10 and fig. 4.5 showed that dual inoculation of *Rhizobium* + PSB increased the nitrogen uptake in seed significantly by 85.08, 12.24 and 32.14 per cent over control, *Rhizobium* and PSB alone, respectively. Inoculation with *Rhizobium* alone increased nitrogen uptake significantly by 17.73 per cent over PSB. The magnitude of increase in nitrogen uptake noted due to *Rhizobium* and PSB alone was 64.88 and 40.05 per cent over control.

Effect of phosphorus

Data in table 4.10 revealed that all the phosphorus levels recorded significantly higher nitrogen uptake in seed of chickpea over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased nitrogen uptake over control which was 33.60 per cent higher but remained at par with 80 kg P₂O₅ ha⁻¹.

4.3.5 Nitrogen uptake in straw

Effect of biofertilizers

Data in table 4.10 and fig. 4.5 showed that dual inoculation of *Rhizobium* + PSB increased the nitrogen uptake in straw significantly by 89.70, 14.12 and 37.65 per cent over control, *Rhizobium* and PSB alone, respectively. Inoculation with *Rhizobium* alone increased nitrogen uptake significantly by 20.61 per cent over PSB. The magnitude of increase in nitrogen uptake noted due to *Rhizobium* and PSB alone was 66.22 and 37.81 per cent over control.

Effect of phosphorus

Data in table 4.10 revealed that all the phosphorus levels recorded significantly higher nitrogen uptake in straw of chickpea over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased nitrogen uptake over control which was 32.24 per cent higher but remained at par with 80 kg P₂O₅ ha⁻¹.

Table 4.10: Effect of biofertilizers and phosphorus levels on nitrogen content and uptake in seed and straw and protein content in seed of chickpea

Treatments	Nitrogen content (%)		Nitrogen uptake (kg ha ⁻¹)		Protein content (%)
	Seed	Straw	Seed	Straw	
Cultures					
C ₀	2.713	0.637	36.20	11.37	16.959
C ₁	3.742	0.907	59.69	18.90	23.387
C ₂	3.086	0.724	50.70	15.67	19.287
C ₃	3.767	0.910	67.00	21.57	23.546
S.Em±	0.021	0.004	0.86	0.52	0.131
CD (P=0.05)	0.051	0.010	2.11	1.27	0.321
Phosphorus levels (kg P ₂ O ₅ ha ⁻¹)					
P ₀	3.230	0.764	43.44	13.74	20.195
P ₁	3.360	0.807	58.04	18.17	21.019
P ₂	3.390	0.812	58.72	18.73	21.170
S.Em±	0.018	0.004	0.59	0.27	0.107
CD (P=0.05)	0.038	0.008	1.26	0.57	0.227

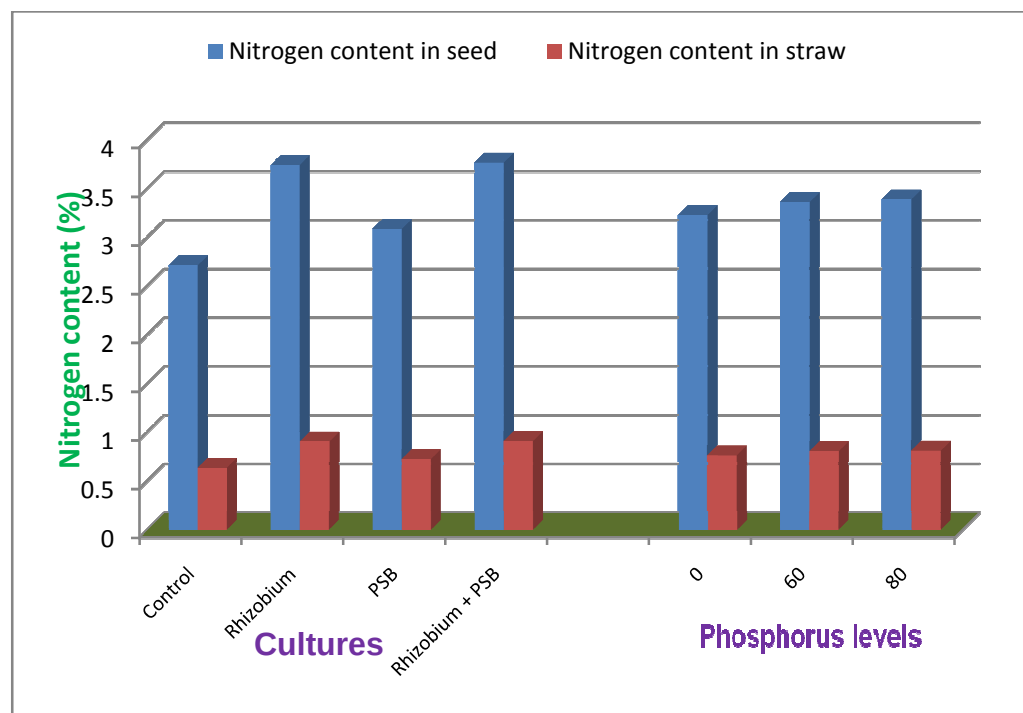


Fig. 4.4 Effect of biofertilizers and phosphorus levels on nitrogen content in seed and straw of chickpea

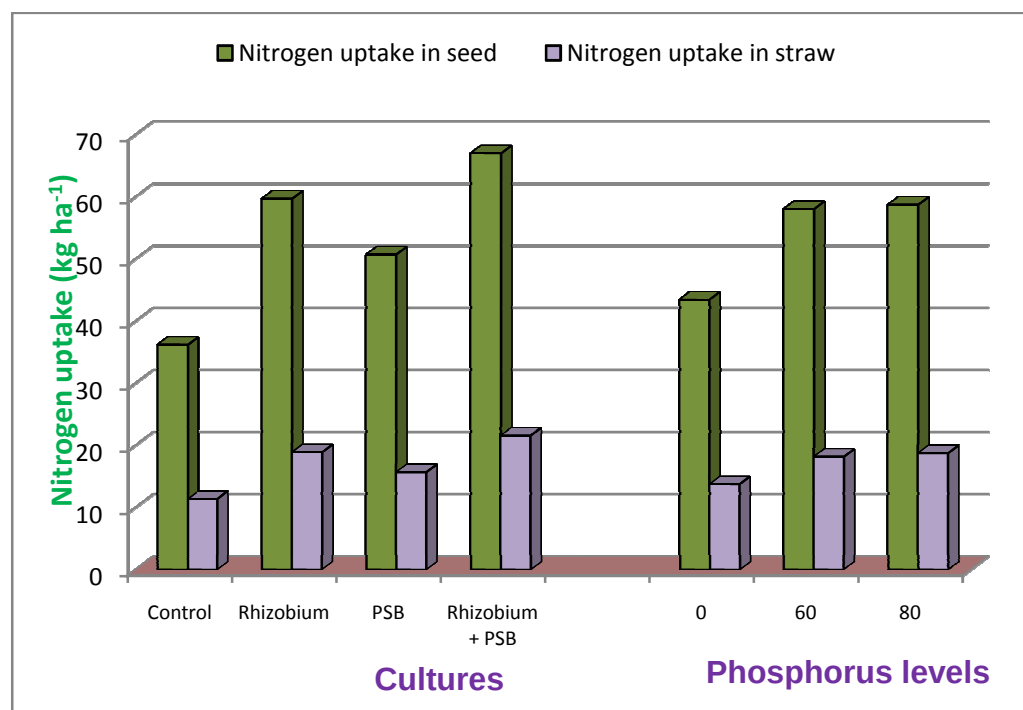


Fig. 4.5 Effect of biofertilizers and phosphorus levels on nitrogen uptake in seed and straw of chickpea

Interaction effect between biofertilizers and phosphorus levels on nitrogen content in seed of chickpea

Data pertaining to the effect of biofertilizers and phosphorus levels on nitrogen content in seed (Table 4.11 and fig. 4.6) revealed that application of 60 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB treatment combination produced significantly highest nitrogen content in seed and which was at par with treatment combination of 80 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB.

Table 4.11: Interaction effect between biofertilizers and phosphorus levels on nitrogen content in seed of chickpea

Phosphorus levels (kg P ₂ O ₅)	Cultures			
	C ₀	C ₁	C ₂	C ₃
P ₀	2.669	3.689	2.960	3.607
P ₁	2.722	3.763	3.130	3.838
P ₂	2.749	3.775	3.170	3.857
S.Em±	0.037			
CD (5%)	0.078			

Interaction effect between biofertilizers and phosphorus levels on nitrogen uptake in seed of chickpea

Data pertaining to the effect of biofertilizers and phosphorus levels on nitrogen uptake in seed (Table 4.12 and fig. 4.7) revealed that application of 60 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB treatment combination produced significantly highest nitrogen uptake in seed and which was at par with treatment combination of 80 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB.

Table 4.12: Interaction effect between biofertilizers and phosphorus levels on nitrogen uptake in seed of chickpea

Phosphorus levels (kg P ₂ O ₅)	Cultures			
	C ₀	C ₁	C ₂	C ₃
P ₀	32.46	49.82	40.40	51.10
P ₁	37.77	63.85	55.80	74.68
P ₂	38.36	65.40	55.90	75.22
S.Em±	1.19			
CD (5%)	2.52			

4.3.6 Phosphorus content in seed

Effect of biofertilizers

Further reference to data given in table 4.13 and fig. 4.8 indicated that seed treatment with *Rhizobium* + PSB recorded the maximum phosphorus content in seed and registered significant increase of 17.93, 14.55 and 4.12 per cent over control, *Rhizobium* and PSB alone respectively. Seed inoculation with PSB alone has significantly increased the phosphorus content at the magnitude of 10.02 per cent over *Rhizobium* alone treatment.

Effect of phosphorus

Data in table 4.13 revealed that all the phosphorus levels recorded significantly higher phosphorus content in seed of chickpea over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased phosphorus content over control which was 6.63 per cent higher but remained at par with 80 kg P₂O₅ ha⁻¹.

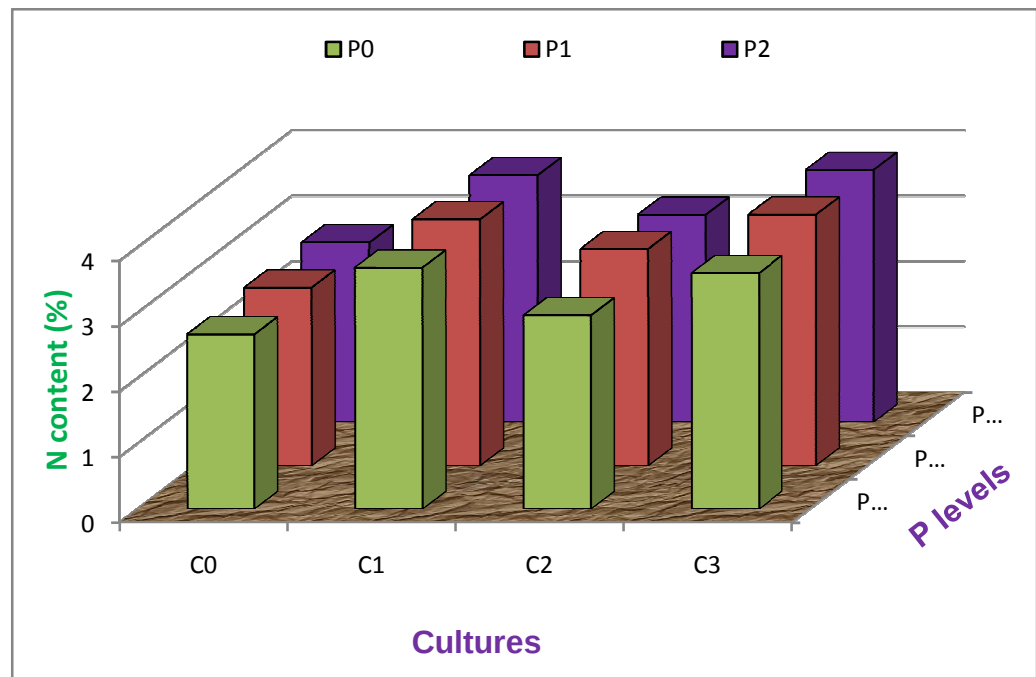


Fig. 4.6 Interaction effect between biofertilizers and phosphorus levels on N content in seed of chickpea

