

**EFFECT OF PHOSPHORUS, MOLYBDENUM AND ORGANICS
ON SOIL QUALITY AND CROP PERFORMANCE OF
BLACKGRAM UNDER RAINFED ECOLOGY OF JAMMU**

By

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Thesis submitted to Faculty of Postgraduate Studies
in partial fulfillment of the requirements
for the degree of

**DOCTOR OF PHILOSOPHY IN AGRICULTURE
SOIL SCIENCE AND AGRICULTURE CHEMISTRY**



**Division of Soil Science and Agricultural Chemistry
Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu,
Main Campus, Chatha, Jammu-180009
2020**

CERTIFICATE-I

This is to certify that the thesis entitled “**Effect of phosphorus, molybdenum and organics on soil quality and crop performance of blackgram under rainfed ecology of Jammu**” submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Agriculture (Soil Science and Agriculture Chemistry)** to the Faculty of Post Graduate Studies, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu is a record of bonafide research work carried out by **Mr. Tajamul Islam Shah**, Registration No. **J-14-D-216-A**, under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma. It is further certified that help and assistance received during the course of thesis investigation have been fully acknowledged.

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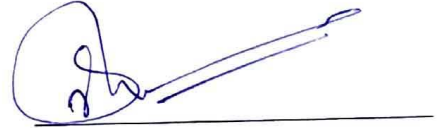
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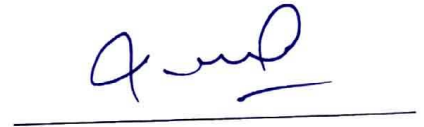
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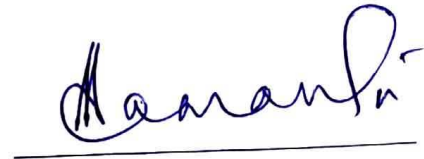
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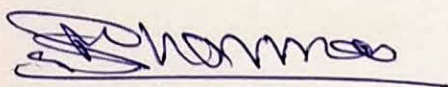
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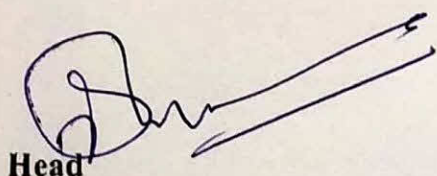


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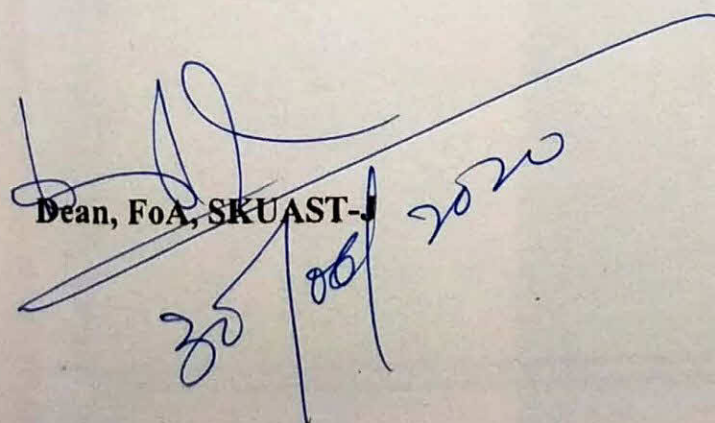
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ABSTRACT

- Title of the Thesis** : “Effect of phosphorus, molybdenum and organics on soil quality and crop performance of blackgram under rainfed ecology of Jammu”
- Name of the Student** : Tajamul Islam Shah
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ABSTRACT

100 soil samples from blackgram growing rainfed areas of Jammu were collected and analyzed for various physico-chemical properties and available nutrients. The results revealed that soil was low in available nitrogen (N) (229.0 kg ha^{-1}) and medium in phosphorus (P) (12.7 kg ha^{-1}) and potassium (K) (178.4 kg ha^{-1}). However, available molybdenum (Mo) (0.282 mg kg^{-1}) in soil was in sufficient range. The correlation matrix revealed that available nutrients were negatively correlated with electrical conductivity, bulk density and sand content where as positive correlation between available nutrients with organic carbon and silt was observed. Also, available nutrients except Mo were negatively correlated with soil pH while positive relationship was obtained between clay and available nutrients (except P).

A field experiment entitled “Effect of phosphorus, molybdenum and organics on soil quality and crop performance of blackgram under rainfed ecology of Jammu” was conducted at research farm of Advance Centre for Rainfed Agriculture, Dhiansar, SKUAST-J during 2016 and 2017. The experiment consisted of 13 treatments comprising different combinations of chemical fertilizers, organic manure and biofertilizers *viz.* T₁: Control, T₂: P20 + PSB, T₃: P20 + PSB + Rhizobium, T₄: P20 + PSB + Rhizobium + FYM, T₅: P20 + 0.5Mo + PSB, T₆: P20 + 0.5Mo + PSB + Rhizobium, T₇: P20 + 0.5Mo + PSB + Rhizobium + FYM, T₈: P40 + PSB, T₉: P40 + PSB + Rhizobium, T₁₀: P40 + PSB + Rhizobium + FYM, T₁₁: P40 + 0.5Mo + PSB, T₁₂: P40 + 0.5Mo + PSB + Rhizobium, T₁₃: P40 + 0.5Mo + PSB +

Rhizobium + FYM. Blackgram cultivar (Uttara) was taken as test crop. The results reflected that soil of the experimental site was sandy loam in texture, slightly acidic in nature, low in organic carbon (OC) content and available N; medium in available P and K and high in available Mo. The water holding capacity (WHC) and soil porosity significantly improved under treatments which received combined applications of inorganics and organics over rest of the treatments as well as initial status of soil. Application of inorganics plus organics brought about significant improvement in general bacterial and fungal count; dehydrogenase activity; labile carbon (LC), particulate organic carbon (POC) and microbial biomass carbon (MBC), available N, P, K and Mo of the post-harvest soil samples. Balanced sheet with regard to available nutrients viz. N, P, K and Mo were found positive under all treatments except control while phosphorus use efficiency was found maximum under treatment T₇. Soil quality index (SQI) developed for different treatment varied from 0.105 to 0.398. The magnitude of share of key soil quality indicators for influencing SQI were WHC, dehydrogenase, bacteria and available P.

The yield of blackgram in terms of grain and straw and yield attributing characters viz. number of pods per plant and number of grains per pod were found significantly higher under T₁₃ during both the years of experiment. The treatment T₁₃ registered higher number of nodules per plant recorded at 40 DAS during 2016 and 2017. The lowest number of nodules, pods per plant, grains per pod, grain and straw yield; N, P, K and Mo uptake by blackgram were obtained under T₁ i.e., control. Also, the results of the present investigation revealed that uptake of nutrients (N, P, K and Mo) by blackgram increased significantly by enriching the soil with P₄₀ + 0.5Mo + PSB + Rhizobium + FYM (T₁₃) during both the years of study.

Key words: Soil quality index, Blackgram, Nitrogen, Phosphorus, Molybdenum, Grain yield, Straw yield, Carbon pools, Microbial population, Phosphorus use efficiency, Enzyme, Farmyard manure.



Signature of Major Advisor



Signature of Student

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ABBREVIATIONS

@	=	At the rate of
&	=	And
Anon.	=	Anonymous
°C	=	Degree Celsius
Fig.	=	Figure
FYM	=	Farm Yard Manure
PSB	=	Phosphate Solubilizing Bacteria
R	=	Rhizobium
N	=	Nitrogen
P	=	Phosphorus
K	=	Potassium
Mo	=	Molybdenum
ha ⁻¹	=	Per hectare
kg	=	Kilogram
g	=	Gram
cm	=	Centimeter
C.D.	=	Critical difference
t	=	Tonnes
SEm	=	Standard error of mean
m	=	Meter
mg	=	Milligram
No.	=	Number
NS	=	Non Significant
%	=	Percent
PP	=	Page
ppm	=	Parts per million
Temp.	=	Temperature
cfu	=	Colony forming unit
m ⁻³	=	meter cubic
g ⁻¹	=	Per gram
viz.,	=	Vide licet

Max.	=	Maximum
Min.	=	Minimum
Avg.	=	Average
J.	=	Journal
T	=	Treatment
Soc.	=	Society
Sci.	=	Science
Dept.	=	Department
Agri.	=	Agriculture
Univ.	=	University
pH	=	Puissance de hydrogen
EC	=	Electrical conductivity
OC	=	Organic carbon
Av.	=	Available
MBC	=	Microbial biomass carbon
NUE	=	Nutrient use efficiency
PUE	=	Phosphorus use efficiency
BD	=	Bulk density
SOM	=	Soil organic matter
SOC	=	Soil organic carbon
J&K	=	Jammu and Kashmir
CFU	=	Colony forming unit
TPF	=	Tri-phenyl formazan
LC	=	Labile carbon
POC	=	Particulate organic carbon
DAS	=	Days after sowing
<i>et al.</i>	=	And others
<i>viz.</i>	=	Namely
g cc ⁻¹	=	Gram per cubic centimeter
DAP	=	Diammonium phosphate
dS m ⁻¹	=	Decisiemen per meter
GPS	=	Geographical positioning system
Mg m ⁻³	=	Mega gram per cubic meter

INTRODUCTION

Pulses, on account of high protein content and their soil enriching capabilities by fixing atmospheric nitrogen, play a key role in the agriculture production. Pulses thus occupy a unique position in dietary habits of our people supplying the major portion of balance protein requirement. India, being the largest pulse cultivating country in the world, pulses share to total food grain production is only 7-10 % in the country. India is the biggest producer as well as consumer and importer of pulses in the world accounting for 32.24 per cent of world area and 23.46 per cent of world's production. India has made an impressive progress to achieve self sufficiency in food grain production and reached a growth rate which is sufficient to meet the requirement of increasing population. However, there has been stagnation in the production and productivity of pulses over the past two decades. The per capita availability of pulses has declined from 64 g per capita per day (1951-56) to less than 44 g per capita per day (Directorate of economics & statistics, 2015-16), as against the FAO/WHO'S recommendation of 80 g . It is estimated that country population will reach nearly 1350 million by 2020 A.D. The country would then need 30.3 million tonnes of pulses to meet the requirement. Therefore, there is urgency to improve the pulse production.

In India, pulses occupy an area of 24.78 million hectares having total production of 17.21 million tonnes with an average productivity of 694 kg ha⁻¹ (Anonymous, 2012). The factors attributed for low yields of pulses in India as compared to the world productivity are non- availability of quality seed, growing of pulses under marginal and less fertile soil with low organics and without pest and disease management, growing of pulses under moisture stress, unscientific post harvest practices and storage under unfavorable conditions. Successful crop production to a great extent depends on adequate availability of nitrogen in soil and other nutrients. There is need to improve the efficiency of biological nitrogen fixation not as an alternative to nitrogen fertilizer but as a supplement to it. Pulses are least preferred by farmers because of high risk and less remunerative than cereals; consequently, the production of the pulses is sufficiently low.

Pulses are most suitable crops under rainfed conditions, covering 26.78 thousand ha area of Jammu region. It contributes 16.28 % of the total area and 11.48 % of the total production with an average productivity of 451.6 kg ha⁻¹. The Blackgram (*Vigna mungo*) is one of important pulse crop which is being practiced under rainfed tracts of Jammu. The average productivity of this crop is being 3.88 q ha⁻¹ which is quite low as compared to the national average of 7.0 q ha⁻¹. Blackgram is widely considered as an excellent source of high quality protein with good digestibility and also contain water soluble vitamins and minerals of dietary significance. It is favorable short duration pulse crop as it thrives better in all seasons either as sole or as intercrop or fallow crop. It is being cooked for consumption with roti and rice. However, the production of blackgram in our country is not enough to meet the domestic demand of population. There is scope to enhance the productivity of black gram by proper agronomic practices and fertilizers. Among the constraints, imbalanced nutrients, moisture stress, less use of organics, inherent poor soil fertility because of coarse texture, low organic matter content are attributed to the lower yield potential in pulses. Out of these, imbalanced application of nutrients is a major factor affecting crop productivity as well as soil quality. Good soil health is the key factor that determines the sustainable crop production.

Current trends in agriculture are centered on reducing the use of inorganic fertilizers by organic manure (FYM) and the application of bio-fertilizers such as *rhizobium* and phosphorus solubilizing bacteria (Gyaneshwar *et al.* 2002 and Darzi *et al.* 2011). However, the use of organics may not meet the immediate requirement of nutrients of the crops as the nutrients become gradually available with its decomposition. Thus, there is a need for integrated application of alternate source of nutrients for sustaining the desired crop productivity (Tiwari, 2002). Hence, there is a scope for improving the production potential of blackgram by use of organic manures, inorganic manures and biofertilizers.

Farmyard manure (FYM) is known to play an important role in improving the fertility and productivity of soils through its positive effects on soil physical, chemical and biological properties and balanced plant nutrition (Kumar *et al.* 2011). FYM is good organic manure, which contains relatively higher amount of plant nutrients compared to

conventional organic manures. Application of farm yard manure (FYM) into soil, prolongs carbon-sequestration, protects soil from erosion, supplies essential plant nutrients through decomposition process (Abiven *et al.* 2009), increases yield parameters and yield of legumes. Pulses are mainly grown in marginal land and poor productivity of the crop is mainly due to inadequate nutrient supply. However, non-judicious use of chemical fertilizers and reduction in use of FYM resulted in deterioration of soil physical and chemical properties of soil and its productivity. Use of farmyard manure and other organic sources are best remedies for maintaining of soil health as well as productivity and partial replacement of mineral fertilizer. Bio-fertilizers are low cost and eco- friendly inputs having potential for supplying nutrients which can reduce the chemical fertilizer dose by 25-50% (Vance, 1997).

Integration of recommended dose of fertilizer along with farmyard manure would result in better yield of black gram under rainfed condition, slow and steady release of nutrients from organics and inorganics would increase the availability of nutrients, which will result in translocation of more photosynthates from source to sink and finally improve the yield attributing character. Blackgram, being a leguminous crop fulfills major part of nitrogen requirement by symbiotic nitrogen fixation (Pareek *et al.* 1978). In legumes, nitrogen fixation due to *rhizobium* helps in increasing the crop yield. Inoculation of legumes with efficient strains of rhizobia has been emphasized for improving soil quality. The successful establishment of legumes is favoured by the presence of sufficient rhizobia, capable of causing prompt and effective nodulation, which in turn depends on survival and multiplication of the applied inoculum. Legumes not only meet the nitrogen demand through atmospheric nitrogen fixation, but also improve the productivity of soils. Thus, the legume - *rhizobium* symbiotic partnership represents inexpensive inmate to the use of chemical fertilizers in the production of food grains. However, the extent of nitrogen fixation is governed by many factors like crop, soil and management practices.

Mineral nutrition plays a key role in exploiting the potential of pulses. Fertilizers play vital role for obtaining higher crop production as the sources of readily available nutrient to plants. Leguminous plants have a high requirement of phosphorus and its

deficiency is probably the major limitation to the growth of legumes (Deo and Khaldelwal, 2009). It is the most important single factor responsible for poor yields of pulses. Phosphorus is second most critical plant nutrient but for pulses, it assumes primary importance, owing to its important role in root proliferation and thereby atmospheric nitrogen fixation. It plays a key role in various physiological processes like root growth and dry matter production and also in metabolic activities especially in protein synthesis. It also helps in establishing seedling quickly and also hastens maturity as well as improves the quality of crop produce (Kokani *et al.* 2015).

The occurrence of deficiencies of phosphorus (P) and molybdenum (Mo) are being widely observed in pulses. Phosphorus plays an important role in nutrition of legumes and improves biological nitrogen fixation. Phosphorus is a key element involved in various functions in growth and metabolism of pulses. Phosphorus deficiency is usually the key factor for low seed yield of pulse crops on all types of soils. The application of P to pulse crops must be one of the most important strategies to increase productivity of pulses in India. Yield of pulses can significantly be increased by applying P on the basis of soil test information. The introduction of efficient phosphorus solubilizing bacteria (PSB) in the rhizosphere further increases the availability of P in soil from insoluble sources of P and also utilization of efficiency of P fertilizers. The phosphorus solubilizing bacteria also enhances P availability to plants by supplementing 20-30 kg ha⁻¹ year⁻¹, increase crop yield by 15-20% and enhance nutrient uptake efficiency of plants. Molybdenum is an important micro nutrient required for growth of most biological organisms including plants. In the absence of Mo, the plant tends to become N deficient even though there was a proliferation of very small root nodules. Molybdenum also plays essential role in the N metabolism of some tropical and subtropical legumes such as soyabean and cowpea. Mo deficiency is usually corrected by addition of soluble compounds such as Na- and NH₄-molybdate or soluble molybdenum trioxide and molybdenized superphosphate. Molybdenum deficiency symptoms are commonly observed on soils derived from quartzic material, sandy pebbly alluviums, and sandy loams on soils with high anion exchange capacities. Moreover, integrated application of phosphorus, molybdenum and bio-fertilizers with organics may

not only play synergistic role in the availability of each other but also enhance yield and soil quality.

The assessment of soil quality starts from the definition of soil quality indicators i.e, processes and properties of the soil that are sensitive to changes caused by both natural and anthropogenic factors (Doran and Jones, 1996). In particular, soil quality indicators are physical, chemical and biological soil properties, able to readily change in response to variations in soil conditions (Brejda *et al.* 2000; Marzaioli *et al.* 2010).

The standard method for calculating soil quality index is comprised of three steps viz. selection of indicators, scoring of indicators and ranking the indicators based on relative importance. Relative importance of indicators is decided based on the kind of soil function involved. The following formula may be applied to work out the soil quality index:

$$\text{SOIL QUALITY INDEX (SQI)} = \sum W_i S_i$$

Where, W_i = weighted factor derived from principle component analysis

S_i = score for the subscripted variable

Molybdenum is a component at least five enzymes that catalyze diverse and unrelated reactions, namely nitrogenase, nitrate reductase, xanthine oxidase, aldehyde oxidase and sulphate oxidase. The principal function of Molybdenum in plants is implicated in the electron transfer system. In legumes, the biological importance of molybdenum is due to its high beneficial action in the fixation of atmospheric nitrogen by nitrogen fixing bacteria. Molybdenum requirement of legumes is relatively high. Molybdenum is an essential micronutrient in the symbiotic nitrogen fixation and is an essential component of nitrogen fixing enzyme “nitrogenase”.

The molybdenum and phosphorus have received attention as the two anions tend to compete for similar sorption sites. Phosphorus fertilizers added to the soil were believed to release molybdenum from the anion sorption complex. Phosphorus and molybdenum through their effect on nitrogenase enzyme and on leghaemoglobin content of nodules in leguminous plants influence the biological nitrogen fixation. Research

work done so far had given indication that pulses respond to the application of phosphorus, but information is lacking on the interaction of phosphorus with molybdenum on the yield of pulse crop.

Jammu and Kashmir (JK) contains 4.38 lakh ha rainfed area including dryland ecosystem which comes out 57.99 per cent (Anonymous, 2013). Keeping in view vast chunk of land under rainfed ecosystem, it becomes imperative to bring the area under cultivation with manipulation of organic and inorganic practices. Simultaneously, inclusion of pulses can be considered as an attempt to enhance the pulse production from rainfed areas. Thus, there is a need to identify the practices in order to improve the soil quality as well increase the crop production. With meager information available and keeping in view the above facts for developing the hypothesis, a study entitled “**Effect of phosphorus, molybdenum and organics on soil quality and crop performance of blackgram under rainfed ecology of Jammu**” was carried out with following objectives:

1. To study the distribution of available phosphorus and molybdenum of representative pulse growing soils of Jammu
2. To evaluate the effect of organic manures, bio-fertilizers, phosphorus, and molybdenum on soil quality and yield of blackgram
3. To monitor the effect of phosphorus, molybdenum, organic manures and bio-fertilizers on nutrient use efficiency and nutrient balance in soil

REVIEW OF LITERATURE

This chapter includes review pertaining to research work entitled the “**Effect of phosphorus, molybdenum and organics on soil quality and crop performance of blackgram under rainfed ecology of Jammu**” and have been discussed under the following headings:

- 2.1 Distribution of available nitrogen, phosphorus, potassium and molybdenum in blackgram growing soils
- 2.2 Soil fertility status
 - 2.2.1 Soil nutrient status
 - 2.2.2 Carbon fractions
 - 2.2.3 Biological properties
- 2.3 Assessment of soil quality
- 2.4 Yield parameters and yield of blackgram
 - 2.4.1 Yield attributes and yield of blackgram
 - 2.4.2 Root nodules
 - 2.4.3 Nutrient content and uptake
 - 2.4.4 Phosphorus use efficiency (PUE)

2.1 Distribution of available nitrogen, phosphorus, potassium and molybdenum in blackgram growing soils

Dhawan (2002) studied the distribution of available Mo in Jammu soils and observed in concentrations of 0.26 to 0.86 ppm (0.46 ppm).

Sharma *et al.* (2003) studied status of micronutrients and effect on soil properties of the semi arid region of Rajasthan and observed that available Zn, Cu, Fe, Mn, B and

Mo contents ranged from 0.1 to 1.7, 0.5 to 3.9, 1.0 to 6.6, 2.7 to 7.2, 0.2 to 2.0 and 0.1 to 1.3 mg kg⁻¹ with the mean values of 0.73, 2.11, 4.32, 5.15, 0.68 and 0.48 mg kg⁻¹, respectively.

Sharma *et al.* (2009) also reported that the soils were low in available nitrogen with the test values ranging from 169 to 265 kg ha⁻¹. The poor nitrogen status of soils has also been reported earlier in Bhalwal block of kandi area (Sumbaria *et al.* 1989). Further the available phosphorus content of the soils varied between 9.0 to 14.3 kg ha⁻¹ and available potassium ranged from low (77 kg ha⁻¹) to medium (144 kg ha⁻¹) with an average value of 110 kg ha⁻¹.

Velmurigan and Mahendran (2015) reported the available Mo status of soils of Madurai and Sivagangai districts of Tamilnadu ranged between 0.026 to 0.869 mg kg⁻¹, respectively. While studying the micronutrient status of Raipur area of Chhattisgarh of Central India, Patel *et al.* (2015) observed that Mo occurs in soils in extremely small quantities and usually found in concentrations of less than 0.1 to 8.9 mg kg⁻¹ with mean 1.5 ± 0.3 mg kg⁻¹, respectively.

2.2 Soil fertility status

2.2.1 Soil nutrient status

Agarwal (2000) reported that application of 1.5 kg Mo ha⁻¹ significantly increased available N and Mo content in soil at harvest of blackgram crop over control. Also, Swaroop (2006) reported that application of doses of P at the rate of 40, 80 and 120 kg P₂O₅ ha⁻¹ significantly increased the available N and P content in soil over control in cowpea. Significantly highest N and P content of soil were recorded with phosphorus application *viz.* 120 kg P₂O₅ ha⁻¹.

Singh *et al.* (2009) conducted a field experiment at the experimental farm of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, to evaluate the performance of greengram under temperate conditions with inoculation of *Rhizobium*, VAM and N levels. The results indicated a significant improvement with respect to nitrogen and phosphorus under the treatments which received *Rhizobium* and VAM and

N doses. Singh (2010) observed that the application of P upto 40 kg P₂O₅ ha⁻¹ significantly increased the available P content in soil after harvest of mungbean crop.

Singh and Sharma (2011) found that available N and P content after harvest of chickpea crop increased significantly with the combined application of organic manure and fertilizer source of P, *Rhizobium* and PSB inoculation over control. Singh *et al.* (2011) also concluded that among treatment of the organic and inorganic sources, observed the highest available N (274.30kg ha⁻¹) was recorded with lime+FYM+50% NPK being at par with FYM+50% NPK (274.30kg ha⁻¹) gave significantly higher available N (274.30 kg ha⁻¹) over other treatment. With the supplementation of micronutrient along with inoculation of *Rhizobium* and phosphorus solubilizing bacteria in chickpea, it was found that biological nitrogen fixation increased and improvement in phosphorous availability was also noted and there by enhancement in its productivity (Gangwar *et al.* 2012).

Khandelwal *et al.* (2012) conducted a field experiment on cowpea at (Jobner) Rajasthan and reported that the organic carbon (0.13%), available nitrogen (130.2 kg), phosphorus (16.5 kg) and potassium (151.9 kg) status of the soil significantly increased due to the application of 75% RDF (15 kg N and 30 kg P₂O₅ ha⁻¹) along with inoculation of *Rhizobium* + PSB over rest of treatments.

Bhatt *et al.* (2013) carried out an experiment to investigate the effect of different levels of vermicompost and phosphorus with and without PSB on yield, quality, nutrient content of *summer* greengram and soil fertility status after harvest of the crop. They reported that application of P @ 40 kg P₂O₅ ha⁻¹ + PSB performed equally as that of 40 kg P₂O₅ ha⁻¹ without PSB and significantly improved the soil fertility status after harvest of the crop.

Choudhary (2013) conducted a field experiment and observed that mungbean inoculated by PSB + VAM noted significantly higher dehydrogenase enzyme activity over PSB alone and control. Khan *et al.* (2013) carried out an experiment on blackgram and indicated that seed inoculation with *Rhizobium* and PSB significantly increased organic carbon, available nitrogen and available phosphorus content in soil over control.

Singh *et al.* (2013) also conducted an experiment to monitor the influence of phosphorus in soil and revealed that the phosphorus applied to crops markedly enhanced available P content of soil after the harvest of mungbean.

Karpagam and Rajesh (2014) conducted a field experiment to evaluate the effects of molybdenum (Mo) application on greengram (Vamban-2) yield and soil properties during the summer season of 2011 at National Pulses Research Centre, Vamban, Pudukkottai and found significantly higher green gram growth and yield under Mo application @ 1000 g ha⁻¹. Available nitrogen and molybdenum contents in soil increased with increasing levels of Mo. Kumar (2015) carried out an experiment on mungbean crop, reported that progressive increase in level of phosphorus upto 40 kg ha⁻¹ significantly increased the available P content in soil but organic carbon content of soil remained unaffected due to increasing levels of phosphorus.

Mondal *et al.* (2015) conducted an experiment and found that application of biofertilizer has significantly increased soil organic matter, nitrogen, phosphorus, and potassium. The use of biofertilizer significantly improved the soil bacterial population count in the soil thereby increasing the soil health under mungbean cropping system. Application of phosphorus upto 40 kg P₂O₅ ha⁻¹ recorded significantly higher microbial biomass carbon, nitrogen and phosphorus in soil as compared to absolute control and 20 kg P₂O₅ ha⁻¹ but was at par with 60 kg P₂O₅ ha⁻¹ (Mohammad *et al.* 2017).

2.2.2 Carbon fractions

Chemical fertilizers and organic materials are the most common amendments applied to soil to improve soil quality and crop productivity. Organic amendments are known to improve soil productivity by influencing soil organic matter (SOM) status. The SOM is considered to be a key attribute of soil quality (Bhattacharyya *et al.* 2000; Singh *et al.* 2003) and thus is a major determinant of sustainability of agricultural systems (Carter, 2002; Blair *et al.* 1995). Maintenance of SOM in agricultural soils is primarily governed by climate, particularly annual precipitation and temperature and cropping practices. A good farming practice can decrease CO₂ evolution into the atmosphere and enhance soil fertility and thus productivity. This is more important in the tropical and

subtropical regions where soils are inherently low in organic carbon content and production system is fragile.

Manna *et al.* (2005) reported that the SOC level in unfertilized plot decreased as compared to initial values, wherein the treatment receiving NPK or NPK + FYM either maintained or improved it over initial SOC content. Active fraction of SOC viz., water soluble carbon and hydrolysable carbohydrates, soil microbial biomass C and N, dehydrogenase and alkaline phosphatase activity, improved significantly with application of NPK and NPK + FYM. The positive yield trend was observed with the addition of NPK and NPK + FYM treated plots. The soil microbial biomass carbon (SMBC) and particulate organic matter was recorded highest in NPK+FYM followed by NPK, N-P, N and lowest in control. The micro aggregates (53-250 μm) were dominated followed by macro aggregates (250-2000 μm). (Manna *et al.* 2006).

Rahangdale (2006) reported that the soil microbial biomass increased with the application of NPK. The effect of integrating chemical fertilizer with organics was more pronounced on microbial biomass carbon at higher level of FYM and green manure. The organic carbon content decreased from its initial value when only nitrogen and phosphorus fertilizers were applied and increased significantly with the application of organic manure alone or with nitrogen and phosphorus fertilizers. The highest organic carbon content of the soil was observed in plot receiving 15 kg FYM + 150 kg N + 30 kg $\text{P}_2\text{O}_5 \text{ ha}^{-1}$. The application of organic manures with or without nitrogen and phosphorus fertilizers could not sustain the original level of N in soil. The buildup of organic carbon and N content was higher in surface soil than that of subsurface soil (Antil *et al.* 2007).

Organic carbon is a key attribute of soil fertility, which serves as soil conditioner, nutrients source and substrate for microbial activity, preserve of the environmental and sustainers of agricultural productivity (Benbi *et al.* 2011). Fertilizer application stimulates crop biomass production which resulted in an increase in the amount of C accumulation in soil. Increasing C returns to the soil as manure or other organic amendments might be increased soil organic C storage directly (Stewart *et al.* 2007). Majumdar *et al.* (2008) assessed the impact of organic and inorganic amendments on SOC stock, its different pools – total organic C (C_{tot}), oxidizable organic C (C_{oc}) and its four fractions of very

labile (C_{frac1}), labile (C_{frac2}), less labile (C_{frac3}) and non labile C (C_{frac4}); microbial biomass C (C_{mic}) and Mineralizable C (C_{min}). Cropping with only chemical application just maintained SOC content, while chemical plus organics improved SOC by 24.3% over the control.

Pathak *et al.* (2011) observed that the final soil organic carbon concentrations in both NPK and NPK+FYM treatments were higher than the control treatment. Compared to the NPK treatment also, the NPK+FYM treatment had higher SOC concentration. Organic sources of nutrient such as FYM decomposed slowly resulting in more SOC accumulation in soil (Mandal *et al.* 2007).

Nayak *et al.* (2012) reported that application of NPK either through inorganic fertilizer or through combination of inorganic fertilizer and organics such as FYM or crop residue or green manure improved the soil organic carbon, particulate organic carbon and their sequestration rate. Integrated use of FYM with chemical fertilizers or use of FYM alone exerted significant effect on the active pools of soil carbon (Verma and Mathur, 2009). Kukal *et al.* (2009) revealed that the soil organic carbon content at different depths in the soil profile was higher in FYM treated plots followed by treatments receiving only NPK.

Brar *et al.* (2013) revealed that effect of long term use of inorganic fertilizer and organic manure on the SOC pools, rate of C sequestration significantly increased to 9.99 mg C per ha, 3.33 Mg C per ha and 0.46 Mg C per ha per year, respectively in the treatments with RDF+FYM.

Das *et al.* (2014) observed that the organic material incorporation improved soil aggregation and structural stability and resulted in higher C content in macro aggregates in 18 years old experiment. The strong linear positive response to C additions indicated C sequestration potential in soils, with preferential location in macro aggregates. A combination of green gram residue and FYM in wheat significantly improved C content in macro aggregates and residue incorporation was beneficial compared to 100% N application through inorganic fertilizer or green gram residues.

Prakash *et al.* (2016) reported that higher concentration of non labile C in treatments involving FYM applications shows the stabilization of organic C in soil. This could be due to the application of already stabilized material in soil through farmyard manure.

2.2.3 Biological properties

The dehydrogenase enzyme activity is commonly used as an indicator of biological activity in soils (Burns 1982). This enzyme is considered to exist as an integral part of intact cells but does not accumulate extracellular in the soil. The enzyme acts by oxidizing soil organic matter via transfer of protons and electrons from substrates to acceptors. Since dehydrogenase activity is only present in viable cells, it is thought to reflect the total range of oxidative activity of soil microflora and consequently may be considered to be a good indicator of microbial activity (Nannipieri *et al.* 1990).

Gupta *et al.* (1983) reported that 40 kg fertilizer applications each of N, P and K had no effect on the microbial population of the soil, while the application of FYM at 16 t ha⁻¹ or green manure at 20 t ha⁻¹ significantly increased the bacterial population. It may be due to improvement in the nutrient status as well as physical and chemical conditions of the soil for the favorable growth of these microorganisms. Organic matter quality alters fungal/bacterial ratios, with low quality organic matter (high C/N ratio) favouring bacteria (Bossuyt *et al.* 2001).

The microbial biomass was greater in soil having annual addition of FYM for nearly hundred years in addition to inorganic NPK (Hopkins and Shiel, 1996). Microbial biomass increased from 122 mg kg⁻¹ in unfertilized treatments to 131 mg kg⁻¹ in soil amended with 100% NPK + farmyard manure. Similarly, Goyal *et al.* (1999) reported that MBC increased from 147 mg kg⁻¹ soil in unfertilized treatment to 433 mg kg⁻¹ soil in amended with wheat straw and inorganic fertilizers.

Alleoni *et al.* (1995) also reported increase in microbial counts in response to fertilization. The mycorrhizal infection of the corn roots was significantly increased by the application of inorganic fertilizers and organic manures probably because fertilizers stimulate root growth (Jumpponen *et al.* 1998).

Naidu *et al.* (2000) studied the effect of manures, bio and chemical fertilizers on the soil microbial population. The results showed that application of manures with biofertilizers significantly improved microbes in soil over control. The bacterial, fungal and actinomycetes count were maximum under FYM 35 t ha⁻¹ + Azospirillum + phosphate solubilizing bacteria. Sharma *et al.* (2000) reported that microbial population enhanced significantly due to crop residues and FYM as compared to the chemical fertilizers alone.

According to studies of Wu and his co-workers (2002), densities of bacteria, protozoa, nematodes and arthropods in soils under organic farming were higher than under conventional farming. Experiment of Bulluck *et al.* (2002) reported that organic fertility amendments enhanced beneficial soil microorganisms, reduced pathogen population, total carbon, cation exchange capacity and lowered down bulk densities, thus improved soil quality.

Panda *et al.* (2003) studied the effect of phosphorus levels and biofertilizers on microbial population in the rhizosphere of wheat. The results showed that phosphorus has a positive influence on the population of *Pseudomonas striata*. The application of P upto 40 kg P₂O₅ ha⁻¹ significantly increased the population of phosphate solubilizing microorganism. Thus application of 40 kg P₂O₅ ha⁻¹ along with inoculation with phosphate solubilizing microorganisms maintained the optimum microbial population in the rhizosphere. Selvi *et al.* (2004) reported that bacteria, fungi and actinomycetes proliferated well under continuous application of NPK and FYM treatments. Among the microbes, bacterial population was highest compared to fungi and actinomycetes.

Tapas and Gupta (2005) studied the effect of bacterial fertilizers with different phosphorus levels on soyabean and soil microflora. The results showed that doses of P fertilizer at the rate of 60, 80 and 100 kg P₂O₅ ha⁻¹ proved suitable for maximizing bacterial population and minimizing fungal population of the rhizosphere soils at different crop growth stages. The addition of FYM in combination with inorganic fertilizer exerted stimulating influence on the preponderance of bacteria (Selvi *et al.* 2005). It was significantly higher in the plots under 100% NPK (41.1 µg g⁻¹ 24h⁻¹) and 100% NP (40.11 µg g⁻¹ 24h⁻¹) compared with 100% N (36.97 µg g⁻¹ 24h⁻¹). The increase

in bacterial numbers in response to chemical fertilizers may be attributed to a better nutrient status of soil (Kang *et al.* 2005).

It has been reported that the increase in dehydrogenase activity was proportional to the addition of number and amount of nutrients (Masto *et al.* 2006). According to Pancholy and Rice (1973), dehydrogenase activity was influenced more by the quality than by the quantity of organic matter incorporated into soil. Thus, the stronger effects of FYM on dehydrogenase activity might be due to the more easily decomposable components of crop residues on the metabolism of soil microorganisms. They found that microbial activities in terms of dehydrogenase were higher in the soils under both organic manures and INM. Hao *et al.* (2008) observed that the microbial biomass was considerably greater in soils receiving FYM along with NPK fertilizer than in plots receiving merely NPK fertilizer in three subtropical paddy soils.

The long-term effect of nutrient management on soil fertility and soil organic carbon pools under a 6-year-old pearl millet-wheat cropping system in an Inceptisol of subtropical India was studied by Moharana *et al.* (2012) and reported that the MBC in surface soil varied from 155 mg kg⁻¹ in unfertilized control to 273 mg kg⁻¹ in integrated use of FYM + NPK. The higher value of MBC with integrated use of FYM and NPK was probably due to higher turnover of root biomass produced under FYM + NPK treatment.

2.3 Assessment of soil quality

Soil health is defined as the continued capacity of soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land-use boundaries (Doran and Zeiss, 2000; Karlen *et al.* 2001). These functions are able to sustain biological productivity of soil, maintain the quality of surrounding air and water environments, as well as promote plant, animal, and human health (Doran *et al.* 1996). The concept of soil quality emerged in the literature in the early 1990s (Doran and Safely, 1997; Wienhold *et al.* 2004), and the first official application of the term was approved by the Soil Science Society of America Ad Hoc Committee on soil quality and discussed by Karlen *et al.* (1997). Soil quality was defined as “the capacity of a reference soil to function, within natural or managed ecosystem

boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.” Subsequently the two terms are used interchangeably (Karlen *et al.* 2001) although it is important to distinguish that, soil quality is related to soil function (Karlen *et al.* 2003; Letey *et al.* 2003) whereas soil health presents the soil as a finite non-renewable and dynamic living resource (Doran and Zeiss, 2000).

The identification of basic soil properties that serve as indicators of soil quality is complicated as many physical, chemical and biological -parameters are involved and there exists varying interactions between their time, space and intensity (Visser and Parkinson, 1992; Holloway and Stork, 1991) listed a number of features that should be used in the selection of soil quality indicators which ultimately determine the sustainability of soil system. Indicators should show a prompt and accurate response to perturbation and should be sensitive to variations in management and climate; the indicators should reflect some aspect of functions of ecosystem; the indicators should be readily and economically accessible; the indicators must be universal in distribution and show individual specificity to special patterns in the environment; and soil quality indicators must be a component of existing soil database.

Larson and Pierce (1991) proposed that MDS must be adopted for assessing the health of soils and that standardized methodologies and procedures is established to asses changes in soil quality. However, a systematic cataloging of ranges and threshold values for these indicators will be required to interpret the significance of changes in soil. The International Organization for Standardization (IOS) has established a technical committee on soil quality issues to clear with the standardization of methods to measure physical, chemical and biological parameters of soil quality and sustainability (Stick and Richard, 1996). Parr *et al.* (1992) suggested that increased infiltration, aeration macropores, aggregate distribution and their stability and soil organic matter, decreased bulk density, soil resistance, erosion and nutrient run off are some of the important indicators for improved soil quality. Soil quality cannot be measured directly however. It can be inferred by measuring soil physico chemical and biological properties that serve as quality indicator (Brejda and Moorman, 2001; Diack and Stott, 2001).

Nortcliff (2002) stated that there are potentially many soil properties which might serve as indicators of soil quality and research is required to identify the most suitable. The recent approach in assessing the soil quality includes normalization of the data from measurements and conversion to a numeric value that is more than a static description called a “soil quality index (SQI)”. Chaudhary *et al.* (2005) identified total soil N, available P, dehydrogenase activity and mean weight diameter (MWD) of aggregate as the key indicators for alluvial soils. Katkar *et al.* (2012) in a long term experiment aimed to assess the impact of continuous application of chemical fertilizers and manures on properties of soil, key indicators of soil quality and yield sustainability under sorghum-wheat cropping sequence, observed the highest soil quality index under integrated nutrient management comprising of 100% NPK + FYM (2.45), followed by only FYM (2.16) and 150% NPK of recommended dose of fertilizer (2.15). The lowest was in control (1.14) followed by 50% NPK of RDF (1.45).

Andrews *et al.* (2002) proposed that indices of soil quality (SQIs) can help to identify the most sustainable management practices. Various methods were tested for choosing a minimum data set (MDS), transforming the indicators, and calculating indices using data. The MDS components were chosen using expert opinion (EO) or principal components analysis (PCA) as a data reduction technique. Multiple regressions of the MDS indicators (as independent variables) against indicators representing management goals showed no significant differences between the EO and PCA selection techniques in their abilities to explain variability within each sustainable management goal. Linear and non-linear scoring techniques were also compared for MDS indicators. The non-linear scoring method was determined to be more representative of system function than the linear method. Finally, indicator scores were combined using either an additive index, a weighted additive index, or a decision support system. For almost all indexing combinations, the organic system received significantly higher SQI values than the low input or conventional treatments. The efficacy of the indices was tested by comparisons with individual indicators, variables representative of management goals, and another multivariate technique for decision making that used all available data rather than a subset (MDS). Comparison with the comprehensive multivariate technique showed results similar to all of the indexing combinations except the additive and weighted

indices using the linearly scored, EO-selected MDS. This suggests that a small number of carefully chosen soil quality indicators, when used in a simple, non-linearly scored index, can adequately provide information needed for selection of best management practices.

Sharma *et al.* (2005) in a long term experiment undertaken to select the appropriate land management treatments and to identify the key indicators of soil quality for dry land semi-arid tropic Alfisol under sorghum- castor- bean rotation observed that the key indicator which contributed considerable towards SQI were available N, K, S, microbial biomass carbon (MBC) and hydraulic conductivity (HC). On average, the order of relative contribution of these indicators towards SQI was available N (32%), MBC (31%), available K (17%), HC (16%) and S (4%).

Sharma *et al.* (2008) conducted a long term experiment comprising tillage and conjunctive nutrient use treatments under sorghum-moongbean system during 1998-05 on semi arid tropical Alfisol at CRIDA, Hyderabad to evaluate soil and nutrient managements treatments for their long term influence on soil quality using key indicators and soil quality indices (SQI). Of the 21 soil quality parameters considered for study, easily oxidisable N (KMnO_4 oxidisable-N), DTPA extractable Zn and Cu, microbial biomass carbon (MBC), mean weight diameter (M.W.D.) of soil aggregate and hydraulic conductivity (HC) were designated as the key indicators of soil quality for the system.

Bandyopadhyay *et al.* (2009) stated that sustaining the productivity at higher level to meet the increasing demands of food and fiber for the growing population from the limited land and water resources is the key issue in Indian agriculture. Unless the soil physical environment is maintained at its optimum level, the genetic yield potential of a crop cannot be realized even when all the other requirements are fulfilled. In this paper an attempt has been made to review how different technologies like optimal uses of manures and fertilizers, tillage practices and mulching can favourably modify the soil physical parameters like bulk density, porosity, aeration, soil moisture, temperature, soil aggregation, water retention properties and water transmission properties and soil processes like evaporation, infiltration, runoff and soil loss for better crop growth and yield. The improvement of soil health through these eco-friendly site specific

technologies will lead to efficient use of inputs and help in sustaining agricultural production at higher level.

Mandal *et al.* (2013) investigated the important soil quality indicators under different land use systems namely, sal forest, agroforestry, rainfed cropland and irrigated cropland to provide base line data for future research in lower north western Himalayan region. The soil properties such as soil depth, texture, organic carbon, total N, available P, available K, CEC and soil pH were investigated for each land use system to assess relative soil quality index (RSQI). The study revealed that there were significant differences in soil quality parameters under different land use systems. The study further revealed that soil quality index (SQI) values varied from 337 in sal forest to 257 in rainfed cropland in Dungakhet village indicating the superiority of forest land use system in terms of maintaining greater SQI than other land-use systems. Similar trend was also observed in the other site of the study area. In general, intensive tillage practices have degraded most of the important soil quality indicators. Therefore, reducing the intensive tillage practices and use of integrated inorganic and organic fertilizers could replenish the degraded soil quality for sustainable agricultural production in the study area.

