AGRO TECHNIQUES IN BHINDI FOR PRECISION FARMING

BY

AMMU PUNNOOSE

(2016-21-018)

THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE

REQUIREMENT FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY IN AGRICULTURE

FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM – 695522
KERALA, INDIA

2019

DECLARATION

I, hereby declare that this thesis entitled **"AGRO TECHNIQUES IN BHINDI FOR PRECISION FARMING"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani,

Date:

Ammu Punnoose

(2016-21-018)

CERTIFICATE

Certified that this thesis entitled **"AGRO TECHNIQUES IN BHINDI FOR PRECISION FARMING"** is a record of research work done independently by **Ms. Ammu Punnoose (2016-21-018)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellayani,
Date:

Dr. T. Sajitha Rani
(Chairman, Advisory Committee)
Professor and Head
Instructional Farm,
College of Agriculture, Vellayani

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Ammu Punnoose (2016-21-018)**, a candidate for the degree of **Doctor of philosophy in Agriculture** with major in Agronomy, agree that the thesis entitled **"AGRO TECHNIQUES IN BHINDI FOR PRECISION FARMING"** may be submitted by Ms. Ammu Punnoose (2016-21-018), in partial fulfilment of the requirement for the degree.

28/11/19

Dr. T. Sajitha Rani
Professor and Head
Instructional Farm
College of Agriculture, Vellayani
Thiruvananthapuram- 695 522

28/11/19

Dr. O. Kumari Swadija
Professor and Head
Department of Agronomy
College of Agriculture, Vellayani
Thiruvananthapuram- 695 522

28/11/2019

Dr. P. Babu Mathew
Professor
Department of Agronomy
College of Agriculture, Vellayani
Thiruvananthapuram- 695 522

28-11-19

Dr. B. Rani
Professor
Department of Soil Science &
Agricultural Chemistry
College of Agriculture, Vellayani
Thiruvananthapuram- 695 522

Dr. Roy Stephen
Professor
Department of Plant Physiology
College of Agriculture, Vellayani,
Thiruvananthapuram- 695 522

EXTERNAL EXAMINER

28/11/19

Dr. S. Mala, Ph. D
Professor (Agronomy)
PAJANCOA & RI
Karaikal- 609 603

Acknowledgements

And so comes the time to look back on the path traversed during the endeavour and to remember the faces and spirits behind the action with a sense of gratitude.

First and foremost I bow my head before the ***Almighty God*** *for enlightening and making me confident and optimistic throughout my life and enabled me to successfully complete the thesis work.*

It is with immense pleasure I avail this opportunity to express my deep sense of whole hearted gratitude and indebtedness to my major advisor ***Dr. Sajitha Rani T,*** *Professor and Head, Instructional Farm, College of Agriculture, Vellayani for her genuine and constant encouragement, worthy guidance and critical comments during the course of investigation, enables me to complete the research successfully.*

I consider it as my privilege to express my deep-felt gratitude to ***Dr. O. Kumari Swadija,*** *Professor and Head, Dept. of Agronomy for her constant support, valuable suggestions and cooperation throughout the research programme.*

I express my heartiest gratitude to ***Dr. P. Babu Mathew,*** *Professor, Department of Agronomy, College of Agriculture, Vellayani for his precious suggestions, generous support and constructive criticisms.*

I am very thankful to ***Dr. Rani B,*** *Professor, Department of Soil Science and Agriculture Chemistry College of Agriculture, Vellayani for her valuable help, advice and constant encouragement which facilitated my research work..*

I like to express my sincere thanks to ***Dr. Roy Stephen,*** *Professor, Department of Plant Physiology, College of Agriculture, Vellayani for his precious suggestions and kind support at various stages of the study.*

I am extremely thankful to all the ***faculty members and other staff members*** *who provided all the facilities for me to conduct this experiment in college. I also thank them for the co-operation and constant support during the conduct of field experiment. The help rendered by the labourers of instructional farm are also very much appreciated.*

I find no words to express my sincere thanks to all my seniors, juniors and my dear friends, ***Aswani, Pintu, Gayathri, Reshma, Nitya, Maheshwari,*** *not only in my research work but also throughout my Ph D programme.*

I express my sincere thanks to my Juniours, ***Shilpa, Merin , Feba, Ishrath Lakshmi, Dhanam, Gritta, Anjana, Tousim, Asu, Aparna, Afna, Namitha, Reni,*** *for their affection and kind help offered during my thesis work. My special thanks to* ***Mr.Shibu,*** *and* ***Mrs.Vimala*** *or their immense help and cooperation during the laboratory work.*

I express my deep sense of gratitude to ***Kerala Agricultural University*** *for financial and technical support for persuasion of my study and research work.*

Above all, I am forever beholden to my loving ***parents*** *(Punnoose and Shirly),* ***husband*** *(Manu),* ***sister*** *(Liya) and* ***brother in law*** *(Jerry) for their constant prayers, personal sacrifice, boundless love, mental support and incessant inspiration throughout my studies.*

I once again express my heartfelt thanks to all those who helped me in completing this venture on time.

Ammu Punnoose

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES AND APPENDIX

LIST OF ABBREVIATIONS

AMF	Arbuscular mycorrhizal fungi
B: C ratio	Benefit cost ratio
CD	Critical difference
cfu	Colony forming unit
CGR	Crop growth rate
DAT	Days after transplanting
DMP	Dry matter production
FAO	Food and Agricultural Organization
Fig.	Figure
FYM	Farm yard manure
GoI	Government of India
ha	Hectare
K	Potassium
KAU	Kerala Agricultural University
LAI	Leaf area index
MOP	Muriate of potash
mt	Million tons
N	Nitrogen
NAR	Net assimilation rate
NS	Non-significant
OC	Organic carbon
P	Phosphorus
PGPR	Plant growth promoting rhizobacteria
POP	Package of practices
RBD	Randomized block design
RDF	Recommended dose of fertilizer
RGR	Relative growth rate
RH	Relative humidity
SE	Standard error
WUE	Water use efficiency

INTRODUCTION

1. INTRODUCTION

India, the second largest producer of vegetables in the world after China, needs still higher vegetable production to fulfil the requirement of its ever increasing population. There is a huge gap between potential yield and the actual yield obtained from the different vegetable crops in India. Moreover, for the production of quality produce, rain shelter is more preferred to open field cultivation during rainy season. During favourable climatic conditions, well maintained open field conditions may result in good yield than protected conditions. In the era of hi-tech farming, rain shelter and precision farming in open field conditions are the most preferable and affordable means of cultivation for farmers. Protected cultivation enables to grow crops throughout the year.

Among the various factors for crop production, increased plant population has been identified as one of the factors that contribute to poor plant growth and lower yields. Spacing determines the area available for a plant for growth resources, such as water, light and nutrients. Inappropriate spacing could result in yield reduction. While proper spacing provides optimum canopy exposure to light and also provide hence uniform area for water and mineral uptake by roots. Hence, optimum plant population is required for higher yields in bhindi since plant growth and yield are affected by inter and intra row spacing.

Along with proper spacing, inoculation with bio inoculants could also positively influence the growth, yield and quality of bhindi. Bio inoculants are able to fix nitrogen (N) and solubilise phosphorus (P) and potassium (K) in soil, thus making them available to plants. Hence, microbial inoculants as bio fertilizers can be a partial substitute for chemical fertilizers in bhindi. Plant growth promoting rhizobacteria (PGPR) are a group of bacteria that colonize plant roots and help in increasing plant growth and yield. Arbuscular micorrhizal fungi (AMF) solubilises P and improves the root activity in soil. Application of bio inoculants helps to improve soil health and increases nutrient availability in soil and thus crop productivity.

Drip system for irrigation and fertigation for nutrient supply, the two basic components of precision farming, could help in accomplishing higher water and nutrient use efficiencies. Fertigation is a method of fertilizer application in which water soluble fertilizers are dissolved in the irrigation water used for the drip system. Fertigation permits application of nutrients directly to the area of high concentration of active roots and as needed by the crop. It also helps in reducing labour charges and increasing the flexibility of fertilizer application. Scheduling fertilizer application on the basis of crop need offers the possibility of reducing nutrient losses associated with conventional application, thereby increasing nutrient use efficiency. Performance of the crop is usually limited by the inadequate availability of nutrients in the soil. This can be rectified by the application of higher dose of fertilizers. But the over use of fertilizers also could degrade soil quality. In order to avoid the unscientific use of fertilizers and to study the crop response towards fertilizers, varying doses of fertigation should be tested to standardise the fertilizer dose.

Foliar application of fertilizers results in rapid nutrient uptake, increased fertilizer use efficiency and reduced nutrient requirement of crops. Foliar application leads to penetration of nutrients through the cuticle and thus helps to rectify nutrient deficiencies rapidly. Use of nano fertilizers as foliar nutrients is gaining much momentum now a days. The most important benefit of nano foliar nutrient application is that it can feed plants gradually in a controlled manner, in contrast to what occurs in the case of common fertilizers. Nano fertilizers intend to improve nutrient use efficiencies by exploiting the unique properties of nano particles. Since nano fertilizers are designed to deliver the nutrients slowly over a long period of time, the loss of nutrients is substantially reduced vis-à-vis environmental safety. The application of fertilizers as foliar spray could be an additional benefit to plants due to improvement in its growth, yield and quality of produce.

Bhindi is one of the important vegetable crops grown throughout the tropics. It has got high nutritional value and hence vast potential for export. India ranks first in the production of bhindi in the world with a production of 6.14 mt from an area of 528.4 ha (GoI, 2017). India accounts for 41 per cent of world acreage and 69 per cent of world production of bhindi (FAO, 2010). For bhindi, grown under rain shelter and open field conditions, the growth periods, microclimate and performance will be different. Optimum crop performance can be limited by environmental as well as crop growth factors. So it is necessary to study the potential of both production systems under the same climatic conditions. To improve the overall production of bhindi and to make the off season cultivation possible we need standardised agro techniques under precision farming techniques. Taking all these into consideration, the present study was formulated with the following objectives:

(1) To standardize the spacing and response of bio inoculants for bhindi under rain shelter and open field conditions

(2) To evaluate the effect of fertigation and foliar nutrition on improving growth, yield and quality of bhindi and

(3) To work out the economics of different cultivation systems.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Bhindi, one of the most important vegetable crops in India plays a major role in the diet of Indians. India ranks first in the production of bhindi indicating its demand in the market among vegetables. Bhindi is basically grown in tropical and subtropical regions and this makes bhindi an important vegetable crop of Kerala as well. Heavy rain and higher humidity in Kerala denies the continuous cultivation of bhindi in the state. Off season cultivation can be made possible by providing rain shelter to meet the demand of vegetables. Adoption of precision techniques such as fertigation and foliar application of fertilizers and the other factors such as spacing and bio inoculants which influence the growth and yield of crops need standardisation. Research results available on rain shelter cultivation, spacing, bio inoculation, fertigation and foliar application in bhindi are reviewed in this chapter.

2.1 EFFECT OF SPACING

2.1.1 Growth Characters

Plant spacing is an important factor for bhindi production both in summer and rainy season (Saimbhi *et al.*, 1975; Palanisamy *et al.*, 1986; Shaha *et al.*, 1989; Hossain *et al.,* 1999). Spacing plays a vital role in influencing the plant growth attributes viz. plant height, number of branches, fruit yield, seed yield and its quality. Optimum plant density ensures that plants grow uniformly and properly through efficient utilization of moisture, nutrients, light and thereby resulting in maximum yield of bhindi.

Feleafel and Ghoneim (2005) studied effect of different plant densities (9.5, 4.8 and 3.2 plants m^{-2}) on vegetative growth. The results indicated that increasing plant density from 3.2 to 9.5 plants m^{-2} was accompanied with reduction in number of branches, number of leaves and leaf area per plant. Agba *et al.* (2011) in a study to compare five populations of bhindi (i.e. 1,11,111 plants ha^{-1}; 55,555 plants ha^{-1}; 35,714 plants ha^{-1}, 27,777 plants ha^{-1} and 23,810 plants ha^{-1}) observed that high density cultivation (1,11,111 plants ha^{-1}) resulted in maximum plant

21

height and reduced number of branches per plant and dry matter production per plant. Under wider plant spacing *ie.,* lower plant population per unit area, the individual plant gets more area for plant nutrient absorption and more light and air for better growth and development. Also, there will be lesser competition for light and nutrients due to reduced overlapping by adjacent bhindi plants within the row. As the plant population is increased, there will be increased competition among plants for nutrients, light and air which results in poor vegetative growth. Desai and Ketan (2011) assessed the response of bhindi to various spacings in terms of stem girth, number of leaves, number of roots and number of branches per plant and these characters were higher for plant grown under low density (45 cm x 40 cm spacing) followed by moderate and high plant density (45 cm x 30 cm and 45 cm x 20 cm, respectively). Maurya *et al.* (2013) also observed higher plant height for closer spacing (30 x 45 cm) and the lowest plant height in wider spacing (60 x 45 cm). It was observed that, the taller bhindi plants had fewer branches and less number of leaves. Leaf number also decreased over time possibly due to unfavourable weather conditions and senescence (Ijoyah *et al.* (2010); Islam *et al.* (2011); Ekwu and Nwokwu (2012); Madisa *et al.* (2015)). Kumar *et al.* (2016) also studied the effect of spacing on plant growth and recorded that the reduced competition for light and other resources as well as reduced overlapping from adjacent bhindi plants within the population might have enabled the plants to utilize its energy for maximum branching.

Increase in number of leaves leading to higher rates of photosynthesis and increased carbohydrate production was obtained by Manuel *et al.* (1998). Leaf area index (LAI) is directly related to photosynthesis and fewer leaves mean a lower LAI, resulting in less light interception and lower total biomass production. Therefore, light interception can be altered by changing the row and plant spacing and plant per row orientation to attain the potential yield of a crop. Similarly, Manuel *et al.* (1998) also obtained the highest LAI of 1.94 from the highest plant density of bhindi crop while lower LAI of 1.31 and 1.36 were obtained from wider spacing treatments (0.50 m x 0.31 m and 0.50 m x 0.41 m respectively).

Warner (2003) also stated that internal penetration of radiation through the canopy decreased as plant density increased in tomato. Cushman *et al.* (2005) observed a decrease in leaf area with increased LAI, as plant population increased in bhindi. Mohammad *et al.* (2012) explained that plant biomass production per unit area of land is directly related to radiation interception and they also mentioned that higher LAI led to increased radiation interception at higher plant densities which resulted in higher biomass and fruit yield in pepper. Zibelo *et al.* (2016) observed an increase in LAI with decreased intra row spacing in bhindi.

Stoffella and Bryan (1988) observed decreased root and shoot weight, shoot: root ratio, stem diameter and increased plant height at higher plant populations. Similar results of increase in root length with increased spacing were also reported by Singh (1996) in bhindi. The larger intra-row spacing led to increased root yield and reduced total shoot yield, resulting in a higher root: shoot ratio, compared to low intra-row spacing (Djurovka *et al.,* 1997). Kabir *et al.* (2013) also reported higher root length with increased spacing in carrot. According to Mi *et al.* (2016), under high plant density, carbon allocated to the roots as well as total length of the roots can be greatly reduced. The reduction in total root length in maize was possibly due to the competition for nutrients and water between the roots of the neighbouring plants.

2.1.2 Yield Attributes and Yield

Improper plant spacing can cause reduction in the yield of bhindi. But planting with proper spacing increases yield and quality. According to Birbal *et al.* (1995), spacing did not affect number of days to 50 per cent flowering for the bhindi variety Varsha Uphar. Singh (1996) and Abdul (1999) also reported that plant spacing had no significant effect on number of days to flowering in bhindi. Ali (1999) reported that minimum number of days was required to flower where the closest inter row spacing and intra row spacing was adopted, probably to escape from the stress and for seed dispersal, resulting in early flowering. Yadav and Dhankhar (1999), Amjad *et al.* (2001), Rahman.

(2005), EL-Waraky (2014) and Celline *et al.* (2015) reported early or minimum days to flowering for widely spaced plants compared to closely spaced plants.

Singh (1996) showed that wider plant spacing improved fruit retention by 23 per cent than higher plant density in bhindi. Turk *et al.* (2003), working on lentil, noted that the denser plant population hastened the days to flowering. Moniruzzaman *et al.* (2007) found that closer spacing (60 cm × 30 cm) forced the plants to grow taller and increased seed yield ha^{-1} but reduced number of mature fruits per plant, length and diameter of mature fruit, number of seeds per fruit, 1000-seed weight and seed $yield^{-1}$ plant. Studies conducted by Ekwu and Nwokwu (2012) showed that the shortest planting distance (50 cm x 25 cm) produced more number of days to 50 per cent anthesis and the biggest fruits. The highest number of fruits, length and diameter of fruits were recorded at the widest plant spacing (50 cm x 75 cm) in bhindi.

Yield attributes *viz.*, days to complete flowering, number of fruits per plant, length of capsule, thickness of fruit, number of seeds per capsule, raw seed yield per plant and processed seed yield per plant were found maximum under wider spacing followed by medium and closer spacing (Singh 1996). The findings of Christo and Onuh (2005) revealed that fruit length increased in plants when grown under wider spacing than those at closer spacing. Similarly, Mushayabasa *et al.* (2014) also noticed higher fruit length under wider spacing. Widely spaced plants produced heavier fruits as they were stronger plants than at closer spacing. Wider spacing facilitated the plants to develop properly with less inter and intra plant competition for utilizing the available resources resulting in higher yield per plant (Madisa *et al.*, 2015) in bhindi.

Asiegbu (1997) stated that one of the reasons for the low yield of bhindi fruit was plant stand ha^{-1}. Dhankhar and Yadav (1999) also reported that there are several reasons for poor growth and yield of bhindi, among which, intra-row spacing plays an important role. Whitehead and Singh (2000) who reported that the establishment of optimum population per unit area in the field is essential to get maximum yield. Higher yield with optimum plant population was observed in bhindi (Ijoyah *et al.*, 2010) and in capsicum (Islam *et al.*, 2011). Desai and Ketan (2011) noticed ideal plant growth under wider spacing resulting in higher number of fruits and yield per plant with increased length, girth and weight of bhindi fruits.

Gupta (1990) noticed the lowest fruit weight (11.6 g per fruit) and the highest yield ha^{-1} with bhindi *cv.* Pusa Sawani under closer plant spacing. Firoz *et al.* (2007); Moniruzzaman *et al.* (2007) and Maurya *et al.* (2013) recorded higher yield from closer spacing. Agba *et al.* (2011) reported the highest fresh fruit yield for high density cultivation (1,11,111 plants ha^{-1}) when compared to lower plant density (23,810 plants ha^{-1}). Ram *et al.* (2013) opined that better vegetative growth attributes due to lower plant population could not compensate for the loss of yield.

2.1.3 Physiological Parameters

According to Radford (1967) closer spacing resulted in maximum CGR as the plants are taller and denser enough to utilize all environmental parameters. Srinivas and Hegde (1984) reported that increased spacing increased the dry matter production (DMP) and reduced the leaf area (LA), LAI and crop growth rate (CGR). Higher relative growth rate (RGR) values at lower population density were reported by Islam *et al.* (2002) in pea. Zajac *et al.* (2005) found a positive relation between dry matter yield and growth indices especially CGR. This result was similar to the findings of Agba *et al.* (2011) who reported that the dry matter per plant fraction gets reduced with higher plant population. Dutta *et al.* (2015) stated that higher dry matter accumulation was due to the combined effect of higher plant height and LAI under closer spacing. Meena *et al.* (2017) revealed that higher plant population levels of 1,66,666 plants ha^{-1} gave higher CGR and a lower population level of 66,666 plants ha^{-1} showed higher RGR in baby corn.

Mbarek and Boujelben (2004) reported higher irrigation water use efficiency with double row planting in tomato under greenhouse. Wondatir *et al.*

(2013) noticed that water productivity can be increased by increasing yield per unit land area. Higher WUE was achieved with closer spacing in baby corn (Dutta *et al.*, 2015).

2.1.4 Fruit Quality

Bhindi can be considered as a high protein vegetable when compared with *Moringa olifera* (4.2 g per 100 g), *Gnetum africanum* (1.5 g per 100 g), and *Pterocarpus* (2.0 g per 100 g) (Nzikou *et al.,* 2006) and this indicates the nutritional quality of bhindi fruit and its potential to use as a good source of protein. Paththinige *et al.* (2008) stated that fruit quality of bhindi was affected by inter and intra-row spacing. Jana *et al.* (2010) conducted an experiment with four different spacings and recorded that wider spacing of 45 cm x 30 cm resulted in high Vitamin C content in fruits (25.3 mg per 100 g). Desai and Ketan (2011) noticed that the ascorbic acid content was higher in the fruits harvested from closer spacing.

2.1.5 Uptake of Nutrients, Available Nutrient Status and Microbial Population in Soil after Experiment

Higher nutrient uptake with wider spacing was reported by Ibeawuchi *et al.* (2005) in brinjal. Bharadwaj *et al.* (2010) stated that the decrease in available nutrient status under closer spacing is due to the uptake of these nutrients by bhindi which was reflected in the increase in DMP, nutrient content and total N and K uptake by the crop. Sollapur and Hiremath (2017) recorded the highest nutrient uptake of N, P and K for wider spacing (90 cm x 90 cm) attributing to higher fruit yield and dry matter.

According to Bulgarelli *et al.* (2013), rhizospheric niche is a hotspot of ecological richness, with plant roots hosting an enormous array of microbial taxa. Also, lesser plant spacing helps in retaining moisture of the soil for a longer period, which provided optimal conditions for soil microbial communities that helped in nutrient transformation and ultimately improved nutrient supplying capacity of the soil as was also advocated by Kumar *et al.* (2013).

2.1.6 Economics of Cultivation

Paththinige *et al.* (2008) reported that high planting densities produced shorter fruits with higher consumer preference, which in turn fetch higher market prices as compared to the longer fruits of wider densities. They also added that increasing the plant density by narrowing of plant spacing, increased the productivity (34.9 per cent) and profitability (38.6 per cent) of bhindi. The highest net realization and benefit cost ratio (B: C ratio) were recorded from bhindi plants planted at dense plant population (Desai and Ketan 2011). Agba *et al.* (2011) also obtained higher net return and B: C ratio with a plant population of 55,555 plants ha^{-1}.

2.2 EFFECT OF BIO INOCULANTS

2.2.1 Growth Characters

Kloepper *et al.* (1991) coined the term PGPR to include bacteria inhabiting the root and rhizosphere of soil which have the ability to increase plant growth. Biofertilizers are the products containing living cells of different microorganisms which have the ability to mobilize nutritionally important elements from non-usable to usable form through biological processes (Arora and Dan, 2003). Bioferilizers applied to the seeds and the soil significantly increased the plant growth parameters *viz.*, plant height, number of branches, number of roots, root length and dry matter accumulation in plant organs (Din and Hendawy, 2010). PGPR mix 1 is a compatible consortium of N, P and K biofertilizers and helps to save 25 per cent N, P and K fertilizers (KAU, 2011).

Biofertilizers containing beneficial microorganisms instead of synthetic chemicals are known to improve plant growth through the supply of plant nutrients and may help to sustain environmental health and soil productivity (O'Connell, 1992). Lucy *et al.* (2004) observed that addition of PGPR improved plant growth due to the increase in N content. Improvement of P nutrition is one of the factors involved in plant growth promotion by PGPR. One of the basic requirements for the effectiveness of PGPR is the ability to colonize host rhizosphere, rhizoplane, or the root interior (Glick *et al.*, 2007). According to Glick *et al.* (2007), the PGPR has both direct as well as indirect means for promoting the growth of the plant. The direct mechanism are through the fixation of atmospheric N, solubilization of minerals such as P, production of siderophores that solubilize and sequester iron, or production of plant growth regulators (hormones) that enhance plant growth at various stages of development. Indirect growth promotion occurs when PGPR promote plant growth by improving the growth restricting conditions. Martinez *et al.* (2010) added that the plant growth stimulation is the net result of multiple mechanisms that may be activated simultaneously.

Adesemoye and Kloepper (2009) and Din and Hendawy (2010) reported that plant–PGPR interactions have the benefit of improvement of seed germination rate, root development, shoot and root weights and leaf area. Tomato root inoculation with PGPR enhanced growth under greenhouse conditions (Sharafzadeh, 2012). Habib *et al.* (2015) reported that the application of PGPR isolates significantly increased the shoot and root growth of bhindi when compared to non inoculated plants. Similar results of increase in plant growth through bio fertilizer application were reported by Viji *et al.* (2018).

Kumar *et al.* (2016) found that AMF inoculation had great potential in enhancing the system productivity and profitability in bhindi–pea production system. AMF inoculation improved seedling emergence, plant height and root growth when compared to uninoculated control as reported by Ali *et al.* (2018) for bhindi, chilli, brinjal and tomato.

2.2.2 Yield Attributes and Yield

Yield augmentation through PGPR application was documented by Sahin *et al.* (2000) in tomato and pepper. According to Richardson (2001), PGPR helps in enhancing crop yield through facilitating plant nutrition by increasing the availability of nutrients in the rhizosphere and thereby improving the plant nutritional status. Karla (2003) reported that bacteria around the rhizosphere area can increase crop growth and yield by atmospheric N fixation, increasing nutrient access at the rhizosphere area, increasing root contact area, growth regulator production and improving useful symbiosis with host plant at different growth stages. Garcia *et al.* (2004) explained that phyto hormones produced by PGPR, are believed to change the assimilate partitioning patterns in plants, altering growth in roots, the fruitification process and development of the fruit under production conditions. Adesemoye and Kloepper (2009) reported an increase in yield as a result of plant–PGPR interactions. Microbes in PGPR mix 1 have the ability to colonize rhizosphere of the host plant which helps in enhancing the nutrient uptake and in turn induce higher plant productivity (Glick *et al.*, 2007; Adesemoye *et al.*, 2009). Improvement in yield was noticed as a result of PGPR application was observed by Mia *et al.* (2010) in musa and Rafique *et al.* (2018) in bhindi.

Arbuscular mycorrhizal fungi (AMF) can save N and P requirement up to 50 per cent in most of the crops and also increases the yield (Khanuja and Narayanan, 2003). Okon (2014) reported that AMF inoculation can enhance the growth and yield of bhindi. Darade (2015) explained that mycorrhizal fungi act like roots as they absorbs minerals and nutrients from the rhizosphere soil of plant and translocate to the aerial part of the plant resulting in higher plant growth and yield.

2.2.3 Physiological Parameters

Zajac *et al.* (2005) found a positive relation between dry matter yield and growth indices like CGR. Adesemoye and Kloepper (2009) reported an enhanced chlorophyll content due to plant–PGPR interactions. Application of bioferilizers in seeds and soil significantly increased the plant growth parameters and dry matter accumulation in plant organs (Leithy *et al.*, 2009; Din and Hendawy, 2010). Ayoob *et al.* (2011) also noticed chlorophyll synthesis in AMF inoculated plants. Higher CGR in bhindi was observed under AMF application (Kumar *et al.*, 2015).

2.2.4 Fruit Quality

The impact of root inoculation with beneficial rhizosphere microorganisms on some quality parameters has been explored (Kaya *et al.*, 2003; Violante *et al.*, 2006). Lucy *et al.* (2004) observed higher plant growth benefits like increased protein content due to the addition of PGPR. Adesemoye and Kloepper (2009) observed higher protein content resulting from plant–PGPR interactions. Studies conducted by Ordookhani *et al.* (2010) showed that PGPR and AMF could increase tomato fruit quality and explained that this might be related to increasing of mineral content in inoculated plants. Youssef and Eissa (2014) reported that the growth, yield and quality parameters of certain plant was significantly increased with the application of biofertilizers containing bacterial N fixer, P and K solubilizing bacteria and microbial strains of some bacteria. Shinde and Khanna (2014) observed that mycorrhizal plants contained higher protein levels than non-mycorrhizal plants. The PGPR application increased the oil and protein content significantly as observed by Mondani *et al.* (2019)

2.2.5 Uptake of Nutrients, Available Nutrient Status and Microbial Population in Soil after Experiment

Biofertilizers are live formulations of beneficial micro organisms which on application to roots or soil, metabolises to available forms of nutrients particularly by their biological activity and help to build up the lost microflora and in turn improves the soil health in general. Timmusk *et al.* (2017) stated that bio inoculalants are environmental friendly renewable sources of nutrients and they activate soil biology and restore soil fertility.

Kloepper *et al.* (1991) noticed increased nutrient uptake by plants inoculated with PGPR and better absorption of water from the soil. He explained that this might be due to the production of plant growth regulators at the root interface, which stimulated root development. Increased nutrient uptake by plants inoculated with PGPR had been attributed to the production of plant growth regulators at the root interface, which stimulated root development and resulted in better absorption of water and nutrients from the soil (Kloepper *et al.*, 1991; Zimmer *et al.*, 1995). Improvement of P nutrition by solubilizing organic and inorganic phosphate sources through phosphatase synthesis or by lowering the pH of the soil which in turn affected the growth and nutrients uptake by PGPR was reported by Rodriguez and Fraga (1999). Increased biological N fixation and the availability of P and K required for growth of plants through the application of liquid biofertilizer was reported by Nanthakumar and Veeraragavathatham (2000) in brinjal and Gowda *et al.* (2002) in chilli. Adesemoye and Kloepper (2009) also reported higher nutrient uptake, including P and N due to plant–PGPR interactions. Shams *et al.* (2013) also described that the application of biofertilizers improved the nutrient availability in lettuce.

The increase in nutrient P uptake attributed to increased root colonization by AMF as reported by Umadevi and Sitaramaiah (1998). The AMF increased the absorption of relatively immobile elements like P by increasing the absorptive area beyond the root hairs (Darade, 2014). Plant growth promoting rhizobacteria promote plant growth directly by their ability for nutrient supply (N, P, K and essential minerals) (Gupta *et al.*, 2015).

Effect of PGPR application on microbial population in soil can be explained as a result of the production of more root exudates through plant-root interactions in rhizosphere which includes root– root, root-insect and root-microbe interactions (Bhattacharyya and Jha, 2012).

2.2.6 Economics of Cultivation

Application of PGPR seems to be a promising alternative as an amendment for profitable crop production and sustainable recovery of degraded soils in groundnut (Kausar *et al.*, 2018). PGPR inoculation along with organic and inorganic nutrient sources resulted in higher growth and yield of cauliflower along with higher B: C ratio (Thakur *et al.,* 2018).

2.3 EFFECT OF FERTIGATION LEVELS

2.3.1 Growth Characters

Studies conducted by Rekha and Mahavishnan (2008) revealed that fertigation through drip irrigation resulted in 40 to 70 per cent savings of fertilizers in vegetables. Fertigation reduced the use of fertilizers and at the same time increased the yield in most of the vegetables (Vijayakumar *et al.*, 2010). Increased plant height with increased fertigation level was observed in capsicum (Sanchita *et al.*, 2010). According to Varughese *et al.* (2014) application of 100 per cent recommended dose of fertilizers (RDF) through drip irrigation recorded statistically maximum growth and growth attributing characters in bhindi. The improvement in plant height with increasing fertigation level might be attributed to the increased cell division and cell elongation with higher content and uptake of N during the growth period (Singhal *et al.*, 2016).

Increased plant height with increase in N availability were observed in bhindi by Shanke *et al.* (2003), Jana *et al.* (2010) and Venkadeswaran *et al.* (2014). In cucumber also, the highest plant height was found in 120 per cent RDF, which was on par with 100 per cent RDF (Pushpendra and Hardaha, 2016). The higher plant height and leaves in fertigation treatments might be attributed to the continuous supply and consequent availability of plant nutrients in the root zone (Nair *et al.*, 2017).

Narda and Chawla (2002) stated that daily fertigation was found superior for higher LAI which resulted in well-developed canopy leading to the synthesis of higher carbohydrate resulting in better yield of bhindi. Also, higher LAI was obtained with higher fertigation levels which can be explained by the adequate amount of nutrients supplied through fertigation leading to better crop growth, which in turn resulted in increased plant height and ultimately more number of leaves and better leaf development (Sampathkumar and Pandian, 2010).

Positive response of root characters to higher fertilizer dose producing higher root biomass under favourable moisture and nutrient status was observed by Parthasarathi *et al.* (1999) in radish. According to Raj *et al*. (2013), higher root growth obtained with higher fertigation level can be explained due to the availability of sufficient quantity of nutrients along with adequate moisture thus resulting in higher root proliferation.

2.3.2 Yield Attributes and Yield

Improvement in fruit length with fertigation of water soluble fertilizers was observed by Mahendran *et al.* (2009) and Gupta *et al.* (2010a). Mahendran *et al.* (2011) also observed higher number of fruits per plant, fruit length, fruit girth and fruit weight with application of 100 per cent NPK fertigation through water soluble fertilizers in bhindi. Nair *et al*. (2017) noticed significantly higher fruit weight under the application of 100 per cent NPK fertigation through water soluble fertilizers than conventional fertilizer application in bhindi.

Fertigation was found to exert a positive influence on individual fruit weight especially at high frequency levels and this was in conformity to the findings of Tumbare and Nikam (2004); Badr and El-Yazied (2007); Mahendran *et al.* (2009); Shedeed *et al.* (2009); Brahma *et al.* (2010); Gupta *et al.* (2010b); Savitha *et al.* (2010) and Shinde *et al.* (2010). The highest irrigation and fertigation levels along with plastic mulching produced maximum values of fruit length, fruit girth, fruit weight, number of fruits per plant, number of harvests and marketable yield in bitter gourd (Abraham *et al*., 2017). Kaur *et al*. (2019) reported that higher rate of fertilizers delayed days to fifty per cent flowering in cucumber.

Compared to soil application, drip fertigation performed better with regard to yield due to the enhanced availability and uptake of nutrients leading to increased metabolite activities in the plant system as reported by

Akande *et al.* (2003); Sasani *et al.* (2006), Shedeed *et al.* (2009). Janapriya *et al.* (2010) found significantly higher fruit yield under increased fertigation level. Varughese *et al.* (2014) also observed the highest yield in bhindi with 100 per cent fertigation of the recommended dose. Goswami *et al.* (2015) also reported significant positive correlation of bhindi fruit yield with above mentioned parameters. All the fertigated plots of bhindi were found to produce significantly higher yield over soil application of recommended fertilisers (Venkadeswaran and Sundaram, 2016). Water and nutrients are supplied directly to the root zone of the crop in drip fertigation. Hence leaching is reduced thereby increasing the availability of nutrients to the plants. Rajasekhar *et al.* (2017). Among the different fertigation treatments, application of recommended dose using water soluble fertilizers through 100 per cent weekly fertigation resulted in highest marketable yields of bhindi (21.65 t ha^{-1}) (Nair *et al.*, 2017).