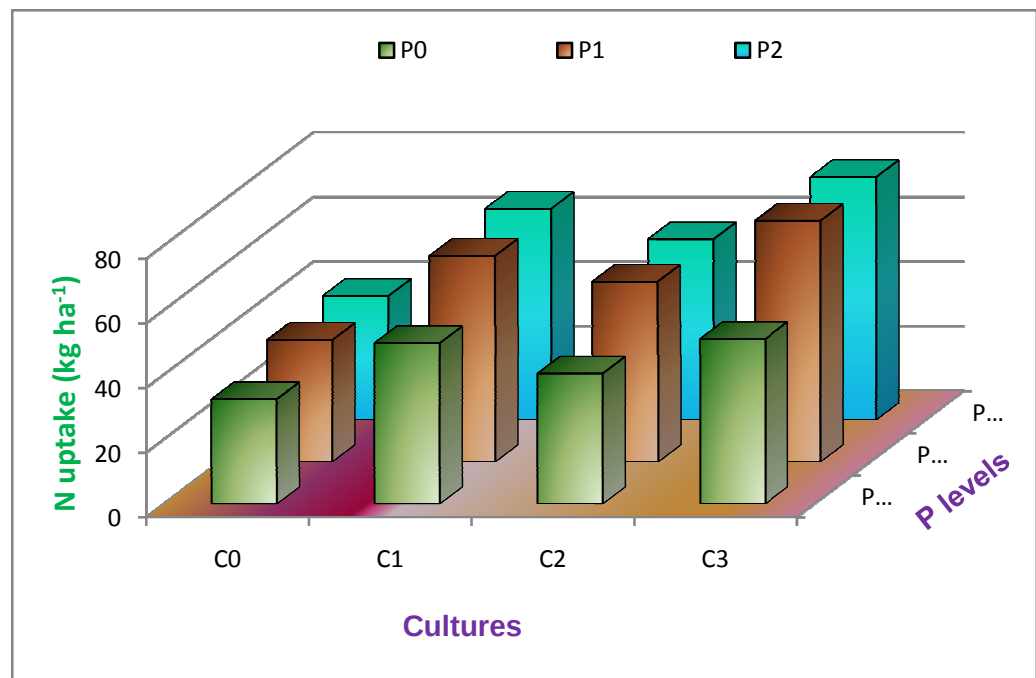


Fig. 4.7 Interaction effect between biofertilizers and phosphorus levels on N uptake in seed of chickpea

4.3.7 Phosphorus content in straw

Effect of biofertilizers

Further reference to data given in table 4.13 and fig. 4.8 indicated that seed treatment with *Rhizobium* + PSB recorded the maximum phosphorus content in straw and registered significant increase of 39.51, 21.70 and 4.37 per cent over control, *Rhizobium* and PSB alone, respectively. Seed inoculation with PSB alone has significantly increased the phosphorus content in straw by 16.59 per cent over *Rhizobium* alone.

Effect of phosphorus

Data in table 4.13 revealed that all the phosphorus levels recorded significantly higher phosphorus content in straw of chickpea over control. Application of 60 kg P_2O_5 ha⁻¹ significantly increased phosphorus content over control which was 25.82 per cent higher but remained at par with 80 kg P_2O_5 ha⁻¹.

4.3.8 Phosphorus uptake in seed

Effect of biofertilizers

Further reference to data given in table 4.13 and fig. 4.9 indicated that seed treatment with *Rhizobium* + PSB recorded the maximum phosphorus uptake in seed and registered significant increase of 58.11, 28.29 and 13.21 per cent over control, *Rhizobium* and PSB alone. Seed inoculation with PSB alone is significant increase of 13.32 per cent over *Rhizobium*.

Effect of phosphorus

Data in table 4.13 revealed that all the phosphorus levels recorded significantly higher phosphorus uptake in seed of chickpea over control. Application of 60 kg P_2O_5 ha⁻¹ significantly increased phosphorus uptake over control which was 37.05 per cent higher but remained at par with 80 kg P_2O_5 ha⁻¹.

Table 4.13: Effect of biofertilizers and phosphorus levels on phosphorus content and uptake in seed and straw of chickpea

Treatments	Phosphorus content (%)		Phosphorus uptake (kg ha ⁻¹)	
	Seed	Straw	Seed	Straw
Cultures				
C ₀	0.407	0.205	5.42	3.66
C ₁	0.419	0.235	6.68	4.91
C ₂	0.461	0.274	7.57	6.02
C ₃	0.480	0.286	8.57	6.91
S.Em±	0.003	0.001	0.09	0.14
CD (P=0.05)	0.007	0.002	0.23	0.36
Phosphorus levels (kg P₂O₅ ha⁻¹)				
P ₀	0.422	0.213	5.64	3.80
P ₁	0.450	0.268	7.73	6.08
P ₂	0.452	0.270	7.79	6.25
S.Em±	0.002	0.001	0.06	0.10
CD (P=0.05)	0.004	0.002	0.14	0.22

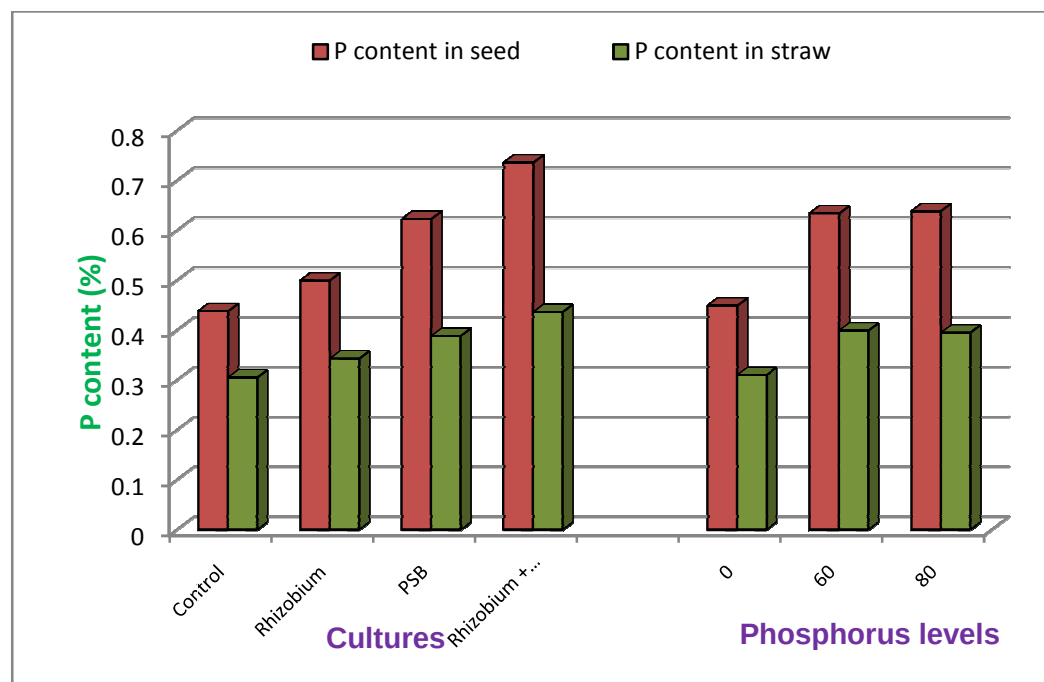


Fig. 4.8 Effect of biofertilizers and phosphorus levels on phosphorus content in seed and straw of chickpea

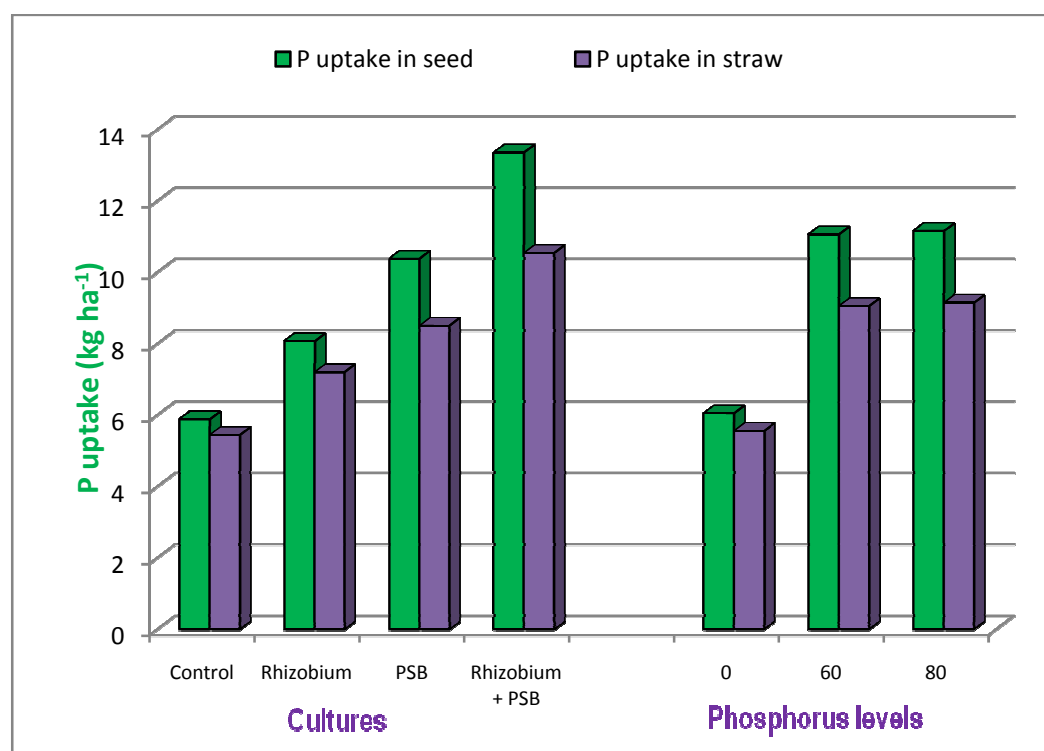


Fig. 4.9 Effect of biofertilizers and phosphorus levels on phosphorus uptake in seed and straw of chickpea

4.3.9 Phosphorus uptake in straw

Effect of biofertilizers

Further reference to data given in table 4.13 and fig. 4.9 indicated that seed treatment with *Rhizobium* + PSB recorded the maximum phosphorus uptake in straw and registered significant increase of 88.79, 40.73 and 14.78 per cent over control, *Rhizobium* and PSB alone, respectively. Seed inoculation with PSB alone is significant increase of 22.60 per cent over *Rhizobium*.

Effect of phosphorus

Data in table 4.13 revealed that all the phosphorus levels recorded significantly higher phosphorus uptake in straw of chickpea over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased phosphorus uptake in straw over control which was 60 per cent higher but remained at par with 80 kg P₂O₅ ha⁻¹.

Interaction effect between biofertilizers and phosphorus levels on phosphorus content in seed of chickpea

Data pertaining to the effect of biofertilizers and phosphorus levels on phosphorus content in seed (Table 4.14 and fig. 4.10) revealed that application of 60 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB treatment combination produced significantly highest phosphorus content in seed and which was at par with treatment combination of 80 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB. The phosphorus content in seed of chickpea with the application of 60 kg ha⁻¹ + seed inoculation with both *Rhizobium* + PSB was 13.92 per cent higher as compared to control.

Table 4.14: Interaction effect between biofertilizers and phosphorus levels on phosphorus content in seed of chickpea

Phosphorus levels (kg P ₂ O ₅)	Cultures			
	C ₀	C ₁	C ₂	C ₃
P ₀	0.401	0.417	0.430	0.438
P ₁	0.407	0.418	0.470	0.502
P ₂	0.413	0.423	0.470	0.499
S.Em±	0.004			
CD (5%)	0.008			

Interaction effect between biofertilizers and phosphorus levels on phosphorus uptake in seed of chickpea

Data pertaining to the effect of biofertilizers and phosphorus levels on phosphorus uptake in seed (Table 4.15 and fig. 4.11) revealed that application of 60 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB treatment combination produced significantly highest phosphorus uptake in seed which was 56.68 per cent higher as compared to control and was at par with treatment combination of 80 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB.