Sumita *et al.* (2018) conducted a study to address the selection of most appropriate soil quality indicators and to know the status of soil quality in the area under different land uses. Principal component analysis (PCA) approach was employed to get the minimum data set. Geo-referred soil samples were collected from five different land uses and analyzed for different physical, chemical, and biological attributes. The PCA was performed which screened out the five principal components (PCs) with eigenvalue >1 . Soil quality index was highest under the land use forest (0.80) followed by grasses (0.79), horticulture (0.78), cultivated (0.75), and bare (0.67). The organic carbon contributed maximum to soil quality (28.5%) followed by available K (19.4%), electrical conductivity (18.3%), K-factor of universal soil loss equation (USLE) (14.9%), plant available water (10.5%), and clay (8.3%). Conclusively, the study area falls under the medium category of soil quality.

2.4 Yield parameters and yield of blackgram

2.4.1 Yield attributes and yield of blackgram

Kumar *et al.* (2000) conducted a field experiment at Rhomehi (Bihar) taking four levels of phosphorus (0, 20, 40 and 60 kg/ha). The results revealed that application of phosphorus at 40 kg P₂O₅ per ha significantly increased the growth attributes viz., plant height, number of branches, leaves and leaf area per plant as well as dry matter production in urdbean over preceding levels. Pattanayak *et al.* (2000) reported that in greengram crop, seed *Rhizobium* inoculation alone resulted in 25 % increase in yield and the same due to Mo treatment either alone or in combination with inoculation varied from 61.7 to 78.4 per cent. Mo @ 0.16 mg g⁻¹ of seed was more effective than at 0.08 mg g⁻¹ applied as sodium molybdate. Stover yields were also significantly increased with inoculation and Mo application @ 0.16 mg g⁻¹ of seed. Reddy and Swamy (2000) carried out a field experiment at Rajendra nagar, Hyderabad taking different levels of phosphorus in blackgram and observed that number of pods/plant, seeds/pod and seed yield increased due to application of phosphorus at 26.2 kg/ha over control.

Bhattacharyya *et al.* (2001) studied the effect of rhizobium inoculation, phosphorus and molybdenum on the growth of summer greengram. The experiment data indicated that the plant height, no. of nodule per plant and dry matter significantly increased with Mo @ 0.5 kg ha⁻¹. Meena *et al.* (2001) carried out a field trial and reported that the application of 40 kg P₂O₅ ha⁻¹ significantly enhanced pods per plant seeds per pod, test weight, seed yield and straw yield, advantages were 36.31 and 8.57% between 20-40 and 40-60 kg P₂O₅ ha⁻¹ respectively. The maximum protein content 23.78 per cent was increased with 40 kg P₂O₅ ha⁻¹. Nagarajan and Balachandar (2001) reported that application of organics like biodigested slurry + *rhizobium* inoculation significantly increased the plant height (42.7 cm), plant biomass (8.31 g/plant), number of nodules per plant (23.3), and dry weight of nodules (45.30 mg/plant) of blackgram. They also reported similar increase in plant height, biomass, and number of nodules per plant and dry weight of nodules in green gram.

Ram and Dixit (2001) reported that phosphorus fertilization at 40 kg P₂O₅ ha⁻¹ significantly increased the grain yield, pods per plant and test weight of summer

greengram in comparison to 20 kg P₂O₅ ha⁻¹ but found at par with 60 kg P₂O₅ ha⁻¹. Singh and Agarwal (2001) found that number of pods per plant, pod length, number of grains per pod, 1000-grain weight and grain yield in blackgram were increased significantly with increasing levels of phosphorus upto 40 kg/ha. Yadav and Jakhar (2001) concluded from a field experiment conducted on loamy sand soils of Jobner that the grain and straw yield of mungbean increased significantly with an increase in phosphorus level upto 40 kg ha⁻¹.

Bandhyopadhyay and Puste (2002) noted that seed inoculation of pulses with *Rhizobium spp.* also played a positive role towards the total crop productivity and residual soil fertility status. Bhat *et al.* (2002) found that number of pods per plant, seeds per pod, 100 seed weight and seed yield increased significantly with increasing rates of phosphorus upto 60 kg ha⁻¹. However further increase in phosphorus rates did not increased the above parameters significantly. Chatterjee and Bhattacharjee (2002) studied the effects of inoculation with *Rhizobium spp.* and PSB on the nodulation and grain yield of mungbean cv. B-1 in field trials. The plants inoculated with *Rhizobium* strains and PSB showed increased rate of nodulation, N content and grain yield. The % increase in grain yield over control was observed to be higher significantly in plants inoculate with *Rhizobium* strains and phosphate solubilizing bacteria.

Kumawat and Khangarot (2002) on loamy sand soil of semi-arid eastern plain zone of Rajasthan found that application of 60 kg P₂O₅ ha⁻¹ increased the seed yield of clusterbean to the time of 27.3 and 11.9 per cent over control and 30 kg P₂O₅ ha⁻¹, respectively.

Sriniwas and Mohammad (2002) conducted a field experiment at Rajendranagar, Hyderabad and found that plant height, number of branches and leaves/plant in mungbean increased significantly with increasing levels of phosphorus upto 75 kg/ha. Thiyageshwari and Perumal (2002) reported that application of organic manure + PSB recorded significantly higher grain yield (986 kg ha⁻¹), haulm yield (1337 kg ha⁻¹), number of pods per plant (21.8), 1000-grain weight (41.00 g) and crude protein content (25.84%) of the blackgram over other nutrient management. Choudhary *et al.* (2003) at

Bikaner observed that grain yield of green gram was 19.5, 28.7 and 31.3 per cent higher as compared to control with the application of 20, 40 and 60 kg P₂O₅ ha⁻¹.

Kumar and Chandra (2003) at Pantnagar observed that every increase in level of phosphorus (0, 25, 50 and 75 kg/ha) upto to its highest level significantly improved the plant dry matter of greengram at 50 DAS and at harvest over preceding levels. Nadeem *et al.* (2003) reported significant increase in length, number of pods per plant, pod length, number of grains per pod and green pod length, number of grains per pod and green pod yield with increasing levels of phosphorus. The number of grains per pod and green pod yield were maximum at the 60 kg P₂O₅ ha⁻¹. In another experiment Singh and Pareek (2003) reported that number of pods per plant, number of seeds per pod, test weight and seed yield were significantly improved with every addition in level of phosphorus upto 45 kg P₂O₅/ha along with a uniform basal dose of 25 kg N/ha. However, it showed statistical similarity with 60 kg/ha.

Tanwar *et al.* (2003) in their study conducted at Udaipur recorded significant improvement in yield attributes *viz.*, pods per plant, seeds per pod, test weight and seed yield of urdbean with every enhancement in level of phosphorus upto 60 kg ha⁻¹ over preceding levels. Gull *et al.* (2004) reported that Inoculation of chickpea with the PSB significantly increased the plant growth, phosphorus and nitrogen concentration in the shoot, nodulation efficiency and nitrogenase activity, showing the positive effect of PSB inoculation on growth and development of chickpea.

A field experiment conducted by Kumar and Sharma (2005) during 1998-99 at Rajasthan, to evaluate the effect of phosphorus and molybdenum on the yield and nutrient uptake of chickpea with four levels of phosphorus (0, 20, 40 and 60 kg ha⁻¹) and four levels of molybdenum (0, 0.5, 1.0 and 1.5 kg ha⁻¹). Result data showed that the application of Mo @ 1.0 kg ha⁻¹, which was at par with 1.5 kg Mo ha⁻¹, significantly enhanced the yield and all the yield attributing characters. Nadeem *et al.* (2004) reported that application of phosphorus at 40 kg ha⁻¹ recorded significantly higher pod bearing branches per plant of greengram over lower levels of phosphorus.

Singh *et al.* (2004) evaluated four biofertilizers (control; *Rhizobium* spp.; vesicular arbuscular mycorrhiza, VAM; VAM + *Rhizobium* spp.) and four phosphorus levels (0, 20, 40 and 60 kg ha⁻¹) were evaluated in relation to their effect on the growth and yield of green gram cv. K-851. Biofertilizers along with increase in phosphorus levels up to 60 kg P₂O₅ ha⁻¹ had a significant effect on the yield attributes viz., pods plant⁻¹, pod length, seeds pod⁻¹, 1000-seed weight and seed yield plant⁻¹. Dual inoculation, *Rhizobium* and VAM resulted in 48.6, 41.6 and 38.7% increase in grain yield (kg ha⁻¹), respectively, over no inoculation, while the relative increase in yield at 20, 40 and 60 kg P₂O₅ ha⁻¹ was 13.5, 20.4 and 23.8%, respectively, over the control.

Yadav (2004) conducted a field experiment at Diggi (Rajasthan) and found that every graded level of phosphorus upto 40 kg/ha brought about significant improvement in plant height and number of branches per plant in greengram. Luikham *et al.* (2005) carried out a field experiment on greengram at Imphal in Manipur and observed that application of phosphorus at 40 kg/ha along with basal dose of N and K (20 and 30 kg/ha) gave significantly more number of branches per plant and dry matter production over 25 kg/ha and control. Beerendra (2006) evaluated the effects of biofertilizers (*Rhizobium*, phosphate solubilizing bacteria, and *Rhizobium* + phosphate solubilizing bacteria) in combination with different levels of P fertilizer (0, 20 and 40 ppm) on the nodulation, yield and quality of blackgram cv. T-9. In general, dual inoculation of *Rhizobium* and phosphate solubilizing bacteria was superior to individual inoculation of these biofertilizers. The highest values for number of root nodules per plant, grain and straw yields, and seed protein content were obtained when dual inoculation was combined with the optimum P dose of 20 ppm.

Gupta *et al.* (2006) studied the response of urdbean to varying levels of phosphorus and found that progressive increase in level of phosphorus upto 60 kg/ha significantly increased the yield attributes, seed yield and straw yield over preceding levels. Gupta and Sharma (2006) evaluated the effect of biofertilizers (Phosphorus solubilizing bacteria, two levels) and phosphorus fertilization (4 levels) on yield and economics of urdbean (*Vigna mungo* L.). The study revealed that crop responded favorably to seed inoculation with phosphorus solubilizing bacteria and phosphorus

fertilization ($60 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$) in influencing seed yield. Karwasra *et al.* (2006) conducted a field experiment at Hisar on greengram and reported that increasing levels of phosphorus upto 50 kg/ha along with basal dose of N at 20 kg/ha significantly increased the plant height, number of branches and dry matter accumulation.

Zaidi and Khan (2006) conducted an experiment to evaluate the effects of nitrogen fixing bacteria [*Bradyrhizobium* sp. (*Vigna*)], phosphate solubilizing bacterium (*Bacillus subtilis*), phosphate solubilizing fungus (*Aspergillus awamori*) and AM fungus (*Glomus fasciculatum*). The triple inoculation of AM fungus, *Bradyrhizobium* sp. (*Vigna*) and *B. subtilis* significantly increased dry matter yield, chlorophyll content in foliage and N and P uptake of greengram plants. Seed yield was enhanced by 24% following triple inoculation of *Bradyrhizobium* + *G. fasciculatum* + *B. subtilis*, over control. Ahmed *et al.* (2007) conducted an experiment to evaluate different methods of *Rhizobium* inoculation on yield attributes, pod and seed yields and protein content in seed of pea cv. ISPA Motorshuti-3 and found that seed or soil or both seed and soil inoculated with *Rhizobium* strains BARI RPs-2001 or BARI RPs-2002 were superior to un inoculated control in all parameters of the crop. Almas and Shagir (2007) reported that the dry matter accumulation in Chickpea plants following PSB microbial inoculations varied considerably at 55 and 90 DAS, relative to the uninoculated control.

The experiment was conducted during *Rabi* season during 2001-2002 at Nagpur, on loamy soils. The results showed that, application of 75 per cent of RDF ($90 \text{ kg N } 60 \text{ kg P}_2\text{O}_5/\text{ha}$) + 25 per cent N through FYM + biofertilizers (*rhizobium* + PSB) recorded the higher plant height (36.04 cm), number of leaves per plant (11.20), number of branches per cent (5.93) and leaf area per plant at 60 DAS (131.10) as compared to other treatments (Band *et al.* 2007). Biswas and Patra (2007) reported that application of phosphorus at 40 kg/ha along with seed inoculation with phosphate solubilizing bacteria (PSB) recorded greater canopy height, dry matter accumulation, leaf area index, CGR, NAR and nodulation in summer greengram than 20 kg/ha and control. Gupta (2007) observed that significant increase in grain yield and N uptake in chickpea due Mo application @ 1 kg ha^{-1} (ammonium molybdate) along with *Rhizobium* + PSB.

Kushwaha (2007) reported that the dual inoculation of *Rhizobium* and PSB resulted significant increase in growth and yield attributes viz., plant height, branches per plant, seeds per plant, seed index, grain and straw yield of chickpea. Owla *et al.* (2007) conducted a field experiment on clay soil that was alkaline in reaction (pH 8.3), deficient in total nitrogen, medium in available phosphorus and potassium at MAU, parbhani on greengram and observed that application of 40 kg P₂O₅ ha⁻¹ significantly increased the number of pods per plant, pod weight, grains per pod, 1000-grain weight, grain and straw yield and harvest index over 25 kg P₂O₅ ha⁻¹.

Patel *et al.* (2007) reported that, application of organics with biofertilizers at the 5 t ha⁻¹ (FYM + *rhizobium* + PSB) recorded the significantly increased number of pods per plant (28.70), grain yield (1171 kg ha⁻¹) and straw yield (1014 kg ha⁻¹) in chickpea as compared to without FYM.

Rahul *et al.* (2007) study the effect of biofertilizers and sulphur levels on the growth and yield of blackgram (*Vigna mungo*) cv. Type-9. The treatments consisted of three levels of sulphur (0, 20 and 30 kg ha⁻¹) and seed inoculation (*Rhizobium*, phosphate solubilizing bacteria, *Rhizobium* + phosphate solubilizing bacteria and uninoculated). The results revealed that application of sulphur at 20 kg ha⁻¹ + dual inoculation with *Rhizobium* and phosphate solubilizing bacteria significantly increased the growth characters (plant height, nodules and dry weight) and grain and straw yields of blackgram. A field experiment was conducted by Singh and Sekhon (2007) at Ludhiana revealed that number of pods per plant, 100-seed weight and biological yield of urdbean were significantly higher with phosphorus at 40 kg/ha along with 12.5 kg N than lower doses.

Suman *et al.* (2007) conducted a field study at Bikaner on greengram and noted that application of phosphorus at 30 kg P₂O₅ ha⁻¹ combined with 20 kg K₂O, significantly increased the number of pods/plant, seeds/pod, test weight and seed yield of greengram than lower fertility levels. Biswas and Bhowmick (2008) studied the effect of seed inoculation either singly with *Rhizobium* or in combination with plant growth promoting rhizobacteria on growth, nodulation and seed yield of urdbean. Result indicated that

significantly highest mean seed yield was obtained under co-inoculation of *Rhizobium* with plant growth promoting rhizobacteria as compared to uninoculated control.

Chaudhary *et al.* (2008) noticed that higher plant height (42.30 cm), number of branches (17.28) and dry matter accumulation (17.65 g plant⁻¹) was observed with FYM @ 2.5 t ha⁻¹ + 50 per cent RDF treated plots. But, it was on par with vermicompost @ 3 t ha⁻¹ + *rhizobium* + PSB as soil inoculation (42.20, 16.75, and 17.64 respectively) of chickpea. Choudhary (2008) at Jobner reported that compared to control and 15 kg P₂O₅ ha⁻¹, application of phosphorus at 30 kg ha⁻¹ significantly increased the plant height, branches per plant, dry matter accumulation, chlorophyll content, total and effective number and fresh and dry weight of root nodules per plant in mothbean. Kumar *et al.* (2008) in their study carried out at Ranchi in Jharkhand on urdbean found that number of nodules per plant and dry weight of nodules were the highest at 60 kg ha⁻¹ of applied phosphorus.

Mandal *et al.* (2008) studied the interaction of plant growth promoting rhizobacteria, phosphate solubilizing bacteria and *Rhizobium* on the yield and N, P uptake by urdbean. Inoculation of *Rhizobium* isolates in combination with phosphate solubilizing bacteria in plant growth promoting rhizobacteria increased nodulation, dry weight of plant, grain and straw yield. Co-inoculation of phosphate solubilizing bacteria and plant growth promoting rhizobacteria produced higher grain and straw yield as compared to inoculation of phosphate solubilizing bacteria and plant growth promoting rhizobacteria alone. A field experiment was conducted during 2005 and 2006 on sandy loam soil at arid zone of Rajasthan, to study the effect of integrated nutrient management system in moth bean. A significant increase of plant height (25.70 cm) was noticed with application of FYM @ 2.5 t per ha + 10 kg N per ha + PSB as compared to the control (Raj Singh, 2008).

An experiment was conducted by Rahman *et al.* (2008) at Bangladesh Agricultural Research Institute during *kharif* season, 2005 to study the effect of phosphorus (P), molybdenum (Mo) and *Rhizobium* inoculation on the yield and yield contributing characters of mungbean (*Vigna radiata*) on a silty clay loam soil. The experiment was laid out in RCBD with four replications. Ten treatments were formulated with the

combination of 4 levels of P (0, 20, 40, 60 kg/ha) and 2 levels of Mo (1.0, 1.5 kg/ha) having a common *Rhizobium* inoculant. P and Mo application at the rate of 40 and 1.0 kg/ha respectively, significantly increased yield and yield contributing characters of mungbean compared to uninoculated and control. Highest stover (26.67 g/plant) and grain yield (14.61 g/plant) were obtained with P (40 kg/ha), Mo (1.0 kg/ha) and *Rhizobium* inoculation. Above these levels of P and Mo decreased yield and yield contributing characters. Dry weight of plant tops, seed yield/plant and yield-contributing characters were positively correlated with the number of nodules/plant. Combined application of *Rhizobium* inoculants along with 40 kg P and 1.0 kg Mo/ha was considered to be the suitable combination of fertilizer for mungbean cultivation in silt clay loam soils.

Ravindar and Chandra (2008) conducted field experiment during *Rabi* 2002-03. The seed inoculation with *Rhizobium leguminosarum* bv. *viceae* (LB-4), phosphate solubilizing bacteria (*Bacillus megaterium*) and plant growth promoting rhizobacterium LK-786 (*Kurthia* spp.) alone significantly increased the nodule number at different intervals, nodule dry weight at 45 and 90 days after sowing, plant dry weight at 70 and 90 days after sowing and N uptake by grain and straw in lentil over the un-inoculated control. Co-inoculation of phosphate solubilizing bacteria and plant growth promoting rhizobacteria further improved the nodule occupancy of inoculated *Rhizobium* spp. and recorded highest value at 90 DAS. Combined inoculation treatment of *Rhizobium* spp. + phosphate solubilizing bacteria + LK-786 produced the highest and significantly more number and dry weight of nodules and plant dry weight than *Rhizobium* spp. alone at different intervals. It also gave highest and significantly more nodule occupancy at 45 and 90 days after sowing of 34.7 to 42.3% than *Rhizobium* spp. alone inoculation.

A field experiment on loamy sand soil of Jobner (Rajasthan) was conducted by Sepat and Yadav (2008). They reported that plant height, branches per plant, dry matter accumulation, number and dry weight of root nodules per plant in mothbean increased with every increase in level of phosphorus upto 30 kg ha⁻¹. Shubhangi *et al.* (2008) a field experiment was conducted to study the effect of bio-fertilizers on nodulation, yield, nutrient uptake and biological properties of soil by soybean. The study revealed that

100% RDF with dual inoculation (*Rhizobium* + PSB) resulted in the highest grain (1363 kg ha⁻¹), straw yield (1798 kg ha⁻¹) and also improve the soil fertility by increasing organic carbon content (6.85 g kg⁻¹). The nutrient uptake of nitrogen (132 kg ha⁻¹), phosphorous (64.3 kg ha⁻¹) and potassium (45.1 kg ha⁻¹) increased in the treatment 100% RDF + dual inoculation.

Singh *et al.* (2008) noticed that the grain yield increased significantly with increase in the level of phosphorus. Application of 20 and 40 kg P₂O₅ ha⁻¹ increased the mean yield of urdbean by 16.4 and 51.4%, respectively over the control.

Singh *et al.* (2008) observed the response of blackgram [*Vigna mungo* L.] cv. JU 2, the optimum level of phosphorus through different sources was determined with or without application of phosphorus solubilizing bacteria. Significantly highest seed yield of 651 kg ha⁻¹ was recorded due to application of 40 kg P₂O₅ ha⁻¹ through diammonium phosphate with phosphorus solubilizing bacteria. The increase in seed yield was attributed mainly due to increase in nodulation, plant height, branches plant⁻¹, leaves plant⁻¹ and pods plant⁻¹. Togay *et al.* (2008) reported that seed inoculation with *Rhizobium* significantly increased the plant height, first pod height, number of branches, pods and seeds per plant, grain and biological yield in chickpea.

Vikram and Hamzehzarghani (2008) observed that inoculation of greengram seeds with PSB (PSB-14) recorded the highest nodule number, nodule dry weight, and total effective nodule over control. Yadav *et al.* (2008) conducted study to assess the individual as well as interaction effect of *Rhizobium*, phosphate solubilizing bacteria and plant growth promoting rhizobacteria on yield response of urdbean under laboratory and field trials. Combined inoculation of *Rhizobium* isolates along with phosphate solubilizing bacteria in plant growth promoting rhizobacteria increased grain and straw yield, nitrogen and phosphorus content over *Rhizobium* culture applied alone. Co-inoculation of phosphate solubilizing bacteria and plant growth promoting rhizobacteria produced higher N and P content in grain and straw as compared to single inoculation.

Akhtar and Siddiqui (2009) studied the effects of phosphate solubilizing microorganisms (*Glomus intraradices*, *Pseudomonas putida*, *P. alcaligenes*, *P.*

aeruginosa, *A. awamori*) and *Rhizobium* sp. were observed on the growth, nodulation yield and root-rot disease complex of Chickpea under field condition. Inoculation of *Rhizobium* sp. caused a greater increase in growth and yield than *P. putida*, *P. aeruginosa* or *G. intraradices*. The number of nodules per root system was significantly higher in plants inoculated with *Rhizobium* sp. compared to plants without *Rhizobium* sp. Inoculation of *P. putida* caused highest reduction in galling followed by *P. aeruginosa*, *P. alcaligenes*, *G. intraradices* and *A. awamori* while *Rhizobium* sp. caused almost similar reduction in galling as caused by *P. putida*.

Athokpam *et al.* (2009) conducted a field experiment at CAU, Imphal on blackgram. They found that phosphorus given to the crop @ 40 kg P₂O₅ ha⁻¹ resulted significant enhancement in plant height, number of branches per plant and dry matter accumulation than lower fertility levels. Bansal (2009) reported that seed inoculation of mungbean with *Rhizobium* + PGPR + PSB recorded significantly highest number of nodules per plant and dry weight of nodules per plant over control. Kachhave *et al.* (2009) studied the associative effect of *Rhizobium*, PSB and fertilizers on nodulation and yield of blackgram (*Vigna mungo* L.) in vertisol. The dual inoculation of bio-fertilizer increased the grain yield either with or without chemical fertilizer. The highest grain yield of 856.36 kg ha⁻¹ was recorded in 100 % RDF with dual inoculation. The fresh weight and dry weight of nodules plant⁻¹ showed significant result in dual inoculation with or without chemical fertilizer. Highest number of nodules (30.35) %, fresh weight of nodules 85.47 mg plant⁻¹ and dry weight of nodules 27.39 mg plant⁻¹ was recorded in dual inoculation without chemical fertilizers.

Pir *et al.* (2009) conducted an experiment on mungbean crop and revealed that highest values of plant height, pods per plant, nodule count and test weight were obtained with 5t FYM ha⁻¹ conjugated with 40 kg P₂O₅ ha⁻¹ through rock phosphate + seed inoculation with PSB. Biswas and Bhowmick (2009) evaluated the performance of different *Rhizobium* strains on growth, nodulation and seed yield of urdbean. *Rhizobium* strains namely PUR 34, BKR 1-04, CRU 7 and UP 3 were used. The results revealed significant improvement in most of the growth parameters in inoculated than uninoculated control. Among the different *Rhizobium* strains, CRU 7 yielded higher plant

height (50.4 cm), dry matter accumulation (291.1 g m⁻²), nodule plant⁻¹ (21.0), nodule weight plant⁻¹ (31.8 mg) than other strains and un-inoculated control. significantly higher yield attributing characters like branches plant⁻¹ (3.6), productive pods plant⁻¹ (18.5), seeds pod⁻¹ (6.1), 100 seed weight (3.9 g) and yield (1382 kg ha⁻¹) were recorded under *Rhizobium* strains PUR 34 compared with un-inoculated control (1023 kg ha⁻¹) and other strains.

A field experiment conducted by Singh *et al.* (2009) at experimental farm of SKUAST (K), Shalimar to evaluate the performance of green gram under temperate conditions with inoculation of *Rhizobium*, VAM and N levels indicated a significant improvement in nodule dry weight, rhizobial counts, root colonization, spore density, availability of N, P, K and yield of grain and straw of green gram over the control. Application of 15 kg N ha⁻¹ alone enhanced nodule dry weight and rhizobial counts over 30 kg N ha⁻¹ whereas application of 30 kg N ha⁻¹ significantly improved root colonization, spore density, available N and yield of grain and straw over 15 kg N ha⁻¹. An increase in yield of grain and straw was 17.8 and 17.1% due to application of 30 kg N ha⁻¹ over 15 kg N ha⁻¹. Interaction effect of *Glomus fasciculatum* x *Rhizobium* was most effective but at par with *Glomus mosseae* x *Rhizobium*. The highest grain and straw yield was recorded with *Rhizobium* along with 30 kg N ha⁻¹ and increase was about 4.6 and 4.2% over the *Rhizobium* x 15 kg N ha⁻¹. However, maximum nodule dry weight and rhizobial counts were observed with *Rhizobium* x 15 kg N ha⁻¹ but further successive increase in nitrogen levels caused significant decreases at both the stages of plant growth. The available N, P and K status in the soil increased by 6.65, 7.18 and 6.30% at flowering and 7.18, 14.82 and 6.20% at harvest over 30 kg N ha⁻¹ alone due to *Rhizobium* x 15 kg N ha⁻¹, respectively.

Selva *et al.* (2009) evaluated the response of biofertilizers on the growth and yield of blackgram (*Vigna mungo* L.) in field condition. The different inoculation (single and dual) of biofertilizers *Azotobacter*, *Azospirillum*, *Rhizobium*, phosphobacteria were incorporated into the top 15 cm of the soil. The results revealed that addition of combined inoculation of *Rhizobium* + phosphobacteria significantly increased growth and yield of blackgram compared with control (without biofertilizers).

Tiwari and Kumar (2009) reported that application of phosphorus at 40 kg ha⁻¹ along with recommended dose of N and K increased the number of nodules per plant, number of pods per plant, seeds per pod and grain yield of greengram. Choudhary *et al.* (2010) observed that application of three levels of fertilizer (0, 50 and 100%) and four levels of bio fertilizer (no inoculation, *Rhizobium*, *Rhizobium* + PSB and *Rhizobium* + VAM) significantly increased yield attributes, seed and straw yield of mungbean over control. Goud *et al.* (2010) observed the effect of different manures along with biofertilizers on growth, yield and yield attributes, uptake and soil fertility status of mungbean. Among the seed inoculation, consortium of *Rhizobium* + phosphorus solubilizing bacteria registered significantly higher grain yield over their individual inoculation and control. Population of diversified microbes was greatly influenced due to addition of different organic manures in comparison to inorganic fertilizer alone.

Kumar *et al.* (2010) conducted a field experiment during the *kharif* season of 2006-07 to study the response of rhizobium and different levels of molybdenum on growth, nodulation and yield of black gram. From the experiment results, they reported that seed inoculation with rhizobium and application of molybdenum at 1.0 kg ha⁻¹, recorded significantly higher growth attributes i.e. plant height, branches plant⁻¹, nodules plant⁻¹ and dry matter accumulation plant⁻¹. The similar results were also followed in terms of yield attributes and finally yield of black gram. Rathore *et al.* (2010) from Udaipur reported that every increase in level of phosphorus from 0 to 40 kg/ha brought about significant improvement in yield determining characters of urdbean like number of pods per plant, seeds per pod, test weight as well as seed and straw yields over 20 kg/ha and control and also fetched higher net returns.

Singh *et al.* (2010) studied the response of *Rhizobium* and different levels of molybdenum on growth, nodulation and yield of blackgram. Results revealed that seed inoculation with *Rhizobium* and application of molybdenum at 0.5 kg ha⁻¹ recorded significantly higher growth attributes i.e. plant height, branches plant⁻¹, nodules plant⁻¹ and dry matter accumulation plant⁻¹. However, the similar results were followed in yield attributes and finally yield of blackgram. Field experiment were conducted at Rajasthan, during winter season for chickpea supplied with P (25.8 kg ha⁻¹) + FYM @ 2 t/ha and

seed inoculation with PSB recorded the highest plant height (57.8 cm) and number of branches per plant (4.36) compared to control (53, 90, and 3.93 respectively) (Tanwar *et al.* 2010). Yadav *et al.*, (2010) observed that seed inoculation of mungbean with PGPR combination of *Rhizobium* + *Azotobacter* + *Pseudomonas* + *Aspergillus* + *Trichoderma* significantly increased the number of nodules, nodule dry weight, dry weight of root and shoot at flowering stage over control.

Hussain *et al.* (2011) studied the response of biofertilizers on growth and yield attributes of blackgram (*Vigna mungo* L.). The treatments consisted of combination of three levels of biofertilizers viz., *Rhizobium*, phosphate solubilizing bacteria and *Rhizobium* + phosphate solubilizing bacteria, replicated three times in randomized block design. The combined inoculation of *Rhizobium* + phosphate solubilizing bacteria slightly improved growth characters (plant height, dry matter production, number and weight of nodules plant⁻¹ at maximum flowering) and yield attributes (branches and pods per plant, seeds per pod, 1000 seed weight) than *Rhizobium* and phosphate solubilizing bacteria inoculated separately. Whereas significant increase was recorded in straw yield with combined inoculation of *Rhizobium* + PSB over individual inoculations. Kumar and Singh (2011) reported that the application of phosphorus up to 40 kg P₂O₅ ha⁻¹ increased pods per plant, pods weight per plant, 1000-seed weight, seed and straw per stalk yields. Application of 40 kg P₂O₅ ha⁻¹ gave 43.5% higher yield than control in pigeon pea.

Ratna *et al.* (2011) studied the influence of plant growth promoting rhizobacteria on the competitive ability and performance of inoculated *Rhizobium* spp. on symbiosis in urdbean. *Rhizobium* spp. alone inoculation significantly increased the nodulation, plant dry matter, grain yield and N, P accumulation in urdbean and residual N and P in soil after crop harvesting. Different plant growth promoting rhizobacteria alone inoculation also improved the root nodulation, grain yield by 24.2 to 54.2%, straw yield by 18.0 to 45.5%, N and P uptake and residual N and P over control. The different plant growth promoting rhizobacteria also gave increase of 4.5 to 29.6% in grain yield and 13.5 to 30.3% in straw yield over *Rhizobium* spp. alone inoculation. Dual inoculation of different plant growth promoting rhizobacteria with *Rhizobium* spp. further improved the various growth parameters and yield; however, significant increase in grain and straw yield over

Rhizobium spp. was recorded only with *Rhizobium* spp. + PUK - 46B6 and *Rhizobium* spp. + KB - 133.

Aditya *et al.* (2012) reported that *Rhizobium* inoculation in combination with different micronutrients (Mo) recorded higher nodulation, plant dry weight, grain and straw yield and uptake of N and P than the treatment with only micronutrients or *Rhizobium* alone. Awomy *et al.* (2012) at Medziphema, Nagaland on sandy loam soil observed that application of 40 kg P₂O₅/ha significantly increased the number of pods per plant, seeds per pod, seed and stover yield of greengram over 20 kg P₂O₅ ha⁻¹ and control. Gangwar and Dubey (2012) reported that application of recommended dose of fertilizer (RDF) in chickpea along with *Rhizobium*, PSB inoculation as well as seed treatment with ammonium molybdate @ 2 g kg⁻¹ recorded higher growth and yield attributes than all other treatments. Gupta and Seema (2012) studied the response of chickpea to micronutrients and biofertilizers in vertisol during 2004-05 and 2005- 06. Grain yield was significantly increased by the application of molybdenum through ammonium molybdate @ 1 kg ha⁻¹ with inoculation (1483 kg ha⁻¹), which was 42.9% higher over the recommended dose of fertilizer (1099 kg ha⁻¹) alone.

Qureshi *et al.* (2012) studied the co-inoculation of phosphate solubilizing bacteria and rhizobia in the presence of L-tryptophan for the promotion of mash bean (*Vigna mungo* L.). Results revealed that co-inoculation improved the pod and straw yield considerably but the effect was more pronounced with L-TRP. Co-inoculation increased the root length, root mass, number of nodules and mass as compared to control with L-TRP. Co-inoculation with L-TRP produced 30.8 pod and 32.7 g pot⁻¹ straw yield followed by 30.4 and 31.1 g pot⁻¹ with rhizobial inoculation, respectively. Co-inoculation produced higher root mass (33.5 g), root length (36.0 cm), nodule number (34), nodule mass (0.131 g) and these values were further increased with L-TRP (40.5 g, 49 cm, 48 and 0.145 g). Co-inoculation enhanced the nutrient concentration in mash plant, grains and improved the nodulation as compared to the separate bacterial inoculations.

Singh (2012) reported from Jobner that application of phosphorus at 20 kg ha⁻¹ significantly increased the number of pods per plant, seeds per pod, test weight and seed yield of mungbean over control. Hossain *et al.* (2013) determined the degree of P-

solubilization using phosphate solubilizing isolates and their effect on growth and yield of mungbean under both laboratory and pot experiments. Based on the results, they concluded that phosphorus @ 20 and 60 kg P ha⁻¹ along with I4 and 11 isolates of PSB were the best treatments for increasing mungbean yield. Khan *et al.* (2013) conducted an experiment and results indicated that seed inoculation with the *Rhizobium* and PSB significantly increased the seed, straw and biological yield over control in cowpea.

Kumawat *et al.* (2013) compared two levels of phosphorus in blackgram on clay loam soil of Udaipur having medium P availability and noted that number of pods per plant, grains per pod, 100-grain weight and seed weight increased significantly due to application of 40 kg P₂O₅ ha⁻¹ than 20 kg/ha. This level of P fertilization also increased the seed, haulm and biological yield of crop by 35.5, 50.6 and 45.6 per cent respectively in comparison to 20 kg P₂O₅ ha⁻¹. Mir *et al.* (2013) found that the inoculation of blackgram seeds with phosphorus solubilizing bacteria recorded slightly higher grain yield (7.49 q ha⁻¹) as compared to no inoculation (7.39 q ha⁻¹). Patel *et al.* (2013) at Sardarkrushi nagar concluded that phosphorus fertilization at 40 kg ha⁻¹ recorded significantly highest number of pods/plant, length of pod, number of seeds/pod, yield/plant as well as seed and stalk yield of kharif mungbean over 20 kg ha⁻¹ and control.

Poonia and Pithia (2014) found that the inoculation treatments influenced significantly the chickpea plant height, nodules/plant and therefore, increased the seed yield. The highest chickpea seed yield (1882 kg ha⁻¹) was produced with combination of RDF+ Ammonium molybdate (1 g kg⁻¹ seed) + *Rhizobium* + PSB over control (1538 kg ha⁻¹) and remained equal with RDF + Ammonium molybdate (2.0gkg⁻¹ seed) + *Rhizobium* + PSB (1832 kg ha⁻¹) and RDF + *Rhizobium* + PSB (1805 kg ha⁻¹) and these treatments produced 22.4, 19.1 and 17.4% more seed yield over control respectively. Prajapati *et al.* (2013) concluded that yield attributes of greengram viz., number of pods per plant, grain and stover yield were significantly enhanced due to progressive increase in level of phosphorus upto 40 kg ha⁻¹ over preceding levels. Tagore *et al.* (2013) observed that among the microbial inoculants, *Rhizobium* + PSB was found most effective in increasing the nodule number (27.66 nodules per plant), nodule fresh weight (144.90 mg per plant),

nodule dry weight (74.30 mg per plant) and leghaemoglobin content (2.29 mg g⁻¹ of fresh nodule) in chickpea.

Tomar *et al.* (2013) carried out a field experiment on sandy clay soil of U.P. and concluded that the number of pods/plant, pod length, grains/pod, 1000- grain weight, grain and straw yield of urdbean increased significantly with every addition in level of phosphorus upto 40 kg/ha. Gajera *et al.* (2014) conducted a field experiment on summer greengram at JAU, Junagadh on clay soil and reported that application of 40 kg P₂O₅ per ha significantly increased the plant height, branches per plant, dry weight of nodules, leaf area index and dry matter accumulation which was at par with 60 kg P₂O₅/ha.

Khan and Prakash (2014) conducted a field experiment during two consecutive years of 2011 and 2012 at Student Instructional Farm of N.D. University of Agriculture and Technology, Narendra Nagar (Kumarganj), Faizabad to study the effect of rhizobial inoculation on growth, yield, nutrient uptake and economics of summer urdbean in relation to zinc and molybdenum. Result data revealed that the seed inoculation with *Rhizobium* culture significantly increased growth attributes viz., plant height, number of primary and secondary branches per plant, number and dry weight of nodules per plant, seed and stover yield, nitrogen, zinc and molybdenum uptake. Application of 2.5 kg Zn/ha significantly increased the growth attributes, nodulation, seed and stover yield, nutrient uptake and economics of urdbean over control. Zinc uptake significantly increased up to 5.0 kg Zn ha⁻¹. Application of molybdenum up to 1.0 kg ha⁻¹ significantly increased growth characters, number and dry weight of root nodules, seed and stover yield, nutrient uptake.

Kumar *et al.* (2014) carried out a field experiment on blackgram at Baghpat (U.P) and found that phosphorus fertilization at 40 P₂O₅ kg per ha significantly increased the yield attributing characters like pods per plant, grains per pod, 1000 grain weight, grain and straw yield as compared to control and 20 P₂O₅ kg per ha. Singh *et al.* (2014) conducted a field experiment on sandy loam Typic Ustochrept at the Agricultural research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, UP during *Kharif* (2009) with mungbean. The results revealed that grain and straw yield increased significantly with increasing levels of both P and S. The percent increase in

grain yield due to P and S application varied from 21.4 to 36.8% and 1.7 to 16.2%, respectively. In the untreated plots, N uptake and protein content in grain and straw was 17.7 and 46.9 kg ha⁻¹ and 21.3 and 11.9 %, respectively.

Tahir *et al.* (2014) conducted a field trial to evaluate the effect of Molybdenum (Mo) on yield and quality of black gram (*Vigna mungo* L.) (mash) at Agronomic Research Farm, University of Agriculture, Faisalabad, Pakistan during spring 2012. The results revealed that the plant height at maturity (55.30 cm), number of nodules per plant (11.17), number of pod bearing branches (13.43), number of pods per plant (27.70), protein content (24.53%), carbohydrate content (59.53%), number of seeds per pod (10.00), pod length (6.98 cm), 1000 seed weight (40.18 g), seed yield (1049.2 kg ha⁻¹), biological yield (6480 kg ha⁻¹) and harvest index (16.67 %) were significantly higher over control. The results of this study highlighted the role of Mo as seed treatment for improving the yield and quality in greengram.

Yadav *et al.* (2014) reported that seed treatment with *Rhizobium* and Phosphate Solubilizing Bacteria + Fertilizer (12.5 kg ha⁻¹ N and 40 kg ha⁻¹ P₂O₅) as basal dose + Borax spray (100 ppm) at flower initiation gave higher seed yield and harvest index and improved seed vigor in the terms of germination, seedling length and vigor index of mungbean. Jha *et al.* (2015) conducted a field experiment at the instructional farm of Rajasthan College of Agriculture, Udaipur, Rajasthan during *kharif* season to study the effect of organic and inorganic sources of nutrients on yield and economics of blackgram and found that split dose of vermicompost indicate that split application of vermicompost 1 t ha⁻¹ at 30 DAS along with FYM 2 t ha⁻¹ (Basal) recorded a significant increase yield and net returns of blackgram over vermicompost 1 t ha⁻¹ (Basal) + vermicompost 1 t ha⁻¹ at 30 DAS and control, respectively.

Kokani *et al.* (2015) conducted an experiment to study the effect of phosphorus and sulphur on yield of summer blackgram and post harvest status of nutrients under South Gujarat condition at college farm, Navsari Agricultural University, Navsari during summer 2013. The results revealed that the phosphorus applied @ 40 kg/ha was recorded significantly superior plant height at 60 DAS and harvest, number of branches, number of pods/ plant, number of seeds/ pod, length of pod, grain (1171 kg/ha) and stover (2667

kg/ha) yields as well as protein yield (232.10 kg/ha) of blackgram and available phosphorus in soil (41.97 kg/ha) over control. Significantly the higher plant height at 60 DAS and harvest, number of branches/plant, number of pods/ plant, seeds/ pod, grain (1153 kg/ha), stover (2548 kg/ha) as well as protein yield of blackgram and available S (21.63 ppm) in soil were observed under 20 kg S/ha compared to control.

Rathore *et al.* (2015) revealed that application of 40 kg P₂O₅ ha⁻¹ from SSP significantly increased growth and yield attributes and seed yield (802 kg ha⁻¹) over control but remain at par with application 20 kg P₂O₅ ha⁻¹ from SSP + PSB inoculation @ 5ml kg⁻¹ seed. Amanullah *et al.* (2017) conducted a field experiment at the Agronomy Research Farm of the University of Agriculture, Peshawar-Pakistan on the phenological development, growth, yield and yield components of moong bean (*Vigna radiata* L.) in comparison to mash bean (*Vigna mungo* L.) under rainfed/moisture stress condition to evaluate the impact of phosphorus (0, 30, 60 and 90 kg P ha⁻¹) and found that increase in P levels resulted in earlier phonological development, improved growth, increased number of nodules plant⁻¹, yield and yield components of both crops.

Balai *et al.* (2017) conducted a field experiment at agronomy farm, College of Agriculture, Bikaner during *Rabi*, 2009-10, assigning four levels of phosphorus (control, 20, 40 and 60 kg ha⁻¹). The results revealed that increase in P content and uptake by grain and straw was significantly increased by applying increasing level of phosphorus upto 60 and 40 kg P₂O₅ ha⁻¹, respectively. Mohammad *et al.* (2017) conducted a field experiment during *Kharif* season 2015 at Agronomy farm of SKN College of Agriculture, Jobner (Rajasthan). The results of the study indicated the application of phosphorus up to 40 kg P₂O₅ ha⁻¹ recorded significantly higher number of pods per plant, number of seeds per pod and seed and straw yield as compared to absolute control.

Singh *et al.* (2018) conducted an experiment at Agronomy Research Farm of Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad (Uttar Pradesh) during the zaid season of 2016. Results revealed that number of pod per plant, number of grain per pod, biological yield, seed yield, stover yield (q ha⁻¹), harvest index (%) and NPK uptake of mung crop increased significantly under the integrated treatment (40 kg P₂O₅ ha⁻¹ + PSB). Serawat *et al.* (2018) revealed that application of 40 kg P₂O₅ ha⁻¹

¹ significantly increased the root nodules per plant, number of pods per plant, number of seeds per pod, seed and straw yield, nitrogen, potassium, sulphur content and their uptake by seed and straw and protein content in seed. Whereas, the phosphorus content in seed and straw significantly increased with increasing levels of phosphorus up to 60 kg P₂O₅.