2.3.3 Physiological Parameters

Akanbi *et al.* (2010) observed an increase in CGR with increased N level. This is in conformity with the finding of Meenakshi and Vadivel (2005) in bitter gourd.

Maximum DMP under frequent fertigation schedule with 150 per cent RDF was due to the production of more number of leaves and effective accumulation of nutrients in different plant parts of maize (Sampathkumar and Pandian, 2010). Al-Kaisi and Yin (2003) also reported that maximum economic DM yields for corn occurred at an N rate of about 150 to 200 kg ha^{-1}.

Muralidhar (1999) stated that higher WUE (2.34 kg m^{-3}) was recorded at an application of 100 per cent recommended dose of water soluble fertilizers through drip irrigation in capsicum. Similarly higher fertigation dose with drip irrigation resulted in higher WUE in cotton as reported by Jayakumar *et al.* (2015).

2.3.4 Fruit Quality

According to FAO (2004), high N content in pointed gourd is often associated with reduced post-harvest-life due to increased susceptibility to mechanical damage, physiological disorders and decay. Nayak *et al.* (2018) recorded higher shelf life with the treatment with 100 per cent RDF applied through fertigation.

Improvement in ascorbic acid content of tomato hybrids through fertigation was observed by Rana *et al.* (2005). Enhanced metabolic activity of the plants under frequent fertigation resulted in increased protein synthesis (Meenakshi and Vadivel, 2005; Tomar and Singhal, 2007) ; Kuppusamy, 2008). Higher dose of fertigation resulted in higher ascorbic acid content was reported by Tomar and Singhal (2007) in tomato and Brahma *et al.* (2010) in capsicum. Lenin *et al.* (2010) observed increased protein content with higher dose of fertigation in four different vegetable crops.

2.3.5 Uptake of Nutrients, Available Nutrient Status and Microbial Population of Soil after Experiment

The uptake of nutrients by the plant roots was higher since the availability to their root system was high in the higher dose of fertigation (Rao, 1996). Silber *et al.* (2003) reported that frequent fertigation improved the uptake of nutrients. Nutrient uptake was higher in higher fertigation level due to the application of fertilisers in small doses at high frequency (*i.e.* on daily basis) through drip fertigation. It could ensure a continuous and stable supply of nutrients to meet the growth demands of hybrid bhindi responsible for the ultimate increase in productivity (Venkadeswan and Sundaram., 2016).

According to the studies conducted by Battilani *et al.* (2008), leachable N was found to be reduced by about 25 to 30 per cent in tomato under fertigation. Drip fertigation of N and K resulted in reduced loss of nutrients when compared to soil application (Singh *et al.*, 2010). Water soluble fertilizers might have activated the physiological processes for the rapid absorption and utilization of the nutrients for the primary metabolic process in fenugreek (Honnappa *et al*., 2017) Water soluble fertilizers through frequent fertigation, in higher fertigation levels, increased nutrient availability in the soil after the experiment (Sahana *et al*., 2018) in pole bean.

2.3.6 Economics of Cultivation

Thirty per cent higher yield was reported in fertigation as compared to surface irrigation in bhindi (Tiwari *et al*., 1998). Drip fertigation has been well recognised as an efficient and precise method of applying fertilizers directly to the root zone for maximising productivity and net returns in horticultural crops (Meenakshi, 2002). Possibility of substantial fertilizer saving of 50 per cent for bhindi under drip fertigation method in comparison to traditional method was reported by Narda and Lubana, (2002). Also, drip fertigation in bhindi saves 20 to 61 per cent of water, increases yield by 13 to 76 per cent besides a saving of 15 to 30 per cent fertilizers when as compared to traditional cultivation methods (Sharma and Kaushal, 2015). Fertigation of 100 per cent RDF resulted in higher net return and B: C ratio for bhindi (Tumbare and Bhoite, 2002; Rajaraman and Pugalendhi, (2013) and Nair *et al.,* 2017).The highest net income (Rs.187852 ha^{-1}) and B: C ratio (1.53) was obtained with the treatment where in 50 per cent of recommended dose of N and K water soluble fertilizers were supplied through fertigation (Nair *et al*., 2017). According to Job *et al*. (2018), the gross income could be increased by about 88.2 per cent by adopting drip with fertigation technology.

2.4 EFFECT OF FOLIAR APPLICATION OF FERTILIZERS

2.4.1 Growth Characters

According to Fageria *et al*. (1992), foliar application of fertilizers can be considered as a supplement to the soil application of nutrients and this technique ensures immediate translocation of nutrients to various plant organs *via* leaf tissues under various nutrient deficiencies. Kolota and Osinska, (2001) observed an increase in yield and quality of fruits through foliar application which lead to improved nutrient balance during the growth and development of crops. The increased plant height is also due to increased uptake of primary nutrients and fast movements of photosynthates within the plant system (Devi and Shanthi, 2013). Among the water soluble fertilizers and inorganic fertilizers tested foliar application of seven sprays of NPK (19:19:19) along with the 100 per cent application of inorganic fertilizer (200:150:100 kg NPK ha^{-1}) recorded the highest growth parameters in brinjal (Anburani, 2018)

Foliar nutrients usually penetrate the cuticle of the leaf or stomata, enter the cells rapidly and fulfill the nutrient demand of the growing plant and thus ameliorate nutrient deficiencies rapidly and improve the growth of the plant (Devi and Shanthi, 2013). According to Sharifi *et al.* (2018), LAI was directly attributed to the higher leaf area. They also noticed that for increasing yield, the formation of optimum photosynthetic stage for longer period was essential which was happened through the application of foliar nutrients in soybean.

Studies conducted by Karpagam *et al.* (2004) revealed the efficiency of foliar feeding of water soluble fertilizers on growth and yield of hybrid brinjal (COBH-1). Results showed that among the different grades of water soluble fertilizers, foliar sprays of NPK complex (19:19:19) along with recommended dose recorded the highest plant height (130.75 cm) compared to control (105.30 cm).

Batra *et al.* (2002) recorded the response of brinjal to foliar feeding of water soluble fertilizers. Maximum plant height (99.40 cm) was recorded with poly feed grade 19:19:19 (three sprays), which was closely followed by Multi-K (three spays) compared to control (74.3 cm). Chaurasia *et al.* (2005) reported that five foliar sprays of water soluble grade fertilizer NPK (19:09:19) in tomato crop significantly increased the plant height (125.40 cm) compared to control (85.50 cm). Premsekhar and Rajashree (2009) from their field experiment conducted on hybrid tomato (COTH-2) concluded that five sprays of water soluble fertilizer NPK (19:19:19) along with the recommended dose of NPK (200:100:100 kg ha^{-1}) recorded the tallest plants (84.5 cm) and the least plant height (70.00 cm) was observed in control plots were no water soluble fertilizers were applied. Devi and Santhi (2013) observed that, a combination of 100 per cent RDF + five sprayings of one per cent water soluble fertilizer produced maximum plant height and number of branches per plant in hybrid chilli.

2.4.2 Yield Attributes and Yield

Foliar fertilization has been recommended for integrated plant production since it not only increases crop yield and quality but is also environmentally safe (Fageria *et al.*, 1992). The probable reason for increase in yield might be due to easy assimilation of nutrients and balance in N, P and K ratio which positively affects the crop productivity (Batra *et al.*, 2002). Similarly, increased fruit weight and yield per plant with foliar application of nutrients was observed by Sundaram and Kanthaswamy (2005). Foliar feeding through water soluble fertilizers (19:19:19) @0.5per cent) in bhindi favourably influenced the plant growth and yield attributes (El-Aal *et al.*, 2010; Singhal *et al.*, 2016).

Devi and Santhi (2013) observed that, a combination of 100 per cent RDF + five spraying of one per cent water soluble fertilizers produced 50 per cent flowering in hybrid chilli. Among the different treatments tested, three sprays of banana pseudostem enriched sap @ 1 per cent or mixed fertilizer (19:19:19 at 0.5 per cent) resulted in achieving higher plant height, number of fruits per plant, yield per plant, dry fruit yield, dry plant yield and commercial green fruit yield in bhindi (Singhal *et al.*, 2016). The increase in yield attributes per plant might be due to application of poly feed foliar fertilizer which increased the number of flowers, seeds and promote full maturity of seeds resulted increase in pods per plant in soybean (Gutte *et al.*, 2018).

2.4.3 Physiological Parameters

Foliar application of poly feed (@ 1.0 per cent and 0.5 per cent) resulted in increased plant height, number of functional leaves and LAI which are the vital part of the plant where the photosynthesis takes place and thereby build up more photosynthates, which reflected ultimately on dry matter accumulation in soybean (Gutte *et al.*, 2018).

Higher chlorophyll content with the application of nano foliar fertilizers had been reported by Nadiya *et al.* (2013) in faba bean. Arun and Jayakumar (2014) explained that the higher dry matter production with foliar application is due to the positive interference in tissue formation and dry matter weight of cucumber in polyhouse. Gutte *et al.* (2018) also reported higher dry matter production with foliar application of poly feed (@ 1.0 per cent) in soybean.

Barooah and Ahmed (1983) elucidated that leaf production is determined both by environment and nutrition. Among the nutrients, N plays an important role in leaf production, Being a chief constituent of proteins and protoplasm it might have enhanced the chlorophyll content of leaves and cell division, thus resulting in more number of leaves. Similar results were obtained by foliar application of nutrients by Manjunatha (2004) in bhindi and Anburani (2018) in brinjal.

2.4.4 Fruit Quality

Manjunatha (2004) noticed in his study that foliar application of poly feed (19:19:19) @ 0.5 per cent along with RDF resulted in higher quality of bhindi fruit including ascorbic acid content and crude protein in bhindi. Similarly, Venkataraman (2007) also studied the effect of foliar application of water soluble NPK fertilizer @ 0.5 per cent and found an increase in quality characters like ascorbic acid and crude protein content.

2.4.5 Uptake of Nutrients, Available Nutrient Status and Microbial Population in Soil after Experiment

Foliar application ensures immediate uptake and translocation of nutrients to various plant organs via the leaf tissues and thus enables rapid correction of nutrient deficiencies (Fageria *et al.*, 1992). Foliar application also triggers a plant response to increased water and nutrient uptake from the soil (Veeramani *et al.*, 2012). Devi and Shanthi (2013) states that the plant N, P and K uptake increased when the combination of 100 per cent RDF + five spraying of one per cent water soluble fertilizers were applied at higher levels in hybrid chilli.

2.4.6 Economics of Cultivation

Karpagam *et al.* (2004) observed that foliar application of five sprays of NPK (19:19:19) along with the normal recommended dose of NPK (200:150:100 kg ha^{-1}) was highly beneficial for maximizing the yield and net returns in brinjal hybrid CoBH-1. The results clearly announced that the use of water soluble fertilizers increased the bhindi yield and thereby gave remunerative return to the bhindi growers. (Premsekhar and Rajashree, 2009). Narayanan *et al.* (2012) studied the effect of foliar application on tomato and reported that more fruits per plant, fruit weight, fruit yield ha^{-1}, the highest B: C ratio and net returns were obtained with 87.5 per cent RDF along with foliar application of water soluble fertilizers. Singhal *et al.* (2016) observed that treatment receiving three sprays of mixed fertilizer (19:19:19) @ 0.5per cent) registered a net return of Rs. 219694 ha^{-1} and a B: C ratio of 3.4: 1.

2.4.7 Foliar Nano Fertilizers

One of the advantages of using nano fertilizers is that its application can be done in smaller amounts than when using common fertilizers (Raikova *et al.*, 2006). Nanotechnology had proved its place in agriculture and related industries (Froggett, 2009). Nair *et al.* (2010) observed that nano fertilizers or nano-encapsulated nutrients had properties effective to release nutrients on demand that regulate plant growth and enhance target activity. Nano-fertilizers can be more efficient, decreasing soil pollution and other environmental risks that may occur when using chemical fertilizers (Naderi *et al.*, 2011; Batsmanova *et al.*, 2013). Nano fertilizers have unique features like increase in production, ultra-high absorption, increase in photosynthesis and significant expansion in the leaves surface area (INIC, 2014).

Positive effects of application of nano -ZnO were reported on seed germination, seedling vigour, leaf chlorophyll content and stem and root growth in peanut (Prasad *et al.*, 2012). Van *et al.* (2013) showed that foliar application of chitosan nanoparticles on coffee seedlings in the green house enhanced significantly the uptake of N content from 20 to 35 per cent P content from 50 to 100 per cent, K content from 30 to 40 per cent, Ca (3.77 %) and Mg (18.75 %) compared to the control.

Subramanian *et al.* (2015) reported that nano fertilizers could be applied in smaller amounts than common fertilizers. Ajirloo *et al.* (2015) observed increased yield and yield components of tomato with K nano fertilizer and N bio fertilizer.

Single foliar spray with relatively low amounts of B or Zn nano fertilizers led to increases in pomegranate fruit yield, improvements in fruit quality *viz.* TSS, maturity index and juice pH at harvest but physical fruit characteristics (including fruit cracking, peel thickness, fruit length, fruit calyx diameter, fruit average weight, aril and peel percentages, the aril: peel ratio, weight of 100 arils and juice content of arils) were unaffected, and the antioxidant activity and total anthocyanins were also unaffected. The application of Zn and B also increased the leaf concentrations of both microelements reflecting the improvement in tree nutrient status (Davarnapah *et al.*, 2016).

Foliar application of chitosan nanoparticles showed improvements of growth and yield of wheat plants especially at a low concentration of 10 per cent (Aziz *et al.*, 2016). Chitosan nanoparticles are easily absorbed by the epidermis of leaves and translocated to stems which facilitated the uptake of active molecules and enhanced the growth and productivity of several crop plants (Malerba and Cerana, 2016).

Aziz *et al*. (2016) conducted an experiment in Egypt to evaluate the effects of nano chitosan-NPK fertilizer application in the foliar form on wheat plants and reported that there was significant increase in all growth variables *viz*. shoot length, fresh weight, dry weight and leaf area of wheat crop and a significant reduction in days taken to 50 per cent ear head stage, days to physiological maturity and days to harvesting by the wheat crop was recorded with the ratio of 23.5 per cent (130 days compared with 170 days for yield production from date of sowing) when sprayed with nano chitosan – NPK fertilizers

The chelated and revolutionary nutritional agricultural inputs (eco-friendly fertilizers- Nano NPK and Nano-K in both granular as well as liquid formulations) developed by Pratishtha company in association with Indian Council of Agricultural Research have been formulated with organic and chelated micro nutrients, trace elements, vitamins, probiotics, seaweed extract and humic acid as complete nutritional fertilizer for all the crops. These high performance and efficient fertilizers are expected to enhance the crop production while protecting the ecosystem (Mehta, 2017).

2.5 RAIN SHELTER AND OPEN FIELD CULTIVATION OF CROPS

Cultivation of crops in the open field is getting strenuous now a days due to the changing season and adverse climatic conditions. Protected cultivation can be a solution to these problems to some extent. Rain shelter is a low cost protected structure and so an affordable means to the small scale farmers which allow them to cultivate even under heavy rainy situations. Protected structures improved the crop growth and yield attributes by providing optimum microclimate around the plant and reducing the insect pest incidence (Singh *et al*., 2003). Protected cultivation enabled vegetable growers to realize greater returns per unit of land and offered other benefits like early harvest, longer harvest duration, reduced leaching of fertilizers and eco-friendly management of pests, weeds and diseases (Kumar *et al.*, 2007).

During heavy rainy situations, runoff of nutrients occurs not only from soil, but also from plant leaves. Kimura *et al.* (1982) examined effect of rain on DMP of kidney bean, and found that the reduction of DMP was attributed to the washing off of photosynthates by the water directly covering leaf surface and clogging of stomata by the water retarded photosynthesis. So rain shelter makes it possible to artificially regulate soil moisture because soils are not exposed to rain. Therefore, the occurrence of cracking fruit or blossom-end rot fruit was reduced in tomato and melon. In addition, good quality of products can be expected, because not only poor fruit bearing and inferior fruit are reduced, but also occurrence of sunscald fruit is prevented.

The most important problem during rain shelter cultivation is to secure source of water supply. The cultivation under rain shelters often requires irrigation facilities, because crops sheltered from rain are cultivated during the season with relatively high temperature, so that they consume a large amount of water (Masaki, 1987). As a large amount of water is transpired by crops, watering is an important task. The method of watering, whether good or not, determines the result of the cultivation.

Siddique *et al.* (1993) have reported the possibilities of raising tomato crop successfully under plastic rain shelter during March to June and July to October, when crop could not be raised in the field without protection due to high rainfall. Megharaja (2000) recorded significantly higher plant height, number of branches and total number of fruits in capsicum under polyhouse condition compared to plants grown under open condition in capsicum. Higher values with regard to fruit length, fruit breadth, fruit weight and fruit volume were also recorded with capsicum fruits grown under greenhouse condition as compared to those procured from open field. Megharaja (2000) also found that lower solar radiation within the polyhouse and rain shelter was the most important factor that influenced height and LAI in the crops transplanted within these structures and this led to greater vegetative vigour and increased biomass production when compared to the crops in the open field. Plant height and inter nodal length of cowpea were significantly higher inside the polyhouse followed by rain shelter and open field during all growth stages as reported by Gokul and Hakkim (2016). They also observed longer fruits inside polyhouse and rain shelter than that in the open field. Incidence of pests and diseases were also comparatively low inside the rain shelter and higher incidence of pests and diseases were noticed in the open field.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The investigation entitled "Agro techniques in bhindi for precision farming" was taken up at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, during 2017 to 2018. The objectives of the field experiment were to standardize the spacing and response of bio inoculants for bhindi under rain shelter and open field conditions, to evaluate the effect of fertigation levels and foliar nutrition levels on improving growth, yield and quality of bhindi and to work out the economics of different cultivation systems.

The materials used and methods followed in the present study are described in this chapter.

3.1 GENERAL DETAILS

3.1.1 Experimental Site

The experiment was conducted in the rain shelter and in the garden land of the Instructional Farm attached to the College of Agriculture, Vellayani, Kerala. The farm is situated at 8.5^0 North latitude and 76.9^0 East longitude, at an altitude of 29 m above mean sea level.

3.1.2 Soil

Prior to the investigation, composite soil samples were drawn from 0 to 30 cm layer from the soil surface, both from inside rain shelter and open condition and analyzed for its mechanical composition and chemical properties. Data on the mechanical composition and chemical nature of soil of the experimental sites are presented in Table 1a and 1b respectively.

Soil of rain shelter and open field were slightly acidic in reaction, high in organic carbon content, medium in available N, high in available P and high in available K.

Table1a. Mechanical composition of soil of the experimental site

Sl. No	Fractions	Content in soil (%)		Method used
		Open field condition	Rain shelter	
1	Coarse sand	48.21	46.48	Bouyoucos hydrometer method (Bouyoucos, 1962)
2	Fine sand	15.44	17.17	
3	Silt	6.25	4.34	
4	Clay	27.50	29.41	
	Texture	Sandy clay loam	Sandy clay loam	

Table1b. Chemical properties of soil of the experimental site

Sl. No.	Parameter	Content in soil		Method used
		Open field condition	Rain shelter	
1	Soil reaction (pH)	5.7	5.9	1:2.5 Soil water ratio using pH meter (Jackson,1973)
2	Organic carbon (%)	1.02	0.92	Walkley and Black rapid titration method (Jackson,1973)
3	Available N (kg ha^{-1})	239.39	251.93	Alkaline permanganate method (Subbiah and Asija, 1956)
4	Available P (kg ha^{-1})	52.05	60.63	Bray colorimetric method (Jackson,1973)
5	Available K (kg ha^{-1})	294.59	308.92	Ammonium acetate method (Jackson,1973)

3.1.3 Estimation of Microbial Population

Soil microbial population was assessed prior to the experiment by serial dilution and plate technique using appropriate medium. The dilutions along with the methods adopted for the estimation are given in Table 2. The details of the media composition are presented in Appendix I.

Table 2. Microbial population in soil prior to the experiment

Microbial population	Open field (log cfu g^{-1} soil)	Rain shelter (log cfu g^{-1}soil)	Method used
Bacteria	7.24	7.09	Nutrient agar medium (Timonin, 1940)
Fungi	5.06	4.76	Martin's Rose Bengal agar medium (Martin, 1950)
Actinomycetes	3.28	3.08	Kenknight's agar medium (Timonin, 1940)

3.1.4 Weather Conditions during the Cropping Period

The field experiment was conducted for two consecutive years, 2017 and 2018 (May to August 2017, September to December 2017 and May to August 2018). The data on weather parameters (average temperature, relative humidity, light intensity and rainfall) during the cropping period under rain shelter and open field are presented in Fig.1 and Fig. 2 and in Appendix II.

3.2 MATERIALS

3.2.1 Cultivar Used

Bhindi variety Varsha Uphar was used for the experiment. It was released by Haryana Agricultural University, Hissar and was derived by inter varietal hybridisation between Lam selection 1 and Parbhani Kranthi. Fruits are five

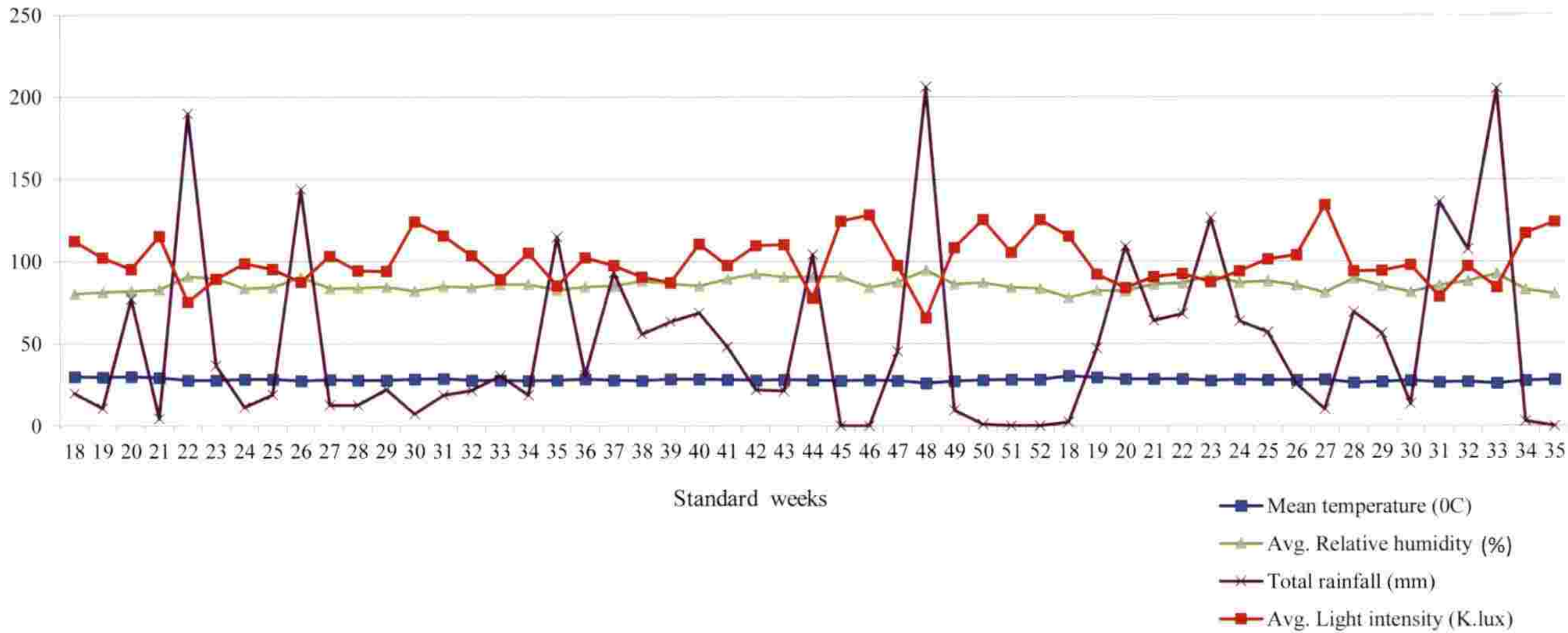

Fig.1. Weather parameters during cropping period in open field condition (May 2017-August 2018)

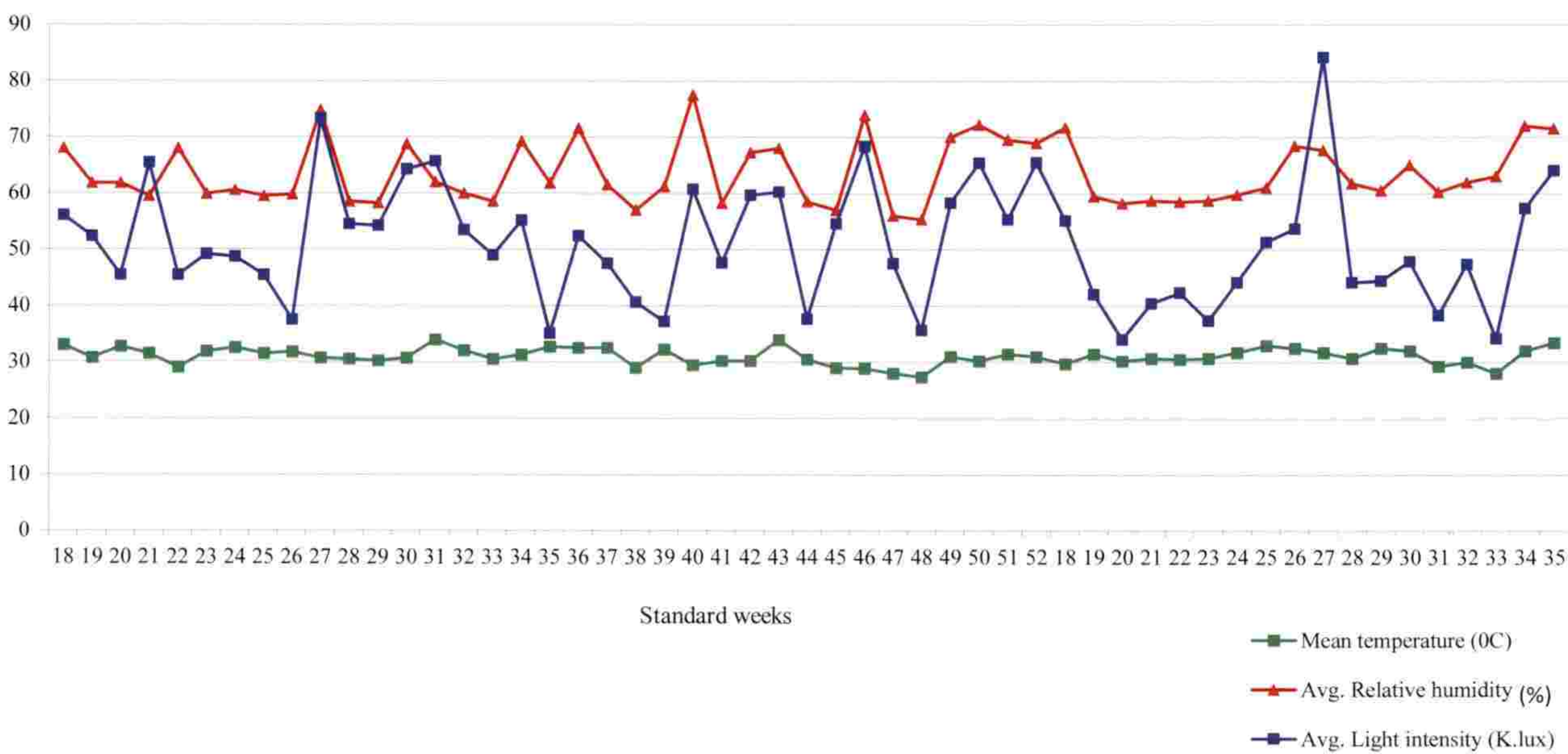

Fig.2. Weather parameters during cropping period inside rain shelter (May 2017- August 2018)

ridged, dark green and medium long in nature. It is an early high yielding variety having resistance to yellow vein mosaic virus.

3.2.2 Source of Seed Material

Seeds of variety Varsha Uphar were obtained from the Instructional Farm, College of Agriculture, Vellayani.

3.2.3 Manures and Fertilizers

As per *Adhoc* package of practices (PoP) recommendation of Kerala Agricultural University (KAU) for bhindi in precision farming, 25 t ha^{-1} farm yard manure (FYM) was applied as basal at the time of land preparation along with 98: 25:136 kg NPK ha^{-1} as fertilizer. Fertilizers used were urea as N source, rajphos as P source and MOP as K source. Half of nitrogen and full dose of phosphorus and potassium were applied as basal dose and remaining half dose of N was applied one month after planting.

3.3 METHODS

3.3.1 Experiment 1: Response of Bhindi to Varying Spacing and Bio inoculants in Rain shelter and Open Field Conditions

3.3.1.1 Design and Layout of the Experiment

The experiment was carried out during May to August 2017, to standardize the optimum intra row spacing and to assess the influence of various bio inoculants on growth and yield of bhindi. The field experiment was laid out in randomized block design (RBD). The lay out plan is depicted in Fig 2.

Design	:	RBD
Treatments	:	9
Replication	:	3
Plot size	:	5.4 m x 1.2 m
Variety	:	Varsha Uphar
Season	:	May- August, 2017

Treatment

Factor A: Spacing (S)

S_1- 60 cm x 30 cm

S_2- 60 cm x 45 cm

S_3- 60 cm x 60 cm

Factor B: Bio inoculants (B)

B_1- Bio inoculant- PGPR mix 1

B_2 - Bio inoculant – Arbuscular mycorrhizal fungi

B_3- No Bio inoculant

Raised beds of 15 cm height were taken with plot size of 5.4 m x 1.2 m and mulched with polythene sheets. Seedlings were plugged as per the treatments. Organic manures and fertilizers were applied as per the *adhoc* POP recommendation for precision farming. Irrigation was given using drip system.

3.3.2 Experiment II: Standardization of Nutrient Schedule for Bhindi under Rain shelter and Open Field Conditions

3.3.2.1 Design and Layout of the Experiment

The best spacing and the best bio inoculant from the experiment I were selected for the second experiment. Second experiment was done to standardize the fertigation schedule for yield improvement. The field experiment was laid out in split plot design (Fig.3). Different levels of fertilizer recommendation for precision farming by KAU as main plot treatment and different levels of foliar application of fertilizers were included as sub plot treatments. The experiment was repeated twice during September to December, 2017 and May to August, 2018.

N

Layout plan of the first experiment field

Open field

s_1b_2	s_3b_2	s_3b_1	s_3b_3	s_2b_2	s_2b_3	s_2b_1	s_1b_3	s_1b_1	R_1
s_2b_2	s_1b_1	s_1b_2	s_2b_1	s_3b_2	s_2b_3	s_1b_3	s_3b_1	s_3b_3	R_2
s_3b_1	s_1b_2	s_1b_3	s_2b_3	s_3b_2	s_1b_1	s_3b_3	s_2b_2	s_2b_1	R_3

Rain shelter

s_3b_3	s_3b_2	s_1b_2	s_2b_2	s_1b_1	s_2b_3	s_1b_3	s_3b_1	s_2b_1	R_1
s_1b_2	s_2b_1	s_1b_1	s_2b_2	s_3b_2	s_3b_3	s_1b_3	s_2b_3	s_3b_1	R_2
s_3b_1	s_2b_2	s_1b_3	s_3b_3	s_1b_1	s_1b_2	s_3b_2	s_2b_1	s_2b_3	R_3

S_1 - 60 cm x 30 cm B_1 - Bio inoculant- PGPR mix 1

S_2 - 60 cm x 45 cm B_2 - Bio inoculant – Arbuscular mycorrhizal fungi

S_3 - 60 cm x 60 cm B_3 - No Bio inoculant


Plate 1: Crop inside rain shelter during first experiment (May-August, 2017)


Plate 2: Crop under open field during first experiment (May-August, 2017)

Design	:	Split plot
Replication	:	5
Plot size	:	5.4 m x 1.2 m
Variety	:	Varsha Uphar
Season	:	September- December, 2017
		May- August, 2018

Treatments

Main plot treatment

Fertigation levels (F) - 4

F_1-50 % *adhoc* POP recommendation for precision farming
F_2-75 % *adhoc* POP recommendation for precision farming
F_3- 100 % *adhoc* POP recommendation for precision farming
F_4-125 % *adhoc* POP recommendation for precision farming

Sub plot treatment

Foliar levels (L) – 2

L_1 -Poly feed fertilizer (19:19:19 at 0.5%)
L_2- Nano fertilizer (4: 4: 4 at 0.3%)

Adhoc POP recommendation for bhindi in precision farming is 98: 25:136 kg NPK ha^{-1}. FYM @ 25 t ha^{-1} and rajphos @ 100 kg ha^{-1} were given uniformly as basal. The fertilizer 19:19:19 @ 0.5 per cent and nano NPK fertilizer (4: 4: 4) @ 0.3 per cent were given as foliar spray at fortnightly intervals.

3.3.3 Irrigation

Based on growth stages of bhindi, uniform irrigation through drip system was given for the entire crop period.

N

Layout plan of the second experiment

Open field

R_1		R_2		R_3		R_4		R_5	
f_1l_1	f_1l_2	f_1l_1	f_1l_2	f_1l_1	f_1l_2	f_1l_1	f_1l_2	f_1l_1	f_1l_2
f_3l_2	f_3l_1	f_3l_2	f_3l_1	f_3l_2	f_3l_1	f_3l_2	f_3l_1	f_3l_2	f_3l_1
f_2l_1	f_2l_2	f_2l_1	f_2l_2	f_2l_1	f_2l_2	f_2l_1	f_2l_2	f_2l_1	f_2l_2
f_4l_2	f_4l_1	f_4l_2	f_4l_1	f_4l_2	f_4l_1	f_4l_2	f_4l_1	f_4l_2	f_4l_1

Rain shelter

R_1		R_2		R_3		R_4		R_5	
f_1l_1	f_1l_2	f_1l_1	f_1l_2	f_1l_1	f_1l_2	f_1l_1	f_1l_2	f_1l_1	f_1l_2
f_3l_2	f_3l_1	f_3l_2	f_3l_1	f_3l_2	f_3l_1	f_3l_2	f_3l_1	f_3l_2	f_3l_1
f_2l_1	f_2l_2	f_2l_1	f_2l_2	f_2l_1	f_2l_2	f_2l_1	f_2l_2	f_2l_1	f_2l_2
f_4l_2	f_4l_1	f_4l_2	f_4l_1	f_4l_2	f_4l_1	f_4l_2	f_4l_1	f_4l_2	f_4l_1

F_1-50 % *adhoc* POP recommendation for precision farming

F_2-75 % *adhoc* POP recommendation for precision farming

F_3- 100 % *adhoc* POP recommendation for precision farming

F_4-125 % *adhoc* POP recommendation for precision farming

L_1 -Poly feed fertilizer (19:19:19 at 0.5%)

L_2- Nano fertilizer (4: 4: 4 at 0.3%)

3.3.4 Drip Fertigation System

Drip irrigation was practiced for all treatments. From the existing tank in the field, irrigation water was diverted to the field using a pump. Delivery of water to individual beds was done through laterals connected to the sub main. One pressure compensating drippers, each with a discharge rate of 4 L hr^{-1} were connected on the laterals to deliver water to individual plants. Water soluble fertilizers were given along with irrigation water. Fertigation was done using a fertilizer injector pump.