Table 4.15: Interaction effect between biofertilizers and phosphorus levels on phosphorus uptake in seed of chickpea

Phosphorus levels (kg P ₂ O ₅)	Cultures			
	C ₀	C ₁	C ₂	C ₃
P ₀	4.99	5.64	5.92	6.21
P ₁	5.65	7.08	8.45	9.76
P ₂	5.76	7.33	8.36	9.73
S.Em±	0.13			
CD (5%)	0.29			

4.4 POST HARVEST AVAILABILITY OF NUTRIENTS

4.4.1 Organic carbon

Effect of biofertilizers

A perusal of data given in table 4.16 indicated that seed treatment with *Rhizobium* + PSB recorded the maximum organic carbon and registered significant increase of 18.18, 5.40 and 3.17 per cent over control, *Rhizobium* and PSB alone treatments, respectively. Seed inoculation with *Rhizobium* and PSB alone being at par with each other had also significant effect on organic carbon content in soil over control.

Effect of phosphorus

Data in table 4.16 revealed that all the phosphorus levels recorded significantly higher organic carbon content in soil over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased organic carbon over control which was 14.97 per cent higher but remained at par with 80 kg P₂O₅ ha⁻¹.

4.4.2 Available nitrogen

Effect of biofertilizers

An appraisal of data (Table 4.16 and fig. 4.17) further showed that available nitrogen increased significantly due to seed treatment with biofertilizers over control. Dual inoculation of *Rhizobium* + PSB increased maximum available nitrogen but remained statistically at par with *Rhizobium* and PSB alone. The magnitude of increase by dual inoculation (*Rhizobium* + PSB) over control was 34.47 per cent. Seed inoculation with *Rhizobium* and PSB alone being at par with each other also had significant effect on available nitrogen in soil over control.

Effect of phosphorus

A perusal of data presented in table 4.16 further revealed that all the phosphorus levels recorded significantly higher available nitrogen over control. Application of 80 kg P_2O_5 ha⁻¹ significantly increased available nitrogen by 35.03 and 5.98 per cent over control and 60 kg P_2O_5 ha⁻¹.

4.4.3 Available phosphorus

Effect of biofertilizers

Data presented in table 4.16 and fig. 4.18 showed that dual inoculation of *Rhizobium* + PSB increased the available phosphorus significantly by 14.05, 11.37 and 2.57 per cent over control, *Rhizobium* and PSB alone, respectively. Inoculation with PSB alone also recorded significantly higher available phosphorus over control. The magnitude of increase in available phosphorus noted due to PSB alone was 11.18 per cent over control.

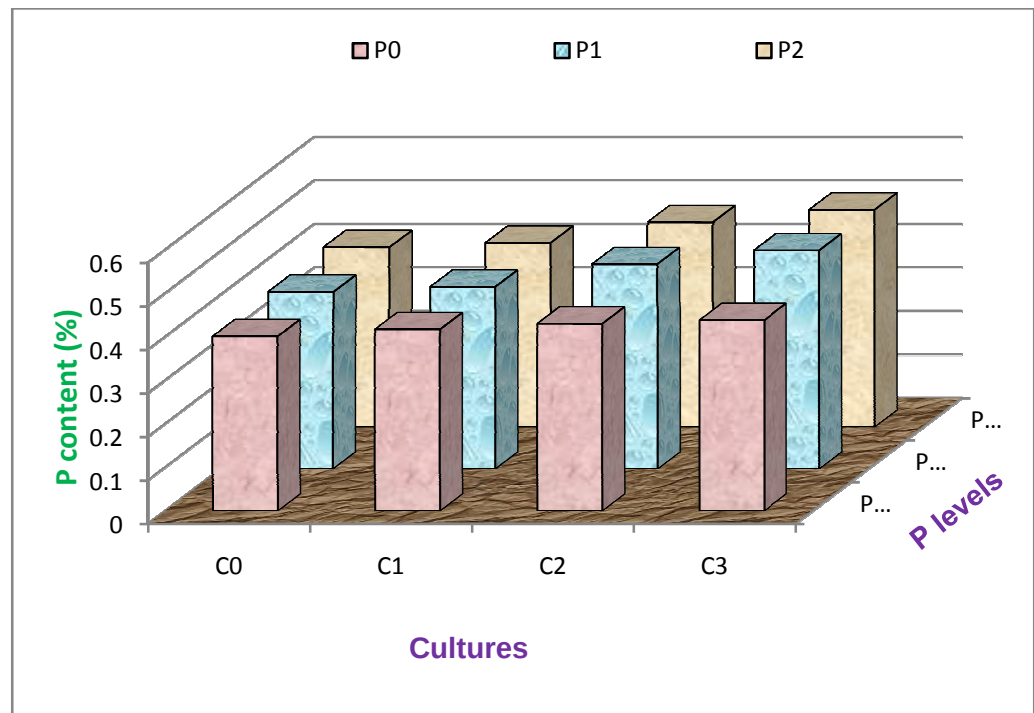


Fig. 4.10 Interaction effect between biofertilizers and phosphorus levels on P content of chickpea

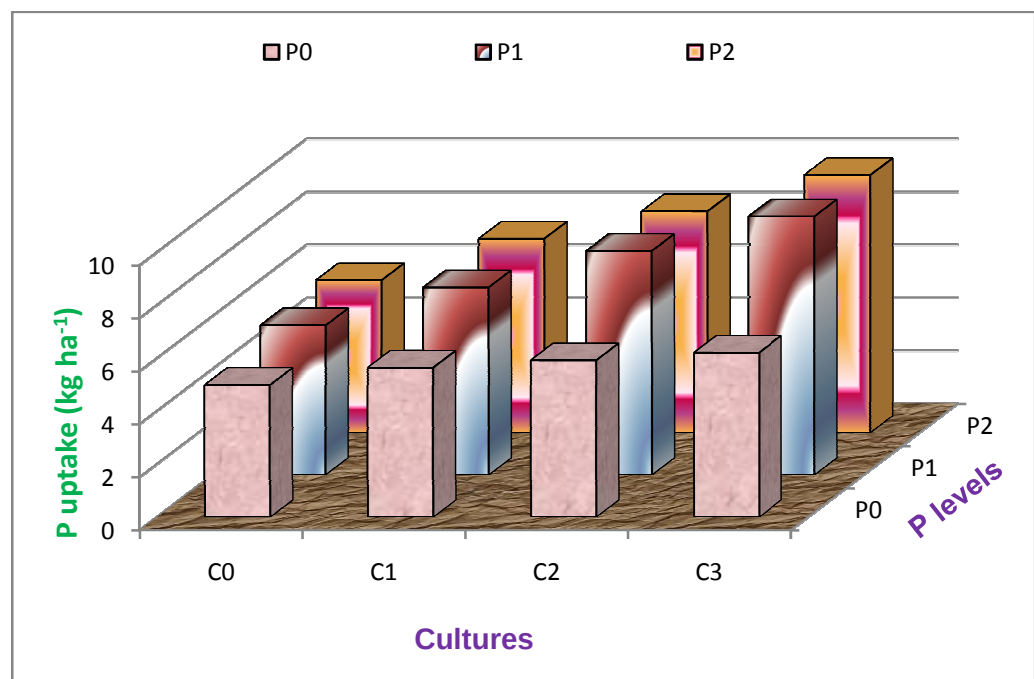


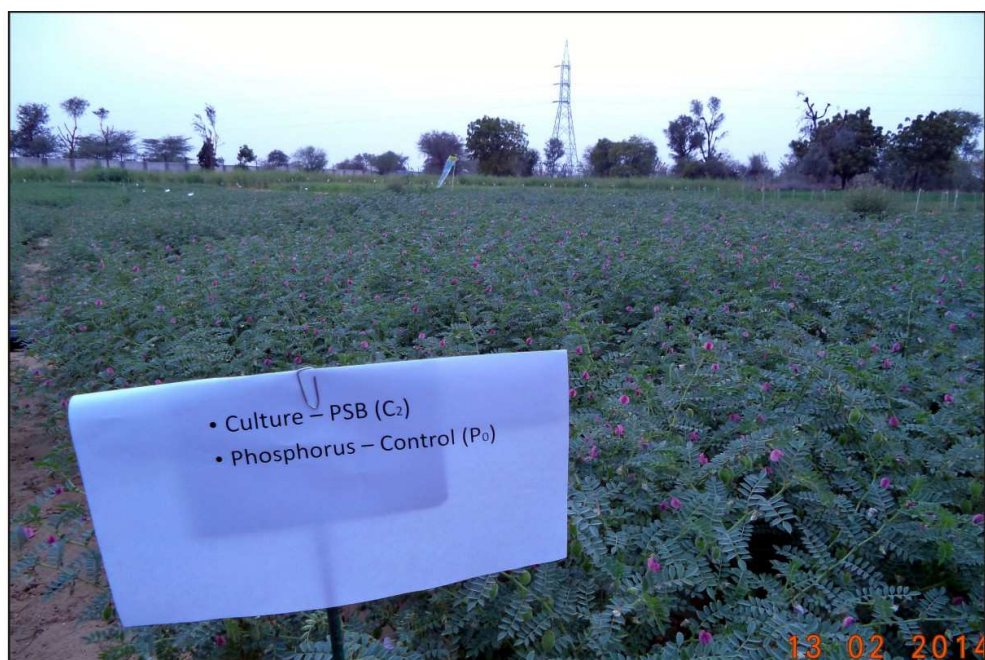
Fig. 4.11 Interaction effect between biofertilizers and phosphorus levels on P uptake of chickpea



Picture 4.1 : Picture view of absolute control plot



Picture 4.2: Picture view of Rhizobium treated plot



Picture 4.3: Picture view of PSB treated plot



Picture 4.4: Picture view of *Rhizobium*+PSB+60 kg P₂O₅ ha⁻¹ treated plot

Table 4.16: Effect of biofertilizers and phosphorus levels on organic carbon, available nitrogen and phosphorus content in soil after harvest of chickpea

Treatments	Organic carbon (%)	Available nitrogen (kg ha⁻¹)	Available phosphorus (kg ha⁻¹)
Cultures			
C ₀	0.165	162.91	17.43
C ₁	0.185	215.09	17.85
C ₂	0.189	210.78	19.38
C ₃	0.195	219.08	19.88
S.Em±	0.002	7.60	0.18
CD (P=0.05)	0.005	18.59	0.46
Phosphorus levels (kg P₂O₅ ha⁻¹)			
P ₀	0.167	167.17	17.25
P ₁	0.192	212.99	19.31
P ₂	0.191	225.73	19.34
S.Em±	0.001	5.98	0.13
CD (P=0.05)	0.002	12.69	0.28

Effect of phosphorus

Data in table 4.16 revealed that all the phosphorus levels recorded significantly higher available phosphorus in soil after harvest of the crop over control. Application of 60 kg P₂O₅ ha⁻¹ significantly increased available phosphorus by 11.94 per cent over control but remained at par with 80 kg P₂O₅ ha⁻¹.

4.5 BIOLOGICAL ACTIVITY

4.5.1 Total bacteria count

Effect of biofertilizers

Further reference to data given in table 4.17 and fig. 4.14 indicated that seed treatment with *Rhizobium* + PSB recorded the maximum total bacteria count and registered significant increase of 141.46, 26.01 and 22.59 per cent over control, *Rhizobium* and PSB alone, respectively. Seed inoculation with PSB alone has significantly increased the total bacteria count by 2.79 per cent over *Rhizobium*.

Effect of phosphorus

Data in table 4.17 revealed that all the phosphorus levels recorded significantly higher total bacteria count over control. Application of 80 kg P₂O₅ ha⁻¹ significantly increased total bacteria count by 39.14 and 3.97 per cent over control and 60 kg P₂O₅ ha⁻¹.