Singh *et al.* (2018) carried out an experiment to determine the effects of PSB and rhizobium inoculation for a chickpea (*Cicer arietinum* L.) variety, Awarodhi, under Central Uttar Pradesh conditions in 2015-16. The result shows that treatment combination Rhizobium + PSB has been found best in respect of number of nodules, seed and stover yield, nitrogen, phosphorus content and its uptake and also in protein content of seed.

2.4.2 Root nodules

Kumpawat and Manohar (1994) reported that the application of Mo @ 1 kg ammonium molybdate ha⁻¹ increased the dry weight of nodules plant⁻¹ significantly. Rhizobium inoculation significantly affected the number and dry weight of nodules plant⁻¹ in Bengal gram. Pattanayak *et al.* (2000) concluded that *Rhizobium* inoculation alone or with Mo significantly increased the nodule number of greengram plants. Mo treatment significantly improved the nodule weight, which was the highest in treatment receiving Mo @ 0.16 mg g⁻¹ seed. The untreated plant nodules possessed less leghaemoglobin (0.668 mg g⁻¹ of fresh weight of nodule) than in inoculated plants viz., 0.757 mg g⁻¹. Mo application increased its level to as high as 1.58 mg g⁻¹ of nodule. Bhattacharya and Pal (2001) observed that application of Mo @ 0, 0.5 and 1.0 kg ha⁻¹ to summer greengram significantly improved the number of nodules per plant, dry matter accumulation and plant height. Maximum growth was obtained in *Rhizobium* treatment compared with P at 40 kg ha⁻¹ and Mo at 0.5 kg ha⁻¹.

Kumawat and Agarwal (2001) found that increasing levels of Mo application significantly increased the number and fresh weight of nodules in chickpea plant upto 1.5 kg Mo ha⁻¹. Shivkumar and Kumutha (2003) reported that inoculation of groundnut seeds along with three levels of 0, 2.5 and 5.0 g per kg seed under pot culture and reported that number of branches per plant, number of nodules per plant, number of branches, number of nodules and dry weight of nodules increased at 30 DAS and at harvest. Application of

molybdenum at 2.5 g per kg of seed was found to be the best treatment in increasing nodulation and yield parameters.

Phogat *et al.* (2018) reported that number of nodules plant⁻¹ increased significantly with increasing levels of phosphorus up to highest level and the optimum values were recorded with combined application of phosphorus 60 kg ha⁻¹.

2.4.3 Nutrient content and uptake

The Mo content of root nodules on dry weight basis was also higher in Mo treated plants as compared to the untreated plants in greengram crop when Mo was applied @ 0.3 g kg⁻¹ seed as seed treatment. The N concentration increased progressively with Mo fertilization. The *Rhizobium* inoculated plants showed higher concentration of N even without added nitrogen as compared to the highest level of nitrogen in the uninoculated plants. The nitrogen concentration at harvest declined in all plant parts (Paricha *et al.*, 1983). Rao *et al.* (1985) reported that uptake of N and P increased significantly due to Mo application @ 1.5 kg ammonium molybdate over control in blackgram crop. The nitrogen content of cowpea grain increased significantly with increasing levels of Mo linearly (Mo @ 0, 1 and 2 kg ha⁻¹). *Rhizobium* inoculation also increased the protein content significantly by about 2 %. Interaction between *Rhizobium* and Mo was also significant; the highest was recorded by the application of 2 kg Mo ha⁻¹ with *Rhizobium* culture (Baldeo Singh *et al.* 1992).

Pattanayak *et al.* (2000) stated that in greengram crop the uptake of N was significantly increased due to *Rhizobium* inoculation and Mo application @ 0.16 mg g⁻¹ of seed. The highest uptake was through grain than stover and husk. The P, K and Ca uptake were also significantly increased by both seed inoculation with *Rhizobium* and Mo application @ 0.16 mg g⁻¹ seed. Mir *et al.* (2013) recorded that application of 40 kg P₂O₅ ha⁻¹ result in maximum phosphorus content of grain (0.356%) in black gram respectively as compared to lower levels. Niraj and Prakash (2014) showed that application of 40 kg ha⁻¹ P produced highest grain and straw yield along with nutrient content and uptake of nitrogen, phosphorus, potassium and sulphur over rest of the treatments in black gram.

Gupta (2009) reported that application of 40 kg P₂O₅ ha⁻¹ through DAP along with basal dose of 20 kg N ha⁻¹ recorded significantly higher N and P uptake by chickpea over lower levels of P₂O₅.

Mohammad *et al.* (2017) showed that application of phosphorus upto 40 kg P₂O₅ ha⁻¹ recorded significantly higher nitrogen, phosphorus and potassium uptake in seed and straw of mungbean as compared to absolute control and 20 kg P₂O₅ ha⁻¹ but was at par with 60 kg P₂O₅ ha⁻¹.

2.4.4 Phosphorus use efficiency (PUE)

Terry *et al.* (2015) explained phosphorus use efficiency can be assessed in several ways, but the "balance" method (i.e. partial nutrient balance) calculated as a P removal-to-input ratio and expressed as a percent best reflects the behavior of fertilizer P in soils and supports the concept of P transfer and availability within the four pools. Improving fertilizer P use and effectiveness is achievable through the implementation of fertilizer best management practices within the context of 4Rs—application of the right nutrient source, applied at the right rate, right time, and in the right place.

Srinivasarao *et al.* (2015) reveals that Indian soils do not have enough P to meet the demands of existing high yielding crops of this era. The phosphorus use efficiency can be improved by following '4R nutrient management approach' through selection of right fertilizer of right amount to be applied at right time to meet the crop demand by right application method. Although there exists 250 cropping systems in India, it is of paramount importance to know P requirement of major cropping systems. The application of P on the basis of cropping sequence instead of individual crop needs to be taken into consideration for improving P use efficiency. There are simple agronomic techniques like crop rotation and intercropping by which P use efficiency may be enhanced. Use of cheaper P sources such as P biofertilizers, organic manures, and low grade rock phosphates available in India can better be used to improve PUE.

Basha *et al.* 2018 carried out experiment with 14 treatments to examine the P release pattern and revealed that highest PUE was found when P source was combined with FYM (Majumdar *et al.* 2007).

MATERIALS AND METHODS

The present investigation entitled “**Effect of phosphorus, molybdenum and organics on soil quality and crop performance of blackgram under rainfed ecology of Jammu**” was conducted at Advance Centre for Rainfed Agriculture at Rakh Dhiansar, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, during 2016 and 2017. The details of materials and methods employed for determination of various parameters of aforesaid study have been described in this chapter under the following sub-heads:

Also, hundred soil samples along with GPS (geographical positioning system) location from different locations of pulse growing areas were collected, processed and analyzed for various physico-chemical properties and available N, P, K and Mo by standard methods and their correlation was also worked out.

3.1 Location of experimental site

The experiment was conducted at Advance Centre for Rainfed Agriculture at Rakh Dhiansar, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, during two consecutive years, i.e. 2016 and 2017. Geographically, the experimental site is located at 32° 39' N latitude and 74° 58' E longitude at an elevation of 332 meters above the mean sea level in the Shivalik foothill plains of North-Western Himalayas.

3.2 Climate

The meteorological data of experimental site with respect to rainfall, temperature and relative humidity were recorded at meteorological observatory located very close to the experimental area and had been presented in Table 3.1 which revealed that the experimental site was mainly sub-tropical in nature endowed with hot and dry summers followed by hot and humid monsoon. The mean annual rainfall varies from 1050 - 1115 mm of which about 75 per cent is received during *kharif* season. Dry spells are

experienced during months of May and June and sometimes *kharif* rains are delayed upto mid of July. However, the total rainfall and its distribution are subjected to large variations. The mean maximum and minimum temperature showed considerable fluctuations during summer and winter season. The temperature often rises to as high as 45°C in the month of May-June, while the temperature remains cold during winter months especially in December-January.

3.3 Soil of the experimental field

Initial soil samples were collected from 0-15 cm soil depth. The soil samples were passed through 2 mm sieve and then processed and analyzed for different physico-chemical and biological properties as per the standard methods. The analysis of the initial samples collected from experimental site revealed that the soil was sandy loam in texture, low in organic carbon and low in available nitrogen, medium in available phosphorus and potassium contents. According to soil taxonomy, the soils of the study area fall in the order Entisol. Initial soil properties of the experimental site are given below in Table 3.2.

3.4 Cropping history of the experimental field

The cropping history for the last 5 years of the experimental site is given in Table 3.3.

3.5 Experimental details

The experiment including 13 treatments was conducted with sowing of blackgram crop *var.* Uttara during 2016 and 2017. The details of treatment combination are given under heading 3.5.3.

3.5.1 Experimental design

Randomized Complete Block Design (RCBD) with three replications was used to carry out the present investigation.

3.5.2 Layout

The experiment consisted thirteen treatment combinations with three replications representing 39 plots, was laid out in Randomized Complete Block Design. The plan of

Table 3.1: Mean weekly weather parameters prevailing during the crop season

SMW. No.	Month	Temperature °C				Relative Humidity				Rainfall (mm)	
		Max.		Min.		2016		2017		2016	2017
		2016	2017	2016	2017	M	E	M	E	2016	2017
25	June	38.4	38.3	18.3	19.5	94	45	90	41	84.5	39.7
26		39.7	39.8	19.3	16.4	90	51	96	40	22.7	85.1
27	July	37.4	37.2	16.9	19.7	88	37	97	63	28.8	23.1
28		35.5	37.8	20.5	23.3	97	44	93	67	138.6	75.4
29		36.9	35.2	19.6	22.6	90	53	88	64	14.3	84.2
30		35.0	34.0	18.1	20.9	96	66	98	60	167.8	96.5
31	August	37.6	35.0	19.7	21.4	96	49	97	63	87.2	83.8
32		35.6	34.2	20.6	22.0	95	41	93	71	40.1	76.6
33		38.2	35.2	18.6	20.7	92	40	91	65	6.8	24.7
34		35.8	34.6	20.5	19.1	95	39	98	64	2.1	25.5
35		34.8	33.5	16.5	21.1	96	56	89	60	91.3	47.5
36	September	36.3	33.9	20.2	20.4	92	38	90	65	00.0	00.0
37		36.3	34.1	15.5	19.6	96	43	87	55	41.5	00.0
38		36.7	34.3	18.1	18.0	97	58	85	40	5.5	00.0
39		33.8	31.2	15.7	21.5	93	48	92	55	8.1	00.0
40	October	34.1	28.1	16.5	18.8	86	49	79	42	00.0	00.0
41		34.0	27.6	14.9	16.8	87	47	74	37	00.0	00.0

*Standard meteorological week

*M= Morning E= Evening

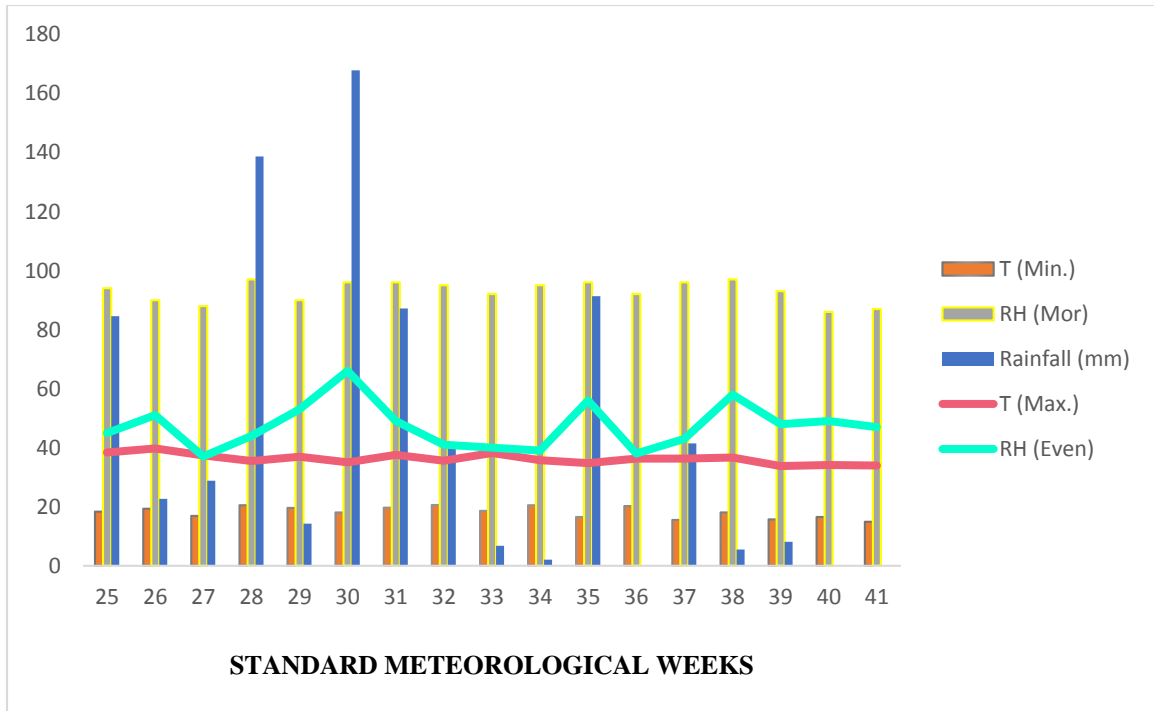


Fig. 3.1: Weekly mean meteorological data during 2016

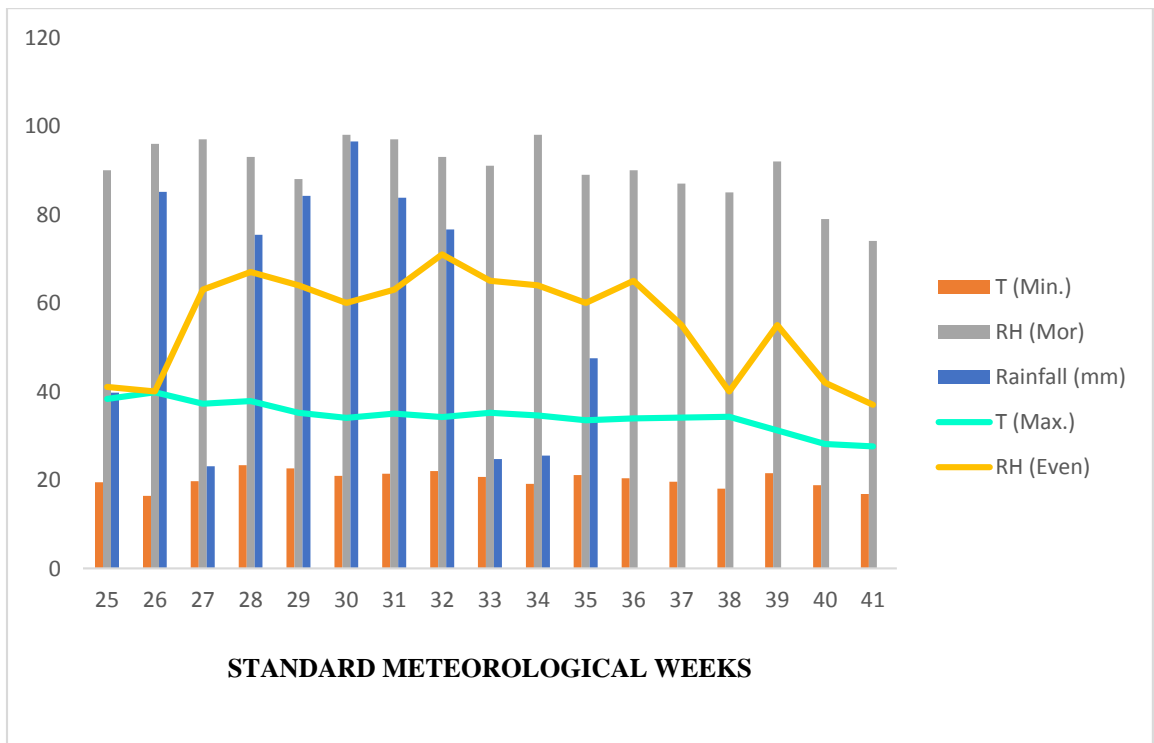


Fig. 3.2: Weekly mean meteorological data during 2017

Table 3.2: Initial values of experimental site

<u>Soil Property</u>	<u>Value</u>
<u>Mechanical composition</u>	
Sand (%)	66.30
Silt (%)	18.90
Clay (%)	14.80
Textural class	Sandy loam
<u>Physico-chemical properties</u>	
Soil reaction (pH)	6.50
Electrical conductivity (dS m ⁻¹)	0.25
Soil Porosity (%)	42.02
Water holding capacity (%)	30.11
Bulk density (Mg m ⁻³)	1.52
Available N (kg ha ⁻¹)	94.76
Available P (kg ha ⁻¹)	8.87
Available K (kg ha ⁻¹)	114.06
Available Mo (mg kg ⁻¹)	0.235
Labile carbon (LC) (mg kg ⁻¹)	303.2
Soil organic carbon (SOC) (g kg ⁻¹)	2.43
Particulate organic carbon (POC) (g/m ²)	255.4
Microbial biomass carbon (mg kg ⁻¹)	28.34

layout of experiment with allocation of the treatments and other details are given in Figure 3.1.

Table 3.3: Cropping history of experimental field

Year	<i>Kharif</i>	<i>Rabi</i>
2012-13	Wheat	Fallow
2013-14	Fallow	Maize
2014-15	Wheat	Maize
2015-16	Wheat	Maize
2016-17	Experimental crop	Fallow

3.5.3 Details of the treatments

The experiment consisted of following 13 treatments as given below:

T ₁	:	Control
T ₂	:	20 kg P + PSB
T ₃	:	20 kg P + PSB+ Rhizobium
T ₄	:	20 kg P + PSB+ Rhizobium+ FYM
T ₅	:	20 kg P+ 0.5Mo kg + PSB
T ₆	:	20 kg P+ 0.5Mo kg + PSB+ Rhizobium
T ₇	:	20 kg P + 0.5Mo kg + PSB+ Rhizobium + FYM
T ₈	:	40 kg P + PSB
T ₉	:	40 kg P + PSB+ Rhizobium
T ₁₀	:	40 kg P + PSB+ Rhizobium+ FYM
T ₁₁	:	40 kg P + 0.5Mo kg + PSB
T ₁₂	:	40 kg P+ 0.5Mo kg + PSB+ Rhizobium
T ₁₃	:	40 kg P + 0.5Mo kg + PSB+ Rhizobium + FYM

Where *P* represents P_2O_5 and *Mo* represents ammonium molybdate

3.5.4 Details of layout

I.	Crop	:	Blackgram
II.	Variety	:	Uttara
III.	Year of experiment	:	2016 and 2017 (<i>Kharif</i> season)
IV.	Seed rate	:	15-20 kg ha ⁻¹
V.	Total No. of treatments	:	13 treatment combinations
VI.	Replications	:	3
VII.	Total no. of plots	:	39
VII.	Plot size		
	(a) Gross	:	4.0 m x 2.6 m
	(b) Net	:	3.5 m x 2.0 m
VIII.	Row spacing	:	30 cm
IX.	Plant spacing	:	10 cm
X.	Experimental design	:	Randomized Complete Block Design

3.5.5 Seed Inoculation

Seeds were inoculated as per treatment with *Rhizobium* and phosphorus solubilizing bacteria (PSB) culture as per method given below:

(a) **Rhizobium**

Required seeds were inoculated with *Rhizobium* culture @ 25 g kg⁻¹ seed. For this, slurry of carrier based culture was prepared in sterilized 20% gur solution. All seeds were uniformly treated, dried in shade.

(b) **PSB (Phosphorus solubilizing bacteria)**

As per treatment, the seeds were inoculated with PSB @ 5 g kg⁻¹ seed as per routine procedure 2-3 hours before sowing and dried in shade.

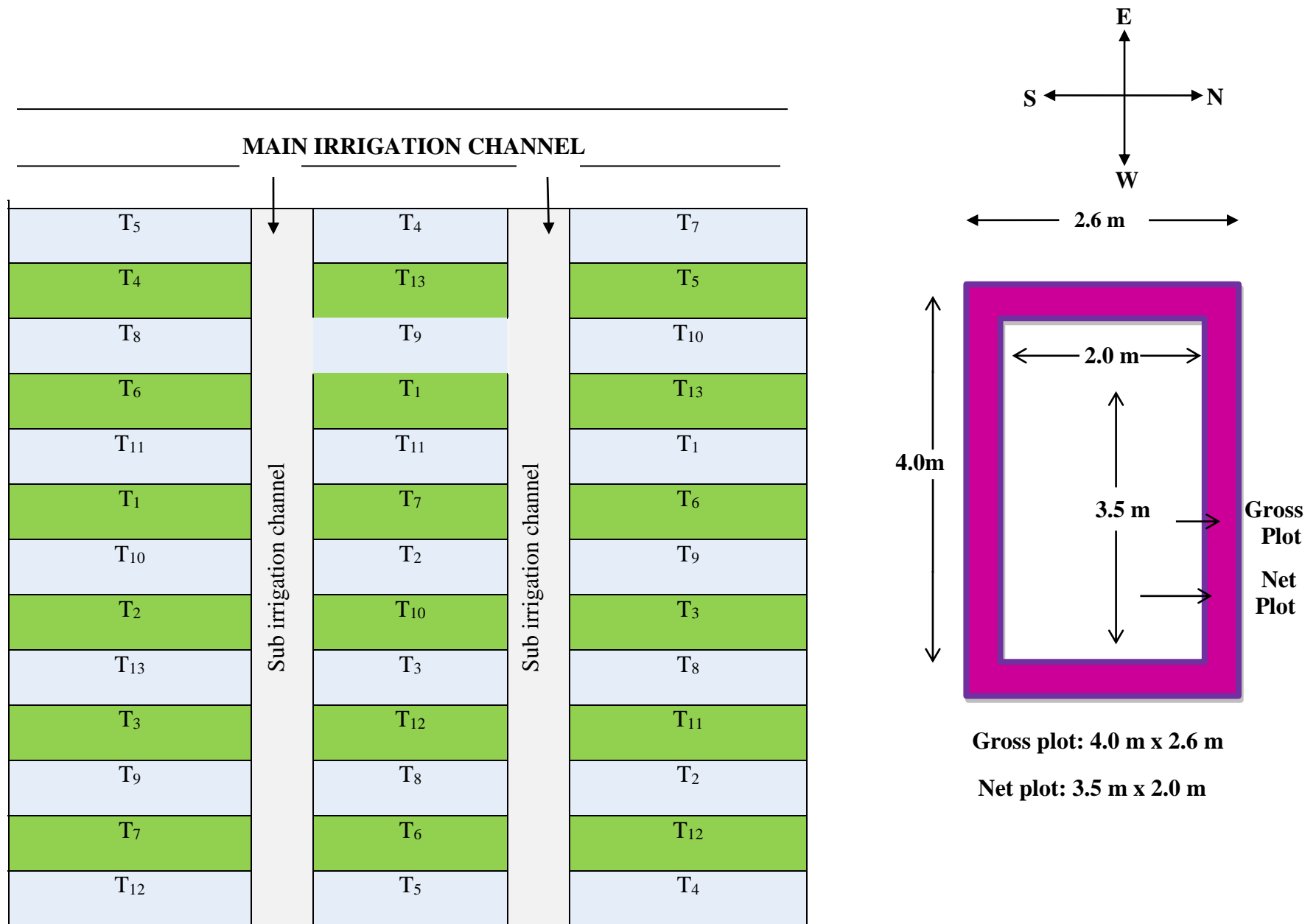


Fig. 3.3: Layout plan of the field experiment

3.5.6 Calendar of cultural operations

The calendar of cultural operations carried out during the course of investigation is given in Table 3.4.

3.5.6.1 Preparatory tillage

Experimental field was ploughed by tractor driven mould board plough followed by two cross harrowing and planking. Planking was also done to obtain fine seedbed. The experimental field was then demarcated as per plan of layout. The same procedure was repeated during the second year of experimentation.

3.5.6.2 Fertilizer application

The whole quantity of phosphorus and molybdenum was applied through diammonium phosphate and ammonium molybdate as per treatment details. The amount of different fertilizers required to supply the needed quantities of nutrients was calculated as per plot basis.

3.5.6.3 Harvesting, threshing and winnowing

The crop was harvested at maturity stage, when the foliage was shaded off and the pods turned yellowish brown to brown colour. One border row from both sides and 30 cm from either ends of each plot were harvested in order to eliminate the border effect. The five tagged plants, for recording the post harvest observations, were harvested separately from the net experimental plots. The rest experimental plot was harvested by sickles and the harvested materials of each plot were tied in bundles. Bundles were kept open in sun as such for drying for 3 - 4 days and then weighed to record biological yield per plot.

Threshing was done by manual labour separately with wooden sticks, followed by winnowing with the help of indigenous winnower *Supa* (local name). After cleaning the seed, yield per plot was recorded. Straw yield was calculated by subtracting grain yield from bundle weight (biological yield) of total produce.

3.6 Post-harvest soil analysis

The processed soil samples were analyzed for various soil physico-chemical and biological properties as per the procedures outlined below:

3.6.1 Soil reaction (pH)

Soil reaction of the soil samples was determined in 1:2.5 soil:water ratio (w/v) with the help of glass electrode pH meter (Jackson, 1973).

3.6.2 Electrical conductivity

Electrical conductivity was estimated in 1: 2.5 soil:water suspension with EC meter as given by Jackson (1973).

3.6.3 Particle size analysis

Mechanical analysis of soil was carried out by hydrometer method using bouyoucous hydrometer as outlined by Piper (1966).

3.6.4 Bulk density

Soil bulk density was determined by the core sampler method. Mass of solids and water content of the soil were determined by weighing the wet core, drying it to constant weight in an oven at 105°C as described by Piper (1950).

3.6.5 Water holding capacity

Water holding capacity was determined by the Keen Rackzowski box method as outlined (Keen and Rackzowski, 1921).

3.6.6 Aggregate stability

The Eijkelkamp wet sieving apparatus was used to determine the aggregate stability (water stable aggregates) of a soil. To determine the stability, 8 sieves were filled with a 4 g of soil aggregates. These sieves were placed in a can filled with water which moves up and downward for a fixed time. Unstable aggregates fall apart, pass through the sieve and are collected in the water filled can underneath the sieve. After the fixed time,

Table 3.4: Schedule of cultural operations carried out in the experimental field

S. No.	Operation	Date of operation		Remarks
		2016	2017	
1	Ploughing by tractor	22-06-2016	24-06-2017	Tractor drawn disc harrow
2	Harrowing and Planking	23-06-2016	25-06-2017	
3	Layout and preparation of beds	24-06-2016	27-06-2017	Manually
4	Application of FYM as per treatment (2 t/ha)	25-06-2016	28-06-2017	Manually
5	Sowing of seed inoculated with PSB and rhizobium culture	01-07-2016	04-07-2017	Line sowing was done manually at spacing i.e, 30 × 10 cm
6	Fertilizer application as per treatment	01-07-2016	04-07-2017	Manually
7	Herbicide application	12-07-2016	14-07-2017	Application of pendimethalin @ 1.0 kg/ha
8	Intercultural operations	28-07-2016	29-07-2017	Manually
9	Hand weeding	31-07-2016	31-07-2017	Weeding was done with <i>khurpi</i> to keep the field free from weeds
10	Harvesting	06-10-2016	07-10-2017	Crop was harvested manually
11	Threshing and winnowing	11-10-2016	12-10-2017	Threshing was also done manually

the cans were removed. Now, all the aggregates were destroyed. Further, cans were kept for drying. After drying, % WSA was calculated.

3.6.7 Infiltration rate

Steady state infiltration rate was measured by using double ring infiltrometer. Readings were recorded at 5, 10, 15, 30 minutes and then one hour intervals till constant steady state rate was obtained (Gupta, 1999).

3.6.8 Soil Porosity

Porosity was determined by the Keen Rackzowski box method as outlined by Piper (1956).

3.6.9 Organic carbon

Organic carbon was analyzed with the help of Rapid titration method as proposed by Walkley and Black (1934).

1 g of air dried soil sample (0.2 mm) was taken in 500 ml conical flask and 10 ml of 1 N potassium dichromate followed by 20 ml of conc. sulphuric acid added to it. Kept this on asbestos sheet for 30 minutes and then added 250 ml of distilled water and 10 ml of orthophosphoric acid. Titrated the sample against 0.5 N ferrous ammonium sulphate after addition of diphenylamine indicator into it. A blank sample was kept for computation of potassium dichromate consumed by carbon in the sample.

3.6.10 Particulate organic carbon (POC)

Particulate organic carbon (POC) was determined by mechanical dispersion and separation method outlined by Camberdella and Elliott, 1992. The 2 mm sieved 10 g soil sample dispersed by sodium hexameta phosphate and shaken continuously for 18 hours and passed the dispersed materials through 53 μm sieve and sand plus POC retained on sieve was collected in an aluminum dish and dried at 50°C for 24 hrs. The retained POC fraction was digested with potassium dichromate and back titrated with ferrous ammonium sulphate for determination of organic carbon.

3.6.11 Microbial Biomass carbon (MBC)

Soil microbial biomass carbon was determined by fumigation- extraction method in fresher incubated soil samples at 27 °C described by Vance *et al.* (1987). 10 g of incubated soil in two sets were taken in 100 ml beakers. Record the moisture content in a sub-set of soil to correct soil weight in case of field moist samples. Incubated the soil for 5 days at 27 ± 1 °C at field capacity. About 40 ml ethanol free chloroform taken along with some glass beads in 100 ml beaker and placed it in the vacuum desiccators. Lined the inner surface of desiccators with moist filter paper. Kept one set of samples for fumigation in vacuum desiccators. Joined lid to ensure proper sealing using a rubber tube to direct exhaust through water then switched on the vacuum pump and kept it on until chloroform boils for about 5 minutes. Closed the outlets and keep the desiccators in the dark place for 24 hours. After 24 hours, release the vacuum, taken out the beaker containing chloroform and inner lined. Also performed back suction to ensure removal of any excess of chloroform vapors and released vacuum slowly.

All the non-fumigated and fumigated samples were taken and transferred these samples in 500 ml conical flask and added 25 ml of 0.5 M potassium sulphate (K₂SO₄). Shaken it for 30 minutes and filtered the content, transferred 10 ml aliquot in 500 ml conical flask and added 2 ml of potassium dichromate (0.4 N), 10 ml conc. sulphuric acid, and 5 ml of orthrophosphoric acid to each flask. Two blanks samples were run with 10 ml of distilled water simultaneously, kept the flasks on a hot plate at 100 ° C for half an hour. Then added about 250 ml of distilled water to each and allowed to cool down to room temperature. Added 1 ml of diphenylamine indicator and titrated the content against 0.035 N ferrous ammonium sulphate until greenish color appeared as end point. A blank extract was kept for computation of potassium dichromate consumed by carbon in the sample. Microbial biomass carbon was estimated by taking difference of carbon content between fumigated and non-fumigated samples as shown in the formula:

$$\text{SMBC in soil } (\mu\text{g g}^{-1} \text{ soil}) = (\text{Ext. } C_F - \text{Ext. } C_{NF}) / K_{EC}$$

Where,

E_{CF} = Extractable carbon in the fumigated soil sample.

E_{CNF} = Extractable soil sample in the non- fumigated soil sample.

K_{EC} = 0.45 ± 0.05 it represents the efficiency of extraction of microbial biomass carbon.

3.6.12 Labile carbon (Permanganate oxidizable soil carbon)

Permanganate oxidizable soil carbon (POSC) in soil sample was analyzed as per procedure outlined by Blair *et al.* (1995). 3 g air dried soil (< 2mm) was taken in centrifugal tube and 30 ml of 20 M $KMnO_4$ was added to it. It was shaken for 15 minutes in horizontal shaker and then centrifuged for 5 minutes at 2000 rpm. 2 ml clear aliquot was taken and made the volume to 50 ml and measured absorbance at 565/560 nm. To prepare the standard curve, pipette out 0, 0.5, 1, 1.5 and 2 ml of 20 M $KMnO_4$ and made the volume to 50 ml. Recorded the absorbance at 560/565 nm and plotted a curve for concentration Vs. absorbance and also recorded the slope of the curve.

3.6.13 Microbial count (bacteria and fungi)

Microbial population in soil samples were determined by standard serial dilution plate technique. In this technique, 1 g on dry weight basis of pre-sieved (sieved through 2 mm sieve) of the soil sample was placed in a test tube. Then sterilized water is added to make the volume to 10 ml and stirred for several minutes to make a suspension, 1 ml of this suspension was immediately drawn (while in motion) through a sterile 1 ml pipette and transferred into a 9 ml sterile water blank. 1 ml samples were immediately transferred through successive 9 ml sterile water blanks until the desired final dilution was achieved.

One ml of the desired dilution was transferred aseptically into each of the several petriplates and 12-15 ml of an appropriate culture medium, cooled to just above the solidification was added to each plate. The petriplates were rotated by hand in a broad swirling motion so that the diluted soil gets dispersed in the culture medium. To assess the population of bacteria, fungi and actinomycetes in the fresh rhizosphere soil samples different culture media were used.

No. of cells/ml or g = No. of colonies \times Dilution factor

Dilution factor = Reciprocal of the dilution (e.g. $10^{-3} = 10^3$)

For determining the total viable count of bacteria, following culture media was utilized.

Nutrient Agar (Aaronson, 1970)

Beef extract	:	3.00 g
Peptone	:	5.00 g
NaCl	:	1.00 g
Agar	:	15.00 g
Distilled water	:	1000 ml

For determining the total viable count of fungi, following culture media was utilized.

Potato Dextrose Agar (Aaronson, 1970)

Potato	:	200.00 g
Dextrose	:	20.00 g
Agar	:	17.00 g
Distilled water	:	1000 ml

After inoculation, these petriplates were kept in the incubator at 28 ± 2 °C for 3 days to get the distinct microbial colonies. These colonies were counted and the average number of colonies per plate was multiplied by the dilution factor to obtain the number of colonies per gram of the original soil sample.

3.6.14 Dehydrogenase activity

Soil dehydrogenase activity was determined by the method as described by Cassida *et al.* (1964). 4 g of field moist soil was taken in a centrifugal tube and 70 mg CaCO₃ plus 4 ml of distilled water and 1 ml of 3 % Triphenyl tetrazolium chloride (TTC) was added into it. The content was mixed thoroughly in vortex and putted on incubator for 24 hours at 28 °C. After 24 hours, the content was centrifuged at 8000 rpm for 10 minutes and washed 3-4 times with methanol till the volume reached 25 ml. The reading of pink colored content was recorded at 485 nm in spectrophotometer using methanol as blank. Calculated the amount of TPF produced by reference to a calibration standard graph prepared from TPF.

3.6.15 Available nitrogen

Nitrogen was determined by using alkaline permanganate as per the modified Kjeldahl method proposed by Subbiah and Asija (1956).

3.6.16 Available phosphorus

The available phosphorus was determined by the method mentioned by Olsen *et al.* (1956).

3.6.17 Available potassium

1 N NH₄OAc was used as extractant and the available potassium content was determined by feeding the extract to flame photometer (Jackson, 1973).

3.6.18 Available molybdenum

Acid ammonium oxalate extractant was used and available molybdenum was estimated by colorimetric method (Chapman and Pratt, 1961).

3.7 Plant studies

3.7.1 Number of pods per plant

Total number of pods of the selected five plants was counted and mean value for number of pods per plant was calculated.

3.7.2 Number of nodules per plant

The number of nodules on the root of the plants was recorded treatment wise at 40 DAS. Five plants were uprooted carefully and soil mass embodying the roots of the plants was washed off in running water. The total number of nodules per plant was counted. The mean value was recorded as number of nodules per plant.

3.7.3 Number of grains per pod

Ten pods were randomly selected from each plot from previously selected plants and number of grains per pod was counted and mean value for the number of grains per pod was calculated.

3.7.4 Grain yield

The material was threshed manually and winnowed. The clean grains obtained from individual plots were weighed and grain yield of plots was converted in terms of kg ha⁻¹.

3.7.5 Straw yield

Straw yield was obtained by subtracting the seed yield from biological yield and the straw yield of each plot was converted into kg ha⁻¹.

3.7.6 Nutrient content

3.7.6.1 Estimation of nitrogen, phosphorus, potassium and molybdenum by grain and straw yield of blackgram

For estimation of nitrogen, phosphorus, potassium, and available molybdenum, representative samples of grain and straw were taken at the time of threshing and were dried and processed separately. The processed plant samples were analyzed by micro-kjeldhal (Jackson, 1967) to determine nitrogen content. Wet digestion (di-acid) method (Jackson, 1973) was used for preparation of aliquot to determine phosphorus and potassium. Extraction with acid ammonium oxalate and estimated by colorimetric method was used for estimation of molybdenum (Chapman and Pratt, 1961).

3.7.6.2 Nutrient uptake

The N, P and K content was expressed as per cent and its uptake in kg ha⁻¹ was calculated by the formula given below:

$$\text{N, P \& K uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient content in grain/straw} \times \text{grain/straw yield (kg ha}^{-1}\text{)}}{100}$$

The molybdenum content was expressed as ppm and its uptake in g ha⁻¹ was calculated by using following formula:

$$\text{Total Mo uptake (g ha}^{-1}\text{)} = \frac{\text{Nutrient content in grain/straw} \times \text{grain/straw yield (kg ha}^{-1}\text{)}}{1000}$$

3.7.7 Nutrient use efficiency

Phosphorus use efficiency: It is the ratio of grain yield (kg ha⁻¹) to the amount of phosphorus (kg ha⁻¹) applied to the crop. PUE is computed by following formula:

$$\text{PUE of applied phosphorus (kg grain kg}^{-1}\text{)} = (\text{F}-\text{C}) / \text{Fertilizer applied (kg P}_2\text{O}_5 \text{ ha}^{-1}\text{)}$$

Where:

F = grain yield in fertilized plot (kg ha⁻¹)

C = grain yield in control plot (kg ha⁻¹)

3.8 Soil quality assessment

Soil quality index was worked out by considering critical soil quality indicators as detailed by Bhardwaj *et al.* (2011). Different soil physical, chemical and biological parameters were considered as indicators for SQI estimation which were reduced to minimum data set (MDS) using Principal Component Analysis (PCA) through a series of univariate and multivariate statistical methods. One way Analysis of Variances (ANOVA) was used to identify indicators with significant treatment differences. Only variables with significant difference among treatments ($P < 0.05$) were chosen for next

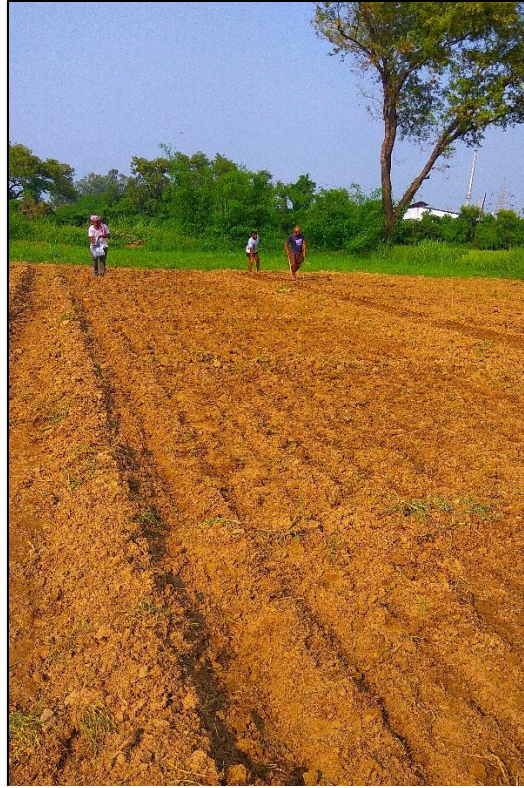
step in MDS formation. After the statistical analysis, the parameters which differed among the treatment means were subjected to principal component analysis (PCA) using SPSS software. Principal components which received eigen values greater than 1 and explained at least 5% of the variation in the data and variables which had higher factor loading were considered as the best representative indicator. Values of soil quality parameters were transformed into unit less score (between 0 to 1) using linear transformation. Under a particular PC, only the variable with the highest factor loading was retained for estimation of SQI. Each PC explained a certain amount of variation (%) in the total dataset. This percentage, divided by the total percentage of variation explained by all PCS with eigen vectors greater than 1, provided the weighted factor for variable chosen under a given PC. Since, some indicators have great influence than others on soil quality; therefore, the scores were multiplied by a weighing factor before taking their averages. The MDS variables for each observation were weighted using PCA results. The final formula for computing soil quality index (SQI):

$$SQI = \sum_{i=0}^n W_i \times S_i$$

Where, W_i is the PC weighting factor and S_i is the indicator score. Here the assumption is that higher index score meant better soil quality or greater performance of soil function.

3.9 Statistical Analysis

The data sets were processed for analysis of variance as applicable to randomized block design using least significant difference as described in Gomez and Gomez (1984). Treatment means were compared at 5% level of significance. Correlation studies were carried out among the different physical, chemical and biological parameters of soil using Microsoft excel. Principal component analysis (PCA) was carried out using SPSS for development of SQI.





EXPERIMENTAL RESULTS

The results obtained with respect to different parameters of the topic entitled “Effect of phosphorus, molybdenum and organics on soil quality and crop performance of blackgram under rainfed ecology of Jammu” have been discussed as per the following heads.

- 4.1 Physico-chemical properties and available N, P, K, Mo of soils and their correlation under blackgram growing rainfed areas of Jammu**
 - 4.2 Post harvest soil analysis of experimental site**
 - 4.3 Assessment of soil quality**
 - 4.4 Yield parameters and yield of grain and straw of blackgram**
 - 4.5 Nutrient concentration and uptake of N, P, K and Mo after harvesting of blackgram**
-
- 4.1 Physico-chemical properties and available N, P, K, Mo of soils and their correlation under blackgram growing rainfed areas of Jammu**

The data with regard to physico-chemical properties of soil *viz.* pH, electrical conductivity, organic carbon, bulk density and particle size analysis under blackgram growing rainfed areas of Jammu are presented in Appendix I. The range and mean values of these properties are given in Table 4.1. An appraisal of the data reveals that pH values of the soils vary from neutral to slightly alkaline in reaction ranging from 5.69 - 7.88 with mean value of 7.08. The values of electrical conductivity ranged from 0.09 - 0.35 dS m⁻¹ with the mean value of 0.23 dS m⁻¹. The values varied from 3.07 - 4.97 g kg⁻¹ with average value of 4.23 g kg⁻¹. Organic carbon status of soils under study revealed that its content in the blackgram growing rainfed areas of Jammu region was found to be falling in low category. The values of bulk density ranged from 1.40 - 1.56 with mean value of

1.48 Mg m⁻³. It is evident that bulk density of blackgram growing rainfed areas of Jammu differed. The values indicated that the soils under study are more compacted. The clay per cent of the soils ranged from 9.00 - 24.60 with a mean value of 16.90 per cent. The per cent silt present in the soils ranged from 13.70 - 28.40 with average value of 21.00 per cent and the percentage of sand ranged from 48.80 - 71.90 with a mean value of 62.10 per cent. On the basis of data presented in table 4.1, most of the soil samples under blackgram growing rainfed areas of Jammu were found sandy loamy in texture.

The data pertaining to available nutrient status and their distribution under blackgram growing rainfed areas of Jammu are presented in Table 4.2 (Appendix II). The data pertaining to the available nitrogen ranged from 164.2 - 279.4 kg ha⁻¹ with mean value of 229.0 kg ha⁻¹. Based on the mean values, the soils fall under low range for available nitrogen content. The available phosphorus content in the soils ranged from 9.4 - 15.6 kg ha⁻¹ with an overall mean value of 12.7 kg ha⁻¹. Overall, the soils were found in low to medium range with respect to available phosphorus. The results regarding the available potassium content were found to be in range of 108.2 - 229.1 kg ha⁻¹ with mean value of 178.4 kg ha⁻¹. The content of available molybdenum ranged from 0.098 - 0.517 mg kg⁻¹ with overall mean value of 0.282 mg kg⁻¹.