The required quantity of fertilizers dissolved in water was supplied along with irrigation water as fertigation. Fertigation was given at three days interval. Flushing of sub mains and laterals were done for five minutes before and after each fertigation. The details regarding fertigation treatments are given in Table 3.

Table 3. Details of fertigation schedule for bhindi

Day (3 days interval)	19:19:19 (kg ha^{-1})	13:0:45 (kg ha^{-1})	Urea (kg ha^{-1})	12-61-0 (kg ha^{-1})
3rd to 18th	3.3	3.3	5.20	0.00
21 to 54th	1.7	9.3	0.36	0.51
57th to120 th	1.7	9.3	2.10	0.51

Plate 3: Fertigation unit

Plate 4: Crop under rain shelter during second experiment (Sept- Dec, 2017)

Plate 5: View of open field during second experiment (Sept- Dec, 2017)

Plate 6: Crop under open field during second experiment (May- August, 2018)

Plate 7: Crop under rain shelter during second experiment (May- August, 2018)

3.4 CULTURAL OPERATIONS

The details of cultural operations carried out during the course of investigation are detailed below.

3.4.1 Nursery

Potting mixture was made by mixing coir pith and dried cowdung in equal proportion and filled in protrays. Seeds were plugged in each hole @ of one seed per hole. The protrays were watered twice daily and the seedlings were ready for transplanting after two weeks.

3.4.2 Land Preparation

The soil was brought to fine tilth and raised seed beds of size 5.4 m x 1.2 m x 0.15 m height were prepared and well rotten powdered FYM was applied and incorporated into the soil. Beds were covered with mulching sheets of silver–black colour. Holes were made as per spacings for different treatments. Basal dose of fertilizers were given as per recommendation. Fourteen days old seedlings were transplanted at the rate of one seedling per hole according to spacing in the main field.

3.4.3 Application of Manures and Fertilizers

Fertilizers were applied as per *Adhoc* POP recommendation of precision farming for bhindi (98: 25:136 kg NPK ha^{-1}). FYM @ 25 t ha^{-1} were given at the time of land preparation and rajphos @100 kg ha^{-1} were given uniformly as basal. Fertilizers used were urea and polyfeed (19:19:19) as N source, mono ammonium phosphate as P source and potassium nitrate as K source.

3.4.4 Drip Irrigation

Drip irrigation was followed both in rain shelter and open field situation. Requirement of water for bhindi was calculated as 53.5 litres per plant and was applied through drip irrigation.

3.4.5 Gap Filling

Gap filling was done eight days after transplanting to ensure optimum plant population.

3.4.6 Other Management Practices

Two hand weedings were done at 25 and 45 days after transplanting (DAT).

3.4.7 Harvest

The crop was ready for first harvest at 45 DAT under both rain shelter and open condition and subsequent harvests were made at alternate days interval (pickings in rain shelter condition and pickings in open condition). The maturity of the fruit was determined by visual appearance for vegetable purpose (Usually seven days after flowering)

3.5 OBSERVATIONS

For analyzing the growth pattern of the crop, five plants were selected randomly from the net plot area in each treatment and various observations were recorded. The average value was recorded. The parameters and procedures followed are given below.

3.5.1 Growth attributes (at monthly interval)

3.5.1.1 *Plant Height*

Height of the observational plants was taken from the base to the growing tip. The mean of the plant height has worked out and expressed in cm at monthly interval

3.5.1.2 *Number of Leaves Plant $^{-1}$*

The number of leaves was noted at monthly interval from each plant and average was calculated.

3.5.1.3 *Number of Branches Plant $^{-1}$*

Numbers of branches per plant at monthly interval was recorded from observational plants and the mean value was calculated.

3.5.1.4 *Leaf Area Index (LAI)*

The LAI was calculated at monthly interval using the following formula developed by Watson (1947).

$$\text{LAI} = \frac{\text{Leaf area per plant (cm}^2\text{)}}{\text{Land area occupied by the plant (cm}^2\text{)}}$$

3.5.1.5 *Length of Tap root*

Plants were uprooted after the final harvest and length of tap root from base of stem to the tip of root was taken and expressed in cm.

3.5.1.6 *Root Volume*

Root volume at the final harvest was recorded by water displacement method. The roots of sample plants were washed free of adhering soil with low jet of water. The roots were immersed in 1000 ml measuring cylinder containing water and the rise in water level was recorded. Displacement in volume of the water was taken as measure of the volume of root measured (Novoselov, 1960) and expressed in cm^3.

3.5.1.7 *Root: Shoot ratio*

The plants were pulled out at final harvest and the dry weights of shoots and roots were recorded. From this, root: shoot ratio was calculated.

3.5.2 Yield Attributes and Yield

3.5.2.1 *Days to 50 per cent Flowering*

The number of days taken for 50 per cent of the plant population to flower in each treatment was recorded.

3.5.2.2 *Number of Flowers Plant^{-1}*

Total number of flowers formed was counted from the five observational plants and the average was worked out to get the number of flowers formed per plant.

3.5.2.3 *Number of Fruits Plant^{-1}*

Numbers of fruits of observational plants were recorded and the mean was worked out.

3.5.2.4 *Fruit Set Percentage*

Total number of flowers opened and the number of fruits formed was recorded and the fruit setting percentage was worked out by the formula:-

$$\text{Setting percentage} = \frac{\text{Number of fruits formed}}{\text{Number of flowers opened}} \times 100$$

3.5.2.5 *Weight of Fruit*

Weight of green fruits obtained per plant was recorded, mean worked out and expressed in g per frui*t*

3.5.2.6 *Weight of Fruits Plant^{-1}*

The weight of green fruits obtained from observational plants was recorded at each harvest. The total weight of fruits per plant from the harvests was worked out and the mean weight was calculated and expressed in grams.

3.5.2.7 *Length of Fruit*

Length of randomly selected fruits from the five observational plants was measured and the mean was worked out and expressed in cm.

3.5.2.8 *Mature Fruit Yield ha^{-1}*

The total weight of mature fruits obtained from the net plot area was recorded and yield in t ha^{-1} was computed.

3.5.2.9 *Harvest Index*

Harvest index is the ratio of economic yield to biological yield expressed in percentage (Donald, 1962).

$$\text{Harvest Index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.5.3 Physiological Observations

3.5.3.1 *Chlorophyll Content*

Total chlorophyll content of fresh green leaves at 45 DAT was estimated using Dimethyl sulphoxide (DMSO) method (Yoshida *et al.*, 1976) and the intensity of colour was read in spectrophotometer. The amount of total chlorophyll was calculated using the formula of Starnes and Hadley (1965) and expressed in mg g^{-1} of fresh weight.

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

Where, V is the volume of extract in millilitre and W is the fresh weight of the sample in grams

A_{645} and A_{663} are the absorbance reading at 645 and 663 nanometer

3.5.3.2 *Dry Matter Production*

The samples of fruits at each harvest and the observational plant which was uprooted at final harvest were separately chopped and oven dried to constant weight at 80^{0}C. The dry weight of the fruits and plants were separately recorded and added. The total dry matter production of plant was calculated and expressed in kilograms per hectare (kg ha^{-1}).

3.5.3.3 *Crop Growth Rate (CGR)*

It is the rate of increase in dry weight per unit area per unit time. Crop growth between stages (30 DAT and 60 DAT) were worked out by using the following formula as explained by Hunt (1978) and expressed in g m^{-2} day^{-1}

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

Where, W_1 and W_2 are the dry weight produced by the plant at the time t_1 and t_2 respectively and P is the ground area.

3.5.3.4 *Relative Growth Rate (RGR)*

The rate of increase in dry weight per unit dry weight per unit time expressed in mg g^{-1} day^{-1} was calculated by the following formula suggested by Blackman (1919)

$$RGR = \frac{2.303\ (\log_{10} W_2 - \log_{10} W_1)}{t_2 - t_1}$$

Where, W_1 and W_2 are the dry weight produced by the plant at the time t_1 and t_2 respectively.

3.5.3.5 *Net Assimilation Rate (NAR)*

The rate of increase in dry weight per unit leaf area per unit time was worked out by the following formula of William (1946). This was expressed in g m^{-2} day^{-1}

$$NAR = \frac{(W_2 - W_1)\ 2.303\ (\log_{10} L_2 - \log_{10} L_1)}{(t_2 - t_1)\ (L_2 - L_1)}$$

Where, W_1, L_1 and W_2, L_2 represent dry weights and leaf area at time t_1 and t_2.

3.5.4 Quality Aspects of Fruit

3.5.4.1 *Protein*

Total soluble proteins were estimated by Bradford method (1976). The experimental samples (fruit) were harvested and prepared in 10 microliters of Phosphate buffered saline (PBS). A known volume (ml) of diluted dye binding solution was added to each tube. The solution was mixed well and allowed to develop a blue colour. The red dye turns blue when it binds protein and its absorbance was measured at 596 nm. A standard curve was plotted using the filed plot absorbance verses concentration. The protein in the experimental sample was calculated using the standard curve and expressed in per cent.

3.5.4.2 *Ascorbic Acid*

Ascorbic acid content of green fruits was estimated by 2, 6- dichlorophenol indophenols dye method (Sadasivam and Manickam, 1992). Ascorbic acid content of the sample was calculated using the formula.

$$\text{Ascorbic acid content (mg 100 g}^{-1}\text{ fresh fruit)} = \frac{\text{Titre value} \times \text{dye factor} \times \text{volume made upto} \times 100}{\text{Aliquot of extract taken} \times \text{weight of sample taken}}$$

3.5.4.3 *Shelf Life*

Sample fruits were taken treatment wise separately and the number of days taken from the harvest of fruits to the stage at which fruits become shrunken and lost firmness was recorded. The shelf life was represented in days.

3.5.5 Plant Analysis

The plant samples were subjected to chemical analysis for determining the total N, P, and K content. For this purpose, plant samples from each plot were dried in an electric hot air oven to constant weights at a temperature of 70^{0}C, ground and passed through a 0.5 mm sieve. The required quantity of sample was weighed out accurately in an electronic balance and was subjected to acid extraction before carrying out the chemical analysis.

3.5.5.1 *Uptake of Nitrogen*

The N content in plants samples was estimated by the modified micro kjeldhal method (Jackson, 1973) and the uptake of nitrogen was calculated by multiplying the N content of plant sample with the total dry weight of plants. The uptake values were expressed in kg ha^{-1}.

3.5.5.2 *Uptake of Phosphorus*

The plant sample was subject to nitric-perchloric (9:4) digestion and P content in plants samples was determined colorimetrically using Vanadomolybdo phosphoric yellow colour method (Jackson, 1973). The uptake of P was calculated by multiplying the P content of plant sample with the total dry weight of plants. The uptake values were expressed in kg ha^{-1}.

3.5.5.3 *Uptake of Potassium*

The plant sample was subject to nitric-perchloric (9:4) digestion and K content in plants samples was determined by flame photometry method (Jackson, 1973). The uptake of K was calculated by multiplying the K content of plant sample with the total dry weight of plants. The uptake values were expressed in kg ha^{1}.

3.5.6 Soil Analysis

Soil samples were taken from the experimental area before and after the experiment. The air dried samples passed through 2 mm sieve were used for the analysis of pH and available N, P and K status adopting the procedures as outlined in Table 1b. Soil samples sieved through 0.5 mm sieve were used for the analysis of organic carbon content.

3.5.7 Microbial Count in Soil

Soil microbial population was assessed before and after the experiment by serial dilution and plate technique using appropriate medium. The colony forming units of bacteria, fungi and actinomycetes were counted after inoculation and expressed in log cfu g^{-1} soil.

3.5.8 Water Requirement

Drip irrigation was given based on the growth stages of the crop. Water requirement of the bhindi plant was calculated and expressed in liters per plant.

3.5.8.1 *Water Use Efficiency*

Water use efficiency was calculated by using the formula

$$\text{WUE (kg m}^{-3}\text{)} = \frac{\text{Yield}}{\text{Total quantity of water used}}$$

(Stanhill, 1987)

3.5.9 Scoring of Pest and Diseases

No incidence of disease or pest attack was found to infect the crop beyond the economic threshold level demanding control measures and hence no scoring was done.

3.5.10 Meteorological Parameters

Meteorological parameters like temperature, relative humidity and light intensity were recorded under rain shelter.

3.5.10.1 *Temperature*

The observations on maximum (at 2.30 pm) and minimum (7.30 am) air temperature inside the rain shelter were recorded daily by using a mercury thermometer (0 to 50 °C) at canopy height in °C and averages were computed.

3.5.10.2 *Relative Humidity*

The relative humidity inside rain shelter was recorded at 2.30 pm and 7.30 am by using wet bulb and dry bulb thermometer (0 to 100%). The average was taken and expressed in per cent.

3.5.10.3 *Light Intensity*

Light intensity between 11 am and 12 pm inside rain shelter and open condition was recorded with lux meter at crop canopy level and expressed in K. lux.

3.5.11 Economics of Cultivation

Economics of cultivation was worked out for the field experiment after taking into account the cost of cultivation and prevailing market price of bhindi. The net income and B: C ratio was calculated as follows.

$$\text{Net return (Rs ha}^{-1}\text{)} = \text{Gross income - total cost of cultivation}$$

$$\text{Benefit: Cost ratio} = \frac{\text{Gross income}}{\text{Total cost of cultivation}}$$

3.5.12 Statistical Analysis

Data generated from the experiment were subjected to statistical analysis applying ANOVA technique and significance tested by 'F' test (Snedecor and Cochran, 1980). In the cases where the effects were found to be significant, CD was calculated using standard techniques.

RESULTS

4. RESULTS

Field experiments were conducted at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, during 2017 to 2018 to standardize the spacing and response of bio inoculants for bhindi under rain shelter and open field conditions and to evaluate the effect of fertigation and foliar nutrition on improving the growth, yield and quality of bhindi. Data obtained from the experiment are described here with appropriate tables after statistical analysis.

4.1 RESPONSE OF BHINDI TO VARYING SPACING AND BIO INOCULANTS IN RAIN SHELTER AND OPEN FIELD CONDITIONS

4.1.1 Growth Characters

4.1.1.1 Plant Height

The effect of various treatments on height of plants at 30, 60 and 90 DAT under rain shelter and open field condition are given in Table 4. Under rain shelter, spacing of 60 cm x 30 cm recorded the highest value at 30 DAT (39.87 cm), 60 DAT (81.23 cm) and at 90 DAT (119.95 cm) and was on par with 60 cm x 45 cm at 30 and 90 DAT. Bio inoculant had no significant influence on the plant height at 30 DAT. Significant variation was noticed at 60 DAT and 90 DAT and was higher for the bio inoculant PGPR mix 1 (83.34 cm at 60 DAT and 123.46 cm at 90 DAT).

Significant interaction was noticed between spacing and bio inoculants with respect to plant height at all growth stages except 30 DAT. Interaction of 60 cm x 30 cm- PGPR mix 1 (86.34 cm) showed higher plant height which was on par with 60 cm x 30 cm- AMF, 60 cm x 45 cm- PGPR mix 1 and 60 cm x 60 cm-PGPR mix 1 at 60 DAT. Interaction of 60 cm x 30 cm- PGPR mix 1 (128.80 cm) recorded higher values at 90 DAT. This was on par with all the treatments, except 60 cm x 30 cm-no bio inoculant, 60 cm x 60 cm- AMF and 60 cm x 60 cm-no bio inoculant. Lower plant height was observed under 60 cm x 60 cm- AMF

71

Table 4. Effect of spacing and bio inoculants on plant height under rain shelter and open field conditions, cm

	Plant height (cm)					
	Rain shelter			Open field condition		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Spacing (S)						
S_1 - 60cm x 30 cm	39.87	81.23	119.95	29.58	73.34	115.38
S_2 - 60 cm x 45 cm	39.27	77.94	117.92	29.12	65.54	107.44
S_3 - 60 cm x 60 cm	35.42	71.02	104.07	25.05	69.79	104.11
SE m (±)	1.05	1.04	2.51	0.96	0.72	2.23
CD(0.05)	3.172	3.154	7.591	2.908	2.168	6.741
Bioinoculant (B)						
B_1 -PGPR mix 1	40.42	83.34	123.46	30. 62	71.33	115.08
B_2 . AMF	36.78	73.94	111.76	27.25	68.41	111.36
B_3 - No Bio inoculant	37.36	72.91	106.73	25.87	68.93	100.49
SE m (±)	1.05	1.04	2.51	0.96	0.72	2.23
CD(0.05)	NS	3.154	7.591	2.908	2.168	6.741
Interaction						
60 cmx 30 cm x PGPR mix 1	43.67	86.40	128.80	34.20	75.60	123.90
60 cmx 30 cm x AMF	38.33	82.37	115.80	29.40	70.87	116.50
60 cmx 30 cm x No Bio inoculant	37.60	74.93	115.25	25.13	73.57	105.73
60 cmx 45 cm x PGPR mix 1	38.80	81.50	118.33	30.40	66.77	115.17
60 cmx 45 cm x AMF	40.00	76.03	117.63	26.77	68.30	110.83
60 cmx 45 cm x No Bio inoculant	39.00	76.30	117.80	30.20	61.57	96.33
60 cmx 60 cm x PGPR mix 1	38.80	82.13	123.23	27.27	71.633	106.17
60 cmx 60 cm x AMF	32.00	63.43	101.83	25. 60	66.07	106.73
60 cmx 60 cm x No Bio inoculant	35.47	67.50	87.13	22.30	71.67	99.42
SE m (±)	1.82	1.81	4.35	1.67	1.24	3.20
CD(0.05)	NS	5.463	13.149	NS	3.756	NS

72

at 60 DAT (63.43 cm) and 60 cm x 60 cm-no bio inoculant (87.13 cm) at 90 DAT.

Under open field condition, plant height was significantly influenced by plant to plant spacing and of bio inoculants. 60 cm x 30 cm showed significantly higher plant height (29.58 cm at 30 DAT, 73.34 cm at 60 DAT and 115.38 cm at 90 DAT) during all the growth stages and was on par with 60 cm x 45 cm at 30 DAT. PGPR mix 1 registered significantly higher plant height at all growth stages (83.34 cm at 60 DAT and 123.46 cm at 90 DAT).

There was no significant interaction between spacing and bio inoculant on plant height at 30 and 90 DAT. At 60 DAT, plant height was found to be significantly higher for 60 cm x 30 cm- PGPR mix 1 (75.60 cm) which was on par with 60 cm x 30 cm-no bio inoculant. Lower plant height was recorded for 60 cm x 45 cm- no bio inoculant (61.57 cm) at 60 DAT.

4.1.1.2 Number of Leaves per Plant

The data regarding the effects of treatments on number of leaves per plant at monthly intervals under rain shelter and open field conditions are presented in Table 5. Number of leaves per plant at 60 DAT (26.14) and 90 DAT (26.60) was significantly higher for the spacing, 60 cm x 60 cm. It was on par with 60 cm x 45 cm at 60 DAT. Among bio inoculants, PGPR mix 1 showed significantly higher number of leaves per plant at 30 DAT (15.53) and 90 DAT (25.74). There was no significant difference between bio inoculants with respect to number of leaves per plant at 60 DAT.

Significant interaction was noticed between spacing and bio inoculants with respect to number of leaves per plant at 30 and 90 DAT. Higher number of leaves per plant was recorded in 60 cm x 60 cm- PGPR mix 1 (16.43) at 30 DAT and was on par with the combinations, 60 cm x 45 cm-PGPR mix 1, 60 cm x 45 cm- AMF, 60 cm x 30 cm-PGPR mix 1 and 60 cm x 60 cm- AMF. At 90 DAT, significantly higher number of leaves per plant was recorded for 60 cm x 60 cm- PGPR mix 1 (34.27).

Table 5. Effect of spacing and bio inoculants on number of leaves per plant under rain shelter and open field conditions

	Number of leaves per plant					
	Rain shelter			Open field condition		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Spacing (S)						
S_1 - 60 cm x 30 cm	12.09	22.47	16.43	9.19	20.79	15.89
S_2 - 60 cm x 45 cm	13.44	25.44	22.81	12.26	21.74	21.29
S_3 - 60 cm x 60 cm	12.71	26.14	26.60	15.13	24.10	24.97
SE m (±)	0.44	0.55	0. 64	0.59	0. 60	0.50
CD(0.05)	NS	1.654	1.948	1.781	1.805	1.504
Bioinoculant (B)						
B_1 -PGPR mix 1	15.53	25.48	25.74	13.10	24.53	24.06
B_2. AMF	13.74	23.89	20.44	12.64	22.91	20.06
B_3 - No Bio inoculant	8.97	24.68	19.66	10.84	19.19	18.03
SE m (±)	0.44	0.55	0. 64	0.59	0. 60	0.50
CD(0.05)	1.315	NS	1.948	1.781	1.805	1.504
Interaction						
60 cmx 30 cm x PGPR mix 1	14.43	24.43	18.48	10.73	21.53	20.73
60 cmx 30 cm x AMF	11.30	21.43	17.30	9.43	22.17	13.13
60 cmx 30 cm x No Bio inoculant	10.53	21.53	13.50	7.40	18.67	13. 80
60 cmx 45 cm x PGPR mix 1	15.73	25.67	24.47	11.75	22.57	23.47
60 cmx 45 cm x AMF	15.63	25.07	21.13	13.27	25.00	23.23
60 cmx 45 cm x No Bio inoculant	8.97	25.58	22.83	11.77	17.67	17.17
60 cmx 60 cm x PGPR mix 1	16.43	26.33	34.27	16.80	29.50	27.97
60 cmx 60 cm x AMF	14.30	25.17	22.90	15.23	21.57	23.80
60 cmx 60 cm x No Bio inoculant	7.40	26.93	22.63	13.37	21.23	23.13
SE m (±)	0.75	0.95	1.12	1.02	1.03	0.86
CD(0.05)	2.278	NS	3.374	NS	3.127	2. 605

74

interaction. The number of leaves per plant was least in 60 cm x 60 cm- no bio inoculant at 30 DAT (7.40) and for 60 cm x 30 cm- no bio inoculant (13.50) at 90 DAT.

Under open field condition, significant variation was noticed between the three spacings on number of leaves per plant. 60 cm x 60 cm showed more number of leaves per plant than other spacing at all the growth stages of the crop (15.13 at 30 DAT, 24.10 at 60 DAT and 24.97 at 90 DAT).

Significant variation was recorded among the different bio inoculants at all growth stages. PGPR mix 1(13.10 at 30 DAT, 24.53 at 60 DAT and 24.06 at 90 DAT) recorded higher and no bio inoculant recorded the lower number of leaves per plant at all stages of observation. Leaf number recorded by PGPR mix 1 was comparable with AMF at 30 and 60 DAT.

Significant interaction was noticed between spacing and bio inoculant at 60 and 90 DAT but not in 30 DAT. Significantly higher number of leaves per plant was recorded in 60 cm x 60 cm- PGPR mix 1 at 60 DAT (29.50) and 90 DAT (27.97) and the least was for 60 cm x 45 cm- no bio inoculant (17.67) at 60 DAT and 60 cm x 30 cm- AMF (13.13) at 90 DAT.

4.1.1.3 Number of Branches per Plant

The effect of various treatments on number of branches per plant at 30, 60 and 90 DAT under rain shelter and open field conditions is depicted in Table 6. Under rain shelter, spacing of 60 cm x 60 cm produced higher number of branches per plant at 60 DAT (3.54) and at 90 DAT (4.11) and was on par with 60 cm x 45 cm at 60 DAT. Bio inoculant had significant influence on the number of branches per plant at 60 and 90 DAT (3.47 and 4.08 respectively). More number of branches per plant was observed for the PGPR mix 1 (3.47 at 60 DAT and 4.08 at 90 DAT) and was on par with AMF at 60 DAT.

Significant interaction was noticed between spacing and bio inoculants with respect to number of branches per plant only at 90 DAT under rain shelter. Interaction of 60 cm x 60 cm- PGPR mix 1 (4.57) showed higher number of branches per plant at 90 DAT. Less number of branches per plant was observed under 60 cm x 30 cm-no bio inoculant at the stage of final observation (2.68).

Under open field condition, number of branches per plant was significantly influenced by plant to plant spacing and bio inoculants. The spacing of 60 cm x 60 cm showed significantly higher number of branches at 30 DAT (1.77), 60 DAT (3.18) and 90 DAT (3.75). Plant height was found to be significantly higher in PGPR mix 1 at all the growth stages among bio inoculants and was on par with AMF at 30 DAT and 60 DAT.

Significant influence on number of branches per plant by the interaction of spacing and bio inoculant was observed at all the stages of observation. Number of branches per plant was significantly higher for the interaction 60 cm x 60 cm- PGPR mix 1 (2.17 at 30 DAT, 3.73 at 60 DAT and 4.12 at 90 DAT). This was on par with 60 cm x 60 cm-AMF at 60 DAT. At 90 DAT, 60 cm x 60 cm- PGPR mix 1 was on par with 60 cm x 60 cm-AMF, 60 cm x 45 cm-PGPR mix 1and 60 cm x 30 cm-PGPR mix 1.

4.1.1.4 LAI

Results on LAI as influenced by the treatments at monthly interval under rain shelter and open field conditions are given in the Table 7. LAI at monthly intervals was found to be non significant under rain shelter condition.

Under open field condition, spacing showed significant influence on LAI. The spacing of 60 cmx 30 cm recorded higher LAI during 60 DAT (1.83) and 90 DAT (1.46). This was on par with the spacing 60 cmx 45 cm at 60 and 90 DAT. Bio inoculants had no significant influence on LAI. Their interaction was also found non significant.

Table 6. Effect of spacing and bio inoculants on number of branches per plant under rain shelter and open field conditions

	Number of branches per plant					
	Rain shelter			Open field condition		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Spacing (S)						
S_1 - 60 cm x 30 cm	2.27	2.61	3.24	1.09	2.82	3.44
S_2 - 60 cm x 45 cm	2.22	3.38	3.64	1.33	2.84	3.22
S_3 - 60 cm x 60 cm	2.37	3.54	4.11	1.77	3.18	3.75
SE m (±)	0.10	0.17	0.10	0.06	0.05	0.07
CD(0.05)	NS	0.522	0.304	0.170	0.150	0.204
Bioinoculant (B)						
B_1 -PGPR mix 1	2.40	3.47	4.08	1.74	3.39	3.96
B_2 . AMF	2.08	3.41	3.68	1.50	3.28	3.39
B_3 - No Bio inoculant	2.38	2.66	3.23	0.96	2.16	3.07
SE m (±)	0.10	0.17	0.10	0.06	0.05	0.07
CD(0.05)	NS	0.522	0.304	0.170	0.150	0.204
Interaction						
60 cmx 30 cm x PGPR mix 1	2.30	2.73	3.77	1.42	3.27	3.92
60 cmx 30 cm x AMF	2.20	2.93	3.27	1.42	2.88	3.33
60 cmx 30 cm x No Bio inoculant	2.31	2.28	2.68	0.43	2.30	3.08
60 cmx 45 cm x PGPR mix 1	2.40	3.83	3.90	1.63	3.17	3.83
60 cmx 45 cm x AMF	1.83	3.70	4.00	1.30	3.37	3.75
60 cmx 45 cm x No Bio inoculant	2.42	2.61	3.01	1.07	1.98	2.08
60 cmx 60 cm x PGPR mix 1	2.50	3.83	4.57	2.17	3.73	4.12
60 cmx 60 cm x AMF	2.22	3.60	3.77	1.77	3.60	4.03
60 cmx 60 cm x No Bio inoculant	2.40	3.20	4.00	1.37	2.20	3.10
SE m (±)	0.174	0.30	0.17	0.10	0.09	0.12
CD(0.05)	NS	NS	0.526	0.294	0.260	0.354

Table 7. Effect of spacing and bio inoculants on leaf area index under rain shelter and open field conditions

	Leaf area index					
	Rain shelter			Open field condition		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Spacing (S)						
S_1 - 60 cm x 30 cm	0.93	1.85	1.35	0.74	1.83	1.46
S_2 - 60 cm x 45 cm	0.80	1.81	1.22	0.82	1.74	1.09
S_3 - 60 cm x 60 cm	0.69	1.77	1.01	0.70	1.19	0.95
SE m (±)	0.12	0.10	0.16	0.06	0.10	0.13
CD(0.05)	NS	NS	NS	NS	0.302	0.403
Bioinoculant (B)						
B_1 -PGPR mix 1	0.98	1.81	1.45	0.77	1.69	1.40
B_2 - AMF	0.57	1.87	0.85	0.71	1.40	1.06
B_3 - No Bio inoculant	0.87	1.75	1.27	0.79	1.67	1.04
SE m (±)	0.12	0.10	0.19	0.06	0.10	0.13
CD(0.05)	NS	NS	NS	NS	NS	NS
Interaction						
60 cmx 30 cm x PGPR mix 1	1.16	1.87	1.63	0.75	1.98	1.47
60 cmx 30 cm x AMF	0.73	2.13	0.99	0.65	1.89	0.63
60 cmx 30 cm x No Bio inoculant	0.91	1.56	1.41	0.81	1.61	1.27
60 cmx 45 cm x PGPR mix 1	0.94	2.03	1.21	0.88	1.74	1.47
60 cmx 45 cm x AMF	0.60	1.61	0.77	0.84	1.63	0.91
60 cmx 45 cm x No Bio inoculant	0.84	1.80	1.68	0.74	1.86	0.91
60 cmx 60 cm x PGPR mix 1	0.83	1.55	1.51	0.67	1.35	1.27
60 cmx 60 cm x AMF	0.37	1.85	0.78	0.62	0.69	0.64
60 cmx 60 cm x No Bio inoculant	0.86	1.90	0.73	0.81	1.54	0.96
SE m (±)	0.21	0.17	0.28	0.10	0.17	0.23
CD(0.05)	NS	NS	NS	NS	NS	NS

78

4.1.1.5 Length of Tap Root

Results on the effect of spacing and bio inoculant on tap root length at harvest under rain shelter and open field conditions are provided in the Table 8. Under rain shelter, different spacings had significant influence on length of tap root. The spacing of 60 cm x 60 cm recorded higher tap root length (19.56 cm) than other two spacing. Among the different bio inoculants, PGPR mix 1 resulted in higher tap root length (19.86 cm) and no bio inoculant recorded lower tap root length (16.22 cm). Significant interaction was observed between treatments and higher tap root length was noted in 60 cm x 60 cm- PGPR mix 1 (25.67 cm). Less tap root length was recorded by 60 cm x 45 cm- No bio inoculant (15.67 cm) combination.

Under open field condition, 60 cm x 45 cm spacing resulted in significantly higher tap root length (26.67 cm) and was on par with 60 cm x 60 cm. PGPR mix 1 reported significantly higher tap root length (27.33 cm) and no bio inoculant showed minimum value (24.39 cm) among different bio inoculant used for seedling inoculation. Higher tap root length was observed for the interaction, 60 cm x 60 cm- PGPR mix 1 (29.00 cm) and lower was for 60 cm x 30 cm- AMF (20.67 cm).

4.1.1.6 Root Volume

The data regarding the effects of treatments on root volume at harvest under rain shelter and open field conditions are detailed in the Table 8. Under rain shelter, root volume was significantly higher for the wider spacing of 60 cm x 60 cm (29.89 cm^3). Among bio inoculants, PGPR mix 1 showed significantly higher root volume (28.56 cm^3). Significant interaction was noticed between spacing and bio inoculants with respect to root volume at harvest. Higher root volume was recorded in 60 cm x 60 cm- PGPR mix 1 (33.67 cm^3) and was on par with the combination, 60 cm x 60 cm-AMF.

Under open field condition, significant variation was noticed between the three spacings regarding root volume. The spacing of 60 cm x 60 cm showed higher root volume (36.78 cm^3) than other spacings at harvest. Significant variation was

Table 8. Effect of spacing and bio inoculants on length of tap root, root volume and root: shoot ratio of plant at harvest under rain shelter and open field conditions

	Rain shelter			Open field condition		
Treatment	Length of taproot (cm)	Root volume (cm^3)	Root: shoot ratio	Length of taproot (cm)	Root volume (cm^3)	Root: shoot ratio
Spacing (S)						
S_1 - 60 cm x 30 cm	17.13	23.11	0.17	23.67	25.67	0.19
S_2 - 60 x 45 cm	16.44	24.83	0.19	26.67	25.00	0.20
S_3 - 60 x 60 cm	19.56	29.89	0.22	26.17	36.78	0.23
SE m (±)	0.58	0.56	0.02	0.59	0.75	0.02
CD(0.05)	1.762	1.684	NS	1.790	2.278	NS
Bioinoculant (B)						
B_1 -PGPR mix 1	19.86	28.56	0.18	27.33	31.44	0.19
B_2 . AMF	17.06	26.06	0.21	24.78	27.67	0.20
B_3 - No Bio inoculant	16.22	23.22	0.18	24.39	28.33	0.22
SE m (±)	0.58	0.56	0.02	0.59	0.75	0.02
CD(0.05)	1.762	1.684	NS	1.790	2.278	NS
Interaction						
60 cmx 30 cm x PGPR mix 1	16.23	25.00	0.18	27.67	30.00	0.18
60 cmx 30 cm x AMF	18.17	20.33	0.16	20.67	20.00	0.19
60 cmx 30 cm x No Bio inoculant	17.00	24.00	0.16	22.67	27.00	0.20
60 cmx 45 cm x PGPR mix 1	17.67	27.00	0.15	25.33	27.00	0.19
60 cmx 45 cm x AMF	16.00	24.50	0.20	26.67	27.00	0.20
60 cmx 45 cm x No Bio inoculant	15.67	23.00	0.20	28.00	21.00	0.20
60 cmx 60 cm x PGPR mix 1	25.67	33.67	0.21	29.00	37.33	0.21
60 cmx 60 cm x AMF	17.00	33.33	0.28	27.00	36.00	0.22
60 cmx 60 cm x No Bio inoculant	16.00	22.67	0.17	22.50	37.00	0.24
SE m (±)	1.01	0.97	0.04	1.03	1.31	0.03
CD(0.05)	3.052	2.92	NS	3.100	3.945	NS

recorded among the different bio inoculants on root volume. PGPR mix 1 resulted in higher root volume (31.44 cm^3) at harvest. Significant interaction was noticed between spacing and bio inoculant on root volume at harvest. Significantly higher root volume was recorded in 60 cm x 60 cm- PGPR mix 1 (37.33 cm^3) and was on par with the combinations, 60 cm x 60 cm- AMF and 60 cm x 60 cm- no bio inoculant and the least was observed for 60 cm x 30 cm- AMF (20 cm^3).