4.5.2 Dehydrogenase activity

Effect of biofertilizers

Further reference to the data given in table 4.17 and fig. 4.12 indicated that seed treatment with *Rhizobium* + PSB recorded the maximum dehydrogenase activity and registered significant increase of 70.86, 33.46 and 25.84 per cent over control, *Rhizobium* and PSB alone, respectively. Seed inoculation with *Rhizobium* and PSB alone being at par with each other had also significant effect on dehydrogenase activity over control.

Effect of phosphorus

Data in table 4.17 revealed that all the phosphorus levels recorded significantly higher dehydrogenase activity over control. Application of 60 kg P_2O_5 ha⁻¹ significantly increased dehydrogenase activity over control which was 44.05 per cent higher but remained at par with 80 kg P_2O_5 ha⁻¹.

4.5.3 Alkaline phosphatase activity

Effect of biofertilizers

Further reference to data given in table 4.17 and fig. 4.13 indicated that seed treatment with *Rhizobium* + PSB recorded the maximum alkaline phosphatase activity and registered significant increase of 61.25, 50.78 and 16.66 per cent over control, *Rhizobium* and PSB alone, respectively. Seed inoculation with PSB alone has significantly increased alkaline phosphatase activity by 24.84 per cent over *Rhizobium*.

Effect of phosphorus

Data in table 4.17 revealed that all the phosphorus levels recorded significantly higher alkaline phosphatase activity over control. Application of 60 kg P_2O_5 ha⁻¹ significantly increased alkaline phosphatase activity over control which was 39.05 per cent higher but remained at par with 80 kg P_2O_5 ha⁻¹.

Table 4.17: Effect of Biofertilizers and phosphorus levels on total bacteria count, dehydrogenase activity and alkaline phosphatase activity at 60 DAS of chickpea

Treatments	Total bacteria count (10^7 CFU g ⁻¹ soil)	Dehydrogenase activity (μ g TPF g ⁻¹ soil h ⁻¹)	Alkaline phosphatase activity (μ g PNP g ⁻¹ soil h ⁻¹)
Cultures			
C ₀	77.66	3.408	7.580
C ₁	148.82	4.363	8.106
C ₂	152.98	4.627	10.477
C ₃	187.54	5.823	12.223
S.Em $\pm$	1.42	0.157	0.095
CD (P=0.05)	3.48	0.384	0.232
Phosphorus levels (kg P₂O₅ ha⁻¹)			
P ₀	114.01	3.518	7.602
P ₁	152.59	5.068	10.571
P ₂	158.65	5.080	10.616
S.Em $\pm$	1.17	0.132	0.047
CD (5%)	2.49	0.280	0.100

CFU = Colony formed unit

TPF = Tri phenyl formazane

PNP = p nitro phenol

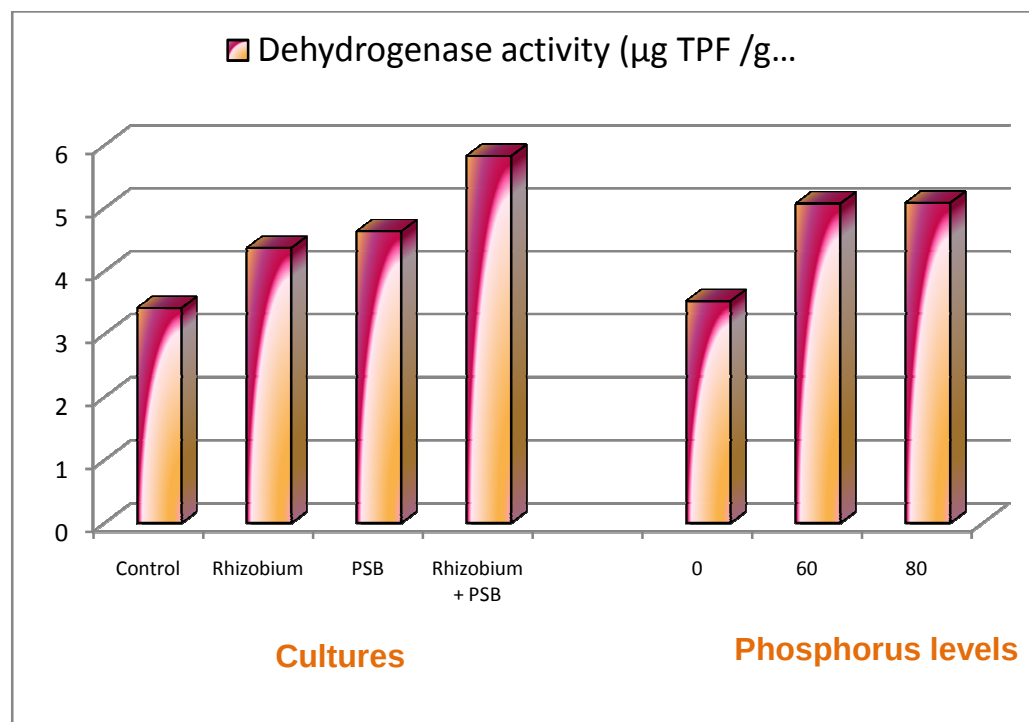


Fig. 4.12 Effect of biofertilizers and phosphorus levels on dehydrogenase activity on 60 DAS of chickpea

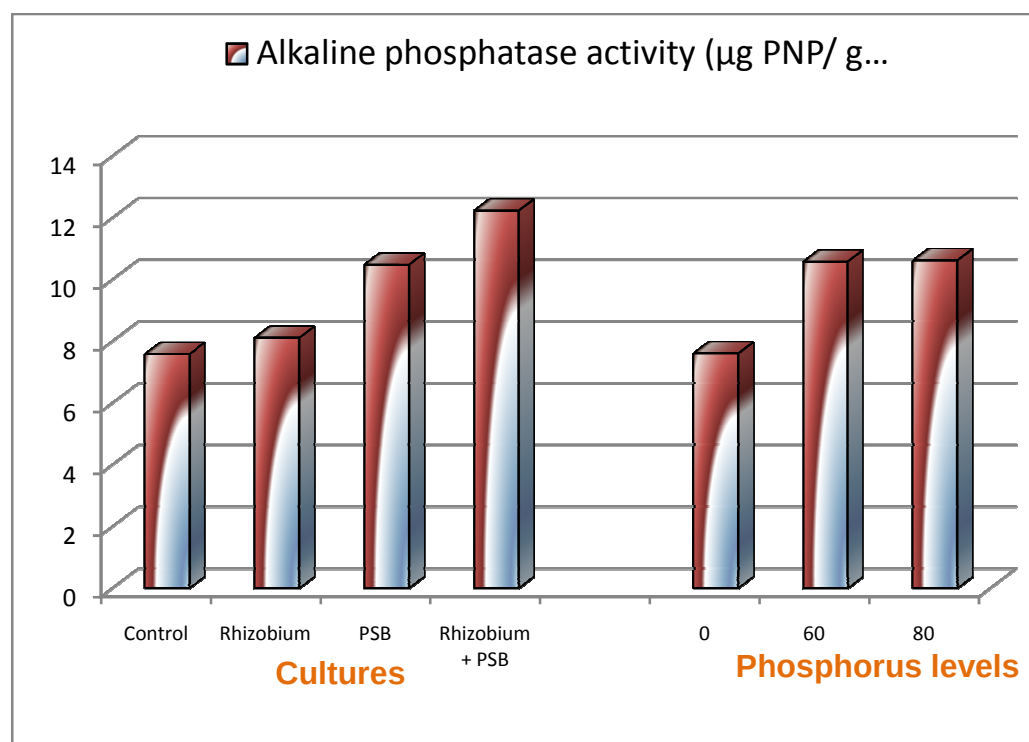


Fig. 4.13 Effect of biofertilizers and phosphorus levels on alkaline phosphatase activity on 60 DAS of chickpea

Interaction effect between biofertilizers and phosphorus levels on total bacteria count of chickpea

Data pertaining to the effect of biofertilizers and phosphorus levels on total bacteria count in soil (Table 4.18 and fig. 4.15) revealed that application of 80 kg P₂O₅ ha⁻¹ + seed inoculation with *Rhizobium* + PSB treatment combination produced significantly highest total bacteria count.

Table 4.18: Interaction effect between biofertilizers and phosphorus levels on total bacteria count of chickpea

Phosphorus levels (kg P ₂ O ₅)	Cultures			
	C ₀	C ₁	C ₂	C ₃
P ₀	76.25	106.05	114.70	159.07
P ₁	76.99	168.86	168.86	195.64
P ₂	79.76	171.56	175.37	207.90
S.Em±	2.35			
CD (5%)	4.99			

4.6 ECONOMICS

4.6.1 Net returns

Details of cost of cultivation for chickpea were worked out on the basis of prevailing market rates of inputs and labour during the crop growing period and market values of produce during the month of April 2014. In order to evaluate the economic feasibility of different treatments, the net returns (Rs ha⁻¹) was worked out and presented in table 4.19. The details of calculation of net return for each treatment are given in appendix.

Effect of biofertilizers

Inoculation of seed with single or dual biofertilizers brought a significant improvement in net returns of chickpea (Table 4.19). The maximum net returns (Rs 30393.29 ha⁻¹) was observed in seed inoculated with *Rhizobium* + PSB treatment and produced significantly higher net returns by 60.97, 17.88 and 13.22 per cent over control, *Rhizobium* and PSB alone, respectively.

Effect of phosphorus

A perusal of data (table 4.19) showed that net returns of chickpea increased significantly due to successive increase in varying levels of phosphorus upto 60 kg P₂O₅ ha⁻¹ and remained at par with 80 kg P₂O₅ ha⁻¹. Application of 60 kg P₂O₅ ha⁻¹ gave net returns (Rs 28728.21 ha⁻¹) and was significantly higher by 53.12 per cent over control.

4.6.2 B:C ratio

Effect of biofertilizers

Data presented in table 4.19 revealed that the seed inoculation either with *Rhizobium* or PSB increased the B:C ratio over control. The maximum B:C ratio 2.66 was obtained with dual inoculation of seed with *Rhizobium* + PSB over control, *Rhizobium* and PSB alone, respectively.

Effect of phosphorus

Data (Table 4.19) further indicated that the significantly increased B:C ratio 2.58 was obtained with application 60 kg P₂O₅ ha⁻¹ which was superior over control and was at par with 80 kg P₂O₅ ha⁻¹ treatment.

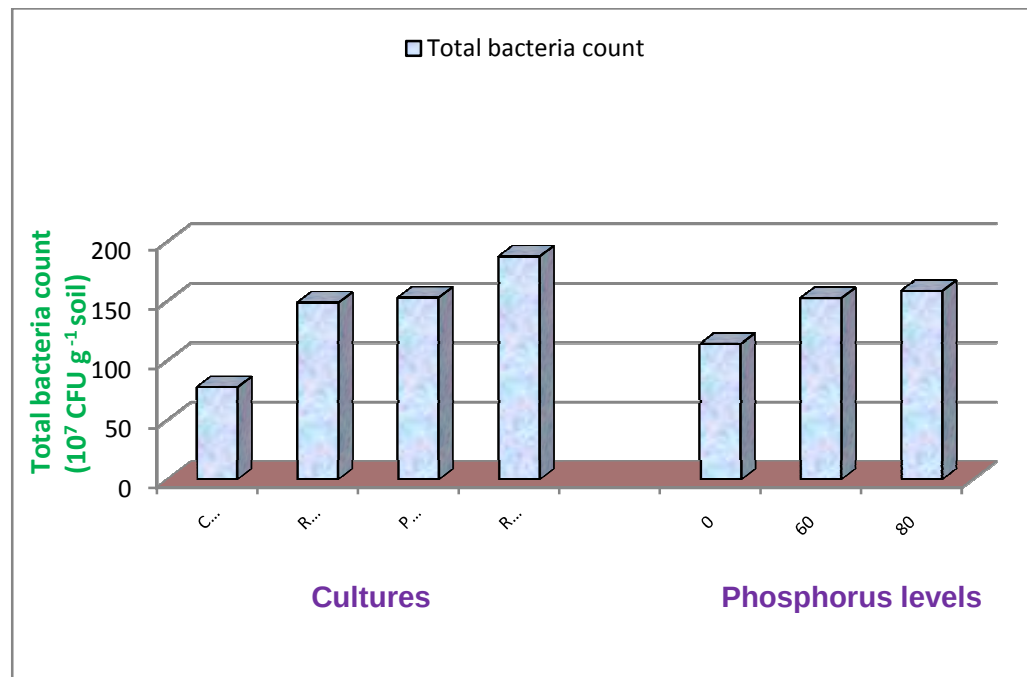


Fig. 4.14 Effect of biofertilizers and phosphorus levels on total bacteria count in soil of chickpea

