EFFECT OF BIOFERTILIZERS ON GROWTH AND YIELD OF BLACK CHICKPEA (*CICER ARIETINUM* L.) VARIETIES UNDER MANGO-BASED AGROFORESTRY SYSTEM

Thesis

by

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CERTIFICATE-I

This is to certify that the thesis titled **"Effect of biofertilizers on growth and yield of black chickpea (*Cicer arietinum* L.) varieties under mango-based agroforestry system"** submitted in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (FORESTRY)** in the discipline of **SILVICULTURE AND AGROFORESTRY** of Dr. Yashwant Singh Parmar University of Horticulture and Forestry (Nauni) Solan (HP)-173230 is a bonafide research work carried out by **Mr. Himanshu Saini (NF-2021-06-M)** son of Sh. Jagdish Saini under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

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CERTIFICATE - II

This is to certify that the thesis entitled **"Effect of biofertilizers on growth and yield of black chickpea (*Cicer arietinum* L.) varieties under mango-based agroforestry system"** submitted by **Mr. HIMANSHU SAINI (NF-2021-06-M)** son of Shri Jagdish Saini to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) – 173 230, India in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (FORESTRY)** in the discipline of **SILVICULTURE AND AGROFORESTRY** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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This is to certify that all the mistakes and errors pointed out by external examiner have been incorporated in the thesis entitled **"Effect of biofertilizers on growth and yield of black chickpea (*Cicer arietinum* L.) varieties under mango-based agroforestry system"** submitted by **Mr. HIMANSHU SAINI (NF-2021-06-M)** son of Shri Jagdish Saini to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) - 173 230 in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (FORESTRY)** in the discipline of **SILVICULTURE AND AGROFORESTRY.**

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All of the errors and oversights are solely my own responsibility.

Place: Neri, Hamirpur **(Himanshu Saini)**
Dated:

CONTENTS

ABBREVIATIONS USED

et al.	:	et alia (co-worker)
viz.	:	videlicet
i.e.	:	id est
m	:	metre
m^2	:	metre square
q ha^{-1}	:	quintal per hectare
t ha^{-1}	:	ton per hectare
ha	:	hectare
cm	:	centimetre
Rh	:	*rhizobium*
PSB	:	phosphate solubilizing bacteria
pH	:	potential of hydrogen
EC	:	electrical conductivity
OC	:	organic carbon
N	:	nitrogen
P	:	phosphorus
K	:	potassium
NS	:	non-significant
dS m^{-1}	:	decisiemens per metre
kg ha^{-1}	:	kilogram per hectare
Rs.	:	rupees
kg	:	kilogram
g	:	gram
B-C	:	benefit-cost
mg g^{-1}	:	milligram per gram
Rs ha^{-1}	:	rupees per hectare
°C	:	degree celsius
g cm^{-3}	:	gram per cubic centimetre
%	:	per cent
CD	:	critical difference
DAS	:	days after sowing
etc	:	et cetera

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Chapter- 1

INTRODUCTION

In the realm of sustainable agricultural practices, agroforestry stands as a pivotal resource management system, seamlessly integrating trees, crops and livestock on the expanse of land. This multifaceted approach not only enhances productivity but also contributes significantly to biodiversity conservation and ecosystem services (Jose, 2009). The intentional integration of trees within agricultural systems optimizes land use, harnessing vertical space to achieve higher productivity per unit area. (Nair *et al*., 2021). Trees plays an important role in ecological functions such as nutrient cycling, erosion control and water regulation, thereby improving soil quality and reducing runoff (Montagnini and Nair, 2004). Along with agriculture, farmlands, water partings and other landscapes are being accompanied with the tree plantation and other vegetation management. Thus, several benefits could be taken from adjoining natural, semi natural or reinstated ecosystem (Pandey, 2002) and from an economic perspective, agroforestry systems offer multiple income streams for farmers. Timber, fruits, nuts and other non-timber forest products derived from trees in agroforestry provide additional revenue sources (Nair *et al*., 2021). This diversification of income can enhance the resilience of farming communities and reduce dependence on single commodities.

Amidst the diverse agricultural landscapes, India's Himalayan states continue to employ ancient agroforestry methods, demonstrating their efficacy in managing trees, intercropping understory crops, raising livestock and safeguarding neighbouring forests (Beer *et al*., 2005). These time-tested practices hold significant potential for elevating overall agricultural production, supporting local livelihoods, and facilitating carbon sequestration. The intercropping system, favoured by farmers for its ability to yield higher crop output, provide insurance against crop failure, promote nutrient cycling and contribute to soil conservation has emerged as a particularly advantageous aspect of agroforestry (Lithourgidis *et al*., 2011, Wang and Cao, 2011; Yu *et al*., 2015).

Mango, scientifically known as *Mangifera indica* L., has long been hailed as the "King of Fruits". The mango tree exhibits adaptability to both tropical and subtropical climates, making it a versatile crop suitable for various regions and farmers are growing mango at specific distances and the interspaces are utilized for growing various crops. It holds significant importance as a major fruit crop in several countries, including the Philippines, Mexico, India, Brazil, Pakistan, China and Thailand. Among these nations, India stands out as the top mango producer globally, accounting for roughly 50% of the world's mango production. The mango tree exhibits adaptability to both tropical and subtropical climates. In the state of Himachal Pradesh, India, renowned as the fruit bowl of the country due to its exceptional fruit quality and abundant harvests, mango cultivation primarily thrives in the low hill zone. Covering a substantial area of 40,298 hectares, mango cultivation in Himachal Pradesh yields an impressive production output of 25,408 metric tons (Kumar and Gupta, 2020). This fruit species has been extensively cultivated in various regions worldwide due to its enticingly sweet taste, nutritional richness, diverse range and high demand for food processing. Mangoes are abundant in essential nutrients such as protein, magnesium, potassium, calcium, fiber, carotene, vitamin A, riboflavin, ascorbic acid and carbohydrates (Sharma and Singh, 2011).

As a complementary facet of agriculture, pulse crops play a vital role in addressing protein-energy malnutrition and contribute substantially to India's pulse production. When pulses are consumed along with cereals, they enhance the biological value of protein intake. Legumes, which belongs to the Fabaceae or Leguminosae family, refer to plants whose seeds and fruits are used as dry grains, commonly known as pulses. Due to their tap root structure, pulse crops play a crucial role in agricultural production systems as they are adaptable to different cropping methods, improve soil fertility, enhance physical properties and increase soil porosity (Verma, 2016). Legumes, including chickpea (*Cicer arietinum* L.), commonly known as Bengal gram or gram, play a crucial role as important pulses crops in India. Over the last 15 years, India has achieved major advances in increasing pulse production. Chickpea is mostly grown primarily for its nutritional value because it contains a high amount of protein in a vegetarian diet and also helps to mitigate the problem of protein-energy malnutrition (Prasad, 2012). It is also a rich source of fat (4.5%), minerals, carbohydrates (61.5%), vitamins, protein (22%) and fibres (Hirdyani, 2014). Chickpea production in India has peaked to all time high at 11.23 million tonnes during 2017-18 and it was sustained to 10.32 million tonnes which has ushered self-sufficiency for this main pulse crop in India. During 2021-22, chickpea production of India was 13.75 million tonnes from an acreage of 10.91 million ha. with a productivity of 12.6 q ha^{-1}. Chickpea solely contributes nearly 50% of the Indian pulse production. States like Maharashtra (25.97% contribution to national production), Madhya Pradesh (18.59%), Rajasthan (20.65%), Gujarat (10.10%) and Uttar Pradesh (5.64%) are major chickpea producing states of India (Sharma *et al*., 2023).

However, challenges such as nitrogen scarcity pose hurdles to food production. In this context, leguminous crops offer a promising solution, as India holds the dual distinction of being the leading global producer and importer of such crops. Expanding leguminous crop cultivation not only addresses nitrogen limitations but also aligns with sustainable agricultural practices, reducing dependence on chemical fertilizers. As India's position as a prominent producer and importer of leguminous crops (Shakya *et al*., 2008).

Further enhancing the sustainable agriculture narrative is the introduction of biofertilizers, biofertilizers are a promising tool in agricultural ecosystems, formulations containing microorganisms that benefit plant growth and nutrition, serving as an alternative, renewable and eco-friendly source of plant nutrients. They possess the ability to convert essential elements required for plant nutrition from inaccessible forms to highly soluble ones, all without causing adverse effects on the natural environment. Consequently, biofertilizers play a significant role as a vital component of the Integrated Plant Nutrient System (IPNS) (Alley and Vanlauwe, 2009). These eco-friendly alternatives to chemical fertilizers hold the promise of improving soil health without adverse environmental effects. *Rhizobium* and phosphate solubilizing bacteria (PSB) are integral components of biofertilizers, playing key roles in nitrogen fixation and phosphate solubilization, respectively. They are widely recognized as cost-effective alternatives to chemical fertilizers, with no harmful effects on soil health or the environment. Additional advantages of biofertilizers include the extended shelf life of microbial cells, ensuring their viability without adverse impacts on the ecosystem (Bhardwaj *et al*., 2014). When applied as seed or soil inoculants, biofertilizers multiply and actively participate in nutrient cycling, thereby contributing to crop growth and overall productivity.

Biofertilizers consist of dormant cells derived from living biomass and function as natural fertilizers. The presence of micro-organisms capable of solubilizing phosphate and fixing nitrogen plays a vital role in supplying plants with essential nutrients such as phosphorous and nitrogen. Furthermore, these microorganisms play a crucial role in transforming initially unusable forms of these nutrients into readily usable forms, enhancing their availability for plant uptake (Tambekar *et al*., 2009). *Rhizobium* bacteria assist in the formation of nodules in pulse crops, enabling direct fixation of atmospheric nitrogen. This process significantly reduces the nitrogen demand of the plants by as much as 70-80%. Similar to this PSB play a crucial role in the conversion of insoluble phosphate compounds into soluble forms, thereby making them readily available for uptake by crop plants. This ability of PSB to transform the insoluble form of phosphates enhances the accessibility and utilization of phosphorus by plants and can solubilize the residual or fixed soil Phosphorous. (Singh *et al*, 2008).

Despite their potential, systematic studies on the growth and yield attributes of chickpea under agroforestry systems with the application of biofertilizers remain limited. Against this backdrop, this thesis endeavours to explore the intricate interplay between agroforestry, mango cultivation, pulse crops and biofertilizers in the unique agro-ecological setting of Himachal Pradesh. The present study, therefore, was planned to study the "**Effect of biofertilizers on growth and yield of black chickpea (*Cicer arietinum* L.) varieties under mango-based agroforestry system**" with the following objectives:

i. To study the effect of biofertilizers and mango tree on growth and yield parameter of different black chickpea varieties
ii. To estimate physical and chemical properties of soil for sustainability of agroforestry system
iii. To assess economic viability of the agroforestry system

Chapter- 2

REVIEW OF LITERATURE

Agroforestry plays a crucial role in promoting sustainable production and preservation of essential natural resources such as soil, water and biodiversity. This approach advocates for effective land utilization as opposed to monocropping, enhancing land productivity and establishing a well-balanced cropping system (Mahato *et al*., 2016). Farmers may meet fundamental necessities like food, fuel wood and fodder, diversify their crop without requiring additional land, produce carbon and increase overall productivity by implementing agroforestry systems (Rao, 2017). Agroforestry with a focus on horticulture is vital for agricultural production, working towards ensuring nutritional security and environmental preservation through carbon sequestration to mitigate the ongoing climate change challenges for the better well-being of mankind. The suggested approach involves using compatible combinations of tree crops, strategically minimizing resource competition while maximizing synergies (Pardon *et al*., 2018). Farmers prefer agroforestry practice to increase their socio-economic status and to gain maximum profit from same unit of land as it enhances income through synchronized production of food, fodder and firewood (Tiwari *et al*., 2017). The relevant available literature pertaining to present research study "**Effect of biofertilizers on growth and yield of black chickpea (*Cicer arietinum* L.) varieties under mango-based agroforestry system**" has been reviewed under following headings:

2.1 Effect of agroforestry systems on growth and yield of agriculture crop

2.2 Effect of biofertilizers on growth and yield of agriculture crop

2.3 Effect of agroforestry system on physico-chemical properties of soil

2.4 Economic feasibility of the agroforestry system

2.1 Effect of agroforestry systems on growth and yield of agriculture crop

Bhatt and Misra (2003) explored an agrihorticulture agroforestry system comprised guava (*Psidium guajava* cv. Allahabad safeda) and Assam lemon (*Citrus lemon* cv. Local) under rainfed conditions at ICAR Research farm, Umiam, Meghalaya, India. They intercropped three rice varieties (RCPL-1-24, RCPL-1-25, and RCPL-1-29) with these fruit trees. The results indicated that the control plots exhibited significantly higher grain yield and total biological yield for all three rice varieties compared to the guava and Assam lemon blocks. However, there were no significant differences in the productivity of rice varieties under guava and Assam lemon.

Shanker *et al*. (2005) carried out investigations to assess the growth and yield of intercrops *viz*., *Brassica campestris* (mustard) and *Glycine max* (soybean) under *Hardwickia binata* based agroforestry system. Yield of the intercrops was significantly higher in pure cultivation as compared to that under intercropping with *Hardwickia binata*.

Pal *et al*. (2009) analyzed the variation in growth characters of different wheat varieties under *Populus deltoides* in an agrisilviculture system. Eight wheat varieties *viz.*, HD-2329, WH-542, PBW-373, PBW-222, Raj-3765, UP-2338, HD-2687 and PBW34 were assessed under 6 years old poplar plantation spaced at 5 m x 4 m. The results revealed better growth in terms of number of shoots (120), plant height (85.2 cm) and leaf dry weight (88.8 g) in WH-542 wheat variety. The study suggested variety WH-542 as the most suitable crop for cultivation under poplar plantation.

Dhiman and Gandhi (2010) conducted a field experiment in Tarai region of Kichha tehsil of district Udham Singh Nagar, Uttarakhand to study the growth and yield attributes of green pea (*Pisum sativum*) grown under poplar (*Populus deltoides*) as well as in open conditions. Results indicated that growth and yield attributes were significantly affected under poplar plantations of different ages. Significant higher yield of green peas was recorded under open and young plantations as compared to old plantations. Gradual decrease in pea yield was observed with increase in age and size of the poplar trees.

Vanlalngurauva *et al.* (2010) intercropped various agricultural crops with *Gmelia arborea* at Regional Research Station (Red and Laterite Zone), Bidhan Chandra Krishi Viswavidyalaya, Jhargram, Paschim Medinipur, West Bengal. It was observed that integration of rice (*Oryza sativa*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*) and black gram (*Vigna mungo*) under 14 years old gamhar (*Gmelia arborea*) resulted in significantly higher yield in cowpea (1.97 t ha^{-1}) and significantly lower yield in blackgram (0.46 t ha^{-1}). The growth of gamhar was influenced due to intercropping with legume intercrops (blackgram, groundnut and cowpea).

Sehgal (2011) performed a field experiment in mid hills of Western Himalayas to investigate the performance of basil (*Ocimum basilicum*) with hedgerows of *Leucaena leucocephala* at three different spacing for two consecutive years. The results showed negative influence on various growths and yield attributes (plant height, number of inflorescence and economic yield of associated herb) in closely spaced *Leucaena* hedgerow compared to wider spaced hedgerows. Increased growth was obtained with the application of organic manures in hedgerows but suppression of growth was observed at a distance closer to hedgerows in all the treatments.

Arya *et al.* (2011) carried out a field experiment to investigate the performance of component crops in tree-crop farming system under arid region of Rajasthan. Variations in growth and yield performances of trees (aonla, ber and karonda) as well as annual crops, namely, cluster bean and moth bean raised during kharif, while mustard and brinjal raised during rabi season, were recorded. Results revealed increase in yield (86.52 q ha^{-1}) of ber under integrated model over sole cropping (56.32 q ha^{-1}). The authors also reported significant increase in plant height and yield of all component crops under tree-crop farming system as compared to the sole cropping.

Gao *et al*. (2013) assessed photosynthesis, growth and yield of *Glycine max* (soybean) and *Arachis hypogaea* (peanut) in *Malus pumila* (apple) plantation spaced at 4 m × 5 m on the Loess Plateau of China. The results indicated suitability of peanut as intercrop under apple for higher economic benefits over soyabean. Deficiency in soil nutrients, moisture content and light also exerted a significant impact on crop yields.

Singh and Bishnoi (2013) carried out a study in the arid regions of Haryana to investigate the performance of kharif bean crops *viz*., clusterbean (*Cyamopsis tetragonoloba*), mothbean (*Vigna aconitifolia*) and mungbean (*Vigna radiata*) in association with Khejri (*Prosopis cineraria*). The results showed that intercropping enhanced the vegetative growth (number of plants, plant height, pods per plant and pod length) as well as number of pods per plant in all bean crops. This might be due to improved soil fertility and moisture retention under this multipurpose tree.

Kaur and Puri (2013) analyzed growth, biomass and productivity of wheat (*Triticum aestivum*) and black gram (*Vigna mungo*) with *Grewia optiva*, *Bauhinia variegata*, *Celtis australis* in agroforestry system and as sole crops in Solan District of Himachal Pradesh. Grain yield showed by *Triticum aestivum* and *Vigna mungo* was 25.40 and 13.63 q ha^{-1} whereas straw yield was 23.50 and 7.87 q h^{-1}, respectively. The harvest index of *Triticum aestivum* and *Vigna mungo* was 51.84 per cent and 63.93 per cent, respectively. The productivity of *Vigna mungo* was almost 1.76 times more as sole crop in comparison to the crop grown under trees however, comparatively narrow variation was observed in *Triticum aestivum*.

Sandhu *et al*. (2015) carried out investigations to assess productivity and growth parameters of wheat under poplar-based agroforestry system. Poplar was grown on boundary and as block plantation. Wheat grain yield was significantly higher in control plots (4.55 t ha^{-1}) than boundary plantation (3.28 t ha^{-1}) and block plantation (2.03 t ha^{-1}). Similar trend was recorded for straw yield in control plots (6.61 t ha^{-1}), boundary plantation (4.83 t ha^{-1}) followed by block plantation (3.5 t ha^{-1}).

Bhutia *et al*. (2015) evaluated the performance of three pea varieties *viz.*, Solan Nirog, Azad P 1 and PB 89 which were grown with different doses of inorganic fertilizers + *Rhizobium* inoculation under three years old peach plantation and in open. The recommended dose of NPK + *Rhizobium* inoculation showed best results in most of the growth and yield attributes of pea crop *viz.,* plant height (cm), number of pods $plant^{-1}$, number of grains pod^{-1}, pod length (cm), pod breadth (cm), 100 grain weight (g), shelling percentage and total biomass production (g). Variety PB 89 exhibited better growth and yield attributes of pea but plant height and shelling percentage was maximum in Solan, Nirog. The investigation concluded that pea variety PB 89 can be grown successfully under peach-based agroforestry system without much reduction in yield as compared to sole cropping. The study also suggested inoculation of seeds with rhizobium and 100 per cent recommended dose of NPK for obtaining maximum yield.

Bhatt et al. (2016) conducted a five-year study to assess crop productivity in agrisilviculture (hedgerow and alder based) and agrihorticulture (guava based) systems in Meghalaya, India. Maize (*Zea mays*), followed by mustard (*Brassica campestris*) and potato (*Solanum tuberosum*), were intercropped throughout the experimental period. The control plots exhibited higher crop yields for maize, mustard and potato compared to those observed under agroforestry systems. Additionally, the total yield of maize, potato and mustard was significantly greater in the agrihorticulture system than in the agrisilviculture system.

Ahmed *et al*. (2018) conducted a trial at experimental farm of King Saud University, Saudi Arabia to examine the effect of four *Acacia* tree species (*A. nilotica, A. seyal, A. senegal* and *A. tortilis*) on growth and yield of sorghum (*Sorghum bicolor* L.). Results showed higher leaf number, fresh and dry weight in intercropped sorghum as compared to control. The higher plant height (168.41 cm) was recorded in sorghum plants grown in strips between pure *A. senegal* (two rows of *A. senegal*) followed by crop grown between *A. seyal* and *A. tortilis* (one row each of *A. seyal* and *A. tortilis*); and *A. nilotica* and *A. senegal* (one row each) and minimum in control (88.75 cm). This might be attributed to increase in soil fertility and improvement of soil physical properties under *Acacia* trees as a result of addition of organic matter and litter mineralization.

Tripathi *et al.* (2020) assessed the effect of organic manures on the growth and yield of three medicinal plant species (*Andrographis paniculata*, *Withania somnifera* and *Ocimum sanctum*) grown under peach (*Prunus persica*) based agroforestry system at Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.). Three different doses of vermicompost (2, 4 and 6 t ha^{-1}) and three different doses of farmyard manure (15, 20 and 25 t ha^{-1}) were given to medicinal plant species with or without peach trees. It was observed that growth and yield attributes of medicinal plants were higher when intercropped under peach than grown as sole crops. The application of organic amendments had a significant effect on growth and yield of medicinal plants with better performance at higher doses.

Bagare *et al.* (2021) analyzed a *Dalbergia sissoo* based agroforestry system intercropped with wheat, mustard and gram. Different treatment combinations were *Dalbergia sissoo* + Mustard (T1), *Dalbergia sissoo* + Gram (T2), *Dalbergia sissoo* + Wheat (T3), *Dalbergia sissoo* (T4), Mustard (T5), Gram (T6), Wheat (T7). *Dalbergia sissoo* is a leguminous tree which provided favourable environment for the under storied crops. Higher yield of wheat was obtained under *Dalbergia sissoo* compared to gram and mustard crop.

Vijaykumar *et al.* (2021) performed a field experiment at Forest Nursery and Research Centre of Sam Higginbottom University of Agriculture, Technology & Sciences, Prayagraj. The experiment was conducted with sixteen treatments (T_0 -T_{15}) and three replications to evaluate growth performance and yield of rice under *Moringa oleifera* based agroforestry system during 2019-20. Highest grain yield, straw yield and biological yield was observed in T_6 (50 per cent goat manure + 50 per cent sun hemp (*Crotalaria juncea*) followed by T_{10} (50 per cent goat manure + 50 per cent pongamia (*Pongamia glabra*) and minimum was recorded in T_0 (control) (no manures no fertilizers).

Tariyal *et al.* (2022) performed a field experiment to find the production potential of barnyard millet (*Echinochloa frumentacea*) and finger millet (*Eleusine coracana*) under *Grewia oppositifolia* based traditional agroforestry systems. The experiment was conducted at two elevational ranges *i.e.* 1000-1400 m and 1400-1800 m in Garhwal, India. The results showed reduced growth and yield attributes of both the millet crops under *Grewia oppositifolia* at both the elevations over control (sole crops). Among the elevations, higher growth and yield parameters in terms of seed weight, grain yield, straw yield, biological yield and harvest index were recorded at the lower elevation in both crops *Echinochloa frumentacea* and *Eleusine coracana*. However, higher plant population per m square was recorded at the upper elevation.

2.2 Effect of biofertilizers on growth and yield of agriculture crop

Pramanik and Singh (2003) conducted a field experiment during the winter seasons of 2000-2001 and 2001-2002, to study the effect of levels and mode of phosphorus and biofertilizers [vesicular arbuscular mycorrhiza (VAM) and phosphate-solubilizing bacteria (PSB)] on yield attributes and yield of chickpea (*Cicer arietinum* L). Inoculation of biofertilizers significantly increased yield attributes of pods plant^{-1} and seeds plant^{-1} and yield of chickpea. Among biofertilizers, dual inoculation of PSB+VAM markedly enhanced these yield attributes and yield compared with PSB or VAM alone.

Khatkar *et al.* (2007) carried out a field experiment at Allahabad during kharif season of 2005 to study the effect of biofertilizers and sulphur levels on growth and yield of Black gram. The treatments comprised of seed inoculation with *Rhizobium* and PSB and different levels of sulphur (0, 20 and 30 kg ha^{-1}). The results revealed that application of sulphur @ 20 kg ha^{-1}+ dual inoculation with *Rhizobium* and PSB significantly increased the growth characters and yield of black gram.

Afzal and Bano (2008) conducted a pot experiment in order to investigate the effects of a rhizobial strain (Thal 8) and a P solubilizer strain (54RB) in single and dual combination with and without P_2O_5 on wheat in a P deficient natural non-sterilized sandy loam soil. The results of this experiment revealed that single and dual inoculation with fertilizer (P_2O_5) significantly increased root and shoot weight, plant height, spike length, grain yield, seed P content, leaf protein and leaf sugar content of the test crop. It is concluded that single and dual inoculation along with P fertilizer is 30-40% better than only P fertilizer for improving grain yield of wheat and dual inoculation without fertilizer (P) improved grain yield up to 20% as compared to P application.

Singh and Yadav (2008) laid out a field trial at Institute of Agricultural Sciences, BHU, Varanasi during rainy season of 2004-05 and 2005-06 to study the effect of phosphorus levels (0, 15, 30, 45 and 60 kg P_2O_5 ha^{-1}) and biofertilizers (untreated control, *Rhizobium*, PSB, *Rhizobium* + PSB) on growth, yield and nutrient uptake of long duration pigeon pea. Among the biofertilizers, *Rhizobium* + PSB produced significantly taller plants (198.7 cm), maximum number of branches plant^{-1} (18.9), dry matter plant^{-1} (156.4 g), grain yield (2060 kg ha^{-1}), stalk yield (7560 kg ha^{-1}) and uptake of N (104.9 kg ha^{-1}) and P (16.9 kg ha^{-1}) than other biofertilizers treatments, Combined effect of 60 kg P+ *Rhizobium* + PSB produced significantly higher dry matter (165.8 g plant^{-1}), grain yield (2510 kg ha^{-1}) and phosphorus uptake (21.4 kg ha^{-1}) than other combinations except 45 kg P_2O_5 + *Rhizobium* + PSB.