The data on coefficient of correlation between various soil physico-chemical properties *viz.* pH, electrical conductivity, organic carbon, bulk density, sand, silt and clay with available nutrients (N, P, K and Mo) are presented in Table 4.3. A perusal of data revealed that the negative correlation was obtained between soil pH with available N, P and K ($r = -0.286, -0.341$ and -0.157) while as soil pH showed positive relationship with available Mo ($r = 0.300^{**}$) (Table 4.3). The EC did not indicate significant relationship with any of the available nutrients, thus a negative correlation was acquired. The correlation coefficients being $r = -0.058, -0.053, -0.042$ and -0.030 with N, P, K and Mo, respectively. The organic carbon was positively and significantly correlated with all the available nutrients. The correlation coefficients were $r = 0.541^{**}, 0.366^{**}, 0.467^{**}$ and 0.226 for N, P, K and Mo, respectively. The bulk density was found to be significantly negatively correlated with all available nutrients *viz.*, N, P, K and Mo ($r = -0.279^{**}, -0.229^*, -0.138$ and -0.075), respectively. A negative correlation was acquired between

Table 4.1: Range and mean values of physico-chemical properties under blackgram growing rainfed areas of Jammu

Physico- chemical properties	Range	Mean
pH	5.69 - 7.88	7.08
EC (dS m ⁻¹)	0.09- 0.35	0.23
Organic carbon (g kg ⁻¹)	3.07 - 4.97	4.23
Bulk density (Mg m ⁻³)	1.40 - 1.56	1.48
Sand (%)	48.30 - 71.90	62.10
Silt (%)	13.70 - 28.40	21.00
Clay (%)	9.00 - 24.60	16.90

Table 4.2: Range and mean values of available nutrients under blackgram growing rainfed areas of Jammu

Available nutrients	Range	Mean
Av. N (kg ha ⁻¹)	164.2 - 279.4	229.0
Av. P (kg ha ⁻¹)	9.4 - 15.6	12.7
Av. K (kg ha ⁻¹)	108.2 - 229.1	178.4
Av. Mo (ppm)	0.098 - 0.517	0.282

Table 4.3: Correlation between soil physico chemical properties and available nutrients under blackgram growing rainfed areas of Jammu

	N	P	K	Mo
pH	-0.286	-0.341	-0.157	0.300**
EC	-0.058	-0.053	-0.042	-0.030
OC	0.541**	0.366**	0.467**	0.226
BD	-0.279**	-0.229*	-0.138	-0.075
Sand	-0.175	-0.271	-0.166	-0.155
Silt	0.159	0.120	0.132	0.016
Clay	0.146	-0.110	0.121	0.164

* 5% level of significance

** 1% level of significance

sand content and all available nutrients. The coefficient of correlation being ($r = -0.175, -0.271, -0.166$ and -0.155) for N, P, K and Mo, respectively. The data on clay content revealed a positively and significant relationship with available N, K and Mo ($r = 0.146, 0.121$ and 0.164) while as negative correlation was registered between clay content and P ($r = -0.110$), respectively.

4.2 Post harvest soil analysis of experimental site

4.2.1 Physico-chemical properties of soil

4.2.1.1 Soil reaction (pH)

The perusal of data with respect to pH after harvesting of blackgram presented in table 4.4 reflected highest in treatment T₁ (6.68) and lowest in T₁₀ (6.45) followed by T₇ (6.46), T₁₃ (6.47), T₄ (6.48), T₁₂ (6.56), T₃ (6.61), T₁₁ (6.61), T₆ (6.62), T₉ (6.63), T₈ (6.64), T₂ (6.64) and T₅ (6.67) during 2016. However, the mean value of soil pH was noted highest under treatment T₁ (6.64) and lowest under T₁₀ (6.42) and was observed in pattern of T₁₃ (6.43), T₇ (6.45), T₄ (6.46), T₉ (6.58), T₃ (6.59), T₆ (6.59), T₁₁ (6.59), T₁₂ (6.60), T₂ (6.61), T₈ (6.61) and T₅ (6.63) during 2017. Incorporation of FYM decreased soil pH under treatments T₄, T₇, T₁₀ and T₁₃, however, the soil pH was found statistically non-significant during both the years.

4.2.1.2 Electrical conductivity (dS m⁻¹)

The mean value of electrical conductivity (dS m⁻¹) after harvesting of blackgram given in Table 4.4 revealed highest under T₁ (0.27) and lowest under T₄ (0.21) and was observed in order of T₇ (0.22), T₁₀ (0.23), T₁₃ (0.24), T₃(0.24) T₆ (0.25), T₁₂ (0.25), T₂ (0.26), T₈(0.26), T₉ (0.26), T₁₁ (0.26) and T₅ (0.27) during 2016, whereas, the highest EC value was observed in treatment T₁ (0.25) and lowest in T₄ (0.20) followed by T₇ (0.21), T₁₀ (0.21), T₁₃ (0.22), T₃ (0.23), T₅ (0.23), T₆ (0.23), T₉ (0.23), T₁₂ (0.23), T₂ (0.24), T₁₁ (0.24) and T₈ (0.25) during 2017. However, no significant difference was obtained among different treatments during 2016 and 2017.

4.2.1.3 Bulk density (Mg m^{-3})

The mean value of bulk density (Mg m^{-3}) after harvesting of blackgram presented in Table 4.5 (Figure 4.1) revealed highest under treatment T_2 (1.55) and lowest under T_4 (1.48) and was recorded in pattern of T_7 (1.49), T_{13} (1.50), T_{10} (1.51), T_3 (1.53), T_6 (1.53), T_9 (1.53), T_5 (1.54), T_8 (1.54), T_{11} (1.54), T_1 (1.54) and T_{12} (1.55) during 2016. However, bulk density (Mg m^{-3}) was found to be highest in treatment T_2 (1.56) and lowest in T_4 (1.47) followed by T_7 (1.48), T_{13} (1.49), T_{10} (1.50), T_3 (1.52), T_6 (1.52), T_1 (1.53), T_9 (1.54), T_{12} (1.54), T_5 (1.55), T_8 (1.55) and T_{11} (1.56) during 2017. It was observed that bulk density decreased with addition of FYM along with inorganics and bio-fertilizers including phosphorus solubilizing bacteria and Rhizobium during both the years. . It is evident from the data that FYM, inorganics and bio-fertilizers brought about significant change in bulk density under different treatments T_7 ($P_{20} + 0.5\text{Mo} + \text{PSB} + \text{Rhizobium} + \text{FYM}$) (1.49, 1.48), T_4 ($P_{20} + \text{PSB} + \text{Rhizobium} + \text{FYM}$) (1.48, 1.47), T_{13} ($P_{40} + 0.5\text{Mo} + \text{PSB} + \text{Rhizobium} + \text{FYM}$) (1.50, 1.49) and T_{10} ($P_{40} + \text{PSB} + \text{Rhizobium} + \text{FYM}$) (1.51, 1.50) during both the years.

4.2.1.4 Water holding capacity (%)

The water holding capacity (%) after harvesting of blackgram given in table 4.5 (Figure 4.2) reflected minimum under T_1 (30.58) and maximum under treatment T_7 (35.13) followed by T_4 (35.06), T_{13} (34.89), T_{10} (34.82), T_6 (30.76), T_3 (30.72), T_9 (30.71), T_{12} (30.69), T_2 (30.65), T_5 (30.63), T_8 (30.62) and T_{11} (30.61) during 2016. Further, the WHC was found to be minimum in treatment T_1 (30.54) and maximum under treatment T_7 (35.49) and observed in pattern of T_4 (35.48), T_{13} (35.31), T_{10} (35.30), T_6 (30.81), T_3 (30.78), T_9 (30.74), T_{12} (30.72), T_2 (30.67), T_5 (30.67), T_8 (30.59) and T_{11} (30.59) during 2017. It is apparent from the observation of water holding capacity that FYM, inorganics and bio-fertilizers brought significant change in water holding capacity under treatments T_7 ($P_{20} + 0.5\text{Mo} + \text{PSB} + \text{Rhizobium} + \text{FYM}$), T_4 ($P_{20} + \text{PSB} + \text{Rhizobium} + \text{FYM}$), T_{13} ($P_{40} + 0.5\text{Mo} + \text{PSB} + \text{Rhizobium} + \text{FYM}$) and T_{10} ($P_{40} + \text{PSB} + \text{Rhizobium} + \text{FYM}$) during both the years.

Table 4.4: Effect of different treatments on soil pH and electrical conductivity after harvesting of blackgram

Treatments	Soil pH		EC (dS m ⁻¹)	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	6.68 ^d	6.64 ^d	0.27 ^e	0.25 ^e
T₂	6.64 ^d	6.61 ^d	0.26 ^e	0.24 ^e
T₃	6.61 ^d	6.59 ^d	0.24 ^e	0.23 ^e
T₄	6.48 ^d	6.46 ^d	0.21 ^e	0.20 ^e
T₅	6.67 ^d	6.63 ^d	0.27 ^e	0.23 ^e
T₆	6.62 ^d	6.59 ^d	0.25 ^e	0.23 ^e
T₇	6.46 ^d	6.45 ^d	0.22 ^e	0.21 ^e
T₈	6.64 ^d	6.61 ^d	0.26 ^e	0.25 ^e
T₉	6.63 ^d	6.58 ^d	0.26 ^e	0.23 ^e
T₁₀	6.45 ^d	6.42 ^d	0.23 ^e	0.21 ^e
T₁₁	6.61 ^d	6.59 ^d	0.26 ^e	0.24 ^e
T₁₂	6.56 ^d	6.60 ^d	0.25 ^e	0.23 ^e
T₁₃	6.47 ^d	6.43 ^d	0.24 ^e	0.22 ^e

*EC means electrical conductivity

Values followed by the same alphabet do not differ significantly ($p < 0.05$)

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

Table 4.5: Effect of different treatments on bulk density, water holding capacity and soil porosity after harvesting of blackgram

Treatments	Bulk density (Mg m ⁻³)		Water holding capacity (%)		Soil porosity (%)	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T ₁	1.54	1.53	30.58	30.54	42.32	42.70
T ₂	1.55	1.56	30.65	30.67	42.08	41.57
T ₃	1.53	1.52	30.72	30.78	42.48	42.64
T ₄	1.48	1.47	35.06	35.48	44.57	44.94
T ₅	1.54	1.55	30.63	30.67	42.32	41.95
T ₆	1.53	1.52	30.76	30.81	42.69	43.07
T ₇	1.49	1.48	35.13	35.49	44.19	44.57
T ₈	1.54	1.55	30.62	30.59	42.32	41.95
T ₉	1.53	1.54	30.71	30.74	42.26	42.32
T ₁₀	1.51	1.50	34.82	35.30	43.45	43.82
T ₁₁	1.54	1.56	30.61	30.59	42.30	41.57
T ₁₂	1.55	1.54	30.69	30.72	42.08	42.32
T ₁₃	1.50	1.49	34.89	35.31	43.82	44.19
S.E.(m) ±	0.01	0.01	0.43	0.043	0.14	0.27
C.D. (P=0.05)	0.02	0.03	1.27	1.28	0.42	0.80

T₁: Control, T₂: P₂₀ + PSB, T₃: P₂₀ + PSB + Rhizobium, T₄: P₂₀ + PSB + Rhizobium + FYM, T₅: P₂₀ + 0.5Mo + PSB, T₆: P₂₀ + 0.5Mo + PSB + Rhizobium, T₇: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, T₈: P₄₀ + PSB, T₉: P₄₀ + PSB + Rhizobium, T₁₀: P₄₀ + PSB + Rhizobium + FYM, T₁₁: P₄₀ + 0.5Mo + PSB, T₁₂: P₄₀ + 0.5Mo + PSB + Rhizobium, T₁₃: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

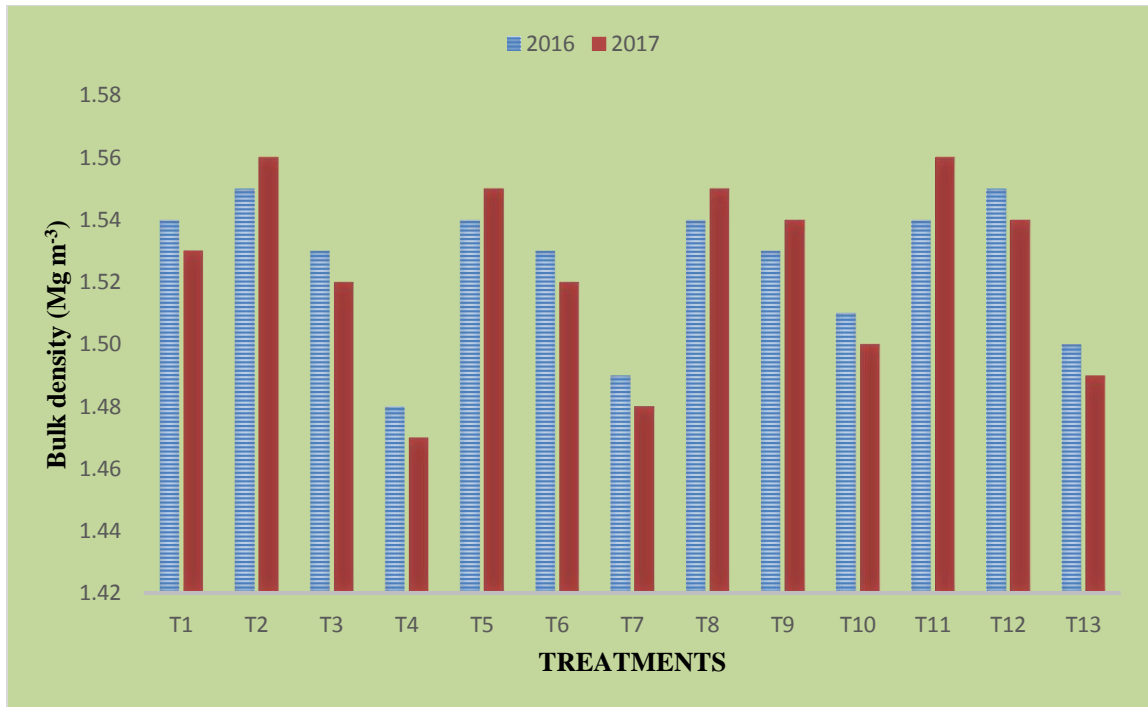


Figure 4.1: Effect of different treatments on bulk density (Mg m⁻³) after harvesting of blackgram

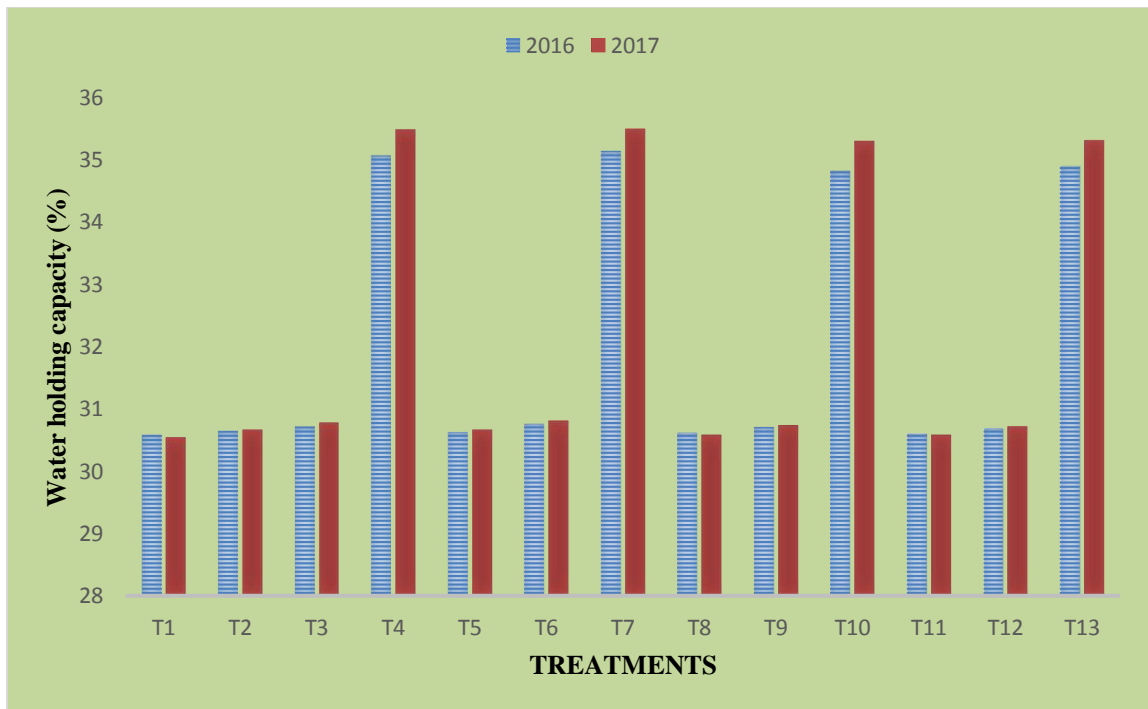


Figure 4.2: Effect of different treatments on water holding capacity (%) after harvesting of blackgram

4.2.1.5 Soil porosity (%)

The soil porosity after harvesting of blackgram presented in Table 4.5 (Figure 4.3) reflected maximum in treatment T₄ (44.57) and minimum in T₂ (42.08) and was found in order of T₇ (44.19), T₁₃ (43.82), T₁₀ (43.45), T₆ (42.69), T₃ (42.48), T₁ (42.32), T₅ (42.32), T₈ (42.32), T₁₁ (42.30), T₉ (44.26) and T₁₂ (42.08) during 2016. However, the soil porosity was noted maximum in treatment T₄ (44.94) and minimum in T₂ (41.57) followed by T₇ (44.57), T₁₃ (44.19), T₁₀ (43.82), T₆ (43.07), T₁ (42.70), T₃ (42.64), T₉ (42.32), T₁₂ (42.32), T₅ (41.95), T₈ (41.95) and T₁₁ (41.57) during 2017. The soil porosity was observed significantly higher due to combined application of organic, inorganic and bio-fertilizers including phosphorus solubilizing bacteria and Rhizobium in treatments T₄ (P₂₀ + PSB + Rhizobium + FYM) (44.57, 44.94), T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM) (44.19, 44.57), T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) (43.82, 44.19) and T₁₀ (P₄₀ + PSB + Rhizobium + FYM) (43.45, 43.82) during 2016 and 2017. The treatment T₄, T₇, T₁₃ and T₁₀ represents 5.32, 4.42, 3.54 and 2.67 percent and 5.26, 4.38, 3.49 and 2.62 percent increase in soil porosity over control during 2016 and 2017, respectively.

4.2.1.6 Infiltration rate (cm h⁻¹)

The mean value of infiltration rate after harvesting of blackgram presented in (Table 4.6) revealed highest in treatment T₁₃ (0.868) and lowest in T₁ (0.847) followed by T₁₀ (0.868), T₁₀ (0.865), T₄ (0.864), T₉ (0.854), T₃ (0.853), T₅ (0.852), T₆ (0.852), T₈ (0.852), T₁₂ (0.852), T₁₁ (0.851) and T₂ (0.850) during 2016 whereas, infiltration rate (cm h⁻¹) was observed to be highest under treatment T₁₃ (0.872) and lowest in T₁ (0.849) and found in pattern of T₁₀ (0.871), T₇ (0.867), T₄ (0.867), T₉ (0.855), T₃ (0.854), T₆ (0.854), T₁₂ (0.854), T₅ (0.853), T₈ (0.853), T₂ (0.852) and T₁₁ (0.852) during 2017. However, different treatments did not yield any significant results during both the years of study i.e, 2016 and 2017.

4.2.1.7 Aggregate stability (%)

The aggregate stability (% water stable aggregates) after harvesting of blackgram presented in Table 4.6 revealed highest in treatment T₁₀ (44.6) and lowest in T₁ (43.1) followed by T₇ (44.5), T₄ (44.5), T₁₃ (44.5), T₉ (43.8), T₁₂ (43.7), T₈ (43.7), T₃ (43.6), T₆

(43.6), T₂ (43.5), T₁₁(43.5) and T₅ (43.4) during 2016. Whereas, water stable aggregates (%) were noted to be highest under treatment T₁₀ (45.2) and lowest in T₁ (43.3) followed by T₄ (45.2), T₁₃ (45.1), T₇ (45.0), T₉ (43.9), T₁₂ (43.8), T₆ (43.8), T₃ (43.7), T₈ (43.7), T₂ (43.6), T₅ (43.6) and T₅ (43.5) during 2017. The results pertaining to water stable aggregates were found statistically non significant during both the years.

4.2.2 Soil carbon fractions after harvesting of blackgram

4.2.2.1 Soil organic carbon (SOC)

The data pertaining to various carbon fractions are presented in Table 4.7. The mean value with regard to soil organic carbon (g kg⁻¹) after harvesting of blackgram revealed highest under treatment T₁₃ (2.57) and lowest in T₈ (2.45) followed by T₁₀ (2.56), T₇ (2.55), T₄ (2.54), T₁₂ (2.50), T₉ (2.49), T₃ (2.48), T₆ (2.48), T₁ (2.47), T₁₁ (2.46), T₂ (2.46) and T₅ (2.46) during 2016 whereas, the mean value of soil organic carbon was reflected to be highest under treatment T₁₃ (2.58) and lowest in T₈ (2.44) and recorded in pattern of T₁₀ (2.58), T₇ (2.57), T₄ (2.56), T₉ (2.50), T₃ (2.49), T₆ (2.49), T₁₂ (2.48), T₁ (2.46), T₁₁ (2.45), T₂ (2.45) and T₅ (2.45) during 2017. However, different treatments did not yield any significant results regarding soil organic carbon during both the years i.e, 2016 and 2017.

4.2.2.2 Labile carbon (Permanganate oxidizable carbon)

The mean value of labile carbon (mg kg⁻¹) after harvesting of blackgram (Table 4.7, Figure 4.4) was observed highest in treatment T₁₃ (1151) and lowest in T₁ (991) and noted in pattern of T₁₀ (1136), T₇ (1119), T₄ (1115), T₁₂ (1100), T₁₁ (1090), T₉ (1092), T₈ (1087), T₆ (1080), T₅ (1071), T₃ (1062) and T₂ (1001) during 2016. However, the mean value of labile carbon was reflected highest in treatment T₁₃ (1170) and lowest in T₁ (986) and found in order of T₁₀ (1156), T₇ (1138), T₄ (1134), T₁₂ (1115), T₁₁ (1115), T₉ (1107), T₈ (1102), T₆ (1095), T₅ (1086), T₃ (1079) and T₂ (1013) during 2017. The labile carbon was found significantly higher under FYM amended plots plus inorganics and biofertilizers including phosphorus solubilizing bacteria and Rhizobium under (T₁₃) P₄₀ + 0.5Mo + PSB + Rhizobium + FYM (1151, 1170) followed by the treatments (T₁₀) P₄₀ + PSB + Rhizobium + FYM (1136, 1156), T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM)

Table 4.6: Effect of different treatments on infiltration rate and aggregate stability (% WSA) after harvesting of blackgram

Treatments	Infiltration rate (cm h ⁻¹)		Total WSA (%)	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	0.847 ^a	0.849 ^a	43.1 ^b	43.3 ^b
T₂	0.850 ^a	0.852 ^a	43.5 ^b	43.6 ^b
T₃	0.853 ^a	0.854 ^a	43.6 ^b	43.7 ^b
T₄	0.864 ^a	0.867 ^a	44.5 ^b	45.2 ^b
T₅	0.852 ^a	0.853 ^a	43.4 ^b	43.6 ^b
T₆	0.852 ^a	0.854 ^a	43.6 ^b	43.8 ^b
T₇	0.865 ^a	0.867 ^a	44.5 ^b	45.0 ^b
T₈	0.852 ^a	0.853 ^a	43.7 ^b	43.7 ^b
T₉	0.854 ^a	0.855 ^a	43.8 ^b	43.9 ^b
T₁₀	0.868 ^a	0.871 ^a	44.6 ^b	45.2 ^b
T₁₁	0.851 ^a	0.852 ^a	43.5 ^b	43.5 ^b
T₁₂	0.852 ^a	0.854 ^a	43.7 ^b	43.8 ^b
T₁₃	0.868 ^a	0.872 ^a	44.5 ^b	45.1 ^b

*WSA means water stable aggregates

Values followed by the same alphabet do not differ significantly ($p < 0.05$)

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

Table 4.7: Effect of different treatments on soil carbon fractions after harvesting of blackgram

Treatments	Soil organic carbon (g kg ⁻¹)		Labile carbon (mg kg ⁻¹)		Particulate organic carbon (g/m ²)	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	2.47	2.46	991	986	260.1	257.6
T₂	2.46	2.45	1001	1013	264.4	266.0
T₃	2.48	2.49	1062	1079	265.3	266.4
T₄	2.54	2.56	1115	1134	267.6	268.8
T₅	2.46	2.45	1071	1086	265.7	267.0
T₆	2.48	2.49	1080	1095	267.0	268.1
T₇	2.55	2.57	1119	1138	268.3	269.7
T₈	2.45	2.44	1087	1102	265.8	266.5
T₉	2.49	2.50	1092	1107	266.9	267.5
T₁₀	2.56	2.58	1136	1156	270.5	272.1
T₁₁	2.46	2.45	1090	1105	266.8	267.3
T₁₂	2.50	2.48	1100	1115	267.6	268.5
T₁₃	2.57	2.58	1151	1170	271.1	272.8
S.E.(m) ±	0.024	0.021	1.21	1.47	0.74	0.53
C.D. (P=0.05)	N.S.	N.S.	3.56	4.33	2.19	1.56

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

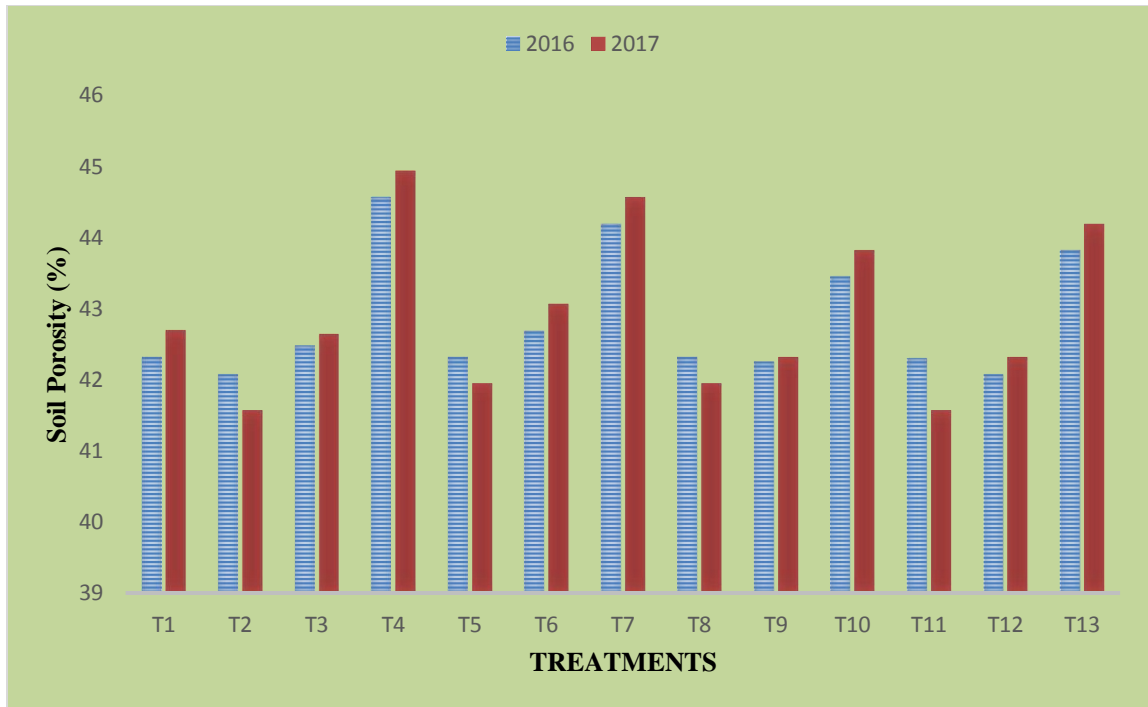


Figure 4.3: Effect of different treatments on soil porosity (%) after harvesting of blackgram

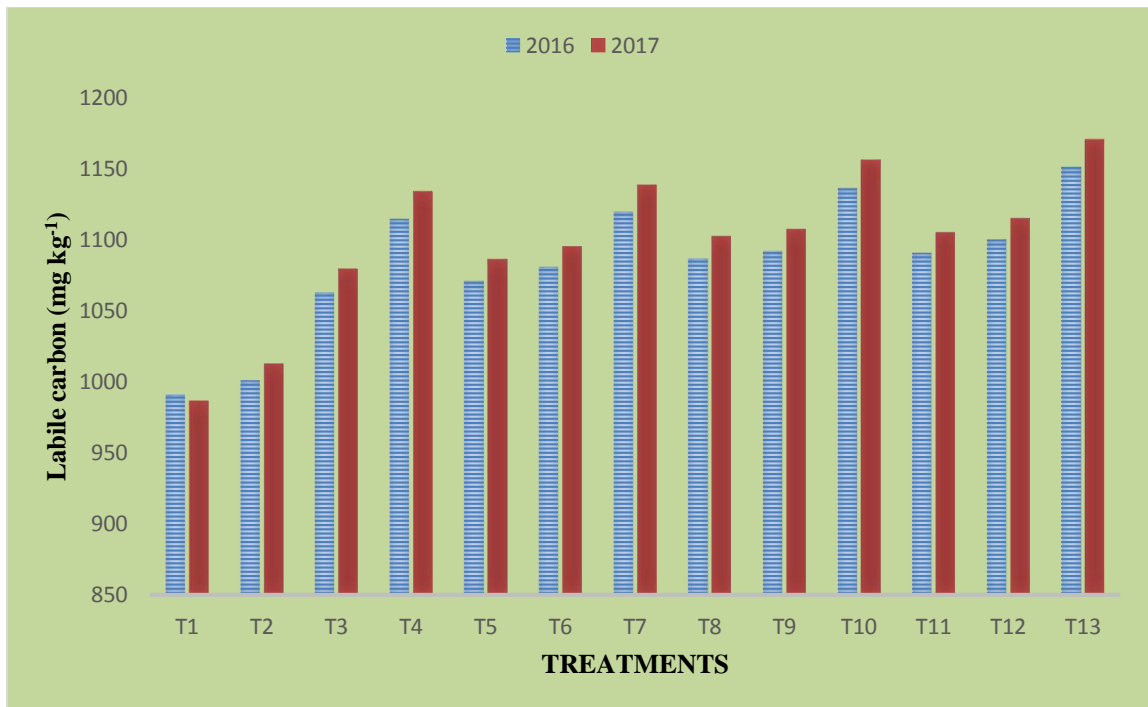


Figure 4.4: Effect of different treatments on labile carbon (mg kg⁻¹) after harvesting of blackgram

(1119, 1138) and T₄ (P₄₀ + PSB + Rhizobium + FYM) (1115, 1134) during both the years. The percent increase in labile carbon under T₁₃, T₁₀, T₇ and T₄ over control was found as: 16.14, 14.63, 12.92 and 12.51, respectively during 2016 and 18.66, 17.24, 15.41 and 15.01, respectively during 2017.

4.2.2.3 Particulate organic carbon (POC)

The mean value of particulate organic carbon (g/m²) after harvesting of blackgram (Table 4.7, Figure 4.5) was found to be highest under treatment T₁₃ (271.1) and lowest in T₁ (260.1) followed by T₁₀ (270.5), T₇ (268.3), T₄ (267.6), T₁₂ (267.5), T₆ (267.0), T₉ (266.9), T₁₁ (266.8), T₈ (265.8), T₅ (265.7), T₃ (265.3) and T₂ (264.4) during 2016 whereas, the mean value of particulate organic carbon was observed highest in treatment T₁₃ (272.8) and lowest in T₁ (257.6) and in order of T₁₀ (272.1), T₇ (269.7), T₄ (268.8), T₁₂ (268.5), T₆ (268.1), T₉ (267.5), T₁₁ (267.3), T₅ (267.0), T₈ (266.5), T₃ (266.4) and T₂ (266.0) during 2017. The combined application of organics, inorganics and biofertilizers including phosphorus solubilizing bacteria and Rhizobium under different treatments such as T₁₃ (271.1), T₁₀ (270.5), T₇ (268.3) and T₄ (267.5) improved particulate organic carbon significantly during 2016. Further, particulate organic carbon significantly increased under treatments T₁₃ (272.8), T₁₀ (272.1), T₇ (269.7) and T₄ (268.8) during 2017. Treatments T₁₃, T₁₀, T₇ and T₄ registered 4.23, 4.00, 3.15 and 2.88 percent increase over control during 2016 while as 5.90, 5.63, 4.70 and 4.38 percent increase over control during 2017 with regard to particulate organic carbon.

4.2.3 Biological properties after harvesting of blackgram

4.2.3.1 Microbial biomass carbon (MBC)

The mean value with respect to microbial carbon biomass (mg kg⁻¹) after harvesting of blackgram depicted in Table 4.8 (Figure 4.6) was found highest under treatment T₁₃ (34.7) and lowest under T₁ (30.4) followed by T₁₀ (34.2), T₇ (33.7), T₄ (33.4), T₁₂ (33.0), T₉ (32.7), T₁₁ (32.6), T₈ (32.4), T₆ (31.8), T₃ (31.3), T₅ (31.2) and T₂ (31.0) during 2016 whereas, the mean value of microbial carbon biomass reflected highest in treatment T₁₃ (35.1) and lowest under T₁ (30.1) followed by T₁₀ (34.9), T₇ (34.2), T₄ (34.0), T₁₂ (33.4), T₉ (33.3), T₁₁ (33.1), T₈ (32.9), T₆ (31.9), T₃ (31.7), T₅ (31.6)

and T₂ (31.4) during 2017. The microbial carbon biomass was found significantly higher under integrated application of organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and Rhizobium under treatments T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM), T₁₀ (P₄₀ + PSB + Rhizobium + FYM), T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM) and T₄ (P₄₀ + PSB + Rhizobium + FYM) during 2016 and 2017.

4.2.3.2 General bacterial population

The general bacterial population in soil after harvesting of blackgram presented in Table (4.9, Figure 4.7) was found highest in treatment T₄ (13.28) and lowest in T₁ (10.74) and noted in pattern of T₇ (13.05), T₁₀ (12.66), T₁₃ (12.42), T₃ (11.74), T₉ (11.56), T₆ (11.48), T₁₂ (11.32), T₂ (11.31), T₅ (11.16), T₈ (11.07) and T₁₁ (11.00) during 2016 whereas, the general bacterial count after harvesting of blackgram reflected highest in treatment T₄ (14.35) and lowest in T₁ (11.33) and found in pattern of T₇ (14.11), T₁₀ (13.80), T₁₃ (13.59), T₃ (12.63), T₆ (12.43), T₉ (12.30), T₂ (12.25), T₁₂ (12.08), T₅ (11.95), T₈ (11.72) and T₁₁ (11.51) during 2017. The values obtained under combined applications of organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and Rhizobium under treatments T₄ (14.35), T₇ (14.11), T₁₀ (13.80) and T₁₃ (13.59) were found statistically significant over control during 2016 and T₄ (14.35), T₇ (14.11), T₁₀ (13.80) and T₁₃ (13.59) during 2017.

4.2.3.3 General fungal population

The general fungal population after harvesting of blackgram given in Table (4.9, Figure 4.8) showed highest in treatment T₄ (9.51) and lowest in T₁ (6.82) and noted in order of T₇ (9.27), T₁₀ (9.16), T₁₃ (9.04), T₃ (7.97), T₉ (7.75), T₆ (7.63), T₂ (7.56), T₁₂ (7.51), T₅ (7.31), T₈ (7.16), and T₁₁ (7.04) during 2016. However, the general fungal population after harvesting of blackgram was observed to be highest under treatment T₄ (10.63) and lowest in T₁ (7.20) followed by T₇ (10.41), T₁₀ (10.15), T₁₃ (10.02), T₃ (8.81), T₆ (8.58), T₉ (8.48), T₂ (8.39), T₁₂ (8.21), T₅ (8.20), T₈ (8.01) and T₁₁ (7.82) during 2017. The results observed under combined applications of organic, inorganic and bio-fertilizers including phosphorus solubilizing bacteria and Rhizobium under different

Table 4.8: Effect of different treatments on microbial biomass carbon (mg kg⁻¹) after harvesting of blackgram

Treatments		<u>2016</u>	<u>2017</u>
T₁	Control	30.4	30.1
T₂	P20 + PSB	31.0	31.4
T₃	P20 + PSB + Rhizobium	31.3	31.7
T₄	P20 + PSB + Rhizobium + FYM	33.4	34.0
T₅	P20 + 0.5Mo + PSB	31.2	31.6
T₆	P20 + 0.5Mo + PSB + Rhizobium	31.8	31.9
T₇	P20 + 0.5Mo + PSB + Rhizobium + FYM	33.7	34.2
T₈	P40 + PSB	32.4	32.9
T₉	P40 + PSB + Rhizobium	32.7	33.3
T₁₀	P40 + PSB + Rhizobium + FYM	34.2	34.9
T₁₁	P40 + 0.5Mo + PSB	32.6	33.1
T₁₂	P40 + 0.5Mo + PSB + Rhizobium	33.0	33.4
T₁₃	P40 + 0.5Mo + PSB + Rhizobium + FYM	34.7	35.1
	S.E.(m) ±	0.249	0.282
	C.D. (P=0.05)	0.731	0.827

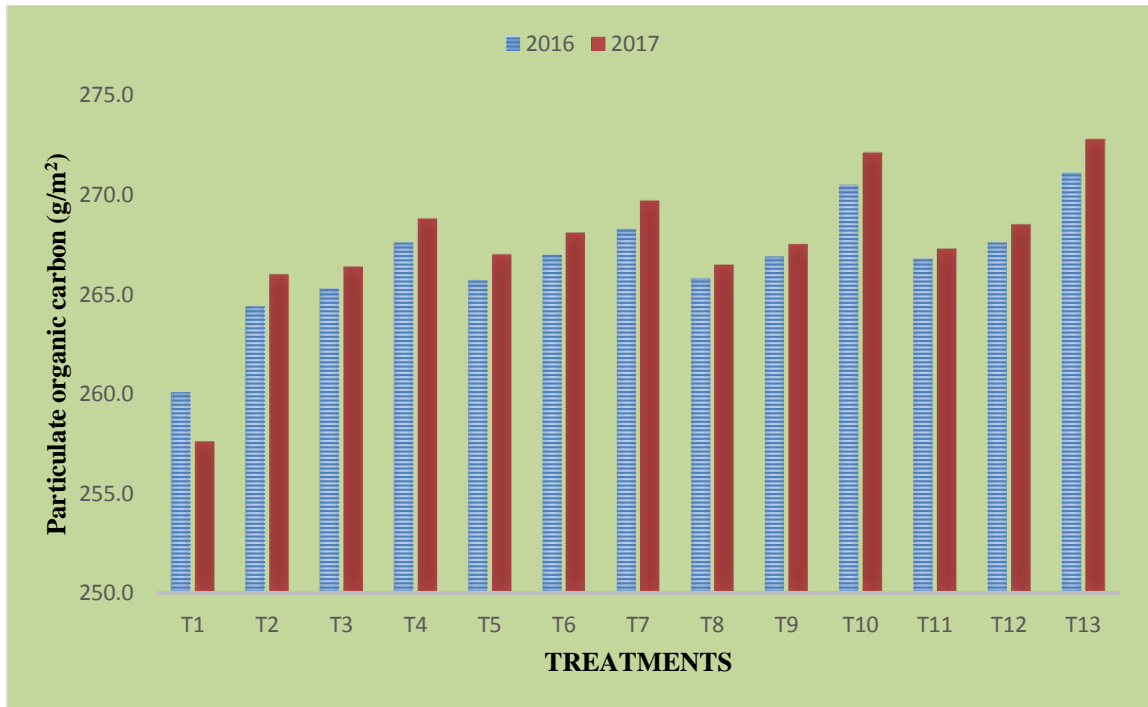


Figure 4.5: Effect of different treatments on particulate organic carbon (g/m²) after harvesting of blackgram

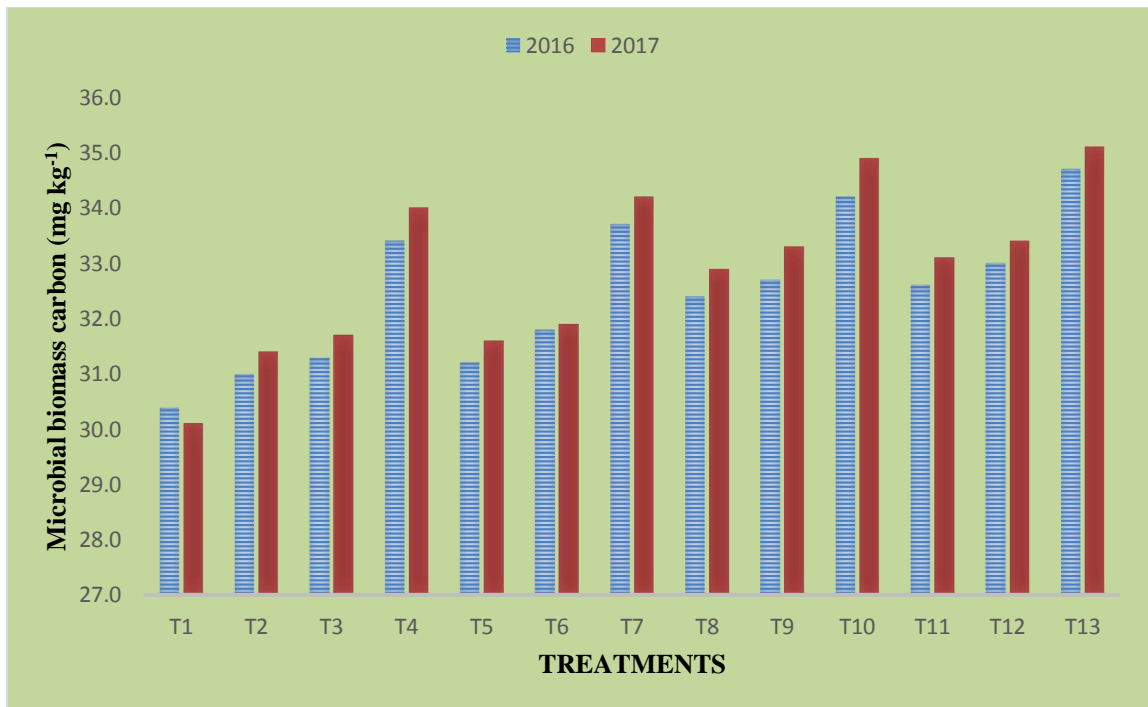


Figure 4.6: Effect of different treatments on microbial biomass carbon (mg kg⁻¹) after harvesting of blackgram

Table 4.9: Effect of different treatments on general bacterial and fungal population after harvesting of blackgram

Treatments	Bacterial population ($\times 10^4$ cfu g ⁻¹ soil)		Fungal population ($\times 10^2$ cfu g ⁻¹ soil)	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	10.74	11.33	6.82	7.20
T₂	11.31	12.25	7.56	8.39
T₃	11.74	12.63	7.97	8.81
T₄	13.28	14.35	9.51	10.63
T₅	11.16	11.95	7.31	8.20
T₆	11.48	12.43	7.63	8.58
T₇	13.05	14.11	9.27	10.41
T₈	11.07	11.72	7.16	8.01
T₉	11.56	12.30	7.75	8.48
T₁₀	12.66	13.80	9.16	10.15
T₁₁	11.00	11.51	7.04	7.82
T₁₂	11.32	12.08	7.51	8.21
T₁₃	12.42	13.59	9.04	10.02
S.E.(m) \pm	0.141	0.067	0.234	0.297
C.D. (P=0.05)	0.413	0.198	0.686	0.872

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

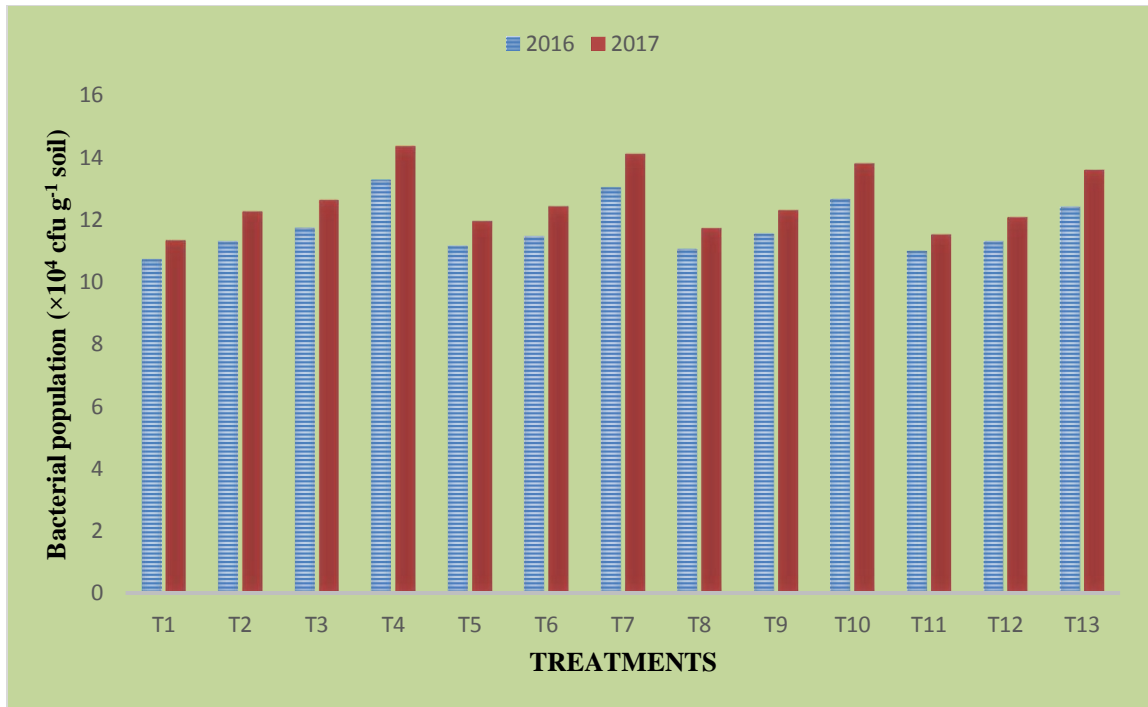


Figure 4.7: Effect of different treatments on bacterial population ($\times 10^4$ cfu g^{-1} soil) after harvesting of blackgram

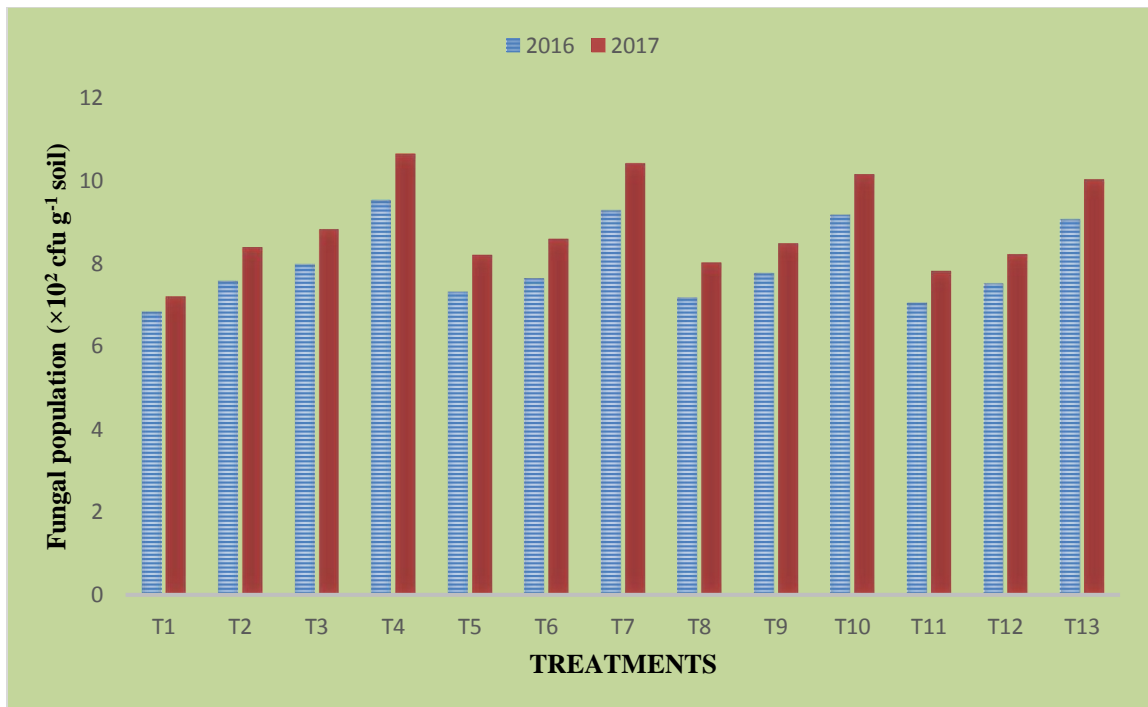


Figure 4.8: Effect of different treatments on fungi population ($\times 10^2$ cfu g^{-1} soil) after harvesting of blackgram

treatments T₄ (9.51), T₇ (9.27), T₁₀ (9.16) and T₁₃ (9.04) were found statistically significant over control during 2016 and T₄ (9.51), T₇ (9.27), T₁₀ (9.16) and T₁₃ (9.04) during 2017.