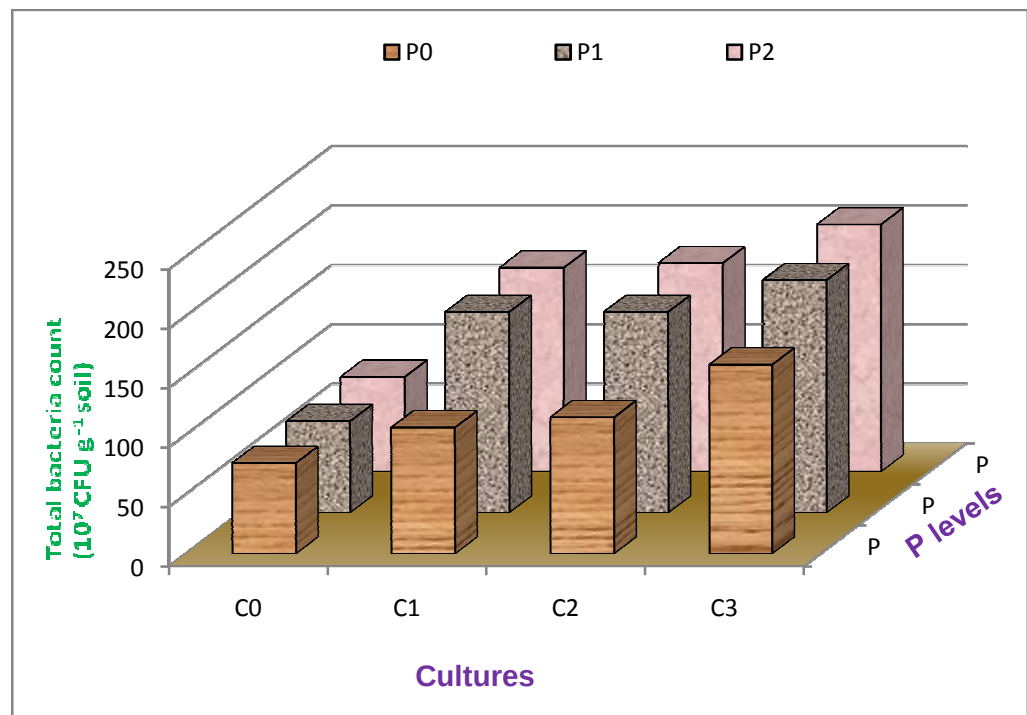


Fig. 4.15 Interaction effect between biofertilizers and phosphorus levels on total bacteria count in soil of chickpea

Table 4.19: Effect of biofertilizers and phosphorus levels on net returns and B:C ratio of chickpea.

Treatments	Net returns (Rs. ha ⁻¹)	B:C Ratio
Cultures		
C ₀	18880.55	2.04
C ₁	25781.66	2.42
C ₂	26842.29	2.47
C ₃	30393.29	2.66
S.Em±	462.21	0.02
CD (P=0.05)	1130.99	0.05
Phosphorus levels (kg P₂O₅ ha⁻¹)		
P ₀	18760.93	2.03
P ₁	28728.21	2.58
P ₂	28934.21	2.59
S.Em±	374.02	0.02
CD (5%)	792.89	0.04

Table 4.20: Seed yield (Y) as a function of phosphorus fertilization
($Y = b_0 + b_1P + b_2P^2$)

S. No.	Parameter	Phosphorus value
1.	Partial regression coefficient	
	b_0	1336
	b_1	10.41
	b_2	-0.071
2.	Coefficient of	
	Determination R^2	1
3.	Maximum level of nutrient	80.00
4.	Yield at maximum level (kg ha^{-1})	1770.46
5.	Optimum level of nutrient (kg ha^{-1})	70.16
6.	Yield at optimum level (kg ha^{-1})	1710.00

4.6.3 Optimum dose of phosphorus

In order to work out the optimum levels of phosphorus for cultivation of chickpea, a quadratic function for determining seed yield as a function of phosphorus fertilization was developed.

The functional relationship between seed yield and phosphorus was found to be as under:

$$Y = -0.071x^2 + 10.41x + 1336$$

The optimum levels of phosphorus worked out with the help of this production function came out to be $70.166 \text{ kg ha}^{-1}$ with optimum yield levels of 1710 kg ha^{-1} at the prevailing market prices (Table 4.20).

DISCUSSION

The results of the field experiment entitled “Impact of Biofertilizers and Phosphorus Levels on Biological Activity of Rhizosphere, Yield and Nutrient Uptake by Chickpea (*Cicer arietinum* L.)” have been presented in the preceding chapter. Only the significant variation observed in the data are being discussed in this chapter. Wherever available, the variations in the experimental results have also been compared with the findings of other workers. Since the information on the effect of biofertilizers on chickpea is meager, therefore, crops other than chickpea selected judiciously have also been considered to understand results.

5.1 Effect of biofertilizers

5.1.1 Growth parameters

Significant increase in plant height at harvest, number of root nodules at flowering stage and number of branches per plant and at harvest was observed due to seed inoculation with *Rhizobium* and PSB alone and their combined inoculation over control (Table 4.1 and 4.2). Seed inoculation with *Rhizobium* + PSB significantly increased plant height at harvest over control (Table 4.1) but *Rhizobium* and PSB remained at par. Number of viable root nodules at flowering stage increased significantly with *Rhizobium*, PSB and *Rhizobium* + PSB inoculation over control. Seed inoculation with *Rhizobium* alone has significantly increased the number of nodules over PSB alone (Table 4.2). Number of viable root nodules has also increased due to inoculation of seed with PSB or control. It might be due to that PSB has increased native P availability in the soil and hence, number of viable root nodules increased as compare to control but less than *Rhizobium* treatment. Number of branches per plant at harvest increased significantly with *Rhizobium*, PSB and *Rhizobium* + PSB inoculation over control but *Rhizobium* and PSB remained at par. Generally,

overall improvement in the crop growth under the influence of microbial fertilization i.e. *Rhizobium*, PSB and *Rhizobium* + PSB seems to be on account of their impact on nutritional environment and involvement in various physiological processes in the plant system which are considered to be prerequisites for growth of the crop.

It is an essential fact that inoculation of leguminous crop with effective and appropriate *Rhizobium* strain plays a pivotal role in fixation of atmospheric nitrogen in association with the crop. These micro-organisms enter in root of host plant and establish a synergistic relationship through fulfilling their requirement for carbohydrate and water for proper growth and development from plant system. On the other hand, nitrogen fixed by *Rhizobium* species is translocate to plant system through xylem vessels mainly in the form of aspergine and to some extent as glutathiamin. Thus, the results obtained in the investigation are in line with the findings of Sibbal *et al.* (2002), Patel and Kalyansundaram (2002), Singh *et al.* (2005) and Singh and Prasad (2008).

Phosphorus is associated with several vital functions and is responsible for many characteristics of plant growth. Inoculation with PSB enhances availability of P through solubilization of insoluble phosphorus is attributed to excretion of organic acids like glutamic, succinic, lactic, oxalic, glyoxalic, malic, fumaric, tartaric, citric, α -ketobutyric, propionic, formic and 2-ketogluconic acids.

The combined inoculation of *Rhizobium* and PSB has proved one of the most efficient inoculation in increasing growth parameters viz., plant height, branches/plant and number of root nodules per plant (Table 4.1 and 4.2) almost at all the phonological stages. *Rhizobium* and phosphate solubilizing micro-organisms improve the N and P status of soil. Dual inoculation might have contributed something towards enhanced plant growth and increased N or soluble P. Furthermore, some of the bacteria involved might be inter acting on

more metabolic level i.e. P solubilisers may also be auxin, indole acetic acid, gibberellins producers and N₂ fixers may also solubilize phosphorus. Increased nodulation under *Rhizobium* + PSB inoculation might be due to close association of both the microbial population and their activities resulting in improved nodulation. Thus, the results obtained in the investigation are in line with the findings of Jat and Ahalawat (2004), Shivakumar *et al.* (2004), Tyagi *et al.* (2003) and Karale and Kulkarni (2005).

5.1.2 Yield attributes and yield

Seed treatment with *Rhizobium*, PSB and *Rhizobium* + PSB significantly increased pods per plant, pods per branch, seed, and straw yield as well as biological yield and seed index over no inoculation (Table 4.4, 4.6 and 4.9). This might be due to the fact that *Rhizobium* inoculation increased the root nodulation through better root development and more nutrient availability, resulting in vigorous plant growth which resulted in better flowering, fruiting and pod formation and ultimately there was beneficial effect on seed yield.

The beneficial effect of phosphobacteria solubilize the insoluble phosphorus and rendering it available to plants for better growth and development. The regulatory function of phosphorus in photosynthesis and carbohydrate metabolism of leaves could be one of the major factors affecting plant growth, particularly during the reproductive phase. Thus, the increased availability of phosphorus and nitrogen along with other nutrients and increased chlorophyll content of leaves enhanced photosynthesis and production of assimilates and their partitioning to different reproductive structures (economic sinks) and helped to improve the yield attributes and ultimately the seed yield of chickpea. The increase in straw yield was the result of increased plant growth and development owing to improvement in overall nutritional environment in the rhizosphere. These results get support from the

findings of Ramesh and Sabale (2001), Singh *et al.* (2004), Shil (2007) and Kumari (2009).

Overall improvement in the crop growth under the influence of microbial fertilization i.e. *Rhizobium*, PSB and *Rhizobium* + PSB seems to be on account of their impact on nutritional environment and involvement in various physiological processes in the plant system which are considered to be prerequisite for growth of the crop. Better nodulation in dual inoculation might be due to increased P availability through PSB and enhanced biological N₂ fixation through *Rhizobium*. Synergism in *Rhizobium* and PSB might have also resulted in better nodulation with their dual inoculation as against single inoculation (Singh and Prasad 2008). Seed treatment with *Rhizobium*, PSB and *Rhizobium* + PSB significantly increased pods per plant, seed, and straw yields as well as biological yield over no inoculation. This might be due to the fact that *Rhizobium* inoculation increased the root nodulation through better root development and more nutrient availability. This caused vigorous plant growth and dry matter production which resulted in better flowering, fruiting and pod formation. Ultimately there was beneficial effect on seed yield. Since the available P was low in experiment field, PSB might have helped in reducing P fixation by its chelating effect and also solubilized the unavailable form of P leading to more uptakes of nutrients and reflected in better growth attributes viz., pods per plant. The increase in seed and straw yield is due to the cumulative effect of increased growth and yield attributes. The results obtained in the investigation are in line with the findings of Pramanik and Singh (2003) and Thenua *et al.* (2010). The synergistic effect of *Rhizobium* and PSB might have increased the growth, yield attributes and ultimately the yield in present investigation due to increased nitrogenase activity and available P status of soil. Similar findings were also reported by Vimla and Natarajan (2000), Meena *et al.* (2001), Jat and Ahalawat (2004), Shivakumar *et al.* (2004) and Singh *et al.* (2005).