Dutta and Bandyopadhyay (2009) conducted field experiments during the winter seasons of 2005-2006 and 2006-2007 at Sekhampur, West Bengal, India, to evaluate the performance of chickpea with variable proportions of phosphorus (P) and bio-fertilizers in laterite soil (entisol) under rainfed conditions. According to investigation seed inoculation with *Rhizobium* and phosphobacterin was significantly superior over no inoculation or phosphobacterin inoculation alone.

Selvakumar *et al*. (2009) conducted a field experiment to determine the effect of biofertilizers on growth and yield of black gram. The different inoculation (single and dual) of biofertilizers *Azotobacter, Azospirillum*, *Rhizobium*, phosphobacteria were incorporated into the top 15 cm of the soil. During the experiment period the plant samples were analysed for attributes such as root length, shoot length, fresh and dry weight, leaf number, leaf area, root nodules and the biochemical content such as chlorophyll 'a', 'b', total chlorophyll, carotenoid, protein content, nodules and yield were analysed. The results revealed that the combination inoculation of *Rhizobium* + phosphobacteria significantly increased growth and yield of black gram compared with control (without biofertilizers).

Gnyandev *et al*. (2009) conducted a field experiment to know the effect of seed treatment on plant growth, seed yield and quality in two chickpea varieties A-1 (desi) and KAV -2 (kabuli) during rabi seasons of 2007 and 2008 at main agricultural Research station, University of Agricultural sciences, Dharwad. The study revealed that seeds treated with *Rhizobium* followed by PSB resulted in higher number of branches, pods plant^{-1}, test weight, seed yield in A1 (31.25 and 28.15) respectively. While maximum plant height was recorded in ICCV-2 variety treated with *Rhizobium* followed by PSB treatment (50.27 and 25.22). The seed quality parameters were more in seed treatment of *Rhizobium* followed by PSB, compared to other treatment and control in both chickpea varieties.

Giri and Joshi (2010) studied the effect of seed inoculation by using *Rhizobium* sp. as a biofertilizer on nodule formation and growth of chickpea plant. To study the efficiency of seed inoculation for nitrogen fixation. The results obtained revealed that, the bacterized seeds showed, 14.06% in total length over control, increase of 10.83% in total weight over control and an increase of 9.0% on germination over control in pot experiment. From the results they concluded that *Rhizobium* inoculation is a promising fertilizer because it is cheap, easy to handle and improves plant growth and seed quality.

Singh *et al*. (2011) studied the effect of irrigation and biofertilizers on chickpea growth. *Rhizobium* inoculation significantly improved the number of nodules and nodule dry weight compared with no treatment. Grain yield was significantly higher with *Rhizobium* than in untreated plots.

Sharma and Chauhan (2011) performed an experiment on pea, taking two levels of chemical fertilizers, farm yard manure and vermicompost and dual inoculation with biofertilizers in different combinations and revealed that the integrated nutrient management was the best option for the maximum yield and quality produce. The biofertilizers, both Azotobacter and PSB, played a major role in increasing the nutrient availability to the plants, which in turn was reflected through the quality of the produce and yield maximization. The biofertilizers, however, showed better responses when applied in conjunction with the organic manures, since the manures provided a favourable environment for the activity of these micro-organisms.

Rokhzadi and Toashish (2011) evaluated the effects of single and combined inoculation with plant growth-promoting rhizobacteria from four genera including *Azospirillum, Azotobacter, MesoRhizobium* and *Pseudomonas* on nutrient uptake, growth and yield of chickpea plants under field conditions. Nodulation were significantly affected by the treatments at the beginning of flowering stage. Grain yield and dry biomass were statistically improved by applying every inoculation treatment in comparison with control plants. Group comparisons between treatments showed that the occurrence of *Azospirillum* or *Azotobacter* inoculants in the treatment composition caused an expressive improvement in grain yield and plant biomass and they concluded that application of every inoculation treatment, especially treatments which contained *Azospirillum* or *Azotobacter* may stimulate growth and yield of chickpea as compared with uninoculated plants.

Pramanik and Bera (2012) investigated a field experiment during the rabi seasons of 2008-2009 and 2009-2010 to find out the response of biofertilizers and phytohormone on growth and yield of chickpea (*Cicer arietinium* L.). The experiment was laid out in factorial RBD with five levels of biofertilizers (No inoculation, *Rhizobium*, Phosphate solubilizing bacteria, Vesicular arbuscular mycorrhizae, *Rhizobium* + Phosphate solubilizing bacteria + Vesicular arbuscular mycorrhizae). Results revealed that inoculation of biofertilizers significantly improved growth parameters like plant height yield parameters like number of pods plant^{-1}, weight of pods plant^{-1}, number of gains plant^{-1}, test weight, grain yield, stalk yield and harvest index. Among the biofertilizers, combined inoculation of *Rhizobium* + PSB + VAM produced higher grain yield over no inoculation, *Rhizobium*, phosphate solubilizing bacteria, vesicular arbuscular mycorrhizae respectively.

Bhattacharjee and Sharma (2012) performed pot experiments in the Department of Life Science and Bioinformatics of Assam University, Silchar. The aim of the study was to investigate the effect of dual inoculation of Arbuscular mycorrhiza (AM) (*Glomus fasciculatum*) and *Rhizobium* on the chlorophyll, nitrogen and phosphorus contents of pigeon pea (*Cajanus cajan* L.). The results revealed an overall increase in chlorophyll, nitrogen and phosphorus contents in the inoculated plants than uninoculated ones. Maximum chlorophyll contents were recorded in the plants dually inoculated with *Glomus fasciculatum* and *Rhizobium*. The dual inoculation with microsymbionts revealed synergistic effect. The results shows that dual inoculation of *Glomus fasciculatum* and *Rhizobium* have the potential to enhance the chlorophyll, nitrogen and phosphorus contents of pigeon pea.

Singh *et al*. (2013) carried out investigations to find out the effect of biofertilizers, nitrogen and phosphorus levels on green gram (*Vigna radiata* L. Wilczek.) under custard apple (*Annona squamosa* L.) based agrihorticulture system during kharif season of 2012-13. The experiment was conducted in randomized block design with seven treatments of biofertilizers and 20 kg N, 40 kg P_2O_5 level in four replications, seed of green gram inoculated by strain *Rhizobium* (MOR-1) and phosphate solubilizing bacteria (*Bacillus subtilis*). Results showed that growth parameters of green gram were affected by biofertilizers (*Rhizobium* + PSB), nitrogen and phosphorus application. Seed inoculation with *Rhizobium* and PSB + 20 kg N, 40 kg P_2O_5 application recorded significantly higher growth parameters viz., plant height (cm), number nodules plant^{-1}, dry matter accumulation plant^{-1}, number of trifoliate leaves plant^{-1} of green gram as compared to uninoculation of biofertilizer and control treatments.

Kumawat *et al.* (2013) carried out an experiment during kharif season of 2009 which consisted of thirteen treatment combinations comprising of two phosphorus levels (20 and 40 kg P_2O_5 ha^{-1}), three phosphorus sources (DAP, SSP and PROM), two biofertilizers (PSB and *Rhizobium*) and one absolute control to evaluate the effect of phosphorus sources, levels and biofertilizers on black gram. Seed inoculation with PSB markedly enhanced yield attributes, seed yield, (10.11 q ha^{-1}), haulm (20.88 q ha^{-1}), biological (30.98 q ha^{-1}) yields net return (Rs

24529.87 ha^{-1}) with benefit cost ratio 2.65 over *Rhizobium* and control of black gram. They also concluded that the combined application of 40 kg P_2O_5 though DAP along with PSB brought significant effect on seed yield on Black gram.

Iwuagwu *et al*. (2013) carried out study to determine the effect of microbial inoculants (biofertilizers) comprising *Azotobacte*r species, *Azospirillum* species and phosphate solubilising micro-organism (PSM) on the growth of *Zea mays* L. The experiment was arranged in a completely randomized design with six treatments and four replicates. Treatment one T1 represents control, T2 = *Azospirillum* inoculants, T3 = *Azotobacter* inoculants, T4 = Phosphate Solubilizing organism, T5 = *Azotobacter* + *Azospirullum* + PSM, T6=*Azotobacter* + *Azospirillum*. Various parameters for growth were used to compare the vegetative growth of the seedlings on different treatment applications. The result showed that seedlings treated with microbial inoculants responded greatly when compared to the control. Analysis of variance showed that there was significant increase in height of seedlings on the application of the microbial inoculants. The result suggests that that biofertilizers enhances the growth of *Zea mays* and as such its usage should be encouraged because of it is ecofriendly.

Das *et al*. (2013) carried out field experiment on chickpea during Rabi season, 2009-10 at Agronomy farm, College of Agriculture, Bikaner. The combined inoculation of *Rhizobium* and PSB significantly enhanced growth, yield attributes and yield of chickpea.

Kiran *et al*. (2013) analyzed the effect of tree shade on nodulation, arbuscular mycorrhizal colonization and growth of pea (*Pisum stivum* L.) under *Dalbergia sissoo* based agroforestry system. The results showed that number of nodules and arbuscular mycorrhizal colonization in pea roots were significantly more in open as compared to their respective values under tree shade.

Tagore *et al*. (2013) carried out an experiment during the rabi season of 2004-05 to find out the effect of *Rhizobium* and phosphate solubilizing bacterial (PSB) inoculants on symbiotic traits, nodule leghemoglobin and yield of five elite genotypes of chickpea. Among the chickpea genotypes, IG-593 performed better in respect of symbiotic parameters including nodule number, nodule fresh weight, nodule dry weight, shoot dry weight, yield attributes and yield. Among microbial inoculants, the *Rhizobium* + PSB was found most effective in terms of nodule number (27.66 nodules $plant^{-1}$), nodule fresh weight (144.90 mg $plant^{-1}$), nodule dry weight (74.30 mg $plant^{-1}$), shoot dry weight (11.76 g $plant^{-1}$) and leghemoglobin content (2.29 mg g^{-1})

and also showed its positive effect in enhancing all the yield attributing parameters, grain and straw yields.

Moinuddin *et al*. (2014) performed an experiment in the net-house to investigate the effect of graded levels of P fertilizer along with *Rhizobium* (BNF) and/or phosphate solubilizing bacteria (PSB) on growth and physiological parameters of chickpea and recorded that among the biofertilizer treatments, BNF+PSB gave the greatest values regarding most growth and physiological parameters.

Singh *et al*. (2014) explored the effects of phosphorus and biofertilizer on the growth, yield and quality of chickpea (*Cicer arietinum* L.) under rainfed conditions over consecutive winter seasons from 2008-09 to 2009-10 in Kumarganj, Faizabad. Their results indicated that the application of a peat-based biofertilizer (PSB + *Rhizobium*) at a rate of 1.60 kg ha^{-1} for seed inoculation led to a significantly higher number of nodules, increased fresh and dry weight of nodules, and elevated yields of seed, straw and biological produce compared to both uninoculated conditions and inoculation with PSB or *Rhizobium* alone.

Rahangdale *et al*. (2014) carried out studies to identify suitable kharif crop combinations with bamboo-based agroforestry system. Non-significant variation for grain as well as straw yield was noticed for kharif crops; soyabean, moong, paddy and sesame intercropped with *Dendrocalamus strictus* and *Bambusa arundinacea*. Among all crops, soybean and moong were found most sensitive with bamboo as compared to paddy and sesame.

Jamir (2016) investigated the effect of different biofertilizers and planting densities on the growth and yield of *Spilanthes acmella* Murr. under Morus based agroforestry system. The experiment was laid out in a split plot design comprising of *Morus alba* as tree component planted at a spacing of 9 m x 3 m and open field condition, under which akarkara plants treated with 5 different biofertilizer combinations *viz*. T1 (Plant growth promoting rhizobacteria + FYM), T2 (*Azotobacter* + Phosphate solubilizing bacteria + FYM), T3 (*Azotobacter* + *Vesicular arbuscular mycorrhiza* + FYM), T4 (*Azospirillum* + Phosphate solubilizing bacteria + FYM), T5 (*Azospirillum* + *Vesicular arbuscular mycorrhiza* + FYM) and T6 (RDF + FYM) as control were grown. All biofertilizer treatments had no significant influence on the growth and yield attributes of akarkara. From the investigation, Jamir concluded that akarkara performed better under sole cropping conditions and the biofertilizers selected for the study had no significant effect on the growth and yield of the plant.

Prajapati *et al*. (2017) conducted an experiment at College Farm, N. M. College of Agriculture, NAU, Navsari with five levels of phosphorus fertilizers and three levels of phosphorus biofertilizers to study the effect of integrated phosphorus management on chickpea and recorded that among different bio-fertilizers, PSB (Phosphorus solubilizing bacteria) + AM (*Arbascular mycorrhiza*) recorded significantly highest plant height, nodule count, number of pods plant^{-1}, seed yield of chickpea.

Chauhan and Raghav (2017) conducted a field experiment during the rabi seasons of 2012-13 and 2013-14 at Jalalpur village in Morena district (M.P.) to investigate the impact of phosphorus and phosphate solubilizing bacteria on the growth, yield and quality of chickpea (*Cicer arietinum*). The results indicated that the combined application of 60 kg P_2O_5 ha^{-1} + PSB inoculation significantly enhanced various aspects including growth attributes (plant height, branches plant^{-1}, number and dry weight of root nodules and root and shoot dry weight plant^{-1}), yield attributes and overall yield (pods plant^{-1}, 1000 seed weight) of chickpea compared to the control.

Singh *et al*. (2018a) carried out an experiment to determine the effects of PSB and *Rhizobium* inoculation for Chickpea (*Cicer arietinum* L.), under Central Uttar Pradesh conditions at Nawabganj Research Farm of Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (U.P.) during Rabi season in 2015-16. The result shows that some plant attributes of the crop like the number of nodules varied from 8 to 25 at 30 days and 12 to 43 at 60 days. The yield of the crop also varied from 12 to 26 q ha^{-1} of seeds of chickpea (*Cicer arietinum* L.) and 13.7 to 35.0 q. ha^{-1} crop stover. The treatment combination *Rhizobium* + PSB was found best in respect of number nodules, seed and stover yield, nitrogen, phosphorus content and its uptake and also in protein content of seed.

Singh *et al*. (2018b) studied the effect of phosphorus, sulphur and biofertilizers on growth attributes and yield of chickpea (*Cicer arietinum* L.) at the Agronomy Research Farm of Narendra Deva University of Agriculture & Technology, Faizabad (U.P.). They concluded that the application of 60 kg ha^{-1} of phosphorus, 20 kg ha^{-1} of sulphur and seed inoculation with PSB + *Rhizobium* led to a significant enhancement in the growth, dry weight, number of nodules per plant and yields (both grain and straw) of chickpea compared to the control/un-inoculated group.

Yadav *et al*. (2019) conducted a field trial at the research farm of College of Forestry, SHUATS, Prayagraj. They tested nine different ways to grow maize, each replicated three times. The best results were observed in T8, where they used *Azotobacter Chroococcum* bacteria, Phosphate Solubilizing Bacteria, and Vermicompost (3 tons ha^{-1}) under subabul trees. This method led to the highest germination rate, tallest plants at different growth stages, most cobs $plant^{-1}$, longest ears, and highest grain and stover yields. The researchers concluded that this combination of bacteria and compost could be recommended for growing maize in subabul-based agroforestry systems to achieve better growth and yield.

Verma and Yadav (2019) investigated a field experiment during rabi season of 2016-17 at Chandra Sekhar Azad University of Agriculture & Technology, Kanpur, U. P. to evaluate the effect of fertility levels and biofertilizers on productivity and profitability of chickpea (*Cicer arietinum* L.). The results showed that among the biofertilizer treatments application of *Rhizobium* + PSB + PGPR recorded significantly higher yield attributes compared to other treatments. The combined application of 100% RDF with *Rhizobium* + PSB + PGPR resulted in significantly higher seed yield, gross return, net return and B: C ratio of chickpea over other combinations.

Yadav *et al*. (2021) carried out a field study at Instructional Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) during Rabi season 2017-2018 to evaluate effect of different bio-fertilizers on growth, yield attributes and yield of chickpea (*Cicer arietinum* L.). The experiment was comprised with eight treatments (T1) Control + RDF 100%, (T2) Azotobacter, (T3) *Rhizobium*, (T4) Phosphorus solubilizing bacteria (PSB), (T5) *Rhizobium* + PSB, (T6) *Rhizobium* + Azotobacter, (T7) Azotobacter + PSB, (T8) *Rhizobium* + PSB + Azotobacter. The result revealed that among all the treatments, *Rhizobium* + PSB + Azotobacter (T8) treatment recorded maximum growth attributes, yield and yield attributes which was closely followed by T5 (*Rhizobium* + PSB).

Singh *et al*. (2021) carried out a field experiment at Student's Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology Kanpur, Uttar Pradesh to study the impact of organic, inorganic and biofertilizers on yield attributes and quality of chickpea (*Cicer arietinum* L) during Rabi season for two consecutive years (2018-19 and 2019-20). Results showed that among the different treatments combination, application of 100% RDF with *Rhizobium* and PSB resulted in significantly higher yield attributes, *viz*., number of pods $plant^{-1}$, numbers of seeds pod^{-1}.

In the zaid season of 2021, Sasidhar *et al*. (2022) set up a field experiment at the crop research farm of SHUATS, Prayagraj. They investigated how spacing and biofertilizer affected the yield and growth of black gram (*Vigna mungo* L.). The results showed that the plant height, number of branches, nodules and pods per plant, number of seeds per pod, test weight, grain yield and stover yield were all significantly higher when the spacing of 30 x 10 cm + *Rhizobium* + PSB was used.

Doifode (2021) studied the influence of biofertilizer inoculation *viz. Azotobacter* and Phosphate Solubilising Bacteria (PSB) alone and in different combinations with the recommended dose of chemical fertilizer (NPK. Nitrogen-Phosphorous- Potassium) on Jowar (*Sorghum bicolor* (L.) Moench) during the Kharif season Maharashtra. The results revealed significant improvement in growth characters such as the height of the plant (4.89% to 15.10%), number of internodes (1.69 to 6.39%), stem diameter (5.08% to 26.27%), the weight of the root system (7.32% to 29.27%), number of functional leaves (6.70% to 19.56%) the weight of fresh plant (8.45% to 17.17%) and weight of dry plant (9.15% to 24.29%) over the control treatment.

Yadav *et al*. (2022) conducted a field trial during the Rabi season of 2017-18 at the Student's Instructional Farm of Chandra Shekhar Azad University of Agriculture and Technology in Kanpur, Uttar Pradesh. The objective was to assess the impact of different fertility levels and bio-fertilizer applications on the yield, yield attributes and quality of late-sown chickpea (*Cicer arietinum* L.). The findings revealed that among the various bio-fertilizer treatments, the application of *Rhizobium* + PSB + PGPR significantly enhanced yield attributes and seed yield compared to *Rhizobium* + PGPR. The combined application of 100% RDF with *Rhizobium* + PSB + PGPR resulted in a significantly higher seed yield for late-sown chickpea during the winter Rabi season.

Singh *et al*. (2023) carried out a field experiment during the rabi season of 2022-23 at the Crop Research Farm, Department of Agronomy, SHUATS, Prayagraj (U.P). Their findings revealed that the application of *Rhizobium* (20 g kg^{-1} seeds) in combination with a spacing of 30cmx10cm had a significant positive impact. This combined treatment led to increased growth parameters such as plant height, number of nodules, plant dry weight and improved yield parameters, including the number of pods per plant, seed index, seed yield and stover yield of chickpea.

2.3 Effect of agroforestry system on physico-chemical properties of soil.

An investigation on productivity and growth of soybeans grown in Raipur, Chhattisgarh, India, under *Populus deltoides* based agrisilviculture system was conducted by

Mishra *et al*. (2006). A randomised block design with three replications was used to plant five poplar clones (G3, G48, 65/27, D121, and S7C1) in the system. According to the investigations, after six years of planting poplars at a depth of 0-20 cm, the amounts of available N, P and K in the soil increased significantly, from 14.9 to 24.1 percent, 17.2 to 23.3 percent and 3.1 to 5.1 percent. Under several poplar clones, however, the contents of N, P and K decreased as soil depth increased.

Chaudhary *et al*. (2007) compared the effects on soil properties of conventional agricultural systems and agroforestry systems based on poplar. When compared to a sole cropping system, it was found that soil under an agroforestry system had higher levels of soil organic carbon, total nitrogen, available phosphorus and potassium.

In their study, Saha *et al*. (2007) planted a variety of multipurpose tree species, including *Alnus nepalensis*, *Gmelina arborea*, *Michelia oblonga*, *Parkia roxburghii* and *Pinus kesiya*, on hilly terrain in northeastern India. The analysis of soil physico-chemical parameters revealed substantial improvements, including a 96.2 per cent increase in soil organic carbon, 10.9 per cent rise in porosity, a 24.0 per cent enhancement in aggregate stability and a 33.2 per cent augmentation in available soil moisture. Concurrently, there was a notable reduction in bulk density by 15.9 per cent and erosion ratio by 39.5 per cent.

Gupta and Sharma (2008) examined the impact of poplar plantation on soil properties in the Uttarakhand region. Their findings indicated significant improvements in soil physical properties, including porosity, density and water-holding capacity, under a 4-year-old poplar plantation compared to a pure agricultural cropping system.

Tandel *et al*. (2009) conducted an experiment to investigate the influence of tree cover on soil physical properties at the Instructional Farm, ASPEE College of Horticulture and Forestry, Navsari (Gujarat). Soil sampling was carried out at depths of 0-30 cm, 30-60 cm and 60-90 cm under twelve-year-old plantations of *Terminalia arjuna*, *Adina cordifolia*, *Tectona grandis*, *Casuarina equisetifoila*, *Eucalyptus tereticornis*, *Dalbergia sissoo*, *Dendrocalamus strictus*, *Pterocarpus marsupium, Albizia procera* and *Acacia catechu*. The highest values of soil physical properties, including particle density, bulk density, porosity and water-holding capacity, were observed under the *Dalbergia sissoo* plantation at a depth of 0-30 cm in the soil.

Oyedele *et al*. (2009) conducted a study at Leventis Foundation Farm in the southwestern part of Nigeria to assess the impact of various species, namely *Pterocarpus santalinoides*, *Gliricidia sepium*, *Enterolobium cyclocarpum* and *Leucaena leucocephala*, planted as hedgerows and intercropped with maize (*Zea mays* L.), on the physico-chemical properties of the soil. The results indicated a significant reduction in soil bulk density under the hedgerow species, decreasing from a maximum of 1.52 g cm^{-3} under control to 1.33 g cm^{-3} under *Pterocarpus santalinoides* and *Enterolobium cyclocarpum* hedgerows. There was an increase in soil porosity ($p < 0.05$), rising from 0.38 under control to a maximum of 0.47 under *Pterocarpus*, while soil pH and other chemical properties were highest under *Leucaena leucocephala* and *Gliricidia sepium* hedgerows. Overall, among the tested hedgerow species, *Gliricidia sepium* demonstrated the most substantial improvement in both soil physical and chemical properties.

Sirinivasan *et al*. (2010) investigated the effects on soil physico-chemical and biological properties, at the instructional farm, Kerala Agricultural University, Vellanikkara, of intercropping three fast growing multipurpose trees: safed babool (*Leucaena leucocephala*), halmaddi (*Ailanthus triphysa*), and Whistling pine (*Casuarina equisetifolia*), planted in one-year-old coconut plantations and reported that he addition of the tree components enhanced the soil's organic matter status, available N, P and K content, water holding capacity and infiltration capacity in the coconut plots.

Das *et al*. (2011) initiated an intercropping trial spanning from 2007 to 2010 on a 6-year-old aonla (*Emblica officinalis*) orchard, specifically the cv. NA-7, planted at a spacing of 6 × 6 m in rainfed calciorthent soil. The goal was to identify suitable and profitable intercrops, namely turmeric, ginger and arbi. The study confirmed that aonla-based agri-horticultural systems proved effective in enhancing soil properties, as evidenced by a significant increase in organic carbon (32.4-56.8 per cent), available nitrogen (26.2-37.8 per cent) and phosphorus (22.2-30.8 percent).

Swain *et al*. (2012) undertook an experiment within a mango-based intercropping system to assess the impact of intercropping on soil health in the rainfed uplands of Orissa. The findings indicated a gradual enhancement in the physicochemical properties of the soil due to intercropping systems. Among all intercropping systems, the mango + guava + cowpea combination demonstrated the most significant improvements in bulk density, electrical conductivity, water-holding capacity, organic carbon content, available nitrogen, potassium contents and pH within soil depths (0-15 cm and 15-30 cm). However, available phosphorus reached its peak in the mango + guava + mango ginger system, showing statistical equivalence with the mango + guava + cowpea system.

Sarvade *et al*. (2014) conducted studies to assess the impact of various agroforestry models combining wheat with *Populus deltoides, Eucalyptas camaeldulensis, Leucaena leucocephala,* and *Melia azedarach* tree species on soil properties. Under a poplar-based agrisilviculture system, the highest levels of organic Carbon and available N were observed, while the soil pH and EC levels were significantly reduced. Under the interfaces of Leucaena and Melia, bulk density dropped.

The experiment conducted by Verma *et al*. (2014) integrating Geranium (*Pelargonium graveolens*) with vegetables, cereals, pulses, fodder and eleven different treatment combinations. These combinations included Geranium sole, Geranium + Wheat, Geranium + Barley, Geranium + Oat, Geranium + Berseem, Geranium + Lentil, Geranium + Mustard, Geranium + Cabbage, Geranium + Cauliflower, Geranium + Pea and Geranium + Radish. The results of the studies showed that intercropping geranium-based with cereals, pulses, fodder and vegetables increased soil organic carbon and total kjeldahl nitrogen compared to geranium alone.

Ghimire and Bana (2015) evaluated the effect of different levels of nitrogen (N), phosphorus (P) and potassium (K) on soil physico-bio-chemical properties under various poplar tree densities with mustard intercropping during the winter seasons of 2008-10 at Agroforestry Research Centre, Pantnagar, India. In both years, a lower soil bulk density was observed under the tree canopy compared to the sole crop. However, soil pH, available N and K were not influenced by tree density.