4.2.3.4 Dehydrogenase activity ($\mu\text{g TPF g}^{-1} \text{ soil } 24 \text{ h}^{-1}$)

The mean value with of dehydrogenase activity after harvesting of blackgram (Table 4.10 & Figure 4.9) revealed highest under treatment T₁₃ (26.46) and lowest T₁ (22.93) and observed in order of T₁₀ (26.25), T₇ (25.81), T₄ (25.57), T₁₂ (25.11), T₉ (24.90), T₁₁ (24.74), T₆ (24.66), T₈ (24.35), T₃ (24.23), T₅ (23.93) and T₂ (23.85) during 2016 whereas, the mean value of dehydrogenase activity was found highest in treatment T₁₃ (27.29) and lowest T₁ (23.65) and observed in order of T₁₀ (27.05), T₇ (26.38), T₄ (26.12), T₁₂ (25.61), T₉ (25.38), T₁₁ (25.20), T₆ (25.18), T₈ (25.04), T₃ (24.88), T₅ (24.55) and T₂ (24.23) during 2017. It is apparent from the observations that dehydrogenase activity was found significantly higher under FYM amended plus inorganic and biofertilizers including phosphorus solubilizing bacteria and Rhizobium in treatments T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM), T₁₀ (P₄₀ + PSB + Rhizobium + FYM), T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM) and T₄ (P₂₀ + PSB + Rhizobium + FYM) over control during both the years.

4.2.4 Soil available nutrient status after harvesting of blackgram

4.2.4.1 Available nitrogen (kg ha^{-1})

The mean value of available nitrogen (kg ha^{-1}) after harvesting of blackgram presented in Table (4.11, Figure 4.10) revealed highest in treatment T₁₃ (120.38) and lowest T₁ (93.63) and found in order of T₁₂ (118.14), T₁₀ (113.63), T₁₁ (112.77), T₉ (111.91), T₇ (110.21), T₆ (107.91), T₄ (102.94), T₅ (100.66), T₃ (99.23), T₈ (97.89) and T₂ (95.52) during 2016. However, mean value of available nitrogen after harvesting of blackgram was found to be highest in treatment T₁₃ (121.30) and lowest T₁ (93.08) and followed the order of T₁₂ (120.08), T₁₀ (116.71), T₁₁ (115.53), T₉ (114.87), T₇ (112.21), T₆ (109.32), T₄ (104.96), T₅ (102.73), T₃ (102.17), T₈ (99.27) and T₂ (96.91) during 2017. The significant improvement in available N under different treatments T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM), T₁₀ (P₄₀ + PSB + Rhizobium + FYM), T₇ (P₂₀ + 0.5Mo + PSB

+ Rhizobium + FYM) and T₄ (P₂₀ + PSB + Rhizobium + FYM) could be due to integrated addition of organic, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* during 2016 and 2017.

4.2.4.2 Available phosphorus (kg ha⁻¹)

The mean value of available phosphorus (kg ha⁻¹) after harvesting of blackgram given in Table (4.11, Figure 4.11) reflected highest in treatment T₁₃ (14.43) and lowest T₁ (8.79) and found in pattern of T₁₀ (13.87), T₁₂ (13.35), T₁₁ (13.18), T₇ (12.94), T₉ (12.37), T₈ (12.19), T₄ (11.76), T₆ (10.96), T₅ (10.83), T₃ (10.11) and T₂ (9.90) during 2016 whereas, mean value of available phosphorus (kg ha⁻¹) after harvesting of blackgram was observed highest in treatment T₁₃ (15.02) and lowest T₁ (8.13) and obtained in order of T₁₀ (14.24), T₁₂ (13.78), T₁₁ (13.50), T₇ (13.48), T₉ (12.86), T₈ (12.70), T₄ (12.45), T₆ (11.63), T₅ (11.40), T₃ (10.77) and T₂ (10.61) during 2017. The significant increase in available phosphorus under different treatments such as T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM), T₁₀ (P₄₀ + PSB + Rhizobium + FYM), T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM) and T₄ (P₂₀ + PSB + Rhizobium + FYM) could be due to integrated addition of organic, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* during both the years.

4.2.4.3 Available potassium (kg ha⁻¹)

The mean value of available potassium (kg ha⁻¹) after harvesting of blackgram depicted in Table (4.11, Figure 4.12) found highest in treatment T₁₃ (117.73) and lowest T₁ (111.98) followed by T₁₀ (117.45), T₁₂ (116.86), T₁₁ (116.38), T₉ (116.08), T₇ (115.84), T₄ (115.46), T₈ (115.21), T₆ (114.38), T₃ (114.08), T₅ (113.66) and T₂ (113.14) during 2016. However, mean value of available potassium (kg ha⁻¹) after harvesting of blackgram reflected highest in treatment T₁₃ (118.28) and lowest T₁ (111.20) followed by T₁₀ (118.15), T₁₂ (117.35), T₁₁ (116.88), T₉ (116.60), T₇ (116.36), T₄ (116.16), T₈ (115.45), T₆ (114.79), T₃ (114.51), T₅ (114.06) and T₂ (113.59) during 2017. The significant improvement in available potassium under different treatments viz. T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM), T₁₀ (P₄₀ + PSB + Rhizobium + FYM), T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM) and T₄ (P₂₀ + PSB + Rhizobium + FYM) might be

Table 4.10: Effect of different treatments on dehydrogenase activity ($\mu\text{g TPF g}^{-1}$ soil 24 h^{-1}) after harvesting of blackgram

Treatments		<u>2016</u>	<u>2017</u>
T₁	Control	22.93	23.65
T₂	P20 + PSB	23.85	24.23
T₃	P20 + PSB + Rhizobium	24.23	24.88
T₄	P20 + PSB + Rhizobium + FYM	25.57	26.12
T₅	P20 + 0.5Mo + PSB	23.93	24.55
T₆	P20 + 0.5Mo + PSB + Rhizobium	24.66	25.18
T₇	P20 + 0.5Mo + PSB + Rhizobium + FYM	25.81	26.38
T₈	P40 + PSB	24.35	25.04
T₉	P40 + PSB + Rhizobium	24.90	25.38
T₁₀	P40 + PSB + Rhizobium + FYM	26.25	27.05
T₁₁	P40 + 0.5Mo + PSB	24.74	25.20
T₁₂	P40 + 0.5Mo + PSB + Rhizobium	25.11	25.61
T₁₃	P40 + 0.5Mo + PSB + Rhizobium + FYM	26.46	27.29
	S.E.(m) \pm	0.211	0.081
	C.D. (P=0.05)	0.619	0.238

Table 4.11: Effect of different treatments on available nutrients (kg ha⁻¹) after harvesting of blackgram

Treatments		Available N		Available P		Available K	
		<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	Control	93.63	93.08	8.79	8.13	111.98	111.20
T₂	P20 + PSB	95.52	96.91	9.90	10.61	113.14	113.59
T₃	P20 + PSB + Rhizobium	99.23	102.17	10.11	10.77	114.08	114.51
T₄	P20 + PSB + Rhizobium + FYM	102.94	104.96	11.76	12.45	115.46	116.16
T₅	P20 + 0.5Mo + PSB	100.66	102.73	10.83	11.40	113.66	114.06
T₆	P20 + 0.5Mo + PSB + Rhizobium	107.91	109.32	10.96	11.63	114.38	114.79
T₇	P20 + 0.5Mo + PSB + Rhizobium + FYM	110.21	112.21	12.94	13.48	115.84	116.36
T₈	P40 + PSB	97.89	99.27	12.19	12.70	115.21	115.45
T₉	P40 + PSB + Rhizobium	111.91	114.87	12.37	12.86	116.08	116.60
T₁₀	P40 + PSB + Rhizobium + FYM	113.63	116.71	13.87	14.24	117.45	118.15
T₁₁	P40 + 0.5Mo + PSB	112.77	115.53	13.18	13.50	116.38	116.88
T₁₂	P40 + 0.5Mo + PSB + Rhizobium	118.14	120.08	13.35	13.78	116.86	117.35
T₁₃	P40 + 0.5Mo + PSB + Rhizobium + FYM	120.38	121.30	14.43	15.02	117.73	118.28
	S.E.(m) ±	0.69	0.87	0.17	0.26	0.24	0.26
	C.D. (P=0.05)	2.03	2.56	0.49	0.79	0.70	0.77

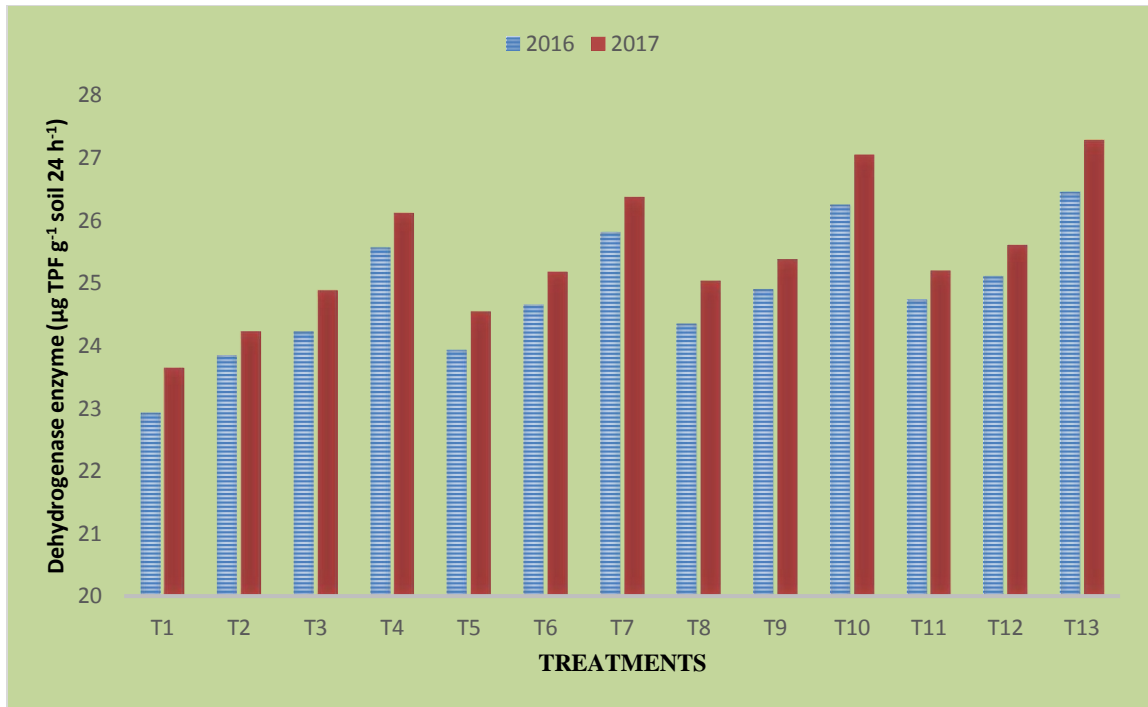


Figure 4.9: Effect of different treatments on dehydrogenase activity ($\mu\text{g TPF g}^{-1}$ soil 24 h^{-1}) after harvesting of blackgram

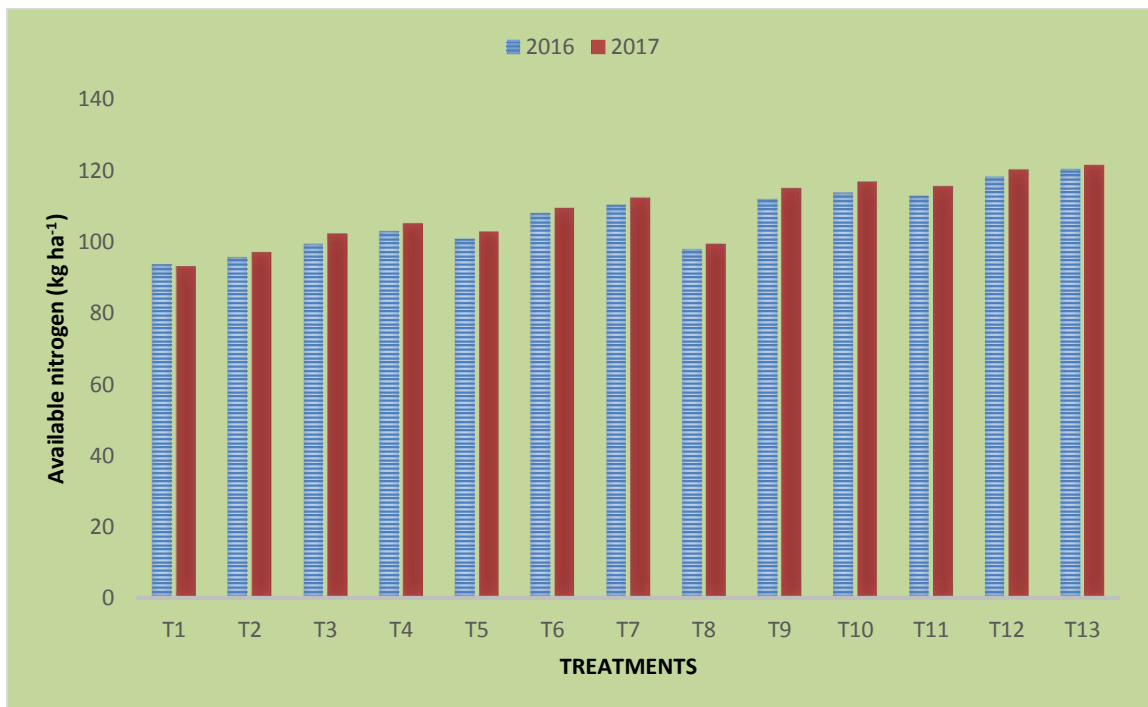


Figure 4.10: Effect of different treatments on available nitrogen (kg ha^{-1}) after harvesting of blackgram

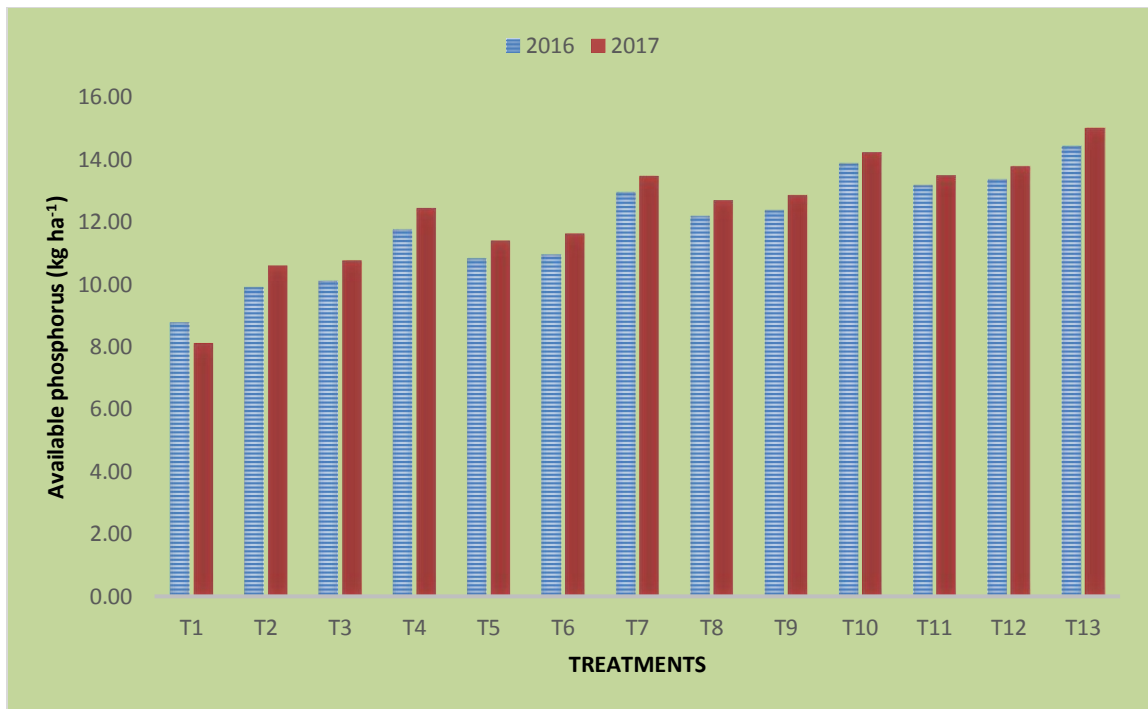


Figure 4.11: Effect of different treatments on available phosphorus (kg ha⁻¹) after harvesting of blackgram

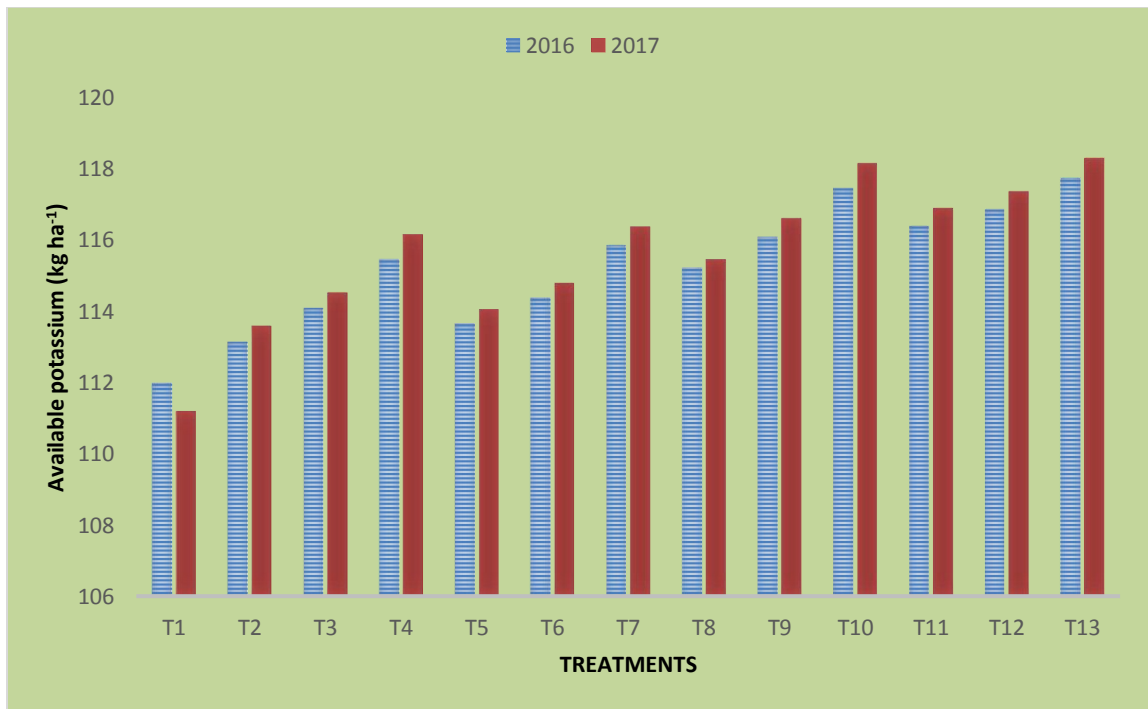


Figure 4.12: Effect of different treatments on available potassium (kg ha⁻¹) after harvesting of blackgram

due to integrated addition of organic, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* during 2016 and 2017.

4.2.4.4 Available molybdenum (mg kg⁻¹)

The mean value of available molybdenum (mg kg⁻¹) after harvesting of blackgram presented in Table (4.12, Figure 4.13) was found to be highest in treatments T₁₃ (0.322) and lowest in T₁ (0.223) and noted in order of T₁₂ (0.319), T₇ (0.317), T₁₁ (0.314), T₆ (0.303), T₁₀ (0.299), T₅ (0.298), T₉ (0.289), T₈ (0.282), T₄ (0.279), T₃ (0.267) and T₂ (0.261) during 2016 whereas, mean value of available molybdenum (mg kg⁻¹) after harvesting of blackgram revealed highest in T₁₃ (0.344) and lowest in T₁ (0.212) and observed in pattern of T₁₂ (0.334), T₁₁ (0.329), T₇ (0.327), T₆ (0.314), T₁₀ (0.313), T₅ (0.305), T₉ (0.298), T₈ (0.293), T₄ (0.287), T₃ (0.278) and T₂ (0.272) during 2017. The significant improvement in available molybdenum was observed under various treatments due to mix use of organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* during 2016 and 2017.

4.2.5 Nutrient use efficiency and nutrient balance (N, P, K and Mo) after harvesting of blackgram

4.2.5.1 Phosphorus use efficiency (kg grain kg⁻¹ P)

The mean value on phosphorus use efficiency (kg grain kg⁻¹ P) given in Table 4.13 was observed highest in T₇ (9.05) and lowest in T₂ (4.60) followed by T₆ (8.35), T₄ (7.00), T₁₃ (6.53), T₅ (6.20), T₁₂ (6.00), T₃ (5.95), T₁₁ (4.98), T₉ and (4.88) during 2016 whereas, the mean value on phosphorus use efficiency reflected highest in treatment T₇ (10.25) and lowest in T₂ (5.50) followed by T₆ (9.30), T₄ (8.10), T₅ (7.50), T₃ (7.20), T₁₃ (7.13), T₁₂ (6.73), T₁₁ (5.76) and T₉ (5.55) during 2017.

4.2.5.2 Nutrient balance of available nutrients: N, P, K and Mo

The appropriate balance sheet of available N, P, K and Mo as affected by different treatments during the two year of study is presented in table 4.14. A negative balance was observed for all available nutrients i.e, N, P, K and Mo under control treatment which could be due to scanty availability of these nutrients. With regards to available N (kg ha⁻¹

¹), a highest net gain was observed in the treatment T₁₀ (+3.08) followed by T₉ (+2.96), T₃ (+2.94), T₁₁ (+2.75), T₅ (+2.06), T₄ (+2.03), T₇ (+2.00), T₁₂ (+1.95), T₆ (+1.41), T₂ (+1.39), T₈ (+1.38) and T₁₃ (+0.92). A highest net gain with respect to available P (kg ha⁻¹) was recorded in treatment T₂ (0.71) and was in order of T₄ (+0.69), T₆ (+0.67), T₃ (+0.66), T₁₃ (+0.59), T₅ (+0.57), T₇ (+0.54), T₈ (+0.51), T₉ (+0.49), T₁₂ (+0.43), T₁₀ (+0.37) and T₁₁ (+0.32). Except control (T₁), the balance sheet with respect to available P and Mo were found positive under all the treatments *viz.* T₂ (+0.71), T₃ (+0.66), T₄ (+0.69), T₅ (+0.57), T₆ (+0.67), T₇ (+0.54), T₈ (+0.51), T₉ (+0.49), T₁₀ (+0.37), T₁₁ (+0.32), T₁₂ (+0.43) and T₁₃ (+0.59) and T₂ (+0.011), T₃ (+0.014), T₄ (+0.010), T₅ (+0.007), T₆ (+0.011), T₇ (+0.010), T₈ (+0.011), T₉ (+0.009), T₁₀ (+0.014), T₁₁ (+0.015), T₁₂ (+0.015) and T₁₃ (+0.022) which might be due to its less removal by crop in comparison to addition.

4.3 Assessment of soil quality

4.3.1 Minimum data set (MDS) formulation for soil quality indicators

The factor loading/ eigen vectors of significant soil quality indicators from principal component analysis (PCA) are given in Table 4.15. The data pertaining to soil quality parameters were statistically analyzed for their level of significance. Soil pH, electrical conductivity, soil organic carbon, infiltration rate, and aggregate stability (WSA) showed no significant difference among the treatments. Out of total soil quality parameters, 13 parameters were subjected to principal component analysis (PCA) using SPSS software to identify the minimum dataset. The principal components receiving high eigen values and variables with high factor loading were assumed as the variables that best represent system attributes (Brejda *et al.* 2000). Within each principal component, only the variables which received highest factor loading were retained for the MDS. Therefore, only the PCs with eigen values 1 or greater, which explained at least 5% of the variation in the data (Wander and Bollero, 1999) were considered for development of SQI. It can be noticed from the data in the Table 4.15 that water holding capacity (WHC, 0.911), dehydrogenase enzyme (DHA, 0.905), bacteria (0.358) and available P (0.746) received the highest loading factor under PC 1, PC 2, PC 3 and PC 4, respectively and as such these four variables were retained as minimum data set (MDS) for developing SQI.

Table 4.12: Effect of different treatments on available molybdenum (mg kg⁻¹) after harvesting of blackgram

Treatments		<u>2016</u>	<u>2017</u>
T₁	Control	0.223	0.212
T₂	P20 + PSB	0.261	0.272
T₃	P20 + PSB + Rhizobium	0.267	0.278
T₄	P20 + PSB + Rhizobium + FYM	0.279	0.287
T₅	P20 + 0.5Mo + PSB	0.298	0.305
T₆	P20 + 0.5Mo + PSB + Rhizobium	0.303	0.314
T₇	P20 + 0.5Mo + PSB + Rhizobium + FYM	0.317	0.327
T₈	P40 + PSB	0.282	0.293
T₉	P40 + PSB + Rhizobium	0.289	0.298
T₁₀	P40 + PSB + Rhizobium + FYM	0.299	0.313
T₁₁	P40 + 0.5Mo + PSB	0.314	0.329
T₁₂	P40 + 0.5Mo + PSB + Rhizobium	0.319	0.334
T₁₃	P40 + 0.5Mo + PSB + Rhizobium + FYM	0.322	0.344
	S.E.(m) ±	0.006	0.004
	C.D. (P=0.05)	0.018	0.013

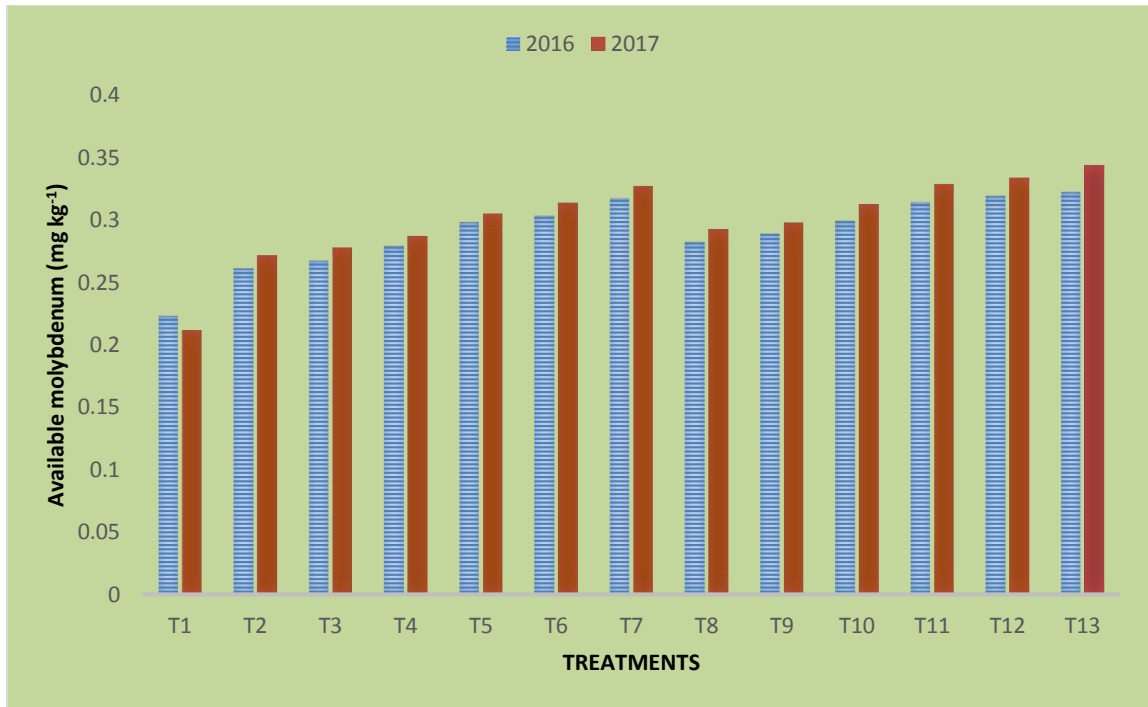


Figure 4.13: Effect of different treatments on available molybdenum (mg kg⁻¹) after harvesting of blackgram

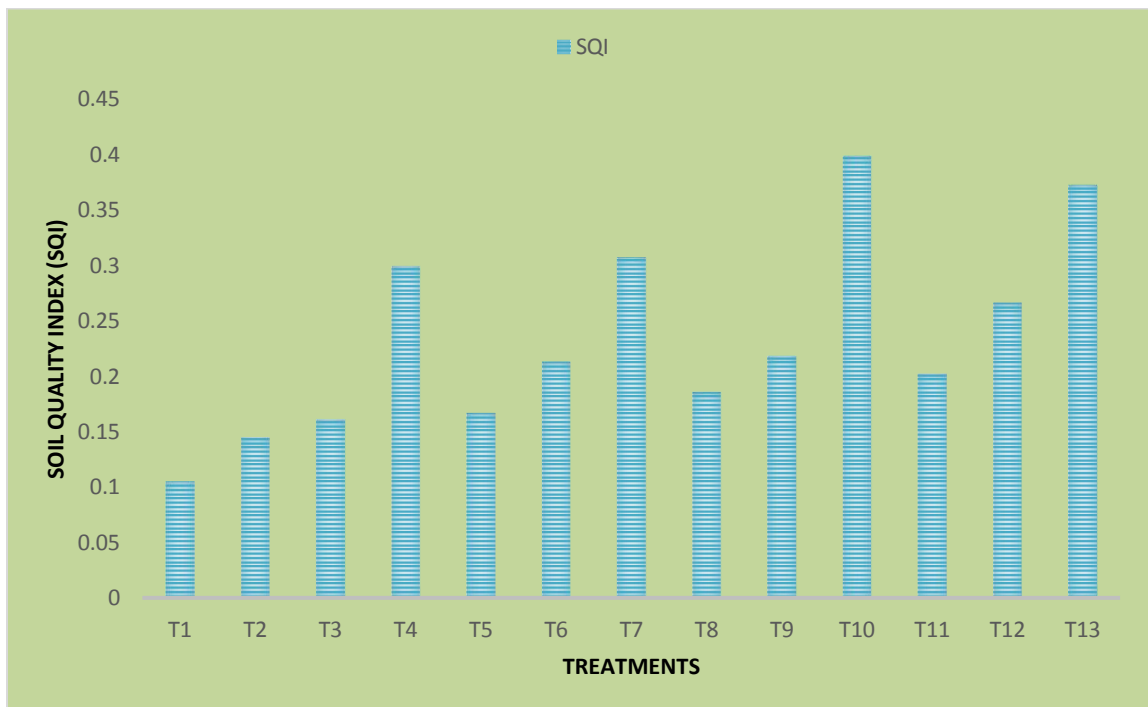


Figure 4.14: Graphical representation of soil quality index under different treatments

Table 4.13: Effect of different treatments on phosphorus use efficiency (kg grain kg⁻¹ P) after harvesting of blackgram

<u>Treatments</u>	<u>2016</u>	<u>2017</u>
T ₁	-	-
T ₂	4.60	5.50
T ₃	5.95	7.20
T ₄	7.00	8.10
T ₅	6.20	7.50
T ₆	8.35	9.30
T ₇	9.05	10.25
T ₈	3.28	3.85
T ₉	4.88	5.55
T ₁₀	5.30	6.00
T ₁₁	4.98	5.76
T ₁₂	6.00	6.73
T ₁₃	6.53	7.13
S.E.(m) ±	0.210	0.258
C.D. (P=0.05)	0.597	0.763

T₁: Control, T₂: P₂₀ + PSB, T₃: P₂₀ + PSB + Rhizobium, T₄: P₂₀ + PSB + Rhizobium + FYM, T₅: P₂₀ + 0.5Mo + PSB, T₆: P₂₀ + 0.5Mo + PSB + Rhizobium, T₇: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, T₈: P₄₀ + PSB, T₉: P₄₀ + PSB + Rhizobium, T₁₀: P₄₀ + PSB + Rhizobium + FYM, T₁₁: P₄₀ + 0.5Mo + PSB, T₁₂: P₄₀ + 0.5Mo + PSB + Rhizobium, T₁₃: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

Table 4.14: Balance sheet of available nutrients in soil after harvesting of blackgram

Treatments	Available N (kg ha ⁻¹)			Available P (kg ha ⁻¹)			Available K (kg ha ⁻¹)			Available Mo (mg kg ⁻¹)		
	Initial status	Status at the end of 2017	Net gain (+) or loss (-)	Initial status	Status at the end of 2017	Net gain (+) or loss (-)	Initial status	Status at the end of 2017	Net gain (+) or loss (-)	Initial status	Status at the end of 2017	Net gain (+) or loss (-)
T₁	93.63	93.08	-0.55	8.79	8.13	-0.66	111.98	111.20	-0.78	0.223	0.212	-0.011
T₂	95.52	96.91	+1.39	9.90	10.61	+0.71	113.14	113.59	+0.45	0.261	0.272	+0.011
T₃	99.23	102.17	+2.94	10.11	10.77	+0.66	114.08	114.51	+0.43	0.267	0.281	+0.014
T₄	102.94	104.96	+2.03	11.76	12.45	+0.69	115.46	116.16	+0.70	0.279	0.289	+0.010
T₅	100.66	102.73	+2.06	10.83	11.40	+0.57	113.66	114.06	+0.40	0.298	0.305	+0.007
T₆	105.91	107.32	+1.41	10.96	11.63	+0.67	114.38	114.79	+0.41	0.303	0.314	+0.011
T₇	108.21	110.21	+2.00	12.94	13.48	+0.54	115.84	116.36	+0.52	0.317	0.327	+0.010
T₈	97.89	99.27	+1.38	12.19	12.70	+0.51	115.21	115.45	+0.24	0.282	0.293	+0.011
T₉	109.91	112.87	+2.96	12.37	12.86	+0.49	116.08	116.6	+0.52	0.289	0.298	+0.009
T₁₀	111.63	114.71	+3.08	13.87	14.24	+0.37	117.45	118.15	+0.70	0.299	0.313	+0.014
T₁₁	110.77	113.53	+2.75	13.18	13.50	+0.32	116.38	116.88	+0.50	0.314	0.329	+0.015
T₁₂	114.14	116.08	+1.95	13.35	13.78	+0.43	116.86	117.35	+0.49	0.319	0.334	+0.015
T₁₃	116.38	117.30	+0.92	14.43	15.02	+0.59	117.73	118.28	+0.55	0.322	0.344	+0.022

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

Table 4.15: Factor loading/ eigenvectors of significant soil quality indicators from PCA

	PC1	PC2	PC3	PC4
Eigen value e	13.57	4.66	2.57	1.43
Percentage of variance explained	67.99	16.21	9.86	5.94
Cumulative e percent age	67.99	84.2	94.06	100
Weighting	0.680	0.162	0.099	0.059
Eigenvectors				
WHC	0.911	0.085	0.236	-0.189
Porosity	0.787	0.077	0.288	0.298
Bacteria	0.421	0.480	0.358	0.218
Fungi	0.811	0.092	-0.107	-0.092
DHA	0.132	0.905	0.296	0.075
Labile carbon	0.383	-0.264	0.295	0.337
Particulate organic carbon	0.647	0.167	0.137	0.043
MBC	0.839	-0.341	-0.068	0.164
Bulk density	-0.681	-0.201	0.186	-0.362
Av. N	0.814	-0.354	0.29	0.19
Av. P	0.735	0.158	-0.337	0.746
Av. Mo	0.624	0.704	-0.031	-0.293
Av. K	0.165	0.297	0.14	0.459

Table 4.16: Score (S), weight (W) and soil quality index (SQI) values of selected minimum data set (MDS) variables for each treatment

	WHC		BACTERIA		DHA		AV.P		SQI
	S	W	S	W	S	W	S	W	
T₁	0.068	0.680	0.162	0.162	0.189	0.099	0.241	0.059	0.105
T₂	0.107	0.680	0.237	0.162	0.113	0.099	0.390	0.059	0.145
T₃	0.104	0.680	0.445	0.162	0.057	0.099	0.207	0.059	0.161
T₄	0.347	0.680	0.284	0.162	0.047	0.099	0.212	0.059	0.299
T₅	0.129	0.680	0.352	0.162	0.187	0.099	0.062	0.059	0.167
T₆	0.127	0.680	0.558	0.162	0.238	0.099	0.216	0.059	0.213
T₇	0.232	0.680	0.686	0.162	0.152	0.099	0.384	0.059	0.307
T₈	0.219	0.680	0.076	0.162	0.191	0.099	0.103	0.059	0.186
T₉	0.301	0.680	0.059	0.162	0.012	0.099	0.045	0.059	0.218
T₁₀	0.343	0.680	0.531	0.162	0.571	0.099	0.375	0.059	0.398
T₁₁	0.187	0.680	0.334	0.162	0.041	0.099	0.284	0.059	0.202
T₁₂	0.081	0.680	0.536	0.162	1.000	0.099	0.432	0.059	0.266
T₁₃	0.295	0.680	1.000	0.162	0.030	0.099	0.117	0.059	0.372

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

After determination of the MDS indicators, each of the MDS variables was scored on the basis of the performance of soil function, considering variation of values within treatments (Table 4.16). Each variable was transformed into unit less score (between 0 to 1) using linear transformation. Once transformed, the MDS variables for each observation were weighted by using PCA results. Each PC explained a certain amount (%) of variation in the total data set. This percentage divided by the total percentage of variation explained by all PCs with eigenvalues greater than 1, provided the weighted factor for variables chosen under a given PC (Table 4.15). Calculated weightage for PC 1, PC 2, PC 3 and PC 4 was 0.680, 0.162, 0.099 and 0.059, respectively. After scoring and weighting, the values were fed into the additive model and finally aggregate score indicating state of soil quality was determined and the numerical value of soil quality index (SQI) was obtained for each treatment as shown in the Table 4.16 (Figure 4.14).

4.3.2 Soil quality index (SQI)

Soil quality index (SQI) developed for different treatment varied from 0.105 to 0.398 as depicted in Table 4.16 and Figure 4.14. SQI followed the order of $T_{10} > T_{13} > T_7 > T_4 > T_{12} > T_9 > T_6 > T_{11} > T_8 > T_5 > T_3 > T_2 > T_1$. The magnitude of share of key soil quality indicators for influencing SQI were WHC, DHA, bacteria and available P.