4.1.1.7 Root: shoot ratio

The data regarding root: shoot ratio under rain shelter and open field conditions are presented in Table 8. Effect of spacing and bio inoculants and their interaction were found to be non significant in the case of root: shoot ratio of bhindi under both growing conditions.

4.1.2 Yield attributes

4.1.2.1 Days to 50 per cent flowering

Result on the effect of treatments on days to 50 per cent flowering under rain shelter and open field conditions are presented in Table 9. Spacing and bio inoculants and their interaction were found to have no significant effect on days to 50 per cent flowering of bhindi under both growing conditions.

4.1.2.2 Number of flowers per plant

The data regarding the effects of treatments on number of flowers per plant under rain shelter and open field conditions are presented in Table 9. Under rain shelter, number of flowers was significantly higher for the spacing of 60 cm x 60 cm (52.30). Among bio inoculants, PGPR mix 1 showed significantly more number of flowers (53.78). Significant difference was observed among interaction of spacing and bio inoculants on flower number and was higher for 60 cm x 45 cm-PGPR mix 1 (62.46).

Table 9. Effect of spacing and bio inoculants on days to 50 per cent flowering, number of flowers per plant and number of fruits per plant under rain shelter and open field conditions.

	Rain shelter			Open field condition		
Treatment	Days to 50 per cent flowering	Number of flowers per plant	Number of fruits per plant	Days to 50 per cent flowering	Number of flowers per plant	Number of fruits per plant
Spacing (S)						
S_1 - 60 x 30 cm	36.56	40.82	26.35	41.33	37.03	20.00
S_2 - 60 x 45 cm	36.22	50.02	31.48	41.33	39.80	23.68
S_3 - 60 x 60 cm	36.89	52.30	32.62	41.22	45.59	25.02
SE m (±)	0.23	0.52	0.49	0.34	0.45	0.33
CD(0.05)	NS	1.584	1.489	NS	1.362	0.984
Bioinoculant (B)						
B_1 -PGPR mix 1	36.33	53.78	33.22	41.33	42.49	25.30
B_2 - AMF	36.78	46.23	30.26	41.44	40.14	22.47
B_3 - No Bio inoculant	36.56	43.13	26.98	41.11	39.79	20.92
SE m (±)	0.23	0.52	0.49	0.34	0.45	0.33
CD(0.05)	NS	1.584	1.489	NS	1.362	0.984
Interaction						
60 cmx 30 cm x PGPR mix 1	36.00	42.52	27.37	41.00	38.12	21.19
60 cmx 30 cm x AMF	36.67	41.38	26.13	41.67	37.56	20.57
60 cmx 30 cm x No Bio inoculant	37.00	38.55	25.55	41.33	35.42	18.24
60 cmx 45 cm x PGPR mix 1	36.00	62.46	37.95	41.33	40.04	23.91
60 cmx 45 cm x AMF	36.33	46.23	31.10	41.00	40.89	23.76
60 cmx 45 cm x No Bio inoculant	36.33	41.36	25.40	41.67	38.47	23.38
60 cmx 60 cm x PGPR mix 1	37.00	56.34	34.38	41.67	49.32	30.81
60 cmx 60 cm x AMF	37.33	51.07	33.54	41.67	41.95	23.09
60 cmx 60 cm x No Bio inoculant	36.33	49.47	29.98	40.33	45.49	21.15
SE m (±)	0.39	0.91	0.85	0.59	0.78	0.56
CD(0.05)	NS	2.744	2.578	NS	2.360	1.704

82

Under open field conditions, significant variation was noticed between spacing. The spacing of 60 cm x 60 cm showed more number of flowers per plant (45.59) than other spacing. Significant variation was also recorded among different bio inoculants. PGPR mix 1 resulted in higher number (42.49) and no bio inoculant recorded the lower number of flowers (39.79). Significant interaction was also noticed between spacing and bio inoculant on number of flowers. Significantly higher number of flowers was recorded by 60 cm x 60 cm- PGPR mix 1 (49.32) and the least was for 60 cm x 30 cm- no bio inoculant (35.42).

4.1.2.3 Number of Fruits per Plant

Results on the effect of treatments on the number of fruits per plant under rain shelter and open field conditions are given in Table 9. Under rain shelter, number of fruits was significantly higher for the spacing, 60 cm x 60 cm (32.62) and was on par with 60 cm x 45 cm (31.48). Among the bio inoculants, PGPR mix 1 recorded significantly more number of fruits (33.22) per plant. There was significant difference among the interaction of spacing and bio inoculants on the number of fruits per plant and was higher for 60 cm x 45 cm-PGPR mix 1 (37.95).

Under open field condition, spacing had significant influence on number of fruits per plant. The spacing of 60 cm x 60 cm recorded higher number of fruits per plant (25.02) than the other spacing. Bio inoculants also influenced the number of fruits produced by plants. PGPR mix 1 recorded higher (25.30) and no bio inoculant (20.92) recorded the lower number of fruits per plant. Significant interaction was noticed between spacing and bio inoculant on number of fruits per plant. Significantly higher number of fruits per plant was recorded by 60 cm x 60 cm-PGPR mix 1 (30.81) and the least was recorded by 60 cm x 30 cm- no bio inoculant (18.24).

4.1.2.4 Fruit Set Percentage

The data regarding the effect of treatments on fruit set percentage under rain shelter and open field conditions are presented in Table 10. Under rain shelter, fruit set percentage was found to be non significant among the treatments and their interaction.

Under open field condition, significant variation was noticed between the three spacings regarding fruit set percentage. 60 cm x 45 cm showed higher fruit set percentage (59.54 %) than the other spacings. Significant variation was recorded among the different bio inoculants on fruit set percentage. PGPR mix 1 resulted in higher fruit set percentage (59.31 %). Interaction between spacings and bio inoculants was also found to be significant on fruit setting percentage. Significantly higher fruit set per cent was recorded by 60 cm x 60 cm- PGPR mix 1 (62.58 %) and was on par with the combinations, 60 cm x 45 cm- AMF, 60 cm x 45 cm- no bio inoculants and 60 cm x 45 cm- PGPR mix 1.

4.1.2.5 Length of Fruit

Result on the effect of spacing and bio inoculant on length of fruit under rain shelter and open field conditions is provided in Table 10. Under rain shelter, different spacing had significant influence on length of fruit. Significantly higher fruit length was recorded by 60 cm x 60 cm (14.72 cm) and was on par with 60 cm x 45 cm. Bio inoculants had no significant influence on fruit length. Significantly higher fruit length was noticed under the interaction, 60 cm x 60 cm- AMF (15.20 cm) and it was on par with all the treatments except 60 cm x 30 cm- AMF and 60 cm x 30 cm- no bio inoculant.

Under open field condition, 60 cm x 60 cm spacing resulted in significantly higher length of fruit (14.97 cm) and was on par with 60 cm x 45 cm. PGPR mix 1 recorded higher fruit length (15.43 cm) among bio inoculants. No significant influence by treatments was noticed between interactions regarding fruit length.

4.1.2.6 Weight of Fruit

Effect of various treatments on weight of fruit under rain shelter and open field conditions is given in Table 10. Under rain shelter, spacing of 60cm x 60 cm

Table 10. Effect of spacing and bio inoculants on percentage of fruit set, length of fruit and weight of fruit under rain shelter and open field conditions

	Rain shelter			Open field condition		
Treatment	Fruit set (%)	Length of fruit (cm)	Weight of fruit (g)	Fruit set (%)	Length of fruit (cm)	Weight of fruit (g)
Spacing (S)						
S_1 - 60 x 30 cm	64.69	13.19	11.61	53.98	13.93	12.65
S_2 - 60 x 45 cm	63.14	14.42	13.27	59.54	14.40	13.03
S_3 - 60 x 60 cm	62.47	14.72	14.10	54.70	14.97	13.86
SE m (±)	1.34	0.27	0.22	0.94	0.23	0.19
CD(0.05)	NS	0.800	0.654	2.843	0.691	0.569
Bioinoculant (B)						
B_1 -PGPR mix 1	62.05	14.39	13.30	59.31	15.43	13.87
B_2 - AMF	65.45	14.00	13.25	55.97	13.77	12.93
B_3 - No Bio inoculant	62.80	13.94	12.43	52.95	14.10	12.74
SE m (±)	1.34	0.27	0.22	0.94	0.23	0.19
CD(0.05)	NS	NS	0.654	2.843	0.691	0.569
Interaction						
60 cmx 30 cm x PGPR mix 1	64.43	14.43	12.34	55.66	15.50	13.89
60 cmx 30 cm x AMF	63.34	12.13	11.76	54.78	13.33	11.29
60 cmx 30 cm x No Bio inoculant	66.30	13.00	10.72	51.52	12.97	12.77
60 cmx 45 cm x PGPR mix 1	60.74	14.17	12.04	59.70	14.93	13.28
60 cmx 45 cm x AMF	67.30	14.67	13.93	58.12	13.73	12.86
60 cmx 45 cm x No Bio inoculant	61.40	14.43	13.85	60.80	14.53	12.96
60 cmx 60 cm x PGPR mix 1	61.00	14.57	15.52	62.58	15.87	14.45
60 cmx 60 cm x AMF	65.71	15.20	14.08	55.01	14.23	14.63
60 cmx 60 cm x No Bio inoculant	60.70	14.40	12.73	46.53	14.8	12.49
SE m (±)	2.33	0.46	0.37	1. 63	0.40	0.33
CD(0.05)	NS	1.385	1.133	4.923	NS	0.985

(14.10 g) produced significantly higher fruit weight. Bio inoculants had significant influence on weight of fruit. Higher fruit weight was observed for the PGPR mix 1 (13.30 g) and was on par with AMF.

Significant interaction was noticed between spacing and bio inoculants with respect to fruit weight under rain shelter. Interaction of 60 cm x 60 cm- PGPR mix 1 (15.52 g) showed higher fruit weight. Lower fruit weight was observed under 60 cm x 30 cm-no Bio inoculant (10.72 g).

Under open field condition, weight of fruit was significantly influenced by plant to plant spacing and bio inoculants. The spacing of 60 cm x 60 cm showed significantly higher fruit weight (13.86 g). Fruit weight was found to be significantly higher in PGPR mix 1 (13.87 g) among bio inoculants.

Interaction between spacing and bio inoculants influenced the weight of fruit. Weight of fruit was significantly higher for 60 cm x 60 cm- AMF (14.63 g), which was on par with 60 cm x 60 cm-PGPR mix 1 and 60 cm x 30 cm-PGPR mix 1.

4.1.2.7 Weight of Fruit per Plant

The effect of spacing and bio inoculant on weight of fruit per plant is provided in Table 11. Under rain shelter, different spacings had significant influence on the weight of fruit per plant. 60 cm x 60 cm recorded significantly higher weight of fruit per plant (461.79 g). Bio inoculants also influenced the weight of fruit per plant and PGPR mix 1 recorded higher fruit weight per plant (442.54 g). Among the interactions between treatments, significantly higher fruit weight per plant was noticed under 60 cm x 60 cm-PGPR mix 1 (532.71 g) and lower fruit weight per plant was noticed under 60 cm x 30 cm-no bio inoculant (274.89 g).

Under open field condition, 60 cm x 60 cm spacing resulted in significantly higher weight of fruit per plant (349.08 g) and PGPR mix 1 showed significantly higher fruit weight per plant (352.40 g) among the different bio inoculants used for seedling inoculation. Interaction was found significant among treatments with respect to fruit weight per plant and was higher for the 60 cm x 60 cm-PGPR mix 1(445.24). Lower fruit weight was observed under 60 cm x 30 cm-AMF (231.97 g).

4.1.2.8 Fruit Yield

The result on the effect of various treatments on fruit yield under rain shelter and open field conditions is depicted in Table 11. Under rain shelter, spacing of 60cm x 30 cm produced significantly higher fruit yield (17.03 t ha^{-1}). Bio inoculant had significant influence on yield and higher fruit yield was recorded for the PGPR mix 1(16.83 t ha^{-1}).

Significant interaction was noticed between spacing and bio inoculants with respect to yield under rain shelter. 60 cm x 30 cm- PGPR mix 1 (18.78 t ha^{-1}) resulted in higher yield. Lower yield was obtained by 60 cm x 60 cm-no Bio inoculant (10.51 t ha^{-1}).

Under open field condition, yield was significantly influenced by plant to plant spacing and bio inoculants. The spacing of 60 cm x 30 cm showed significantly higher fruit yield (14.07 t ha^{-1}). Fruit yield was found to be significantly higher in PGPR mix 1 (13.50 t ha^{-1}) among the different bio inoculants.

Significant interaction was observed between spacing and bio inoculant on yield and was higher for 60 cm x 30 cm- PGPR mix 1 (16.36 t ha^{-1}). Lowest yield was recorded by 60 cm x 60 cm- PGPR mix 1 (7.33 t ha^{-1}) combination.

4.1.2.9 Harvest Index

The data regarding harvest index under rain shelter and open field conditions are presented in Table 11. Spacing and bio inoculants and their interaction were found to be non significant in case of harvest index of bhindi under both growing conditions.

Table 11. Effect of spacing and bio inoculants on weight of fruits per plant and mature fruit yield per hectare and harvest index under rain shelter and open field conditions

	Rain shelter			Open field condition		
Treatment	Weight of fruits per plant (g $plant^{-1}$)	Fruit yield (t ha^{-1})	Harvest index	Weight of fruits per plant (g $plant^{-1}$)	Fruit yield (t ha^{-1})	Harvest index
Spacing (S)						
S_1 - 60 x 30 cm	306.59	17.03	0.23	253.29	14.07	0.28
S_2 - 60 x 45 cm	414.30	15.34	0.25	308.39	11.42	0.23
S_3 - 60 x 60 cm	461.79	12.79	0.24	349.08	9.70	0.24
SE m (±)	5.79	0.11	0.02	5.91	0.26	0.03
CD(0.05)	17.521	0.318	NS	17.865	0.776	NS
Bioinoculant (B)						
B_1 -PGPR mix 1	442.54	16.83	0.24	352.40	13.50	0.21
B_2 - AMF	404.19	15.41	0.22	291.81	11.20	0.25
B_3 - No Bio inoculant	335.95	12.92	0.27	266.56	10.50	0.29
SE m (±)	5.79	0.11	0.02	5.91	0.26	0.03
CD(0.05)	17.521	0.318	NS	17.865	0.776	NS
Interaction						
60 cmx 30 cm x PGPR mix 1	337.98	18.78	0.21	294.47	16.36	0.25
60 cmx 30 cm x AMF	307.40	17.08	0.26	231.97	12.89	0.27
60 cmx 30 cm x No Bio inoculant	274.89	15.24	0.24	233.42	12.97	0.34
60 cmx 45 cm x PGPR mix 1	456.91	16.92	0.22	317.48	11.76	0.23
60 cmx 45 cm x AMF	434.32	16.09	0.2	305.40	11.31	0.23
60 cmx 45 cm x No Bio inoculant	351.65	13.02	0.33	302.30	11.20	0.23
60 cmx 60 cm x PGPR mix 1	532.71	14.80	0.29	445.24	12.37	0.16
60 cmx 60 cm x AMF	470.85	13.08	0.21	338.05	9.40	0.25
60 cmx 60 cm x No Bio inoculant	381.82	10.51	0.24	263.97	7.33	0.32
SE m (±)	0.347	0.18	0.04	10.23	0.44	0.05
CD(0.05)	10.04	0.552	NS	30.943	1.344	NS

88

4.1.3 Physiological Observations

4.1.3.1 Crop Growth Rate (CGR)

The data regarding the effect of treatments on CGR under rain shelter and open field conditions are presented in Table 12. Under rain shelter, spacing had significant influence on CGR. The spacing of 60 cm x 30 cm spacing recorded higher CGR (1.24 g m^{-2} day^{-1}) and was on par with 60 cm x 45 cm. Among the bio inoculants, PGPR mix 1 showed significantly higher CGR (1.28 g m^{-2} day^{-1}) and was on par with AMF. There was significant difference among the interaction of spacing and bio inoculants on CGR and was significantly higher for 60 cm x 30 cm-AMF (1.85 g m^{-2} day^{-1}).

Under open field condition, significant variation was noticed among the spacing. The spacing of 60 cm x 30 cm showed more CGR (1.39 g m^{-2} day^{-1}) than other spacings. Significant variation was also recorded among the different bio inoculant treatments. PGPR mix 1 resulted in higher CGR (1.25 g m^{-2} day^{-1}) and no bio inoculant (1.06 g m^{-2} day^{-1}) recorded lower CGR. Significant interaction was noticed between spacing and bio inoculant on CGR. Significantly higher CGR was recorded in 60 cm x 45 cm- PGPR mix 1 (1.65 g m^{-2} day^{-1}) and the least was for 60 cm x 60 cm- AMF (0.74 g m^{-2} day^{-1}).

4.1.3.2 Relative Growth Rate (RGR)

Results on the effects of treatments on RGR under rain shelter and open field conditions are presented in Table 12. Under rain shelter, RGR was significantly influenced by plant to plant spacing and was higher for 60 cm x 60 cm (30.15 mg g^{-1} day^{-1}) which was on par with 60 cm x 45 cm. Among the bio inoculant treatments, PGPR mix 1 (30.49 mg g^{-1} day^{-1}) showed significantly higher RGR and was on par with AMF. There was significant difference among interaction of spacing and bio inoculants on RGR and was significantly higher for 60 cm x 60 cm-PGPR mix 1 (39.13 mg g^{-1} day^{-1}). This was on par with 60 cm x 45 cm-PGPR mix 1 (37.87 mg g^{-1} day^{-1}).

Table 12. Effect of spacing and bio inoculants on CGR, RGR and NAR of the plant between 30 and 60 DAT under rain shelter and open field conditions

	Rain shelter			Open field condition		
Treatment	CGR ($g\ m^{-2}\ day^{-1}$)	RGR ($mg\ g^{-1} day^{-1}$)	NAR ($g\ m^{-2}\ day^{-1}$)	CGR ($g\ m^{-2}\ day^{-1}$)	RGR ($mg\ g^{-1} day^{-1}$)	NAR ($g\ m^{-2}\ day^{-1}$)
Spacing (S)						
S_1 - 60 x 30 cm	1.24	26.17	1.18	1.39	15.78	1.16
S_2 - 60 x 45 cm	1.17	29.60	1.31	1.25	16.40	1.25
S_3 - 60 x 60 cm	0.93	30.15	1.16	0.83	26.35	1.29
SE m (±)	0.07	0.63	0.15	0.03	0.47	0.20
CD(0.05)	0.211	1.904	NS	0.077	1.417	NS
Bioinoculant (B)						
B_1 -PGPR mix 1	1.28	30.49	1.33	1.25	20.97	1.49
B_2 - AMF	1.15	28.90	1.31	1.16	19.45	1.23
B_3 - No Bio inoculant	0.91	26.54	1.02	1.06	18.11	0.99
SE m (±)	0.07	0.63	0.15	0.03	0.47	0.20
CD(0.05)	0.211	1.904	NS	0.077	1.417	NS
Interaction						
60 cmx 30 cm x PGPR mix 1	1.42	27.50	1.69	1.33	17.13	0.82
60 cmx 30 cm x AMF	1.85	27.48	1.40	1.47	15.90	0.93
60 cmx 30 cm x No Bio inoculant	0.46	23.55	0.46	1.38	14.31	1.74
60 cmx 45 cm x PGPR mix 1	1.71	37.87	0.43	1.65	18.01	1.54
60 cmx 45 cm x AMF	0.43	23.57	1.82	1.28	15.30	1.77
60 cmx 45 cm x No Bio inoculant	1.37	26.10	1.67	0.83	15.90	0.45
60 cmx 60 cm x PGPR mix 1	0.71	39.13	1.85	0.78	27.76	2.11
60 cmx 60 cm x AMF	1.16	35.65	0.72	0.74	27.15	1.00
60 cmx 60 cm x No Bio inoculant	0.91	16.93	0.91	0.96	24.13	0.78
SE m (±)	0.12	1.09	0.26	0.04	0.81	0.34
CD(0.05)	0.366	3.298	0.770	0.133	NS	1.028

Under open field condition, significant variation was noticed between spacing. The spacing of 60 cm x 60 cm showed more RGR (26.35 mg g^{-1} day^{-1}) than other spacing. Significant variation was also recorded among different bio inoculants. PGPR mix 1 resulted in higher RGR (20.97 mg g^{-1} day^{-1}) and no bio inoculant recorded the lower RGR (18.11 mg $g^{-1}day^{-1}$). Interaction was found non significant between spacing and bio inoculant on RGR.

4.1.3.3 Net Assimilation Rate (NAR)

The data regarding the effects of treatments on NAR under rain shelter and open field conditions are presented in Table 12. Under rain shelter, NAR was found to be non significant among spacing and bio inoculants. There was significant difference among the interaction effect of spacing and bio inoculants on NAR and was significantly higher for 60 cm x 60 cm-PGPR mix 1 (1.85 g m^{-2} day^{-1}). This was on par with all the interactions except 60 cm x 30 cm-no bio inoculant and 60 cm x 45 cm-PGPR mix 1.

Under open field condition, significant variation was noticed among the different spacings. NAR was non significant among spacing and bio inoculants. There was significant difference among interaction of spacing and bio inoculants on NAR and was significantly higher for 60 cm x 60 cm-PGPR mix 1 (2.11 g m^{-2} day^{-1}). This was on par with the interactions, 60 cm x 45 cm-AMF, 60 cm x 45 cm-PGPR mix 1 and 60 cm x 30 cm-no bio inoculant.

4.1.3.4 Chlorophyll Content

Effect of treatments on chlorophyll content of leaves at 45 DAT under rain shelter and open field conditions is presented in Table 13. Spacing and bio inoculants and their interaction were found to be non significant in case of chlorophyll content of bhindi leaves under both growing conditions.

Table 13. Effect of spacing and bio inoculants on dry matter production at harvest and chlorophyll content at 45 DAT of plants under rain shelter and open field conditions

	Rainshelter		Open field condition	
Treatment	Chlorophyll content (mg g^{-1})	Dry matter production (kg ha^{-1})	Chlorophyll content (mg g^{-1})	Dry matter production (kg ha^{-1})
Spacing (S)				
S_1 - 60 x 30 cm	1.96	6977	1.42	4965
S_2 - 60 x 45 cm	1.67	5623	2.02	4340
S_3 - 60 x 60 cm	2.14	4029	1.48	3333
SE m (±)	0.18	358.09	0.22	190.34
CD(0.05)	NS	1082.789	NS	575.550
Bioinoculant (B)				
B_1 -PGPR mix 1	1.85	6527	1.46	4885
B_2 - AMF	2.01	5505	1.66	4168
B_3 - No Bio inoculant	1.92	4599	1.80	3586
SE m (±)	0.18	358.09	0.22	190.34
CD(0.05)	NS	1082.789	NS	575.550
Interaction				
60 cmx 30 cm x PGPR mix 1	1.48	8859	1.02	5912
60 cmx 30 cm x AMF	2.38	5351	1.73	5016
60 cmx 30 cm x No Bio inoculant	2.02	6723	1.51	3969
60 cmx 45 cm x PGPR mix 1	1.72	6466	1.82	4512
60 cmx 45 cm x AMF	2.02	6511	1.70	4310
60 cmx 45 cm x No Bio inoculant	1.28	3893	2.53	4199
60 cmx 60 cm x PGPR mix 1	2.34	4255	1.53	4230
60 cmx 60 cm x AMF	1.62	4652	1.54	3177
60 cmx 60 cm x No Bio inoculant	2.45	3180	1.37	2591
SE m (±)	0.31	620.23	0.38	329.68
CD(0.05)	NS	1875.445	NS	NS

4.1.3.5 Dry Matter Production

Results on the effect of spacing and bio inoculant on total dry matter production under rain shelter and open field conditions are provided in Table 13. Under rain shelter, different spacing had significant influence on dry matter production. The spacing of 60 cm x 30 cm recorded significantly higher dry matter production (6977 kg ha^{-1}) than other two spacing. Higher dry matter production was recorded for the PGPR mix 1 (6193 kg ha^{-1}) among the bio inoculants and no bio inoculant recorded lower dry matter production (4599 kg ha^{-1}). Significant interaction was observed for higher dry matter production and 60 cm x 30 cm-PGPR mix 1 was found superior (8859 kg ha^{-1}) to other treatments. Lower dry matter production was recorded by 60 cm x 60 cm- no bio inoculant (3180 kg ha^{-1}) combination.

Under open field condition, 60 cm x 30 cm (4965 kg ha^{-1}) spacing resulted in significantly higher dry matter production. PGPR mix 1 recorded significantly higher dry matter production (4885 kg ha^{-1}) and no bio inoculant (3586 kg ha^{-1}) gave lower values among the different bio inoculants used for seedling inoculation. Higher dry matter production was observed for the interaction, 60 cm x 30 cm-PGPR mix 1 (5912 kg ha^{-1}) and lower was obtained for 60 cm x 60 cm- no bio inoculant (2591 kg ha^{-1}).

4.1.4 Quality Aspects of Fruits

4.1.4.1 Shelf Life

Effect of treatments on shelf life of bhindi fruits under rain shelter and open field conditions are presented in the Table 14. Under rain shelter and open field conditions, shelf life was found to be non significant among the treatments and their interactions.

4.1.4.2 Ascorbic Acid

The data regarding the effects of treatments on ascorbic acid content of bhindi fruits under rain shelter and open field conditions are presented in Table 14.

Table 14. Effect of spacing and bio inoculants on shelf life, ascorbic acid and protein content of fruits under rain shelter and open field conditions

	Rain shelter			Open field condition		
Treatment	Shelf life (days)	Ascorbic acid (mg 100 g^{-1})	Protein (%)	Shelf life (days)	Ascorbic acid (mg 100 g^{-1})	Protein (%)
Spacing (S)						
S_1 - 60 x 30 cm	4.19	17.97	1.39	3.94	16.74	1.35
S_2 - 60 x 45 cm	4.06	19.24	1.44	4.13	17.36	1.41
S_3 - 60 x 60 cm	3.94	19.86	1.44	3.72	17.36	1.42
SE m (±)	0.32	0.65	0.02	0.19	1.10	0.04
CD(0.05)	NS	NS	0.044	NS	NS	NS
Bioinoculant (B)						
B_1 -PGPR mix 1	4.17	19.24	1.45	4.00	17.36	1.44
B_2 - AMF	4.00	19.22	1.48	4.14	17.36	1.43
B_3 - No Bio inoculant	4.03	18.60	1.35	3.66	16.11	1.30
SE m (±)	0.32	0.65	0.02	0.19	1.10	0.04
CD(0.05)	NS	NS	0.044	NS	NS	NS
Interaction						
60 cmx 30 cm x PGPR mix 1	4.83	19.86	1.45	3.50	16.11	1.35
60 cmx 30 cm x AMF	4.50	17.95	1.38	4.83	17.99	1.39
60 cmx 30 cm x No Bio inoculant	3.25	16.09	1.35	3.50	16.11	1.30
60 cmx 45 cm x PGPR mix 1	3.17	17.99	1.45	4.33	17.99	1.46
60 cmx 45 cm x AMF	4.33	19.86	1.54	4.27	17.99	1.44
60 cmx 45 cm x No Bio inoculant	4.67	19.86	1.34	3.80	16.11	1.32
60 cmx 60 cm x PGPR mix 1	4.50	19.86	1.44	4.17	17.99	1.51
60 cmx 60 cm x AMF	3.17	19.86	1.54	3.33	17.99	1.45
60 cmx 60 cm x No Bio inoculant	4.17	19.86	1.35	3.67	16.11	1.30
SE m (±)	0.55	1.12	0.03	0.34	1.90	0.07
CD(0.05)	NS	NS	0.076	NS	NS	NS

under rain shelter and open field conditions, shelf life was found non significant among the treatments.

4.1.4.3 Protein

The effect of various treatments on protein content under rain shelter and open field conditions is given in Table 14. Under rain shelter, wider spacing of 60 cm x 60 cm (1.44 %) and 60 cm x 45 cm (1.44 %) produced significantly higher protein content. Bio inoculant had significant influence on protein content. Higher protein content was recorded for AMF (1.48 %) and was on par with PGPR mix 1 (1.45 %).

Significant interaction was noticed between spacing and bio inoculants with respect to protein content under rain shelter. Interaction of 60 cm x 60 cm- AMF (1.54 %) and 60 cm x 45 cm- AMF (1.54 %) showed the highest protein content.

Under open field condition, significant variation in protein content was not observed among spacing and bio inoculants and their interaction.

4.1.5 Plant Analysis

4.1.5.1 N uptake

Results on the effect of spacing and bio inoculant on N uptake under rain shelter and open field conditions are provided in Table 15. Under rain shelter, different spacing had significant influence on N uptake and 60 cm x 30 cm (70.12 kg ha^{-1}) recorded significantly higher N uptake by plants. Among the bio inoculants, PGPR mix 1 (70.38 kg ha^{-1}) showed higher N uptake and was on par with AMF (65.96 kg ha^{-1}). Significantly higher N uptake was noticed under 60 cm x 30 cm-PGPR mix 1 (85.29 kg ha^{-1}) interaction. This was on par with 60 cm x 30 cm-AMF and 60 cmx 45 cm-AMF.

Under open field condition, 60 cm x 30 cm spacing resulted in significantly higher N uptake (64.40 kg ha^{-1}) and PGPR mix 1 showed significantly higher N uptake (64.40 kg ha^{-1})among the different bio inoculants used for seedling inoculation and this was on par with AMF. Interaction was found non significant among treatments regarding N uptake.

4.1.5.2 P uptake

Effect of spacing and bio inoculant on P uptake under rain shelter and open field conditions is provided in Table 15. Under rain shelter, different spacing had significant influence on P uptake and 60 cm x 30 cm recorded significantly higher P uptake (15.02 kg ha^{-1}) by plants. Bio inoculants had significant influence on P uptake and were higher for PGPR mix 1 (14.82 kg ha^{-1}). Interaction of treatments was found non significant regarding P uptake.

Under open field condition, 60 cm x 30 cm spacing resulted in significantly higher P uptake (14.34 kg ha^{-1}) and bio inoculants had no significant effect on P uptake. Interaction was also found to be non significant among the treatments with respect to P uptake.

4.1.5.3 K uptake

Results on the effect of spacing and bio inoculants on K uptake under rain shelter and open field conditions are provided in Table 15. Under rain shelter, different spacing had significant influence on K uptake and 60 cm x 30 cm recorded significantly higher K uptake (67.35 kg ha^{-1}) by plants. Among the bio inoculants, PGPR mix 1 showed higher K uptake (67.52 kg ha^{-1}). Interaction was found to be non significant among treatments regarding K uptake.

Under open field condition, 60 cm x 30 cm spacing resulted in significantly higher K uptake (61.94 kg ha^{-1}) and among the bio inoculants, significantly higher K uptake was observed under PGPR mix 1 (62.35 kg ha^{-1}). Interaction was found to be non significant among the treatments regarding K uptake.

Table 15. Effect of spacing and bio inoculants on NPK uptake of plant at harvest under rain shelter and open field conditions (kg ha^{-1})

	Rain shelter			Open field condition		
Treatment	N uptake	P uptake	K uptake	N uptake	P uptake	K uptake
Spacing (S)						
S_1 - 60 x 30 cm	70.12	15.02	67.35	64.40	14.34	61.94
S_2 - 60 x 45 cm	57.94	14.53	60.40	54.56	13.79	50.98
S_3 - 60 x 60 cm	54.44	13.8	44.70	50.30	13.64	45.49
SE m (±)	2.84	0.15	4.44	2.72	0.13	1.50
CD(0.05)	8.579	0.464	13.41	8.210	0.377	4.533
Bioinoculant (B)						
B_1 -PGPR mix 1	70.38	14.82	67.52	64.40	14.14	62.35
B_2 - AMF	65.96	14.30	55.49	57.91	13.94	51.97
B_3 - No Bio inoculant	46.15	14.23	49.45	46.96	13.68	44.09
SE m (±)	2.84	0.15	4.44	2.72	0.13	1.50
CD(0.05)	8.579	0.464	13.41	8.210	NS	4.53
Interaction						
60 cmx 30 cm x PGPR mix 1	85.29	15.51	83.45	73.64	14.53	72.68
60 cmx 30 cm x AMF	74.28	14.39	68.14	63.92	14.51	60.01
60 cmx 30 cm x No Bio inoculant	50.78	15.16	50.47	55.64	13.97	63.45
60 cmx 45 cm x PGPR mix 1	57.75	14.94	71.16	58.63	13.90	63.45
60 cmx 45 cm x AMF	73.35	14.71	46.71	60.66	13.66	46.41
60 cmx 45 cm x No Bio inoculant	42.73	13.94	63.32	44.40	13.80	43.08
60 cmx 60 cm x PGPR mix 1	68.12	14.00	47.95	60.92	13.98	50.94
60 cmx 60 cm x AMF	50.25	13.80	51.61	49.14	13.65	49.49
60 cmx 60 cm x No Bio inoculant	44.95	13.58	34.54	40.84	13.28	36.06
SE m (±)	4.91	0.27	7.68	4.70	0.22	2.60
CD(0.05)	14.859	NS	NS	NS	NS	NS

97

4.1.6 Soil Analysis

4.1.6.1 Available N

Effect of spacing and bio inoculant on soil available N after the experiment under rain shelter and open field condition are provided in Table 16. Under rain shelter and open field condition, treatments and their interactions had no effect on available N status of the soil after experiment. But a decrease in available N was observed in soil from the initial N status after harvest.

4.1.6.2 *Available P*

Results on the effect of spacing and bio inoculant on available P in soil under rain shelter and open field condition are provided in Table 16. Decrease in available P was observed in soil from the initial status under both growing condition.

Under rain shelter, different spacings had significant influence on available P. Spacing of 60 cm x 60 cm (52.54 kg ha^{-1}) recorded significantly higher available P and was on par with 60 cm x 45 cm (52.27 kg ha^{-1}). Bio inoculants had no significant effect on available P. Significant influence was recorded between the interaction of treatments and was higher for 60 cm x 60 cm x PGPR mix 1 (52.89 kg ha^{-1}) and was on par with all the combinations except 60 cm x 30 cm x PGPR mix 1.