Available soil nitrogen, phosphorous, exchangeable calcium, diethylenetriamine pentaacetate extractable zinc, copper and manganese were significantly higher under Poplar based agroforestry system as compared to sole crop. Higher concentration of nutrients was reported in surface layer *i.e*., 0-15 cm which decreased significantly with successive increase in soil depth. (Uthappa *et al*. 2015). While, available K, exchangeable Mg and available S were not significantly influenced by the tree density classes.

Dhara *et al*. (2015) laid out fruit-based agroforestry systems to identify a suitable agroforestry model in West Bengal, India. The mango trees were planted at a spacing of 10 m × 10 m and *Eucalyptus tereticornis* was planted within the fruit plants at 5m spacing in between two mango rows and at boundary of the field as shelterbelt. The crops *viz*., pigeon pea, black gram, bottle gourd, lady's finger and maize were cultivated during kharif and mustard in rabi season. Results revealed increased profitability and improved soil health in fruit-based agroforestry system. Under mango-based agroforestry system, the models T1: *Eucalyptus tereticornis* + Mango + Pigeon pea and T2: *Eucalyptus tereticornis* + Mango + Black gram showed increase in soil N by 34.3 per cent and 2 per cent, soil P by 35 per cent and 27 per cent, soil K by 18 per cent and 13 per cent, organic C by 29 per cent and 24 per cent, respectively after 2 years.

Swain (2016) conducted an experiment to investigate the impact of various intercropping systems on the plant and soil health of a guava orchard. The guava-based intercropping systems consisted of nine intercrops, including mango, ginger, turmeric, tomato, cowpea, French bean, ragi, ginger, upland paddy and a control group without intercrop. The findings highlighted a significant enhancement in bulk density, electrical conductivity, water-holding capacity, organic carbon content, available nitrogen, potassium and pH of the orchard soil under the guava + cowpea system

Johar *et al*. (2017) conducted a study at the research farm of CCS Haryana Agricultural University in Hisar, India, the impact of a three-tier system (*Eucalyptus*-Kinnow-Wheat) on the wheat production potential recorded that the agroforestry system had a notable impact on soil physical and chemical properties. The study found significant effects on soil organic carbon and electrical conductivity, while no changes were observed in soil pH. Additionally, the soil nutrient status was significantly affected, indicating a notable decrease in nitrogen (N) and potassium (K) concentrations after the wheat crop harvest.

Kaushik *et al*. (2017) conducted a study on soil chemical properties within four agrisilvihorticulture systems. The results revealed the highest available nitrogen (N) content in the Shisham + guava system with cluster bean-barley (155.00 kg ha^{-1}) and the lowest in the Khejri + aonla with pearl millet-oat (100.00 kg ha^{-1}) at the surface soil depth. The study also reported that the available nitrogen (N), phosphorus (P), and potassium (K) content increased under agrisilvihorticulture systems and decreased with increasing soil depth.

Sirohi *et al*. (2017) conducted a study to examine the impact of a Poplar and Wheat agroforestry system on soil chemical properties, including soil pH, electrical conductivity, soil organic carbon and the availability of nitrogen, phosphorus, and potassium. The results revealed that the Poplar-based agroforestry system exhibited higher levels of organic carbon, available nitrogen, phosphorus and potassium compared to those observed under sole Wheat cropping.

Chen *et al*. (2017) investigated various agroforestry models that integrated rubber with cash crops, focusing on soil physico-chemical properties in southwestern China. The study included treatments such as rubber monoculture and four rubber-based agroforestry systems: *Hevea brasiliensis* + *Coffea arabica*, *Hevea brasiliensis* + *Theobroma cacao*, *Hevea brasiliensis* + *Flemingia macrophylla* and *Hevea brasiliensis* + *Dracaena cochinchinensis*. The findings indicated a significant enhancement in soil physical properties and nutrient status under the rubber-based agroforestry systems.

Nawaz *et al*. (2017) conducted a study at Forestry research area, University of Agriculture Faisalabad, Pakistan to observe the effects of trees on the physicochemical properties of soils. Soil samples were collected under each tree species at two depths: 0-15cm and 16-30 cm, to determine the physico-chemical properties of soils such as pH, EC, N, P, K, C and organic matter (O.M.). It was found that nitrogen contents (%) were found the maximum in the soils under *Dalbergia sissoo* (0.063 ± 0.04) > *Acacia nilotica* (0.058 ± 0.008) and *Albizia lebbeck*.

An experiment was conducted by Singh *et al*. (2018) to assess the impact of various agroforestry systems on the physicochemical and biological characteristics of soil. When compared to a solitary agricultural cropping system, the results showed that various agroforestry tree species had a positive impact on the physical, chemical, and biological properties of the soil. The lowest recorded soil bulk density (1.25, 1.27 and 1.28 g cm^{-3}), particle density (2.62, 266 and 2.71 g cm^{-3}) and pH (6.50, 6.90 and 6.80) under *Populus deltoids*, *Anthocephalus cadamba* and *Madhuca indica*-based agroforestry systems, respectively, were found at 0-15, 15-30 and 30-45 cm soil depth. Under *Quercus leucotrichophora*, the highest recorded soil organic carbon content (1.06, 0.90 and 0.84%) was found at soil depths of 0-15, 15-30 and 30-45 cm. Agroforestry systems based on *Quercus leucotrichophora* also had higher levels of nitrogen, phosphorus and potassium.

Sao and Prajapati (2018) explored the nutrient status of soil and wheat crop in the *Ceiba pentandra* agri-silviculture system. Their findings indicated elevated levels of organic carbon and increased availability of nitrogen (N), phosphorus (P) and potassium (K) in the soil under the wheat-*Ceiba pentandra* agroforestry system.

Desta *et al*. (2018) conducted a study to evaluate the effect of *Faidherbia albida* and *Acacia tortilis* on soil physico-chemical properties at Langano and Tuka in farm fields of Bora District, Ethiopia. Mean moisture levels of all sites, 1.35 (14.32%) were significantly ($p < 0.05$)

greater than that of open land (10.79%) at 26.35 m from tree trunk. Bulk density was also significantly affected by tree canopies ($p<0.05$). It increased from 1.20 g cm^{-3} under canopy to 1.29 g cm^{-3} in the open land. At both sites, pH was significantly lower ($p < 0.05$) under the canopy than out of the canopy. Soil organic matter, total nitrogen available phosphorus was significantly higher ($p < 0.05$) under the canopy of trees as compared to open land. Apart from these, the recorded values of exchangeable sodium, potassium and electrical conductivity revealed statistically non-significant difference among the treatments.

Kumar *et al*. (2019) conducted a trial in the experimental area of the Forestry Department, CCS Haryana Agricultural University, Hisar, during 2015-16 to examine the impact of different spatial arrangements (3 m × 3 m, 6 m × 1.5 m and paired row 17 m × 1 m) of eucalyptus within an agroforestry system. The eucalyptus-based system outperformed the sole crop in terms of various soil chemical properties at different soil depths. Among the different spacings, organic carbon was highest under the 3 m × 3 m arrangement. However, soil pH did not exhibit significant changes at various soil depths under eucalyptus plantation. The results indicated an increase in the content of available nitrogen, phosphorus and potassium in the soil with decreasing depth under different spacings of the eucalyptus-based agroforestry system. The highest available soil nitrogen, phosphorus and potassium contents were recorded in the surface soil under the 3 m × 3 m spacing compared to other spacings.

Pralhad *et al*. (2020) conducted an experiment in 2019-20 at Forest College and Research Institute, Mettupalayam, the impact of various agroforestry practices on soil physicochemical properties and microbial activity was assessed. The block plantation tree species comprises *viz*., *Khaya senegalensis*, *Melia dubia*, *Dalbergia sissoo, Populus deltoides*, *Casuarina equositifolia* and Control (Open area) with four different intercrops *viz*., green gram, cowpea, black gram and garden pea. Soil analysis compared to the control revealed trends such as a decrease in soil pH for intercrops, while soil electrical conductivity (EC), organic carbon, available nitrogen, available phosphorus, available potassium and microbial populations showed increasing trends. The combination of *Melia dubia* + black gram (T9) exhibited significantly higher soil fertility status and microbial activity compared to other tree crop combinations. Notably, *Khaya senegalensis* trees alone (T1) had the lowest EC, soil organic carbon, available soil nitrogen, available soil phosphorus and available soil potassium.

In order to assess the impact of the agrisilvihorticultural system on the chemical properties of the soil and the availability of nutrients at varying depths in Hisar, Devi *et al*.

(2020) conducted research from 2017 to 2018. At depths of 0-15, 15-30, 30-60, and 60-90 cm, soil samples were collected from several tree-based agroforestry systems, including kinnow + eucalyptus + wheat, kinnow + wheat, and a control (no tree). The findings showed that, in comparison to the control, the kinnow + eucalyptus + wheat system considerably decreased soil pH and electrical conductivity by 1.5% and 25%, respectively. Furthermore, compared to sole cropping at various depths, the kinnow + eucalyptus + wheat system showed higher organic carbon content and available nutrients (N, P and K). As a result, the authors claimed that tree-based systems improved soil properties, increased the amount of organic matter in the soil, and made nutrients more accessible.

Sharma *et al*. (2022) conducted a winter season experiment in 2016-17 at G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. Different wheat varieties (UP-2526, UP-2565, UP-2628 and DPW-621-50) were cultivated alongside poplar and eucalypts. Following the wheat harvest, soil sampling was carried out to assess parameters such as electrical conductivity, organic carbon, nitrogen, phosphorus and potassium content. These parameters were found to be higher under the agroforestry systems compared to the open wheat farming system. However, the soil pH was higher in the open wheat farming system than in the agroforestry systems. Soil electrical conductivity in the agroforestry system was slightly higher than in the open farming system, whereas organic carbon was more abundant under the poplar-based agroforestry system.

Singh *et al*. (2022) compared the depth wise distribution of physicochemical properties and soil nutrient status under seven land use systems in Hoshiarpur, Punjab, India. The evaluated systems were poplar (*Populus deltoides* Bartr.) + fodder wheat rotation (T1), eucalyptus (*Eucalyptus tereticornis* Smith) + fodder wheat rotation (T2), sole fodder-wheat rotation (T3), poplar + citrus (kinnow) (T4), eucalyptus + citrus (T5), sole citrus (T6) and fallow land (T7). In comparison to T7 (fallow land), tree-based agroforestry systems exhibited significantly lower pH and higher electrical conductivity (EC). Bulk density was higher in subsurface layers than the surface layer. T1 showed the highest available nitrogen (69.2 - 115 kg ha^{-1}) across all soil depths. Additionally, available phosphorus and potassium were 74.3% and 73.6%, respectively, higher in T1 compared to T7 in the surface depth.

2.4 Economic feasibility of the agroforestry system

Bhatt and Misra (2003) conducted a study in the northeast Indian state of Meghalaya, revealing that agri-horticultural agroforestry systems centered around guava and Assam lemon, which involve the combination of domesticated fruit trees and crops, yielded significantly higher net returns. They reported a 2.96 and 1.98 higher net return, respectively, for guava and Assam lemon-based agroforestry systems compared to treeless farmlands. The average net monetary benefit for guava-based agroforestry systems was Rs. 20,610 per hectare, while Assam lemon-based systems yielded Rs. 13,787.60 per hectare. These systems emerged as valuable strategies for improving livelihoods in rainfed agriculture in Meghalaya.

Kareemulla *et al*. (2003) conducted experiments on the aonla + black gram agroforestry system, comparing it to pure aonla and pure black gram under rainfed conditions. Economic analysis, considering costs and returns, payback period, and internal rate of return, revealed favorable results for the aonla + crops system over an 11-year period. The study suggests that opting for agroforestry systems instead of pure grain crops in rainfed areas can lead to higher returns for farmers.

Verma *et al*. (2004) found that net returns from an agrihorticultural system were higher (Rs. 43, 424.14) than the sole crop (Rs. 26, 876.73) when 100 kg of nitrogen per hectare was applied and the productive wheat cultivar HD-2380 was used.

Tomar and Bhatt (2020) carried out an experiment to investigate productivity in a six-year-old plantation of guava (*Psidium guajava* cv. Allahabad safeda), assam lemon (*Citrus lemon* cv. Local) and peach (*Prunus persica* cv. TA 170) with upland rice cultivation in 2002 and 2003 on acid alfisol under rain-fed conditions in Umiam, Meghalaya, Regardless of the rice cultivars used, they discovered that the peach intercropped with rice yielded the highest net financial benefit per hectare on average (Rs 48,044), followed by the guava (Rs 27,887) and the assam lemon (Rs 20,991). Peach, Guava and Assam lemon all had net returns that were 5.09, 2.95 and 2.22 times greater than the control, respectively. For rain-fed agricultural environments, peach-based agroforestry systems were identified to be the most promising.

In the Allahabad district of Uttar Pradesh, India, Lal *et al*. (2005) conducted a field experiment from 1998 to 2003 to ascertain the economic feasibility of an agroforestry-based system. In order to use the interspace in the papaya plantation, the rabi (*Cicer arietinum* and *Vigna mungo*) and kharif (green gram *Vigna radiata*) crops were interplanted. In comparison to traditional cultivation (sole papaya and sole pulse crop), they found that cultivating papaya + crop was relatively more profitable. The cost of the first stage of the plantation was higher than the recurring cost, and the cost of the papaya + crop was higher than the cost of the papaya alone. The agroforestry system under irrigated conditions yielded the highest benefit-cost ratio (3.79) for papaya + crop at discounted prices, followed by sole papaya crop (2.65).

Sharma *et al*. (2008) studied the economics of kinnow based agroforestry system with wheat and gobhi-sarson in Himachal Pradesh. Average yields (q ha^{-1}) of wheat (18.68) and gobhi-sarson (10.34) under kinnow plants were less in comparison to that of wheat (22.34) and gobhi-sarson (12.00) grown in open. However, overall return from agrihorticulture system was higher in comparison to sole crops. Cultivation of gobhi-sarson with kinnow was observed to be more profitable than wheat. The maximum returns per hectare (Rs. 56407.55) were realized under kinnow-gobhi-sarson combination.

Das *et al*. (2011) conducted an intercropping trial in a six-year-old aonla (*Phyllanthus emblica* cv. NA-7) orchard with a spacing of 6 m x 6 m under rainfed conditions. The objective was to identify suitable and profitable intercrops. The economic analysis, considering the benefit-cost ratio, indicated that aonla + turmeric was the most lucrative option (6.29), followed by aonla + ginger (3.44) and aonla + arbi (3.20).

Prakash and Pant (2015) conducted an experiment by intercropping flower crop *Godetia grandiflora* with *Grewia optiva* at Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, H.P. They reported high benefit-cost ratio in agroforestry system compared to pure plantation.

Chauhan *et al*. (2015) carried out investigations on Poplar based agroforestry system in Balachaur, Punjab. Poplar was intercropped with rice and wheat, block plantation of Polar was done. Results revealed highest benefit-cost ratio (3.30) in block planting (1.90) and sole cropping of rice and wheat (1.61).

Kaler *et al*. (2017) conducted an evaluation of existing agroforestry systems in the Kangra district of Himachal Pradesh, India. Their aim was to assess the economic returns from various agroforestry systems during the 2014-15 period. The study involved a survey in which 220 farmers were randomly selected from four groups-marginal, small, medium, and large-based on their landholding capacity. The findings revealed three prevalent agroforestry systems: Agrisilviculture, Agrisilvihorticulture, and Agrihorticulture, adopted by farmers in different categories. The economic analysis indicated higher net returns in Agrisilviculture, particularly among large farmers. Additionally, the benefit-cost ratio was observed to be the highest in the Agrisilvihorticulture category among large farmers.

The tree-crop relationship in the Agrisilvihorticulture system and its economic return were investigated by Verma *et al*. in 2020. *Grewia optiva* + Almond + Wheat showed greater gross returns and net returns than *Morus alba* + Almond + Wheat, according to the results. When comparing the *Grewia optiva* + Almond + Wheat association to the single wheat crop, the increase in net returns was 2.69 times greater, with a 25% higher nitrogen level than the recommended dosage. At this nitrogen level, *Grewia optiva* + Almond + Wheat had higher cost-benefit ratio values than did sole wheat.

Rahman *et al*. (2021) evaluated the performance of radish, sweet gourd, and mustard leaf under a mango fruit tree-based agroforestry system. The aim was to utilize fallow land within mango gardens to boost vegetable production and increase farmers income in char areas of Jamalpur and Sherpur. The findings indicated that radish cultivation in agroforestry systems gives more yield profit compared to the cultivation of other winter vegetables.

Chapter-3

MATERIALS AND METHODS

The present study entitled " **Effect of biofertilizers on growth and yield of black chickpea (*Cicer arietinum* L.) varieties under mango-based agroforestry system** " was carried out at RHRTS, Jachh Distt. Kangra (H.P.) during 2022-2023. The materials used and methodology adopted during the course of investigation has been detailed under the following heads:

3.1 Experimental Site

3.2 Experimental description and methodology

3.3 Layout and statistical analysis

3.1 EXPERIMENTAL SITE

3.1.1 Location

The experimental site lies in Jachh of Kangra district (H.P.) at 32°16'54.02"N latitude, 75°51'4.38" E longitude. The Regional Horticultural Research and Training Station, Jachh is situated on Pathankot -Mandi National Highway (NH-22) at an altitude of 428 m.

3.1.2 Weather and Climate

The site represent the sub-mountain and low hill sub-tropical agro-climatic zone (Zone-I) of Himachal Pradesh. The temperature goes as high as 43.5°C in summer and as low as -0.10°C during winter months. However, the mean summer and winter temperatures average at 29.30°C and 13.60°C, respectively. The mean annual rainfall received by the area is 1500 mm. Mean weekly meteorological data during the crop period have been illustrated graphically in figure 3.1 and illustrated in Appendix-I.

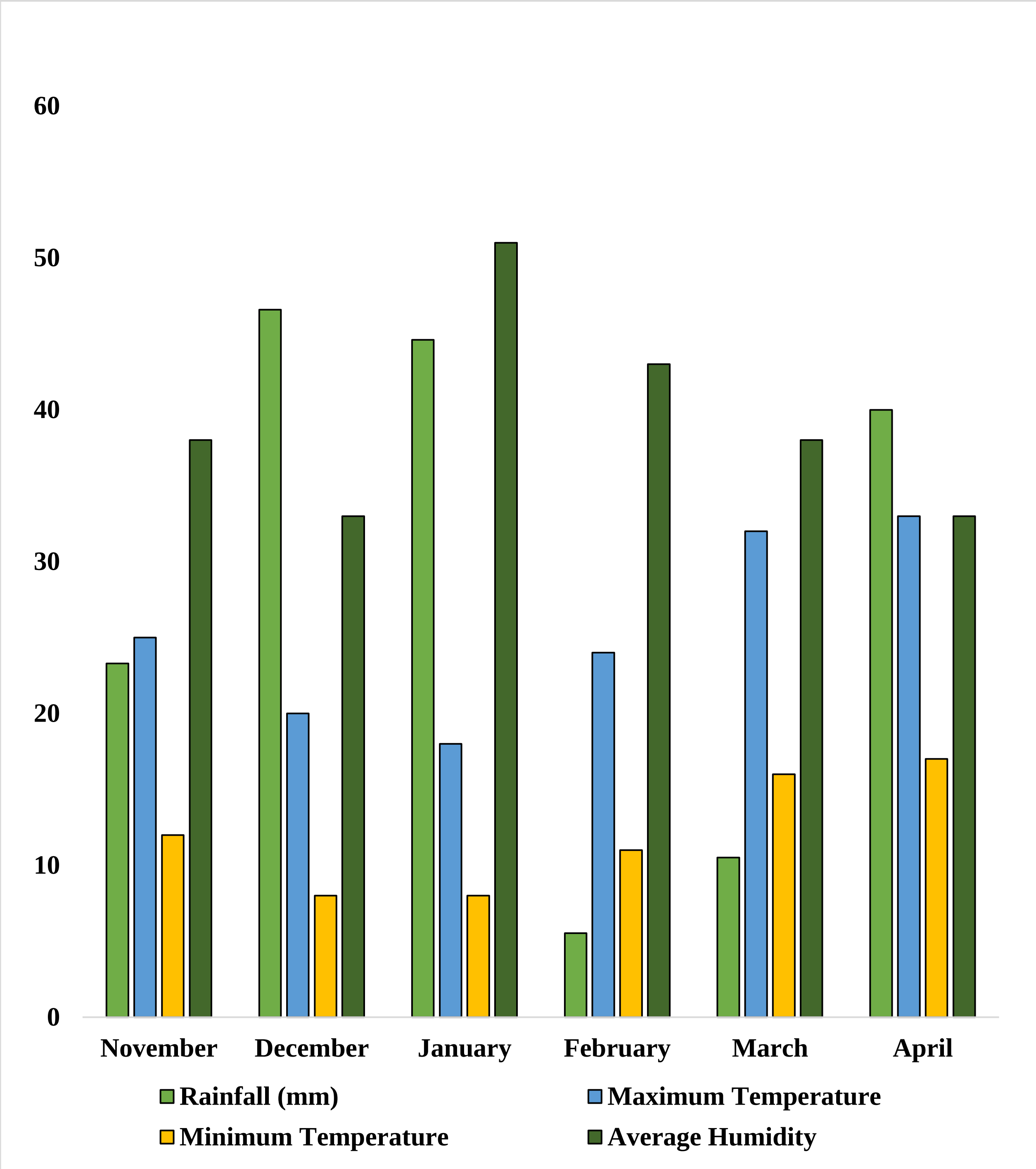

Fig 3.1: Mean monthly meteorological data at Regional Horticultural Research and Training Station, Jachh for the year 2022-2023

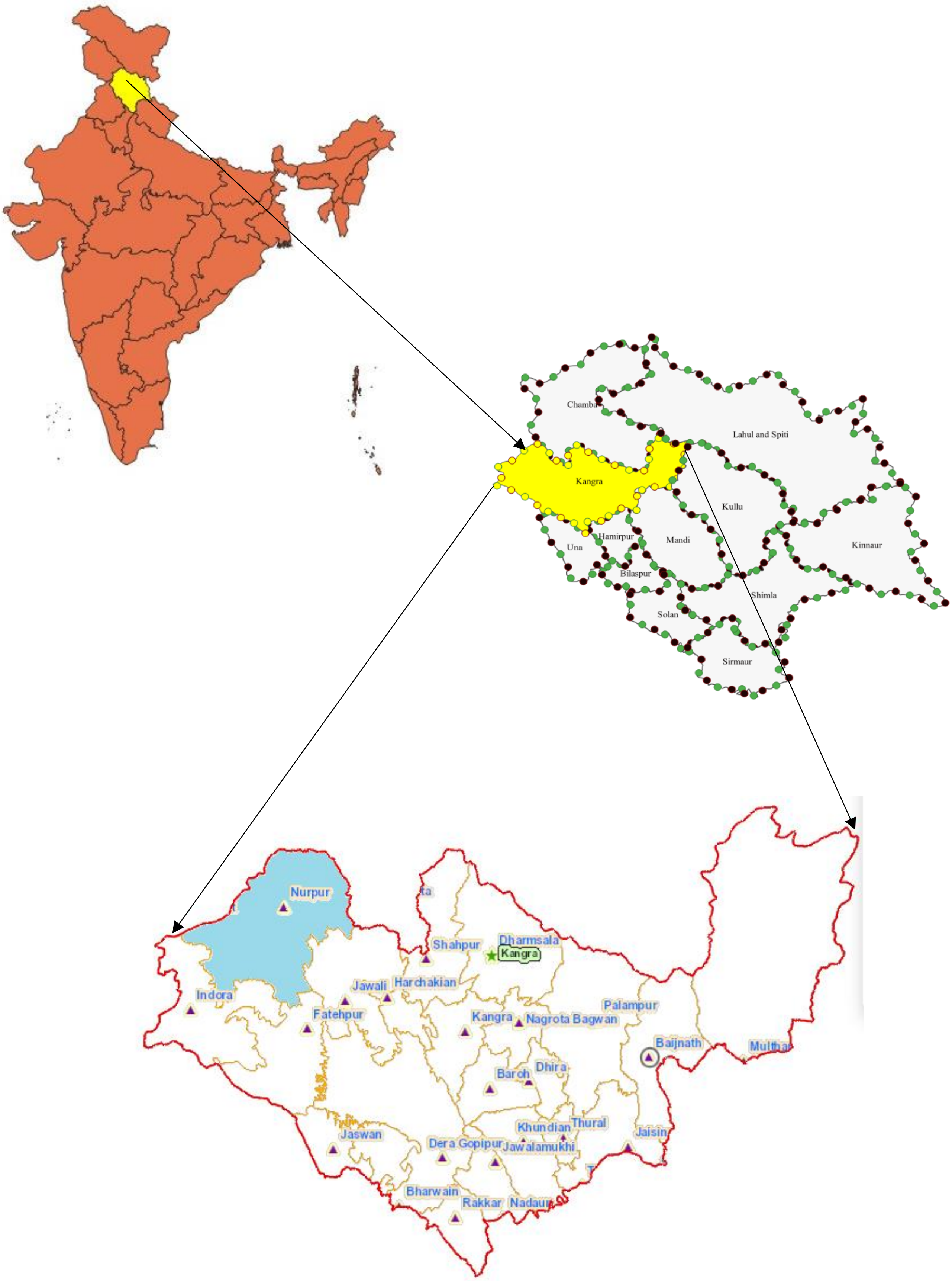

Fig. 3.2: Geographical location of study area

Plate 3.1: *Mangifera indica* + Black Chickpea

Table 3.1: Soil physico-chemical properties of the experimental field before sowing

S. No.	Parameters	With trees	Open (without trees)
1	**Bulk density (g cm^{-3})**	1.24	1.22
2	**Particle density (g cm^{-3})**	2.58	2.53
3	**Porosity (%)**	51.38	51.59
4	**Soil moisture content (%)**	7.52	7.38
5	**Soil pH**	6.88	7.19
6	**EC soil (dS m^{-1})**	0.19	0.24
7	**Organic carbon (%)**	1.29	1.08
8	**Available Nitrogen (kg ha^{-1})**	128.78	125.44
9	**Available Phosphorus (kg ha^{-1})**	11.07	10.68
10	**Available Potassium (kg ha^{-1})**	170.74	165.78

3.2 EXPERIMENTAL DETAILS AND MEHODOLOGY

The experimental details and methodology used are described as below:

3.2.1 Structural and functional components of the agroforestry systems

A. Trees species

Mango (*Mangifera indica*)

Variety : Chanusa/Chausa

Year of planting : 2015

Spacing : 10 m x 8 m

Age of trees : 8 years

B. Agricultural/field crops

Black chickpea (*Cicer arietinum* L.)