4.4 Yield parameters and grain and straw yield of blackgram

4.4.1 Number of pods per plant

The data on number of pods per plant recorded at harvest presented in Table (4.17, Figure 4.15). The mean value with regard to number of pods per plant after harvesting of blackgram was recorded highest in treatment T_{13} (20.45) and lowest in treatment T_1 (13.73) and was recorded in order of T_{12} (19.92), T_{10} (19.33), T_{11} (19.19), T_9 (19.06), T_7 (18.80), T_6 (18.23), T_4 (17.39), T_8 (17.13), T_5 (16.96), T_3 (16.83) and T_2 (16.05) during 2016 whereas, the mean value with respect to number of pods per plant were found highest under treatment T_{13} (23.60) and lowest in treatment T_1 (15.30) followed by T_{12} (23.26), T_{10} (22.42), T_{11} (22.20), T_9 (22.11), T_7 (21.61), T_6 (21.14), T_4 (19.51), T_8 (19.40), T_5 (19.19), T_3 (19.02) and T_2 (18.28) during 2017. The number of pods per plant significantly increased with integrated application of organics, inorganics

and biofertilizers in treatments *viz.* T₄ (P₂₀ + PSB + Rhizobium + FYM) (17.39, 19.51), T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM) (18.80, 21.61), T₁₀ (P₄₀ + PSB + Rhizobium + FYM) (19.33, 22.42) and T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) (20.45, 23.60) over control during 2016 and 2017.

4.4.2 Number of grains per pod

The data pertaining to the effect of different treatments on number of grains per pod is given in Table (4.18, Figure 4.16). The mean value of number of grains per pod of blackgram was found to be highest in treatment T₁₃ (8.08) and lowest under treatment T₁ (3.46) and was observed in order of T₁₂ (7.58), T₁₀ (7.34), T₁₁ (6.89), T₉ (6.82), T₇ (6.49), T₆ (6.04), T₄ (5.36), T₈ (5.02), T₅ (4.91), T₃ (4.80) and T₂ (4.28) during 2016, however, the mean value with regard to number of grains per pod was observed to be highest under T₁₃ (8.94) and lowest under T₁ (4.03) followed by T₁₂ (8.65), T₁₀ (7.81), T₁₁ (7.54), T₉ (7.47), T₇ (7.10), T₆ (6.88), T₄ (5.89), T₈ (5.79), T₅ (5.61), T₃ (5.48) and T₂ (5.07) during 2017. Further, number of grains per pod increased significantly with integrated addition of organic, inorganic and bio-fertilizers under treatments T₄ (P₂₀ + PSB + Rhizobium + FYM) (5.36, 5.89), T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM) (6.49, 7.10), T₁₀ (P₄₀ + PSB + Rhizobium + FYM) (7.34, 7.81) and T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) (8.08, 8.94) over control during 2016 and 2017.

4.4.3 Number of nodules per plant

The data regarding number of nodules per plant recorded at 40 DAS of the blackgram given in Table 4.19 and depicted in Figure 4.17. The mean value of number of nodules per plant of blackgram was recorded highest under treatment T₁₃ (13.15) and lowest under treatment T₁ (4.81) followed by T₁₂ (12.41), T₁₀ (11.56), T₁₁ (10.99), T₉ (10.86), T₇ (10.55), T₆ (9.76), T₄ (8.40), T₈ (8.23), T₅ (7.92), T₃ (7.30) and T₂ (6.79) during 2016 whereas, mean value with regard to number of nodules per plant of blackgram was noted highest under treatment T₁₃ (13.81) and lowest in treatment T₁ (5.48) and found in pattern of T₁₂ (13.28), T₁₀ (11.88), T₁₁ (11.55), T₉ (11.34), T₇ (11.00), T₆ (10.38), T₄ (9.37), T₈ (9.44), T₅ (8.96), T₃ (8.44) and T₂ (7.92) during 2017. The increasing number of nodules per plant during both the years might be due mixed

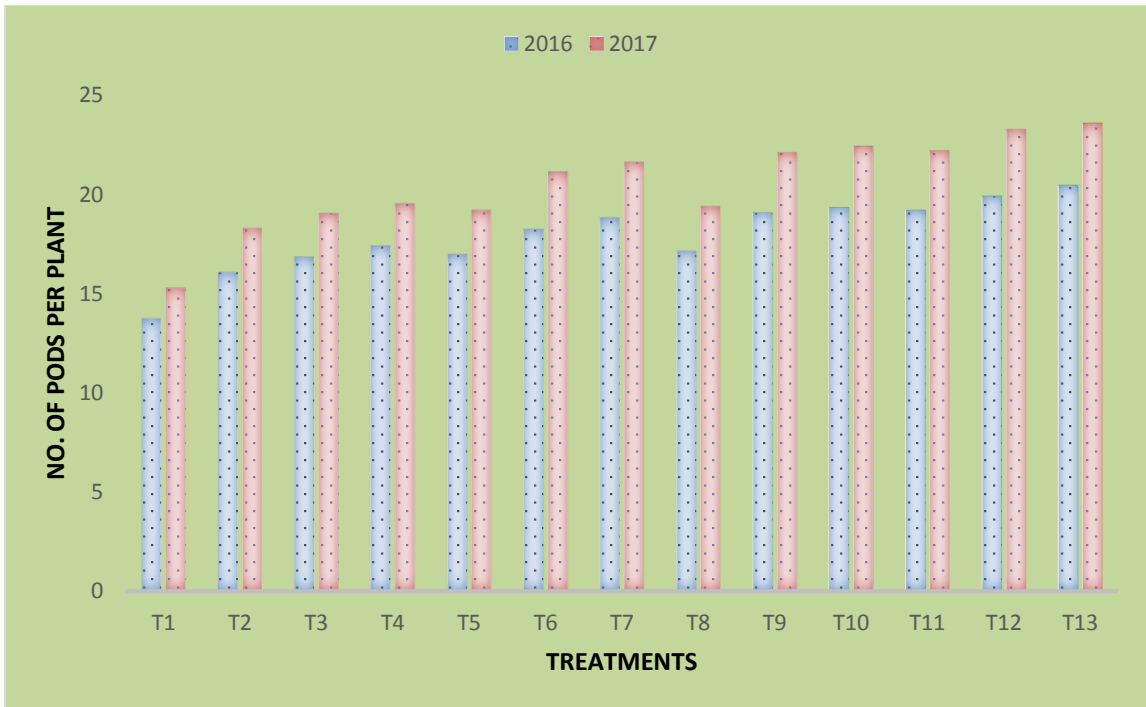


Figure 4.15: Effect of different treatments on number of pods per plant of blackgram during 2016 and 2017

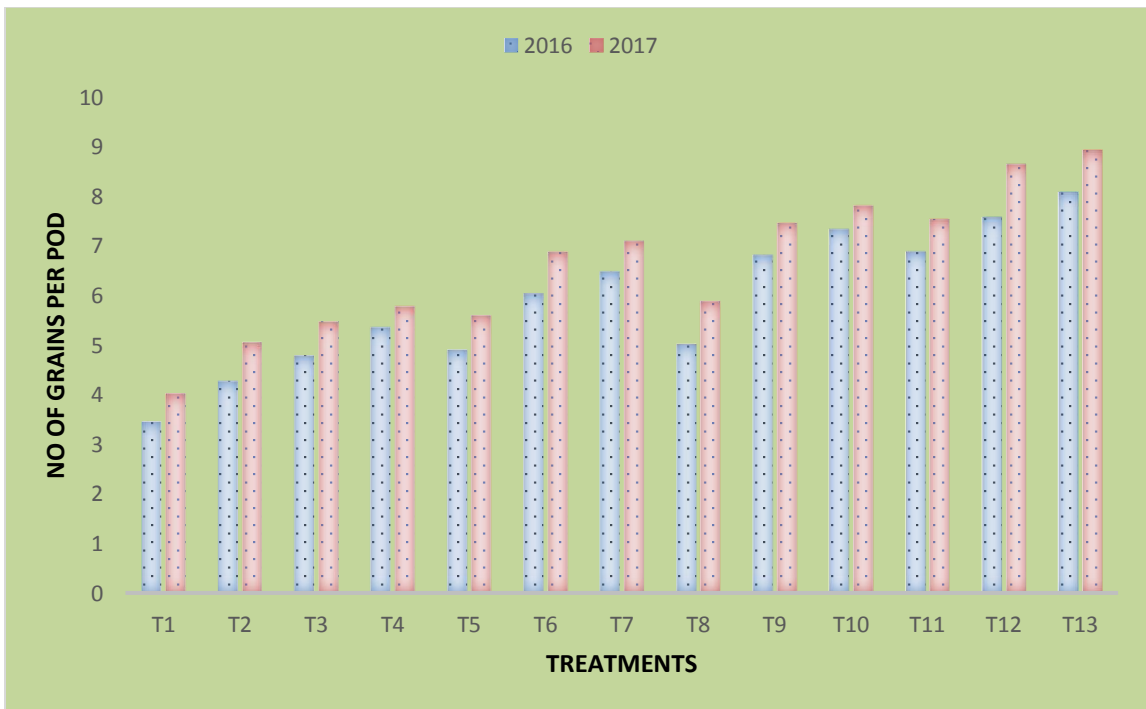


Figure 4.16: Effect of different treatments on number of grains per pod of blackgram during 2016 and 2017

Table 4.17: Effect of different treatments on number of pods per plant of blackgram during 2016 and 2017

<u>Treatments</u>		<u>2016</u>	<u>2017</u>
T₁	Control	13.73	15.30
T₂	P20 + PSB	16.05	18.28
T₃	P20 + PSB + Rhizobium	16.83	19.02
T₄	P20 + PSB + Rhizobium + FYM	17.39	19.51
T₅	P20 + 0.5Mo + PSB	16.96	19.19
T₆	P20 + 0.5Mo + PSB + Rhizobium	18.23	21.14
T₇	P20 + 0.5Mo + PSB + Rhizobium + FYM	18.80	21.61
T₈	P40 + PSB	17.13	19.40
T₉	P40 + PSB + Rhizobium	19.06	22.11
T₁₀	P40 + PSB + Rhizobium + FYM	19.33	22.42
T₁₁	P40 + 0.5Mo + PSB	19.19	22.20
T₁₂	P40 + 0.5Mo + PSB + Rhizobium	19.92	23.26
T₁₃	P40 + 0.5Mo + PSB + Rhizobium + FYM	20.45	23.60
	S.E.(m) ±	0.242	0.151
	C.D. (P=0.05)	0.710	0.444

Table 4.18: Effect of different treatments on number of grains per pod of blackgram during 2016 and 2017

<u>Treatments</u>		<u>2016</u>	<u>2017</u>
T ₁	Control	3.46	4.03
T ₂	P20 + PSB	4.28	5.07
T ₃	P20 + PSB + Rhizobium	4.80	5.48
T ₄	P20 + PSB + Rhizobium + FYM	5.36	5.79
T ₅	P20 + 0.5Mo + PSB	4.91	5.61
T ₆	P20 + 0.5Mo + PSB + Rhizobium	6.04	6.88
T ₇	P20 + 0.5Mo + PSB + Rhizobium + FYM	6.49	7.10
T ₈	P40 + PSB	5.02	5.89
T ₉	P40 + PSB + Rhizobium	6.82	7.47
T ₁₀	P40 + PSB + Rhizobium + FYM	7.34	7.81
T ₁₁	P40 + 0.5Mo + PSB	6.89	7.54
T ₁₂	P40 + 0.5Mo + PSB + Rhizobium	7.58	8.65
T ₁₃	P40 + 0.5Mo + PSB + Rhizobium + FYM	8.08	8.94
S.E.(m) ±		0.149	0.049
C.D. (P=0.05)		0.438	0.143

Table 4.19: Effect of different treatments on number of nodules per plant at 40 DAS of blackgram during 2016 and 2017

<u>Treatments</u>		<u>2016</u>	<u>2017</u>
T ₁	Control	4.81	5.48
T ₂	P20 + PSB	6.79	7.92
T ₃	P20 + PSB + Rhizobium	7.30	8.44
T ₄	P20 + PSB + Rhizobium + FYM	8.40	9.37
T ₅	P20 + 0.5Mo + PSB	7.92	8.96
T ₆	P20 + 0.5Mo + PSB + Rhizobium	9.76	10.38
T ₇	P20 + 0.5Mo + PSB + Rhizobium + FYM	10.55	11.00
T ₈	P40 + PSB	8.23	9.44
T ₉	P40 + PSB + Rhizobium	10.86	11.34
T ₁₀	P40 + PSB + Rhizobium + FYM	11.56	11.88
T ₁₁	P40 + 0.5Mo + PSB	10.99	11.55
T ₁₂	P40 + 0.5Mo + PSB + Rhizobium	12.41	13.28
T ₁₃	P40 + 0.5Mo + PSB + Rhizobium + FYM	13.15	13.81
S.E.(m) ±		0.236	0.172
C.D. (P=0.05)		0.693	0.504



Figure 4.17: Effect of different treatments on number of nodules per plant at 40 DAS of blackgram during 2016 and 2017

addition of organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and Rhizobium.

4.4.4 Grain yield (kg ha⁻¹)

The mean value of grain yield (kg ha⁻¹) of blackgram presented in Table 4.20 (Figure 4.18) revealed highest in treatment T₁₃ (1291) and lowest in treatment T₁ (1043) followed by T₁₂ (1277), T₁₀ (1251), T₁₁ (1240), T₉ (1233), T₇ (1217), T₆ (1203), T₄ (1183), T₈ (1174), T₅ (1167), T₃ (1162) and T₂ (1135) during 2016. The mean value of grain yield (kg ha⁻¹) of blackgram was found to be highest under treatment T₁₃ (1388) and lowest in treatment T₁ (1103) and observed in pattern T₁₂ (1372), T₁₀ (1343), T₁₁ (1332), T₉ (1323), T₇ (1308), T₆ (1290), T₄ (1273), T₈ (1257), T₅ (1253), T₃ (1246) and T₂ (1213) during 2017. The grain yield significantly increased under treatments which received inorganics, organics and bio-fertilizers including phosphorus solubilizing bacteria and Rhizobium under the treatments T₄ (P₂₀ + PSB + Rhizobium + FYM), T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM), T₁₀ (P₄₀ + PSB + Rhizobium + FYM) and T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) in comparison to control during 2016 and 2017. The per cent increase in grain yield due to treatment T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) was to the tune of 23.77 and 25.83 over control (T₁) during 2016 and 2017, respectively.

4.4.5 Straw yield (kg ha⁻¹)

The average value of straw yield (kg ha⁻¹) of blackgram given in Table (4.20 and Figure 4.19) was found to be highest under treatment T₁₃ (2334) and lowest in treatment T₁ (1847) and were recorded in order of T₁₂ (2319), T₁₀ (2290), T₁₁ (2269), T₉ (2261), T₇ (2245), T₆ (2229), T₄ (2182), T₈ (2144), T₅ (2122), T₃ (2113) and T₂ (1954) during 2016. However, the mean value of straw yield (kg ha⁻¹) of blackgram was noticed highest under treatment T₁₃ (2423) lowest in treatment T₁ (1903) and was found in order of T₁₂ (2400), T₁₀ (2364), T₁₁ (2334), T₉ (2332), T₇ (2321), T₆ (2298), T₄ (2254), T₈ (2244), T₅ (2220), T₃ (2212) and T₂ (2004) during 2017. The combined application of organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and Rhizobium recorded significantly higher straw yield under treatments T₄ (P₂₀ + PSB + Rhizobium + FYM), T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM), T₁₀ (P₄₀ + PSB + Rhizobium + FYM) and T₁₃

(P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) over control during both the years. The per cent increase in straw yield (kg ha⁻¹) of blackgram due to treatment T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) was to the tune of 26.37 and 27.33 over control (T₁) during 2016 and 2017, respectively.

4.5 Nutrient concentration and total uptake of N, P, K and Mo after harvesting of blackgram

4.5.1 Nutrient content (%)

4.5.1.1 Nitrogen content (%) by grain

The data pertaining to nitrogen content by grain of blackgram is given in Table 4.21. The mean value of nitrogen content by grain after harvesting of blackgram was observed to be highest under treatment T₁₃ (2.375) and lowest under treatment T₁ (2.392) followed by T₁₂ (2.894), T₁₀ (2.860), T₁₁ (2.824), T₉ (2.788), T₇ (2.716), T₆ (2.652), T₄ (2.603), T₅ (2.525), T₃ (2.488), T₈ (2.430) and T₂ (2.392) during 2016 whereas, the average value of nitrogen content (%) by grain was recorded highest in treatment T₁₃ (3.073) and lowest in treatment T₁ (2.485) and was in order of T₁₂ (3.004), T₁₀ (2.960), T₁₁ (2.924), T₉ (2.888), T₇ (2.816), T₆ (2.752), T₄ (2.703), T₅ (2.625), T₃ (2.595), T₈ (2.520) and T₂ (2.492) during 2017. The combined applications of organics and inorganics under various treatments significantly improved nitrogen content of blackgram during both the years.

4.5.1.2 Nitrogen content (%) by straw

The nitrogen content by straw recorded after harvesting of blackgram given in Table 4.21 reflected highest under treatment T₁₃ (1.540) and lowest under treatment T₁ (0.902) and was recorded in pattern of T₁₂ (1.508), T₁₀ (1.460), T₁₁ (1.414), T₉ (1.392), T₇ (1.346), T₆ (1.315), T₄ (1.284), T₅ (1.209), T₃ (1.180), T₈ (0.978) and T₂ (0.940) during 2016. However, the mean value of N content (%) by straw was observed highest in treatment T₁₃ (1.590) and lowest in treatment T₁ (0.945) followed by T₁₂ (1.551), T₁₀ (1.494), T₁₁ (1.444), T₉ (1.425), T₇ (1.380), T₆ (1.349), T₄ (1.318), T₅ (1.242), T₃ (1.220),

Table 4.20: Effect of different treatments on grain and straw yield (kg ha⁻¹) of blackgram during 2016 and 2017

<u>Treatments</u>	<u>Grain yield</u>		<u>Straw yield</u>	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	1043	1103	1847	1903
T₂	1135	1213	1954	2004
T₃	1162	1246	2113	2212
T₄	1183	1273	2182	2254
T₅	1167	1253	2122	2220
T₆	1203	1290	2229	2298
T₇	1217	1308	2245	2321
T₈	1174	1257	2144	2244
T₉	1233	1323	2269	2334
T₁₀	1251	1343	2290	2364
T₁₁	1240	1332	2269	2332
T₁₂	1277	1372	2319	2400
T₁₃	1291	1388	2334	2423
S.E.(m) ±	5.345	6.140	6.869	9.721
C.D. (P=0.05)	15.694	18.029	20.168	28.543

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

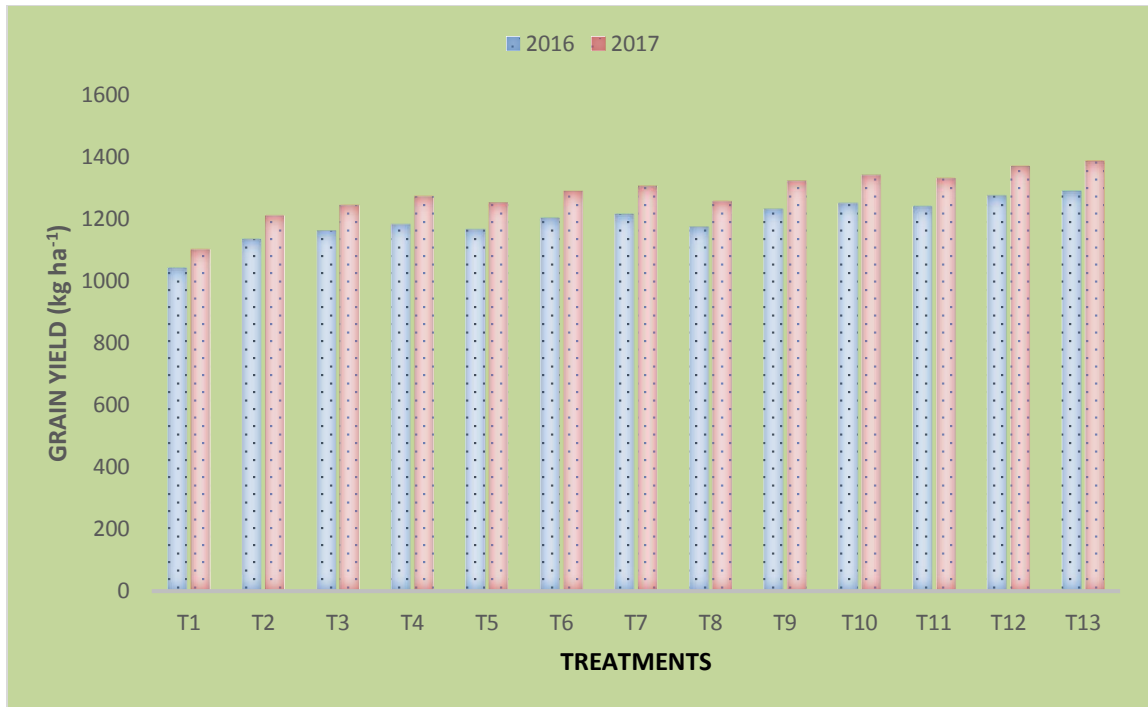


Figure 4.18: Effect of different treatments on grain yield (kg ha⁻¹) of blackgram during 2016 and 2017

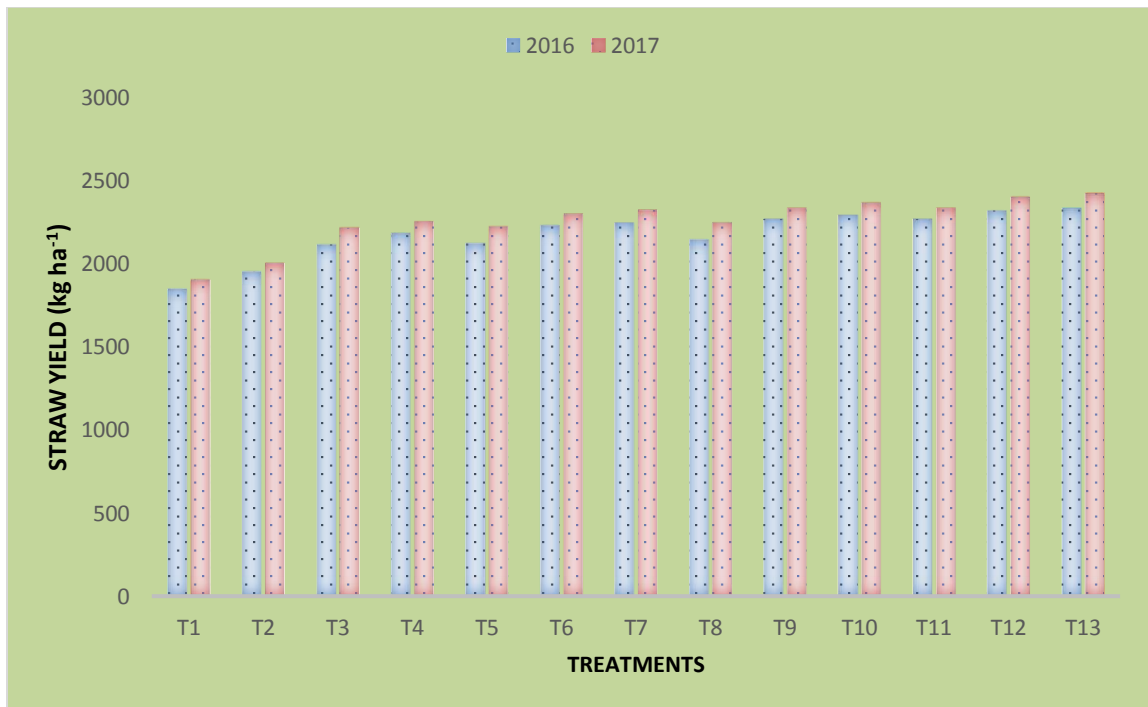


Figure 4.19: Effect of different treatments on straw yield (kg ha⁻¹) of blackgram during 2016 and 2017

Table 4.21: Effect of different treatments on N content (%) by grain and straw after harvesting of blackgram

<u>Treatments</u>	<u>N content by grain</u>		<u>N content by straw</u>	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	2.375	2.485	0.902	0.945
T₂	2.392	2.492	0.940	0.974
T₃	2.488	2.595	1.180	1.220
T₄	2.603	2.703	1.284	1.318
T₅	2.525	2.625	1.209	1.242
T₆	2.652	2.752	1.315	1.349
T₇	2.716	2.816	1.346	1.380
T₈	2.430	2.520	0.978	1.001
T₉	2.788	2.888	1.392	1.425
T₁₀	2.860	2.960	1.460	1.494
T₁₁	2.824	2.924	1.414	1.444
T₁₂	2.894	3.004	1.508	1.551
T₁₃	2.957	3.073	1.540	1.590
S.E.(m) ±	0.011	0.015	0.012	0.014
C.D. (P=0.05)	0.033	0.043	0.036	0.040

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

T₈ (1.001) and T₂ (0.974) during 2017. Nitrogen content by straw was affected significantly due to various treatments during both the years.

4.5.1.3 Phosphorus content (%) by grain

The data regarding phosphorus content by grain registered after harvesting of blackgram under different treatments is given in Table 4.22 and recorded highest in treatment T₁₃ (0.497) and lowest in treatment T₁ (0.315) followed by T₁₂ (0.465), T₁₀ (0.456), T₁₁ (0.440), T₇ (0.438), T₉ (0.419), T₆ (0.417), T₄ (0.407), T₈ (0.392), T₅ (0.385), T₃ (0.378), and T₂ (0.350) during 2016 whereas, the mean value of P content (%) by grain was recorded highest in treatment T₁₃ (0.530) and lowest in treatment T₁ (0.335) and was observed in order of T₁₂ (0.501), T₁₀ (0.480), T₁₁ (0.464), T₇ (0.463), T₉ (0.451), T₆ (0.440), T₄ (0.421), T₈ (0.413), T₅ (0.398), T₃ (0.389), and T₂ (0.376) during 2017. The phosphorus content by grain under various treatments was significantly influenced due to combined applications of organics and inorganics over control (T₁) during both the years i.e, 2016 and 2017.

4.5.1.4 Phosphorus content (%) by straw

The phosphorus content by straw after harvesting of blackgram presented in Table 4.22 revealed highest in treatment T₁₃ (0.288) and lowest in T₁ (0.123) and observed in pattern of T₁₂ (0.277), T₁₀ (0.265), T₁₁ (0.243), T₇ (0.238), T₉ (0.224), T₆ (0.212), T₄ (0.186), T₈ (0.176), T₅ (0.165), T₃ (0.159), and T₂ (0.147) during 2016. Further, the mean value of phosphorus content by straw was recorded highest under treatment T₁₃ (0.299) and lowest in T₁ (0.148) followed by T₁₂ (0.288), T₁₀ (0.274), T₁₁ (0.268), T₇ (0.265), T₉ (0.259), T₆ (0.243), T₄ (0.224), T₈ (0.218), T₅ (0.204), T₃ (0.195), and T₂ (0.173) during 2017. A perusal of data revealed that phosphorus application along with organic sources significantly increased phosphorus content by straw during both the years.

4.5.1.5 Potassium content (%) by grain

The mean value regarding potassium content (%) by grain after harvesting of blackgram presented in Table 4.23 was found to be highest in treatment T₁₃ (0.737) and lowest in T₁ (0.561) followed by T₁₂ (0.709), T₁₀ (0.686), T₁₁ (0.659), T₇ (0.656), T₉

Table 4.22: Effect of different treatments on P content (%) by grain and straw after harvesting of blackgram

<u>Treatments</u>	<u>P content by grain</u>		<u>P content by straw</u>	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	0.315	0.335	0.123	0.148
T₂	0.350	0.376	0.147	0.173
T₃	0.378	0.389	0.159	0.195
T₄	0.407	0.421	0.186	0.224
T₅	0.385	0.398	0.165	0.204
T₆	0.417	0.440	0.212	0.243
T₇	0.438	0.463	0.238	0.265
T₈	0.392	0.413	0.176	0.218
T₉	0.419	0.451	0.224	0.259
T₁₀	0.456	0.480	0.265	0.274
T₁₁	0.440	0.464	0.243	0.268
T₁₂	0.465	0.501	0.277	0.288
T₁₃	0.497	0.530	0.288	0.299
S.E.(m) ±	0.006	0.005	0.005	0.006
C.D. (P=0.05)	0.017	0.014	0.016	0.017

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

Table 4.23: Effect of different treatments on potassium (K) content (%) by grain and straw after harvesting of blackgram

<u>Treatments</u>	<u>K content by grain</u>		<u>K content by straw</u>	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	0.561	0.594	0.765	0.803
T₂	0.587	0.617	0.792	0.831
T₃	0.591	0.629	0.810	0.845
T₄	0.620	0.654	0.843	0.893
T₅	0.598	0.635	0.817	0.859
T₆	0.631	0.668	0.857	0.909
T₇	0.656	0.685	0.882	0.945
T₈	0.607	0.641	0.824	0.868
T₉	0.642	0.674	0.870	0.926
T₁₀	0.686	0.724	0.916	0.978
T₁₁	0.659	0.685	0.892	0.945
T₁₂	0.709	0.740	0.926	0.997
T₁₃	0.737	0.763	0.957	1.118
S.E.(m) ±	0.009	0.011	0.008	0.016
C.D. (P=0.05)	0.025	0.032	0.025	0.046

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

(0.642), T₆ (0.631), T₄ (0.620), T₈ (0.607), T₅ (0.598), T₃ (0.591), and T₂ (0.587) during 2016, whereas, the average value with respect to K content (%) by grain was observed highest in treatment T₁₃ (0.763) and lowest in T₁ (0.594) and noted in order of T₁₂ (0.740), T₁₀ (0.724), T₁₁ (0.685), T₇ (0.681), T₉ (0.674), T₆ (0.668), T₄ (0.654), T₈ (0.641), T₅ (0.635), T₃ (0.629), and T₂ (0.617) during 2017. The combined applications of organics, inorganics and bio-fertilizer including phosphorus solubilizing bacteria and *Rhizobium* significantly enhanced the potassium content by grain after harvesting of blackgram during both the years.

4.5.1.6 Potassium content (%) by straw

The potassium content (%) by straw of blackgram after harvesting of blackgram is presented in Table 4.23. The mean value reflected highest under treatment T₁₃ (0.957) and lowest under T₁ (0.765) followed by T₁₂ (0.926), T₁₀ (0.916), T₁₁ (0.892), T₇ (0.882), T₉ (0.870), T₆ (0.857), T₄ (0.843), T₈ (0.824), T₅ (0.817), T₃ (0.810), and T₂ (0.792) during 2016, whereas, the average value of K content (%) by straw at harvest was found to be highest under T₁₃ (1.118) and lowest under T₁ (0.803) followed by T₁₂ (0.997), T₁₀ (0.978), T₁₁ (0.945), T₇ (0.945), T₉ (0.926), T₆ (0.909), T₄ (0.893), T₈ (0.868), T₅ (0.859), T₃ (0.845), and T₂ (0.831) during 2017. The potassium content (%) by straw was significantly affected under combined applications of inorganics, organics and bio-fertilizer including phosphorus solubilizing bacteria and *Rhizobium* over control (T₁) during both the years.

4.5.1.7 Molybdenum content (%) by grain

The molybdenum content (%) by grain after harvesting of blackgram presented in Table 4.24 revealed highest under treatment T₁₃ (1.978) and lowest in T₁ (1.766) and was found in order of T₁₂ (1.947), T₁₁ (1.928), T₇ (1.918), T₆ (1.897), T₁₀ (1.866), T₅ (1.860), T₉ (1.852), T₈ (1.837), T₄ (1.828), T₃ (1.816), and T₂ (1.798) during 2016, whereas, the average value of molybdenum content (%) by grain was found highest in treatment T₁₃ (2.045) and lowest under T₁ (1.780) followed by T₁₂ (1.991), T₁₁ (1.968), T₇ (1.943), T₆ (1.928), T₁₀ (1.910), T₅ (1.902), T₉ (1.896), T₈ (1.877), T₄ (1.869), T₃ (1.848), and T₂ (1.815) during 2017. It was noticed that Mo content (%) by grain was recorded

significantly influenced under combined applications of organics and inorganics over control (T₁) during both 2016 and 2017.

4.5.1.8 Molybdenum content (%) by straw

The data regarding molybdenum content (%) by straw after harvesting of blackgram presented in Table 4.24 observed highest in treatment T₁₃ (0.948) and lowest in T₁ (0.705) and was found in pattern of T₁₂ (0.919), T₁₁ (0.880), T₇ (0.867), T₆ (0.839), T₁₀ (0.822), T₅ (0.820), T₉ (0.808), T₈ (0.793), T₄ (0.783), T₃ (0.767), and T₂ (0.736) during 2016, whereas, the mean value of molybdenum content (%) by straw was found to be highest under treatment T₁₃ (0.970) and lowest in T₁ (0.739) followed by T₁₂ (0.938), T₁₁ (0.915), T₇ (0.900), T₆ (0.869), T₁₀ (0.859), T₅ (0.844), T₉ (0.839), T₈ (0.805), T₄ (0.796), T₃ (0.773), and T₂ (0.749) during 2017. The combined applications of organics and inorganics significantly affected molybdenum content under different treatments during the crop growing periods i.e, 2016 and 2017.

4.5.2 Total nutrient uptake

4.5.2.1 Total nitrogen uptake (kg ha⁻¹)

The data with regard to total nitrogen uptake after harvesting of blackgram presented in Table 4.25 (Figure 4.20) revealed highest under treatment T₁₃ (74.143) and lowest in treatment T₁ (41.381) and observed in pattern of T₁₂ (71.920), T₁₀ (69.213), T₁₁ (67.181), T₉ (65.945), T₇ (63.268), T₆ (61.206), T₄ (58.817), T₅ (55.091), T₃ (53.832), T₈ (49.514) and T₂ (45.485) during 2016. Whereas, the total nitrogen uptake was found highest in treatment T₁₃ (81.183) and lowest under treatment T₁ (45.355) followed by T₁₂ (78.424), T₁₀ (75.010), T₁₁ (72.782), T₉ (71.509), T₇ (68.828), T₆ (66.452), T₄ (64.070), T₅ (60.407), T₃ (59.295), T₈ (54.113) and T₂ (49.686) during 2017. The nitrogen uptake under different treatments was significantly affected by combined applications of organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* during both crop growing periods i.e, 2016 and 2017.

4.5.2.2 Total phosphorus uptake (kg ha^{-1})

It is apparent from the data depicted in Table (4.25, Figure 4.21) that total phosphorus uptake (kg/ha) after harvesting of blackgram was significantly influenced by different treatments during both the years of experiment i.e, 2016 and 2017. The total phosphorus uptake was noted in treatment T_{13} (13.176) and lowest in treatment T_1 (5.584) and observed in order of T_{12} (12.408), T_{10} (11.811), T_{11} (10.995), T_7 (10.704), T_9 (10.271), T_6 (9.776), T_4 (8.898), T_8 (8.386), T_5 (8.002), T_3 (7.776), and T_2 (6.856) during 2016. Further, the total phosphorus uptake reflected highest under T_{13} (14.611) and lowest in treatment T_1 (6.511) and recorded in pattern of T_{12} (13.791), T_{10} (12.930), T_{11} (12.477), T_7 (12.217), T_9 (12.033), T_6 (11.243), T_4 (10.398), T_8 (10.094), T_5 (9.533), T_3 (9.170), and T_2 (8.026) during 2017. The integrated application of phosphorus, molybdenum and organics under aforesaid treatments brought about significant influence on total phosphorus uptake during both the years.

4.5.2.3 Total potassium uptake (kg ha^{-1})

The total potassium uptake after harvesting of blackgram recorded in Table 4.25 (Figure 4.22) revealed highest under treatment T_{13} (31.878) and lowest in T_1 (19.901) and found in order of T_{12} (30.479), T_{10} (29.498), T_{11} (28.425), T_7 (27.732), T_9 (27.623), T_6 (26.643), T_4 (25.679), T_8 (24.731), T_5 (24.274), T_3 (23.945), and T_2 (22.065) during 2016. However, total potassium uptake was recorded highest in T_{13} (37.604) and lowest in T_1 (21.774) followed by T_{12} (34.071), T_{10} (32.824), T_{11} (31.262), T_7 (30.876), T_9 (30.558), T_6 (29.463), T_4 (28.679), T_8 (27.488), T_5 (26.972), T_3 (26.492), and T_2 (24.083) during 2017. The mixed addition of organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* under different treatments significantly influenced total potassium uptake during both the years i.e, 2016 and 2017.

4.5.2.4 Total molybdenum uptake (g ha^{-1})

The total molybdenum uptake after harvesting of blackgram presented in Table 4.25 (Figure 4.23) revealed highest in treatment T_{13} (4.779) and lowest in T_1 (3.140) and was found in order of T_{12} (4.611), T_{11} (4.386), T_7 (4.240), T_{10} (4.211), T_6 (4.147), T_9 (4.110), T_5 (3.906), T_4 (3.866), T_8 (3.852), T_3 (3.726), and T_2 (3.475) during 2016,

Table 4.24: Effect of different treatments on molybdenum (Mo) content (%) by grain and straw after harvesting of blackgram

<u>Treatments</u>	<u>Mo content by grain</u>		<u>Mo content by straw</u>	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	1.766	1.780	0.705	0.739
T₂	1.798	1.815	0.736	0.749
T₃	1.816	1.848	0.767	0.773
T₄	1.828	1.869	0.783	0.796
T₅	1.860	1.902	0.820	0.844
T₆	1.897	1.928	0.839	0.869
T₇	1.918	1.943	0.867	0.900
T₈	1.837	1.877	0.793	0.805
T₉	1.852	1.896	0.808	0.839
T₁₀	1.866	1.910	0.822	0.859
T₁₁	1.928	1.968	0.880	0.915
T₁₂	1.947	1.991	0.919	0.938
T₁₃	1.978	2.045	0.948	0.970
S.E.(m) ±	0.008	0.010	0.005	0.010
C.D. (P=0.05)	0.023	0.029	0.013	0.028

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

whereas, total molybdenum uptake was found highest in treatment T₁₃ (5.190) and lowest in T₁ (3.369) followed by T₁₂ (4.983), T₁₁ (4.767), T₇ (4.628), T₁₀ (4.593), T₆ (4.479), T₉ (4.472), T₅ (4.254), T₄ (4.157), T₈ (4.163), T₃ (4.012), and T₂ (3.701) during 2017. The molybdenum uptake under various treatments was significantly influenced by combined addition of organics and inorganics during crop growing period i.e, 2016 and 2017.