5.1.3 Nutrient content, uptake and quality

Seed inoculation with *Rhizobium*, PSB and *Rhizobium* + PSB significantly enhanced N and P content and their uptake in seed and straw and protein content in seed over untreated control. Inoculation with *Rhizobium* + PSB recorded the maximized content and uptake and found superior to control, PSB and *Rhizobium* alone (Table 4.10 and 4.12). The inoculation of seeds with *Rhizobium* increased the N and P contents in seeds as well as straw. This may be due to more nitrogen fixation by the bacteria which in turn helped in better absorption and utilization of all the plant nutrients, thus resulting in more N and P content in seed and straw and protein content in seed. Similar results have also been reported by Singh and Chauhan (2005) and Singh and Prasad (2008). The inoculation with PSB helps in releasing P from native as well as protecting fixation of added phosphate and rendered more available P for the plants leading to increased nutrient content of the plant. These results are in close conformity with findings of Meena *et al.* (2004). The combined inoculation of *Rhizobium* + PSB was more beneficial in enhancing N and P content due to more nitrogen fixation by *Rhizobium* and solubilizing native phosphorus by PSB and thus making the nutrients available to plants. The uptake of N and P might have increased due to increased content and biological yield with the use of biofertilizers. The results obtained in this study are in accordance with those of Meena (1997), El. Sayed (1999), Meena *et al.* (2001) and Shivakumar *et al.* (2004).

5.1.4 Soil nutrient status

Significant increase in organic carbon, available N and P was observed due to seed inoculation with *Rhizobium* and PSB alone and their combined inoculation over control (Table 4.15). It plays a vital role in nitrogen and phosphorus nutrition by enhancing its availability to plants. It has been reported by various researchers that the P supplied

through rock phosphate and inoculated with PSB, *Rhizobium* and VAM increased the N and P content of soil. PSB and VAM application over respective level of P enhanced the availability of different fraction of inorganic-P in soybean crop. Phosphorus is available to plant through release from inorganic and organic soil P pools by solubilisation and mineralization. Principal mechanism in soil for mineral phosphate solubilisation is lowering of soil pH by microbial production of organic acids and mineralization of organic P by acid phosphates. The available P content in soil higher with the treatment of combined applications of biofertilizers is due to physico-chemical release of inorganic and organic phosphorus by organic acids through the action of low molecular weight organic anions such as oxalate which can replace phosphorus sorbed at metal hydroxide surfaces through ligand exchange reactions and dissolve metal oxide surfaces that sorb phosphorus (Fox *et al.*, 1990). The organic acids released during decomposition of organic influence pH from stable complexes or chelates with cations responsible from P fixation, then increase P availability.

5.1.5 Biological activity

Significant increase in total bacteria count, dehydrogenase activity and alkaline phosphatase activity were observed due to seed inoculation with *Rhizobium* and PSB alone and their combined inoculation over control (Table 4.16). Seed treatment with biofertilizer had their significant effect on microbial population in conjunction with P application (Sarawgi *et al.*, 2012). Jagtap and Utpal (2013) stated that after application of agrochemicals at 1, 30 DAS and at harvest the total number of fungi, bacteria, actinomycetes, *Pseudomonas*, *Azotobacter*, *Rhizobium* were counted. The result with regard to bacterial population in soybean field was significantly influenced by bioinoculant viz., *Rhizobium*. *Rhizobium* soil inoculation improved shoot dry weight and nodulation status (Nodules number and weight/plant), nitrogenase (N₂-

ase) activity of peanut roots and enhanced microbial (bacterial and fungal) counts and dehydrogenase (DHA) enzyme activity in rhizosphere soil of peanut after 50 and 80 days from planting compared to the untreated control (Khalifa *et al.*, 2013). The activity of dehydrogenase basically depends on the metabolic state of the soil biota. It is significantly correlated with soil biomass carbon in organic amended soil (Garcia-Gill *et al.* 2000). Several studies showed negative correlations between available P and phosphatase activities (Moscatelli *et al.*, 2005). Tadano *et al.* (1993) stated that P cycle enzyme activities are inversely related to P availability and when P is a limiting nutrient, its demand increases resulting in an increase in phosphatase activity. In general, alkaline phosphatase activity was higher with the treatment with higher amount of available phosphorus. (Spier and Ross, 1978). Higher alkaline phosphatase activity would promote the rate of hydrolysis of organic phosphorous compounds and thus more inorganic phosphorus would be formed.

5.1.6 Economics

Seed inoculation with *Rhizobium* + PSB significantly fetched higher net returns (Rs 30393.29 ha⁻¹) over control, *Rhizobium* and PSB alone (Table 4.18). As net return is calculated by multiplying the seed and straw yields by their sale prices and subtracting the cost of cultivation including treatment cost. As the price of biofertilizers is very low (Rs 10.0 per packet for *Rhizobium* or PSB) in comparison to the added output, hence individual as well combined inoculation of seed with *Rhizobium* and PSB was found profitable over uninoculated control, therefore, dual inoculation of seed with *Rhizobium* + PSB led to the maximum returns as it provided a B:C ratio of 2.66. Das *et al.* (2013) has also reported a higher net return (22247 ha⁻¹) and B:C ratio of (2.98) by seed inoculation with *Rhizobium* and PSB in chickpea crop.

5.2 Effect of phosphorus

5.2.1 Growth parameters

Phosphorus has long been recognized as an essential constituent of all living organisms which plays an important role in the conservation and transfer of energy in the metabolic reactions of living cells including biological energy transformations.

A significant effect of increasing levels of phosphorus up to 60 kg P₂O₅ ha⁻¹ was observed over control on the plant height (at harvest), and number of branches (primary and secondary) per plant at harvest, viable root nodules per plant at flowering stage (Table 4.1 and 4.2). This increase in growth parameters may be attributed to better nutritional environment for plant growth and development not only due to increased availability of phosphorus in soil but of other nutrients too, which are considered vitally important for growth and development. It might be obvious since phosphorus has long been considered as an essential constituent of all living organisms which plays an important role in conservation and transfer of energy in metabolic reactions of living cells including biological energy transformations. The overall improvement in crop growth under the influence of phosphorus application could be ascribed to better root development and proliferation and increased nitrogen fixation in the soil improving thereby the nitrogen status in the soil. The increase in photosynthetic activity in plant led to overall development in terms of growth. Thus, phosphorus fertilization enhanced the photosynthesis and other metabolic processes in the plant which ultimately enhanced growth in terms of number of branches per plant and chlorophyll content. Similar results have also been reported by Sharma and Singh *et al.* (1986), Rana and Singh (1998), Muhammad *et al.* (2005), Bhunia *et al.* (2006) Sammuria and Yadav (2008) and Singh *et al.* (2010).

5.2.2 Yield and yield attributes

Application of 60 kg P_2O_5 ha⁻¹ significantly increased the number of pods per plant, pods per branch, seeds per pod, seed, straw and biological yield of seed and seed index (Table 4.4, 4.6 and 4.9).

This might be attributed to the role of phosphorus in root development and proliferation, nodules formation and N_2 fixation by supplying assimilates to the roots. Since the soil status of phosphorus is low in experiment field, dose of phosphorus up to 60 kg P_2O_5 ha⁻¹ fulfilled the phosphorus requirement of crop. It is the main constituent of energy rich phosphate molecules viz. ATP and ADP which acts as “energy currency” within plants. Phosphorus influences photosynthesis, biosynthesis of protein and phospholipids, nucleic acid synthesis, membrane transports, energy transformation and cell division of the plant system. Increased availability of phosphorus due to its application in the soil which was otherwise poor in content improved the nutrient availability status resulting in to greater uptake of nutrient. The greater uptake of nutrients led to increased root and shoot development, nodulation, plant height, branching. Application of 60 kg P_2O_5 ha⁻¹ significantly increased the number of pods per plant, seeds per pod, and seed, straw and biological yield and seed index. The regulatory function of phosphorus in photosynthesis and carbohydrate metabolism of leaves can be considered to be one of major factor limiting growth particularly during the reproductive phase. The favorable influence of phosphorus on yield attributes could be attributed to the overall improvement in crop growth as reflected by plant height, number of branches and root nodulation. Adequate phosphorus resulted in proper supply of photosynthates and nutrient. Synchronized with the demand of crop for formation of more reproductive structure and thus might have favored the yield attributes viz. number of pod per plant, number of seed per pod and seed index. These results are in agreement to the findings of Kumar and Singh (2004). The significant increase in seed

yield of chickpea due to phosphorus application was largely a function of improved growth and the consequent increase in different yield attributes. The significant increase in straw yield due to application of phosphorus could be attributed due to the increased vegetative growth, possibly a result of the effective uptake and utilization of nutrients absorbed through its extensive root system development under phosphorus fertilization. The biological yield is a function of seed and straw yield. Thus, a significant increase in biological yield with the application of phosphorus could be attributed to the increased grain and straw yield. These results are in agreement to the findings of Kumpawat and Manohar (1994a), Lakpale *et al.* (2003) and Kumar and Singh (2004), Jat and Ahalawat (2004) and Singh and Chauhan (2005).

5.2.3 Nutrient content, uptake and quality

Percent nitrogen content and uptake in seed and straw at harvest significantly increased with the application of phosphorus @ 60 kg P_2O_5 ha⁻¹ (Table 4.10). Better root development and increased *Rhizobium* multiplication resulted in better utilization of soil and atmospheric nitrogen with the increasing levels of phosphorus and thereby nitrogen content of seed increased. A significantly increasing trend of phosphorus content and uptake in seed and straw were up to 60 kg P_2O_5 ha⁻¹ at harvest of crop was recorded (Table 4.12). This might be due to improved nutritional environment in the rhizosphere as well as in the plant system leading to enhanced translocation especially of N and P to reproductive structures viz. pods and seeds. Since uptake is the function of seed and straw yield as well as their nutrient content, the significant increase in content of the nutrients coupled with increased seed and straw yield increased the uptake of N and P substantially. These results are in agreement with that of Bahl and Singh (1997), Kasturikrishna and Ahalawat (1999), Jat and Ahalawat (2004) and Tiwari *et al.* (2005). The protein content increased

significantly with increasing levels of phosphorus upto 60 kg P₂O₅ ha⁻¹ (Table 4.10). Better root development and increased *Rhizobium* multiplication resulted in better utilization of soil and atmospheric nitrogen with the increasing levels of phosphorus and thereby nitrogen content of seed increased. The reason behind the improvement of protein content might be that it is a function of nitrogen content, phosphorus being an energy source also plays an important role in protein synthesis. Similarly, fertilization with phosphorus enhanced the protein content in seed, which may be due to more protein synthesis in the presence of phosphorus and the formation of some stable phosphoprotein compounds. These results are in close conformity with the findings of Kanwar and Poliyal (2002), Jat *et al.* (2006), Dutta (2008) and Deo and Khaldelwal (2009).

5.2.4 Soil nutrient status

Increasing levels of phosphorus application upto 60 kg P₂O₅ ha⁻¹ significantly increased organic carbon and available P in soil after harvest of chickpea, whereas, availability of N were affected significantly upto 80 kg P₂O₅ ha⁻¹. This could be due to the fact that ample supply of phosphorus in soil provides a congenial environment in rhizosphere for vigorous root growth and microbial population that might have increased the organic carbon and available N in soil. As expected, the P availability in soil after harvest of chickpea increased significantly due to increased addition of P, as only a part of it was utilized by the crop and a part of the remaining P contributed to its available pool of the soil. Besides, on addition of fertilizer to the soil, there might be a sort of triggering action on native soil P, resulting in increased availability. In alkaline soils phosphatase activities are enhanced which also led to increase phosphorus availability. Similar findings were reported by Patel (1988), Sharma and Sinha (1989), Enania and Vyas (1994), Jakhar (1997), Bahl and Singh (1997), Panwar (1997) and Khoja *et al.* (2002).