Varieties : 1. Him Palam Chana-1(DKG-986)
2. HPG-17
3. PBG-7

Spacing : 1. 30 cm x 10 cm
2. 50 cm x 10 cm
3. 30 cm x 10 cm

Plot Size : 6 m x 3 m

Plot Area : 18 m^2

C. Biofertilizers

1. *Rhizobium*

2. Phosphate solubilizing bacteria (PSB)

D. Biofertilizers treatments (Seed treatment)

Treatments	:	4
T1	:	*Rhizobium*
T2	:	Phosphate solubilizing bacteria (PSB)
T3	:	*Rhizobium* + PSB
T4	:	Control (without biofertilizers)

3.2.2 Treatment Details

Treatments		**Treatment combination**
T1	:	Mango + Him Palam Chana-1 + *Rhizobium*
T2	:	Mango + Him Palam Chana-1 + PSB
T3	:	Mango + Him Palam Chana-1 + *Rhizobium* + PSB
T4	:	Mango + HPG-17 + *Rhizobium*
T5	:	Mango + HPG-17 + PSB
T6	:	Mango + HPG-17 + *Rhizobium* + PSB
T7	:	Mango + PBG-7 + *Rhizobium*
T8	:	Mango + PBG-7 + PSB
T9	:	Mango + PBG-7 + *Rhizobium* + PSB
T10	:	Sole Him Palam Chana-1
T11	:	Sole HPG-17
T12	:	Sole PBG-7
Replications	:	3
Design	:	RBD factorial

*RDF (recommended doses of fertilizers) is common in all treatments.

Table 3.2: Doses of fertilizers applied (kg ha^{-1})

Crop	N	P_2O_5	K_20
Black Chickpea	65	375	50

*N, P and K were applied in the form of urea, single super phosphate (SSP) and muriate of potash (MOP), respectively.

3.2.3 Selection of plants for recording growth and yield parameters

Thirty-six plots of 6 m x 3 m were laid out under tree species intercropped with black chickpea and in sole black chickpea crop area with no biofertilizers application (control). Each plot served as one replication. Five representative plants (agricultural crop) plot^{-1} were selected for recording observations on growth and yield parameters of black chickpea.

A. Observations recorded for Chickpea

i. Plant height (cm)

Plant height was measured in cm from the ground to the tip of the leading shoot using measuring tape. Average of five representative plants selected randomly at 30, 60, 90, 120 DAS and at harvest was worked out and expressed as plant height.

ii. Number of nodules plant^{-1}

Number of nodules plant^{-1} were counted by separating the nodules carefully from the root system after uprooting the five sample plants from each plot after 60 and 90 DAS.

iii. Number of pods plant^{-1}

All the pods of five plants sampling^{-1} plot were counted and averaged to obtain the number of pods plant^{-1}.

iv. Pod length (cm)

Pod length was measured from base to tip of the pod with the help a thread and then thread length was measured with graduated scale and expressed in cm.

v. Number of seeds pod^{-1}

Total numbers of seeds counted from all the pods obtained from five plants were averaged to get number of seeds pod^{-1}.

vi. Seed yield (kg ha^{-1})

At maturity, the representative black chickpea plants in each plot were harvested and threshed to calculate yield plant^{-1} and then seed yield calculated plant^{-1} was multiplied with number of plants ha^{-1} to register seed yield ha^{-1}.

vii. Total chlorophyll content

Chlorophyll was extracted from 100 mg of the sample using 20 ml of 80% acetone. The supernatant was transferred to a volumetric flask after centrifugation at 5000 rpm for 10 minutes. The extraction was repeated until the residue became colorless. The volume in the flask was made up to 100 ml with 80% acetone. The absorbance of the extract was read in a spectrophotometer at 645 and 663 nm against 80% acetone blank. The amount of the chlorophyll content was calculated by using the formula as given below:

$$\textbf{Total chlorophyll (mg g}^{-1}\textbf{ Fresh Weight)} = 20.2(A645) + 8.02(A663) \times \frac{V}{1000 \times W}$$

where, V= Final volume of the extract, W= Fresh weight of the leaves, A= Absorbance at the specific wavelength. The value is expressed as the mg g^{-1} fresh weight.

viii. Biomass plant^{-1} (q ha^{-1})

The average weight of the plants (oven dried at 70°C till a constant weight was achieved) obtained from five plants was averaged to get biomass plant^{-1}.

ix. Above ground biomass (q ha^{-1})

Above ground biomass of crop calculated plant^{-1} (five representative plants from each plot) was multiplied with number of plants ha^{-1} to register above ground biomass of crop ha^{-1}.

x. Below ground biomass (q ha^{-1})

Below ground biomass of crop calculated plant^{-1} (five representative plants from each plot) was multiplied with number of plants ha^{-1} to register below ground biomass of crop ha^{-1}.

xi. Total plant biomass (q ha^{-1})

Total plant biomass calculated by adding plant biomass and root biomass.

Total plant biomass = Above ground biomass + Below ground biomass

3.2.5 Observation recorded for tree

i. Tree height (m)

Tree height from base to tip of the leading shoot was measured with the help of wooden rod and expressed in meters.

ii. Tree diameter (cm)

Tree diameter was measured in cm at 20 cm above the ground level with the help of tree calliper.

iii. Crown spread (m)

The crown spread was measured in meters by holding tape beneath the canopy of the tree at points vertically under the tips of most extending branches from east to west and north to south directions. The average of the two was taken as crown spread.

$$CS = (D1+D2)/2$$

where,

CS = Crown Spread

D1 = Crown Spread in N-S direction (m)

D2 = Crown Spread in E-W direction (m)

iv. Fruit size (cm)

Fruit size was recorded with the help of scale by averaging lengths from north to south and east to west direction.

v. Fruit yield (kg tree^{-1})

Fruit yield was recorded by weighing total number of fruits tree^{-1} and expressed in 'kg'.

3.2.6 Soil parameters

Collection and preparation of soil samples

Representative soil samples from each sampling unit at 0-15 cm depth were collected separately with the help of post hole auger. The collected samples were put in cloth bags, tagged and transported to laboratory. These were then air dried, crushed thoroughly, passed through 2 mm plastic sieve and analyzed for various soil parameters listed below;

i. Bulk density (g cm^{-3})

Bulk density was measured with the help of Pycnometer method (Chopra and Kanwar, 2011).

ii. Particle density (g cm^{-3})

Particle density was measured with the help of Pycnometer method (Gupta and Dhakshinamoorthy, 1980).

iii. Porosity (%)

Porosity was measured with the help of Empirical method (Gupta and Dhakshinamoorthy, 1980).

iv. Soil moisture content (%)

Soil moisture content measured with the help of Gravimetric method (Reynolds, 1970).

v. Soil pH

Soil pH was measured with the help Potentiometric method (Jackson, 1973).

vi. Organic Carbon (%)

Soil organic carbon was determined with the help of rapid titration method (Walkley and Black, 1934).

vii. Electrical conductivity (dS m^{-1})

The electrical conductivity was measured with the help of Conductimetric method (Jackson, 1973).

viii. Available nitrogen (kg ha^{-1})

Available nitrogen was determined with the help of Alkaline potassium permanganate method (Subbiah and Asija, 1956).

ix. Available phosphorus (kg ha^{-1})

Available phosphorus was determined with the help of Olsen's method (Olsen *et al.* (1954)

x. Available potassium (kg ha^{-1})

Available potassium was determined with the help of Ammonium acetate method (Merwin and Peech, 1951).

3.2.7 Economic feasibility analysis

i. Total expenditure (Rs. ha^{-1})

The cost of cultivation of different field crops and harvest of its produce was worked out on the basis of net cropped area hectare^{-1}. The requirements of labor and mechanical power for different operations such as ploughing, harrowing, weeding and harvesting were calculated hectare^{-1} as per the rates prevalent at Experimental Farm. Cost of inputs such as seeds, farm yard manure and pesticides were calculated based on the actual amounts applied to the land use system. Similarly, cost of cultivation of tree (*Mangifera indica*) and harvest of its produce was computed with respect to variable cost involved in raising of tree rows at three different spacing on hectare^{-1} basis.

ii. Gross returns (Rs. ha^{-1})

Gross returns (Rs. ha^{-1}) were worked out by converting the economic yield of crop *i.e.*, seed yield of chickpea into monetary terms on the basis of prevailing university prices.

iii. Net returns (Rs. ha^{-1})

Net returns were worked out by subtracting the cost of cultivation (total expenditure) from the gross return of the respective treatment and expressed as net returns in (Rs. ha^{-1}).

Net returns (Rs. ha^{-1}) = Gross returns (Rs. ha^{-1}) – cost of cultivation (Rs. ha^{-1})

iv. Benefit-Cost Ratio

Ratio of the gross returns rupee^{-1} invested was calculated as per following formula:

BCR= Gross returns/Total cost of cultivation

3.3 STATISTICAL ANALYSIS

The data originated from the present studies were statistically analyzed by employing analysis of variance (ANOVA) for 02 factorial Randomized Block Design (FRBD) in accordance with the procedure suggested by Gomez and Gomez (1984).

Table 3.3: Skeleton for analysis of variance (ANOVA)

Source of variation	**Degrees of freedom**	**Sum of squares**	**Mean sum of squares**	**Fcal**
Replication	(r-1)	SSR	SSR/ (r-1)=MSR	MSR/MSE
Variety	(D-1)	SSD	SSD/(D-1) =MSR	MSD/MSE
Biofertilizers	(d-1)	SSd	SSd(d-1) = MSd	MSd/MSE
Interaction	(D-1)(d-1)	SSI	SSI/(D-1)(d-1)=MSI	MSI/MSE
Error	Dd(r-1)	SSE	SSE/Dd(r-1) = MSE	
Total	(Ddr-1)	SST		

*r=Number of replications, D=Varieties, d=Biofertilizers.

Chapter-4

RESULTS AND DISCUSSION

The present investigations entitled, "**Effect of biofertilizers on growth and yield of black chickpea (*Cicer arietinum* L.) varieties under mango-based agroforestry system**" was conducted at Regional Horticultural Research & Training Station, Jachh of Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during year 2022-2023. The results obtained during the course of study are presented in this chapter under the following heads:

4.1 Effect of biofertilizers on growth and yield of black chickpea varieties grown under agroforestry system

4.2 Correlation analysis between growth and yield parameter of black chickpea varieties under mango-based agroforestry system

4.3 Growth and yield parameters of Mango tree (*Mangifera indica*)

4.4 Soil properties under mango-based agroforestry system compared to control

4.5 Bio-economics of mango-based agroforestry systems

4.1 Effect of biofertilizers on growth and yield parameters of black chickpea grown under agroforestry and in control

4.1.1 Plant height (cm)

The data in table 4.1, 4.2, 4.3 and fig. 4.1 depicts, that biofertilizers had shown positive and significant effect on chickpea plant growth, recorded at 30, 60,90,120 DAS and at harvest. At 30 DAS (table 4.1), the critical examination of data pertaining to the plant height reveals that there was significant variation in plant height among varieties and biofertilizers application under mango-based agroforestry system. However, the interaction (varieties x biofertilizers) was found to be non-significant.

Under different treatments, the maximum (14.38 cm) plant height was observed in T6 (Mango + HPG-17 + *Rh* + PSB) and the minimum (9.17 cm) was observed in T10 (Sole Him Palam Chana-1). Among three black chickpea varieties the significantly higher (12.40 cm) plant height was recorded for V2 (HPG-17), followed by V3 (PBG-7) at 11.58 cm, and lowest (10.28 cm) was recorded for V1(Him Palam Chana-1). Among biofertilizers application on chickpea varieties, the maximum (13.34 cm) growth was recorded for the combined application of biofertilizers (*Rh* + PSB), whereas the minimum (10.33 cm) growth was recorded in the control.

Similarly at 60 DAS (table 4.1 and fig. 4.1), among different treatments, the maximum plant height of 26.71 cm was observed in T6 (Mango + HPG-17 + *Rh* + PSB) and minimum plant height of 17.62 cm was observed in T10 (Sole Him Palam Chana-1). Among three black chickpea varieties the significantly highest (24.42 cm) plant height was recorded for V2 (HPG-17), followed by V3(PBG-7) at 20.93 cm, and lowest (19.40 cm) height was recorded for V1 (Him Palam Chana-1). Among the biofertilizers application on chickpea varieties, the maximum (23.99 cm) plant height was reported for the combined application of biofertilizers (*Rh* + PSB), whereas the minimum (19.61 cm) plant height was obtained in the control.

Table 4.1: Effect of biofertilizers on height of black chickpea grown under mango-based agroforestry system at 30 DAS and 60 DAS

Plant height (30 DAS)						Plant height (60 DAS)			
Treatments		**Varieties**			**Mean**	**Varieties**			**Mean**
		V_1	**V_2**	**V_3**		**V_1**	**V_2**	**V_3**	
Mango	***Rhizobium***	10.28	12.22	11.55	**11.35**	19.71	24.81	21.61	**22.04**
	PSB	9.60	11.69	10.69	**10.66**	18.54	23.61	19.94	**20.70**
	***Rh* + PSB**	12.07	14.38	13.58	**13.34**	21.71	26.71	23.54	**23.99**
	Control	9.17	11.32	10.51	**10.33**	17.62	22.56	18.65	**19.61**
	Mean	**10.28**	**12.40**	**11.58**		**19.40**	**24.42**	**20.93**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.74	0.35	0.25		0.67	0.32	0.23	
Biofertilizers (B)		0.85	0.41	0.29		0.78	0.37	0.26	
V x B		NS	0.71	0.50		NS	0.64	0.46	

At 90 DAS, the perusal of data in table 4.2 and fig 4.1 revealed that, across various treatments, the highest plant height (35.39 cm) was observed in T6 (Mango + HPG-17 + *Rh* + PSB), while the lowest (27.93 cm) was observed in T10 (Sole Him Palam Chana-1). Among the three black chickpea varieties, V2 (HPG-17) exhibited significantly higher plant height (33.23 cm), followed by V3 (PBG-7) at 31.59 cm, whereas V1 (Him Palam Chana-1) attained lowest height of 29.47 cm. Biofertilizers showed positive and significant effect on chickpea plant height. Among biofertilizers application, the maximum plant height (33.53 cm) was

reported due to combined application of biofertilizers (*Rh* + PSB), while the minimum (29.86 cm) plant height was observed in the control.

The data in table 4.2 and fig. 4.1, at 120DAS, revealed that the maximum plant height (45.70 cm) was observed in T6 (Mango + HPG-17 + *Rh* + PSB), while the lowest (36.73 cm) was noted in T10 (Sole Him Palam Chana-1). Among the three black chickpea varieties, V2 (HPG-17) exhibited significantly higher plant height (43.30 cm), followed by V3 (PBG-7) at 41.39 cm and V1 (Him Palam Chana-1) recorded lowest (38.45 cm) plant height. Plant height of chickpea varieties was maximum (43.30 cm) when combined application of biofertilizers (*Rh* + PSB) was applied, whereas the minimum (39.29 cm) was recorded in the control.

Table 4.2: Effect of biofertilizers on height of black chickpea grown under mango-based agroforestry system at 90 DAS and 120 DAS

Plant height (90 DAS)						Plant height (120 DAS)			
Treatments		**Varieties**			**Mean**	**Varieties**			**Mean**
		V_1	**V_2**	**V_3**		**V_1**	**V_2**	**V_3**	
Mango	***Rhizobium***	29.82	33.14	32.02	**31.66**	38.70	43.55	41.70	**41.31**
	PSB	28.58	32.62	30.85	**30.68**	37.60	42.33	40.58	**40.17**
	***Rh* + PSB**	31.56	35.39	33.63	**33.53**	40.76	45.70	43.75	**43.40**
	Control	27.93	31.76	29.88	**29.86**	36.73	41.62	39.52	**39.29**
	Mean	**29.47**	**33.23**	**31.59**		**38.45**	**43.30**	**41.39**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.82	0.39	0.28		0.68	0.33	0.23	
Biofertilizers (B)		0.95	0.45	0.32		0.79	0.38	0.27	
V x B		NS	0.79	0.56		NS	0.65	0.46	

The data from table 4.3 and fig. 4.1 revealed that the plant height at harvest (150 DAS), showed significant variation only among varieties and biofertilizers application, whereas the interaction was non-significant. The highest plant height of 53.30 cm was observed in T6 (Mango + HPG-17 + *Rh* + PSB), while the lowest (44.56 cm) was observed in T10 (Sole Him Palam Chana-1). Among the three black chickpea varieties, V2 (HPG-17) exhibited significantly higher plant height of 51.65 cm, followed by V3 (PBG-7) with 48.37 cm tall plant and V1 (Him Palam Chana-1) recorded lowest plant height of 46.48 cm. The effect of biofertilizers on chickpea varieties showed that the maximum plant height of 50.95 cm due to combined application of biofertilizers (*Rh* + PSB), whereas the minimum plant height of 46.90 cm was observed in the control.

Table 4.3: Effect of biofertilizers on height of black chickpea grown under mango-based agroforestry system at harvest

Plant height (at harvest)					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	46.92	51.76	48.81	**49.16**
	PSB	45.52	50.75	47.50	**47.93**
	***Rh* +PSB**	48.91	53.30	50.63	**50.95**
	Control	44.56	49.59	46.55	**46.90**
	Mean	**46.48**	**51.35**	**48.37**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.76	0.36	0.26	
Biofertilizers (B)		0.87	0.42	0.30	
V x B		NS	0.72	0.51	

The application of biofertilizer significantly enhanced the plant height. The maximum plant height for the three varieties was recorded when the *Rhizobium* and PSB were applied together. The combination of biofertilizers (*Rhizobium* and PSB) and RDF 100% enhanced the nutrient availability and encourage the plant height. The biofertilizer inoculation increased the nitrogen, phosphorus and all other major nutrient which enhanced the vegetative growth and thus the plant height. Moreover, growth promoting substances (phytohormones) are produced by these microorganisms which further promote plant growth. Similar results were also reported by Rabieyan *et al*. (2011), Beg and Singh (2009), Singh *et al*. (2013) and Yadav *et al*. (2021). Bacteria are able to promote plant growth by establishing symbiotic association with plant or as free-living entities. Rhizobia are a unique group of bacterial symbionts of legumes that fix inert elemental atmospheric nitrogen. Among all the N_2 fixing micro-organisms, symbiotic relationships between legumes and rhizobia are responsible for the largest contributions of fixed N to farming systems. Furthermore, it has also been reported that rhizobial strains promote plant growth through other mechanisms such as phosphate solubilisation ability in some legumes (Singh and Singh, 2018).

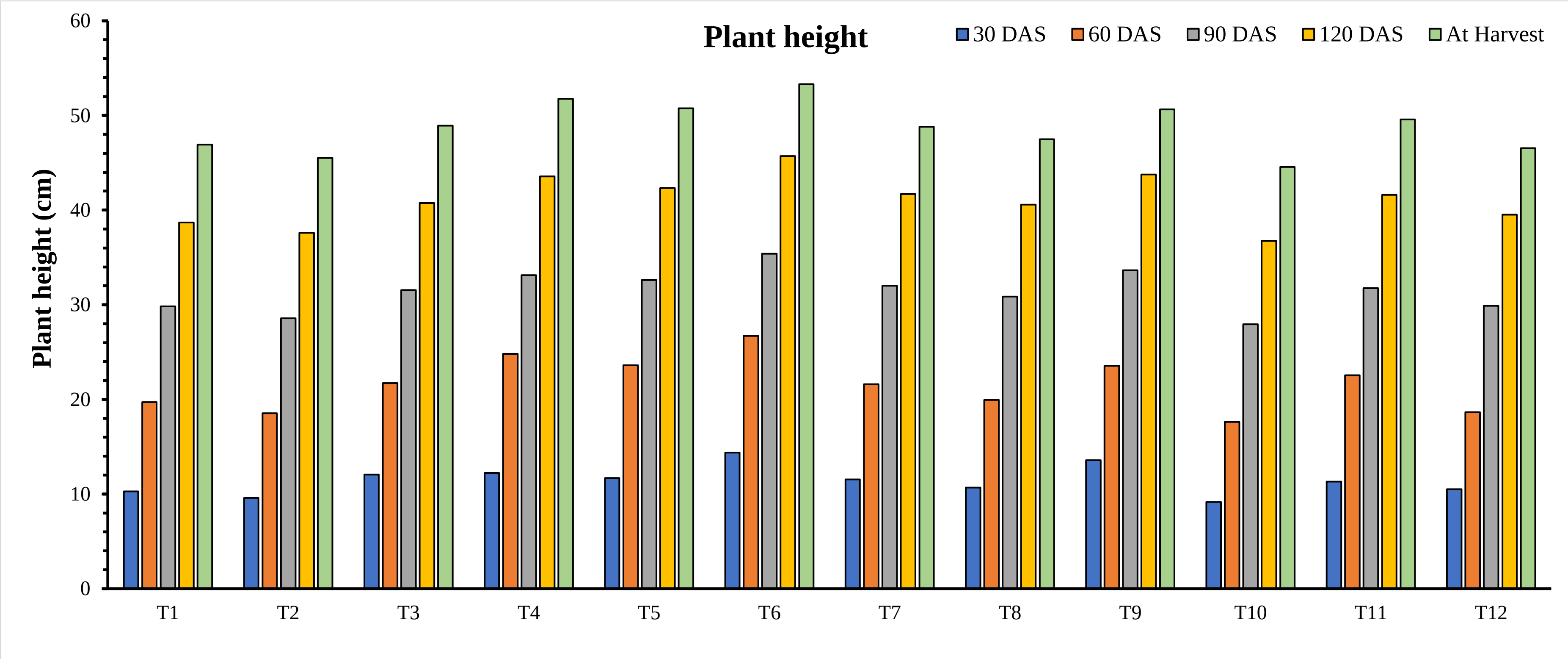

Fig 4.1: Plant height of black chickpea at 30 DAS, 60DAS, 90DAS, 120DAS and at harvest under mango-based agroforestry system in response to different biofertilizers treatments

4.1.2 Number of nodules plant^{-1}

The studies with regard to the root nodules were conducted at 60 and 90 days after sowing. The data pertaining to nodulation and impact of biofertilizers among different chickpea varieties is shown in table 4.4 and fig. 4.2. The table data indicates the significant variations in root nodule count of chickpea varieties and biofertilizers application. However, the statistical analysis indicates that the interaction between chickpea varieties and biofertilizers application was not found to be statistically significant.

At 60 DAS, among various treatments, the highest (13.92) number of root nodules plant^{-1} were observed in T6 (Mango + HPG-17 + *Rh* + PSB), while the lowest (8.42) were observed in T10 (Sole Him Palam Chana-1). Among black chickpea varieties, V2 (HPG-17) exhibited significantly highest (11.60) root nodules plant^{-1}, followed by V3 (PBG-7) with 11.04 root nodules plant^{-1} and V1 (Him Palam Chana-1) recorded lower (10.35) root nodules plant^{-1}. The maximum of 13.38 root nodule plant^{-1} were reported for the combined application of biofertilizers (*Rh* + PSB), whereas the minimum of 9.12 root nodule plant^{-1} were observed in the control.

Similarly, at 90 DAS, within the various treatments, the highest (20.73) number of root nodules plant^{-1} were recorded in T6 (Mango + HPG-17 + *Rh* + PSB), and the lowest number of root nodules plant^{-1} (13.38) were in T10 (Sole Him Palam Chana-1). Among the three black chickpea varieties, V2 (HPG-17) exhibited a significantly higher count (17.77) of root nodules plant^{-1}, followed by V3 (PBG-7) with 17.33 root nodules plant^{-1}, while V1 (Him Palam Chana-1) recorded a lower count (16.52) of root nodules plant^{-1}. The maximum count of 20.17 root nodules plant^{-1} was reported for the combined application of biofertilizers (*Rh* + PSB), whereas the minimum count of 14.20 root nodules plant^{-1} was observed in the control.

The application of biofertilizer *viz. Rhizobium* and PSB increased the number of nodules considerably in comparison to control. The inoculation of rhizobium and PSB enhance the microbial population in legume crop and form higher number of nodules plant^{-1}. The activity of microorganism increased in legumes crop due to rhizobium and PSB and this inoculation of Rhizobium and PSB increased the number of nodules plant^{-1}. It is also due to the fact that phosphate solubilizing bacteria by virtue of their property of producing organic acids solubilize insoluble or fixed form of phosphorus in the rhizosphere and make it available to the growing plants, which promotes root development in plants. The increase in nodulation was highest in the combination of *Rhizobium* and PSB. Similar results are also reported by

Tagore *et al.* (2014), Verma (2014), Singh *et al.* (2018), Yadav *et al.* (2021) and Singh *et al.* (2021).