Table 4.25: Effect of different treatments on total nutrient uptake by blackgram during 2016 and 2017

Treatments	Total uptake (kg ha ⁻¹)						Total uptake (g ha ⁻¹)	
	Nitrogen		Phosphorus		Potassium		Molybdenum	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
T₁	41.381	45.355	5.584	6.511	19.901	21.774	3.140	3.369
T₂	45.485	49.686	6.856	8.026	22.065	24.083	3.475	3.701
T₃	53.832	59.295	7.776	9.170	23.945	26.492	3.726	4.012
T₄	58.817	64.070	8.898	10.398	25.679	28.348	3.866	4.157
T₅	55.091	60.407	8.002	9.533	24.274	26.972	3.906	4.254
T₆	61.206	66.452	9.776	11.243	26.643	29.463	4.147	4.479
T₇	63.268	68.828	10.704	12.217	27.732	30.876	4.240	4.628
T₈	49.514	54.113	8.386	10.094	24.731	27.488	3.852	4.163
T₉	65.945	71.509	10.271	12.033	27.623	30.558	4.110	4.472
T₁₀	69.213	75.010	11.811	12.930	29.498	32.824	4.211	4.593
T₁₁	67.181	72.782	10.995	12.477	28.425	31.262	4.386	4.767
T₁₂	71.920	78.424	12.408	13.791	30.479	34.071	4.611	4.983
T₁₃	74.143	81.183	13.176	14.611	31.878	37.604	4.779	5.190
S.E.(m) ±	0.482	0.398	0.191	0.193	0.237	0.350	0.025	0.036
C.D. (P=0.05)	1.415	1.169	0.562	0.567	0.696	1.027	0.075	0.106

T₁: Control, **T₂**: P₂₀ + PSB, **T₃**: P₂₀ + PSB + Rhizobium, **T₄**: P₂₀ + PSB + Rhizobium + FYM, **T₅**: P₂₀ + 0.5Mo + PSB, **T₆**: P₂₀ + 0.5Mo + PSB + Rhizobium, **T₇**: P₂₀ + 0.5Mo + PSB + Rhizobium + FYM, **T₈**: P₄₀ + PSB, **T₉**: P₄₀ + PSB + Rhizobium, **T₁₀**: P₄₀ + PSB + Rhizobium + FYM, **T₁₁**: P₄₀ + 0.5Mo + PSB, **T₁₂**: P₄₀ + 0.5Mo + PSB + Rhizobium, **T₁₃**: P₄₀ + 0.5Mo + PSB + Rhizobium + FYM

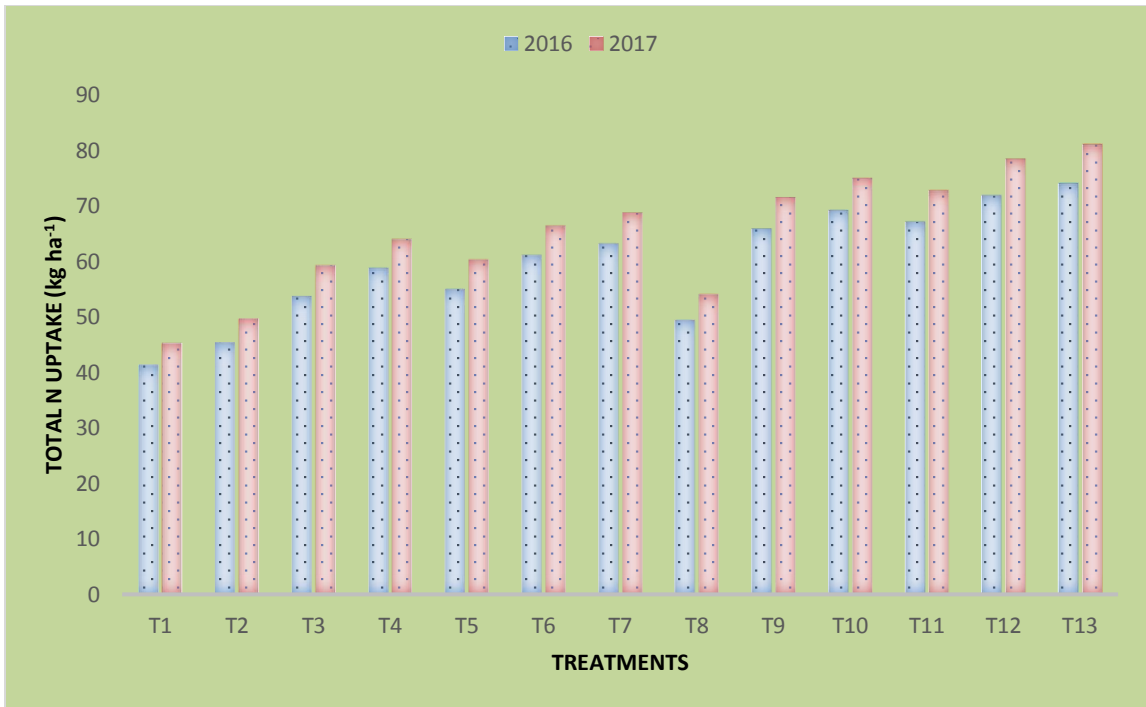


Figure 4.20: Effect of different treatments on total N uptake (kg ha⁻¹) by blackgram during 2016 and 2017

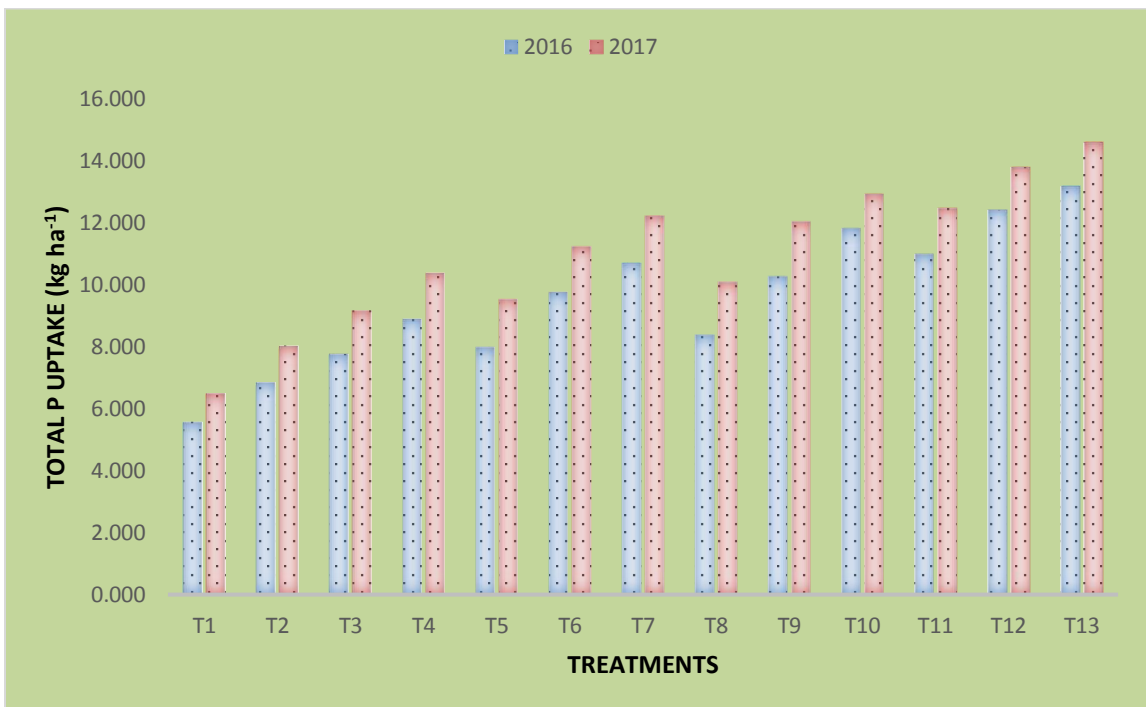


Figure 4.21: Effect of different treatments on total P uptake (kg ha⁻¹) by blackgram during 2016 and 2017

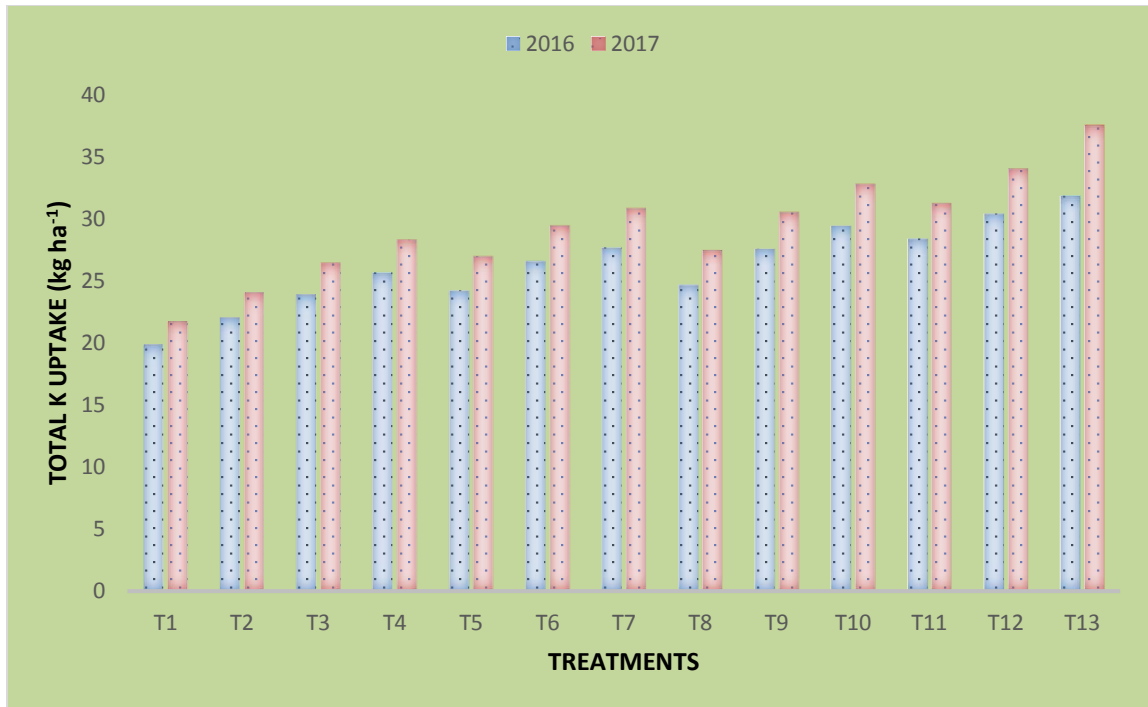


Figure 4.22: Effect of different treatments on total K uptake (kg ha⁻¹) by blackgram during 2016 and 2017

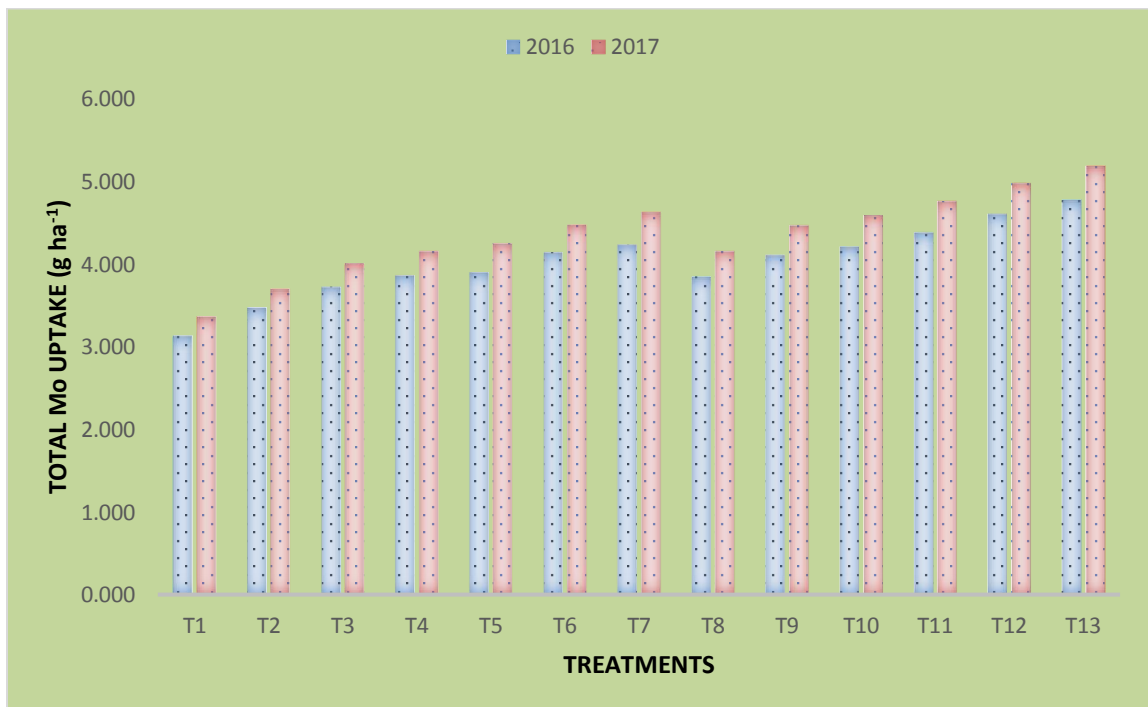


Figure 4.23: Effect of different treatments on total Mo uptake (g ha⁻¹) by blackgram during 2016 and 2017

DISCUSSION

The results observed with respect to different parameters entitled “Effect of phosphorus, molybdenum and organics on soil quality and crop performance of blackgram under rainfed ecology of Jammu” have been discussed under the following heads:

- 5.1 Physico chemical properties and available nutrients (N, P, K and Mo) and their correlation under blackgram growing rainfed areas of Jammu
- 5.2 Post harvest soil analysis of experimental site
- 5.3 Assessment of soil quality
- 5.4 Yield parameters and grain and straw yield of blackgram
- 5.5 Nutrient uptake (N, P, K and Mo) after harvesting of blackgram

5.1 Physico chemical properties and available nutrients (N, P, K and Mo) and their correlation under blackgram growing rainfed areas of Jammu

The pH value showed wide variation and were acidic to moderately alkaline in reaction under blackgram growing soils of Jammu region. On an average, pH value ranged from 5.69 - 7.88 with mean value of 7.08. The values of electrical conductivity (1:2.5 soil water extract) ranged from 0.09- 0.35 dS m⁻¹ with the mean value of 0.23 dS m⁻¹. The soluble salt content in these soils were in the safe limit for growing the crop. Decrease in EC might be due to leaching of salts to rains and utilization of nutrients by the crop. These findings corroborate with the findings of Chauhan *et al.* (1984).

The bulk density ranged from 1.42 - 1.56 with mean value of 1.48 (Mg m⁻³). With mean value of 3.46 g kg⁻¹, the organic carbon content varied from 2.50 - 4.30 g kg⁻¹. The soils under blackgram growing rainfed areas of Jammu were found low in category and the probable reason could be due to less use of organics and imbalanced fertilization as

well as poor microbial community. These findings are in collaboration with those of Ram and Yadav (1994).

The soils under blackgram grown rainfed areas were found higher in sand content and the probable reason for higher sand content could be due to formation of soil by feldspar, mica, quartz, microlime dominated mineral. These results corroborate with findings of Gupta *et al.* (2001).

As for as status of nitrogen, phosphorus and potassium is concerned, most of the soils fall in low category in available nitrogen while phosphorus and potassium showed medium status. This may be due to intensive cropping, poor organic matter content, nutrient losses due to leaching and volatilization. Also, lesser plant and microbial activity and low clay content might be reasons for lower availability of these nutrients. Similar results were reported by Tripathi and Singh (1992), Ram *et al.* (1993) and Gupta *et al.* (2004).

Acid ammonium oxalate is the commonly used extractant of molybdenum availability in soils. The results (Table 4.1) revealed a range of 0.098 - 0.517 mg kg⁻¹ (mean 0.282) in respect to available molybdenum under blackgram growing rainfed soils of Jammu. On an average, the content of available Mo was higher in soils having pH above 7.0. These results support the observations of Gupta and Debas (1980) who also recorded more available Mo content in high pH soils as compared to normal soils.

The coefficient of correlation was worked out between soil available nutrients and physico-chemical properties. A perusal of data (Table 4.3) revealed that soil pH had a negative correlation with all available nutrients except available Mo. Availability of soil molybdenum is reported to increase with an increase in soil pH because molybdenum is weakly absorbed on soils and hydrous oxides of Fe (Kariman and Cox, 1979) at alkaline pH, these soils have a relatively large proportion of Mo in solution phase (Reisenauer *et al.* 1962). The results of the current investigation resembles with those of Gupta and Dabas (1980) who had also observed significant positive relationship between pH and available Mo. A non-significant relationship was observed between electrical conductivity with all available nutrients. Also, bulk density and sand content were found

negatively correlated with all available nutrients. Further, organic carbon and silt content were found positively correlated with all available nutrients. In general, available N, P, K and Mo levels tends to increase with increase in organic carbon content of soils. Clay content developed positive relationship with available N and K while as phosphorus was negatively correlated with clay content. In our study, there was not any definite relationship between available Mo and soil texture. Kavimandan *et al.* (1964) and Pathak *et al.* (1969) have also failed a consistent relationship or significant correlation between available Mo and soil texture.

5.2 Post harvest soil analysis of experimental site

5.2.1 Physico-chemical properties

5.2.1.1 Soil pH

The highest pH of soil after harvesting of blackgram was observed in treatment T₁ (6.68) and lowest in T₁₀ (6.45) followed by T₇ (6.46), T₁₃ (6.47), T₄ (6.48), T₁₂ (6.56), T₃ (6.61), T₁₁ (6.61), T₆ (6.62), T₉ (6.63), T₈ (6.64), T₂ (6.64) and T₅ (6.67) during 2016. Non significant effect of different sources of nutrients was observed among various treatments. However, higher value of soil pH after harvesting of blackgram was observed under T₁ (6.64) and lowest under T₁₀ (6.42). Rest of the treatments were found in pattern of T₁₃ (6.43), T₇ (6.45), T₄ (6.46), T₉ (6.58), T₃ (6.59), T₆ (6.59), T₁₁ (6.59), T₁₂ (6.60), T₂ (6.61), T₈ (6.61) and T₅ (6.63) during 2017. There was no statistical difference obtained among various treatments with respect to soil pH. Similar results were reported by Sharma *et al.* (2009).

5.2.1.2 Electrical conductivity (dS m⁻¹)

The highest value of EC after harvesting of blackgram was observed under T₁ (0.27) and lowest under T₄ (0.21) and was observed in pattern of T₇ (0.22), T₁₀ (0.23), T₁₃ (0.24), T₃ (0.24) T₆ (0.25), T₁₂ (0.25), T₂ (0.26), T₈ (0.26), T₉ (0.26), T₁₁ (0.26) and T₅ (0.27) during 2016. There was no significant difference observed among various treatments with regard to EC. Whereas, highest EC value was found under treatment T₁ (0.25) and lowest under T₄ (0.20) and recorded in order of T₇ (0.21), T₁₀ (0.21), T₁₃ (0.22), T₃ (0.23), T₅ (0.23), T₆ (0.23), T₉ (0.23), T₁₂ (0.23), T₂ (0.24), T₁₁ (0.24) and T₈ (0.25)

during 2017. However, EC was found statistically non-significant under various treatments. These findings corroborate with the observations reported by Srikanth *et al.* (2000).

5.2.1.3 Bulk density (Mg m^{-3})

The bulk density after harvesting of blackgram found highest in treatment T₂ (1.55) and lowest under T₄ (1.48) and was recorded in order of T₇ (1.49), T₁₃ (1.50), T₁₀ (1.51), T₃ (1.53), T₆ (1.53), T₉ (1.53), T₅ (1.54), T₈ (1.54), T₁₁ (1.54), T₁ (1.54) and T₁₂ (1.55) during 2016. The higher bulk density could be due to high sand content and poor organic matter while as lower bulk density might be due to increase in organic carbon content in the soil. These observations corroborate the results obtained by Prakash *et al.* (2002) and Dadhich *et al.* (2011). However, bulk density after harvesting of blackgram was found highest in treatment T₂ (1.56) and lowest in T₄ (1.47) and followed the pattern of by T₇ (1.48), T₁₃ (1.49), T₁₀ (1.50), T₃ (1.52), T₆ (1.52), T₁ (1.53), T₉ (1.54), T₁₂ (1.54), T₅ (1.55), T₈ (1.55) and T₁₁ (1.56) during 2017. It was observed that bulk density decreased with addition of farmyard manure along with inorganics and bio-fertilizers. The decrease in bulk density under organic manure amended plots could be attributed to the addition of farmyard manure that promotes the porosity of the soil as the microbial decomposition products of organic manure such as polysaccharides and bacterial gums are known to act as soil particle binding agents. These binding agents increase the porosity and decrease bulk density of the soil. Similar findings were obtained by Andleeb *et al.* (2017).

5.2.1.4 Water holding capacity (%)

The water holding capacity after harvesting of blackgram reflected minimum under T₁ (30.58) and maximum under T₇ (35.13) followed by T₄ (35.06), T₁₃ (34.89), T₁₀ (34.82), T₆ (30.76), T₃ (30.72), T₉ (30.71), T₁₂ (30.69), T₂ (30.65), T₅ (30.63), T₈ (30.62) and T₁₁ (30.61) during 2016. The highest water holding capacity under treatments (T₄, T₇, T₁₀ and T₁₃) might be due to addition of farmyard manure, inorganic and biofertilizers including phosphorus solubilizing bacteria and *Rhizobium* which collectively enhanced organic carbon under aforesaid treatments. These findings corroborate the observations of

Sharma *et al.* (2014). However, the water holding capacity was found to be minimum in treatment T₁ (30.54) and maximum in T₇ (35.49) and observed in order of T₄ (35.48), T₁₃ (35.31), T₁₀ (35.30), T₆ (30.81), T₃ (30.78), T₉ (30.74), T₁₂ (30.72), T₂ (30.67), T₅ (30.67), T₈ (30.59) and T₁₁ (30.59) during 2017. The improvement in water holding capacity in response to the addition of farmyard manure along with inorganic and bio-fertilizers could be due to better environment for root development, improved soil structure and water stable aggregates, as well as moisture retention capacity by increasing the total number of storage pores. These results are in accordance with the findings of Datt *et al.* (2013) and Bhattacharyya *et al.* (2004).

5.2.1.5 Soil porosity (%)

The soil porosity after harvest of blackgram was found maximum in treatment T₄ (44.57) and minimum in T₂ (42.08) and was found in order of T₇ (44.19), T₁₃ (43.82), T₁₀ (43.45), T₆ (42.69), T₃ (42.48), T₁ (42.32), T₅ (42.32), T₈ (42.32), T₁₁ (42.30), T₉ (44.26) and T₁₂ (42.08) during 2016. The increased porosity in farmyard manure plus inorganic and bio-fertilizer treated plots might be due to aggregation of the soil particles by the action of microorganisms in the farmyard manure which produced polysaccharides providing a cementing action between the soil particles. These results are in conformity with those reported by Parthasarathi *et al.* (2008). Whereas, the soil porosity reflected maximum in treatment T₄ (44.94) and minimum in T₂ (41.57) and observed in order of T₇ (44.57), T₁₃ (44.19), T₁₀ (43.82), T₆ (43.07), T₁ (42.70), T₃ (42.64), T₉ (42.32), T₁₂ (42.32), T₅ (41.95), T₈ (41.95) and T₁₁ (41.57) during 2017. The combined application of organic, inorganic and biofertilizers under different treatments could be due to aggregation of soil particles. Similar findings were reported by Parthasarathi *et al.* (2008).

5.2.1.6 Infiltration rate (cm ha⁻¹)

The infiltration rate after harvesting of blackgram reflected highest in treatment T₁₃ (0.868) and lowest in T₁ (0.847) and was found in order of T₁₀ (0.868), T₁₀ (0.865), T₄ (0.864), T₉ (0.854), T₃ (0.853), T₅ (0.852), T₆ (0.852), T₈ (0.852), T₁₂ (0.852), T₁₁ (0.851) and T₂ (0.850) during 2016. Whereas, infiltration rate after harvesting of blackgram was observed to be highest under treatment T₁₃ (0.872) and lowest under T₁ (0.849) followed

by T₁₀ (0.871), T₇ (0.867), T₄ (0.867), T₉ (0.855), T₃ (0.854), T₆ (0.854), T₁₂ (0.854), T₅ (0.853), T₈ (0.853), T₂ (0.852) and T₁₁ (0.852) during 2017. However, different treatments did not yield any significant results during both the years.

5.2.1.7 Aggregate stability

The aggregate stability (% water stable aggregates) after harvesting of blackgram revealed highest in treatment T₁₀ (44.6) and lowest in T₁ (43.1) and found in order of T₇ (44.5), T₄ (44.5), T₁₃ (44.5), T₉ (43.8), T₁₂ (43.7), T₈ (43.7), T₃ (43.6), T₆ (43.6), T₂ (43.5), T₁₁ (43.5) and T₅ (43.4) during 2016. Whereas, water stable aggregates were noted to be highest under treatment T₁₀ (45.2) and lowest in T₁ (43.3) followed by T₄ (45.2), T₁₃ (45.1), T₇ (45.0), T₉ (43.9), T₁₂ (43.8), T₆ (43.8), T₃ (43.7), T₈ (43.7), T₂ (43.6), T₅ (43.6) and T₅ (43.5) during 2017. However, results pertaining to water stable aggregates were found statistically non significant during both the years. These findings corroborate with the observations reported by Benbi and Senapati (2010).

5.2.2 Soil carbon fractions

5.2.2.1 Soil organic carbon (g kg⁻¹)

The soil organic carbon after harvesting of blackgram was found to be highest in treatment T₁₃ (2.57) and lowest in T₈ (2.45) and observed in pattern of T₁₀ (2.56), T₇ (2.55), T₄ (2.54), T₁₂ (2.50), T₉ (2.49), T₃ (2.48), T₆ (2.48), T₁ (2.47), T₁₁ (2.46), T₂ (2.46) and T₅ (2.46) during 2016. However, the soil organic carbon was reflected highest under treatment T₁₃ (2.58) and lowest in T₈ (2.44) and recorded in pattern of T₁₀ (2.58), T₇ (2.57), T₄ (2.56), T₉ (2.50), T₃ (2.49), T₆ (2.49), T₁₂ (2.48), T₁ (2.46), T₁₁ (2.45), T₂ (2.45) and T₅ (2.45) during 2017. The organic carbon did not show any significant variation among various treatments during both the years. These observations are in line with those reported by Datt *et al.* (2013).

5.2.2.2 Labile carbon (mg kg⁻¹)

The labile carbon (LC) after harvesting of blackgram reflected highest in treatment T₁₃ (352.8) and lowest in T₁ (310.8) and noted in order of T₁₀ (350.8), T₇ (342.2), T₄ (340.5), T₁₂ (335.8), T₁₁ (333.3), T₉ (332.9), T₈ (330.6), T₆ (325.4), T₅ (320.8),

T₃ (318.4) and T₂ (318.1) during 2016. The labile carbon was significantly affected under combined applications of organic, inorganic along with bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium*. This significant improvement could be due to the application of farmyard manure as well as higher turn-over of root biomass because of better growth of black gram under combined application of chemical fertilizers along with farmyard manure. These results are in line with those reported by Andleeb *et al.* (2017). However, labile carbon was found to be highest in treatment T₁₃ (358.1) and lowest in T₁ (306.3) followed by T₁₀ (356.6), T₇ (347.0), T₄ (345.5), T₁₂ (336.6), T₁₁ (333.9), T₉ (334.0), T₈ (332.1), T₆ (326.1), T₅ (321.9), T₃ (321.4) and T₂ (320.6) during 2017. The labile carbon was found significantly higher under farmyard manure amended plots plus inorganic sources and biofertilizers including phosphorus solubilizing bacteria and *Rhizobium*. Labile soil organic carbon is considered as the readily accessible source of microorganisms which turns over rapidly and has direct impact on nutrient supply. Higher variations in labile carbon under integrated applications indicated that this pool of soil organic carbon was more sensitive to change due to manuring and fertilization. Higher turnover of root biomass under integrated addition also might have attributed to higher increase in this pool as compared to other treatments. These results are in agreement with the findings reported by Rudrappa *et al.* (2006) and Moharana *et al.* (2012).

5.2.2.3 Particulate organic carbon (g/m²)

The particulate organic carbon (POC) after harvesting of blackgram was found to be highest under treatment T₁₃ (271.1) and lowest in T₁ (260.1) followed by T₁₀ (270.5), T₇ (268.3), T₄ (267.6), T₁₂ (267.5), T₆ (267.0), T₉ (266.9), T₁₁ (266.8), T₈ (265.8), T₅ (265.7), T₃ (265.3) and T₂ (264.4) during 2016. The significant increase in particulate organic carbon under different treatments might be due to combined application of inorganics, organics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium*. This could be ascribed to the additional organic carbon input resulting further enhance in particulate organic carbon accumulation. These observations are in line with those reported by Nayak *et al.* (2012). Whereas, the particulate organic carbon was observed highest in treatment T₁₃ (272.8) and lowest in T₁ (257.6) and recorded in order

of T₁₀ (272.1), T₇ (269.7), T₄ (268.8), T₁₂ (268.5), T₆ (268.1), T₉ (267.5), T₁₁ (267.3), T₅ (267.0), T₈ (266.5), T₃ (266.4) and T₂ (266.0) during 2017. Application of farmyard manure in plots along with chemicals fertilizers and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* resulted in a significant positive built up of particulate organic carbon. This might be due to the addition of farmyard manure resulting in enhancing organic carbon content leading improvement in particulate organic carbon accumulation. These findings are in conformity with those observed by Purakayastha *et al.* (2008) and Nayak *et al.* (2012).

5.2.3 Biological properties

5.2.3.1 Microbial biomass carbon (mg kg⁻¹)

The microbial biomass carbon after harvesting of blackgram was found highest under treatment T₁₃ (34.7) and lowest under T₁ (30.4) and found in pattern of T₁₀ (34.2), T₇ (33.7), T₄ (33.4), T₁₂ (33.0), T₉ (32.7), T₁₁ (32.6), T₈ (32.4), T₆ (31.8), T₃ (31.3), T₅ (31.2) and T₂ (31.0) during 2016. The microbial biomass carbon was found significantly higher under different treatments receiving organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium*. The increasing microbial biomass carbon could be attributed to several factors, such as higher moisture content, greater soil aggregation and higher soil organic carbon content. The farmyard manure amended plots provided a steady source of organic carbon to support the microbial community resulting increase in microbial biomass carbon. These findings are in line with those observed by Nayak *et al.* (2012). However, the microbial biomass carbon after harvesting of blackgram reflected highest in treatment T₁₃ (35.1) and lowest under T₁ (30.1) followed by T₁₀ (34.9), T₇ (34.2), T₄ (34.0), T₁₂ (33.4), T₉ (33.3), T₁₁ (33.1), T₈ (32.9), T₆ (31.9), T₃ (31.7), T₅ (31.6) and T₂ (31.4) during 2017. The microbial biomass carbon was found significantly higher under the treatments received integrated application of organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium*. The microbial biomass carbon is an important component of the soil organic matter that regulates the transformation and storage of nutrients. The soil microbial biomass carbon regulates all soil organic matter transformations and considered to be the major component of the active soil organic matter pool. The higher value of

microbial biomass carbon under aforesaid plots (T₄, T₇, T₁₀ and T₁₃) could be due to higher turnover of root biomass produced under integrated organics and inorganics amended plots. Similar results under combined applications of organics and inorganics have been reported by Moharana *et al.* (2012) and Andleeb *et al.* (2017).

5.2.3.2 General bacterial population

The bacterial population in soil after harvesting of blackgram reflected highest in treatment T₄ (13.28) and lowest in T₁ (10.74) and noted in order of T₇ (13.05), T₁₀ (12.66), T₁₃ (12.42), T₃ (11.74), T₉ (11.56), T₆ (11.48), T₁₂ (11.32), T₂ (11.31), T₅ (11.16), T₈ (11.07) and T₁₁ (11.00) during 2016. The significant improvement in general bacterial count was observed under integrated application of organic, inorganic and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* in treatments T₄, T₇, T₁₀ and T₁₃. The increase in bacterial population could be ascribed to additional supply of nutrients through application of farmyard manure which increased the biomass, root exudates and ultimately provides carbon and energy to the soil microbes resulting into multiplication of bacterial population. These results are in line with the finding of Chand *et al.* (2010). However, the general bacterial population after harvesting of blackgram was observed highest in treatment T₄ (14.35) and lowest in T₁ (11.33) and noted in pattern of T₇ (14.11), T₁₀ (13.80), T₁₃ (13.59), T₃ (12.63), T₆ (12.43), T₉ (12.30), T₂ (12.25), T₁₂ (12.08), T₅ (11.95), T₈ (11.72) and T₁₁ (11.51) during 2017. The increased bacterial population might be due to application of organic manures which in turn provides adequate biomass as a feed for the microbes and helps in increasing microbial population in soil. These observations corroborate the findings of Singh *et al.* (2012). Further, application of 20 kg P₂O₅ ha⁻¹ recorded significantly higher bacterial count as compared to 40 kg P₂O₅ ha⁻¹. It reflected that application of 40 kg P₂O₅ ha⁻¹ appeared detrimental as microbial population decreased significantly over 20 kg P₂O₅ ha⁻¹ which was safe limit for maximum microbial build-up in the blackgram. In general, it was evident from the present investigation that application of phosphorus have improved the microbial population as it had provided energy and constituents for new cell synthesis and thus favoured the multiplication of these microorganisms. The results are in conformity to earlier reports of Chesti (2005).

5.2.3.3 General fungal population

The general fungal population after harvesting of blackgram showed highest in treatment T₄ (9.51) and lowest in T₁ (6.82) and noted in order of T₇ (9.27), T₁₀ (9.16), T₁₃ (9.04), T₃ (7.97), T₉ (7.75), T₆ (7.63), T₂ (7.56), T₁₂ (7.51) T₅ (7.31), T₈ (7.16), and T₁₁ (7.04) during 2016. The higher fungal count could be due to combined uses of organic, inorganic and biofertilizers including phosphorus solubilizing bacteria and *Rhizobium* which directly multiply fungal count and increasing their population whereas, lowest value of fungal count might be due to no scanty availability of nutrients. These results are in line with those reported by Mali *et al.* (2015) and Garcha *et al.* (2016). However, the general fungal population after harvesting of blackgram was observed to be highest under treatment T₄ (10.63) and lowest in T₁ (7.20) followed by T₇ (10.41), T₁₀ (10.15), T₁₃ (10.02), T₃ (8.81), T₆ (8.58), T₉ (8.48), T₂ (8.39), T₁₂ (8.21), T₅ (8.20), T₈ (8.01) and T₁₁ (7.82) during 2017. The significant improvement in general microbial count (fungi) was observed with the application of farmyard manure along with inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* under the treatments T₄, T₇, T₁₀ and T₁₃. Incorporation of farmyard manure might have produced favorable influences on soil microbial population. It indicated the importance of easily degradable carbonaceous compounds for the proliferation of microbial population in soil (Mukherjee *et al.* 1990). These results corroborate with the findings of Dinesh *et al.* (2000) and Sharma *et al.* (2000) who also reported that soils amended with organic manures registered significantly greater microbial biomass (fungi) than the unamended. The phosphorus fertilization indicated that application of 20 kg P₂O₅ ha⁻¹ recorded significantly higher fungal population as compared to 40 kg P₂O₅ ha⁻¹. However application of 40 kg P₂O₅ ha⁻¹ appeared detrimental as microbial population decreased significantly over 20 kg P₂O₅ ha⁻¹ which was safe limit for maximum microbial build-up in the blackgram. In general, application of phosphorus have improved the fungal population as it had provided energy and constituents for new cell synthesis and thus favoured the multiplication of these microorganisms. These findings are in line with those reported by Chesti (2005).

5.2.3.4 Dehydrogenase activity ($\mu\text{g TPF g}^{-1}$ soil 24 h^{-1})

The dehydrogenase activity after harvesting of blackgram revealed highest under treatment T₁₃ (26.46) and lowest T₁ (22.93) and observed in pattern of T₁₀ (26.25), T₇ (25.81), T₄ (25.57), T₁₂ (25.11), T₉ (24.90), T₁₁ (24.74), T₆ (24.66), T₈ (24.35), T₃ (24.23), T₅ (23.93) and T₂ (23.85) during 2016. The significant improvement in activity of dehydrogenase enzyme under different treatments might be attributed to integrated addition of organic, inorganic and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium*. Moreover, farmyard manure amended plots plus inorganic and bio-fertilizers might have stimulated the activity of microorganisms to utilize the native pool of organic carbon as a source of carbon, which acts as substrate for dehydrogenase. These results are in accordance with the findings of Bedi *et al.* (2009) and Rai and Yadav, 2011. Whereas, the dehydrogenase activity after harvesting of blackgram was found highest in treatment T₁₃ (27.29) and lowest T₁ (23.65) and observed in order of T₁₀ (27.05), T₇ (26.38), T₄ (26.12), T₁₂ (25.61), T₉ (25.38), T₁₁ (25.20), T₆ (25.18), T₈ (25.04), T₃ (24.88), T₅ (24.55) and T₂ (24.23) during 2017. The significant increase in dehydrogenase activity under organic manure treated plots plus inorganic as well as bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* might be due to fact that farmyard manure increased the availability of substrate for dehydrogenase activity. Further, farmyard manure application promotes biological and microbial activities and accelerated the breakdown of organic substances which is known to stimulate the dehydrogenase activity (Pedrazzini and Mckee, 1984). Similar results were reported by Nath *et al.* (2012). The increased activity of dehydrogenase enzyme by increasing levels of fertilizer application might be attributed to the fact that inorganic source of nutrient stimulated the activity of microorganisms to utilize the native pool of organic carbon as a source of carbon, which acts as substrate for the enzyme. These findings are in line with those reported by Masto *et al.* (2006).

5.2.4 Soil available nutrients

5.2.4.1 Available nitrogen (kg ha^{-1})

The available nitrogen in soil after harvesting of blackgram found to be highest in treatment T₁₃ (120.38) and lowest T₁ (93.63) followed by T₁₂ (118.14), T₁₀ (113.63), T₁₁

(112.77), T₉ (111.91), T₇ (110.21), T₆ (107.91), T₄ (102.94), T₅ (100.66), T₃ (99.23), T₈ (97.89) and T₂ (95.52) during 2016. The significant effect on available N could be attributed to increased N fixation with the application of P along with *Rhizobium* inoculation in terms of root proliferation. Also, increase in available N could be ascribed to the favorable effect of P on nodulation and in turn on fixation of higher amounts of atmospheric N. Another reason might be due to increased availability of P by *Rhizobium*, which resulted in higher availability of N (Takankhar *et al.* 1997). Mo plays a remarkable role in symbiotic fixation of N and hence Mo treated soil has shown a significant difference in the N per cent. The exertion of N from roots into the soil increases as the plant reaches towards the maturity (Khare and Rai, 1968). However, mean value of available nitrogen after harvesting of blackgram was found to be highest in treatment T₁₃ (121.30) and lowest T₁ (93.08) and followed the order of T₁₂ (120.08), T₁₀ (116.71), T₁₁ (115.53), T₉ (114.87), T₇ (112.21), T₆ (109.32), T₄ (104.96), T₅ (102.73), T₃ (102.17), T₈ (99.27) and T₂ (96.91) during 2017. The significant increase in available N could be due to addition of farmyard manure and also due to conversion of organically bound N to inorganic form. These results are in line with those reported by Patidar and Mali (2004) and Singh *et al.* (2012).

5.2.4.2 Available phosphorus (kg ha⁻¹)

The available phosphorus after harvesting of blackgram reflected highest in treatment T₁₃ (14.43) and lowest T₁ (8.79) and noted in order of T₁₀ (13.87), T₁₂ (13.35), T₁₁ (13.18), T₇ (12.94), T₉ (12.37), T₈ (12.19), T₄ (11.76), T₆ (10.96), T₅ (10.83), T₃ (10.11) and T₂ (9.90) during 2016. The application of organic, inorganic and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* significantly increased the available P in soil under aforesaid treatments over control. The increase in P availability might be due to the mineralization of organic P and release of P from Al-P and Fe-P fractions. Molybdate (MoO₄⁻²) ions also release phosphate ions (PO₄⁻³) from the soil colloidal complex through anion exchange phenomena. Moreover, the increase in available P could be ascribed to retardation of soil P fixation by organic anions formed during farmyard manure decomposition. These findings are in conformity with those reported by Singh *et al.* (2012). Further, the possible reason for increase in available P

after harvest of blackgram could be due to seed inoculation with PSB that might have helped in releasing native P as well as in protecting fixation of added phosphorus. The phosphorus solubilizing bacteria stimulate the microbial activity in soil and after decaying of their bodies in soil increase in available N, P and K content in soil (Gaur, 1990). Similar results regarding increase in available nutrients in soil were also reported by Kumar (1998). However, available phosphorus after harvesting of blackgram was observed highest in treatment T₁₃ (15.02) and lowest T₁ (8.13) and obtained in pattern of T₁₀ (14.24), T₁₂ (13.78), T₁₁ (13.50), T₇ (13.48), T₉ (12.86), T₈ (12.70), T₄ (12.45), T₆ (11.63), T₅ (11.40), T₃ (10.77) and T₂ (10.61) during 2017. The significant improvement in available P under different treatments could be due to direct addition of phosphorus through organics, P₂O₅ and PSB, leading to increase in P content in soil, probably due to mobilization of native soil phosphorus resulted in increased P availability. Similar results were reported by Kokani *et al.* (2015), Nagar *et al.* (2016) and Mohammad *et al.* (2017).

5.2.4.3 Available potassium (kg ha⁻¹)

The available potassium after harvesting of blackgram found highest in treatment T₁₃ (117.73) and lowest T₁ (111.98) followed by T₁₀ (117.45), T₁₂ (116.86), T₁₁ (116.38), T₉ (116.08), T₇ (115.84), T₄ (115.46), T₈ (115.21), T₆ (114.38), T₃ (114.08), T₅ (113.66) and T₂ (113.14) during 2016. The increase in available K in FYM amended plots could be due to beneficial effect of FYM which might have resulted in reduction of K and release of potassium due to interaction of organic matter with clay (Tandon, 1987), whereas, lowest value of available K might be due to its scanty availability. These findings are in conformity with those reported by Panwar, 2008 and Mishra, 2008. However, available potassium after harvesting of blackgram reflected highest in treatment T₁₃ (118.28) and lowest T₁ (111.20) followed by T₁₀ (118.15), T₁₂ (117.35), T₁₁ (116.88), T₉ (116.60), T₇ (116.36), T₄ (116.16), T₈ (115.45), T₆ (114.79), T₃ (114.51), T₅ (114.06) and T₂ (113.59) during 2017. The improvement in availability of potassium under different treatments might be due to the built of K in the soils leading to the beneficial effect of P fertilization along with other sources on the root proliferation and *Rhizobium* inoculation as reported by Mathan *et al.* (1996).

5.2.4.4 Available molybdenum (mg kg⁻¹)

The available molybdenum after harvesting of blackgram noted to be highest in treatment T₁₃ (0.322) and lowest in T₁ (0.223) and found in order of T₁₂ (0.319), T₇ (0.317), T₁₁ (0.314), T₆ (0.303), T₁₀ (0.299), T₅ (0.298), T₉ (0.289), T₈ (0.282), T₄ (0.279), T₃ (0.267) and T₂ (0.261) during 2016, whereas, available molybdenum after harvesting of blackgram revealed highest in T₁₃ (0.344) and lowest in T₁ (0.212) and observed in pattern of T₁₂ (0.334), T₁₁ (0.329), T₇ (0.327), T₆ (0.314), T₁₀ (0.313), T₅ (0.305), T₉ (0.298), T₈ (0.293), T₄ (0.287), T₃ (0.278) and T₂ (0.272) during 2017. The availability of Mo under different treatments significantly increased with the application of P and Mo. The increase in available Mo might be attributed to the release of MoO₄²⁻ ions from soil complex in exchange for OH⁻ ions in soil solution. Similar results were reported by Masto (2000).

5.3 Assessment of soil quality

The data with respect to soil quality parameters were statistically analyzed for their level of significance. The data were reduced to a minimum data set through a series of uni- and multivariate statistical methods using SPSS software (SPSS 1998). Only variables with significant differences between treatments ($p < 0.05$) were chosen for the next step in MDS formation. The standardized principal component analysis (PCA) was performed for each statistically significant variables (Andrews and Carroll 2001; Andrews *et al.* 2002). Principal components (PC) for a data set are defined as linear combinations of variables that account for maximum variance within the set by describing vectors of closet fit to the n observation in p -dimensional space, subject to being orthogonal to one another. The principal components receiving high eigen values and variables with high factor loading were assumed as the variables that best represent system attributes (Brejda *et al.* 2000). Therefore, only the PCs with eigen values 1 or greater, which explained at least 5% of the variation in the data (Wander and Bollero 1999) were examined. Within each principal component, only highly weighted factors (*i.e.*, those with absolute values within 10% of the highest weight) were retained for the MDS.

In principal component analysis (PCA), out of total soil quality parameters, 13 parameters were subjected to principal component analysis (PCA) using SPSS software to identify the minimum dataset (Table 4.15) Soil pH, electrical conductivity, soil organic carbon, infiltration rate, and aggregate stability (WSA) showed no significant difference between treatments at $p < 0.05$ level. It can be inferred from the data in the Table 4.15 that water holding capacity (WHC, 0.911), dehydrogenase activity (DHA, 0.905), bacterial population (0.358) and available P (0.746) received the highest loading factor under PC 1, PC 2, PC 3 and PC 4, respectively and as such these four variables were retained as minimum data set (MDS) for developing SQI.

After determination of the MDS indicators, each of the MDS variables was scored on the basis of the performance of soil function, considering variation of values within treatments (Table 4.16). Each variable was transformed into unit less score (between 0 to 1) using linear transformation. Once transformed, the MDS variables for each observation were weighted by using PCA results. Each PC explained a certain amount (%) of variation in the total data set. This percentage divided by the total percentage of variation explained by all PCs with eigenvectors greater than 1, provided the weighted factor for variables chosen under a given PC (Table 4.15). Calculated weightage for PC 1, PC 2, PC 3 and PC 4 was 0.680, 0.162, 0.099 and 0.059, respectively. After scoring and weighting, the values were fed into the additive model and finally aggregate score indicating state of soil quality was determined and the numerical value of soil quality index (SQI) was obtained for each treatment as shown in the Table 4.16.

5.3.1 Soil quality index interpretation

The integrated application i.e, inorganics and organics including bio-fertilizers phosphorus solubilizing bacteria and *Rhizobium* (T₁₀, P40 + PSB + Rhizobium + FYM) received the highest SQI value (Figure 4.14) followed by (T₁₃, P40 + 0.5Mo + PSB + Rhizobium + FYM), (T₇, P20 + 0.5Mo + PSB + Rhizobium + FYM), (T₄, P20 + PSB + Rhizobium + FYM), (T₁₂, P40 + 0.5Mo + PSB + Rhizobium), (T₉, P40 + PSB + Rhizobium), (T₆, P20 + 0.5Mo + PSB + Rhizobium), (T₁₁, P40 + 0.5Mo + PSB), (T₈, P40 + PSB), (T₅, P20 + 0.5Mo + PSB), (T₃, P20 + PSB + Rhizobium), (T₂, P20 + PSB) and (T₁, control).

5.4 Yield parameters and grain and straw yield of blackgram

5.4.1 No. of pods per plant

The number of pods per plant of blackgram were recorded highest in treatment T₁₃ (20.45) and lowest in treatment T₁ (13.73) followed by T₁₂ (19.92), T₁₀ (19.33), T₁₁ (19.19), T₉ (19.06), T₇ (18.80), T₆ (18.23), T₄ (17.39), T₈ (17.13), T₅ (16.96), T₃ (16.83) and T₂ (16.05) during 2016. The data revealed that there was significant effect of FYM on number of pods per plant. Priya and Vijayalakshmi (2001) also observed increase in nodule number of green gram by the organic manure application. The increase in nodulation with organic manure application could be due to its effect on the enhanced availability of nitrogen and organic carbon content, increased available water retention capacity, decreased bulk density (Chaudhary *et al.* 2003; Tolanur and Badanur, 2003) and the manures also provide energy for N-fixation by microorganisms Gaur *et al.* (1984). The increase in number of pods per plant could also be due to application of phosphorus supplying adequate supply of P₂O₅ resulted in laying down primordial for reproductive parts of the plants (Thomson and Abraham, 2002). Further, the integrated application of organics and inorganics could be the possible reason for increase in number of pods per plant. These observations are in line with those reported by Akter *et al.* (2013). Whereas, the number of pods per plant were found highest under treatment T₁₃ (23.60) and lowest under treatment T₁ (15.30) and noted in order of T₁₂ (23.26), T₁₀ (22.42), T₁₁ (22.20), T₉ (22.11), T₇ (21.61), T₆ (21.14), T₄ (19.51), T₈ (19.40), T₅ (19.19), T₃ (19.02) and T₂ (18.28) during 2017. Similar observations were also recorded by Akter *et al.* (2013).