Under open field condition, available P was not influenced by spacing. Significant influence was observed among bio inoculants and AMF (44.60 kg ha^{-1}) resulted in significantly higher available P and was on par with PGPR mix 1. Interaction was found non significant among treatments regarding available P.

4.1.6.3 *Available K*

Results on the effect of spacing and bio inoculant on available K under rain shelter and open field condition are provided in Table 16. Available K also showed a Among the bio inoculants, PGPR mix 1 (216.50 kg ha^{-1}) showed higher available K and was on par with AMF (213.60 kg ha^{-1}). Interaction was significant among treatments and was higher for the 60 cm x 60 cm – PGPR mix 1 (220.79 kg ha^{-1}) and was on par with all the treatments except 60 cm x 30 cm – PGPR mix 1 and 60 cm x 30 cm – AMF.

Under open field condition, spacing had significant influence on available K. Spacing of 60 cm x 60 cm (233.57 kg ha^{-1}) spacing resulted in significantly higher available K and was on par with 60 cm x 45 cm. Among the bio inoculants, significantly higher available K was observed under PGPR mix 1 (225.35 kg ha^{-1}). Significant interaction was not found among treatments regarding available K.

4.1.6.4 pH

The data regarding the effects of treatments on pH of the soil after experiment under rain shelter and open field conditions are presented in Table 17. Under rain shelter and open field conditions, pH was found to be non significant among treatments.

4.1.6.5 Organic Carbon

Effects of treatments on OC of the soil after experiment under rain shelter and open field conditions are given in Table 17. Under rain shelter and open field conditions, OC was found to be non significant among the treatments.

4.1.6.6 Bacteria

Results on the effect of spacing and bio inoculants on bacterial count under rain shelter and open field conditions are provided in Table 18. Under rain shelter, spacings had significant influence on bacterial count 60 cm x 30 cm recorded significantly higher soil bacteria (7.19 log cfu g $soil^{-1}$) and was on par with

Table 16. Effect of spacing and bio inoculants on available NPK of the soil after the experiment under rain shelter and open field conditions (kg ha^{-1})

	Rain shelter			Open field condition		
Treatment	Available N	Available P	Available K	Available N	Available P	Available K
Spacing (S)						
S_1 - 60 x 30 cm	204.75	51.48	205.01	188.16	44.21	167.01
S_2 - 60 x 45 cm	205.60	52.27	213.88	180.33	43.62	211.84
S_3 - 60 x 60 cm	211.28	52.54	216.90	192.74	44.24	233.57
SE m (±)	11.64	0.25	2.75	4.51	0.32	9.84
CD(0.05)	NS	0.743	8.315	NS	NS	29.77
Bioinoculant (B)						
B_1 -PGPR mix 1	219.71	51.80	216.50	188.85	44.52	225.35
B_2 - AMF	198.16	52.25	213.60	183.58	44.60	204.75
B_3 - No Bio inoculant	203.76	52.25	205.70	188.80	42.94	182.31
SE m (±)	11.64	0.25	2.75	4.51	0.32	9.84
CD(0.05)	NS	NS	8.315	NS	0.967	29.770
Interaction						
60 cmx 30 cm x PGPR mix 1	228.62	50.22	190.92	183.98	44.95	162.78
60 cmx 30 cm x AMF	184.92	51.86	209.27	188.16	44.45	175.41
60 cmx 30 cm x No Bio inoculant	200.70	52.36	213. 66	192.34	43.22	162.85
60 cmx 45 cm x PGPR mix 1	206.50	52.27	213.87	180.66	44.59	238.23
60 cmx 45 cm x AMF	184.67	52.41	215.38	174.43	44.01	217.44
60 cmx 45 cm x No Bio inoculant	225.64	52.14	212.40	185.89	42.26	179.87
60 cmx 60 cm x PGPR mix 1	224.01	52.89	220.79	201.91	44.04	275.07
60 cmx 60 cm x AMF	224.89	52.48	216.14	188.16	45.34	221.43
60 cmx 60 cm x No Bio inoculant	184.95	52.26	213.76	188.16	43.35	204.21
SE m (±)	20.16	0.43	4.76	7.81	0.55	17.05
CD(0.05)	NS	1.287	14.401	NS	NS	NS

Table 17. Effect of spacing and bio inoculants on pH and organic carbon content of the soil after the experiment under rain shelter and open field conditions

	Rain shelter		Open field condition	
Treatment	pH	OC (%)	pH	OC (%)
Spacing (S)				
S_1 - 60 x 30 cm	5.49	0.99	5.29	0.98
S_2 - 60 x 45 cm	5.54	1.08	5.34	0.91
S_3 - 60 x 60 cm	5.59	0.98	5.39	1.07
SE m (±)	0.05	0.12	0.05	0.08
CD(0.05)	NS	NS	NS	NS
Bioinoculant (B)				
B_1 -PGPR mix 1	5.59	1.12	5.39	1.01
B_2 - AMF	5.53	0.98	5.33	1.04
B_3 - No Bio inoculant	5.50	0.94	5.30	0.90
SE m (±)	0.05	0.15	0.05	0.08
CD(0.05)	NS	NS	NS	NS
Interaction				
60 cmx 30 cm x PGPR mix 1	5.47	1.16	5.27	0.97
60 cmx 30 cm x AMF	5.47	1.07	5.27	0.97
60 cmx 30 cm x No Bio inoculant	5.53	0.73	5.33	1.00
60 cmx 45 cm x PGPR mix 1	5.67	1.26	5.47	1.03
60 cmx 45 cm x AMF	5.50	0.93	5.30	0.93
60 cmx 45 cm x No Bio inoculant	5.47	1.06	5.27	0.75
60 cmx 60 cm x PGPR mix 1	5.63	0.96	5.43	1.04
60 cmx 60 cm x AMF	5.63	0.93	5.43	1.21
60 cmx 60 cm x No Bio inoculant	5.50	1.05	5.30	0.96
SE m (±)	0.09	0.20	0.09	0.13
CD(0.05)	NS	NS	NS	NS

60 cm x 45 cm (7.16 log cfu g soil^{-1}). Among bio inoculants, PGPR mix 1 (7.20 log cfu g soil^{-1}) recorded higher bacterial count and was on par with AMF. Significantly higher bacterial population was noticed under 60 cm x 30 cm-PGPR mix 1 (7.28 log cfu g soil^{-1}) interaction and was on par with 60 cm x 30 cm-AMF, 60 cm x 45 cm-PGPR mix 1 and 60 cm x 45 cm-AMF.

Under open field condition, 60 cm x 30 cm (7.27 log cfu g soil^{-1}) spacing resulted in significantly higher bacterial count. PGPR mix 1 (7.27 log cfu g soil^{-1}) showed significantly higher number of bacteria among the different bio inoculants used for seedling inoculation. Interaction was found non significant among the treatments regarding bacterial count.

4.1.6.7 Fungi

Results on the effect of spacing and bio inoculants on fungal population under rain shelter and open field conditions are provided in Table 18. Under rain shelter, different spacing had no significant influence on fungal population. Fungal population was influenced by bio inoculants and AMF showed higher fungal population (4.96 log cfu g soil^{-1}) which was on par with PGPR mix 1 (4.84 log cfu g soil^{-1}). Among the interactions, significantly higher fungal population was reported by 60 cm x 30 cm-AMF (4.99 log cfu g soil^{-1}) and was on par with 60 cm x 45 cm-AMF, 60 cm x 60 cm-PGPR mix 1 and 60 cm x 60 cm-AMF.

Under open field condition, fungal population was significantly influenced by spacing and higher fungal population was observed under 60 cm x 30 cm (4.91 log cfu g soil^{-1}) and was on par with 60 cm x 45 cm. AMF (4.92 log cfu g soil^{-1}) showed significantly higher fungal count among different bio inoculant used for seedling inoculation and was on par with PGPR mix 1 (4.89 log cfu g soil^{-1}). Interaction was found significant among the treatments regarding fungal population. Interaction of 60 cm x 30 cm-AMF (5.06 log cfu g soil^{-1}) resulted in higher fungal population and was on par with 60 cm x 30 cm- PGPR mix 1 and 60 cm x 45 cm- AMF.

Table 18. Effect of spacing and bio inoculants on microbial population in soil after the experiment under rain shelter and open field conditions (log cfu g $soil^{-1}$)

	Rain shelter			Open field condition		
Treatment	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
Spacing (S)						
S_1 - 60 x 30 cm	7.19	4.84	3.38	7.27	4.91	3.49
S_2 - 60 x 45 cm	7.16	4.86	3.32	7.11	4.85	3.42
S_3 - 60 x 60 cm	7.04	4.84	3.27	7.15	4.78	3.35
SE m (±)	0.02	0.05	0.04	0.03	0.02	0.03
CD(0.05)	0.067	NS	NS	0.099	0.057	0.098
Bioinoculant (B)						
B_1 -PGPR mix 1	7.20	4.84	3.45	7.27	4.89	3.55
B_2 - AMF	7.13	4.96	3.32	7.15	4.92	3.46
B_3 - No Bio inoculant	7.07	4.74	3.20	7.10	4.74	3.25
SE m (±)	0.02	0.05	0.08	0.03	0.02	0.03
CD(0.05)	0.067	0.160	0.131	0.099	0.057	0.098
Interaction						
60 cmx 30 cm x PGPR mix 1	7.28	4.82	3. 62	7.33	5.01	3.58
60 cmx 30 cm x AMF	7.19	4.99	3.32	7.25	5.06	3.53
60 cmx 30 cm x No Bio inoculant	7.11	4.72	3.19	7.23	4. 67	3.36
60 cmx 45 cm x PGPR mix 1	7.27	4.83	3.48	7.26	4.91	3.55
60 cmx 45 cm x AMF	7.18	4.95	3.28	7.02	5.04	3.56
60 cmx 45 cm x No Bio inoculant	7.03	4.81	3.19	7.04	4. 62	3.15
60 cmx 60 cm x PGPR mix 1	7.05	4.88	3.23	7.23	4.74	3.52
60 cmx 60 cm x AMF	6.99	4.93	3.37	7.19	4. 68	3.27
60 cmx 60 cm x No Bio inoculant	7.07	4.69	3.22	7.04	4.93	3.25
SE m (±)	0.04	0.09	0.08	0.06	0.03	0.06
CD(0.05)	0.116	0.130	NS	NS	0.099	0.170

103

4.1.6.8 Actinomycetes

Results on the effect of spacing and bio inoculants on actinomycetes population under rain shelter and open field conditions are provided in Table 18. Under rain shelter, different spacings had no significant influence on actinomycetes population. Among the bio inoculants, PGPR mix 1 showed higher actinomycetes population (3.45 log cfu g $soil^{-1}$) and was on par with AMF. Significant interaction was not found among the treatments regarding actinomycetes count.

Under open field condition, 60 cm x 30 cm (3.49 log cfu g $soil^{-1}$) spacing resulted in significantly higher actinomycetes population. PGPR mix 1 (3.55) showed significantly higher number of actinomycetes among the different bio inoculant used for seedling inoculation and was on par with AMF (3.46 log cfu g $soil^{-1}$). Interaction was found significant among the treatments regarding actinomycetes population. Interaction of 60 cm x 30 cm-PGPR mix 1(3.58 log cfu g $soil^{-1}$) resulted in higher actinomycetes population and was on par with 60 cm x 30 cm- AMF, 60 cm x 45 cm- PGPR mix 1, 60 cm x 45 cm- AMF and 60 cm x 60 cm-PGPR mix 1.

4.1.7 Water Use Efficiency

The data regarding the effect of treatments on water use efficiency under rain shelter and open field conditions are depicted in the Table 19. Under rain shelter, water use efficiency was significantly higher for the lower spacing of 60 cm x 30 cm (5.73 kg m^{-3}). Among the bio inoculants, PGPR mix 1 showed significantly higher water use efficiency (5.66 kg m^{-3}). Significant interaction was noticed between spacing and bio inoculants with respect to water use efficiency. Higher water use efficiency was recorded by the interaction, 60 cm x 30 cm- PGPR mix 1 (6.32 kg m^{-3}).

Under open field condition, significant variation was noticed between the three spacings regarding water use efficiency. The spacing of 60 cm x 30 cm showed higher water use efficiency (4.73 kg m^{-3}) than other spacings at harvest. Significant

Table 19. Effect of spacing and bio inoculants on water use efficiency under rain shelter and open field conditions (kg m^{-3})

Treatment	Rain shelter	Open field condition
Spacing (S)		
S_1 - 60 x 30 cm	5.73	4.73
S_2 - 60 x 45 cm	5.16	3.84
S_3 - 60 x 60 cm	4.31	3.26
SE m (±)	0.04	0.09
CD(0.05)	0.107	0.261
Bioinoculant (B)		
B_1 -PGPR mix 1	5.66	4.54
B_2 - AMF	5.19	3.77
B_3 - No Bio inoculant	4.35	3.53
SE m (±)	0.04	0.09
CD(0.05)	0.107	0.261
Interaction		
60 cmx 30 cm x PGPR mix 1	6.32	5.50
60 cmx 30 cm x AMF	5.75	4.33
60 cmx 30 cm x No Bio inoculant	5.13	4.36
60 cmx 45 cm x PGPR mix 1	5.69	3.95
60 cmx 45 cm x AMF	5.41	3.81
60 cmx 45 cm x No Bio inoculant	4.38	3.77
60 cmx 60 cm x PGPR mix 1	4.98	4.16
60 cmx 60 cm x AMF	4.40	3.17
60 cmx 60 cm x No Bio inoculant	3.54	2.47
SE m (±)	0.061	0.15
CD(0.05)	0.186	0.452

105

variation was recorded among the different bio inoculants on water use efficiency. PGPR mix 1 resulted in higher water use efficiency (4.54 kg m^{-3}) and was on par with AMF (3.77 kg m^{-3}). Significant interaction was noticed between spacing and bio inoculant on water use efficiency. Significantly higher water use efficiency was recorded by 60 cm x 60 cm- PGPR mix 1(5.50 kg m^{-3}) interaction.

4.1.8 Economics of Cultivation

4.1.8.1 Net Return

The results on the effects of treatments on net return under rain shelter and open field conditions are presented in Table 20. Under rain shelter, net return was significantly influenced by spacing and was higher for the 60 cm x 30 cm (Rs. 2.21 lakhs ha^{-1}) spacing. Among the bio inoculants, PGPR mix 1 showed higher net return (Rs. 2.18 lakhs ha^{-1}). Significant difference was observed among interaction of spacing and bio inoculants on net return and was higher for 60 cm x 30 cm-PGPR mix 1 (Rs. 2.73 lakhs ha^{-1}).

Under open field condition, significant variation was noticed among the three spacings. Higher net return was observed under 60 cm x 30 cm (Rs. 1.64 lakhs ha^{-1}) than other spacing. Significant variation was also recorded among different bio inoculants. PGPR mix 1 (Rs. 1.49 lakhs ha^{-1}) resulted higher and no bio inoculant (Rs. 0.60 lakhs ha^{-1}) recorded lower net return. Significant interaction was noticed between spacing and bio inoculants on net return. Significantly higher net return was recorded by 60 cm x 30 cm- PGPR mix 1 (Rs. 2.32 lakhs ha^{-1}) and the least was observed under 60 cm x 60 cm- no bio inoculant (Rs. -0.33 lakhs ha^{-1}).

4.1.8.2 B: C ratio

The data regarding the effects of treatments on B: C ratio under rain shelter and open field conditions are presented in Table 20. Under rain shelter, B: C ratio was significantly higher for the spacing 60 cm x 30 cm (1.76). Bio inoculants also showed significant influence on B: C ratio. PGPR mix 1 (1.75) showed significantly

Table 20. Effect of spacing and bio inoculants on net returns and B: C ratio under rainshelter and open field conditions

	Rain shelter		Open field condition	
Treatment	Net return (Rs. lakhs ha^{-1})	B: C ratio	Net return (Rs. lakhs ha^{-1})	B: C ratio
Spacing (S)				
S_1 - 60 x 30 cm	2.21	1.76	1.64	1.63
S_2 - 60 x 45 cm	1.74	1.61	0.88	1.34
S_3 - 60 x 60 cm	0.99	1.34	0.38	1.15
SE m (±)	0.03	0.11	0.08	0.03
CD(0.05)	0.095	0.033	0.234	0.090
Bioinoculant (B)				
B_1 -PGPR mix 1	2.18	1.75	1.49	1.58
B_2 - AMF	1.75	1.61	0.80	1.31
B_3 - No Bio inoculant	1.00	1.35	0.60	1.23
SE m (±)	0.03	0.11	0.08	0.03
CD(0.05)	0.095	0.033	0.234	0.090
Interaction				
60 cmx 30 cm x PGPR mix 1	2.73	1.94	2.32	1.90
60 cmx 30 cm x AMF	2.22	1.76	1.28	1.50
60 cmx 30 cm x No Bio inoculant	1.67	1.58	1.31	1.50
60 cmx 45 cm x PGPR mix 1	2.21	1.77	0.98	1.38
60 cmx 45 cm x AMF	1.96	1.68	0.85	1.33
60 cmx 45 cm x No Bio inoculant	1.04	1.37	0.81	1.32
60 cmx 60 cm x PGPR mix 1	1.59	1.55	1.18	1.46
60 cmx 60 cm x AMF	1.07	1.38	0.28	1.11
60 cmx 60 cm x No Bio inoculant	0.30	1.10	-0.33	0.87
SE m (±)	0.05	0.02	0.13	0.05
CD(0.05)	0.164	0.057	0.405	0.156

higher B: C ratio. There was significant difference among the interaction of spacing and bio inoculants on B: C ratio and was higher for 60 cm x 30 cm-PGPR mix 1 (1.94). Lowest B: C ratio was recorded by 60 cm x 30 cm-No bio inoculant (1.10).

Under open field condition, significant variation was noticed among the spacings. 60 cm x 30 cm (1.63) showed higher B: C ratio than other spacing.

Significant variation was also recorded among different bio inoculants. PGPR mix 1 resulted in higher (1.58) and no bio inoculant recorded the lower (1.23) B: C ratio. Significant interaction was noticed between spacing and bio inoculant on B: C ratio. Significantly higher B: C ratio was recorded by 60 cm x 30 cm- PGPR mix 1 (1.90) and the least was recorded by 60 cm x 60 cm- no bio inoculant (0.87).

4.2 STANDARDIZATION OF NUTRIENT SCHEDULE FOR BHINDI UNDER RAIN SHELTER AND OPEN FIELD CONDITIONS

4.2.1 Growth Characters

4.2.1.1 Plant Height

The effect of various treatments on height of plants at 30, 60 and 90 DAT under rain shelter are given in Table 21. During the first year (Sept - Dec, 2017), fertigation level of 100 % RDF (F_3) produced the tallest plants at 30 DAT (28.88 cm), 60 DAT (82.68 cm) and at 90 DAT (135.20 cm). It was on par with 125 % (F_4) at 30 and 60 DAT. Foliar nutrition had significant influence on plant height at all growth stages and was higher for poly feed @ 0.5% (L_1) (29.75 cm at 30 DAT, 82.69 cm at 60 DAT and 125.40 cm at 90 DAT).

Significant interaction was noticed between fertigation and foliar application of nutrients with respect to plant height at all growth stages. Interaction of f_3l_1 (100 % RD+ Poly feed @ 0.5%) (32.51 cm) recorded higher plant height at 30 DAT which was on par with f_4l_1. During 60 DAT, f_2l_1 (75 % RD+ poly feed @ 0.5%) (89.57 cm) recorded higher value regarding plant height and was on par with f_3l_1 and

f_4l_1. At 90 DAT, f_3l_1 (100 % RD+ poly feed @ 0.5%) (144.00 cm) recorded taller plants among the different interactions.

During the second crop (May-Aug, 2018), fertigation level of 100 % RD (F_3) produced taller plants at 30 DAT (32.98 cm), 60 DAT (117.22 cm) and at 90 DAT (149.81 cm) and was on par with 125 % RD (F_4) at 30 and 90 DAT. Foliar of nutrients had significant influence on plant height at all the growth stages and was higher for poly feed @ 0.5 % (L_1) (31.65 cm at 30 DAT, 112.01 cm at 60 DAT and 147.92 cm at 90 DAT).

Significant interaction was noticed between fertigation and foliar application of nutrients with respect to plant height at all growth stages. Interaction of 100 % RD + poly feed @ 0.5 % (f_3l_1) (33.39 cm) showed the highest plant height at 30 DAT which was on par with f_3l_2 (32.03 cm) f_4l_1 (31.32 cm), f_4l_2 (31.67 cm) and f_2l_1 (31.34 cm). During 60 DAT, 100 % RD + nano NPK @ 0.3 % (f_3l_2) recorded taller plants (117.60 cm) and was on a par with f_3l_1 and f_1l_1. At 90 DAT, 125 % RD + poly feed @ 0.5 % (f_4l_1) recorded tallest plants (159.77 cm) among interactions.

Effect of fertigation and foliar nutrition on plant height under open field condition is given under Table 22. During the first crop, plant height was significantly influenced by fertigation levels and foliar nutrition. Application of 125 % RDF (F_4) recorded significantly higher plant height (20.90 cm at 30 DAT, 72.36 cm at 60 DAT and 101.00 cm at 90 DAT) during all the growth stages and was on par with F_3. Plant height was found to be significantly higher for the foliar application of F_1 (20.67 cm at 30 DAT, 75.62 cm at 60 DAT and 102.65 cm at 90 DAT) at all the growth stages.

Significant interaction was found between fertigation and foliar nutrition on plant height at all growth stages. At 30 DAT (23.60 cm) and at 60 DAT (85.33 cm), the height was found to be significantly higher for 125 % RDF + poly feed @ 0.5 % (f_4l_1). At 90 DAT, higher plant height was observed under f_3l_1 (113.40 cm) among interactions.

109

Table 21. Effect of fertigation and foliar levels of nutrients on height of the plant at monthly intervals under rain shelter, cm

	Sept-Dec (2017)			May-Aug (2018)		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Fertigation (F)						
F_1	25.97	62.86	102.60	27. 67	108.13	141.72
F_2	23.58	71.46	107.40	28.57	103.72	135.04
F_3	28.88	82.68	135.20	32.98	117.22	149.81
F_4	28.70	81.97	120.70	31.49	105.41	149.43
SE m (±)	0. 65	1.25	3.06	1.03	1.54	1.74
CD(0.05)	2.016	3.907	9.521	3.218	4.798	5.413
Foliar (L)						
L_1	29.75	82.69	125.40	31. 65	112.01	147.92
L_2	23.83	66.80	107.55	28.71	105.22	140.08
SE m (±)	0.45	0. 65	2.38	0.44	1.00	1.29
CD(0.05)	1.351	1.950	7.193	1.335	3.035	3.893
fxl Interaction						
f_1l_1	27.84	65.69	106.20	30.00	114.09	150.44
f_1l_2	24.10	60.03	99.00	25.34	102.17	133.01
f_2l_1	28.25	89.57	127.00	31.34	106.59	131.95
f_2l_2	18.91	53.35	87.80	25.81	100.85	138.13
f_3l_1	32.51	87.84	144.00	33.39	116.84	149.53
f_3l_2	25.26	77.52	126.40	32.03	117. 60	150.09
f_4l_1	30.37	87.66	124.40	31.32	110.54	159.77
f_4l_2	27.03	76.29	117.00	31. 67	100.27	139.09
SE m (±)	0.92	1.77	4.32	1.46	2.18	7.72
CD(0.05)	2.744	3.977	14.584	2.730	6.169	7.898

110

Table 22. Effect of fertigation and foliar levels of nutrients on height of the plant at monthly intervals under open field condition, cm

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Fertigation (F)						
F_1	17.31	70.65	93.00	22.56	82.75	106.88
F_2	18.49	68.95	97.60	24.15	95.07	121.03
F_3	20.14	70.74	100.90	24. 68	100.16	136.77
F_4	20.90	72.36	101.00	27.09	127.71	140.08
SE m (±)	0.30	0.58	1.12	0.38	1.54	2.04
CD(0.05)	0.923	1.805	3.481	1.178	4.795	6.347
Foliar (L)						
L_1	20. 67	75. 62	102. 65	27.07	109. 06	136.02
L_2	17.75	65.73	93. 60	22.16	93. 60	116.36
SE m (±)	0.28	0.41	0.87	0.42	1.44	1.21
CD(0.05)	0.846	1.237	2. 632	1.273	4.339	3. 656
fxl Interaction						
f_1l_1	17. 68	75.70	90.00	23.08	84.16	113.05
f_1l_2	16.93	65.59	96.00	22.04	81.34	100.71
f_2l_1	21.17	72.75	102. 60	26.79	102.35	130.73
f_2l_2	15.81	65.14	92. 60	21.50	87.79	111.34
f_3l_1	20.22	68. 69	113.40	26.96	115.89	151.76
f_3l_2	20.05	72.80	88.40	22.40	84.43	121.79
f_4l_1	23. 60	85.33	104. 60	31.46	133.84	148.56
f_4l_2	18.20	59.38	97.40	22.72	121.59	131. 60
SE m (±)	0.42	0.82	1.58	0.54	2.18	2.88
CD(0.05)	1.711	2.511	5.336	2.569	8.774	7.442

During the second crop (May-Aug, 2018), fertigation level of 125 % (F_4) produced the tallest plants at 30 DAT (27.09 cm), 60 DAT (127.71 cm) and at 90 DAT (140.08 cm) and this was on par with F_3 at 90 DAT. Foliar application of nutrients had significant influence on the plant height at all the growth stages and was higher for poly feed @ 0.5 % (L_1) (27.07 cm at 30 DAT, 109.06 cm at 60 DAT and 136.02 cm at 90 DAT). Significant interaction was noticed between fertigation and foliar nutrition with respect to plant height at all the growth stages. Interaction of 125 % RD + poly feed @ 0.5 % (f_4l_1) (31.46 cm) showed highest plant height at 30 DAT and 60 DAT (133.84 cm). At 90 DAT, 100 % RD + poly feed @ 0.5 % (f_3l_1) (151.76 cm) recorded taller plants and was on par with f_4l_1 among the interactions.

4.2.1.2 Number of Leaves per Plant

The data regarding the effect of treatments on number of leaves per plant at monthly intervals under rain shelter are presented in Table 23. Number of leaves per plant at 30 DAT (14.19), 60 DAT (22.13) and at 90 DAT (24.77) was significantly higher for the fertigation level of 100 % RDF (F_3). Among the foliar nutrition levels, poly feed @ 0.5 % (L_1) recorded more leaves at 30 DAT (12.90), 60 DAT (19.34) and 90 DAT (22.41).

Significant interaction was noticed between fertigation and foliar application of nutrients with respect to number of leaves per plant at all growth stages. Higher number of leaves per plant was recorded by 100 % RDF + poly feed @ 0.5 % (f_3l_1) (30 DAT-16.11, 60 DAT-26.20 and 90 DAT (29.20). The number of leaves per plant was least in the case of f_1l_2 during all the growth stages.

During the second crop (May-Aug, 2018), fertigation level of 100 % RDF (F_3) produced more leaves at 30 DAT (13.66), 60 DAT (23.92) and at 90 DAT (27.81) and was on par with F_4 at all stages of observation and with F_2 at 60 DAT. Foliar nutrition had significant influence on the number of leaves at all the growth stages and was higher for poly feed @ 0.5% (L_1) (13.68 at 30 DAT, 23.27 at 60 DAT and 23.91 at 90 DAT) spray.

Significant interaction was noticed between fertigation and foliar nutrition with respect to leaf number at all growth stages. Interaction of 125 % RDF + poly feed @ 0.5 % (f_4l_1) (14.13) showed more leaves at 30 DAT which was on par with all the treatments except f_1l_2, f_2l_2 and f_4l_2. During 60 DAT, 125 % RDF + poly feed @ 0.5 % (f_4l_1) (26.08) recorded more leaves per plant and was on par with all treatments except f_1l_2, f_2l_1, and f_4l_2. At 90 DAT, 100 % RDF + poly feed @ 0.5 % (f_3l_1) (30.43) recorded more number of leaves per plant among the interactions.

Results on the influence of fertigation and foliar levels of nutrients on number of leaves per plant under open field condition are depicted in Table 24. During first crop, significant variation was noticed among the fertigation levels. Application of 100 % RDF (F_3) showed more number of leaves per plant (11.89) than other fertigation levels at 30 DAT and was on par with F_4. At 60 (18.56) and 90 DAT (21.71), significantly more number of leaves per plant was recorded by 125 % RDF (F_4). Significant variation was recorded among the different foliar application of nutrients at all growth stages of observation. Poly feed @ 0.5 % (L_1) recorded higher number of leaves per plant than nano NPK @ 0.3 % (L_2).

Significant interaction was noticed between fertigation and foliar nutrition on leaf number per plant at all growth stages. Significantly higher number of leaves per plant was recorded in 100 % RDF + poly feed @ 0.5 % (f_3l_1) at 30 DAT and 125 % RDF + poly feed @ 0.5 % (f_4l_1) at 60 DAT (20.86) and 90 DAT (24.35).

During the second crop (May-Aug, 2018), fertigation level of 125 % RDF (F_4) produced more leaves per plant at 30 DAT (10.28), 60 DAT (24.20) and at 90 DAT (16.62) and was on par with F_3 at 30 DAT (9.30). Foliar application of nutrients had significant influence on the number of leaves per plant at 90 DAT and was higher for poly feed @ 0.5% (L_1) (13.00).

Interaction was found to be non significant between fertigation and foliar nutrition with respect to leaf number per plant at all growth stages under open field condition.

Table 23. Effect of fertigation and foliar levels of nutrients on number of leaves per plant at monthly intervals under rain shelter

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Fertigation (F)						
F_1	9.69	15.91	18.71	11.80	19. 65	18. 63
F_2	11.83	17.64	20.72	10. 63	21. 61	17. 60
F_3	14.19	22.13	24.77	13. 66	23.92	27.81
F_4	12.54	17.48	20. 60	13.21	22.49	24.03
SE m (±)	0.24	0.27	0.41	0.44	0.83	1.54
CD(0.05)	0.734	0.846	1.262	1.362	2.582	4.784
Foliar (L)						
L_1	12.90	19.34	22.41	13. 68	23.27	23.91
L_2	11.23	17.24	19.99	10.97	20.56	20.13
SE m (±)	0.16	0.20	0.25	0.25	0. 63	0.74
CD(0.05)	0.495	0. 608	0.759	0.757	1.902	2.236
fxl Interaction						
f_1l_1	9.97	16. 69	19.40	13.34	22.71	22.76
f_1l_2	9.40	15.13	18.02	10.26	16.59	14.51
f_2l_1	12.28	17.80	21.00	13. 62	20.11	16.90
f_2l_2	11.39	17.49	20.44	7. 64	23.11	18.30
f_3l_1	16.11	26.20	29.20	13. 62	24.19	30.43
f_3l_2	12.28	18.06	20.33	13.71	23. 66	25.20
f_4l_1	13.24	16. 68	20.02	14.13	26.08	25.55
f_4l_2	11.84	18.28	21.18	12.29	18.90	22.52
SE m (±)	0.33	0.38	0.57	0. 62	1.17	2.17
CD(0.05)	1.005	1.233	1.544	1.541	3.857	4.564

Table 24. Effect of fertigation and foliar levels of nutrients on number of leaves per plant at monthly intervals under open field condition

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Fertigation (F)						
F_1	10.54	15.77	18.42	4.72	16. 64	10.48
F_2	9.73	14.15	17.06	6.96	16.25	9. 64
F_3	11.89	17.95	20.04	9.30	22.10	10.70
F_4	11.23	18.56	21.71	10.28	24.20	16. 62
SE m (±)	0.26	0.17	0.44	0.76	0.58	0.76
CD(0.05)	0.800	0.519	1.383	2.368	1.798	2.363
Foliar (L)						
L_1	11.43	17.09	19.99	8.27	19.56	13.00
L_2	10.27	16.12	18.63	7.36	20.03	10.72
SE m (±)	0.16	0.22	0.22	0.57	0.72	0. 64
CD(0.05)	0.469	0. 654	0. 677	NS	NS	1.931
fxl Interaction						
f_1l_1	10.89	15.46	18.06	5.35	17.50	10.56
f_1l_2	10.20	16.07	18.78	4.09	15.78	10.41
f_2l_1	9.80	13.55	16.66	7.02	14.95	10.74
f_2l_2	9. 67	14.75	17.46	6.91	17.55	8.55
f_3l_1	14.09	18.50	20.88	10.10	20.10	14.05
f_3l_2	9. 69	17.40	19.20	8.50	24.10	7.35
f_4l_1	10.95	20.86	24.35	10. 62	25.70	16.66
f_4l_2	11.51	16.27	19.07	9.94	22.70	16.58
SE m (±)	0.36	0.24	0. 63	1.08	0.82	1.07
CD(0.05)	0.954	1.316	1.381	NS	NS	NS

4.2.1.3 Number of Branches per Plant

The effect of various treatments on the number of branches per plant at 30, 60 and 90 DAT under rain shelter are given in Table 25. During the first crop, fertigation of 100 % RDF (F_3) produced higher number of branches per plant at 60 DAT (3.19). Number of branches per plant at 30 and 90 DAT were found to be non significant during the first crop. Foliar nutrition had no significant influence on the number of branches per plant during all the growth stages.

Significant interaction was noticed between fertigation and foliar nutrition with respect to number of branches per plant only at 60 DAT under rain shelter. Interaction of 100 % RDF + poly feed @ 0.5 % (f_3l_1) showed highest number of branches per plant (3.25) and was on par with f_2l_1, f_3l_2 and f_4l_2. Less number of branches per plant was observed under f_1l_2 at 60 DAT (2.66).

During the second crop, number of branches per plant was significantly influenced by fertigation and foliar nutrition. Application of 100 % RDF (F_3) showed significantly higher number of branches per plant at 30 DAT (3.60), 60 DAT (3.70) and 90 DAT (3.75) and was on par with F_2 at 30 DAT and F_4 at 60 DAT and 90 DAT. Number of branches per plant was found to be non significant among the foliar levels of nutrients.

Significant interaction was observed between fertigation and foliar nutrition at 60 DAT. Number of branches per plant was significantly higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (3.75) and 125 % RDF + poly feed @ 0.5 % (f_4l_1) (3.75), and was on par with f_2l_2 and f_3l_2. Other interactions were found to be non significant.