Table 4.4: Effect of biofertilizers on number of root nodules of black chickpea grown under mango-based agroforestry system

		No. of nodules (60 DAS)				No. of nodules (90 DAS)			
Treatments		Varieties			Mean	Varieties			Mean
		V_1	V_2	V_3		V_1	V_2	V_3	
Mango	***Rhizobium***	10.83	11.92	11.48	**11.41**	17.36	18.53	18.22	**18.04**
	PSB	9.41	10.60	10.24	**10.08**	15.87	16.76	16.61	**16.41**
	***Rh* + PSB**	12.76	13.92	13.46	**13.38**	19.46	20.73	20.32	**20.17**
Control		8.42	9.95	9.00	**9.12**	13.38	15.05	14.17	**14.20**
	Mean	**10.35**	**11.60**	**11.04**		**16.52**	**17.77**	**17.33**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.77	0.37	0.26		0.74	0.36	0.25	
Biofertilizers (B)		0.89	0.43	0.30		0.86	0.41	0.29	
V x B		NS	0.74	0.53		NS	0.71	0.50	

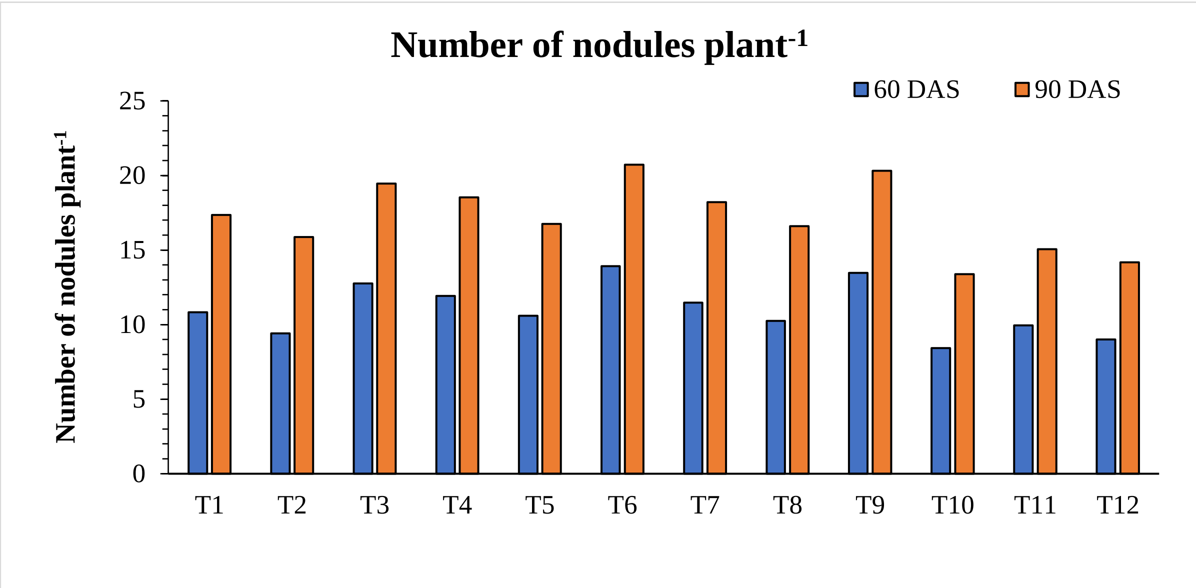

Fig 4.2: Number of root nodules plant^{-1} in black chickpea at 30 DAS and 60 DAS grown under mango-based agroforestry system in response to biofertilizers application

4.1.3 Total chlorophyll content (mg g^{-1})

Total chlorophyll content was measured at 60 and 90 days after sowing. The data concerning total chlorophyll content in the leaves of black chickpea varieties under mango-based agroforestry systems as affected by biofertilizers application, is outlined in table 4.5 and fig. 4.3. The table data indicates significant variations in chlorophyll content of chickpea leaves across varieties and biofertilizers and their interaction.

At 60 DAS, among various treatments, the highest amount of leaf chlorophyll content (2.16 mg g^{-1}) was observed in T6 (Mango + HPG-17 + *Rh* + PSB), while the lowest (1.50 mg g^{-1}) was in T10 (Sole Him Palam Chana-1). Among the three black chickpea varieties, V2 (HPG-17) exhibited significantly highest (1.90 mg g^{-1}) leaf chlorophyll content, followed by V3 (PBG-7) with 1.81 mg g^{-1} and V1 (Him Palam Chana-1) recorded lowest (1.74 mg g^{-1}) amount leaf chlorophyll content. Within the mango-based agroforestry system under study, among the biofertilizers application on chickpea varieties, the maximum amount of leaf chlorophyll content (2.10 mg g^{-1}) was reported in combined application of biofertilizers (*Rh* + PSB), while the minimum (1.65 mg g^{-1}) amount of leaf chlorophyll content was observed in control.

At 90 DAS, within treatments, the highest (2.58 mg g^{-1}) amount of leaf chlorophyll content was observed in T6 (Mango + HPG-17 + *Rh* + PSB), while the lowest (1.96 mg g^{-1}) was observed in T10 (Sole Him Palam Chana-1). Among the three black chickpea varieties, V2 (HPG-17) exhibited significantly higher (2.40 mg g^{-1}) leaf chlorophyll content, followed by V3 (PBG-7) at 2.24 mg g^{-1} and V1 (Him Palam Chana-1) recorded lowest (2.06 mg g^{-1}) amount leaf chlorophyll content. Within the mango-based agroforestry system under study, among the biofertilizers application on chickpea varieties, the maximum (2.34 mg g^{-1}) amount of leaf chlorophyll content was due to combined application of biofertilizers, while the minimum (2.13 mg g^{-1}) amount of leaf chlorophyll content was observed in control.

Nitrogen is essential for the formation of chlorophyll and there is generally a significant correlation between them. Combined biofertilizers application (*Rh* + PSB) increased the level of essential nutrients in the soil through fixation. *Rhizobium* through N_2 fixation and its symbiotic relationship with black chickpea fixed the atmospheric nitrogen and increased the concentration of nitrogen in soil which results in the increase in the total chlorophyll content in the leaves of black chickpea varieties. Chlorophyll content of leaf tissue is a good index of photosynthetic activity and is a crucial pigment which plays an important role as an index of plant growth (Shinde *et al.,* 2021). It is evident from the data that total chlorophyll content was higher in chickpea leaves raised under agroforestry system by the combined application of biofertilizers as compared to control. Arumugam *et al.* (2009), Bejandi *et al.* (2012) and Shinde *et al.* (2021) also recorded higher chlorophyll content by the combined application of biofertilizers.

Table 4.5: Effect of biofertilizers on total chlorophyll content of black chickpea leaves grown under mango-based agroforestry system

Chlorophyll content (60 DAS)						Chlorophyll content (90 DAS)			
Treatments		**Varieties**			**Mean**	**Varieties**			**Mean**
		V_1	**V_2**	**V_3**		**V_1**	**V_2**	**V_3**	
Mango	***Rhizobium***	1.70	1.85	1.82	**1.79**	2.12	2.46	2.26	**2.28**
	PSB	1.65	1.81	1.73	**1.73**	2.01	2.33	2.20	**2.18**
	***Rh* + PSB**	1.88	2.16	2.02	**2.10**	2.14	2.58	2.31	**2.34**
	Control	1.50	1.79	1.67	**1.65**	1.96	2.24	2.19	**2.13**
	Mean	**1.74**	**1.90**	**1.81**		**2.06**	**2.40**	**2.24**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.04	0.02	0.01		0.04	0.02	0.02	
Biofertilizers (B)		0.05	0.02	0.02		0.05	0.02	0.02	
V x B		0.08	0.04	0.03		0.09	0.04	0.03	

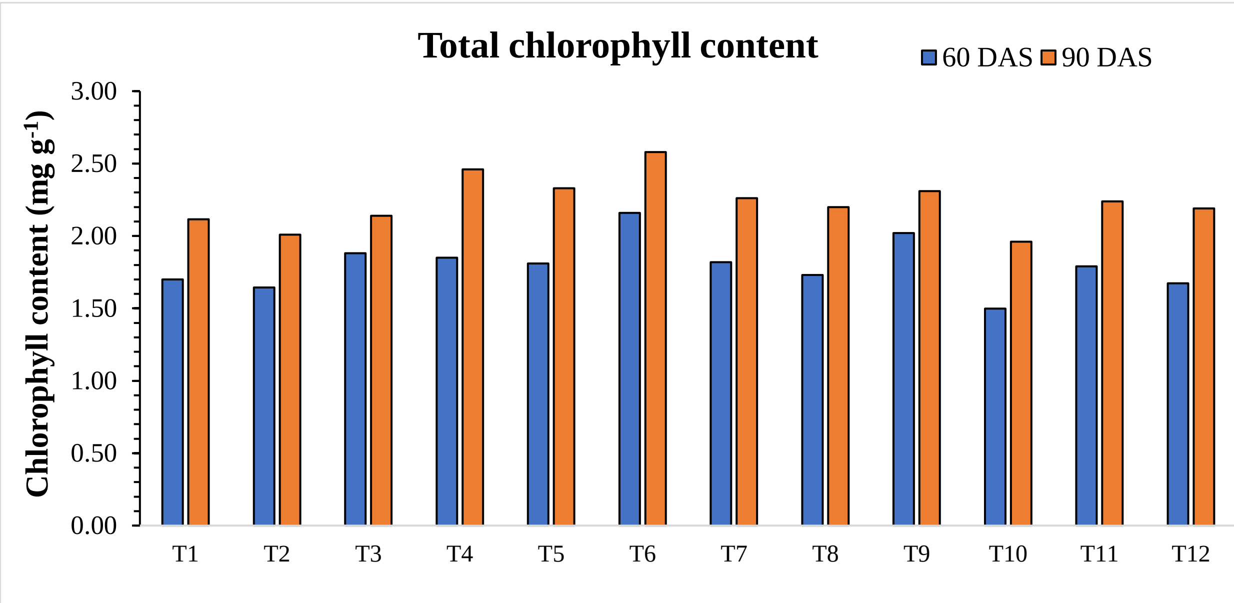

Fig 4.3: Total chlorophyll content of black chickpea leaves at 60 DAS and 90 DAS grown under mango-based agroforestry system in response to biofertilizers application

4.1.4 Number of pods plant^{-1}

A perusal of the data presented in table 4.6 and fig. 4.4 reveals that the number of pods plant^{-1} were affected by biofertilizers application in the mango-based agroforestry system under study. However, the interaction between variety and biofertilizers did not achieve statistical significance.

The value in fig 4.4 reveals that, the maximum count of pods plant^{-1} (38.43) was observed for T6 (Mango + HPG-17 + *Rh* + PSB), with the lowest count (22.65) recorded for T10 (Sole Him Palam Chana-1). The data in table 4.7 reveals that among the black chickpea varieties, V2 (HPG-17) recorded a significantly highest count of pods plant^{-1} (36.00), followed by V3 (PBG-7) at 32.73, whereas V1 (Him Palam Chana-1) exhibited a significantly lowest count (25.71) of pods plant^{-1}. In the studied mango-based agroforestry system, among the application of biofertilizers on chickpea varieties, the maximum count of pods plant^{-1} (34.36) was reported for the combined application of biofertilizers (*Rh* + PSB), whereas the minimum count of pods plant^{-1} (28.49) was obtained in the control.

The *rhizobium* and PSB application together increased the nitrogen and phosphorous availability in the soil which further affect the flowering, fruiting and pod formation which results in better growth parameters. The maximum number of pods plant^{-1}, treatment under dual inoculation of seed with Rhizobium and PSB in mango-based agroforestry system. When sufficient amount of nitrogen, phosphorus and all other major nutrient provided to the plant they increased the growth parameter which increases the number of seed pod^{-1} and number of pods plant^{-1}. Similar results are also reported by Zaman *et al.* (2011), Yasari *et al.* (2007), Verma (2014), Singh *et al.* (2021) and Yadav *et al.* (2021).

Table 4.6: Effect of biofertilizers on number of pods plant^{-1} of black chickpea grown under mango-based agroforestry system

No. of pods plant^{-1}					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	26.40	37.11	33.53	**32.35**
	PSB	24.83	35.42	31.94	**30.73**
	***Rh* +PSB**	28.95	38.43	35.70	**34.36**
	Control	22.65	33.06	29.75	**28.49**
	Mean	**25.71**	**36.00**	**32.73**	
Factors		**C.D. at 5%**	**SE(d)**	**SE(m)**	
Variety (V)		1.45	0.69	0.49	
Biofertilizers (B)		1.67	0.80	0.57	
V x B		NS	1.39	0.98	

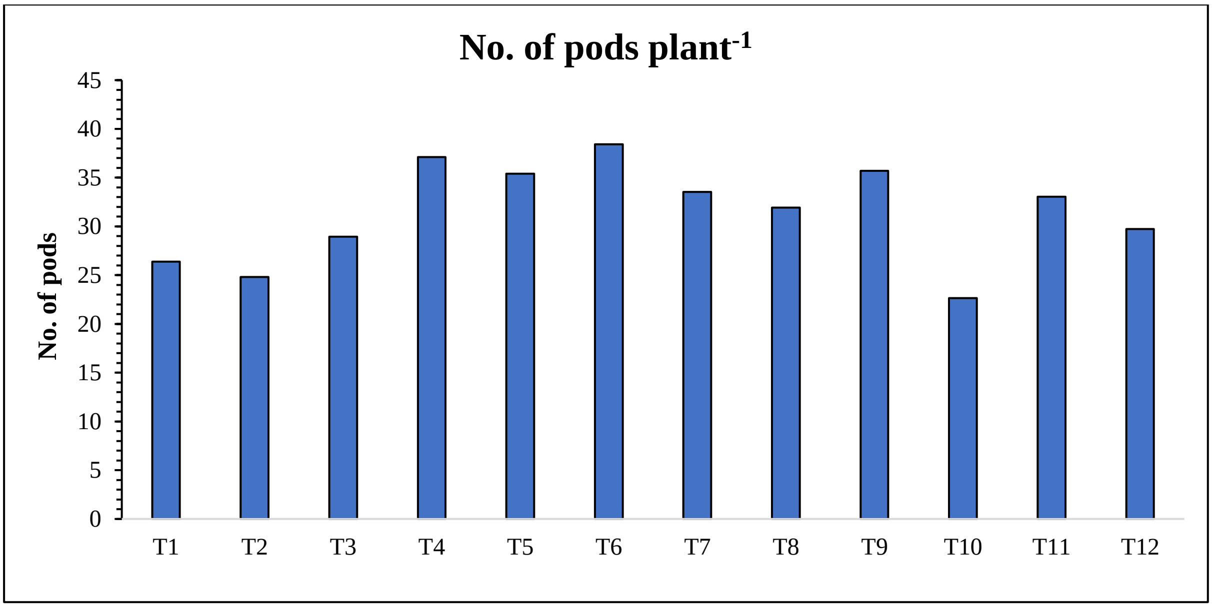

Fig 4.4: Number of pods plant^{-1} of black chickpea grown under mango-based agroforestry system in response to biofertilizers application

4.1.5 Pod length (cm)

Data regarding pod length of various black chickpea varieties as affected by biofertilizers is presented in table 4.7 and fig 4.5. The tabulated data reveals variations in pod length among chickpea varieties subjected to different biofertilizers, however, the interaction between chickpea varieties and biofertilizers did not achieve statistical significance.

Within the treatments, the highest pod length (2.25 cm) was observed for T6 (Mango + HPG-17 + *Rh* + PSB), however the lowest pod length (1.75 cm) was due to treatment T10 (Sole Him Palam Chana-1). Among the three black chickpea varieties, V2 (HPG-17) demonstrated significantly maximum pod length of 2.09 cm, followed by V3 (PBG-7) at 1.85 cm, whereas V1 (Him Palam Chana-1) exhibited significantly smallest pod length of 1.79 cm. Overall the biofertilizers showed positive impact on the pod length and among biofertilizer application, the maximum pod length of 2.03 cm was reported for the combined application of biofertilizers (*Rh* + PSB), whereas the minimum pod length of 1.80 cm was reported in the control.

Table 4.7: Effect of biofertilizers on pod length of black chickpea grown under mango-based agroforestry system

Pod length (cm)					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	1.80	2.10	1.85	**1.92**
	PSB	1.70	2.03	1.80	**1.84**
	***Rh* + PSB**	1.90	2.25	1.95	**2.03**
	Control	1.75	1.97	1.80	**1.80**
	Mean	**1.79**	**2.09**	**1.85**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.05	0.02	0.02	
Biofertilizers (B)		0.05	0.03	0.02	
V x B		NS	0.04	0.03	

4.1.6 Number of seeds pod^{-1}

The data on the number of seeds pod^{-1} for various black chickpea varieties with the biofertilizers types in mango-based agroforestry systems is presented in table 4.8 and fig 4.5. The results showed that the number of seeds pod^{-1} varied among chickpea varieties and biofertilizers application.

Overall, the highest count of 1.53 seeds pod^{-1} was observed for T9 (Mango +PBG-7 + *Rh* + PSB), and the lowest count of 1.07 seeds pod^{-1} recorded for T2 (Mango + HPC-1 + PSB) and T10 (Sole Him Palam Chana-1). Among the black chickpea varieties, V3 (PBG-7) demonstrated significantly highest (1.43) seeds pod^{-1}, followed by V2 (HPG-17) at 1.30, while V1 (Him Palam Chana-1) exhibited significantly lowest seeds pod^{-1} (1.12). The combined biofertilizers (*Rh* + PSB) application resulted in maximum of 1.38 seeds pod^{-1} irrespective of the varieties of black chickpea, whereas the minimum seeds pod^{-1} (1.22) was obtained without biofertilizers in open. The seeds pod^{-1} were increased due to the application of *Rhizobium* and PSB.

Table 4.8: Effect of biofertilizers on number of seeds pod^{-1} of black chickpea grown under mango-based agroforestry system

No. of seeds pod^{-1}					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	1.13	1.27	1.47	**1.29**
	PSB	1.07	1.27	1.40	**1.24**
	***Rh* + PSB**	1.20	1.40	1.53	**1.38**
	Control	1.07	1.27	1.33	**1.22**
	Mean	**1.12**	**1.30**	**1.43**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.09	0.04	0.03	
Biofertilizer s (B)		0.10	0.05	0.03	
V x B		NS	0.08	0.06	

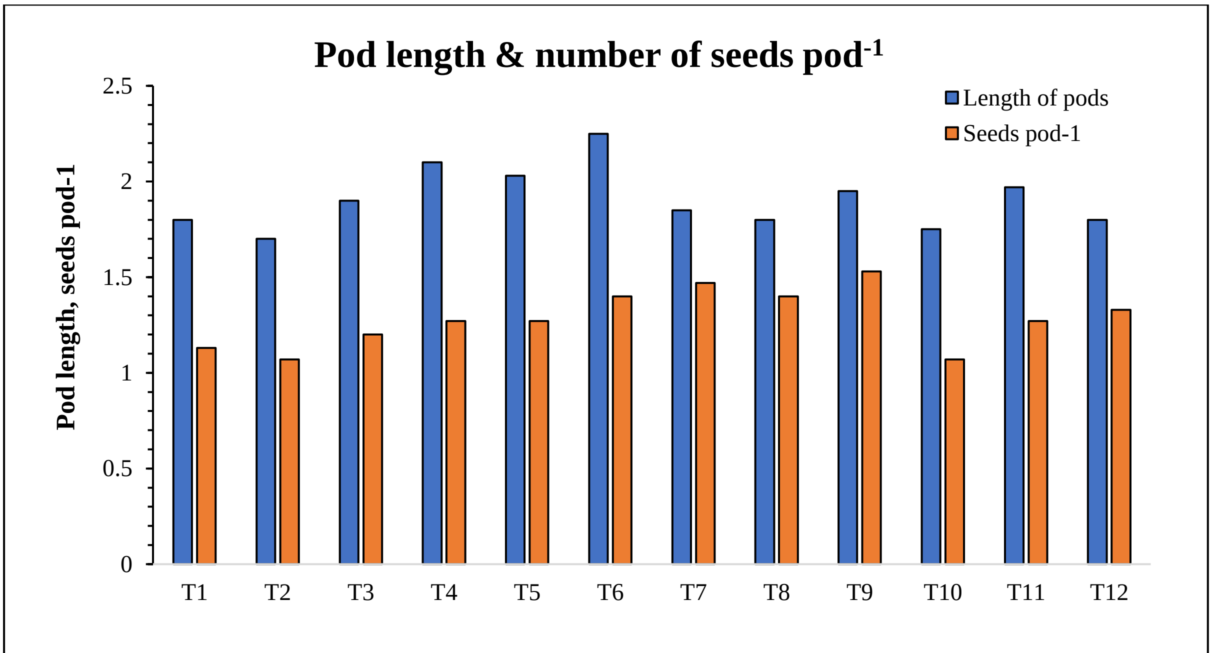

Fig 4.5: Pod length & number of seeds pod^{-1} of black chickpea grown under mango-based agroforestry system in response to biofertilizers application

4.1.7 Above ground biomass (q ha^{-1})

The data pertaining to the effect of biofertilizers on above ground biomass of different black chickpea varieties is shown in table 4.9 and fig 4.6 under mango-based agroforestry system.

Overall, the highest above ground biomass of 4.62 q ha^{-1} was observed in T6 (Mango + HPG-17 + *Rhizobium* + PSB), while the lowest 3.22 q ha^{-1} was observed in T10 (Sole Him

Palam Chana-1). Among the black chickpea varieties, V2 (HPG-17) recorded significantly highest (4.37 q ha^{-1}) above ground biomass, followed by V3 (PBG-7) at 4.08 q ha^{-1}, and V1 (Him Palam Chana-1) recorded significantly lowest (3.48 q ha^{-1}) above ground biomass. Data in the table 4.8 clearly shows that the maximum above ground biomass of 4.24 q ha^{-1} was recorded in case of *Rh* + PSB when applied in combination, whereas the minimum 3.47 q ha^{-1} was obtained in control.

Table 4.9: Effect of biofertilizers on above ground biomass of black chickpea grown under mango-based agroforestry system

Above ground biomass (q ha^{-1})					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	3.55	4.44	4.16	**4.05**
	PSB	3.37	4.28	4.02	**3.89**
	***Rh* + PSB**	3.80	4.62	4.29	**4.24**
	Control	3.22	4.14	3.85	**3.73**
	Mean	**3.48**	**4.37**	**4.08**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.05	0.03	0.02	
Biofertilizers (T)		0.06	0.03	0.02	
V x T		NS	0.05	0.04	

4.1.8 Below ground biomass (q ha^{-1})

The data pertaining to the effect of mango tree and biofertilizers on below ground biomass of black chickpea varieties is presented in table 4.10 and fig. 4.6. The results revealed significant variation in below ground biomass of chickpea varieties occurred due to biofertilizers and mango tree canopy. Whereas, the interaction between chickpea varieties and biofertilizers is not statistically significant.

The highest below ground biomass was observed for T6 (Mango + HPG-17 + *Rhizobium* + PSB), while the lowest (0.28 q ha^{-1}) was recorded for T10 (Sole Him Palam Chana-1) as shown in fig. 4.6. Among the black chickpea varieties, V2 (HPG-17) exhibited significantly highest (0.43 q ha^{-1}) below ground biomass, followed by V3 (PBG-7) at 0.39 q ha^{-1}, and V1 (Him Palam Chana-1) displayed significantly lowest (0.32 q ha^{-1}) below ground biomass. As regards the effect of biofertilizers on chickpea varieties, the maximum (0.42 q ha^{-1}) below ground biomass was due to combined application of biofertilizers (*Rh* + PSB) and the minimum (3.73 q ha^{-1}) was obtained in the control.

Table 4.10: Effect of biofertilizers on below ground biomass of black chickpea grown under mango-based agroforestry system

Below ground biomass (q ha^{-1})					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	0.33	0.44	0.40	**0.39**
	PSB	0.31	0.42	0.38	**0.37**
	***Rh* + PSB**	0.36	0.47	0.43	**0.42**
	Control	0.28	0.40	0.34	**0.34**
	Mean	**0.32**	**0.43**	**0.39**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.005	0.003	0.002	
Biofertilizers (T)		0.006	0.003	0.002	
V x T		NS	0.005	0.004	

4.1.9 Total plant biomass (q ha^{-1})

The data pertaining to total plant biomass of black chickpea varieties under mango-based agroforestry systems, while accounting the influence of biofertilizers are shown in table 4.11 and fig. 4.6. The results indicate the significant variations in total plant biomass of chickpea varieties across varieties and biofertilizers application, however, the interaction between chickpea varieties and biofertilizers was not statistically significant.

Within the treatments, total plant biomass was observed highest (5.09 q ha^{-1}) for T6 (Mango + HPG-17 + *Rhizobium* + PSB), whereas the lowest (3.50 q ha^{-1}) was observed for T10 (Sole Him Palam Chana-1). Among the three black chickpea varieties, V2 (HPG-17) exhibited significantly higher (4.80 q ha^{-1}) total plant biomass, followed by V3 (PBG-7) at 4.46 q ha^{-1}, and V1 (Him Palam Chana-1) displayed significantly lower (3.81q ha^{-1}) total plant biomass. The result showing the effect of biofertilizers on chickpea crop revealed that the maximum (4.66 q ha^{-1}) total plant biomass was reported due to the combined application of biofertilizers (*Rh* + PSB), whereas the minimum (4.07 q ha^{-1}) total plant biomass was obtained in the control.