5.2.5 Biological activity

Increasing levels of phosphorus application upto 60 kg P_2O_5 ha⁻¹ significantly increased dehydrogenase activity and alkaline phosphatase activity in soil after 60 DAS of chickpea, whereas, total bacteria count affected significantly upto 80 kg P_2O_5 ha⁻¹ over control and 60 kg P_2O_5 ha⁻¹. Wen-Hui *et al.* (2007) in a long term field experiment applied different rates of inorganic fertilizers to the rice crop and found significant higher enzymes (dehydrogenase) activities by the application of mineral fertilizers. On an average, they recorded 43 % increase in dehydrogenase activity when the combined dose of NPK was applied. They further observed that the dehydrogenase activity was influenced by both P and N applications. Alkaline phosphatase activity is largely related to the concentration of soil phosphorus (Zebrowska *et al.*, 2008). Typically, soil phosphatase activity is inversely proportional to the amount of mineral phosphorus in the soil, because low levels of inorganic phosphorus in the soil increased activity of phosphatase. A significant effect of nitrogen fertilization on the activity of alkaline phosphatase in the soil was found. Increasing the nitrogen dose resulted in decreased activity of alkaline phosphatase activity. Phosphorus deficiency is generally cited the reason for increased phosphatase activity in the rhizosphere with the growth of many species (Tabatabai , 1982; Tadano *et al.* , 1993; Tarafdar and Marschner, 1994). Tadano *et al.* (1993) demonstrated enhanced phosphatase activity in P deficient conditions with the growth of soybean, lupine, rice, wheat, radish, cabbage, tomato and sugarbeat. In our study, we found increased alkaline phosphatase activities (61.25%) in the rhizosphere soil compared to non-rhizosphere soil.

5.2.6 Economics

Application of increasing levels of phosphorus up to 60 kg P₂O₅ ha⁻¹ gave significantly higher net returns (Rs 28728.21) and B:C ratio (2.58) over control (Table 4.18). This increase in net return is due to the fact that seed and straw yield were also significantly higher with 60 kg P₂O₅ ha⁻¹ as compared to rest of the treatments. This increase in the net return due to application of increasing levels of phosphorus also has been reported by Bhunia *et al.* (2006), Dutta *et al.* (2008) and Singh *et al.* (2010).

SUMMARY AND CONCLUSION

A field experiment entitled “Impact of Biofertilizers and Phosphorus levels on Biological Activity of Rhizosphere, Yield and Nutrient uptake by chickpea (*Cicer arietinum* L.)” was conducted in the loamy sand soil of Agronomy Farm, College of Agriculture, Bikaner during *Rabi*, 2013-14. The experiment comprising four levels of biofertilizers and three levels of phosphorus was carried out in split plot design with three replications. The salient findings presented and discussed in preceding chapters have been summarized in this chapter.

6.1 Effect of biofertilizers

- 6.1.1 Biofertilizers could not exert significant effect on plant stand at harvest indicating a uniform plant population in all the plots.
- 6.1.2 Dual inoculation with *Rhizobium* + PSB significantly increased the plant height at harvest and number of primary and secondary branches per plant at harvest over control, but *Rhizobium* and PSB alone remained at par with *Rhizobium* + PSB. Number of viable root nodules per plant at flowering stage was significantly increased with *Rhizobium* + PSB over control, *Rhizobium* and PSB alone.
- 6.1.3 Significantly higher number of pods per plant and pods per branch were obtained due to dual inoculation of *Rhizobium* + PSB over control, *Rhizobium* and PSB alone. *Rhizobium* and PSB alone remained at par in number of pods per plant. Biofertilizers could not exert significant effect on number of seeds per pods.
- 6.1.4 Inoculation of seed with *Rhizobium* + PSB induced significant increase in the seed, straw and biological yields over no

inoculation, *Rhizobium* and PSB alone. However, *Rhizobium* and PSB alone remained at par in straw and biological yield.

- 6.1.5 Inoculation of seed with *Rhizobium* + PSB induced significant increase in the seed index over no inoculation, *Rhizobium* and PSB alone. However, *Rhizobium* and PSB alone remained at par.
- 6.1.6 Biofertilizers could not exert significant effect on harvest index.
- 6.1.7 Chickpea seeds treated with either *Rhizobium* or PSB inoculation or dual inoculation of *Rhizobium* + PSB showed significantly higher N and P content in seed and straw, protein content in seed and uptake of N and P by seed and straw over control.
- 6.1.8 Seeds treated with either *Rhizobium* or PSB inoculation or dual inoculation of *Rhizobium* + PSB showed significantly higher organic carbon, available N and P over control. While, *Rhizobium* and PSB inoculation alone proved equally effective in organic carbon and available N content in soil after harvesting of chickpea.
- 6.1.9 Inoculation of seed with *Rhizobium* + PSB induced significant increase in the total bacteria count, dehydrogenase activity and alkaline phosphatase activity over no inoculation, *Rhizobium* and PSB alone but *Rhizobium* and PSB alone remained at par in dehydrogenase activity.
- 6.1.10 Seed inoculation with *Rhizobium* + PSB fetched net returns of Rs. 30393.29 ha⁻¹ with the B:C ratio 2.66, which was significantly higher over control, *Rhizobium* and PSB alone. Inoculation of seed with *Rhizobium* and PSB alone remained at par to each other.

6.2 Effect of phosphorus levels

- 6.2.1 Plant stand was not influenced significantly due to phosphorus levels at any stage of plant growth.
- 6.2.2 Plant height at harvest increased significantly by application of 60 kg P_2O_5 ha⁻¹ over control.
- 6.2.3 Number of primary and secondary branches per plant at harvest significantly increased by the application of 60 kg P_2O_5 ha⁻¹ over control.
- 6.2.4 Number of viable root nodules per plant at flowering stage significantly increased by the application of 60 kg P_2O_5 ha⁻¹ over control.
- 6.2.5 Increased levels of phosphorus up to 60 kg P_2O_5 ha⁻¹ significantly increased the number of pods per plant and pods per branch of chickpea over control. Number of seeds per pod was not influenced significantly due to phosphorus levels.
- 6.2.6 The seed, straw and biological yield of chickpea increased significantly due to application of 60 kg P_2O_5 ha⁻¹ as compared to control.
- 6.2.7 Increased levels of phosphorus up to 60 kg P_2O_5 ha⁻¹ significantly increased the seed index of chickpea over control.
- 6.2.8 Harvest index was not influenced significantly due to different phosphorus levels.
- 6.2.9 Application of phosphorus significantly increased the N and P content in seed and straw and N and P uptake in seed and straw up to 60 kg P_2O_5 ha⁻¹ over control.
- 6.2.10 The protein content in seed significantly increased by the application of 60 kg P_2O_5 ha⁻¹ over control.
- 6.2.11 Application of phosphorus significantly increased the organic carbon and available P up to 60 kg P_2O_5 ha⁻¹ over control but

available N significantly increased up to 80 kg P_2O_5 ha⁻¹ over control and 60 kg P_2O_5 ha⁻¹.

6.2.12 Increased levels of phosphorus up to 80 kg P_2O_5 ha⁻¹ significantly increased the total bacteria count at 60 DAS of chickpea over control and 60 kg P_2O_5 ha⁻¹ but dehydrogenase and alkaline phosphatase activity significantly increased up to 60 kg P_2O_5 ha⁻¹ over control.

6.2.13 Application of 60 kg P_2O_5 ha⁻¹ significantly increased the net returns of Rs 28728.21 ha⁻¹ with B:C ratio 2.58 over control.

6.2.14 The optimum level of phosphorus was worked out from the production function was 70.16 kg P_2O_5 ha⁻¹.

Conclusion

On the basis of one year experimentation, it may be concluded that yield of chickpea can be maximized by combined application of 60 kg P_2O_5 ha⁻¹ along with seed inoculation *Rhizobium* + PSB on loamy sand soils of zone IC (Hyper Arid Partially Irrigated Western Plains). This treatment combination resulted in the maximum seed yield of 1770.46 kg ha⁻¹ and net returns of Rs 30393.29 ha⁻¹ with the B: C ratio 2.66.

However, these results are only indicative and require further experimentation for confirmation before making final recommendation to the farmers.

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Impact of Biofertilizers and Phosphorus Levels on Biological Activity of Rhizosphere, Yield and Nutrient Uptake by Chickpea (*Cicer arietinum* L.)

Neha Bharti*
(Scholar)

Dr. Yogesh Sharma**
(Major Advisor)

ABSTRACT

A field experiment was conducted on chickpea during *Rabi*, 2013-14 at Agronomy farm, College of Agriculture, Bikaner. The soil of the experimental field was loamy sand in texture, alkaline in reaction (pH 8.15), low in organic carbon (0.08%), available nitrogen (87.72 kg ha⁻¹), available phosphorus (20.72 kg ha⁻¹) and potassium (164.14 kg ha⁻¹). The treatment comprised of four levels of biofertilizers [Control (C₀), *Rhizobium* (C₁), PSB (C₂) and *Rhizobium* + PSB (C₃)] and three levels of phosphorus (0, 60 and 80 kg P₂O₅ ha⁻¹). The 12 treatments combinations were laid out in split plot design and replicated three times.

The results indicated that the dual inoculation of *Rhizobium* and PSB significantly enhanced the plant height at harvest, branches (primary and secondary) per plant, number of viable root nodules per plant at flowering stage, number of pods per plant, number of pods per branch, seed yield (1770.46 kg ha⁻¹), straw yield (2360.46 kg ha⁻¹), biological yield (4130.92 kg ha⁻¹), seed index, N and P content in seed, straw and uptake, protein content in seed, organic carbon, available N and P in soil, total bacteria count, dehydrogenase and alkaline phosphatase activity over no inoculation and *Rhizobium* or PSB inoculation alone. Seed inoculation with *Rhizobium* + PSB significantly gives higher net return (Rs 30393.29 ha⁻¹) and B: C ratio (2.66).

* Post graduate student, Department of Soil science and Agricultural Chemistry, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner – 334 006.

** Professor, Department of Soil science and Agricultural Chemistry, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner – 334 006.

Increasing levels of phosphorus up to 60 kg P_2O_5 ha⁻¹ significantly increased the plant height and number of branches (primary and secondary) per plant at harvest, number of viable root nodules per plant at flowering stage, pods per plant, pods per branch, seed yield (1703.13 kg ha⁻¹) straw yield (2225.56 kg ha⁻¹), biological yield (3928.70 kg ha⁻¹), seed index, N and P content in seed and straw and uptake, protein content in seed, organic carbon, available N and P, total bacteria count, dehydrogenase and alkaline phosphatase activity over control. Significantly higher net return (Rs 28728.21 ha⁻¹) and B: C ratio (2.58) was recorded due to application of 60 kg P_2O_5 ha⁻¹.

जैव उर्वरक एवं फॉस्फोरस स्तर का राइजोस्फेयर की जैविक क्रिया और चने (साईसर अराईटिनम एल.) की उपज एवं पोषक तत्व उद्ग्रहण पर प्रभाव

नेहा भारती*
(शोधकर्ता)

डॉ. योगेश शर्मा**
(मुख्य सलाहकार)

अनुक्षेपण

कृषि महाविद्यालय, बीकानेर के शस्य प्रक्षेत्र पर रबी 2013-14 के दौरान एक प्रयोग किया गया। प्रायोगिक प्रक्षेत्र की मृदा कण में दोमट बलुई, स्वभाव में क्षारीय (पी.एच-8.15) तथा कार्बनिक पदार्थ (0.08%), उपलब्ध नत्रजन (87.72 किग्रा प्रति है.), फॉस्फोरस (20.72 कि.ग्रा. प्रति है.) व पोटाश (164.14 कि.ग्रा. प्रति है.) में न्यून पाई गई। जैव उर्वरक के चार स्तर (नियंत्रित, राइजोबियम फॉस्फेट विलायक जीवाणु और राइजोबियम + फॉस्फेट विलायक जीवाणु) एवं फॉस्फोरस के तीन स्तर (0, 60 तथा 80 कि.ग्रा. प्रति है.), 12 उपचार संयोजन बनाकर खण्डित भूखण्ड परिकल्पना में तीन बार पुनरावृत्ति की गई।