Effect of fertigation and foliar levels of nutrients on number of branches per plant under open field condition is given in the Table 26. During the first crop, significant variation was noticed between the fertigation levels regarding the number of branches per plant at 30 DAT and was higher for 125 % (F_4) (1.37) and was on par with F_3. Significant variation was not observed among the different foliar application of nutrients at all growth stages of observation.

Table 25. Effect of fertigation and foliar levels of nutrients on number of branches per plant at monthly intervals under rain shelter

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Fertigation (F)						
F_1	1.13	2.73	3.03	1.91	2.08	2.48
F_2	1.16	2.93	3.20	2.95	3.10	3.18
F_3	1.53	3.19	3.46	3.60	3.70	3.75
F_4	1.30	2.95	3.29	3.08	3.43	3.60
SE m (±)	0.14	0.07	0.14	0.22	0.17	0.15
CD(0.05)	NS	0.209	NS	0. 694	0.513	0.456
Foliar (L)						
L_1	13.36	2.95	3.26	3.06	3.18	3.43
L_2	1.20	2.95	3.23	2.71	2.98	3.08
SE m (±)	0.08	0.06	0.09	0.18	0.09	0.17
CD(0.05)	NS	NS	NS	NS	NS	NS
fxl Interaction						
f_1l_1	1.20	2.80	3.06	2.42	2.40	2.70
f_1l_2	1.06	2.66	2.99	1.40	1.75	2.25
f_2l_1	1.40	3.06	3.26	3.10	2.80	3.15
f_2l_2	0.93	2.80	3.13	2.80	3.40	3.20
f_3l_1	1.46	3.25	3.52	3.55	3.75	3.70
f_3l_2	1.60	3.13	3.40	3.65	3.65	3.80
f_4l_1	1.40	2.71	3.19	3.15	3.75	4.15
f_4l_2	1.20	3.20	3.40	3.00	3.10	3.05
SE m (±)	0.20	0.10	0.20	0.32	0.23	0.21
CD(0.05)	NS	0.378	NS	NS	0.547	NS

117

Table 26. Effect of fertigation and foliar application of fertilizers on number of branches per plant at monthly intervals under open condition

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Fertigation (F)						
F_1	0.63	1.66	2.30	1.95	3.03	3.18
F_2	0.73	2.13	2.42	1.48	3.03	3.13
F_3	0.96	2.03	2.43	2.63	3.13	3.40
F_4	1.37	2.18	2.73	2.93	3.65	3.90
SE m (±)	0.15	0.13	0.19	0.18	0.12	0.15
CD(0.05)	0.470	NS	NS	0.574	0.386	0.479
Foliar (L)						
L_1	0.86	1.88	2.39	2.35	3.25	3.55
L_2	0.98	2.13	2.55	2.14	3.16	3.25
SE m (±)	0.09	0.10	0.08	0.15	0.10	0.14
CD(0.05)	NS	NS	NS	NS	NS	NS
fxl Interaction						
f_1l_1	0.80	1.50	2.16	2.75	3.20	3.20
f_1l_2	0.46	1.83	2.43	1.15	2.85	3.15
f_2l_1	0.60	2.10	2.22	1.70	3.10	3.56
f_2l_2	0.86	2.16	2.63	1.25	2.95	2.70
f_3l_1	0.86	1.83	2.50	2.40	3.15	3.50
f_3l_2	1.06	2.23	2.36	2.85	3.10	3.30
f_4l_1	1.20	2.08	2.70	2.55	3.55	3.95
f_4l_2	1.53	2.28	2.76	3.30	3.75	3.85
SE m (±)	0.21	0.18	0.27	0.26	0.18	0.22
CD(0.05)	NS	NS	NS	0.904	NS	NS

118

Interaction was also found to be non significant between fertigation and foliar nutrition on the number of branches per plant at all the stages of observation.

During the second crop (May-Aug, 2018), fertigation level of 125 % RDF (F_4) produced more number of branches per plant at 30 DAT (2.93), 60 DAT (3.65) and at 90 DAT (3.90) and was on par with F_3 at 30 DAT (2.63). Foliar nutrition was found to be non significant for the number of branches per plant at all the stages of observation.

Interaction was found to be significant between fertigation and foliar nutrition with respect to number of branches per plant at 30 DAT and was higher for 125 % RDF + poly feed @ 0.5 % (f_4l_2) and on par with all the treatments except f_1l_2, f_2l_1 and f_2l_2 under open field condition.

4.2.1.4 LAI

The data regarding the effects of treatments on LAI at monthly intervals under rain shelter are presented in Table 27. LAI at monthly intervals was found to be significant for 30 DAT and 60 DAT among the fertigation levels. Significantly higher LAI was recorded for 100 % RDF (F_3) at 30 DAT and 60 DAT and was on par with F_2 and F_4 during 30 DAT and F_2 during 60 DAT. LAI was found to be non significant during 90 DAT. Considering the foliar levels of nutrients, poly feed @ 0.5 % (L_1) recorded higher LAI than L_2 during 30 DAT. LAI was found to be non significant during the other stages of observation.

Interaction was found to be non significant between fertigation and foliar levels of nutrients during all the stages of observation regarding LAI.

During the second crop, (May-Aug, 2018), fertigation level of 100 % RDF (F_3) produced more LAI at 30 DAT (1.42) and at 90 DAT (1.42) and was on par with F_4 at both stages. At 60 DAT, LAI had no significant difference among the treatments. Foliar nutrition had significant influence on LAI at 30 DAT and was higher for poly feed @ 0.5% (L_1) (1.38) and was found non significant during other stages of observation.

Interaction was found non significant between fertigation and foliar nutrition with respect to LAI during 60 and 90 DAT. Significantly higher LAI was observed for 125 % RDF + poly feed @ 0.5 % (f_4l_1) during 30 DAT and was on par with f_3l_1, f_3l_2 and f_1l_1 under rain shelter.

LAI as influenced by fertigation and foliar levels of nutrients under open field condition is presented in Table 28. During the first crop, fertigation levels showed significant effect on LAI. Application of 125 % RDF (F_4) recorded higher LAI during all the growth stages (30 DAT (1.27), 60 DAT (1.86) and 90 DAT (1.94). This was on par with the fertigation level, F_3 at all the growth stages (30 DAT-1.05, 60 DAT-1.61 and 90 DAT-1.75) and was on par with F_1 (1.50). Foliar levels of nutrients showed significant difference and was higher for F_1 during 30 and 60 DAT. At 90 DAT, LAI showed non significant effect. Interaction was found to be significant during 30 DAT and was higher for 125 % RDF + poly feed @ 0.5 % (f_4l_1) and on par with f_3l_2, f_4l_2 and f_1l_1.

During the second crop, (May-Aug, 2018), fertigation level of 125 % RDF (F_4) produced more LAI at 30 DAT (0.92) and was on par with F_3. Effect of fertigation was found to be non significant on LAI during 60 and 90 DAT. Regarding foliar levels of nutrients, poly feed @ 0.5 % (L_1) recorded higher LAI during 30 DAT and was found to be non significant during the other stages of observations.

Interaction was found to be non significant between fertigation and foliar application of nutrients with respect to LAI during all the stages of observation under rain shelter.

Table 27. Effect of fertigation and foliar levels of nutrients on leaf area index of the plant at monthly intervals under rain shelter

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Fertigation (F)						
F_1	0.95	1.06	1.72	1.18	1.29	1.02
F_2	1.34	1.37	1.88	0.80	1.13	1.08
F_3	1.43	1.71	1.98	1.42	1.41	1.42
F_4	1.19	1.12	1.80	1.30	1.32	1.36
SE m (±)	0.11	0.16	0.12	007	0.08	0.06
CD(0.05)	0.340	0.485	NS	0.221	NS	0.186
Foliar (L)						
L_1	1.36	1.37	1.89	1.38	1.37	1.22
L_2	1.09	1.26	1.80	0.97	1.21	1.21
SE m (±)	0.07	0.12	0.10	0.05	0.06	0.06
CD(0.05)	0.205	NS	NS	0.156	NS	NS
fxl Interaction						
f_1l_1	1.24	0.91	1.76	1.40	1.45	1.09
f_1l_2	0.66	1.22	1.69	0.96	1.14	0.95
f_2l_1	1.50	1.47	1.86	1.11	1.10	0.91
f_2l_2	1.17	1.27	1.91	0.50	1.17	1.26
f_3l_1	1.59	1.81	2.14	1.42	1.44	1.59
f_3l_2	1.26	1.60	1.82	1.41	1.38	1.24
f_4l_1	1.12	1.28	1.79	1.59	1.50	1.31
f_4l_2	1.26	0.95	1.80	1.02	1.14	1.41
SE m (±)	0.15	0.22	0.16	0.10	0.12	0.09
CD(0.05)	NS	NS	NS	0.317	NS	NS

Table 27. Effect of fertigation and foliar levels of nutrients on leaf area index of the plant at monthly intervals under rain shelter

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Fertigation (F)						
F_1	0.95	1.06	1.72	1.18	1.29	1.02
F_2	1.34	1.37	1.88	0.80	1.13	1.08
F_3	1.43	1.71	1.98	1.42	1.41	1.42
F_4	1.19	1.12	1.80	1.30	1.32	1.36
SE m (±)	0.11	0.16	0.12	007	0.08	0.06
CD(0.05)	0.340	0.485	NS	0.221	NS	0.186
Foliar (L)						
L_1	1.36	1.37	1.89	1.38	1.37	1.22
L_2	1.09	1.26	1.80	0.97	1.21	1.21
SE m (±)	0.07	0.12	0.10	0.05	0.06	0.06
CD(0.05)	0.205	NS	NS	0.156	NS	NS
fxl Interaction						
f_1l_1	1.24	0.91	1.76	1.40	1.45	1.09
f_1l_2	0.66	1.22	1.69	0.96	1.14	0.95
f_2l_1	1.50	1.47	1.86	1.11	1.10	0.91
f_2l_2	1.17	1.27	1.91	0.50	1.17	1.26
f_3l_1	1.59	1.81	2.14	1.42	1.44	1.59
f_3l_2	1.26	1.60	1.82	1.41	1.38	1.24
f_4l_1	1.12	1.28	1.79	1.59	1.50	1.31
f_4l_2	1.26	0.95	1.80	1.02	1.14	1.41
SE m (±)	0.15	0.22	0.16	0.10	0.12	0.09
CD(0.05)	NS	NS	NS	0.317	NS	NS

122

Table 28. Effect of fertigation and foliar levels of nutrients on leaf area index of the plant at monthly intervals under open field condition

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Fertigation (F)						
F_1	0.93	1.50	1.59	0.23	1.18	1.10
F_2	0.89	1.32	1.36	0.56	1.36	1.03
F_3	1.05	1.61	1.75	0.73	1.42	1.23
F_4	1.27	1.86	1.94	0.92	1.45	1.35
SE m (±)	009	0.12	0.09	0.10	0.10	0.09
CD(0.05)	0.283	0.372	0.292	0.303	NS	NS
Foliar (L)						
L_1	1.14	1.69	1.64	0.75	1.36	1.15
L_2	0.93	1.45	1.68	0.47	1.35	1.20
SE m (±)	0.06	0.07	0.10	0.08	0.04	0.05
CD(0.05)	0.171	0.196	NS	0.253	NS	NS
fxl Interaction						
f_1l_1	1.15	1.79	1.58	0.26	1.30	1.09
f_1l_2	0.70	1.21	1.61	0.20	1.06	1.10
f_2l_1	1.05	1.45	1.43	0.64	1.33	1.09
f_2l_2	0.73	1.20	1.28	0.49	1.38	0.96
f_3l_1	0.93	1.68	1.77	1.03	1.39	1.08
f_3l_2	1.16	1.53	1.73	0.42	1.46	1.37
f_4l_1	1.43	1.86	1.78	1.06	1.40	1.35
f_4l_2	1.11	1.87	2.11	0.77	1.50	1.35
SE m (±)	0.13	0.17	0.13	0.14	0.14	0.12
CD(0.05)	0.347	NS	NS	NS	NS	NS

123

4.2.1.5 Length of Tap root

Results on the effect of fertigation and foliar application of nutrients on tap root length at harvest under rain shelter are provided in Table 29. During the first crop, different fertigation levels had significant influence on length of tap root. Application of 100 % RDF (F_3) (25.00 cm) recorded significantly higher length of tap root than the other three fertigation levels and was on par with F_4. Among the different foliar levels of nutrients, poly feed @ 0.5 % (L_1) (24.10 cm) resulted in higher tap root length than L_2. Interaction was found to be non significant for the tap root length.

During the second crop, 100 % RDF (F_3) (26.80 cm) fertigation resulted in significantly higher tap root length. Foliar level had no significant effect on tap root length. The interaction was also found to be non significant among the treatments.

Results on the effect of fertigation and foliar application of nutrients on tap root length at harvest under open field condition are provided in Table 30. During the first crop, fertigation showed significant effect on tap root length. Application of 100 % RDF (F_3) (23.10 cm) recorded higher tap root length at harvest. This was on par with the fertigation, F_4 and F_2. Foliar levels of nutrients showed significant difference and was higher for poly feed @ 0.5 % (L_1) (22.20 cm). Interaction was found to be non significant with respect to tap root length.

During the second crop, (May-Aug, 2018), fertigation level of 100 % RDF (F_3) produced higher tap root length and was on par with F_4. Effect of foliar application of nutrients was found to be non significant on tap root length. Interaction was also found to be non significant under open field condition regarding tap root length.

4.2.1.6 Root Volume

The data regarding the effects of treatments on root volume at harvest under rain shelter are presented in Table 29. During the first crop, root volume was significantly higher for the fertigation of 100 % RDF (F_3) (35.50 cm^3).

Foliar application of nutrients was not significant among the treatments. Significant interaction was noticed between fertigation and foliar levels of nutrients with respect to root volume at harvest. Higher root volume was recorded in 100 % RDF + poly feed @ 0.5 % (f_3l_1) (37.20 cm^3) and was on par with the combinations, f_4l_1, f_2l_2 and f_1l_1.

During the second crop, (May-Aug, 2018), fertigation level of 100 % RDF (F_3) produced more root volume (28.10 cm^3) at harvest. Foliar application of nutrients had significant influence on the root volume and was higher for poly feed @ 0.5 % (L_1) (25.95 cm^3) interaction of fertigation and foliar application of nutrients had significant influence on root volume and was significantly higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (33.80 cm^3) and was on par with f_4l_1 under rain shelter.

The data on the effect of feritigation and foliar levels of nutrients on root volume under open field condition is given in the Table 30. During the first crop, significant variation was noticed among fertigation levels regarding root volume. Application of 125 % RDF (F_4) (30.60 cm^3) showed higher root volume and was on par with the other two levels except F_1. Significant variation was recorded among the different foliar levels of nutrients on root volume. Poly feed @ 0.5 % (L_1) (30.55 cm^3) resulted in higher root volume at harvest. Significant interaction was noticed between fertigation and foliar levels of nutrients on root volume at harvest. Significantly higher root volume was recorded in 100 % RDF + poly feed @ 0.5 % (f_3l_1) (37.33 cm^3) and was on par with the combinations, f_4l_2, (34.20 cm^3), f_2l_1 (32.40 cm^3) and f_2l_2 (30.40 cm^3).

During the second crop, (May-Aug, 2018), fertigation level of 125 % RDF (F_4) produced more root volume (29.10 cm^3) at harvest and was on par with F_3. Foliar application of nutrients had significant influence on the root volume and was higher for poly feed @ 0.5 % (L_1) (29.05 cm^3). Interaction of fertigation and foliar application of nutrients had significant influence on root volume and was

Table 29. Effect of fertigation and foliar application of fertilizers on length of tap root, root volume and root: shoot ratio of the plant at harvest under rain shelter

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Tap root length (cm)	Root volume (ml plant^{-1})	Root: shoot ratio	Taproot length (cm)	Root volume (ml plant^{-1})	Root: shoot ratio
Fertigation (F)						
F_1	23.00	32.10	0.23	20.20	19.30	0.27
F_2	17.10	30.50	0.27	17.80	23.20	0.26
F_3	25.00	35.50	0.29	26.80	28.10	0.28
F_4	22.00	32.10	0.27	22.85	24.30	0.28
SE m (±)	0. 81	1.09	0.06	0.78	0.70	0.014
CD(0.05)	2.517	3.388	NS	2.440	2.177	NS
Foliar (L)						
L_1	24.10	33.50	0.25	21.60	25.95	0.27
L_2	19.55	31. 60	0.28	22.22	21.50	0.27
SE m (±)	0.54	0.77	0.04	0.56	0.861	0.013
CD(0.05)	1.637	NS	NS	NS	2.603	NS
fxl Interaction						
f_1l_1	25.40	27.80	0.24	21.20	20.60	0.26
f_1l_2	20. 60	36.40	0.22	19.20	18.00	0.28
f_2l_1	17.80	32.20	0.26	17.60	20.80	0.25
f_2l_2	16.40	28.80	0.28	18.00	25.60	0.26
f_3l_1	28.60	37.20	0.19	27.00	33.80	0.27
f_3l_2	21.40	33.80	0.39	26.60	22.40	0.28
f_4l_1	24. 60	36.80	0.32	20.60	28.60	0.31
f_4l_2	19.80	27.40	0.23	25.10	20.00	0.25
SE m (±)	1.14	1.54	0.08	1.11	0.99	0.020
CD(0.05)	NS	4.735	NS	NS	5.246	NS

174741

126

Table 30. Effect of fertigation and foliar levels of nutrients on length of tap root, root volume and root: shoot ratio of the plant at harvest under open field condition

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Tap root length (cm)	Root volume (ml plant^{-1})	Root: shoot ratio	Taproot length (cm)	Root volume (ml plant^{-1})	Root: shoot ratio
Fertigation (F)						
F_1	16.00	27.90	0.23	19.90	25.40	0.22
F_2	19.90	30.40	0.25	18.80	24.90	0.23
F_3	23.10	30.10	0.27	26.00	27.90	0.25
F_4	21.90	30.60	0.25	23.20	29.10	0.23
SE m (±)	1.102	0.57	0.01	0.93	0.66	0.02
CD(0.05)	3.435	1.768	NS	2.897	2.074	NS
Foliar (L)						
L_1	22.20	30.55	0.26	22.50	29.05	0.23
L_2	18.25	28.95	0.25	21.45	24.60	0.24
SE m (±)	0.56	0.83	0.02	0.73	0.27	0.01
CD(0.05)	1.689	2.514	NS	NS	0.828	NS
fxl Interaction						
f_1l_1	19.80	28.80	0.25	20.60	27.80	0.22
f_1l_2	12.20	27.00	0.22	19.20	23.00	0.22
f_2l_1	22.00	30.40	0.22	20.00	28.20	0.23
f_2l_2	17.80	30.40	0.28	17.60	21.60	0.23
f_3l_1	24.20	34.20	0.29	27.40	30.20	0.26
f_3l_2	22.00	26.00	0.25	24.60	25.60	0.25
f_4l_1	22.80	28.80	0.26	22.00	30.00	0.22
f_4l_2	21.00	32.40	0.24	24.40	28.20	0.25
SE m (±)	1.56	0.80	0.02	1.32	0.94	0.02
CD(0.05)	NS	5.057	NS	NS	1.694	NS

127

significantly higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (30.20 cm^3) and on par with f_4l_1 under open field condition.

4.2.1.7 *Root: Shoot ratio*

The data regarding root: shoot ratio under rain shelter are presented in Table 29. Effect of fertigation and foliar application of nutrients and their interactions were found to be non significant in case of root: shoot ratio of bhindi.

The data regarding root: shoot ratio under open field condition are presented in Table 30. Effect of fertigation and foliar application of nutrients and their interaction were found to be non significant regarding root: shoot ratio of bhindi.

4.2.2 Yield Attributes

4.2.2.1 Days to 50 Per cent Flowering

The data regarding days to 50 per cent flowering under rain shelter are presented in Table 31. During the first crop, fertigation had significant influence on the days to 50 per cent flowering. Lower dose of fertigation, 50 % RDF (F_1) (40.40 days) resulted in more days to 50 per cent flowering. Foliar application of nutrients and their interaction were found to be non significant regarding days to 50 per cent flowering of bhindi.

During the second crop, effect of fertigation and foliar nutrition and their interaction was found to be non significant among the treatments. Results on the effect of treatments on days to 50 per cent flowering under open field condition is given in Table 32. It is found that fertigation and foliar levels of nutrients and their interactions had no significant influence on days to 50 per cent flowering of bhindi under both crop season.

4.2.2.2 Number of Flowers per Plant

The data regarding the effects of treatments on number of flowers per plant under rain shelter are presented in Table 31. During the first crop, number of flowers per plant was significantly higher for the fertigation level, 100 % RDF (F_3) (39.83) and was on par with F_1. Among foliar nutrient levels, treatments were found significant and were higher for poly feed @ 0.5 % (L_1) (38.35). Interaction was found to be non significant for number of flowers per plant.

During the second crop, number of flowers per plant was significantly higher for the fertigation of 125 % RDF (F_4) (33.25) and was on par with the other two levels except F_2. Among the foliar levels of nutrients, treatments were found significant and were higher under poly feed @ 0.5 % (L_1) (34.24). Interaction of fertigation and foliar levels of nutrients had no influence on the number of flowers per plant.

The The data regarding the effects of treatments on number of flowers per plant under open field condition are presented in Table 32. During first crop, number of flowers was significantly higher for the fertigation of 100 % RDF (F_3) (31.50). Among foliar levels of nutrients, treatments were found to be non significant. Interaction of fertigation and foliar levels of nutrients was also found to be non significant on number of flowers.

During the second crop, number of flowers was significantly higher for the fertigation of 75 % RDF (F_2) (33.78) and was on par with the other two levels except F_1. Among the foliar levels of nutrients, treatments were found significant and was higher under poly feed @ 0.5 % (L_1) (33.49). Interaction was also found to be non significant on fertigation and foliar nutrition levels on number of flowers per plant.

4.2.2.3 Number of Fruits per Plant

The data regarding the effect of treatments on the number of fruits per plant under rain shelter are presented in Table 31. During the first crop, number of fruits was significantly higher for the fertigation of 100 % RDF (F_3) (28.93) and was on par with F_1. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) recorded more number of fruits (27.63). There was significant difference among the interaction of fertigation and foliar levels of nutrients on the number of fruits per plant and was higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (29.73) which was on par with f_4l_1 and f_1l_2.

During the second crop, (May-Aug, 2018), fertigation level of 100 % RDF (F_3) (26.28) produced more number of fruits at harvest. This was on par with F_4 (25.53). Foliar nutrition had significant influence on the fruit number and was higher for poly feed @ 0.5 % (L_1) (25.41). Interaction of fertigation and foliar nutrition was significantly higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (28.05) with respect to number of fruits and was on par with f_4l_1 under rain shelter.

Results on the effect of treatments under open field condition are depicted in Table 32. During the first crop, significant variation was noticed among the fertigation levels. Application of 125 % RDF (F_4) (20.93) showed more number of fruits per plant and was on par with F_3. Significant variation was also recorded among the different foliar levels of nutrients. Poly feed @ 0.5 % (L_1) (20.13) resulted in higher number of fruits. Significant Interaction was noticed between fertigation and foliar nutrition on the number of fruits. Significantly higher number of fruits was recorded in 125 % RDF + poly feed @ 0.5 % (f_4l_1) (22.40).

During the second crop, (May-Aug, 2018), fertigation level of 125 % RDF (F_4) produced more number of fruits (20.59) at harvest. Foliar nutrition had significant influence on the fruit number and was higher for poly feed @ 0.5 % (L_1) (20.33). Interaction of fertigation and foliar levels of nutrients were significantly higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (21.45) with respect to number of fruits under open field condition.

4.2.2.4 Fruit Set Per cent

The data regarding the effect of treatments on fruit set per cent under rain shelter are presented in Table 33. During the first crop, fruit setting per cent was found non significant among fertigation and foliar levels of nutrients. The interaction was

Table 31. Effect of fertigation and foliar levels of nutrients on days to 50 per cent flowering, number of flowers per plant and number of fruits per plant under rain shelter

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Days to 50 per cent flowering	Number of flowers per plant	Number of fruits per plant	Days to 50 per cent flowering	Number of flowers per plant	Number of fruits per plant
Fertigation (F)						
F_1	40.40	38.03	27.23	41.60	32.80	22.51
F_2	39.00	34.93	25.53	43.30	30.76	22.48
F_3	37.80	39.83	28.93	43.20	33.05	26.28
F_4	38.80	36.64	27.20	42.80	33.25	25.53
SE m (±)	0.34	0.69	0.55	0.59	0.41	0.56
CD(0.05)	1.049	2.140	1.697	NS	1.290	1.757
Foliar (L)						
L_1	38.95	38.35	27.63	42.75	34.24	25.41
L_2	39.05	36.37	26.81	42.70	30.70	22.99
SE m (±)	0.21	0.36	0.22	0.23	0.32	0.43
CD(0.05)	NS	1.084	0.669	NS	0.959	1.293
fxl Interaction						
f_1l_1	40.40	38.53	26.07	42.00	35.50	22.13
f_1l_2	40.40	37.53	28.40	41.20	30.10	22..90
f_2l_1	39.00	35.53	26.06	43.00	31.70	24.81
f_2l_2	39.00	34.33	25.00	43.60	29.85	20.15
f_3l_1	37.60	41.73	29.73	43.40	34.80	28.05
f_3l_2	38.00	37.93	28.13	43.00	31.30	24.51
f_4l_1	38.80	37.62	28.66	42.60	34.95	26.66
f_4l_2	38.80	35.66	25.73	43.00	31.55	24.40
SE m (±)	0.48	0.97	0.77	0.83	0.59	0.80
CD(0.05)	NS	NS	1.368	NS	NS	2.622

131

Table 32. Effect of fertigation and foliar levels of nutrients on days to 50 per cent flowering, number of flowers per plant and number of fruits per plant under open field condition

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Days to 50 per cent flowering	Number of flowers per plant	Number of fruits per plant	Days to 50 per cent flowering	Number of flowers per plant	Number of fruits per plant
Fertigation (F)						
F_1	41.80	30.47	18.10	41.60	31.33	18.05
F_2	40.80	29.39	18.90	43.30	33.78	17.48
F_3	40.40	31.50	20.67	43.20	33.08	19.14
F_4	40.40	29.36	20.93	42.80	32.85	20.59
SE m (±)	0.40	0.25	0.18	0.59	0.46	0.23
CD(0.05)	NS	0.785	0.558	NS	1.439	0.720
Foliar (L)						
L_1	40.85	30.61	20.13	42.75	33.49	20.33
L_2	40.85	29.74	19.17	42.70	32.03	17.30
SE m (±)	0.26	0.33	0.15	0.23	0.40	0.20
CD(0.05)	NS	NS	0.456	NS	1.219	0.589
fxl Interaction						
f_1l_1	42.00	30.53	18.73	42.00	30.80	18.64
f_1l_2	41.60	30.40	17.46	41.20	31.85	17.45
f_2l_1	40.20	30.33	19.26	43.00	35.45	19.95
f_2l_2	41.40	28.44	18.53	43.60	32.10	15.01
f_3l_1	41.00	30.93	20.13	43.40	33.80	21.45
f_3l_2	39.80	32.07	21.20	43.00	32.35	16.83
f_4l_1	40.20	30.66	22.40	42.60	33.90	21.27
f_4l_2	40.60	28.06	19.46	43.00	31.80	19.91
SE m (±)	0.57	0.36	0.25	0.83	0.65	0.33
CD(0.05)	NS	NS	0.924	NS	NS	1.193

found significant and was higher for 125 % RDF + poly feed @ 0.5 % (f_4l_1) (76.28 %) and was on par with all the treatments except f_1l_1.

During the second crop, (May-Aug, 2018), fertigation level of 100 % RDF (F_3) produced higher fruit set per cent (79.51 %). This was on par with F_4 and F_2. Foliar nutrition had no significant influence on fruit set per cent. Interaction of fertigation and foliar levels of nutrients had significant influence on fruit set per cent. Higher fruit set per cent was recorded by 100 % RDF + poly feed @ 0.5 % (f_3l_1) (80.67 %) and was on par with all the treatments except f_1l_1 and f_2l_2 under rain shelter.

The data on the percentage fruit set under open field condition is presented in Table 34. During the first crop, significant variation was noticed between the fertigation levels regarding fruit set per cent. Application of 125 % RDF (F_4) (71.22 %) showed higher fruit set per cent than the other fertigation levels. Foliar levels of nutrients and interaction had no significant effect on fruit setting percentage.

During the second crop, (May-Aug, 2018), fertigation level of 125 % RDF (F_4) recorded more fruit set per cent (62.71 %) at harvest. Foliar nutrition had significant influence on the fruit set per cent and was higher for poly feed @ 0.5 % (L_1) (60.77 %) than L_2. Interaction of fertigation and foliar levels of nutrients were significantly higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (63.46 %) and was on par with f_4l_1, f_4l_2 and f_1l_1 with respect to fruits set per cent under open field condition.

4.2.2.5 Length of Fruit

Results on the effect of fertigation and foliar levels of nutrients on the length of fruit under rain shelter are provided in Table 33. During the first crop, different fertigation levels had significant influence on the length of fruit 100 % RDF (F_3) (12.49 cm) recorded significantly higher fruit length and was on par with F_2. Foliar nutrition had no significant effect on fruit length. Fruit length was found to be non significant among treatments.

During the second crop, different fertigation levels had significant influence on length of fruit. Application of 100 % RDF (F_3) (14.54 cm) recorded significantly higher fruit length and was on par with F_2 (14.30 cm). Foliar nutrition had no significant effect on fruit length. Significant interactions were observed and higher fruit length was noticed under 100 % RDF + poly feed @ 0.5 % (f_3l_1) (14.75 cm). This was on par with all the interactions except f_1l_1 and f_4l_2.

Effect of treatments on length of fruit under open field condition is given in Table 34. During the first crop 125 % RDF (F_4) (12.53 cm) of fertigation level resulted in significantly higher length of fruit. Foliar levels of nutrients and interaction was found non significant among the treatments regarding fruit length.

During the second crop, different fertigation levels had significant influence on the length of fruit. Application of 125 % RDF (F_4) (14.00 cm) recorded significantly higher fruit length and was on par with F_1 (13.98 cm). Foliar nutrition had no significant effect on fruit length. Interaction was found significant among the treatments and was higher for 125 % RDF + poly feed @ 0.5 % (f_4l_1) (14.26 cm) and on par with all the treatments except f_2l_1 and f_3l_2.

4.2.2.6 Weight of Fruit

The effect of various treatments on weight of fruit under rain shelter is given in Table 33. During the first crop, fertigation of 125 % RDF (F_4) produced significantly higher fruit weight (12.90 g) and was on par with F_3. Foliar levels of nutrients had significant influence on weight of fruit. Higher fruit weight was observed for poly feed @ 0.5% (L_1) (12.94 g). Significant interaction was noticed between fertigation and foliar levels of nutrients with respect to fruit weight under rain shelter and was higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (14.33 g). This was found to be on par with f_4l_1.

Table 33. Effect of fertigation and foliar levels of nutrients on percentage of fruit set, length of fruit and weight of fruit under rain shelter

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Percentage of fruit set (%)	Length of fruit (cm)	Weight of fruit (g)	Percentage of fruit set (%)	Length of fruit (cm)	Weight of fruit (g)
Fertigation (F)						
F_1	71.69	10.86	10.99	69.14	13.64	13.73
F_2	73.32	11.97	11.51	72.94	14.30	13.92
F_3	72.92	12.49	12.80	79.51	14.54	14.56
F_4	74.23	11.40	12.90	77.23	13.75	15.06
SE m (±)	1.92	0.20	0.24	2.06	0.15	0.20
CD(0.05)	NS	0.636	0.741	6.899	0.471	0.614
Foliar (L)						
L_1	72.19	12.08	12.94	74.43	14.01	14.63
L_2	73.90	11.28	11.16	74.98	14.10	14.00
SE m (±)	0.99	0.13	0.15	1.65	0.13	0.12
CD(0.05)	NS	0.393	0.439	NS	NS	0.349
fxl Interaction						
f_1l_1	67.68	11.39	10.99	62.23	13.37	13.33
f_1l_2	75.70	10.33	10.98	76.06	13.97	14.13
f_2l_1	73.38	12.44	12.80	78.36	13.87	14.24
f_2l_2	73.27	11.51	10.21	67.52	14.73	13.59
f_3l_1	71.40	12.90	14.33	80.67	14.75	15.91
f_3l_2	74.44	12.08	11.28	78.35	14.33	13.22
f_4l_1	76.28	11.59	13.63	76.47	14.07	15.04
f_4l_2	72.19	11.20	12.16	77.98	13.43	15.07
SE m (±)	2.71	0.29	0.34	2.91	0.21	0.28
CD(0.05)	6.119	NS	0.893	9.079	0.814	0.710

Table 34. Effect of fertigation and foliar levels of nutrients on percentage fruit set, length of fruit and weight of fruit under open field condition

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Percentage fruit set (%)	Length of fruit (cm)	Weight of fruit (g)	Percentage fruit set (%)	Length of fruit (cm)	Weight of fruit (g)
Fertigation (F)						
F_1	59.56	11.64	10.24	57.68	13.98	12.80
F_2	64.33	11.64	10.57	51.54	13.24	13.51
F_3	65.61	11.34	11.34	58.06	13.57	14.22
F_4	71.22	12.53	11.49	62.71	14.00	14.56
SE m (±)	0.84	0.14	0.32	1.09	0.13	0.19
CD(0.05)	2.612	0.419	0.993	3.403	0.391	0.582
Foliar (L)						
L_1	65.75	11.81	11.13	60.77	13.70	14.03
L_2	64.61	11.77	10.69	54.23	13.70	13.52
SE m (±)	0.64	0.21	0.19	0.70	0.10	0.10
CD(0.05)	NS	NS	NS	2.118	NS	0.297
fxl Interaction						
f_1l_1	61.33	12.08	10.13	60.54	13.79	13.28
f_1l_2	57.79	11.19	10.36	54.81	14.18	12.33
f_2l_1	63.50	11.01	10.66	56.29	12.52	14.03
f_2l_2	65.16	12.27	10.48	46.78	13.96	12.99
f_3l_1	65.12	11.52	10.96	63.46	14.23	14.18
f_3l_2	66.11	11.16	11.72	52.67	12.91	14.25
f_4l_1	73.08	12.62	12.79	62.76	14.26	14.63
f_4l_2	69.36	12.43	10.18	62.66	13.74	14.49
SE m (±)	1.19	0.19	0.45	1.55	0.18	0.26
CD(0.05)	NS	NS	1.189	4.306	0.588	0.605

During the second crop, weight of fruit was found higher for 125 % RDF (F_4) (15.06 g) and was on par with F_3. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) (14.63 g) recorded higher fruit weight. Interaction was also found significant among the treatments and was higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (15.91 g).