Table 4.11: Effect of biofertilizers on total plant biomass of black chickpea grown under mango-based agroforestry system

Total plant biomass (q ha^{-1})					
Treatments		Varieties			Mean
		V_1	V_2	V_3	
Mango	*Rhizobium*	3.88	4.88	4.56	**4.44**
	PSB	3.68	4.70	4.39	**4.26**
	Rh + PSB	4.17	5.09	4.71	**4.66**
	Control	3.50	4.54	4.19	**4.07**
	Mean	**3.81**	**4.80**	**4.46**	
Factors		C.D. (0.05)	SE(d)	SE(m)	
Variety (V)		0.06	0.03	0.02	
Biofertilizers (T)		0.06	0.03	0.02	
V x T		NS	0.05	0.04	

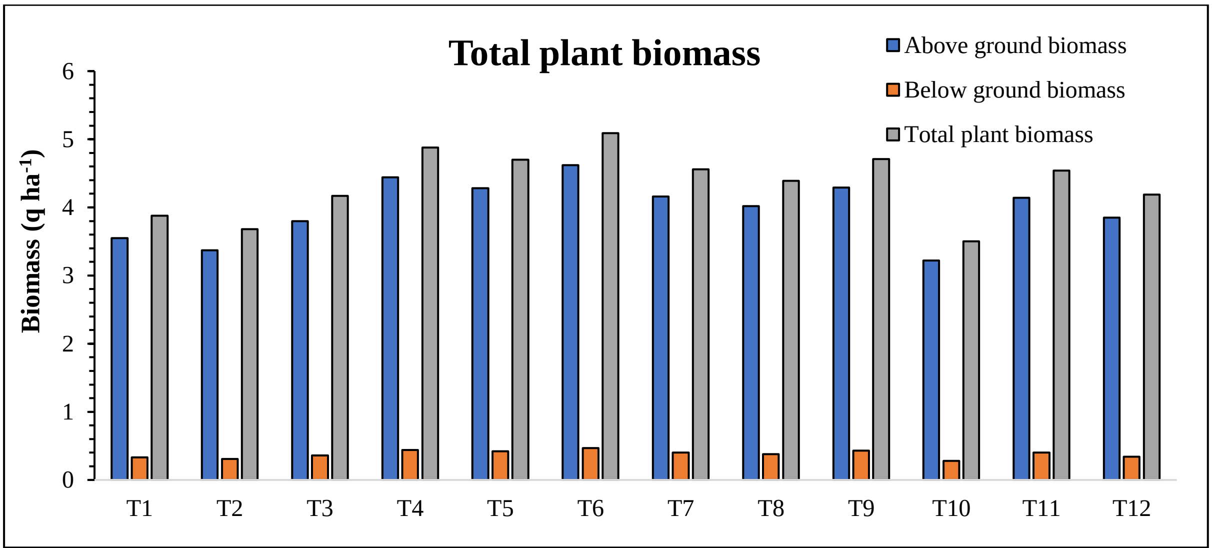

Fig 4.6: Total plant biomass of black chickpea grown under mango-based agroforestry system in response to biofertilizers application

The significant increase in total plant biomass of chickpea can be attributed to the combined application of the biofertilizers (*Rh* + PSB). Biofertilizers (*Rhizobium* and PSB) enhances the fertility levels of the soil and also plants metabolic system and having efficient rooting system which is helpful to grow the plant more vigorously as compared to other and control treatments. Nitrogen fixation by *rhizobium* benefit the plant by providing them atmospheric nitrogen, which contributes to the development of plant growth and biomass production. *Rhizobium* plays a vital role in boosting biomass production through the activity of the enzyme nitrogenase, which facilitates nitrogen fixation and enhances nitrogen availability for plant growth. The PSB, on the other hand, it contributes to increased biomass production by improving the availability of phosphates to the chickpea plants by solubilizing phosphates, Furthermore, the application of 100% RDF independently contributes to the observed increase in plant biomass. Phosphorous, after the fixation by PSB is involved in vital physiological processes within plants, including energy production through respiration, as well as cell elongation, cell division, and the activation of amino acids. By ensuring proper supply of phosphorous and nitrogen, all these metabolic processes are optimized, leading to improved growth attributes and a higher accumulation of dry matter in the chickpea plants. Verma *et al.* (2010), Singh *et al.* (2013), Dakshayini *et al.* (2016), Kumar and Singh (2023) and Sowmya (2023).

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

The data pertaining to the seed yield of black chickpea varieties grown under mango-based agroforestry systems with the effect of biofertilizers are presented in table 4.12 and fig. 4.7. The results showed that there was significant variation in seed yield for varieties, biofertilizers and the interaction between varieties and biofertilizers.

Among treatments, maximum (14.70 q ha^{-1}) seed yield was recorded for T6 (Mango + HPG-17 + *Rh* + PSB) and minimum (9.93 q ha^{-1}) was for T10 (Sole Him Palam Chana -1). Within the three chickpea varieties, significantly higher (12.75 q ha^{-1}) seed yield was obtained for V2, followed by V3 (11.91 q ha^{-1}) and lower for V1 (10.72 q ha^{-1}). Among studied mango-based agroforestry system along with control, maximum (13.47 q ha^{-1}) seed yield was reported under agroforestry system with the combined application of biofertilizers (*Rh* + PSB), whereas minimum (10.50 q ha^{-1}) seed yield was obtained in control.

Table 4.12: Effect of biofertilizers on seed yield of black chickpea grown under mango-based agroforestry system

Seed yield (q ha^{-1})					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	10.89	13.50	11.70	**12.03**
	PSB	10.06	12.75	10.75	**11.19**
	***Rh* + PSB**	12.56	14.70	13.15	**13.47**
	Control	9.39	12.06	10.06	**10.50**
	Mean	**10.72**	**12.75**	**11.91**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.30	0.14	0.10	
Biofertilizers (T)		0.34	0.16	0.12	
V x T		0.59	0.28	0.20	

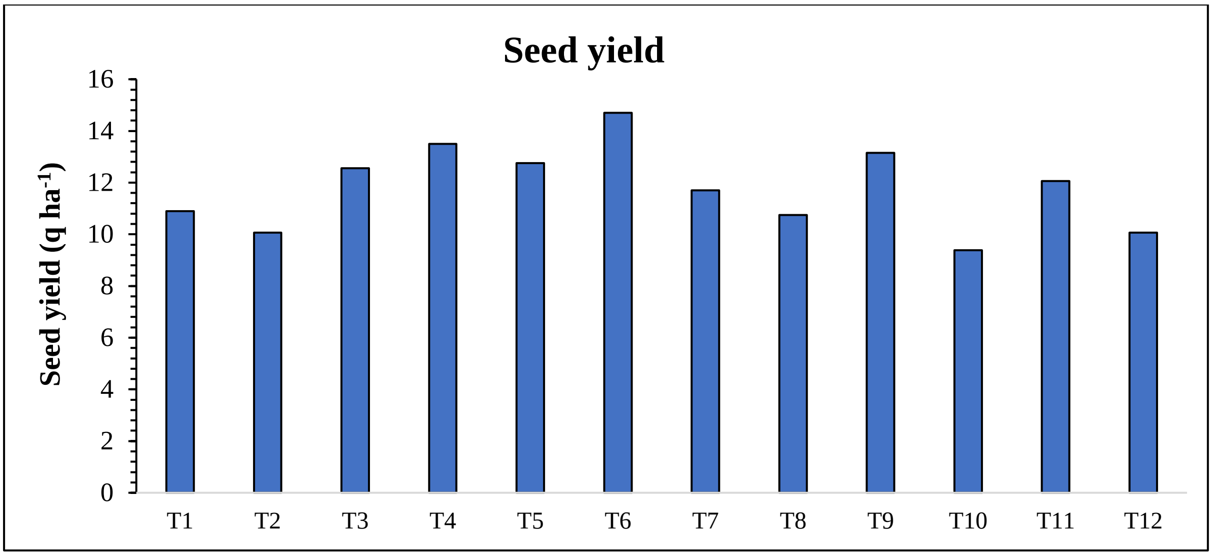

Fig 4.7: Seed yield ha^{-1} of black chickpea grown under mango-based agroforestry system in response to biofertilizers application

Increase in yield of chickpea with bioinoculants was mainly due to better root growth which helped for better nutrient absorption and vigorous shoot growth which help to enhance the growth and yield parameters. The increase in growth and yield of chickpea was due to nutrient supplementation among the inoculated organisms, which enhanced their efficiencies like N_2 fixation by *Rhizobium*, P-solubilization by PSB. The bacteria, through biological nitrogen fixation, meet about 80 –90 per cent of the total N requirements of legumes. (Verma, 1993). Likewise, phosphate-solubilizing bacteria (PSB) have the capability to solubilize the residual or fixed soil P (Singh *et al.* 2008). Chickpea (*Cicer arietinum* L.) is more efficient than other pulses in taking up P from soil, as it secrets more acid which helps in solubilizing P. The increase in seed yield was due to the cumulative effect of increased growth and yield parameters. The combined application of *Rhizobium* and PSB enhance the phosphorus availability and this available phosphorus enhances the number of seed yield. The increases in seed yield were highest with the biofertilizer combination (*Rh* + PSB) along with RDF 100%. Similar results are also reported by Gupta (2006), Singh *et al.* (2014), Tagore *et al.* (2014), Singh *et al.* (2021) and Sasidhar *et al.* (2022).

4.2 Correlation analysis between growth and yield parameter of black chickpea varieties under mango-based agroforestry system.

4.2.1 Corelation analysis

Karl Pearson's coefficient of correlation was worked out between growth and yield parameters of black chickpea varieties grown with or without mango (*Mangifera indica*).

Table 4.13: Correlation coefficients between growth and yield parameters of black chickpea

Parameters	Plant height	No. of nodules	Chlorophyll content	No. of pods $plant^{-1}$	Pod length	Seeds pod^{-1}	Seed yield	Total plant biomass
Plant height	1.000							
No. of nodules	0.752^{**}	1.000						
Chlorophyll content	0.950^{**}	0.663^{*}	1.000					
No. of pods $plant^{-1}$	0.871^{**}	0.617^{*}	0.937^{**}	1.000				
Pod length	0.955^{**}	0.625^{*}	0.933^{**}	0.794^{**}	1.000			
Seeds pod^{-1}	-0.249^{NS}	0.292^{NS}	-0.244^{NS}	-0.046^{NS}	-0.417^{NS}	1.000		
Seed yield	0.852^{**}	0.790^{**}	0.865^{**}	0.873^{**}	0.817^{**}	0.011^{NS}	1.000	
Total plant biomass	0.950^{**}	0.652^{*}	0.962^{**}	0.955^{**}	0.876^{**}	-0.156^{NS}	0.806^{**}	1.000

**Correlation is significant at 1% level, *Correlation is significant at 5% level, NS – non-significant

The correlation coefficients among 8 growth and yield parameters of black chickpea are presented in table 4.13 the result indicated that plant height had positive and significant correlation of (0.752), (0.950), (0.871), (0.955), (0.852) and (0.950) with number of nodules $plant^{-1}$, chlorophyll content, number of pods $plant^{-1}$, pod length, seed yield and total plant biomass respectively. Total plant biomass had positive and significant association with plant height (0.950), number of nodules (0.652), chlorophyll content (0.962), number of pods $plant^{-1}$ (0.955), pod length (0.876) and seed yield (0.806). It was also observed that seed yield exhibited positive and significant correlation with plant height (0.852), number of nodules $plant^{-1}$(0.790), chlorophyll content (0.865), number of pods $plant^{-1}$(0.873) and pod length (0.817).

4.2.2 Regression Analysis

Various linear functions have been tried on various characteristics *viz*. plant height number of nodules $plant^{-1}$, pod length, number of pods $plant^{-1}$, total plant biomass to estimate seed yield by considering one character at a time as independent variable and results are presented in table 4.14. R^2 and standard error of estimate are also presented along with the respected fitted functions. Maximum amount of variation of 76 per cent was explained by number of pods $plant^{-1}$ followed by 72 per cent by plant height and 66 per cent by pod length, 65 per cent by total plant biomass and 62 per cent by number of nodules.

Table 4.14: Estimation function for seed yield (Y)

Independent variables	Function	Equation	Standard Error	t-value	R^2
Plant height	Linear	Y = -2.472 + 0.094 X	0.018	5.147	0.726
No. of nodules	Linear	Y = 0.444 + 0.098 X	0.024	4.078	0.624
Pod length	Linear	Y = -0.709 + 1.485 X	0.332	4.475	0.666
No. of pods	Linear	Y = 0.535 + 0.051 X	0.009	5.665	0.762
Total plant biomass	Linear	Y = 0.037 + 0.003 X	0.001	4.312	0.650

4.3 Growth and yield parameters of Mango tree (*Mangifera indica*)

The data pertaining to the growth and yield parameters of Mango (*Mangifera indica*) are presented in table 4.15.

4.3.1 Tree height (m)

The height of mango trees ranged from 1.34 m to 3.29 m. The average height of Mango (*Mangifera indica*) trees was 2.31m.

4.3.2 Tree diameter (cm)

The diameter of mango trees ranged from 4.7 cm to 9.07 cm. The average tree diameter of Mango (*Mangifera indica*) at 20 cm above the ground level was 7.29 cm.

4.3.3 Crown spread (m^2)

The crown spread of mango trees varied from 1.00 m to 2.68 m. The average crown spread of Mango (*Mangifera indica*) trees was as 1.95 m^2.

4.3.4 Fruit yield (kg $tree^{-1}$)

The average fruit yield per tree of Mango (*Mangifera indica*) was 14 kg.

4.3.5 Fruit size (cm)

The average fruit size of Mango was 12.2 cm.

Table 4.15: Growth and yield parameters of Mango tree (*Mangifera indica*)

Parameters / Species	Growth and yield parameters				
	Height of trees (m)	Diameter (cm)	Crown spread (m)	Fruit size (cm)	Fruit yield (kg $tree^{-1}$)
Mango	2.31	7.29	1.95	12.2	14

4.4 Soil properties under agroforestry system compared to control

4.4.1 Bulk density (g cm^{-3})

The data in the table 4.16 and fig. 4.8 represents soil bulk density at time of harvest of chickpea crop. The analysis revealed that there was no significant difference before sowing and after harvesting the crop in all treatment *viz.* variety and biofertilizers and their interaction (variety x biofertilizers). The bulk density before sowing ranged between 1.22 g cm^{-3} to 1.24 g cm^{-3} and bulk density after harvesting ranged between 1.23 g cm^{-3} to 1.26 g cm^{-3}.

Table 4.16: Effect of biofertilizers on bulk density of soil under mango-based agroforestry system

Bulk density (g cm^{-3})					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	1.25	1.25	1.25	**1.25**
	PSB	1.24	1.24	1.23	**1.24**
	***Rh* + PSB**	1.23	1.25	1.24	**1.24**
	Control	1.26	1.23	1.24	**1.25**
	Mean	**1.25**	**1.24**	**1.24**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		NS	0.01	0.01	
Biofertilizers (B)		NS	0.01	0.01	
V x B		NS	0.01	0.01	

4.4.2 Particle density (g cm^{-3})

The data in the table 4.17 and fig 4.8 pertains to soil particle density after the harvest of chickpea crop. The analysis revealed that there was no significant difference before sowing and after harvesting the crop in all treatments *viz.* variety and biofertilizers and their interaction (variety x biofertilizers). The average value for particle density before sowing ranged to 2.53 g cm^{-3} to 2.58 g cm^{-3} and particle density after harvesting ranged to 2.52 g cm^{-3} to 2.64 g cm^{-3}.

Table 4.17: Effect of biofertilizers on particle density of soil under mango-based agroforestry system

Particle density (g cm^{-3})					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	2.61	2.58	2.54	**2.58**
	PSB	2.58	2.56	2.54	**2.56**
	***Rh* + PSB**	2.60	2.52	2.54	**2.55**
	Control	2.62	2.63	2.64	**2.63**
	Mean	**2.60**	**2.57**	**2.57**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		NS	0.04	0.03	
Biofertilizers (B)		NS	0.04	0.03	
V x B		NS	0.07	0.05	

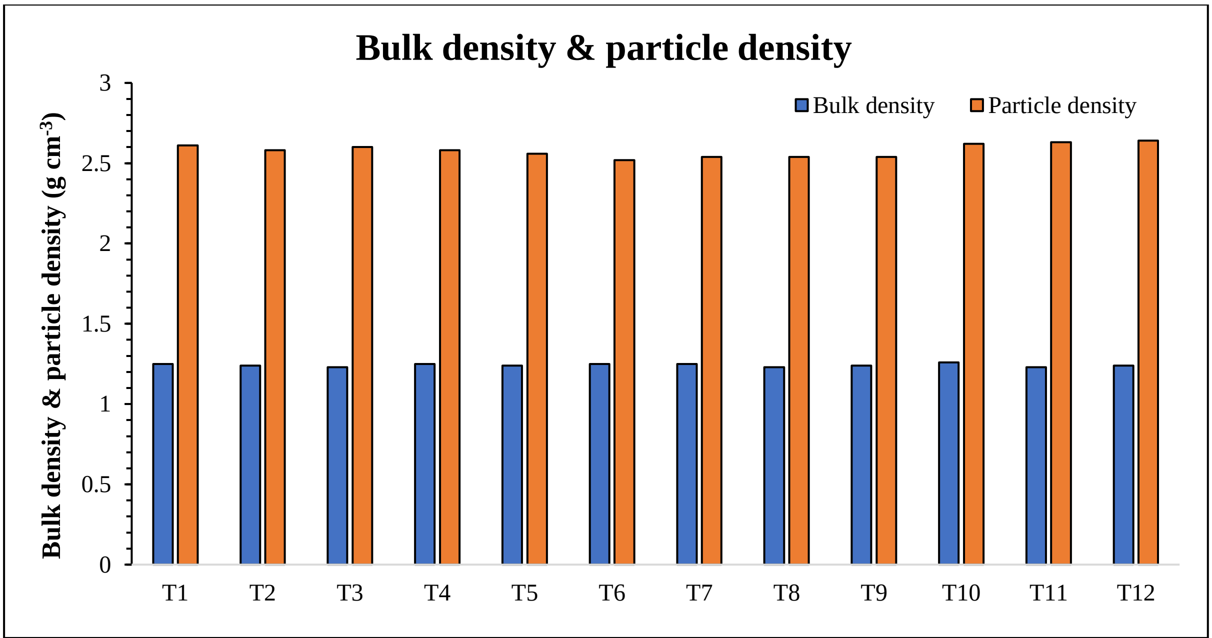

Fig 4.8: Bulk density & particle density of soil under mango-based agroforestry system in response to biofertilizers application

4.4.3 Soil moisture content (%)

The table 4.18 and fig 4.9 presents data on soil moisture content at the harvest of chickpea crop. The analysis reveals that there was no significant difference in the soil moisture content before sowing and after harvesting the crop in all treatments *viz.* variety and biofertilizers and their interaction (variety x biofertilizers). The soil moisture content before sowing varied between 7.38% and 7.52% and soil moisture content after harvesting varied between 7.19% and 7.53%.

Table 4.18: Effect of biofertilizers on moisture content of soil under mango-based agroforestry system

Soil moisture content (%)					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	7.28	7.29	7.30	**7.29**
	PSB	7.46	7.28	7.37	**7.37**
	***Rh* + PSB**	7.25	7.53	7.29	**7.36**
	Control	7.22	7.19	7.20	**7.20**
	Mean	**7.30**	**7.32**	**7.29**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		NS	0.08	0.06	
Biofertilizers (B)		NS	0.09	0.07	
V x B		NS	0.16	0.11	

4.4.4 Porosity (%)

Like bulk density, particle density and soil moisture content, no significant difference in soil porosity among all treatments *viz*. chickpea varieties and biofertilizer application, and their interactions was also observed to be non-significant statically (table 4.19). The soil porosity before sowing exhibited a range of 51.38% to 51.59% and after harvesting soil porosity exhibited a range of 50.36% to 53.17%.

Table 4.19: Effect of biofertilizers on porosity of soil under mango-based agroforestry system

Porosity (%)					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	51.79	51.36	50.72	**51.29**
	PSB	51.84	51.50	51.67	**51.67**
	***Rh* + PSB**	52.74	50.36	50.94	**51.35**
	Control	51.70	53.17	52.89	**52.59**
	Mean	**52.02**	**51.60**	**51.56**	
Factors		**C.D. at 5%**	**SE(d)**	**SE(m)**	
Variety (V)		NS	0.78	0.55	
Biofertilizers (B)		NS	0.90	0.63	
V x B		NS	1.55	1.10	

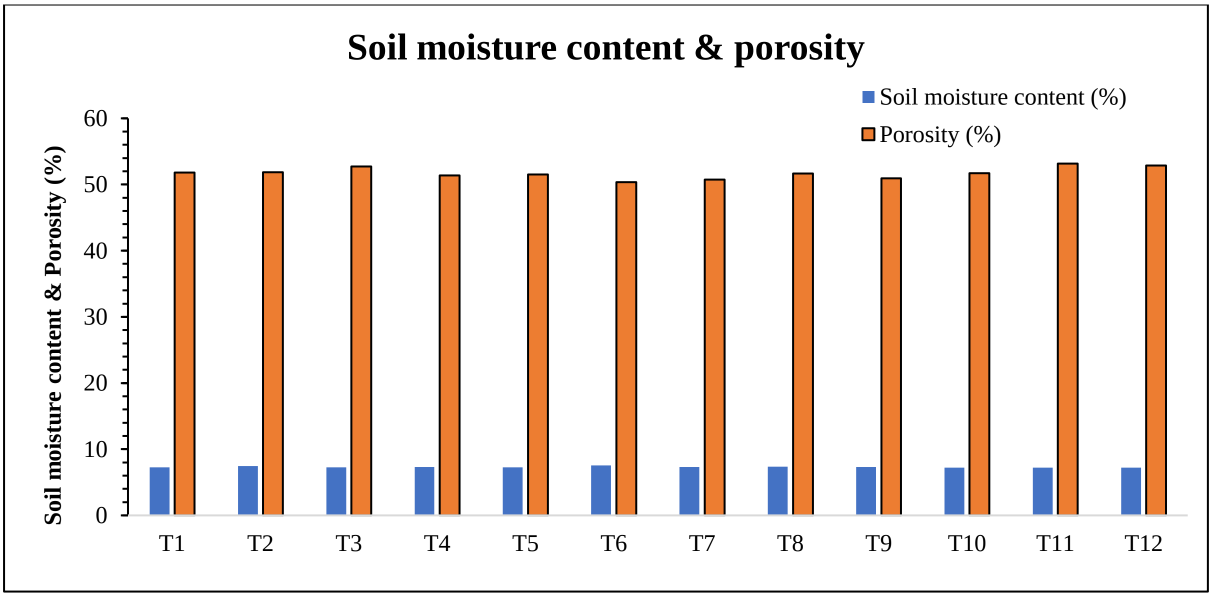

Fig 4.9: Soil moisture content & porosity of soil under mango-based agroforestry system in response to biofertilizers application

4.4.5 Soil pH

The data pertaining to soil pH after harvesting of chickpea presented in the table 4.20 and fig. 4.10. The analysis showed a non-significant difference in pH before sowing and after harvesting the crop in all treatments *viz.* variety and biofertilizers application and their interaction (varieties x biofertilizers). The soil pH before sowing ranged from 6.88 to 7.19 and soil pH after harvesting ranged from 6.90 to 7.16

Table 4.20: Effect of biofertilizers on soil pH under mango-based agroforestry system

Soil pH					
Treatments		Varieties			Mean
		V_1	V_2	V_3	
Mango	***Rhizobium***	7.16	7.13	7.16	**7.15**
	PSB	6.97	7.15	7.13	**7.08**
	Rh **+ PSB**	7.10	7.03	6.96	**7.03**
	Control	7.00	6.90	7.04	**6.98**
	Mean	**7.06**	**7.05**	**7.07**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		NS	0.10	0.07	
Biofertilizers (B)		NS	0.11	0.08	
V x B		NS	0.20	0.14	

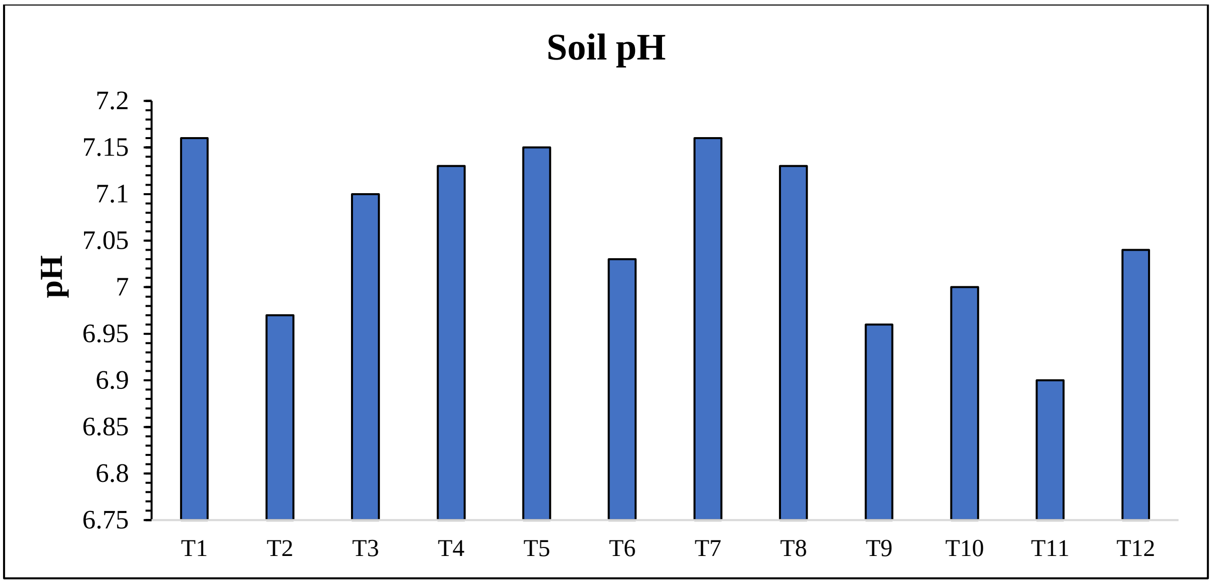

Fig 4.10: pH of soil under mango-based agroforestry system in response to biofertilizers application

4.4.6 Electrical conductivity (dS m^{-1})

The table 4.21 and fig. 4.11 display data on soil electrical conductivity at harvest of chickpea. The analysis showed a non-significant difference in soil E.C. before sowing and after harvesting the crop in all treatments. The soil electrical conductivity before sowing was in range of 0.19 dS m^{-1} to 0.24 dS m^{-1} and after harvesting it ranged from 0.22 dS m^{-1} to 0.26 dS m^{-1}.

Table 4.21: Effect of biofertilizers on electrical conductivity of soil under mango-based agroforestry system

Electrical conductivity (dS m^{-1})					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	0.24	0.26	0.24	**0.24**
	PSB	0.23	0.23	0.24	**0.23**
	***Rh* + PSB**	0.25	0.24	0.25	**0.24**
	Control	0.24	0.22	0.24	**0.24**
	Mean	**0.24**	**0.23**	**0.24**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		NS	0.01	0.01	
Biofertilizers (B)		NS	0.01	0.01	
V x B		NS	0.01	0.01	

4.4.7 Organic carbon (%)

The data presented in the table 4.22 and fig. 4.11 on soil organic carbon showed non - significant variation for varieties, biofertilizers and their interaction (variety x biofertilizers) for black chickpea varieties under mango-based agroforestry system. Soil organic carbon showed a slight increase after harvesting the crop. Among treatments, maximum (1.54 %) soil organic carbon was recorded for T9 (Mango + PBG-7 + *Rh* + PSB) and minimum (1.39 %) was for T10 (Sole Him Palam Chana -1).