5.4.2 Number of grains per pod

The highest grains per pod of blackgram were recorded in treatment T₁₃ (8.08) and lowest under T₁ (3.46) and was observed in order of T₁₂ (7.58), T₁₀ (7.34), T₁₁ (6.89), T₉ (6.82), T₇ (6.49), T₆ (6.04), T₄ (5.36), T₈ (5.02), T₅ (4.91), T₃ (4.80) and T₂ (4.28) during 2016. The increasing number of grains per pod might be due to integrated application of organic, inorganic and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* under different treatments. These results corroborate the findings of Akter *et al.* (2013). However, significant improvement regarding number of grains per

pod were observed under T₁₃ (8.94) and lowest under T₁ (4.03) and found in order of T₁₂ (8.65), T₁₀ (7.81), T₁₁ (7.54), T₉ (7.47), T₇ (7.10), T₆ (6.88), T₄ (5.89), T₈ (5.79), T₅ (5.61), T₃ (5.48) and T₂ (5.07) during 2017. Similar findings were also reported by Akter *et al.* (2013) while studied the influence of organic and inorganic and bio-fertilizers on blackgram.

5.4.3 Number of nodules per plant

The higher number of nodules per plant of blackgram were observed in treatment T₁₃ (13.15) and lowest under treatment T₁ (4.81) and noted in pattern of T₁₂ (12.41), T₁₀ (11.56), T₁₁ (10.99), T₉ (10.86), T₇ (10.55), T₆ (9.76), T₄ (8.40), T₈ (8.23), T₅ (7.92), T₃ (7.30) and T₂ (6.79) during 2016. The increase in number of nodules per plant could be ascribed to application of phosphorus. Phosphorus plays an important role in nitrogen-fixation in legumes, where it acts as a source of energy. It plays a pivotal role in early formation of roots, their proliferation, increased microbial activity in nodules and symbiotic biological N-fixation process. This might also led to efficient and greater partitioning of metabolites and adequate translocation of photosynthates and nutrients to develop reproductive structures (Tisdale *et al.*, 1995). Also, inoculation had a significant positive effect on the formation of nodules. Seed inoculation with *Rhizobium* markedly increased nodule number. These results are in agreement with Chowdhury and Fujita (1998). They reported that P application promotes early root formation and the formation of lateral fibrous and healthy roots. The increasing number of nodules per plant could also attributed to combined addition of organic, inorganic and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium*. These observations are in line with those reported by Chaudhary and Das, 1996. However, the number of nodules per plant of blackgram were found highest under treatment T₁₃ (13.81) and lowest in T₁ (5.48) and found in order of T₁₂ (13.28), T₁₀ (11.88), T₁₁ (11.55), T₉ (11.34), T₇ (11.00), T₆ (10.38), T₄ (9.37), T₈ (9.44), T₅ (8.96), T₃ (8.44) and T₂ (7.92) during 2017. The combined addition of organic, inorganic and bio-fertilizers could be possible reason for enhancing number of nodules per plant. These observations resemble with those reported by Chaudhary and Das (1996).

5.4.4 Grain yield (kg ha⁻¹)

The highest grain yield of blackgram was recorded in treatment T₁₃ (1291) and lowest in treatment T₁ (1043) and followed by T₁₂ (1277), T₁₀ (1251), T₁₁ (1240), T₉ (1233), T₇ (1217), T₆ (1203), T₄ (1183), T₈ (1174), T₅ (1167), T₃ (1162) and T₂ (1135) during 2016. The higher yield under T₁₃ might be due to faster mineralization of farmyard manure and beneficial effects of phosphorus solubilizing bacteria and *Rhizobium* application for seed treatment. The increasing pattern of grain yield under aforesaid treatments might be due to balanced addition of P, Mo and farmyard manure, phosphorus solubilizing bacteria and *Rhizobium* which enhanced nutrients availability and resulted in improvement of grain yield. These results are in line with those reported by Kannan *et al.* (2015). In legumes, N fixation due to inoculation with *Rhizobium* culture helps in increasing the yield. Here, phosphorus plays a key role since it is essential for the bacteria for the initial infection and nodulation of root system. For infection, the cells must be in a motile form and P has a pronounced effect on retention of this particular state. It is also essential for maintaining the rhizobial population of the soil (Huges and Heath, 1953). However, grain yield of blackgram observed to be highest in treatment T₁₃ (1388) and lowest under treatment T₁ (1103) and found in order of T₁₂ (1372), T₁₀ (1343), T₁₁ (1332), T₉ (1323), T₇ (1308), T₆ (1290), T₄ (1273), T₈ (1257), T₅ (1253), T₃ (1246) and T₂ (1213) during 2017. The increasing grain yield under different treatments could be due to combined addition of organic, inorganic as well as bio-fertilizers. The increasing grain yield of blackgram could be ascribed to advantage of phosphorus solubilizing bacteria and *Rhizobium* in making the P more available on one hand and fixing atmospheric N on the other (Sharma and Saxena, 1984).

5.4.5 Straw yield (kg ha⁻¹)

The higher straw yield of blackgram was observed under T₁₃ (2334) and lowest in treatment T₁ (1847) and were recorded in order of T₁₂ (2319), T₁₀ (2290), T₁₁ (2269), T₉ (2261), T₇ (2245), T₆ (2229), T₄ (2182), T₈ (2144), T₅ (2122), T₃ (2113) and T₂ (1954) during 2016. This could be due to speedy mineralization of farmyard manure and useful influence of phosphorus solubilizing bacteria and *Rhizobium* application at the time of seed treatment. The increasing pattern of straw yield under different treatments might be

due to integrated application of P, Mo, farmyard manure as well as phosphorus solubilizing bacteria and *Rhizobium* application. These results corroborate with findings of Kannan *et al.* (2015). Moreover, higher straw yield of blackgram was noted in T₁₃ (2423) lowest in treatment T₁ (1903) and was found in pattern of T₁₂ (2400), T₁₀ (2364), T₁₁ (2334), T₉ (2332), T₇ (2321), T₆ (2298), T₄ (2254), T₈ (2244), T₅ (2220), T₃ (2212) and T₂ (2004) during 2017. The highest straw yield in T₁₃ realized with integrated application of organic, inorganic and bio-fertilizer might be ascribed to its profound influence on vegetative growth on the blackgram whereas lowest straw yield under T₁ might be due to poor nutrient retention and fragile soil properties. These observations are in conformity with those reported by Kannan *et al.* (2015) and Mohammad *et al.* (2017).

5.5 Nutrient uptake (N, P, K and Mo) after harvesting of blackgram

5.5.1 Uptake of Nitrogen (kg ha⁻¹)

The nitrogen uptake reflected highest under T₁₃ receiving phosphorus, molybdenum, organic manure along with phosphorus solubilizing bacteria and *Rhizobium*. The higher uptake of N might be due to the fact that P promotes a well developed root system along with root biomass increased the availability of nitrogen to soil microbes which lead to better utilization of soil N by crop through fixation. The higher nitrogen uptake could also be attributed to the favorable effect of P on nodulation and in turn on fixation of higher amounts of atmospheric nitrogen (Takankhar *et al.* 1997). The significant increase in nitrogen uptake could be ascribed to the fact that Mo favoured the nitrogen fixation by the root nodules and nitrate reduction activity in plants. Similar results were reported by Paricha *et al.* (1983), Baldeo Singh *et al.* (1992) and Pattanayak *et al.* (2000).

5.5.2 Uptake of Phosphorus (kg ha⁻¹)

The significant increase in P uptake under combined treatments of organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* might be due to solubilization of native P by organic acid production from phosphorus solubilizing bacteria in addition to applied fertilizers which ultimately results in better root growth and increased physiological activity of roots to absorb more P. Thereby

increased the biomass production and subsequently greater P accumulation by plant with higher dose of P and PSB inoculation. These results are in conformity with the findings of Mohammad *et al.* (2017).

Further, the increase in P uptake could be due to the release of phosphate ions from the soil colloidal complex in exchange of MoO_4 through the process of anion exchange (Basak *et al.* 1982). The enhancing effect of Mo on P uptake might be because of the accumulation of organic P compounds in plants due to Mo application as described by Sabachkina and Vasilenko, (1963). Similar results were reported by Pattanayak *et al.* (2000). Further, increase in P uptake might be because of the synergistic effect of the two nutrients (P and Mo) due to the formation of phosphomolybdate complex, which were absorbed more readily by the plants (Barshad, 1951). Similar results were also reported by Shukla and Pathak (1973) and Krishnasamy *et al.* (1985).

5.5.3 Uptake of Potassium (kg ha^{-1})

Application of phosphorus, molybdenum, farmyard manure along with inoculation of seeds with phosphorus solubilizing bacteria and *Rhizobium* markedly increased the uptake of K. The significant increase in potassium uptake might be ascribed to better plant growth leading to higher uptake of nutrients. The nutrients in the root zone coupled with increased metabolic activity at cellular levels resulted in higher K uptake and their accumulation in the vegetative parts of the plants resulted in increased concentration and uptake of potassium by straw and seed of blackgram. These findings are in conformity with those of Singh *et al.* (2016). Also, Mohammad *et al.* (2017) reported that the application of P upto 40 kg ha^{-1} recorded higher K concentration and uptake in straw and grain.

Another probable reason for increase in potassium uptake at higher levels of P might be due to increase in the root surface area resulting from the application of P facilitating more absorption of K from soil, in turn more dry matter production and more K uptake. These findings are in line with those reported by Srinivas (1989).

5.5.4 Uptake of molybdenum (g ha^{-1})

The uptake of molybdenum by blackgram under different treatments could be attributed to the stimulating effect of P on Mo by the formation of complex phosphomolybdate anions in soils, which are observed to be more readily and easily absorbed by the plants. Also, P reduces Mo sorption; thereby the availability and uptake of Mo by crop in the present experiment might have increased. Similar results were reported by Krishnasamy *et al.* (1991) and Xie and Mackenzie (1991). Also, the increased uptake of Mo under various treatments by blackgram could be attributed to increased availability of Mo in the soil. Increased Mo uptake has also been reported by Syed Anwarulla, 1981 and Sharma and Minhas, 1986. These findings are in line with earlier reports of Vijaya Lakshmi (2004).

SUMMARY AND CONCLUSIONS

The integrated effect of inorganic, organic and bio-fertilizers on soil characteristics and crop yield of blackgram under rainfed ecology of Jammu was investigated during 2016 and 2017. Due to scanty organic carbon and poor nutrient availability of the soil under investigation, the productivity was far less than that of irrigated ecology. However, there is scanty information available with respect to soil characteristics as well as yield of blackgram of rainfed region of Jammu. Keeping this fact in view, aforesaid study was conducted and summarized with the following objectives:

1. To study the distribution of available phosphorus and Mo of representative pulse growing soils of Jammu
2. To evaluate the effect of organic manures, bio-fertilizers, phosphorus, and molybdenum on soil quality and yield of blackgram
3. To monitor the effect of phosphorus, molybdenum, organic manures and bio-fertilizers on nutrient use efficiency and nutrient balance in soil

Soil status of blackgram growing rainfed areas of Jammu

- The soil pH of the blackgram growing rainfed areas of Jammu ranged from neutral to slightly alkaline with values ranged from 5.69 to 7.88 with mean value of 7.08. The salinity status of soils was found to be under the safe limits with values ranged between 0.09 to 0.35 dS m⁻¹ having mean value of 0.23 dS m⁻¹.
- The soil organic carbon of these soils ranged from 3.07 to 4.97 with mean value of 4.23 (g kg⁻¹). As regards, the bulk density was registered between 1.40 to 1.56 with mean value of 1.48 (Mg m⁻³).
- The textural separates of blackgram growing rainfed soils vary with sand content ranged from 48.80 to 71.90 percent with mean value of 62.10 percent. The silt

content of blackgram growing rainfed soils ranged from 13.70 to 29.20 with mean value of 21.00 percent and clay content ranged from 9.00 to 24.60 with mean value of 16.90 percent.

- The available N, P and K (kg ha^{-1}) of blackgram rainfed soils ranged between 164.2 to 279.4, 9.4 to 15.6 and 108.2 to 229.1 with the mean values of 229.0, 12.7 and 178.4 kg ha^{-1} , respectively. On the other hand, available Mo (mg kg^{-1}) of blackgram growing rainfed soils ranged from 0.098 - 0.517 with mean value of 0.282 mg kg^{-1} .
- The correlation matrix revealed that pH, EC, bulk density and sand were found to be negatively correlated with the available N, P and K while as positive significant relationship was obtained between soil pH and available Mo. Organic carbon and silt content were found to be significantly and positively correlated with all available plant nutrients while as clay content developed positive relationship with available N, K and Mo and negative relationship obtained between clay and available P.

Yield and yield attributing characters

- The yield attributing characters *viz.* number of pods per plant and number of grains per pod of blackgram inoculated with PSB and *rhizobium* were significantly influenced with combined application of phosphorus, molybdenum and FYM during both the years. The highest were registered under treatment T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) while treatment T₁ (control) recorded lowest during 2016 and 2017.
- The P₄₀ + 0.5Mo + PSB + Rhizobium + FYM (T₁₃) receiving treatment registered significantly highest number of nodules per pant at 40 DAS while significantly lower value was recorded in control (T₁) during 2016 and 2017.
- The productivity of crop in terms of grain and straw yield significantly increased under integrated application of organics and inorganics. The treatment T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) recorded significantly highest grain and

straw yield whereas control (T₁) registered lowest grain and straw yield during 2016 and 2017. In general, grain and straw yield were registered higher during 2017 in comparison to 2016.

Nutrient uptake

- The N uptake by grain and straw of blackgram significantly influenced under combined application of P, Mo and organics during both the years. The significantly higher N uptake was found in treatment T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) while treatment T₁ (control) recorded the lowest N uptake during 2016 and 2017.
- Integrated application of phosphorus, molybdenum and organics significantly affected P uptake both by grain and straw. The maximum phosphorus uptake by grain and straw of blackgram was obtained with the combined application of organics and inorganics i.e, P₄₀ + 0.5Mo + PSB + Rhizobium + FYM (T₁₃) while minimum P uptake was registered under treatment T₁ (control).
- Application of chemical fertilizer along with FYM & biofertilizers (*Rhizobium* and PSB) in different treatments increased potassium uptake as compare to control. The maximum potassium uptake by grain and straw of blackgram was obtained with the application of P₄₀ + 0.5Mo + PSB + Rhizobium + FYM (T₁₃) while treatment T₁ (control) recorded lowest potassium uptake both in 2016 and 2017.
- The molybdenum uptake significantly increased under integrated application of organics and inorganics. The highest Mo uptake by grain and straw of blackgram was registered in treatment T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) while as lowest Mo uptake was found under treatment T₁ (control) during 2016 and 2017.

Soil status

- There was no significant variation noticed in soil pH, EC, bulk density, infiltration rate and aggregate stability after harvesting of blackgram during 2016 and 2017.

- The soil porosity significantly influenced in treatments incorporated with FYM along with inorganics. Incorporation of FYM had significantly positive on soil porosity. The soil porosity after harvesting of blackgram reflected maximum in treatment T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) while minimum soil porosity was noted in treatment T₁ (control) during both the years i.e. 2016 and 2017.
- The water holding capacity of soil after harvesting of blackgram significantly improved under treatments received combined application of organics and inorganics over T₁ (control). Incorporation of FYM had pronounced effect on water holding capacity. The treatment T₇ (P₂₀ + 0.5Mo + PSB + Rhizobium + FYM) reflected maximum WHC after harvesting of blackgram while minimum WHC was noticed under treatment T₁ (control) during 2016 and 2017.
- Different treatments did not yield any significant results on soil organic carbon during both the years. The soil carbon fractions (LC and POC) after harvesting of blackgram significantly improved under combined applications of organics and inorganics i.e. P₄₀ + 0.5Mo + PSB + Rhizobium + FYM (T₁₃) over control (T₁) during 2016 and 2017.
- The combined application of phosphorus, molybdenum and organics brought about significant increase on available N, P, K and Mo over no fertilization. The highest available (N, P, K and Mo) after harvesting of blackgram were found highest under treatment T₁₃ (P₄₀ + 0.5Mo + PSB + Rhizobium + FYM) while treatment T₁ (control) revealed lowest value during 2016 and 2017.
- Soil biological properties (MBC, bacterial and fungal count) significantly improved under treatment receiving combined application of organics, inorganics and bio-fertilizers. The dehydrogenase activity was found significantly higher under treatments which received mixed addition of organics, inorganics and bio-fertilizers including phosphorus solubilizing bacteria and *Rhizobium* in comparison to control.

Soil quality index

The data pertaining to soil quality parameters were statistically analyzed for their level of significance. Thirteen parameters were subjected to principal component analysis (PCA) using SPSS software to identify the minimum dataset. Within each principal component, only the variables which received highest factor loading were retained for the MDS. After determination of the MDS indicators, each of the MDS variables was scored on the basis of the performance of soil function, considering variation of values within treatments. Finally, SQI was developed and for different treatments, it varied from 0.105 to 0.398. The magnitude of share of key soil quality indicators for influencing SQI were WHC, DHA, bacteria and available P.

CONCLUSIONS

The results of the present study concluded with respect to all the parameters taken into consideration under the topic “Effect of phosphorus, molybdenum and organics on soil quality and crop performance of blackgram under rainfed ecology of Jammu” as summarized hereunder:

- The soil pH of blackgram growing rainfed areas of Jammu ranged from neutral to slightly alkaline, whereas EC was found to be in safe limit. Organic carbon of the blackgram growing rainfed areas of Jammu was found to be in low status. Majority of the soil samples were found sandy loam in texture.
- The available nitrogen of blackgram growing rainfed areas of Jammu were found to be in low range while as available P and K lie under medium range. Available Mo was found in sufficient range considering 0.2 mg kg^{-1} as sufficiency limit.
- Combined application of organic and inorganic sources of nutrients proved beneficial in augmenting the fertility status of the soil by improving soil characteristics under rainfed conditions.
- Physical properties like WHC and soil porosity were found significantly affected with the incorporation of organics along with inorganics.
- While SQI varied from 0.105 to 0.398, the magnitude of share of key soil quality indicators for influencing SQI were WHC, DHA, bacteria and available P.
- Among the various treatments, application of $40 \text{ kg ha}^{-1} \text{ P}_2\text{O}_5$ along with 0.5 kg Mo , bio-inoculants and FYM recorded significantly higher grain and straw yield. Also, treatment (T₁₃) produced highest number of pods per plant, number of grains per pod and number of nodules of blackgram during 2016 and 2017.

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APPENDIX – I

Physico-chemical properties of soils under rainfed growing areas of Jammu region along with GPS location

S. No.	GPS location		pH (1:2.5)	EC (dS m ⁻¹)	O.C. (g kg ⁻¹)	B.D. (Mg m ⁻³)	Sand (%)	Silt (%)	Clay (%)	Textural Class
1	N 32° 32'546"	E 075° 09'270"	7.57	0.13	3.39	1.49	64.50	21.00	14.50	Sandy loam
2	N 32° 32'559"	E 075° 09'281"	7.65	0.21	4.44	1.54	67.00	19.30	13.70	Sandy loam
3	N 32° 32'565"	E 075° 09'290"	6.43	0.16	4.74	1.54	65.36	16.42	18.22	Sandy loam
4	N 32° 32'961"	E 075° 09'602"	7.71	0.13	4.10	1.46	71.90	18.70	9.40	Loamy sand
5	N 32° 32'973"	E 075° 09'597"	6.59	0.29	3.54	1.56	63.40	21.65	14.95	Sandy loam
6	N 32° 32'977"	E 075° 09'599"	7.27	0.18	3.36	1.50	67.20	16.50	16.30	Sandy loam
7	N 32° 32'991"	E 075° 09'585"	6.81	0.20	4.58	1.41	70.60	14.58	14.82	Loamy sand
8	N 32° 32'005"	E 075° 09'571"	7.37	0.26	4.75	1.47	48.80	27.30	23.90	Sandy clay loam
9	N 32° 32'029"	E 075° 09'554"	6.48	0.19	4.84	1.44	68.00	20.00	12.00	Sandy loam
10	N 32° 33'032"	E 075° 09'512"	7.28	0.21	4.00	1.43	57.30	28.40	14.30	Sandy loam
11	N 32° 32'742"	E 075° 08'800"	6.72	0.27	4.16	1.40	59.00	24.72	16.28	Sandy loam
12	N 32° 32'700"	E 075° 08'774"	7.64	0.21	3.98	1.54	63.10	21.20	15.70	Sandy loam
13	N 32° 32'688"	E 075° 08'752"	7.34	0.22	4.20	1.42	68.40	19.00	15.60	Sandy loam
14	N 32° 32'702"	E 075° 08'759"	6.92	0.31	3.40	1.49	70.30	16.70	13.00	Loamy sand
15	N 32° 32'744"	E 075° 08'795"	7.37	0.09	4.63	1.46	57.60	24.10	18.30	Sandy loam
16	N 32° 32'786"	E 075° 08'720"	6.69	0.12	3.38	1.53	64.00	23.42	12.58	Sandy loam
17	N 32° 32'815"	E 075° 08'623"	5.69	0.26	4.20	1.43	68.20	22.80	9.00	Sandy loam
18	N 32° 32'855"	E 075° 08'507"	7.85	0.14	4.00	1.46	59.60	23.20	17.20	Sandy loam
19	N 32° 32'927"	E 075° 08'043"	6.35	0.23	3.93	1.50	69.00	19.20	11.80	Sandy loam

S. No.	GPS location		pH (1:2.5)	EC (dS m⁻¹)	O.C. (g kg⁻¹)	B.D. (Mg m⁻³)	Sand (%)	Silt (%)	Clay (%)	Textural Class
20	N 32° 33'026"	E 075° 07'896"	6.18	0.22	4.57	1.52	63.20	20.00	16.80	Sandy loam
21	N 32° 33'063"	E 075° 07'779"	6.49	0.31	4.80	1.45	56.00	20.70	23.30	Sandy clay loam
22	N 32° 33'184"	E 075° 07'716"	7.21	0.22	4.77	1.53	59.30	21.10	19.60	Sandy loam
23	N 32° 33'403"	E 075° 07'556"	6.62	0.15	4.20	1.44	64.00	19.00	17.00	Sandy loam
24	N 32° 33'527"	E 075° 07'361"	7.87	0.31	4.46	1.51	67.00	18.72	14.28	Sandy loam
25	N 32° 33'599"	E 075° 07'227"	6.58	0.21	3.52	1.45	67.30	21.70	11.00	Sandy loam
26	N 32° 33'680"	E 075° 07'140"	7.42	0.32	4.64	1.46	57.80	25.20	17.00	Sandy loam
27	N 32° 33'774"	E 075° 07'067"	6.78	0.29	4.75	1.43	65.40	19.10	15.50	Sandy loam
28	N 32° 33'798"	E 075° 07'140"	7.31	0.26	4.26	1.44	63.20	23.70	13.10	Sandy loam
29	N 32° 33'837"	E 075° 07'227"	7.18	0.17	3.10	1.48	59.00	24.20	16.80	Sandy loam
30	N 32° 33'916"	E 075° 07'260"	7.54	0.21	4.85	1.53	67.10	22.90	10.00	Sandy loam
31	N 32° 34'026"	E 075° 07'366"	6.74	0.21	4.10	1.44	53.90	23.30	22.80	Sandy clay loam
32	N 32° 34'088"	E 075° 07'413"	6.68	0.29	4.07	1.48	62.80	19.10	18.10	Sandy loam
33	N 32° 34'200"	E 075° 07'482"	7.21	0.33	4.01	1.52	68.40	17.30	14.30	Sandy loam
34	N 32° 34'449"	E 075° 07'839"	6.83	0.26	4.92	1.44	69.30	18.60	12.10	Sandy loam
35	N 32° 34'462"	E 075° 07'862"	7.26	0.32	4.74	1.42	67.00	19.00	14.00	Sandy loam
36	N 32° 34'702"	E 075° 08'205"	7.52	0.22	4.30	1.44	71.40	17.60	11.00	Loamy sand
37	N 32° 34'734"	E 075° 08'246"	6.47	0.28	4.90	1.46	62.60	17.20	20.20	Sandy clay loam
38	N 32° 34'789"	E 075° 08'297"	7.30	0.35	4.61	1.40	57.30	21.00	22.70	Sandy clay loam
39	N 32° 34'843"	E 075° 08'363"	7.37	0.32	4.26	1.47	60.00	23.70	16.30	Sandy loam
40	N 32° 34'880"	E 075° 08'492"	7.65	0.11	4.10	1.43	65.20	20.40	14.40	Sandy loam
41	N 32° 35'520"	E 075° 08'725"	6.84	0.17	3.07	1.52	59.50	23.50	17.00	Sandy loam

S. No.	GPS location		pH (1:2.5)	EC (dS m⁻¹)	O.C. (g kg⁻¹)	B.D. (Mg m⁻³)	Sand (%)	Silt (%)	Clay (%)	Textural Class
42	N 32° 35'155"	E 075° 08'886"	7.38	0.22	4.41	1.42	67.00	19.00	14.00	Sandy loam
43	N 32° 35'182"	E 075° 08'995"	6.87	0.26	4.57	1.44	58.30	20.00	21.70	Sandy clay loam
44	N 32° 35'252"	E 075° 09'105"	6.55	0.14	4.42	1.51	56.50	23.00	20.50	Sandy clay loam
45	N 32° 35'316"	E 075° 09'073"	6.70	0.27	4.58	1.43	63.00	18.60	19.40	Sandy loam
46	N 32° 35'340"	E 075° 09'122"	7.43	0.18	4.60	1.47	67.40	21.30	11.30	Sandy loam
47	N 32° 35'361"	E 075° 09'161"	7.68	0.23	3.46	1.45	64.80	20.20	15.00	Sandy loam
48	N 32° 35'389"	E 075° 09'207"	6.67	0.09	4.62	1.43	60.10	21.60	18.30	Sandy loam
49	N 32° 35'562"	E 075° 09'335"	7.57	0.31	4.01	1.51	62.70	21.30	16.00	Sandy loam
50	N 32° 35'442"	E 075° 09'272"	7.37	0.26	3.70	1.47	68.30	15.50	16.20	Sandy loam
51	N 32° 35'642"	E 075° 09'344"	7.16	0.19	4.40	1.50	61.50	20.30	18.20	Sandy loam
52	N 32° 35'573"	E 075° 09'440"	6.94	0.28	4.18	1.47	56.90	22.10	21.00	Sandy clay loam
53	N 32° 35'707"	E 075° 09'494"	6.80	0.21	3.97	1.53	59.70	21.30	19.00	Sandy loam
54	N 32° 35'619"	E 075° 09'573"	6.97	0.24	4.59	1.44	64.00	19.00	17.00	Sandy loam
55	N 32° 35'653"	E 075° 09'572"	7.69	0.13	4.70	1.48	57.00	20.80	22.20	Sandy clay loam
56	N 32° 35'668"	E 075° 09'608"	6.78	0.32	3.47	1.54	68.10	21.50	10.40	Sandy loam
57	N 32° 35'684"	E 075° 09'627"	7.36	0.23	4.90	1.46	59.30	20.00	20.70	Sandy clay loam
58	N 32° 35'429"	E 075° 09'721"	7.21	0.31	3.85	1.53	62.00	19.70	18.30	Sandy loam
59	N 32° 35'737"	E 075° 09'736"	7.53	0.27	4.60	1.48	65.20	17.50	17.30	Sandy loam
60	N 32° 35'798"	E 075° 09'717"	7.18	0.24	4.04	1.42	58.50	22.20	19.30	Sandy loam
61	N 32° 35'757"	E 075° 09'766"	7.82	0.29	3.30	1.50	67.10	18.10	14.80	Sandy loam
62	N 32° 35'770"	E 075° 09'834"	7.60	0.17	4.70	1.48	61.70	20.30	18.00	Sandy loam
63	N 32° 35'797"	E 075° 09'870"	6.52	0.10	4.10	1.43	59.30	20.60	20.10	Sandy clay loam

S. No.	GPS location		pH (1:2.5)	EC (dS m⁻¹)	O.C. (g kg⁻¹)	B.D. (Mg m⁻³)	Sand (%)	Silt (%)	Clay (%)	Textural Class
64	N 32° 35'821"	E 075° 09'885"	6.85	0.33	3.27	1.52	65.00	19.50	15.50	Sandy loam
65	N 32° 35'860"	E 075° 09'904"	7.47	0.25	4.21	1.49	63.30	20.70	16.00	Sandy loam
66	N 32° 35'899"	E 075° 09'971"	7.28	0.34	4.38	1.50	59.80	21.20	19.00	Sandy loam
67	N 32° 35'870"	E 075° 10'017"	7.46	0.33	4.68	1.53	53.80	23.80	22.40	Sandy clay loam
68	N 32° 35'845"	E 075° 10'054"	6.90	0.16	4.87	1.45	59.40	20.60	20.00	Sandy loam
69	N 32° 35'838"	E 075° 10'090"	7.71	0.21	4.67	1.53	57.80	23.00	19.20	Sandy loam
70	N 32° 35'829"	E 075° 10'120"	7.16	0.32	3.86	1.48	64.10	19.20	16.70	Sandy loam
71	N 32° 35'828"	E 075° 10'170"	7.88	0.12	4.10	1.50	56.00	22.60	21.40	Sandy clay loam
72	N 32° 35'826"	E 075° 10'134"	7.21	0.29	4.75	1.44	62.30	21.90	15.80	Sandy loam
73	N 32° 35'838"	E 075° 10'065"	7.46	0.31	3.85	1.52	65.00	19.00	16.00	Sandy loam
74	N 32° 34'169"	E 075° 07'432"	6.87	0.23	4.25	1.50	61.60	21.60	16.80	Sandy loam
75	N 32° 34'102"	E 075° 07'407"	7.21	0.31	3.80	1.53	62.20	18.20	19.60	Sandy loam
76	N 32° 34'020"	E 075° 07'351"	7.37	0.17	4.75	1.49	62.40	21.60	16.00	Sandy loam
77	N 32° 33'962"	E 075° 07'286"	6.83	0.21	3.70	1.48	59.70	22.10	18.20	Sandy loam
78	N 32° 33'806"	E 075° 07'142"	6.74	0.28	4.93	1.51	60.60	18.30	21.10	Sandy clay loam
79	N 32° 33'785"	E 075° 07'064"	7.29	0.30	4.25	1.46	66.30	19.80	13.90	Sandy loam
80	N 32° 33'987"	E 075° 06'756"	7.12	0.25	3.30	1.49	61.60	21.00	17.40	Sandy loam
81	N 32° 34'316"	E 075° 06'176"	6.94	0.22	4.21	1.51	67.00	20.40	12.60	Sandy loam
82	N 32° 34'455"	E 075° 06'121"	7.23	0.16	4.37	1.45	63.10	20.30	16.60	Sandy loam
83	N 32° 34'588"	E 075° 06'254"	6.94	0.28	3.65	1.52	65.00	14.40	20.60	Sandy clay loam
84	N 32° 35'005"	E 075° 06'614"	7.16	0.19	3.20	1.52	53.10	22.30	24.60	Sandy clay loam
85	N 32° 35'188"	E 075° 06'650"	7.20	0.23	4.71	1.48	57.80	22.90	19.30	Sandy loam

S. No.	GPS location		pH (1:2.5)	EC (dS m⁻¹)	O.C. (g kg⁻¹)	B.D. (Mg m⁻³)	Sand (%)	Silt (%)	Clay (%)	Textural Class
86	N 32° 35'356"	E 075° 06'833"	6.73	0.26	4.10	1.45	62.50	24.00	13.50	Sandy loam
87	N 32° 35'372"	E 075° 07'062"	7.28	0.19	4.00	1.50	59.60	28.00	13.00	Sandy loam
88	N 32° 33'060"	E 075° 04'570"	7.10	0.29	4.93	1.53	67.90	19.30	12.80	Sandy loam
89	N 32° 33'041"	E 075° 04'512"	7.21	0.14	4.31	1.45	64.40	22.60	13.00	Sandy loam
90	N 32° 33'637"	E 075° 04'417"	6.85	0.28	3.10	1.48	52.30	26.20	21.50	Sandy clay loam
91	N 32° 33'036"	E 075° 04'233"	7.19	0.20	4.80	1.52	69.00	13.70	17.30	Sandy loam
92	N 32° 33'129"	E 075° 03'746"	6.90	0.17	4.48	1.44	61.30	17.70	21.00	Sandy clay loam
93	N 32° 33'423"	E 075° 03'082"	7.46	0.25	3.85	1.49	68.10	21.60	10.30	Sandy loam
94	N 32° 33'585"	E 075° 02'575"	6.79	0.13	4.55	1.52	64.20	19.20	16.60	Sandy loam
95	N 32° 33'833"	E 075° 01'882"	7.13	0.29	3.85	1.51	71.60	19.40	9.00	Loamy sand
96	N 32° 33'907"	E 075° 01'681"	6.26	0.31	4.38	1.54	63.60	20.70	15.70	Sandy loam
97	N 32° 34'207"	E 075° 00'407"	6.50	0.18	4.87	1.45	67.60	17.20	15.20	Sandy loam
98	N 32° 36'221"	E 075° 56'937"	7.21	0.24	4.57	1.53	57.30	20.00	22.70	Sandy clay loam
99	N 32° 36'901"	E 075° 56'096"	6.98	0.15	4.97	1.50	62.10	21.60	16.30	Sandy loam
100	N 32° 37'783"	E 075° 55'128"	6.73	0.22	4.82	1.47	65.00	19.70	15.30	Sandy loam

APPENDIX – II

Available nutrient status of soils under rainfed growing areas of Jammu region along with GPS location

S. No.	GPS location		Available nutrients			
			N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Mo (mg kg ⁻¹)
1	N 32° 32'546"	E 075° 09'270"	185.8	9.4	142.5	0.215
2	N 32° 32'559"	E 075° 09'281"	210.6	10.4	215.0	0.323
3	N 32° 32'565"	E 075° 09'290"	273.2	14.6	157.2	0.167
4	N 32° 32'961"	E 075° 09'602"	203.8	11.6	153.1	0.378
5	N 32° 32'973"	E 075° 09'597"	183.0	13.1	217.5	0.292
6	N 32° 32'977"	E 075° 09'599"	178.5	12.1	178.7	0.517
7	N 32° 32'991"	E 075° 09'585"	276.5	14.6	217.2	0.212
8	N 32° 32'005"	E 075° 09'571"	210.0	13.3	180.0	0.330
9	N 32° 32'029"	E 075° 09'554"	208.5	13.6	219.4	0.275
10	N 32° 33'032"	E 075° 09'512"	212.4	11.1	171.9	0.327
11	N 32° 32'742"	E 075° 08'800"	211.2	14.6	198.3	0.283
12	N 32° 32'700"	E 075° 08'774"	171.0	9.7	156.8	0.179
13	N 32° 32'688"	E 075° 08'752"	217.3	13.3	174.5	0.241
14	N 32° 32'702"	E 075° 08'759"	194.1	10.5	143.0	0.285
15	N 32° 32'744"	E 075° 08'795"	210.5	14.7	146.2	0.385
16	N 32° 32'786"	E 075° 08'720"	198.4	9.5	118.3	0.255
17	N 32° 32'815"	E 075° 08'623"	214.8	15.4	210.8	0.163
18	N 32° 32'855"	E 075° 08'507"	239.3	13.6	166.1	0.227

S. No.	GPS location		Available nutrients			
			N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Mo (mg kg ⁻¹)
19	N 32° 32'927"	E 075° 08'043"	195.0	12.5	177.4	0.145
20	N 32° 33'026"	E 075° 07'896"	265.0	14.2	203.0	0.237
21	N 32° 33'063"	E 075° 07'779"	204.2	13.8	150.5	0.327
22	N 32° 33'184"	E 075° 07'716"	272.0	13.6	203.1	0.222
23	N 32° 33'403"	E 075° 07'556"	217.6	14.2	195.7	0.385
24	N 32° 33'527"	E 075° 07'361"	215.1	10.1	110.1	0.249
25	N 32° 33'599"	E 075° 07'227"	252.5	14.3	213.2	0.329
26	N 32° 33'680"	E 075° 07'140"	225.7	13.1	212.6	0.241
27	N 32° 33'774"	E 075° 07'067"	247.8	12.7	166.1	0.187
28	N 32° 33'798"	E 075° 07'140"	228.4	13.9	175.9	0.282
29	N 32° 33'837"	E 075° 07'227"	262.8	14.5	217.5	0.327
30	N 32° 33'916"	E 075° 07'260"	273.5	9.9	219.5	0.283
31	N 32° 34'026"	E 075° 07'366"	235.2	15.1	217.4	0.294
32	N 32° 34'088"	E 075° 07'413"	217.9	10.8	148.7	0.227
33	N 32° 34'200"	E 075° 07'482"	175.5	12.5	217.4	0.385
34	N 32° 34'449"	E 075° 07'839"	275.0	14.0	215.9	0.385
35	N 32° 34'462"	E 075° 07'862"	249.7	12.7	115.6	0.268
36	N 32° 34'702"	E 075° 08'205"	252.9	13.5	166.3	0.379
37	N 32° 34'734"	E 075° 08'246"	237.2	12.9	177.0	0.297
38	N 32° 34'789"	E 075° 08'297"	270.5	14.1	225.1	0.285
39	N 32° 34'843"	E 075° 08'363"	190.8	15.3	108.7	0.221
40	N 32° 34'880"	E 075° 08'492"	227.1	11.7	190.2	0.338

S. No.	GPS location		Available nutrients			
			N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Mo (mg kg ⁻¹)
41	N 32° 35'520"	E 075° 08'725"	183.0	13.4	117.6	0.364
42	N 32° 35'155"	E 075° 08'886"	274.1	12.0	210.6	0.226
43	N 32° 35'182"	E 075° 08'995"	251.1	10.1	154.2	0.238
44	N 32° 35'252"	E 075° 09'105"	187.6	12.5	206.7	0.274
45	N 32° 35'316"	E 075° 09'073"	275.8	11.2	229.1	0.474
46	N 32° 35'340"	E 075° 09'122"	264.4	12.3	174.0	0.227
47	N 32° 35'361"	E 075° 09'161"	276.7	10.9	206.4	0.243
48	N 32° 35'389"	E 075° 09'207"	268.8	13.6	213.7	0.263
49	N 32° 35'562"	E 075° 09'335"	181.3	10.3	184.8	0.378
50	N 32° 35'442"	E 075° 09'272"	199.0	12.8	120.5	0.374
51	N 32° 35'642"	E 075° 09'344"	271.5	10.5	216.4	0.284
52	N 32° 35'573"	E 075° 09'440"	204.1	10.9	199.3	0.274
53	N 32° 35'707"	E 075° 09'494"	180.7	12.2	124.1	0.232
54	N 32° 35'619"	E 075° 09'573"	260.3	12.4	198.5	0.158
55	N 32° 35'653"	E 075° 09'572"	251.6	10.6	203.4	0.378
56	N 32° 35'668"	E 075° 09'608"	172.0	9.9	120.1	0.258
57	N 32° 35'684"	E 075° 09'627"	256.8	14.7	146.7	0.194
58	N 32° 35'429"	E 075° 09'721"	167.1	9.7	124.5	0.364
59	N 32° 35'737"	E 075° 09'736"	273.4	10.4	140.3	0.384
60	N 32° 35'798"	E 075° 09'717"	230.1	13.6	217.0	0.353
61	N 32° 35'757"	E 075° 09'766"	187.7	12.3	226.5	0.421
62	N 32° 35'770"	E 075° 09'834"	250.9	14.7	169.2	0.274

S. No.	GPS location		Available nutrients			
			N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Mo (mg kg ⁻¹)
63	N 32° 35'797"	E 075° 09'870"	217.3	11.1	151.0	0.287
64	N 32° 35'821"	E 075° 09'885"	271.8	14.2	223.8	0.284
65	N 32° 35'860"	E 075° 09'904"	194.5	13.4	210.1	0.237
66	N 32° 35'899"	E 075° 09'971"	265.9	12.2	183.5	0.220
67	N 32° 35'870"	E 075° 10'017"	250.4	13.1	205.2	0.227
68	N 32° 35'845"	E 075° 10'054"	267.6	14.6	139.9	0.278
69	N 32° 35'838"	E 075° 10'090"	254.0	13.2	212.8	0.327
70	N 32° 35'829"	E 075° 10'120"	195.2	10.5	132.6	0.294
71	N 32° 35'828"	E 075° 10'170"	277.4	12.1	220.3	0.484
72	N 32° 35'826"	E 075° 10'134"	240.7	14.8	151.7	0.365
73	N 32° 35'838"	E 075° 10'065"	174.0	13.2	148.5	0.295
74	N 32° 34'169"	E 075° 07'432"	254.5	12.4	131.6	0.378
75	N 32° 34'102"	E 075° 07'407"	164.2	9.9	214.1	0.273
76	N 32° 34'020"	E 075° 07'351"	260.6	10.5	149.3	0.274
77	N 32° 33'962"	E 075° 07'286"	198.9	14.7	129.8	0.227
78	N 32° 33'806"	E 075° 07'142"	279.4	13.1	138.7	0.185
79	N 32° 33'785"	E 075° 07'064"	209.0	12.8	194.2	0.226
80	N 32° 33'987"	E 075° 06'756"	190.3	14.3	132.7	0.217
81	N 32° 34'316"	E 075° 06'176"	264.9	13.1	209.0	0.273
82	N 32° 34'455"	E 075° 06'121"	204.4	11.3	152.3	0.153
83	N 32° 34'588"	E 075° 06'254"	271.0	15.0	221.3	0.184
84	N 32° 35'005"	E 075° 06'614"	182.2	12.8	138.6	0.236

S. No.	GPS location		Available nutrients			
			N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Mo (mg kg ⁻¹)
85	N 32° 35'188"	E 075° 06'650"	258.8	13.6	149.9	0.264
86	N 32° 35'356"	E 075° 06'833"	236.4	13.1	108.2	0.257
87	N 32° 35'372"	E 075° 07'062"	195.5	11.5	139.2	0.278
88	N 32° 33'060"	E 075° 04'570"	269.0	14.8	207.8	0.264
89	N 32° 33'041"	E 075° 04'512"	197.6	12.6	212.6	0.283
90	N 32° 33'637"	E 075° 04'417"	178.4	9.9	136.1	0.197
91	N 32° 33'036"	E 075° 04'233"	261.9	13.3	204.9	0.227
92	N 32° 33'129"	E 075° 03'746"	211.3	12.1	208.3	0.098
93	N 32° 33'423"	E 075° 03'082"	187.0	10.2	139.0	0.363
94	N 32° 33'585"	E 075° 02'575"	257.7	13.5	210.6	0.195
95	N 32° 33'833"	E 075° 01'882"	174.0	12.8	221.1	0.486
96	N 32° 33'907"	E 075° 01'681"	251.2	15.6	211.5	0.217
97	N 32° 34'207"	E 075° 00'407"	275.6	14.0	207.2	0.278
98	N 32° 36'221"	E 075° 56'937"	266.2	12.4	216.0	0.360
99	N 32° 36'901"	E 075° 56'096"	263.8	14.6	214.6	0.290
100	N 32° 37'783"	E 075° 55'128"	270.0	13.9	162.6	0.228

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CERTIFICATE-IV

Certified that all the necessary corrections as suggested by the External Examiner and the advisory committee have been duly incorporated in the thesis entitled “**Effect of phosphorus, molybdenum and organics on soil quality and crop performance of blackgram under rainfed ecology of Jammu**” submitted by **Mr. Tajamul Islam Shah**, Registration No. **J-14-D-216-A**.



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