Results on the weight of fruit as influenced by fertigation and foliar levels of nutrients under open field condition is given under Table 34. During first crop, weight of fruit was significantly influenced by fertigation and foliar nutrition. Application of 125 % RDF (F_4) (11.49 g) recorded significantly higher fruit weight. This was on par with F_3 and F_2. Fruit weight was found non significant among the foliar levels of nutrients. Significant interaction was observed between fertigation and foliar levels of nutrients. Weight of fruit was significantly higher for 125 % RDF + poly feed @ 0.5 % (f_4l_1) (12.79 g), which was on par with f_3l_2.

During second crop, weight of fruit was significantly influenced by fertigation and foliar nutrition. Application of 125 % RDF (F_4) (14.56 g) showed significantly higher fruit weight. This was on par with F_3. Fruit weight was found significantly higher for poly feed @ 0.5 % (L_1) (14.03 g) among foliar levels of nutrients. Significant interaction was observed between fertigation and foliar levels of nutrients. Weight of fruit was significantly higher for 125 % RDF + poly feed @ 0.5 % (f_4l_1) (14.63 g), which was on a par with the treatments except f_1l_1, f_1l_2 and f_2l_2.

4.2.2.7 Weight of Fruits per Plant

Results on the effect of fertigation and foliar nutrition on weight of fruits per plant under rain shelter are provided in Table 35. During the first crop, different fertigation levels had significant influence on weight of fruits per plant. Application of 100 % RDF (F_3) (371.27 g) recorded significantly higher weight of fruits per plant and was on par with F_4. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) (359.10 g) showed higher fruit weight per plant. Significantly higher fruit weight per plant was noticed under 100 % RDF + poly feed @ 0.5 % (f_3l_1) (426.05 g) interaction.

During the second crop, different fertigation had significant influence on weight of fruits per plant. Application of 100 % RDF (F_3) (384.91 g) recorded significantly higher weight of fruits per plant and was on par with F_4. Among foliar levels of nutrients, poly feed @ 0.5% (L_1) (373.55 g) showed higher fruit weight per plant. Significantly higher fruit weight per plant was noticed under 100 % RDF + poly feed @ 0.5 % (f_3l_1) (445.84 g) interaction.

The data on the effect of treatments on weight of fruits per plant under open field condition is given in Table 36. During the first crop, 125 % RDF (F_4) (242.25 g) of fertigation level resulted in significantly higher weight of fruits per plant and was on par with F_3. Foliar levels of nutrients had significant influence on weight of fruits per plant. Poly feed @ 0.5 % (L_1) (255.53 g) showed significantly higher fruit weight per plant among the different foliar levels of nutrients used for seedling inoculation. Interaction was found significant among the treatments regarding fruit weight per plant and was higher for the 125 % RDF + poly feed @ 0.5 % (f_4l_1) (286.39 g).

During the second crop, 125 % RDF (F_4) (299.83 g) fertigation levels resulted in significantly higher weight of fruits per plant. Poly feed @ 0.5 % (L_1) (285.60 g) showed significantly higher fruit weight per plant among different foliar levels of nutrients. Interaction was found significant among the treatments regarding fruit weight per plant and was higher for the 125 % RDF + poly feed @ 0.5 % (f_4l_1) (311.15 g) and was on par with f_3l_1.

4.2.2.8 Fruit Yield

The effect of various treatments on fruit yield under rain shelter is given in Table 35. During the first crop, fruit yield was significantly influenced by fertigation and foliar levels of nutrients. Application of 100 % RDF (F_3) recorded significantly higher fruit yield (20.63 t ha^{-1}) among the fertigation levels. Fruit yield was found to be significantly higher for poly feed @ 0.5 % (L_1) (19.95 t ha^{-1}) among the foliar levels of nutrients. Significant interaction was observed between fertigation and foliar nutrition on fruit yield and was significantly higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (23.67 t ha^{-1}). Lower yield was recorded for 75 % RDF + poly feed @ 0.5 % (f_2l_2) (14.20 t ha^{-1}) combination.

During the second crop, fertigation level of 100 % RDF (F_3) (21.38 t ha^{-1}) produced significantly higher fruit yield and was on par with F_4. Foliar levels of nutrients had significant influence on yield. Higher fruit yield was recorded for poly feed @ 0.5 % (L_1) (20.75 t ha^{-1}). Significant interaction was noticed between fertigation and foliar levels of nutrients with respect to yield under open field condition. Interaction of 100 % RDF + poly feed @ 0.5 % (f_3l_1) (24.77 t ha^{-1}) showed the highest yield. The lowest yield was observed under f_1l_2 (15.24 t ha^{-1}).

Fruit yield as influenced by treatments under open field condition is given in Table 36. During the first crop, fertigation level of 125 % RDF (F_4) (13.46 t ha^{-1}) produced significantly higher fruit yield and was on par with F_3 (13.05 t ha^{-1}). Foliar levels of nutrients had significant influence on fruit yield. Higher fruit yield was recorded for poly feed @ 0.5 % (L_1) (12.53 t ha^{-1}). Significant interaction was noticed between fertigation and foliar levels of nutrients with respect to fruit yield under open field condition. Interaction of 125 % RDF + poly feed @ 0.5 % (f_4l_1) (15.91 t ha^{-1}) showed the highest fruit yield. The lowest fruit yield was observed under f_1l_2 (10.07 t ha^{-1}).

During the second crop, fertigation level of 125 % RDF (F_4) (16.66 t ha^{-1}) produced significantly higher fruit yield. Foliar levels of nutrients had significant influence on fruit yield. Higher fruit yield was recorded for poly feed @ 0.5 % (L_1) (15.87 t ha^{-1}). Significant interaction was noticed between fertigation and foliar levels of nutrients with respect to fruit yield under open field condition. Interaction of 125 % RDF + poly feed @ 0.5 % (f_4l_1) (17.29 t ha^{-1}) showed higher fruit yield and was on par with f_3l_1. Lowest fruit yield was observed under f_2l_2.

4.2.2.9 *Harvest Index*

The data regarding harvest index under rain shelter are presented in Table 35. Fertigation and foliar levels of nutrients and their interaction were found to be non significant in case of harvest index of bhindi during both the crop seasons.

Table 35. Effect of fertigation and foliar levels of nutrients on weight of fruit per plant, fruit yield per hectare and harvest index under rain shelter

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Weight of fruit per plant (g plant^{-1})	Fruit yield (t ha^{-1})	Harvest index	Weight of fruit per plant (g plant^{-1})	Fruit yield (t ha^{-1})	Harvest index
Fertigation (F)						
F_1	298.40	16.58	0.33	309.08	17.17	0.28
F_2	294.71	16.37	0.33	313.72	17.43	0.32
F_3	371.27	20.63	0.33	384.91	21.38	0.28
F_4	351.92	19.55	0.36	384.12	21.34	0.33
SE m (±)	7.54	0.42	0.01	9.33	0.56	0.02
CD(0.05)	23.477	1.304	NS	29.05	1.729	NS
Foliar (L)						
L_1	359.10	19.95	0.32	373.55	20.75	0.30
L_2	299.06	16.61	0.36	322.37	17.91	0.31
SE m (±)	4.21	0.234	0.01	4.96	0.27	0.01
CD(0.05)	12.722	0.708	NS	14.99	0.832	NS
fxl Interaction						
f_1l_1	285.70	15.87	0.29	294.50	16.36	0.26
f_1l_2	311.10	17.28	0.38	323.66	17.98	0.30
f_2l_1	333.87	18.55	0.31	353.16	19.62	0.32
f_2l_2	255.56	14.20	0.35	274.29	15.24	0.31
f_3l_1	426.05	23.67	0.31	445.84	24.77	0.26
f_3l_2	316.49	17.58	0.34	323.97	18.00	0.31
f_4l_1	390.77	21.71	0.35	400.69	22.26	0.33
f_4l_2	313.07	17.39	0.36	367.54	20.42	0.33
SE m (±)	10.66	0.59	0.02	13.19	0.73	0.03
CD(0.05)	25.919	1.441	NS	30.566	1.697	NS

140

Table 36. Effect of fertigation and foliar levels of nutrients on weight of fruit per plant, fruit yield per hectare and harvest index under open field condition

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Weight of fruit per plant (g plant $^{-1}$)	Fruit yield (t ha $^{-1}$)	Harvest index	Weight of fruit per plant (g plant $^{-1}$)	Fruit yield (t ha $^{-1}$)	Harvest index
Fertigation (F)						
F_1	185.54	10.31	0.39	231.26	12.85	0.24
F_2	199.90	11.11	0.35	237.43	13.19	0.21
F_3	234.87	13.05	0.34	271.86	15.10	0.27
F_4	242.25	13.46	0.37	299.83	16.66	0.23
SE m (±)	5.56	0.31	0.02	3.88	0.22	0.02
CD(0.05)	17.328	0.961	NS	12.087	0.672	NS
Foliar (L)						
L_1	255.53	12.53	0.37	285.60	15.87	0.24
L_2	205.76	11.43	0.35	234.60	13.03	0.23
SE m (±)	4.44	0.25	0.01	2.74	0.15	0.01
CD(0.05)	13.418	0.745	NS	8.284	0.459	NS
fxl Interaction						
f_1l_1	189.74	10.54	0.41	247.28	13.74	0.25
f_1l_2	181.34	10.07	0.37	215.24	11.96	0.22
f_2l_1	205.31	11.41	0.37	280.11	15.56	0.23
f_2l_2	194.48	10.81	0.32	194.76	10.82	0.19
f_3l_1	220.66	12.26	0.39	303.85	16.88	0.27
f_3l_2	249.09	13.84	0.30	239.88	13.33	0.27
f_4l_1	286.39	15.91	0.32	311.15	17.29	0.22
f_4l_2	198.12	11.01	0.42	288.50	16.03	0.24
SE m (±)	7.87	0.44	0.02	5.49	0.31	0.02
CD(0.05)	27.193	1.510	NS	16.820	0.933	NS

141

Results on the effect of fertigation and foliar levels of nutrients under open field condition are presented in Table 36. Treatments and their interaction were found to be non significant in case of harvest index of bhindi during both the crop seasons.

4.2.3 Physiological Observations

4.2.3.1 Crop Growth Rate (CGR)

The data regarding the effects of treatments on CGR under rain shelter are presented in Table 37. During the first crop, CGR was significantly higher for the fertigation of 125 % RDF (F_4) (1.38 g m^{-2} day^{-1}) and was on par with F_3. Among foliar levels of nutrients, poly feed @ 0.5 % (L_1) showed significantly higher CGR (1.23 g m^{-2} day^{-1}). There was no significant difference among interaction of fertigation and foliar levels of nutrients on CGR.

During second crop, CGR was significantly higher for the fertigation of 125 % RDF (F_4) (1.43 g m^{-2} day^{-1}) and was on par with F_3. Foliar levels of nutrients had no significant difference on CGR. Significant difference was found among the interaction of fertigation and foliar levels of nutrients on CGR. Higher CGR was recorded by 125 % RDF + poly feed @ 0.5 % (f_4l_1) (1.91) and was on par with f_3l_2.

The data on CGR under open field condition is given in the Table 38. During the first crop, significant variation was noticed among fertigation levels on CGR. Application of 100 % RDF (F_3) (1.43 g m^{-2} day^{-1}) recorded more CGR and was on par with F4. Non significant effect was found among different foliar levels of nutrients. Significant interaction was noticed between fertigation and foliar levels of nutrients on CGR. Significantly higher CGR was recorded in 100 % RDF + poly feed @ 0.5 % (f_3l_1) (1.91 g m^{-2} day^{-1}) and was on par with f_4l_2.

During second crop, significant variation was noticed between the fertigation levels on CGR. Application of 125 % RDF (F_4) (1.24 g m^{-2} day^{-1}) recorded more CGR and was on par with all fertigation levels except F_3. Significant variation was also recorded among the different foliar levels of nutrients. Poly feed @ 0.5 % (L_1)

resulted higher (1.31 g m^{-2} day^{-1}) CGR than L_2. Significant interaction was noticed between fertigation and foliar level on CGR. Significantly higher CGR was recorded in 100 % RD + poly feed @ 0.5 % (f_3l_1) (1.50 g m^{-2} day^{-1}) and was on par with f_4l_1 and f_2l_1.

4.2.3.2 Relative Growth Rate (RGR)

The data regarding the effect of treatments on RGR under rain shelter are presented in Table 37. During the first crop, RGR was significantly higher for the fertigation of 125 % RDF (F_4) (34.62 mg g^{-1} day^{-1}) and was on par with F_3. Among foliar levels of nutrients, poly feed @ 0.5 % (L_1) showed significantly higher RGR (33.56 mg g^{-1} day^{-1}). There was significant difference among the interaction of fertigation and foliar levels of nutrients on RGR and was higher for 125 % RDF + poly feed @ 0.5 % (f_4l_1) (39.39 mg g^{-1} day^{-1}) and on par with f_3l_1.

During the second crop, RGR was significantly higher for the fertigation of 125 % RDF (F_4) (36.78 mg g^{-1} day^{-1}) and was on par with F_3 (32.59 mg g^{-1} day^{-1}). Foliar levels of nutrients had no significant difference on RGR. Significant difference was found among interaction of fertigation and foliar levels of nutrients on RGR. Higher RGR was recorded by 100 % RDF + poly feed @ 0.5 % (f_4l_1) (45.25 mg g^{-1} day^{-1}).

Results on RGR under open field condition are given in Table 38. During the first crop, significant variation was noticed among the fertigation levels on RGR. Application of 125 % RDF (F_4) (28.43 mg g^{-1} day^{-1}) recorded more RGR. Significant variation was also recorded among the different foliar levels of nutrients. Poly feed @ 0.5 % (L_1) resulted higher (27.61 mg g^{-1} day^{-1}) RGR than L_2. Significant interaction was noticed between fertigation and foliar level on RGR. Significantly higher RGR was recorded in 125 % RDF + poly feed @ 0.5 % (f_4l_1) (34.70 mg g^{-1} day^{-1}) and the least was for f_2l_2 (19.77 mg g^{-1} day^{-1}).

During the second crop, significant variation was noticed among the fertigation levels on RGR. 100 % RDF (F_3) (32.04 mg g^{-1} day^{-1}) recorded more RGR and was on par with fertigation level except F_4. Significant variation was also recorded among different foliar levels of nutrients. Poly feed @ 0.5 % (L_1) resulted in higher (33.80 mg g^{-1} day^{-1}) RGR than L_2. Significant interaction was noticed between fertigation and foliar level on RGR. Significantly higher RGR was recorded in 100 % RDF + poly feed @ 0.5 % (f_3l_1) (41.10 mg g^{-1} day^{-1}).

4.2.3.3 Net Assimilation Rate (NAR)

The data regarding the effect of treatments on NAR under rain shelter are presented in Table 37. During first crop, NAR was significantly higher for the fertigation of 125 % RDF (F_4) (1.26 g m^{-2} day^{-1}). Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) recorded significantly higher NAR (1.13 g m^{-2} day^{-1}). There was no significant difference among interaction of fertigation and foliar levels of nutrients on NAR.

During the second crop, NAR was significantly higher for the fertigation of 125 % RDF (F_4) (1.98 g m^{-2} day^{-1}). Foliar levels of nutrients had no significant influence on NAR. Significant difference was found among the interaction of fertigation and foliar levels of nutrients on NAR. Higher NAR was recorded by 125 % RDF + poly feed @ 0.5 % (f_4l_1) (2.50) and was on par with f_3l_1.

The data on NAR under open field condition is given in the Table 38. During the first crop, significant variation was noticed between the fertigation levels on NAR. Application of 125 % RDF (F_4) (1.08 g m^{-2} day^{-1}) recorded more NAR and was on par with all fertigation levels except F_1. Significant variation was also recorded among the different foliar levels of nutrients. Poly feed @ 0.5 % (L_1) resulted higher (0.98 g m^{-2} day^{-1}) NAR than L_2. Significant interaction was noticed between fertigation and foliar level of nutrients on NAR. Significantly higher NAR was recorded in 125 % RDF + poly feed @ 0.5 % (f_4l_1) (1.25 g m^{-2} day^{-1}) and was on par with f_3l_2.

During the second crop, significant variation was noticed among the fertigation levels on NAR. Application of 125 % RDF (F_4) (1.79 g m^{-2} day^{-1})

144a

Table 37. Effect of fertigation and foliar levels of nutrients on CGR, RGR and NAR between 30 and 60 DAT under rain shelter condition

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	CGR ($g\ m^{-2}\ day^{-1}$)	RGR ($mg\ g^{-1}\ day^{-1}$)	NAR ($g\ m^{-2}\ day^{-1}$)	CGR ($g\ m^{-2}\ day^{-1}$)	RGR ($mg\ g^{-1}\ day^{-1}$)	NAR ($g\ m^{-2}\ day^{-1}$)
Fertigation (F)						
F_1	0.77	26.84	0.92	0.96	27.38	1.18
F_2	0.61	29.46	0.87	1.12	26.72	1.30
F_3	1.29	30.97	0.97	1.40	32.59	1.47
F_4	1.38	34.62	1.26	1.43	36.78	1.98
SE m (±)	0.11	1.46	0.07	0.05	1.95	0.12
CD(0.05)	0.337	4.256	0.230	0.150	6.061	0.383
Foliar (L)						
L_1	1.23	33.56	1.13	1.28	30.70	1.53
L_2	0.79	27.39	0.88	1.17	30.99	1.44
SE m (±)	0.10	1.03	0.05	0.06	0.84	0.09
CD(0.05)	0.313	3.010	0.140	NS	NS	NS
fxl Interaction						
f_1l_1	1.05	26.12	1.03	0.50	15.98	0.87
f_1l_2	0.49	27.55	0.82	1.41	38.78	1.48
f_2l_1	0.93	31.54	1.06	1.49	34.99	0.73
f_2l_2	0.29	27.38	0.67	0.74	18.45	1.88
f_3l_1	1.55	37.18	1.10	1.20	26.60	2.03
f_3l_2	1.03	24.75	0.85	1.59	38.58	0.92
f_4l_1	1.40	39.39	1.31	1.91	45.25	2.50
f_4l_2	1.36	29.86	1.20	0.94	28.17	1.47
SE m (±)	0.15	2.07	0.10	0.07	2.75	0.17
CD(0.05)	NS	6.019	NS	0.373	5.219	0.520

Table 38. Effect of fertigation and foliar levels of nutrients on CGR, RGR and NAR between 30 and 60 DAT under open field condition

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	CGR ($g\ m^{-2}\ day^{-1}$)	RGR ($mg\ g^{-1}\ day^{-1}$)	NAR ($g\ m^{-2}\ day^{-1}$)	CGR ($g\ m^{-2}\ day^{-1}$)	RGR ($mg\ g^{-1}\ day^{-1}$)	NAR ($g\ m^{-2}\ day^{-1}$)
Fertigation (F)						
F_1	1.12	22.10	0.62	0.86	29.36	1.07
F_2	0.96	22.55	0.84	1.01	29.55	1.05
F_3	1.43	24.06	0.97	1.18	32.04	1.68
F_4	1.40	28.43	1.08	1.24	31.50	1.79
SE m (±)	0.05	0.86	0.08	0.06	0.66	0.14
CD(0.05)	0.150	2.679	0.237	0.189	2.047	0.420
Foliar (L)						
L_1	1.28	27.61	0.98	1.31	33.80	1.87
L_2	1.17	20.96	0.78	0.84	27.42	0.93
SE m (±)	0.06	0.53	0.03	0.04	0.43	0.09
CD(0.05)	NS	1.613	0.091	0.119	1.293	0.265
fxl Interaction						
f_1l_1	1.49	22.18	0.91	0.98	21.00	1.39
f_1l_2	0.74	22.01	0.33	0.74	37.71	0.75
f_2l_1	0.50	25.32	0.98	1.38	35.10	1.71
f_2l_2	1.41	19.77	0.70	0.65	24.00	0.41
f_3l_1	1.91	28.26	0.78	1.50	41.10	1.95
f_3l_2	0.94	19.87	1.17	0.85	22.99	1.40
f_4l_1	1.20	34.70	1.25	1.37	38.00	2.44
f_4l_2	1.59	22.17	0.90	1.11	25.00	1.14
SE m (±)	0.07	1.22	0.11	0.09	0.93	0.19
CD(0.05)	0.373	3.282	0.186	0.243	2.628	NS

recorded more NAR and was on par with fertigation level F_3. Significant variation was also recorded among the different foliar levels of nutrients. Poly feed @ 0.5 % (L_1) (1.87 g m^{-2} day^{-1}) recorded higher NAR than L_2. Interaction was not significant among the fertigation and foliar levels of nutrients regarding NAR.

4.2.3.4 Chlorophyll content

The data regarding chlorophyll content of leaves at 45 DAT under rain shelter are presented in Table 39. During the first crop, fertigation had significant influence on chlorophyll content and was higher for the 125 % RDF (F_4) (1.72 mg g^{-1}). Foliar nutrition was found non significant on chlorophyll content. Interaction was found to be non significant regarding chlorophyll content of bhindi under rain shelter.

During the second crop, fertigation had significant influence on chlorophyll content and was higher for the 100 % RDF (F_3) (1.78 mg g^{-1}). Significant effect of foliar nutrition was found on chlorophyll content and was higher for nano NPK @ 0.3 % (L_2) (1.47 mg g^{-1}). Interaction was found to be significant in case of chlorophyll content of bhindi under rain shelter and was higher for the 100 % RDF + poly feed @ 0.5 % (f_3l_2) (1.83 mg g^{-1}) and was on par with f_3l_1, f_4l_2 and f_1l_2.

The data on chlorophyll content under open field condition is given in Table 40. During the first crop, fertigation had significant influence on chlorophyll content and was higher for the 125 % RDF (F_4) (1.52 mg g^{-1}). Foliar nutrition was found significant on chlorophyll content and was higher for the nano NPK @ 0.3 % (L_2) (1.45 mg g^{-1}). Interaction was found to be significant in case of chlorophyll content and was higher for f_4l_2 (1.55 mg g^{-1}) and was on par with f_4l_1 and f_3l_2 of bhindi under rain shelter.

During the second crop, fertigation and foliar levels of nutrients and their interactions had no significant effect on chlorophyll content under open field condition.

4.2.3.5 Dry Matter Production

Results on the effect of spacing and bio inoculants on total dry matter production under rain shelter are provided in Table 39. During the first crop, different fertigation levels had significant influence on dry matter production. Application of 100 % RDF (F_3) (4222 kg ha^{-1}) recorded significantly higher dry matter production than other fertigation levels. Among the different foliar levels of nutrients, poly feed @ 0.5 % (L_1) (4265 kg ha^{-1}) resulted in higher dry matter production than L_2. Significantly higher dry matter production was noted in 100 % RDF + poly feed @ 0.5 % (f_3l_1) (5034 kg ha^{-1}) and lower dry matter production was shown by f_4l_2 (2891 kg ha^{-1}) combination.

During the second crop different fertigation levels had significant influence on dry matter production. 100 % RDF (F_3) (6145 kg ha^{-1}) recorded significantly higher dry matter production than other fertigation levels. Among the different foliar levels of nutrients, poly feed @ 0.5 % (L_1) (5430 kg ha^{-1}) resulted in higher dry matter production than L_2. Non significant effect was found among interaction on dry matter production.

Dry matter production as influenced by treatments under open field condition is given in Table 40. During the first crop, 125 % RDF (F_4) (3072 kg ha^{-1}) resulted in significantly higher dry matter and was on par with F3. Poly feed @ 0.5 % (L_1) showed significantly higher dry matter production (2845 kg ha^{-1}) than L_2. Interaction was found non significant among treatments.

During the second crop different fertigation levels had significant influence on dry matter production. Application of 125 % RDF (F_4) (5115 kg ha^{-1}) recorded significantly higher dry matter production and was on par with F_3. Among the different foliar levels of nutrients, poly feed @ 0.5 % (L_1) (4787 kg ha^{-1}) resulted in higher dry matter production than L_2. Non significant effect was found among interaction on the dry matter production.

Table 39. Effect of fertigation and foliar levels of nutrients on dry matter production at harvest and chlorophyll content at 45 DAT of the plant under rain shelter

Treatment	Sept-Dec, 2017		May-Aug, 2018	
	Chlorophyll content (mg g^{-1})	Dry matter production (kg ha^{-1})	Chlorophyll content (mg g^{-1})	Dry matter production (kg ha^{-1})
Fertigation (F)				
F_1	1.42	3484	1.28	4627
F_2	1.44	3502	0.83	4330
F_3	1.44	4222	1.78	6145
F_4	1.72	3616	1.31	4863
SE m (±)	0.05	116.10	0.09	140.25
CD(0.05)	0.150	361.70	0.284	436.94
Foliar (L)				
L_1	1.46	4265	1.13	5430
L_2	1.55	3147	1.47	4552
SE m (±)	0.05	90.14	0.07	116.92
CD(0.05)	NS	272.57	0.203	353.55
fxl Interaction				
f_1l_1	1.38	3713	1.03	4961
f_1l_2	1.45	3256	1.52	4294
f_2l_1	1.41	3971	0.92	4860
f_2l_2	1.47	3033	0.74	3800
f_3l_1	1.42	5034	1.73	6863
f_3l_2	1.45	3410	1.83	5426
f_4l_1	1.62	4341	0.84	5038
f_4l_2	1.81	2891	1.78	4689
SE m (±)	0.07	164.19	0.13	198.34
CD(0.05)	NS	552.624	0.412	NS

Table 40. Effect of fertigation and foliar levels of nutrients on dry matter production at harvest and chlorophyll content at 45 DAT of the plant under open field condition

	Sept-Dec, 2017		May-Aug, 2018	
Treatment	Chlorophyll content (mg g^{-1})	Dry matter production (kg ha^{-1})	Chlorophyll content (mg g^{-1})	Dry matter production (kg ha^{-1})
Fertigation (F)				
F_1	1.20	2419	1.19	4196
F_2	1.23	2575	1.97	4402
F_3	1.35	2795	1.78	4714
F_4	1.52	3072	1.59	5115
SE m (±)	0.03	118.83	0.28	148.70
CD(0.05)	0.085	370.213	NS	463.25
Foliar (L)				
L_1	1.20	2845	1.60	4787
L_2	1.45	2585	1.66	4426
SE m (±)	0.02	47.05	0.17	117.61
CD(0.05)	0.047	142.26	NS	355.63
fxl Interaction				
f_1l_1	1.02	2566	1.34	4586
f_1l_2	1.38	2273	1.04	3806
f_2l_1	1.11	2811	1.91	4355
f_2l_2	1.35	2339	2.03	4449
f_3l_1	1.18	2818	1.84	5017
f_3l_2	1.52	2773	1.73	4411
f_4l_1	1.49	3187	1.32	5191
f_4l_2	1.55	2958	1.86	5038
SE m (±)	0.04	168.05	0.40	117.61
CD(0.05)	0.095	NS	NS	NS

150

4.2.4 Quality Aspects of Fruits

4.2.4.1 Shelf Life

The data regarding the effects of treatments on shelf life of bhindi fruits under rain shelter are presented in Table 41. During the first crop, fertigation levels had significant influence on shelf life. 50 % RDF (F_1) (4.82 days) showed significantly higher shelf life and was on par with F_2. Non significant effect was recorded among the foliar levels of nutrients on shelf life. Interaction also had no influence on shelf life of bhindi fruit under rainshelter.

During second crop, higher shelf life was observed for lower dose of fertigation, 50 % RDF (F_1) (4.98 days) which was on par with F_2. Foliar nutrition and the interaction between fertigation and foliar levels of nutrients were found non significant regarding shelf life.

Effect of treatments on shelf life under open field condition is given in Table 42. During the first crop, fertigation levels showed significant effect on shelf life. Application of 50 % RDF (F_1) (5.05 days) showed significantly higher shelf life and was on par with F_2. Foliar levels of nutrients were found non significant regarding shelf life. Interaction among treatments was also found non significant under rain shelter.

During the second crop, higher shelf life was observed for lower dose of fertigation, 50 % RDF (F_1) (4.05 days) which was on par with F_2. Foliar nutrition and the interaction between fertigation and foliar levels of nutrients were found non significant regarding shelf life.

4.2.4.2 Ascorbic Acid

The data regarding the effect of treatments on ascorbic acid content of bhindi fruits under rain shelter are presented in Table 41. During the first crop, ascorbic acid was found non significant among treatments.

During the second crop, fertigation levels showed significant effect on ascorbic acid content. Application of 125 % RDF (F_4) (20.19 mg 100g $^{-1}$) showed significantly higher ascorbic acid and was on par with F_3 (18.75 mg 100g $^{-1}$). Significant effect was found among foliar levels of nutrients regarding ascorbic acid content. Higher ascorbic acid was found under nano NPK @ 0.3 % (L_2) (19.47 mg 100g $^{-1}$) than L_1. Interaction was also found significant and was higher for 125 % RDF + nano NPK @ 0.3 % (f_4l_2) (21.64 mg 100g $^{-1}$) and was on par with 100 % RDF + nano NPK @ 0.3 % (f_3l_2) (20.68 mg 100g $^{-1}$) under rain shelter.

The data on ascorbic acid content under open field condition is given in Table 42. During the first crop, fertigation and foliar levels of nutrients and their interaction was found non significant regarding ascorbic acid content.

During, second crop, fertigation levels showed significant effect on ascorbic acid content. Application of 125 % RDF (F_4) (19.23 mg 100g $^{-1}$) showed significantly higher ascorbic acid and was on par with F_2. Significant effect was found among foliar levels of nutrients regarding ascorbic acid content. Higher ascorbic acid was found under nano NPK @ 0.3 % (L_2) (18.27 mg 100g $^{-1}$) than L_1. Interaction was also found significant and was higher for 125 % RDF + nano NPK @ 0.3 % (f_4l_2) (21.64 mg 100g $^{-1}$) under open field condition.

4.2.4.3 Protein

The data regarding the effect of treatments on protein content of bhindi fruits under rain shelter are presented in Table 41. During the first crop, protein content was found significant among fertigation levels and was higher for 125 % RDF (F_4) (1.82 %). Among the foliar levels of nutrients, higher protein content was reported under nano NPK (L_2) (1.70 %). Interaction was found non significant among the treatments.

During the second crop, fertigation levels showed significant effect on protein content. Application of 125 % RDF (F_4) (1.74 %) showed significantly higher protein content. Significant effect was found among foliar levels of nutrients

Table 41. Effect of fertigation and foliar levels of nutrients on shelf life, ascorbic acid content and protein content of the fruit under rain shelter

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Shelf life (days)	Ascorbic acid (mg 100g $^{-1}$)	Protein (%)	Shelf life (days)	Ascorbic acid (mg 100g $^{-1}$)	Protein (%)
Fertigation (F)						
F_1	4.82	16.84	1.54	4.98	17.30	1.31
F_2	4.70	15.44	1.44	4.73	17.78	1.34
F_3	3.56	17.33	1.57	4. 60	18.75	1.49
F_4	3.60	18.45	1.82	3.82	20.19	1.74
SE m (±)	0.28	0.86	0.05	0.27	0. 61	0.02
CD(0.05)	0.869	NS	0.159	0.833	1.890	0.075
Foliar (L)						
L_1	4.37	16.43	1.49	4.53	17.54	1.17
L_2	4.47	17.60	1.70	4.54	19.47	1.77
SE m (±)	0.15	0. 61	0.03	0.16	0.38	0.02
CD(0.05)	NS	NS	0.094	NS	1.152	0.063
fxl Interaction						
f_1l_1	4.57	15.23	1.41	4.77	17.78	0.91
f_1l_2	5.07	18.44	1.68	5.20	16.82	1.71
f_2l_1	5.13	14.82	1.43	5.00	16.82	1.34
f_2l_2	4.26	16.05	1.45	4.47	18.75	1.34
f_3l_1	3.31	17.62	1.47	4.66	16.82	1.04
f_3l_2	3.82	17.04	1.66	4.53	20.68	1.95
f_4l_1	4.46	18.04	1.64	3.68	18.75	1.40
f_4l_2	4.73	18.86	2.00	3.95	21.64	2.07
SE m (±)	0.39	1.21	0.07	0.38	0.86	0.034
CD(0.05)	NS	NS	NS	NS	2.343	0.122

153

Table 42. Effect of fertigation and foliar levels of nutrients on shelf life, ascorbic acid content and protein content of the fruit under open field condition

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Shelf life (days)	Ascorbic acid (mg $100g^{-1}$)	Protein (%)	Shelf life (days)	Ascorbic acid (mg $100g^{-1}$)	Protein (%)
Fertigation (F)						
F_1	5.05	16. 62	1.34	4.05	16.82	1.24
F_2	4.80	16.33	1.57	3.76	18.27	1.55
F_3	4.23	16.33	1.68	3.28	16.82	1.56
F_4	4.33	18.24	1.87	3.46	19.23	1.84
SE m (±)	0.16	0. 63	0.06	0.16	0.39	0.04
CD(0.05)	0.482	NS	0.179	0.489	1.141	0.116
Foliar (L)						
L_1	4.61	17.27	1.58	3.69	17.30	1.45
L_2	4.60	16.69	1.65	3.58	18.27	1.65
SE m (±)	0.09	0. 65	0.03	0.09	0.28	0.05
CD(0.05)	NS	NS	NS	NS	0.807	0.127
fxl Interaction						
f_1l_1	4.83	17.62	1.25	3.83	16.82	1.09
f_1l_2	5.26	15.62	1.43	4.26	16.82	1.40
f_2l_1	4.80	16.04	1.53	3.80	18.75	1.40
f_2l_2	4.80	16.63	1.61	3.73	17.78	1.71
f_3l_1	4.47	17.82	1.71	3.55	16.82	1.53
f_3l_2	4.00	15.64	1.66	3.00	16.82	1.58
f_4l_1	4.33	17.62	1.82	3.60	16.82	1.80
f_4l_2	4.33	18.86	1.91	3.33	21.64	1.89
SE m (±)	0.22	0.89	0.08	0.22	0.55	0.05
CD(0.05)	NS	NS	NS	NS	1.614	0.127

regarding protein content. Higher protein content was found for nano NPK @ 0.3 % (L_2) (1.77 %) than L_1. Interaction was also found significant and was higher for 125 % RDF + nano NPK @ 0.3 % (f_4l_2) (2.07 %) and on par with f_3l_2 under rain shelter.

Effect of treatments on protein content under open field condition is given in Table 42. During first crop, fertigation levels were found significant regarding protein content and was higher for the 125 % RDF (F_4) (1.87 %). Foliar levels of nutrients and interaction had no significance on protein content.