Table 4.22: Effect of biofertilizers on soil organic carbon under mango-based agroforestry system

Soil organic carbon (%)					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	1.42	1.49	1.51	**1.47**
	PSB	1.42	1.40	1.49	**1.43**
	***Rh* + PSB**	1.50	1.48	1.54	**1.51**
	Control	1.39	1.51	1.45	**1.45**
	Mean	**1.43**	**1.47**	**1.50**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.03	0.02	0.01	
Biofertilizers (B)		0.04	0.02	0.01	
V x B		0.07	0.03	0.02	

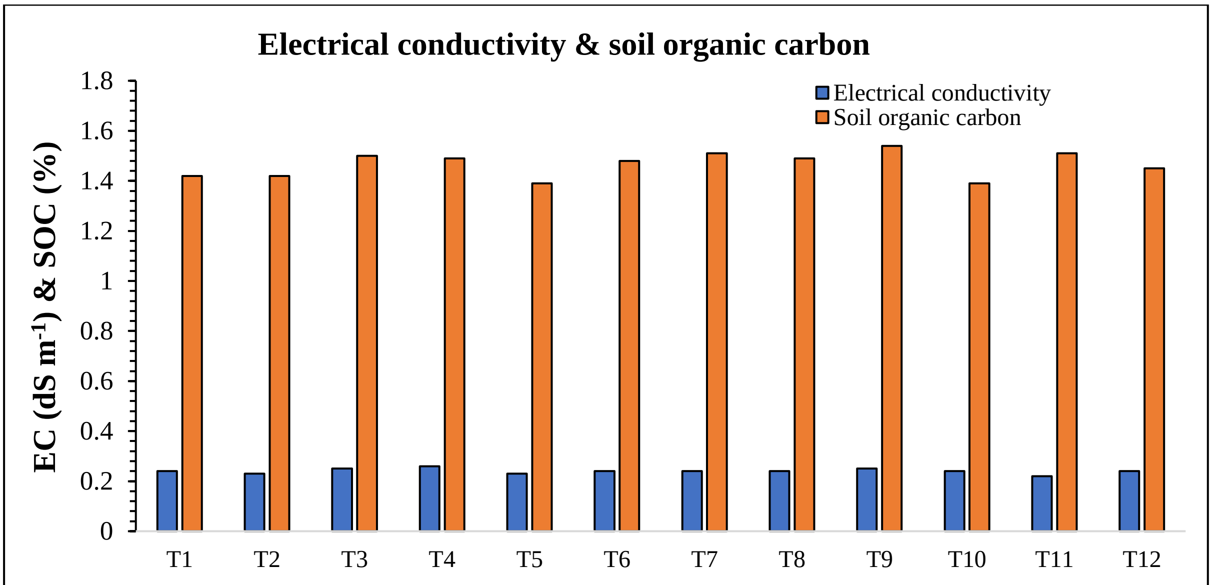

Fig 4.11: Soil electrical conductivity & soil organic carbon under mango-based agroforestry system in response to biofertilizers application

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

The data pertaining to the available nitrogen under mango-based agroforestry system are presented in table 4.23 and fig. 4.12. The data presented in the table showed that there was significant variation in available nitrogen for varieties, biofertilizers and the interaction between varieties and biofertilizers.

Among the varieties significantly highest (308.84 kg ha^{-1}) amount of available nitrogen was recorded in V2(HPG-17), followed by V1(Him Palam Chana-1) with 306.52 kg ha^{-1} and lowest (304.61 kg ha^{-1}) amount of available nitrogen was recorded in V3(PBG-7). In case of effect of biofertilizers on available nitrogen studied in mango-based agroforestry systems, significantly higher (324.26 kg ha^{-1}) amount of available nitrogen was recorded under agroforestry system in the combined application of biofertilizers (*Rhizobium* + PSB) followed by the *Rhizobium* application (320.19 kg ha^{-1}) and significantly lower (264.52 kg ha^{-1}) amount of available nitrogen was recorded in control. In case of interaction between variety and biofertilizers, T6 (Mango + HPG-17 + *Rh* + PSB) showed significantly higher (326.57 kg ha^{-1}) amount of available nitrogen followed by T3 (Mango + Him Palam Chana-1 + *Rhizobium* + PSB) with 324.61 kg ha^{-1} of available nitrogen and T10 (Sole Him Palam Chana-1) showed significantly lowest (262.56 kg ha^{-1}) amount of available nitrogen. Combined application of biofertilizers (*Rh* + PSB) along with RDF 100% significantly increased the nitrogen content in the soil after harvest of the crop. *Rhizobium* increased the amount of nitrogen in the soil by improving its ability to fix nitrogen from the atmosphere.

Table 4.23: Effect of biofertilizers on available nitrogen in soil under mango-based agroforestry system

Available nitrogen (kg ha^{-1})					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	320.26	322.71	317.59	**320.19**
	PSB	318.67	319.49	314.81	**317.66**
	***Rh* + PSB**	324.61	326.57	321.62	**324.26**
	Control	262.56	266.59	264.41	**264.52**
	Mean	**306.52**	**308.84**	**304.61**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		1.19	0.57	0.40	
Biofertilizers (B)		1.37	0.66	0.46	
V x B		2.37	1.14	0.80	

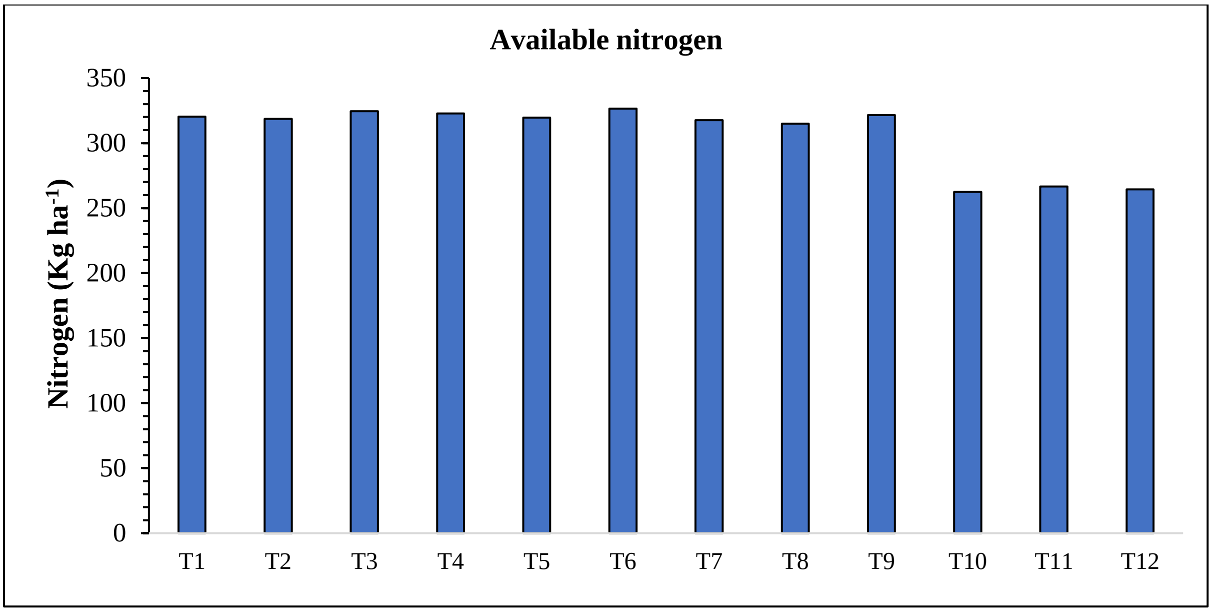

Fig 4.12: Available nitrogen in soil under mango-based agroforestry system in response to biofertilizers application

4.4.9 Available phosphorus (kg ha^{-1})

The data presented in the table 4.24 and fig 4.13 revealed that the available phosphorus, showed significant variation for variety, biofertilizers and their interaction (variety x biofertilizers). The interaction effect of variety and biofertilizers showed significantly higher (22.34 kg ha^{-1}) available phosphorus for T8 (Mango + PBG-7 + PSB) followed by T6 (Mango + HPG-17 + *Rh* + PSB) with 22.00 kg ha^{-1} available phosphorus and significantly lowest (14.85 kg ha^{-1}) value of available phosphorus was observed for T11 (Sole HPG-17). Within the varieties significantly highest (19.08 kg ha^{-1}) available phosphorus was recorded for V3 followed by V2 and V1 i.e. 18.95 kg ha^{-1} and 18.35 kg ha^{-1}, respectively. The perusal of data in table 4.24 further reveals that combined (*Rh* + PSB) application of biofertilizers had significant effect on the available phosphorus in the soil. Significantly higher (20.77 kg ha^{-1}) available phosphorus was recorded in the combined application biofertilizers (*Rh* + PSB) followed by PSB application (20.64 kg ha^{-1}) and significantly lower value (15.68 kg ha^{-1}) was recorded in control.

Table 4.24: Effect of biofertilizers on available phosphorus in soil under mango-based agroforestry system

Available phosphorus (kg ha^{-1})					
Treatments		Varieties			Mean
		V_1	V_2	V_3	
Mango	*Rhizobium*	17.51	18.78	17.96	**18.08**
	PSB	19.40	20.17	22.34	**20.64**
	Rh + PSB	20.82	22.00	19.48	**20.77**
	Control	15.66	14.85	16.54	**15.68**
	Mean	**18.35**	**18.95**	**19.08**	
Factors		C.D. (0.05)	SE(d)	SE(m)	
Variety (V)		0.40	0.19	0.14	
Biofertilizers (B)		0.47	0.22	0.16	
V x B		0.81	0.39	0.27	

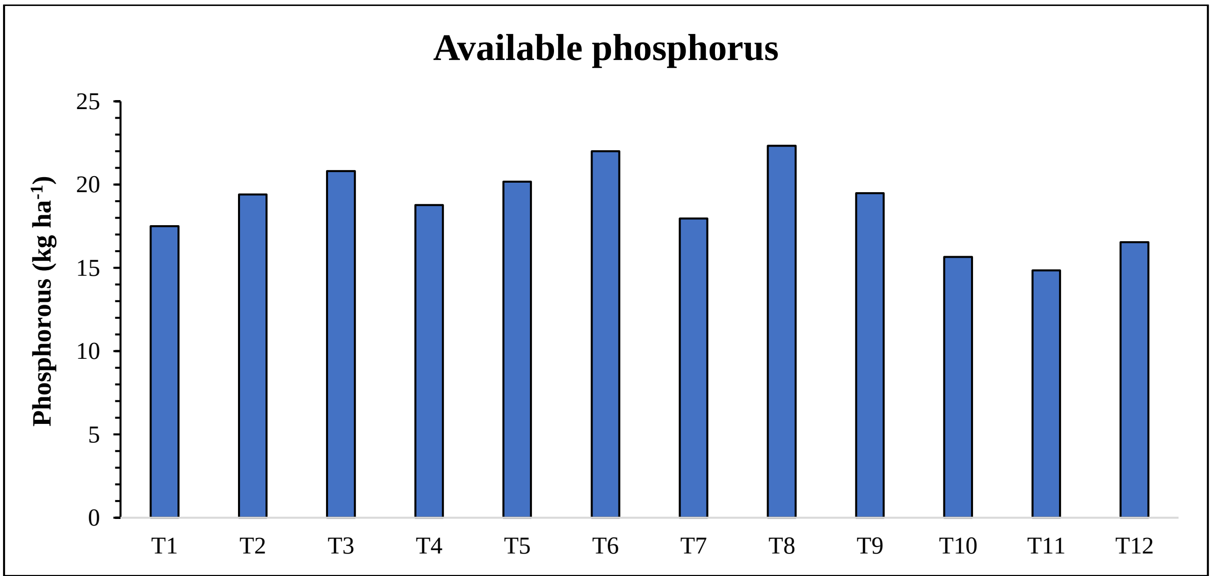

Fig 4.13: Available phosphorous in soil under mango-based agroforestry system in response to biofertilizers application

4.4.10 Available potassium (kg ha^{-1})

The data pertaining to the available potassium under mango-based agroforestry system are presented in table 4.25 and fig. 4.14. The data presented in the table showed that there was significant variation in available potassium for varieties, biofertilizers and the interaction between varieties and biofertilizers.

Among the varieties significantly highest (206.47 kg ha^{-1}) amount of available potassium was reported in V2 (HPG-17), followed by V1 (Him Palam Chana-1) with 203.89 kg ha^{-1} and lowest (203.33 kg ha^{-1}) amount of available potassium was reported in V3 (PBG-

7). Among biofertilizers application significantly higher (211.80 kg ha^{-1}) amount of available potassium was recorded under agroforestry system in the combined application of biofertilizers (*Rh* + PSB) followed by the PSB application (209.54 kg ha^{-1}) and significantly lower (209.09 kg ha^{-1}) amount of available potassium was recorded in control. In case of interaction between variety and biofertilizers, T6 (Mango + HPG-17 + *Rh* + PSB) showed significantly highest (215.53 kg ha^{-1}) amount of available potassium followed by T5 (Mango + HPG-17 + PSB) with 213.44 kg ha^{-1} of available potassium and T11 (Sole HPG-17) showed significantly lowest (185.45 kg ha^{-1}) amount of available potassium.

Table 4.25: Effect of biofertilizers on available potassium in soil under mango-based agroforestry system

Available potassium (kg ha^{-1})					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	209.64	211.43	210.22	**209.09**
	PSB	207.57	213.44	207.61	**209.54**
	***Rh* + PSB**	210.94	215.53	204.90	**211.80**
	Control	187.41	185. 45	190.57	**187.81**
	Mean	**203.89**	**206.47**	**203.33**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.97	0.46	0.33	
Biofertilizers (B)		1.12	0.54	0.38	
V x B		1.94	0.93	0.66	

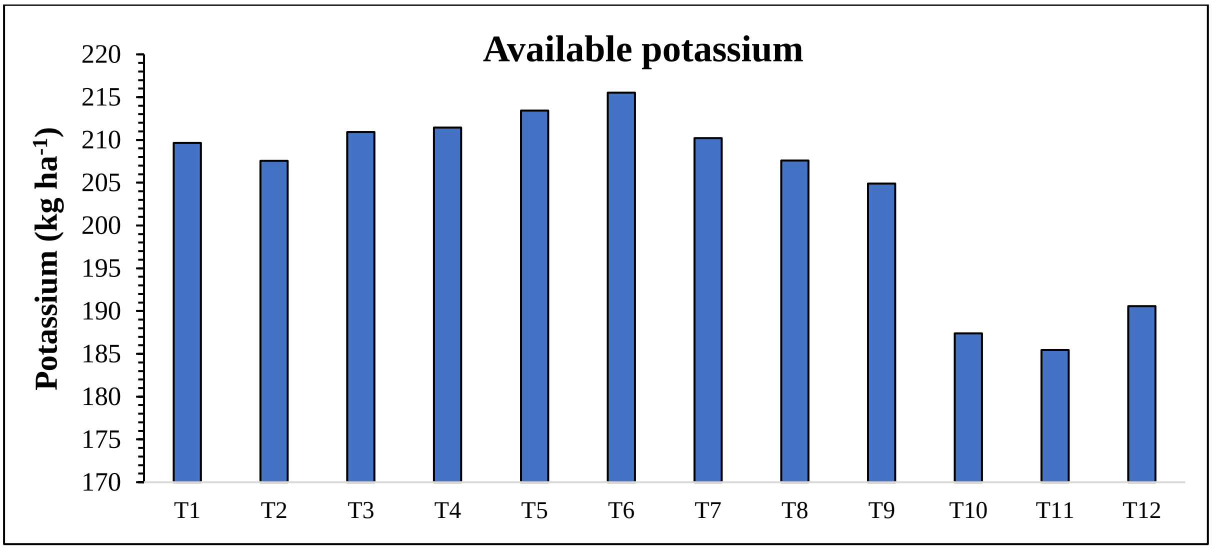

Fig 4.14: Available potassium in soil under mango-based agroforestry system in response to biofertilizers application

It was observed that soil chemical properties *viz*. electrical conductivity, pH, organic carbon showed non-significant difference among all treatments as well as before sowing and after harvesting the crop. Soil pH and EC remain unaffected under different treatments. Whereas soil nutrients N, P and K enhanced with the application of biofertilizers. Similar results were found out by Tagore *et al.* (2013). Biofertilizers enhanced the nitrogen and phosphorous content in the soil by increasing nitrogen fixation due to *rhizobium* application and by solubilizing the phosphorus in the soil. Both the land use systems *i.e*., agroforestry system (mango + chickpea) and open system (chickpea) were compared individually for soil properties before sowing and at harvesting of chickpea crop. Increase in the soil properties of mango + chickpea agroforestry system after harvesting chickpea indicated that this system can sustain over time. The improvement in soil properties under agroforestry system might be due to the decomposition of accumulated leaf litter of mango and biofertilizers application. The increase in nitrogen content under agroforestry system might be due to the nitrogen fixation ability of chickpea crop along with the biofertilizers application. Whereas, comparatively less increase in available nitrogen content under the control can be ascribed to the use of fixed nitrogen by chickpea only. The increase in potassium content in soil under the agroforestry system might be due to recycling of this nutrient by mango trees in the agroforestry system.

Prasad *et al*. (2019) reported significant increase in soil organic carbon (0.67 %), N (181.50 kg ha^{-1}), P (18.36 kg ha^{-1}) and K (140.66 kg ha^{-1}) under *Albizzia procera* + wheat-based agroforestry system as compared to pure crop exhibiting 0.52 per cent organic carbon, 150.33 kg ha^{-1} N, 11.32 kg ha^{-1} P and 113.16 kg ha^{-1} K. Maria *et al.* (2013) also revealed improvement in N, P and K status of soil under the agroforestry system integrating *Leucaena diversifolia*, maize (*Zea mays* L.) and black oats (*Avena strigosa*) as compared to pure crops. Gebrewahid *et al*. (2019) reported a significant increase in organic carbon, available nitrogen and phosphorus contents under the association of *Sesamum indicum*, *Sorghum bicolor* and *Gossypium* with *Oxytenanthera abyssinica* and *Dalbergia melanoxylon* as compared to the crops in open system. Similar findings were reported by Kewessa *et al*. (2015) who revealed maximum organic carbon and phosphorus content under *Hypericum revolutum*, *Faidherbia albida*, *Croton macrostachyus* and *Cordia africana* based agroforestry system as compared to open system. Kar *et al*. (2019) reported significant increase in electrical conductivity, organic carbon, nitrogen, phosphorous and potassium contents under *Grewia optiva* + garden pea agroforestry system as compared to sole cropping of garden pea. However, Rhizobium and PSB application had also resulted in better plant growth, nodulation and rhizospheric environment which finally resulted in more availability of plant nutrients (NPK) in the soil. (Tagore *et al*. 2014)

4.5 Bio-economics of mango-based agroforestry system.

The economics of chickpea cultivation under mango-based agroforestry system have been worked out by calculating cost of cultivation, gross returns, net returns and benefit cost ratio of sole agricultural crops, sole trees and tree-crop combinations to know the economic feasibility. Data pertaining to economics of mango-based agroforestry system is presented in table 4.26, fig. 4.15 and fig. 4.16.

4.5.1 Cost of cultivation (Rs. ha^{-1})

The data presented in table 4.26 and fig. 4.15 revealed that the cost of cultivation under the agroforestry system, integrating mango and black chickpea varieties was higher (Rs. 51229.11 ha^{-1}) compared to that computed for the sole black chickpea crop (Rs. 34778.59 ha^{-1}). Cost of cultivation of agricultural crop and mango tree is appended in appendix II and III, respectively.

4.5.2 Total gross returns (Rs. ha^{-1})

The maximum gross returns (Rs. 134750.00 ha^{-1}) were recorded in T6 (Mango + HPG-17 + *Rh* + PSB) and minimum (Rs. 46944.44 ha^{-1}) gross return were recorded in T11 (Sole Him Palam Chana-1). Among three varieties under mango-based agroforestry system, higher (Rs. 134750.00 ha^{-1}) gross returns were recorded for V2 (HPG-17), followed by V3 (PBG-7) *i.e.* Rs. 127000.46 ha^{-1} and lower (Rs. 124027.78 ha^{-1}) gross returns were recorded for V1 (Him Palam Chana-1). Maximum gross returns were obtained under agroforestry system due to additional income generated by fruit tree as compared to sole cropping.

4.5.3 Total net returns (Rs ha^{-1})

The data obtained for net return showed the similar trend as observed for gross return. The maximum (Rs. 83520.89 ha^{-1}) net returns were obtained from in T6 (Mango + HPG-17 + *Rh* + PSB) and minimum (Rs. 12165.85 ha^{-1}) net returns were obtained from T11 (Sole Him Palam Chana-1). Among three varieties under mango-based agroforestry system, higher (Rs. 83520.89 ha^{-1}) net returns were obtained from V2 (HPG-17), followed by V3 (PBG-7) *i.e.* Rs. 75770.89 ha^{-1} and lower (Rs. 72798.67 ha^{-1}) net returns were from V1 (Him Palam Chana-1).

4.5.4 Benefit-cost ratio

The data for benefit cost ratio also showed the similar trend as observed for gross returns. Among the different treatments the maximum benefit cost ratio (2.63) was recorded in T6

(Mango + HPG-17 + *Rh* + PSB) and rest of the treatments were in the following order: T4 (2.51) > T9 (2.48) > T5 (2.44) > T3 (2.42) > T7 (2.34) > T1 (2.26) > T8 (2.24) > T2 (2.18) > T11 (1.60) and T12 (1.45). The minimum (1.35) benefit cost ratio was recorded in T10 (Sole Him Palam Chana-1). Since the experiment is conducted in mango-based agroforestry system, where the substantial income is also generated from the fruits, in addition to above income generated from agriculture component only.

Table 4.26: Bio-economics of mango-based agroforestry system

Treatments	Cost of cultivation (Rs. ha^{-1})	Total gross returns (Rs. ha^{-1})	Total net returns (Rs. ha^{-1})	B:C Ratio
Mango + HPC-1 + *Rhizobium*	51229.11	115694.39	64465.28	2.26
Mango + HPC-1+ PSB	51229.11	111527.78	60298.67	2.18
Mango + HPC-1 + *Rh* + PSB	51229.11	124027.78	72798.67	2.42
Mango + HPG-17 + *Rhizobium*	51229.11	128750.05	77520.89	2.51
Mango + HPG-17 + PSB	51229.11	125000.38	73770.89	2.44
Mango + HPG-17 + *Rh* + PSB	51229.11	134750.00	83520.89	2.63
Mango + PBG-7 + *Rhizobium*	51229.11	119750.21	68520.89	2.34
Mango + PBG-7 + PSB	51229.11	115000.45	63770.89	2.24
Mango + PBG-7 + *Rh* + PSB	51229.11	127000.46	75770.89	2.48
Sole Him Palam Chana-1	34778.59	46944.44	12165.85	1.35
Sole HPG-17	34778.59	60277.78	20776.97	1.60
Sole PBG-7	34778.59	50277.78	15499.19	1.45

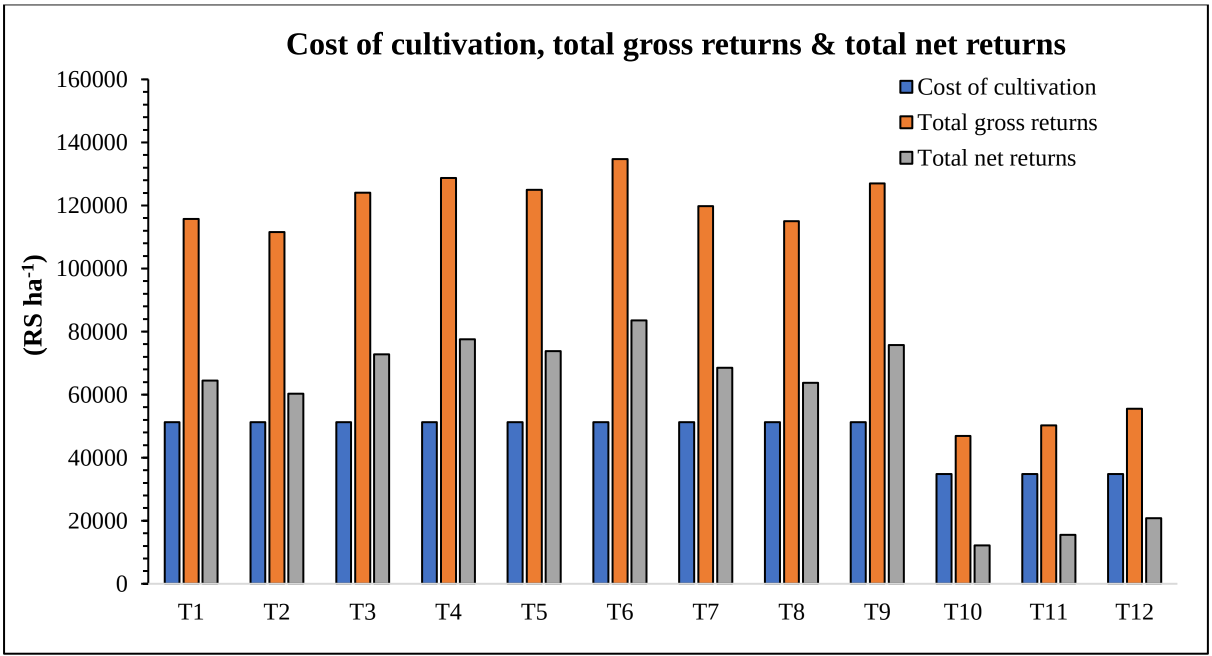

Fig: 4.15: Bio-economics of mango-based agroforestry system

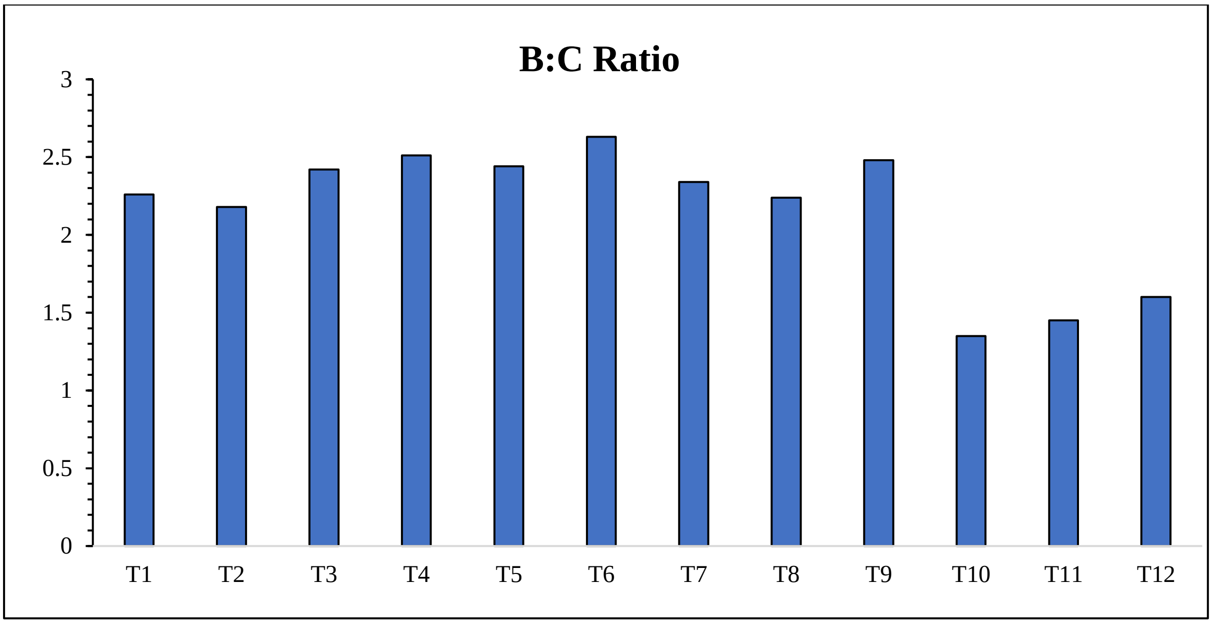

Fig 4.16: Benefit cost ratio of the studied mango-based agroforestry system

Results of the present investigations exhibited that growing agricultural crops with mango is profitable over sole agricultural crop cultivation. This shows that agroforestry is an efficient land use system which makes judicious use of space and other limiting factors like nutrients, moisture, etc. The total net returns were substantially higher under agroforestry compared to sole cropping systems. The higher net returns under agroforestry intervention may be due to additional income realised from the mango trees. The results of the present study are in agreement with Padma (2018) who reported highest net returns for coconut and patchouli combination. Dev *et al*. (2017) also revealed higher B-C ratio (2.83) under bamboo + sesame agroforestry system as compared to sole sesame farming (1.43). Similarly, Das *et al*. (2011) registered higher BC ratio in aonla + turmeric, aonla + ginger and aonla + arbi (6.29, 3.45 and 3.20, respectively) over the sole respective crops (5.86, 3.38 and 1.60, respectively) grown in open field. Prakash and Pant (2015) recorded higher BC ratio (2.66) in *Godetia grandiflora* + *Grewia optiva* agroforestry system as compared to sole flower crop (1.50). Likewise, Bhatt and Mishra (2003) and Sharma *et al*. (2008) obtained higher net returns from agroforestry systems as compared to the sole cropping.