परिणामों से ज्ञात हुआ कि राइजोबियम एवं फॉस्फेट विलायक जीवाणु के सम्मिलित बीज संचरण के प्रयोग से कटाई के समय पौधों की ऊँचाई, प्रति पौधा शाखाओं (प्राथमिक व द्वितीयक) की संख्या, फूल खिलने की अवस्था पर प्रति पौधा जड़ों में जीवंत गांठों की संख्या, प्रति पौधा फलियों की संख्या, प्रति शाखा फलियों की संख्या, बीज उपज (1770.46 कि.ग्रा. प्रति है.), भूसा उपज (20360.46 कि.ग्रा. प्रति है.) और कुल भार उपज (4130.92 कि.ग्रा. प्रति है.) बीज सूचकांक, नत्रजन और फॉस्फोरस की बीज व भूसे में मात्रा और उनके उद्ग्रहण, बीज में प्रोटीन की मात्रा, मृदा में कार्बनिक पदार्थ, उपलब्ध नत्रजन एवं फॉस्फोरस तथा कुल जीवाणु संख्या, डी-हाइड्रोजेनेज एवं क्षारीय फॉस्फेटेज क्रिया बिना बीज संचरण एवं राइजोबियम या फॉस्फेट विलायक जीवाणु की तुलना में सार्थक वृद्धि पाई गयी। राइजोबियम तथा फॉस्फेट विलायक जीवाणु के सम्मिलित संचरण से शुद्ध प्रतिफल (30393.29₹ प्रति है.) एवं लाभ : लागत अनुपात (2.66) में सार्थक वृद्धि हुई।

फॉस्फोरस के बढ़ते हुए स्तर 60 कि.ग्रा. प्रति है. तक के अनुप्रयोग से कटाई के समय पौधों की ऊँचाई, प्रति पौधा शाखाओं (प्राथमिक एवं द्वितीयक) की संख्या, फूल खिलने की अवस्था में

* कृषि स्नातकोत्तर छात्रा, मृदा विज्ञान एवं कृषि रसायन विभाग, कृषि महाविद्यालय, स्वामी केशवानन्द राजस्थान कृषि विश्वविद्यालय, बीकानेर 334006

** आचार्य, मृदा विज्ञान एवं कृषि रसायन विभाग, कृषि महाविद्यालय, स्वामी केशवानन्द राजस्थान कृषि विश्वविद्यालय, बीकानेर-334006

प्रति पौधा जड़ों में जीवंत गांठों की संख्या, प्रति पौधा फलियों की संख्या, प्रति शाखा फलियों की संख्या, बीज उपज (1703.13 कि.ग्रा. प्रति है.), भूसा उपज (2225.56 कि.ग्रा. प्रति है.), कुल भार उपज (3928.70 कि.ग्रा. प्रति है.), बीज सूचकांक, नत्रजन एवं फॉस्फोरस की बीज व भूसे में मात्रा व उनका उद्ग्रहण, बीज में प्रोटीन की मात्रा, मृदा में कार्बनिक पदार्थ, उपलब्ध नत्रजन व फॉस्फोरस तथा कुल जीवाणु संख्या, डी-हाइड्रोजिनेज एवं क्षारीय फॉस्फेटेज क्रिया नियंत्रित की तुलना में सार्थक वृद्धि पाई गई।

60 कि.ग्रा. प्रति है. फॉस्फोरस के अनुप्रयोग से शुद्ध लाभ (28728.21₹ प्रति है.)

और लाभ : लागत अनुपात (2.58) में सार्थक वृद्धि पाई गयी।

Appendix-I

Analysis of variance for plant stands and plant height at harvest of chickpea

Treatments	d.f.	Mean sum of squares	
		Plant stands (per meter row length)	Plant height (cm)
Replication	2	0.08	2.74
Culture (C)	3	0.12	124.36**
Error	6	0.04	0.64
Phosphorus (P)	2	0.09	224.07**
C X P	6	0.03	5.63**
Error (b)	16	0.07	0.73

Appendix-II

Analysis of variance for number of branches and nodule per plant of chickpea

Treatments	d.f.	Mean sum of squares		
		Number of branches per plant at harvest		Number of viable root nodules at flowering stage
		Primary	Secondary	
Replication	2	1.67	6.32	3.29
Culture (C)	3	10.64**	60.85**	2068.088**
Error	6	0.34	1.72	0.64
Phosphorus (P)	2	20.3**	84.08**	663.414**
C X P	6	0.93*	3.77*	67.513**
Error (b)	16	0.30	1.32	2.01

** and *Significant at 1% and 5% level of significance

Appendix-III

Analysis of variance for yield attribute characters of chickpea

Treatments	d.f.	Mean sum of squares		
		Number of pods per plant	Number of pods per branch	Number of seeds per pod
Replication	2	16.17	0.94	0.004
Culture (C)	3	1595.63**	18.14**	0.005
Error	6	3.296	0.02	0.002
Phosphorus (P)	2	2046.99**	23.718**	0.003
C X P	6	112.21**	1.09**	0.001
Error (b)	16	1.956	0.02	0.001

Appendix-IV

Analysis of variance for seed, straw and biological yield of chickpea

Treatments	d.f.	Mean sum of squares		
		Seed yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)
Replication	2	14159.87	40870.91	100361.77
Culture (C)	3	301950.13**	513541.44**	1599122.11**
Error (a)	6	1095.05	8442.42	14401.57
Phosphorus (P)	2	548162.47**	857205.91**	2773013.61**
C X P	6	22132.38**	45441.93**	129521.17**
Error (b)	16	1045.66	6761.57	10982.77

** and *Significant at 1% and 5% level of significance

Appendix-V

Analysis of variance for seed and harvest index of chickpea

Treatments	d.f.	Mean sum of squares	
		Seed index (g)	Harvest index (%)
Replication	2	6.72	0.540000
Culture (C)	3	40.5**	0.670000
Error	6	1.33	0.300000
Phosphorus (P)	2	39.43**	0.960000
C X P	6	2.16	0.210000
Error (b)	16	1.14	0.360000

Appendix-VI

Analysis of variance for nitrogen content, uptake in seed and straw and protein content in seed of chickpea

Treatments	d.f.	Mean sum of squares				
		Nitrogen content (%)		Nitrogen uptake (kg ha ⁻¹)		Protein content in seed (%)
		Seed	Straw	Seed	Straw	
Replication	2	0.036	0.002	48.56	6.94	1.38
Culture (C)	3	2.4**	0.16**	1583.26**	173.79**	93.81**
Error	6	0.002	0.00006	3.37	1.21	0.077
Phosphorus (P)	2	0.085**	0.008**	894.42**	89.7**	3.29**
C X P	6	0.007**	0.0004**	55.87**	6.36**	0.28**
Error (b)	16	0.002	0.0001	2.12	0.43	0.06

** and *Significant at 1% and 5% level of significance

Appendix-VII

Analysis of variance for phosphorus content and uptake in seed and straw of chickpea

Treatments	d.f.	Mean sum of squares			
		Phosphorous content (%)		Phosphorous uptake (kg ha ⁻¹)	
		Seed	Straw	Seed	Straw
Replication	2	0.0006	0.0002	0.93	0.75
Culture (C)	3	0.0105**	0.01**	15.66**	17.77**
Error	6	0.00004	0.00001	0.04	0.09
Phosphorus (P)	2	0.003**	0.01**	17.27**	22.37**
C X P	6	0.0007**	0.002**	1.49**	2.65**
Error (b)	16	0.00003	0.000009	0.02	0.068

Appendix-VIII

Analysis of variance for organic carbon, available N and P in soil of chickpea

Treatments	d.f.	Mean sum of squares		
		Organic carbon	Available N	Available P
Replication	2	0.0003	1239.49	3.28
Culture (C)	3	0.002**	6204.37**	12.57**
Error (a)	6	0.00001	259.98	0.16
Phosphorus (P)	2	0.003**	11382.55**	17.29**
C X P	6	0.00025**	290.14	1.11**
Error (b)	16	0.000008	215.17	0.1

** and *Significant at 1% and 5% level of significance

Appendix-IX

Analysis of variance for total bacteria count, dehydrogenase and alkaline phosphatase activity in soil of chickpea

Treatments	d.f.	Mean sum of squares		
		Total bacteria count	Dehydrogenase activity	Alkaline phosphatase activity
Replication	2	30.13	0.49	0.82
Culture (C)	3	19137.69**	8.89**	41.9**
Error (a)	6	9.13	0.11	0.04
Phosphorus (P)	2	7033.24**	9.67**	35.78**
C X P	6	788.05**	0.53**	1.68**
Error (b)	16	8.34	0.1	0.01

Appendix-X

Analysis of variance for net returns and B: C ratio of chickpea

Treatments	d.f.	Mean sum of squares	
		Net returns (Rs. ha ⁻¹)	B:C ratio
Replication	2	11279955.81	0.01
Culture (C)	3	208919557.9**	0.59**
Error (a)	6	961381.96	0.002
Phosphorus (P)	2	405769597.5**	1.2**
C X P	6	17202574.7**	0.05**
Error (b)	16	839365.6	0.003

** and *Significant at 1% and 5% level of significance

Appendix- XI

Cost of cultivation of chickpea

S.No.	Particulars of operation	Cost (Rs ha ⁻¹)	Inputs	Rate/unit (Rs.)
1.	Pre sowing irrigation including labour charges	800.00		
2.	Field preparation			
	i. Ploughing by disc plough	1400.00	Tractor drawn disc plough	1400.00 ha ⁻¹
	ii. Ploughing by harrow and planking	900.00	Tractor drawn disc harrow	900.00 ha ⁻¹
	iii. Layout and preparation of beds (8 labours)	1400.00	Labour	175.00 Rs./labour
3.	Sowing of seeds by kera method including labour charges (6 labours)	1550.00	Bullock drawn plough labour	500.00 ha ⁻¹ 175.00 Rs./labour
4.	Nitrogen (20 kg ha ⁻¹)	220.00	Through urea	5.0 Rs./kg
5.	Seed (80 kg ha ⁻¹)	2000.00	Gram seed RSG-945	25.00 kg ha ⁻¹
6.	Seed treatment	400.00	Chloropyripos	Rs. 400.00 lit ⁻¹
7.	Thinning (4 labour)	700.00	Labour	Rs. 175 labour ⁻¹
8.	Plant protection measure	1630	Endosulphan, Phorate	
9	Hoeing and weeding two(4 labour per operation)	1400.00	Labour	Rs. 175 labour ⁻¹
10	Irrigation including labour charge	2400.00	Labour	Rs. 175 labour ⁻¹
11.	Harvesting (8 labour)	1400.00	Labour	Rs. 175 labour ⁻¹
12.	Threshing and winnowing (8 labours)	1400.00	Labour	Rs. 175 labour ⁻¹
13.	Miscellaneous	400.00		
	Total	18000.00		

Appendix-XII

Comparative economics of various Treatments combinations

S.No.	Treatments combinations	Treatments cost (Rs. ha ⁻¹)	Common cost of cultivation (Rs. ha ⁻¹)	Total cost (Rs. ha ⁻¹)	Yield (kg ha ⁻¹)		Gross returns (Rs ha ⁻¹)	Net returns (Rs ha ⁻¹)	B : C ratio
					Seed	Straw			
1.	C ₀ P ₀	0.00	18000	18000.00	1216.00	1642.66	33685.33	15685.33	1.87
2.	C ₀ P ₁	20.00	18000	18020.00	1387.64	1850.18	38391.37	20371.37	2.13
3.	C ₀ P ₂	20.00	18000	18020.00	1395.36	1860.48	38604.96	20584.96	2.14
4.	C ₁ P ₀	40.00	18000	18040.00	1350.80	1801.06	37372.13	19332.13	2.07
5.	C ₁ P ₁	281.25	18000	18281.25	1697.07	2157.51	46741.69	28460.44	2.55
6.	C ₁ P ₂	301.25	18000	18301.25	1732.28	2273.33	47853.66	29552.41	2.61
7.	C ₂ P ₀	301.25	18000	18301.25	1363.08	1817.44	37711.88	19410.63	2.06
8.	C ₂ P ₁	321.25	18000	18321.25	1783.41	2340.43	49266.14	30944.89	2.68
9.	C ₂ P ₂	562.50	18000	18562.50	1764.10	2315.66	48733.85	30171.35	2.62
10.	C ₃ P ₀	582.50	18000	18582.50	1416.80	1889.06	39198.13	20615.63	2.10
11.	C ₃ P ₁	582.50	18000	18582.50	1944.41	2554.14	53718.61	35136.11	2.89
12.	C ₃ P ₂	602.50	18000	18602.50	1950.17	2638.19	54030.63	35428.13	2.90

Seed price of chickpea =Rs. 25.00 per kg

Straw price of chickpea = Rs. 2.0 per kg