Chapter – 5

SUMMARY AND CONCLUSION

The present investigation entitled "**Effect of biofertilizers on growth and yield of black chickpea (*Cicer arietinum* L.) varieties under mango-based agroforestry system**" was carried out during the year 2022-2023 at RHRTS, Jachh District Kangra (H.P). The aim of the research was to determine the effect of biofertilizers (*Rhizobium* and Phosphate Solubilizing Bacteria) and mango trees on growth and yield attributes of black chickpea varieties grown as an intercrop along with the effect of the agroforestry system on the soil properties. The experiment was laid out in Factorial Randomized Block (02 factorial) Design with combination of factors; varieties (Him Palam Chana-1, HPG-17, PBG-7) and biofertilizers having twelve treatment combinations replicated thrice in order to estimate growth, yield, economic feasibility and soil properties under agroforestry system and control. The crop chickpea was grown as per package of practices published by Directorate of Extension Education, CSK HPKV, Palampur. The observations on growth and yield parameters of black chickpea were recorded at the time of harvesting whereas soil sampling from agroforestry system and control was done after the harvesting. The outcomes of the present findings are summarized here as under:

5.1 Effect of biofertilizers on growth and yield of chickpea varieties under mango-based agroforestry system

The results indicated that growth and yield parameters of black chickpea varieties *viz.,* plant height (cm), no. of nodules plant^{-1}, chlorophyll content (mg g^{-1}), pod length (cm), no. of seeds pod^{-1}, no. of pods plant^{-1}, above ground biomass (q ha^{-1}), below ground biomass (q ha^{-1}), total plant biomass (q ha^{-1}), seed yield (q ha^{-1}) were found to be significantly and positively affected by mango trees and biofertilizers types (*Rhizobium* and Phosphate Solubilizing Bacteria) along with the recommended doses of fertilizers (100%). The higher values for all growth and yield parameters of chickpea varieties were recorded when crop was grown in association with trees along with combination of biofertilizers. The highest seed yield of black chickpea for all three varieties *viz.* Him Palam Chana-1, HPG-17 and PBG-7 was registered when the seeds are treated with both *Rhizobium* as well as phosphate solubilizing bacteria (*Rh* + PSB) along with RDF (100%) *i.e.*, 12.56 q ha^{-1}, 14.70 q ha^{-1} and 13.15 q ha^{-1}, respectively. The lowest seed yield for each variety was however, recorded in control *i.e.,* 9.39 q ha^{-1}, 12.06 q ha^{-1} and 10.06 q ha^{-1}, respectively.

5.2 Biomass production of chickpea varieties

Agricultural crop grown in open had less total plant biomass as compared to crop grown under mango along with biofertilizers and RDF (100%). Highest total plant biomass *i.e.*, 4.17 q ha^{-1}, 5.09 q ha^{-1} and 4.71 q ha^{-1} of black chickpea for all three varieties *viz.* Him Palam Chana-1, HPG-17 and PBG-7 was registered in *Rh* + PSB combination, respectively. The lowest total plant biomass accounting to 3.50 q ha^{-1}, 4.54 q ha^{-1} and 4.46 q ha^{-1} for each variety was however recorded in sole chickpea cropping (control), respectively.

5.3 Total chlorophyll content in leaves of chickpea varieties

Total chlorophyll content was higher in chickpea leaves raised under agroforestry system as compared to control due to the effect of biofertilizers. Highest chlorophyll content in leaves of black chickpea for all three varieties *viz.* Him Palam Chana-1, HPG-17 and PBG-7 was 2.14 mg g^{-1}, 2.58 mg g^{-1}, and 2.31 mg g^{-1}, respectively and lowest for each variety recorded was 1.96 mg g^{-1}, 2.24 mg g^{-1} and 2.19 mg g^{-1}, respectively.

5.2 Soil physico-chemical properties

All physical properties of soil *viz.,* bulk density, particle density, porosity and soil moisture content were not found to be significantly affected in various treatments under mango tree and control. Whereas slight changes in the values have been recorded before and after the harvesting of the chickpea crop.

Nutrient status of the soil under agroforestry system and control was estimated. Among chemical properties *viz* pH and electrical conductivity showed no changes after the harvesting of the crop. On the other hand, it was observed that trees had significant positive effect on the organic carbon, available N, P and K contents. Mostly, tree-crop combinations showed higher values of nutrient contents along with the biofertilizers application compare to control.

5.3 Bio – economics of mango-based agroforestry system

Within varieties higher gross returns, net returns and benefit cost ratio was reported for V2 (HPG-17) in comparison to V1 (Him Palam Chana-1) and V3 (PBG-7). Under the mango-based agroforestry system, highest gross returns (Rs. 134750.00 ha^{-1}), net returns (Rs. 83520.89 ha^{-1}) and benefit cost ratio (2.63) was reported in T6 (Mango + HPG-17 + *Rh* + PSB) and lowest gross returns (Rs. 46944.44 ha^{-1}), net returns (Rs. 12165.85 ha^{-1}) and benefit cost ratio (1.35) was reported in T1 (Sole Him Palam Chana-1).

CONCLUSION

- The present study revealed that chickpea varieties performed better under mango tree as a result of combined application biofertilizers (*Rhizobium* and PSB) and recommended doses of fertilizers as compared to control.
- The performance of chickpea varieties under mango tree was better which led to the higher biomass production of the system.
- Physico-chemical properties of soil were improved under the tree – crop combination with the use of biofertilizers which results in higher amount of nutrients. Improvement in soil properties indicated that agroforestry systems can be sustained for long.
- Higher economic returns were obtained from tree - crop combination. Among varieties, HPG-17 showed the maximum benefit cost ratio *i.e*., 2.63.
- Overall, it was concluded that among the three chickpea varieties V2 (HPG-17) performed best when grown with the mango tree and combined application of *Rhizobium* and PSB. Farmers should adopt this combination (Mango + black chickpea) under similar agro-ecological conditions for higher economic returns.

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APPENDIX

Appendix-I: Meteorological data of the study site on monthly basis for the year 2022-2023

Months	Rainfall (mm)	Temperature (ºC)		Average humidity (%)
		Maximum	Minimum	
November	23.3	25	12	38
December	46.6	20	8	33
January	44.6	18	8	51
February	5.54	24	11	43
March	10.52	32	16	38
April	40	33	17	33

Source: https://www.worldweatheronline.com/kangra-weather-averages/himachal-pradesh/in.aspx

Appendix II: Cost of cultivation of growing Black Chickpea (*Cicer arietinum*) Rs ha^{-1}

Cost components	Unit	Cost/ unit	Qty	Value (Rs)
A. Variable costs				
1) Non-labour input i) Seeds/seedlings	Kg	50/ Unit	3	150
ii) FYM	Qtls.	150/ Unit	100	14500
iii) Fertilizers				
1. Urea	Kg	6.4/ Unit	2	12.8
2. SSP	Kg	8.4/ Unit	4	33.6
3. MOP	Kg	19.6/ Unit	2	39.2
iv) Plant protection chemical	Rs.	-	-	-
v) Others		-	-	1000
Sub-total (1)	Rs.	-	-	15,735.6
2) Labour input				
i) Ploughing	hour	750	1.5	1125
ii) Field preparation	MD	220	4	880
iii) Sowing	MD	220	7	1540
iv) Weeding	MD	220	6	1320
v) Irrigation	MD	220	4	780
vi) Fertilizer application	MD	220	3	660
vii) Harvesting	MD	220	4	880
viii) Others	Rs.	-	-	1000
Sub-total (2)	Rs.	-	-	8,185
Total variable costs Sub-total (1) + (2)	Rs.	-	-	26045.683
3) Miscellaneous (2% of total variable cost)	Rs.	-	-	1254.412
4) Interest on working capital (5 %)	Rs.	-	-	9733.495
B. Fixed costs		-		
i) Depreciation	Rs.		300	300
ii) Land revenue	Rs.	-	31.25	31.25
iii) Rental value of owned land	Rs.	-	7410	7410
iv) Interest on fixed capital Sub-total	Rs. Rs.	-	516.56	516.56 8257.81
Total Costs	Rs.	-	-	45167

Appendix III: Cost of cultivation of growing Mango (*Mangifera indica*) Rs ha^{-1}

Item of Cost	Units	Quantity	Unit Rate	2015	2016	2017	2018	2019	2020	2021	2022	Total (Rs)
Bush Clearing	MD	33	120	3960	0	0	0	0	0	0	0	3960
Digging of pits (45*45*45cm) @25 pits/MD	MD	5	120	600	0	0	0	0	0	0	0	600
Cost of seedlings	Seedlings	156	20	3120	0	0	0	0	0	0	0	3120
Planting and refilling of pits	MD	3	120	360	0	0	0	0	0	0	0	360
Cost of FYM @2kg per pit	kg	156	2.0	220	270	290	290	310	310	320	320	2330
Fertilizer	Rs.	-		180	220	250	250	250	250	250	250	1900
Insecticide/pesticide	Rs.	-		280	340	370	370	400	400	430	430	3020
Intercultural operations	MD	-		160	210	230	230	250	250	250	250	1830
Fruit extraction	MD	-		0	800	1100	1800	2000	2200	2400	3000	13300
Miscellaneous (2% of total cost)	Rs.	-		221.24	77.90	88.50	113.70	123.20	134.4	140.27	145.50	1044.71
Interest on working capital (5%)	Rs.	-		553.1	194.75	221.25	226.75	308	346	372	395	2616.85
Land Revenue	Rs.	-		31.50	31.50	31.50	31.50	31.50	31.50	31.50	31.50	252
Land rental fee	Rs.	-		3734	3734	3734	3734	3734	3734	3734	3734	29872
Interest on fixed capital (10%)	Rs.	-		460.75	452.05	449.55	448.05	446.05	444.55	443.50	441.25	3585.75
Depreciation and maintenance	Rs.	-		342	255	230	215	195	180	165	150	1732
Grand total	Rs.	-		14222.59	6585.2	6994.8	7709	8047.75	8280.45	8536.27	9147.25	71524

Appendix-IV: Analysis of variance of effect of biofertilizers on height of black chickpea grown under mango-based agroforestry system at 30, 60, 90, 120DAS and at harvest

Source of variation	df	Mean squares				
		Plant height(cm) 30 DAS	Plant height(cm) 60 DAS	Plant height(cm) 90 DAS	Plant height(cm) 120 DAS	Plant height(cm) 150 DAS
Replication	2					
Variety (V)	2	13.755	79.592	42.516	71.647	72.334
Biofertilizers (B)	3	16.376	31.996	22.431	28.390	27.320
V X B	6	0.036	0.149	0.117	0.021	0.100
Error	22	0.749	0.623	0.924	0.639	0.785
Total	35					

Appendix-V: Analysis of variance of effect of biofertilizers on number of root nodules of black chickpea grown under mango-based agroforestry system at 60 DAS and 90 DAS

Source of variation	df	Mean squares	
		No. of nodules (60 DAS)	No. of nodules (90 DAS)
Replication	2		
Variety (V)	2	4.662	4.838
Biofertilizers (B)	3	30.571	57.381
V X B	6	0.061	0.101
Error	22	0.826	0.756
Total	35		

Appendix-VI: Analysis of variance of effect of biofertilizers on chlorophyll content of black chickpea leaves grown under mango-based agroforestry system at 60 DAS and 90 DAS

Source of variation	df	Mean squares	
		Chlorophyll content (60 DAS)	Chlorophyll content (90 DAS)
Replication	2		
Variety (V)	2	0.077	0.354
Biofertilizers (B)	3	0.353	0.084
V X B	6	0.014	0.007
Error	22	0.002	0.003
Total	35		

Appendix-VII: Analysis of variance of effect of biofertilizers on number of pods plant^{-1} of black chickpea grown under mango-based agroforestry system

Source of variation	df	Sum of squares	Mean squares
		Number of pods plant^{-1}	
Replication	2	8.126	
Variety (V)	2	664.006	332.003
Biofertilizers (B)	3	166.945	55.648
V X B	6	1.459	0.243
Error	22	63.536	2.888
Total	35	904.072	

Appendix-VIII: Analysis of variance of effect of biofertilizers on length of pods of black chickpea grown under mango-based agroforestry system

Source of variation	df	Sum of squares	Mean squares
		Length of pods	
Replication	2	0.012	
Variety (V)	2	0.602	0.301
Biofertilizers (B)	3	0.219	0.073
V X B	6	0.022	0.004
Error	22	0.062	0.003
Total	35	0.918	

Appendix-IX: Analysis of variance of effect of biofertilizers on number of seeds pod^{-1} of black chickpea grown under mango-based agroforestry system

Source of variation	df	Sum of squares	Mean squares
		Number of seeds pod^{-1}	
Replication	2	0.007	
Variety (V)	2	0.607	0.303
Biofertilizers (B)	3	0.128	0.043
V X B	6	0.016	0.003
Error	22	0.233	0.011
Total	35	0.990	

Appendix-X: Effect of biofertilizers on above plant biomass of plot^{-1} of black chickpea grown under mango-based agroforestry system

Above ground biomass (kg plot^{-1})					
Treatments		Varieties			Mean
		V_1	V_2	V_3	
Mango	***Rhizobium***	0.64	0.80	0.75	**0.73**
	PSB	0.61	0.77	0.72	**0.70**
	***Rh* + PSB**	0.68	0.83	0.77	**0.76**
	Control	0.58	0.75	0.69	**0.67**
	Mean	**0.63**	**0.79**	**0.73**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.01	0.01	0.00	
Biofertilizers (T)		0.01	0.01	0.00	
V x T		NS	0.01	0.01	

Appendix-XI: Analysis of variance of effect of biofertilizers on above ground biomass of black chickpea grown under mango-based agroforestry system

Source of variation	df	Mean squares	
		Above ground biomass (kg plot^{-1})	Above ground biomass (q ha^{-1})
Replication	2		
Variety (V)	2	0.079	2.441
Biofertilizers (B)	3	0.014	0.418
V X B	6	0.000	0.004
Error	22	0.000	0.004
Total	35		

Appendix-XII: Effect of biofertilizers on below ground biomass plot^{-1} of black chickpea grown under mango-based agroforestry system

Below ground biomass (kg plot^{-1})					
Treatments		Varieties			Mean
		V_1	V_2	V_3	
Mango	***Rhizobium***	0.06	0.08	0.07	**0.07**
	PSB	0.06	0.08	0.07	**0.07**
	***Rh* + PSB**	0.07	0.09	0.08	**0.08**
	Control	0.05	0.07	0.06	**0.06**
	Mean	**0.06**	**0.08**	**0.07**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.00	0.00	0.00	
Biofertilizers (T)		0.00	0.00	0.00	
V x T		NS	0.00	0.00	

Appendix-XIII: Analysis of variance of effect of biofertilizers on below ground biomass of black chickpea grown under mango-based agroforestry system

Source of variation	df	Mean squares	
		Below ground biomass (kg plot^{-1})	Below ground biomass (q ha^{-1})
Replication	2		
Variety (V)	2	0.001	0.038
Biofertilizers (B)	3	0.000	0.011
V X B	6	0.000	0.000
Error	22	0.000	0.000
Total	35		

Appendix-XIV: Effect of biofertilizers on total plant biomass plot^{-1} of black chickpea grown under mango-based agroforestry system

Total Plant Biomass (kg plot^{-1})					
Treatments		**Varieties**			**Mean**
		V_1	**V_2**	**V_3**	
Mango	***Rhizobium***	0.70	0.88	0.82	**0.80**
	PSB	0.66	0.85	0.79	**0.77**
	***Rh* + PSB**	0.75	0.92	0.85	**0.84**
	Control	0.63	0.82	0.75	**0.73**
	Mean	**0.69**	**0.86**	**0.80**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.01	0.01	0.00	
Biofertilizers (T)		0.01	0.01	0.00	
V x T		NS	0.01	0.01	

Appendix-XV: Analysis of variance of effect of biofertilizers on total plant biomass of black chickpea grown under mango-based agroforestry system

Source of variation	df	Mean squares	
		Total plant biomass (kg plot^{-1})	Total plant biomass (q ha^{-1})
Replication	2		
Variety (V)	2	0.100	3.082
Biofertilizers (B)	3	0.018	0.558
V X B	6	0.000	0.005
Error	22	0.000	0.004
Total	35		

Appendix-XVI: Effect of biofertilizers on seed yield plot^{-1} of black chickpea grown under mango-based agroforestry system

Seed yield (kg plot^{-1})					
Treatments		Varieties			Mean
		V_1	V_2	V_3	
Mango	***Rhizobium***	1.96	2.43	2.11	**2.17**
	PSB	1.81	2.29	1.93	**2.01**
	***Rh* + PSB**	2.26	2.65	2.37	**2.42**
	Control	1.69	2.17	1.81	**1.89**
	Mean	**1.93**	**2.30**	**2.14**	
Factors		**C.D. (0.05)**	**SE(d)**	**SE(m)**	
Variety (V)		0.05	0.03	0.02	
Biofertilizers (T)		0.06	0.03	0.02	
V x T		0.11	0.05	0.04	

Appendix-XVII: Analysis of variance of effect of biofertilizers on seed yield of black chickpea grown under mango-based agroforestry system

Source of variation	**df**	**Mean squares**	
		Seed yield plot^{-1}	**Seed yield (q ha^{-1})**
Replication	2		
Variety (V)	2	0.404	12.477
Biofertilizers (B)	3	0.478	14.713
V X B	6	0.089	2.736
Error	22	0.004	0.121
Total	35		

Appendix-XVIII: Analysis of variance of effect of biofertilizers on bulk density, particle density, porosity and soil moisture content of soil under mango-based agroforestry system

Source of variation	**df**	**Mean squares**			
		Bulk density (g cm^{-3})	**Particle density (g cm^{-3})**	**Porosity (%)**	**Soil moisture content (%)**
Replication	2				
Variety (V)	2	0.000	0.005	0.785	0.003
Biofertilizers (B)	3	0.001	0.011	3.238	0.052
V X B	6	0.000	0.002	2.204	0.029
Error	22	0.000	0.008	3.611	0.039
Total	35				

Appendix-XVIX: Analysis of variance of effect of biofertilizers on soil pH, soil electrical conductivity and soil organic carbon under mango-based agroforestry system

Source of variation	df	Mean squares		
		pH	**Electrical conductivity (dS m^{-1})**	**Soil organic carbon (%)**
Replication	2			
Variety (V)	2	0.001	0.000	0.013
Biofertilizers (B)	3	0.050	0.000	0.009
V X B	6	0.019	0.000	0.005
Error	22	0.059	0.000	0.002
Total	35			

Appendix-XVX: Analysis of variance of effect of biofertilizers on available nitrogen, available phosphorous and available potassium under mango-based agroforestry system

Source of variation	df	Mean squares		
		Nitrogen (kg ha^{-1})	**Phosphorus (kg ha^{-1})**	**Potassium (kg ha^{-1})**
Replication	2			
Variety (V)	2	54.213	1.827	33.390
Biofertilizers (B)	3	7169.499	52.387	1.134.564
V X B	6	5.024	4.434	30.707
Error	22	1.934	0.224	1.294
Total	35			

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Title of the thesis	**:**	**"Effect of biofertilizers on growth and yield of black chickpea (*Cicer arietinum* L.) varieties under mango-based agroforestry system"**
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Date of Thesis Submission	**:**	
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ABSTRACT

The present investigation entitled "**Effect of biofertilizers on growth and yield of black chickpea (*Cicer arietinum* L.) varieties under mango-based agroforestry system**" was carried out during the year 2022-2023 at Regional Horticultural Research and Training Station, Jachh-Kangra under sub-tropical conditions of Himachal Pradesh. The aim of the research was to determine the effect of biofertilizers (*Rhizobium* and Phosphate Solubilizing Bacteria) and mango trees on growth and yield attributes of black chickpea varieties grown as an intercrop along with the effect of the agroforestry system on the soil properties. The experiment was laid out in Randomized Block Design with combination of factors; varieties (Him Palam Chana-1, HPG-17, PBG-7) and biofertilizers having twelve treatment combinations, replicated thrice in order to estimate growth, yield, economic feasibility and soil properties under agroforestry system and control. Result showed the maximum values for growth and yield parameters of black chickpea varieties treated with combined application of *rhizobium* and phosphate solubilizing bacteria under mango-based agroforestry system as compared to control. The highest seed yield of black chickpea for all three varieties *viz.* Him Palam Chana-1, HPG-17, PBG-7 was registered in which with the seeds are treated with both Rhizobium as well as phosphate solubilizing bacteria (*Rh* + PSB) *i.e.,* 12.56 q ha^{-1}, 14.70 q ha^{-1} and 13.15 q ha^{-1} respectively. The lowest seed yield for each variety was however, recorded in control in which seeds are not treated with biofertilizers *i.e.,* 9.39 q ha^{-1}, 12.06 q ha^{-1} and 10.06 q $ha^{-1,}$ respectively. Among all treatments the highest (4.66q ha^{-1}) total plant biomass was recorded (except seed yield) when biofertilizers were used in combination and the lowest (4.07 q ha^{-1}) in control where no biofertilizers were applied. Physical properties bulk density, particle density, porosity and soil moisture content of soil and chemical properties namely pH and electrical conductivity does not show a significant change before and after the application of biofertilizers while there was significant increase in soil nutrients N, P and K. HPG-17 variety recorded the maximum available nitrogen and potassium content in the soil followed by Him Palam Chana-1 and PBG-7. The highest phosphorus content in the soil was recorded under variety PBG-7. From economic point of view, higher (Rs. 1,34,750.00 ha^{-1}) gross returns and B:C (2.63) ratio were obtained in T6 (Mango + HPG-17 + *Rh* + PSB) as compared to control.

Overall, it was concluded that among the three chickpea varieties HPG-17 performed best when grown with the mango tree and combined application of *Rhizobium* and PSB. Farmers should adopt this combination (Mango + black chickpea) with biofertilizers applications under similar agro-ecological conditions for higher economic returns.

Himanshu Saini	**Dr. Vipan Guleria**
Date:	**Date:**

Head of the Department

BRIEF BIO-DATA

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10+2	2017	HPBOSE	77.6	First
Graduation	2021	HNBGU, Srinagar (Garhwal), Uttarakhand	71	First

Whether sponsored by some state/Central Govt./Univ./SAARC	:	No
Scholarship/ Stipend/ Fellowship, any other financial assistance received during the study period	:	University Stipend