During, the second crop, protein content was significantly influenced by fertigation levels. Application of 125 % RDF (F_4) (1.84 %) showed significantly higher protein content. Significant effect was found among foliar levels of nutrients regarding protein content. Higher ascorbic acid was found under nano NPK @ 0.3 % (L_2) (1.65 %) than L_1. Interaction was also found significant and was higher for 125 % RDF + nano NPK @ 0.3 % (f_4l_2) (1.89 %) and on par with f_4l_1 under open field condition.

4.2.5 Plant Analysis

4.2.5.1 N uptake

Results on the effect of fertigation and foliar levels of nutrients on N uptake under rain shelter are provided in Table 43. During the first crop, different fertigation levels had significant influence on N uptake and 100 % RDF (F_3) (57.88 kg ha^{-1}) recorded significantly higher N uptake by plants. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) (56.66 kg ha^{-1}) showed higher N uptake. Significantly higher N uptake was noticed under 100 % RDF + poly feed @ 0.5 % (f_3l_1) (62.50 kg ha^{-1}) interaction and was on a par with f_4l_1.

During the second crop, different fertigation levels had significant influence on N uptake and 100 % RDF (F_3) (74.29 kg ha^{-1}) recorded significantly higher N uptake by plants. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1)

(68.57 kg ha^{-1}) showed higher N uptake. Significantly higher N uptake was noticed under 100 % RDF + poly feed @ 0.5 % (f_3l_1) (85.49 kg ha^{-1}) interaction.

Effect of fertigation and foliar levels of nutrients on N uptake under open field condition is provided in Table 44. During the first crop, 125 % RD (F_4) (42.02 kg ha^{-1}) fertigation level resulted in significantly higher N uptake and was on par with F_3. Foliar levels of nutrients had no significant effect on N uptake. Interaction was also found non significant among treatments regarding N uptake.

During the second crop, different fertigation levels had significant influence on N uptake and 125 % RDF (F_4) (53.91 kg ha^{-1}) recorded significantly higher N uptake by plants and was on par with F_3. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) showed higher N uptake (47.70 kg ha^{-1}). Interaction was found non significant among treatments regarding N uptake.

4.2.5.2 P uptake

Results on the effect of fertigation and foliar levels of nutrients on P uptake under rain shelter are provided in Table 43. During the first crop, different fertigation levels had no significant influence on P uptake. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) showed higher N uptake (12.36 kg ha^{-1}). Interaction was non significant regarding P uptake.

During the second crop, different fertigation levels had significant influence on P uptake and 100 % RDF (F_3) (15.16 kg ha^{-1}) recorded significantly higher P uptake by plants. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) showed higher P uptake (14.57 kg ha^{-1}). Significant interaction was not observed for P uptake.

Effect of treatments on P uptake by plants under open field condition is presented in the Table 44. During the first crop, 125 % RDF (F_4) fertigation level resulted in significantly higher P uptake (12.91 kg ha^{-1}) and was on par with all the levels except F_1. Foliar levels of nutrients had no significant effect on P uptake. Interaction was found significant among the treatments regarding P uptake and was higher for 125 % RDF + nano NPK @ 0.3 % (f_4l_2) (13.25 kg ha^{-1}).

During the second crop, different fertigation levels had significant influence on P uptake and 125 % RDF (F_4) recorded significantly higher P uptake (13.91 kg ha^{-1}) by plants and were on par with F_3. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) showed higher P uptake (15.30 kg ha^{-1}). Interaction was found non significant among the treatments regarding P uptake.

4.2.5.3 K uptake

Results on the effect of fertigation and foliar levels of nutrients on K uptake under rain shelter are provided in Table 43. During the first crop, different fertigation levels had significant influence on K uptake. Application of 100 % RDF (F_3) recorded significantly higher K uptake (56.52 kg ha^{-1}). Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) (55.76 kg ha^{-1}) showed higher K uptake. Interaction was non significant regarding K uptake.

During second crop, different fertigation levels had significant influence on K uptake and 100 % RDF (F_3) recorded significantly higher K uptake (65.06 kg ha^{-1}) by plants. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) showed higher K uptake (56.13 kg ha^{-1}). Significant interaction was observed under K uptake. Application of % RDF + poly feed @ 0.5 % (F_3l_1) recorded higher K uptake (65.24 kg ha^{-1}) and was on par with f_3l_2, f_4l_1 and f_2l_1.

Results on the K uptake by plants under open field condition are given in Table 44. During the first crop, 125 % RDF (F_4) (33.27 kg ha^{-1}) fertigation level resulted in significantly higher K uptake and was on par with F_3. Foliar levels of nutrients had no significant effect on K uptake. Interaction was also found non significant among treatments regarding K uptake.

During the second crop, different fertigation levels had significant influence on K uptake and 125 % RDF (F_4) (55.94 kg ha^{-1}) recorded significantly higher K

Table 43. Effect of fertigation and foliar levels of nutrients on nitrogen, phosphorus and potassium uptake of plant at harvest under rain shelter (kg ha^{-1})

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Nitrogen uptake	Phosphorus uptake	Potassium uptake	Nitrogen uptake	Phosphorus uptake	Potassium uptake
Fertigation (F)						
F_1	50.05	11.68	48.15	54.49	12.69	42.63
F_2	50.06	11.12	45.38	58.67	12.60	45.46
F_3	57.88	11.99	56.52	74.29	15.16	65.06
F_4	50.70	11.17	48.51	61.70	13.83	50.75
SE m (±)	1.86	0.23	2.50	2.85	0.26	4.55
CD(0.05)	5.802	NS	7.79	8.880	0.813	14.181
Foliar (L)						
L_1	56.66	12.36	55.76	68.57	14.57	56.13
L_2	47.68	10.62	43.51	56.01	12.56	45.82
SE m (±)	0.84	0.18	1.88	2.10	0.25	2.02
CD(0.05)	2.539	0.549	5.695	6.280	0.749	6.115
fxl Interaction						
f_1l_1	53.29	12.36	55.10	55.59	13.49	38.81
f_1l_2	46.81	11.00	41.21	53.39	11.89	46.44
f_2l_1	52.26	12.16	52.98	63.95	13.69	60.63
f_2l_2	47.86	10.07	37.78	53.38	11.49	30.28
f_3l_1	62.50	12.81	63.72	85.49	16.63	65.24
f_3l_2	53.25	11.17	49.32	63.09	13.68	64.89
f_4l_1	58.61	12.09	51.26	69.24	14.48	59.82
f_4l_2	42.80	10.26	45.75	54.17	13.18	41.67
SE m (±)	2.63	0.326	3.54	4.03	0.37	6.44
CD(0.05)	5.187	NS	NS	6.280	NS	12.495

Table 44. Effect of fertigation and foliar levels of nutrients on nitrogen, phosphorous and potassium uptake of plant at harvest under open field condition (kg ha^{-1})

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Nitrogen uptake	Phosphorous uptake	Potassium uptake	Nitrogen uptake	Phosphorous uptake	Potassium uptake
Fertigation (F)						
F_1	32.15	11.63	19.01	40.92	12.38	28.59
F_2	34.78	12.15	21.98	37.95	12.33	34.98
F_3	41.97	12.49	31.88	47.07	13.22	41.92
F_4	42.02	12.91	33.27	53.91	13.91	55.94
SE m (±)	1.83	0.29	1.92	1.18	0.27	3.36
CD(0.05)	5.710	0.894	5.981	3.667	0.828	10.481
Foliar (L)						
L_1	38.25	12.23	28.43	47.70	15.30	43.78
L_2	37.21	12.36	24.64	42.23	12.62	36.94
SE m (±)	1.01	0.075	1.66	1.73	0.21	2.55
CD(0.05)	NS	NS	NS	5.229	0.648	NS
fxl Interaction						
f_1l_1	29.76	11.69	18.02	44.04	12.59	33.00
f_1l_2	34.55	11.57	19.99	37.80	12.17	24.18
f_2l_1	35.82	12.32	21.05	41.08	12.24	39.87
f_2l_2	33.73	11.98	22.91	34.82	12.41	30.10
f_3l_1	43.71	12.35	33.50	48.16	13.98	44.50
f_3l_2	40.23	12.63	30.27	45.97	12.45	39.34
f_4l_1	43.72	12.56	41.15	57.50	14.37	57.73
f_4l_2	40.32	13.25	25.39	50.32	13.44	54.14
SE m (±)	2.59	0.41	2.72	1.67	0.38	4.76
CD(0.05)	NS	0.466	NS	NS	NS	NS

159

uptake. Foliar levels of nutrients and interaction was found non significant among the treatments regarding K uptake.

4.2.6 Soil Analysis

4.2.6.1 Available N

Results on the effect of fertigation and foliar levels of nutrients on available N under rain shelter are provided in Table 45. During the first crop, different fertigation levels had significant influence on available N and 100 % RDF (F_3) (155.54 kg ha^{-1}) recorded significantly higher soil available N. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) (149.27 kg ha^{-1}) showed higher available N. Significantly higher available N was noticed under 100 % RDF + poly feed @ 0.5 % (f_3l_1) (173.11 kg ha^{-1}) interaction.

During the second crop, different fertigation levels had significant influence on available N and 125 % (F_4) recorded significantly higher available N (120.46 kg ha^{-1}) in soil and was on par with F_3 and F_1. Foliar levels of nutrients found non significant on available N. Significantly higher available N was noticed under 125 % RDF + poly feed @ 0.5 % (f_4l_1) (125.47 kg ha^{-1}) and was on par with f_3l_2, f_1l_1 interaction.

The data on the effect of treatments under open field condition regarding available N is presented in Table 46. During first crop, 125 % RDF (F_4) fertigation levels resulted in significantly higher available N (136.73 kg ha^{-1}) and was on par with F_3. Foliar levels of nutrients had no significant effect on available N interaction was found significant among the treatments regarding available N and was higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (140.49 kg ha^{-1}) which was on par with f_4l_1, f_4l_2 and f_2l_2.

During the second crop, different fertigation levels had significant influence on available N and 125 % RDF (F_4) recorded significantly higher available N (115.44 kg ha^{-1}). Foliar levels of nutrients had no significant effect on available N.

Interaction was found significant among treatments regarding available N and was higher for 125 % RDF + nano NPK @ 0.3 % (f_4l_2) (122.96 kg ha^{-1}).

4.2.6.2 Available P

Results on the effect of fertigation and foliar levels of nutrients on available P under rain shelter are provided in Table 45. During the first crop, different fertigation levels had significant influence on available P and 100 % RDF (F_3) (42.14 kg ha^{-1}) recorded significantly higher available P. Among the foliar levels of nutrients, significant effect was not found on available P. Significantly higher available P was noticed under 100 % RDF + poly feed @ 0.5 % (f_3l_1) (42.59 kg ha^{-1}) interaction and was on par with f_4l_2.

During the second crop, different fertigation levels had significant influence on available P and 100 % RDF (F_3) recorded significantly higher available P (30.79 kg ha^{-1}) in soil and were on par with F_3. Foliar levels of nutrients found non significant on available P. Significantly higher available P was noticed under 125 % RDF + poly feed @ 0.5 % (f_4l_2) (31.48 kg ha^{-1}) and was on par with f_3l_2 and f_3l_1 interaction.

Available P as influenced by treatments under open field condition is depicted in the Table 46. During the first crop, 100 % RDF (F_3) fertigation level resulted in significantly higher available P (36.19 kg ha^{-1}). Foliar levels of nutrients had no significant effect on available phosphorus. Interaction was found significant among treatments regarding available P and was higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (36.65 kg ha^{-1}).

During the second crop, different fertigation and foliar levels of nutrients and their interactions had no significant influence on available P.

4.2.6.3 *Available K*

Results on the effect of fertigation and foliar levels of nutrients on available K after the experiment under rain shelter are provided in Table 45. During the first

Table 45. Effect of fertigation and foliar levels of nutrients on available nitrogen, phosphorous and potassium in soil after experiment under rain shelter (kg ha^{-1})

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Available Nitrogen	Available Phosphorous	Available Potassium	Available Nitrogen	Available Phosphorous	Available Potassium
Fertigation (F)						
F_1	132.97	41.07	185.29	115.44	29.21	172.89
F_2	135.47	41.18	192. 69	104.15	29.35	170.65
F_3	155.54	42.14	247.84	117.95	30.79	182.93
F_4	149.27	41.71	259.48	120.46	30.44	226.04
SE m (±)	1.77	0.12	11.50	2.56	0.35	2.73
CD(0.05)	5.517	0.372	35.841	7.974	1.103	8.495
Foliar (L)						
L_1	149.27	41.53	212.27	115.44	29.75	186.60
L_2	137.35	41.52	230.88	113.56	30.15	189.65
SE m (±)	1.38	0.06	6.94	1.21	0.22	2.92
CD(0.05)	4.186	NS	NS	NS	NS	NS
fxl Interaction						
f_1l_1	135.47	41.16	189.98	120.46	28.94	177.21
f_1l_2	130.46	40.97	180.61	110.42	29.48	168.57
f_2l_1	132.96	41.45	153.69	100.39	29.53	214.50
f_2l_2	137.98	40.91	231.68	107.97	29.17	126.81
f_3l_1	173.11	42.59	254.12	115.44	31.12	155.03
f_3l_2	137.98	41.68	241.55	120.46	30.46	210.82
f_4l_1	155.55	40.91	251.29	125.47	29.39	199.67
f_4l_2	143.00	42.51	267.67	115.44	31.48	252.41
SE m (±)	2.50	0.17	16.27	3.62	0.50	3.86
CD(0.05)	8.486	0.384	42.706	7.498	1.346	17.845

162

Table 46. Effect of fertigation and foliar levels of nutrients on available nitrogen, phosphorous and potassium in soil after the experiment in open field condition (kg ha^{-1})

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Available Nitrogen	Available Phosphorous	Available Potassium	Available Nitrogen	Available Phosphorous	Available Potassium
Fertigation (F)						
F_1	112.90	34.74	185.95	105.41	28.13	144.26
F_2	121.68	35.26	195.00	102.90	28.97	133.89
F_3	125.44	36.19	207.20	106.66	28.44	155.86
F_4	136.73	34.98	207.32	115.44	29.33	172.21
SE m (±)	4.03	0.15	3.02	1.79	0.43	2.05
CD(0.05)	12.562	0.471	9.412	5.580	NS	6.387
Foliar (L)						
L_1	125.44	35.33	198.27	106.03	28.20	134.13
L_2	122.93	35.26	199.46	109.17	29.24	168.98
SE m (±)	2.28	0.10	4.35	1.22	0.40	1.76
CD(0.05)	NS	NS	NS	NS	NS	5.321
fxl Interaction						
f_1l_1	112.90	34.53	202.37	107.92	28.65	149.87
f_1l_2	112.90	34.95	169.53	102.90	27.61	138.64
f_2l_1	112.90	35.24	201.66	110.42	28.18	117.76
f_2l_2	130.46	35.29	188.34	95.37	29.77	150.03
f_3l_1	140.49	36.65	174.97	97.88	27.36	132.79
f_3l_2	110.39	35.72	239.43	115.44	29.51	178.93
f_4l_1	135.47	34.88	214.09	107.92	28.59	136.12
f_4l_2	137.98	35.08	200.55	122.96	30.06	208.30
SE m (±)	5.70	0.21	4.27	2.53	0.60	2.90
CD(0.05)	14.062	0.600	26.436	7.462	NS	10.772

163

crop, different fertigations had significant influence on available K and was higher for 125 % RDF (F_4) (259.48 kg ha^{-1}) and was on par with F_3. Foliar levels of nutrients had no significant effect on available K. Interaction was significant among treatments and was higher for 125 % RDF + nano NPK @ 0.3 % (f_4l_2) (267.67 kg ha^{-1}) and was on par with all the treatments except f_1l_1, $f_1l_2$and f_2l_1.

During the second crop, different fertigation levels had significant influence on available K and 125 % RDF (F_4) (226.04 kg ha^{-1}) recorded significantly higher available K in soil. Foliar levels of nutrients found non significant with respect to available K. Significantly higher available K was noticed under 125 % RDF + nano NPK @ 0.3 % (f_4l_2) (252.41 kg ha^{-1}) interaction.

Effect of treatments on available K under open field condition is presented in Table 46. During the first crop, 125 % RDF (F_4) (207.32 kg ha^{-1}) spacing resulted in significantly higher available K and was on par with F_3. Foliar levels of nutrients had no significant influence on available K. Interaction was found significant among treatments and was higher for the 100 % RDF + nano NPK @ 0.3 % (f_3l_2) (239.43 kg ha^{-1}) and on par with f_4l_1 regarding available K.

During the second crop, different fertigation levels had significant influence on available K and 125 % RDF (F_4) recorded significantly higher available K (172.21 kg ha^{-1}) in soil. Foliar levels of nutrients were found significant on available K and were higher for poly feed @ 0.5 % (L_2) (168.98 kg ha^{-1}). Significantly higher available K was noticed under 125 % RDF + nano NPK @ 0.3 % (f_4l_2) (208.30 kg ha^{-1}) interaction.

4.2.6.4 pH

The data regarding the effects of treatments on pH of the soil after experiment under rain shelter are presented in Table 47. During both the crop, significant

Table 47. Effect of fertigation and foliar levels of nutrients on OC and pH in soil after the experiment under rain shelter

	Sept-Dec, 2017		May-Aug, 2018	
Treatment	OC (%)	pH	OC (%)	pH
Fertigation (F)				
F_1	0.89	6.72	0.93	6.70
F_2	0.93	6.78	0.92	6.71
F_3	0.97	6.80	0.94	6.89
F_4	0.89	6.79	0.97	6.77
SE m (±)	0.02	0.04	0.02	0.04
CD(0.05)	NS	NS	NS	NS
Foliar (L)				
L_1	0.94	6.69	0.96	6.89
L_2	0.91	6.59	0.92	6.77
SE m (±)	0.02	0.04	0.02	0.03
CD(0.05)	NS	NS	NS	NS
fxl Interaction				
f_1l_1	0.95	6.60	0.97	6.68
f_1l_2	0.85	6.84	0.89	6.72
f_2l_1	0.98	6.74	0.91	6.72
f_2l_2	0.88	6.82	0.93	6.70
f_3l_1	0.95	6.76	0.95	7.00
f_3l_2	0.99	6.84	0.94	6.78
f_4l_1	0.89	6.84	1.03	7.16
f_4l_2	0.89	6.74	0.90	6.88
SE m (±)	0.03	0.06	0.03	0.06
CD(0.05)	NS	NS	NS	NS

Table 48. Effect of fertigation and foliar levels of nutrients on OC and pH of soil after the experiment under open field condition

	Sept-Dec, 2017		May-Aug, 2018	
Treatment	OC (%)	pH	OC (%)	pH
Fertigation (F)				
F_1	0.98	6. 63	0.91	6.92
F_2	1.05	6. 66	0.96	7.03
F_3	0.95	6.70	0.93	6.83
F_4	1.04	6.70	1.02	6.84
SE m (±)	0.04	0.08	0.03	0.07
CD(0.05)	NS	NS	NS	NS
Foliar (L)				
L_1	1.04	6.61	0.95	6.80
L_2	0.98	6.74	0.91	7.01
SE m (±)	0.02	0.06	0.04	0.08
CD(0.05)	NS	NS	NS	NS
fxl Interaction				
f_1l_1	0.98	6.58	0.93	6.82
f_1l_2	0.99	6.68	0.89	7.02
f_2l_1	1.07	6.58	1.01	6.90
f_2l_2	1.04	6.74	0.91	7.16
f_3l_1	1.04	6.58	0.94	6.86
f_3l_2	0.86	6.82	0.92	6.80
f_4l_1	1.05	6.68	0.91	6.62
f_4l_2	1.02	6.72	1.13	7.06
SE m (±)	0.06	0.10	0.04	0.10
CD(0.05)	NS	NS	NS	NS

difference was not found among the treatments. But in general, an increase in pH was observed after the experiment.

Effect of treatments on pH under open field condition is given in Table 48. No significant effect was seen among the treatments and their interactions were also found non significant. Increase in pH was observed under open field condition as in rain shelter after the experiment.

4.2.6.5 Organic Carbon (OC)

Effect of treatments on OC of the soil after the experiment under rain shelter is presented in Table 47. OC was found non significant among treatments.

Effect of treatments on OC of the soil after the experiment under open field condition is presented in Table 48. Significant influence was not seen among the treatments regarding OC.

4.2.6.6 Bacteria

Results on the effect of spacing and bio inoculants on bacterial count under rain shelter are provided in Table 49. During the first crop, fertigation and foliar levels of nutrients and their interaction had no significant influence on bacterial count.

During the second crop, different spacings had significant influence on bacterial count, 125 % RDF (F_4) recorded significantly higher soil bacteria (7.23 log cfu g $soil^{-1}$) and was on par with F_2. Among the foliar levels of nutrients, nano NPK @ 0.3 % (L_2) showed higher bacterial count (7.23 log cfu g $soil^{-1}$). Significantly higher bacterial population was noticed under 100 % RDF + nano NPK @ 0.3 % (f_4l_2) (7.30 log cfu g $soil^{-1}$) interaction and was on par with f_2l_2, f_3l_2 and f_1l_1.

Bacterial count as influenced by treatments under open field condition is given in Table 50. During the first crop, 125 % RDF (F_4) spacing resulted in significantly higher bacterial count (7.32 log cfu g soil^{-1}) and non significant effect was found among foliar levels of nutrients on bacterial count. Interaction was also found non significant among the treatments regarding bacterial count.

During second crop, 125 % RDF (F_4) spacing resulted in significantly higher bacterial count (7.33 log cfu g soil^{-1}) and non significant effect was found among

foliar levels of nutrients on bacterial count. Interaction was also found non significant among treatments regarding bacterial count.

4.2.6.7 Fungi

Results on the effect of fertigation and foliar levels of nutrients on fungal population under rain shelter are provided in Table 49. During the first crop, fertigation level of 125 % RDF (F_4) spacing resulted in significantly higher fungal population (5.10 log cfu g soil^{-1}). Foliar levels of nutrients had significant effect on fungal population and were higher for nano NPK @ 0.3 % (L_2) (4.99 log cfu g soil^{-1}). Interaction was found significant among treatments regarding fungal population. Application of 100 % RDF + poly feed @ 0.5 % (F_4l_1) (5.11) resulted in higher fungal population and was on par with f_4l_2, f_3l_2 and f_1l_2.

During the second crop, fertigation level of 125 % RDF (F_4) spacing resulted in significantly higher fungal population (5.14 log cfu g soil^{-1}). Foliar levels of nutrients had no significant effect on fungal population. Interaction was found significant among treatments regarding fungal population and was higher for 100 % RDF + nano NPK @ 0.3 % (f_4l_2) (5.17 log cfu g soil^{-1}).

Fungal population as influenced by treatments under open field condition is given in the Table 50. During the first crop, different fertigation levels had significant influence on fungal population and were higher for 125 % RDF (F_4) (5.07 log cfu g soil^{-1}). Among the foliar levels of nutrients, significant influence was not observed under fungal count. Significantly higher fungal population was noticed under the interactions 100 % RDF + poly feed @ 0.5 % (f_4l_1) and (f_4l_2) (5.07 log cfu g soil^{-1}) and was on par with f_3l_2 and f_2l_1.

During the second crop, different fertigation levels had significant influence on fungal population and were higher for 125 % RDF (F_4) (5.11 log cfu g soil^{-1}). Among the foliar levels of nutrients, significant influence was not seen. Significantly higher fungal population was noticed under 100 % RDF + poly feed @ 0.5 % (f_4l_1) and (f_4l_2) (5.11 log cfu g soil^{-1}) interaction.

4.2.6.8. Actinomycetes

Results on the effect of fertigation and foliar levels of nutrients on actinomycetes population under rain shelter are provided in Table 49. During the first crop, different fertigation levels had significant influence on actinomycetes population and were higher for 125 % RDF (F_4) (4.44 log cfu g soil^{-1}). Among foliar levels of nutrients, nano NPK @ 0.3 % (L_2) showed higher actinomycetes population (4.45 log cfu g soil^{-1}). Significant interaction was found among treatments and was higher under 75 % RDF + nano NPK @ 0.3 % (f_2l_2) (4.51 log cfu g soil^{-1}) and was on par with all the interactions except f_1l_1, f_2l_1 and f_3l_1.

During the second crop, different fertigation levels had significant influence on actinomycetes population and was higher for 125 % RDF (F_4) (4.53 log cfu g soil^{-1}) which was on par with F_2. Among the foliar levels of nutrients, nano NPK @ 0.3 % (L_2) (4.51 log cfu g soil^{-1}) showed higher actinomycetes population. Significant interaction was found among the treatments and was higher under 75 % RDF + nano NPK @ 0.3 % (f_2l_2) (4.57 log cfu g soil^{-1}) and on par with the interactions f_3l_2, f_4l_1 and f_4l_2.

The data on the effect of treatments on the actinomycetes population under open field condition is presented in Table 50. During the first crop, fertigation and foliar levels of nutrients had no significant effect on actinomycetes population. Interaction was found significant among the treatments regarding actinomycetes population. Application of 100 % RDF + poly feed @ 0.5 % (F_4l_1) (4.59 log cfu g soil^{-1}) resulted

Table 49. Effect of fertigation and foliar levels of nutrients on microbial count in soil after the experiment under rain shelter (log cfu g $soil^{-1}$)

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
Fertigation (F)						
F_1	7.05	4.88	4.36	7.21	5.05	4.42
F_2	7.05	4.89	4.36	7.18	4.98	4.49
F_3	7.10	4.90	4.32	7.15	5.07	4.44
F_4	7.09	5.10	4.44	7.23	5.14	4.53
SE m (±)	0.05	0.05	0.02	0.02	0.02	0.02
CD(0.05)	NS	0.144	0.075	0.052	0.063	0.076
Foliar (L)						
L_1	7.06	4.90	4.29	7.16	5.05	4.43
L_2	7.09	4.99	4.45	7.23	5.07	4.51
SE m (±)	0.03	0.02	0.02	0.02	0.01	0.01
CD(0.05)	NS	0.061	0.055	0.062	NS	0.023
fxl Interaction						
f_1l_1	7.11	4.77	4.31	7.28	5.09	4.42
f_1l_2	6.99	4.99	4.41	7.13	5.01	4.42
f_2l_1	6.97	4.91	4.21	7.06	4.94	4.41
f_2l_2	7.13	4.87	4.51	7.29	5.03	4.57
f_3l_1	7.07	4.80	4.18	7.12	5.06	4.37
f_3l_2	7.13	5.00	4.46	7.19	5.08	4.52
f_4l_1	7.09	5.11	4.47	7.15	5.11	4.53
f_4l_2	7.09	5.08	4.42	7.30	5.17	4.53
SE m (±)	0.06	0.06	0.03	0.02	0.03	0.04
CD(0.05)	NS	0.125	0.112	0.125	0.062	0.047

170

Table 50. Effect of fertigation and foliar levels of nutrients on microbial count in soil after the experiment under open field condition (log cfu g soil^{-1})

	Sept-Dec, 2017			May-Aug, 2018		
Treatment	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
Fertigation (F)						
F_1	7.22	4.88	4.51	7.24	4.93	4. 62
F_2	7.08	4.93	4.55	7.11	4.99	4. 64
F_3	7.22	4.87	4.43	7.24	4.92	4.51
F_4	7.32	5.07	4.45	7.33	5.11	4.55
SE m (±)	0.02	0.02	0.05	0.03	0.01	0.02
CD(0.05)	0.064	0.063	NS	0.082	0.042	0.071
Foliar (L)						
L_1	7.23	4.93	4.49	7.25	4.98	4.58
L_2	7.19	4.95	4.47	7.22	4.99	4.58
SE m (±)	0.02	0.02	0.03	0.02	0.01	0.01
CD(0.05)	NS	NS	NS	NS	NS	NS
fxl Interaction						
f_1l_1	7.27	4.92	4.50	7.29	4.96	4.63
f_1l_2	7.17	4.85	4.51	7.19	4.89	4.61
f_2l_1	7.07	4.97	4.50	7.11	5.04	4.61
f_2l_2	7.10	4.88	4.58	7.12	4.93	4.66
f_3l_1	7.21	4.75	4.37	7.23	4.82	4.42
f_3l_2	7.24	4.99	4.49	7.26	5.02	4.59
f_4l_1	7.35	5.07	4.59	7.37	5.11	4.66
f_4l_2	7.28	5.07	4.32	7.29	5.11	4.44
SE m (±)	0.03	0.03	0.07	0.04	0.02	0.03
CD(0.05)	NS	0.138	0.204	NS	0.061	0.081

in higher actinomycetes population and was on par with all the treatments except f_3l_1 and f_4l_2.

During the second crop, fertigation had significant effect on actinomycetes population and was higher for 75 % RDF (F_2) (4.64 log cfu g soil^{-1}) and was on par with F_1. Foliar nutrition had no significant effect on actinomycetes population. Interaction was found significant among treatments regarding actinomycetes population. Application of 125 % RDF + poly feed @ 0.5 % (f_4l_1) and 75 % RDF + nano NPK @ 0.3 % (f_2l_2) (4.66 log cfu g soil^{-1}) resulted in higher actinomycetes population and was on par with all the treatments except f_3l_1 and f_4l_2.

4.2.7. Water Use Efficiency

The data regarding the effects of treatments on water use efficiency under both growing condition are presented in Table 51. Under rain shelter, during the first crop, water use efficiency was significantly higher for 100 % RDF (F_3) (6.92 kg m^{-3}). Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) showed significantly higher water use efficiency (6.87 kg m^{-3}). Significant interaction was noticed between fertigation and foliar levels of nutrients with respect to water use efficiency. Higher water use efficiency was recorded in 125 % RDF + poly feed @ 0.5 % (f_4l_1) (7.95 kg m^{-3}) and was on par with f_3l_1.

During the second crop water use efficiency was significantly higher for 100 % RDF (F_3) (7.42 kg m^{-3}) and on par with F_4. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) showed significantly higher water use efficiency (7.00 kg m^{-3}). Significant interaction was noticed between fertigation and foliar levels of nutrients with respect to water use efficiency. Higher water use efficiency was recorded for 100 % RDF + nano NPK @ 0.3 % (f_3l_2) (7.52 kg m^{-3}) and was on par with f_4l_1, f_4l_2, f_3l_1 and f_2l_1.

Under open field condition, during the first crop, significant variation was noticed between fertigation levels regarding water use efficiency. Application of 125 % RDF (F_4) (4.53 kg m^{-3}) showed higher water use efficiency and was on par

Table 51. Effect of fertigation and foliar levels of nutrients on water use efficiency under rain shelter and open field conditions (kg m^{-3})

	Sept-Dec, 2017		May-Aug, 2018	
Treatment	Rain shelter	Open field condition	Rain shelter	Open field condition
Fertigation (F)				
F_1	5.58	3.47	5.80	4.48
F_2	5.96	3.74	6.35	4.55
F_3	6.92	4.39	7.42	4.94
F_4	6.43	4.53	7.18	5.44
SE m (±)	0.13	0.10	0.18	0.09
CD(0.05)	0.403	0.324	0.569	0.243
Foliar (L)				
L_1	6.87	4.22	7.00	5.33
L_2	5.58	3.85	6.37	4.38
SE m (±)	0.08	0.08	0.16	0.07
CD(0.05)	0.254	0.251	0.473	0.207
fxl Interaction				
f_1l_1	5.34	3.55	5.86	4.94
f_1l_2	5.82	3.39	5.74	4.02
f_2l_1	6.24	3.84	7.33	5.46
f_2l_2	5.68	3.64	5.36	3.64
f_3l_1	7.93	4.13	7.32	5.33
f_3l_2	5.92	4.66	7.52	4.56
f_4l_1	7.95	5.35	7.50	5.58
f_4l_2	4.92	3.70	6.87	5.31
SE m (±)	0.18	0.15	0.26	0.11
CD(0.05)	0.516	0.509	0.958	0.419

173

with F_3. Significant variation was recorded among the different foliar levels of nutrients on water use efficiency. Poly feed @ 0.5 % (L_1) (4.22 kg m^{-3}) resulted in higher water use efficiency. Significant Interaction was noticed between fertigation and foliar levels of nutrients on water use efficiency. Significantly higher water use efficiency was recorded in 125 % RDF + poly feed @ 0.5 % (f_4l_1) (5.35 kg m^{-3}) interaction.

During the crop, fertigation levels had significant influence on water use efficiency. Application of 125 % RDF (F_4) (5.44 kg m^{-3}) showed higher water use efficiency. Significant variation was recorded among the different foliar levels of nutrients also. Poly feed @ 0.5 % (L_1) (5.33 kg m^{-3}) resulted in higher water use efficiency. Significant interaction was noticed between fertigation and foliar levels of nutrients on water use efficiency. Significantly higher water use efficiency was recorded in 125 % RDF + poly feed @ 0.5 % (f_4l_1) (5.58 kg m^{-3}) and was on par with f_2l_1, f_3l_1 and f_4l_2 interactions.

4.2.8 Economics of Cultivation

4.2.8.1 Net Return

The data regarding the effect of treatments on net return under rain shelter are presented in Table 52. During the first crop, net return was significantly higher for the fertigation of 100 % RDF (F_3) (Rs.3.16 lakhs ha^{-1}) which was on par with F_4. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) (Rs.2.97 lakhs ha^{-1}) showed significantly higher net return. There was significant difference among the interaction of fertigation and foliar levels of nutrients on net return and was higher for 125 % RDF + poly feed @ 0.5 % (f_3l_1) (Rs.4.07 lakhs ha^{-1}).

During the second crop, net return was significantly higher for the fertigation of 100 % RDF (F_3) (Rs.3.39 lakhs ha^{-1}) which was on par with F_4. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) (Rs.3.21 lakhs ha^{-1}) showed significantly higher net returns. Significant difference was observed among the interaction of fertigation and foliar levels of nutrients on net return and was higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (Rs.4.41 lakhs ha^{-1}).

Net return as influenced by treatments under open field condition is presented in the Table 53. During first crop, significant variation was noticed among the fertigation levels. Application of 125 % RDF (F_4) (Rs.1.58 lakhs ha^{-1}) showed higher net return and was on par with F_3. Significant variation was also recorded among the different foliar levels of nutrients. Poly feed @ 0.5 % (L_1) (Rs.1.36 lakhs ha^{-1}) resulted in higher net returns. Significant interaction was also noticed between fertigation and foliar levels of nutrients on net returns. Significantly higher net return was recorded in 125 % RDF + poly feed @ 0.5 % (f_4l_1) (Rs.2.32 lakhs ha^{-1}) and the least was for 50 % RDF + poly feed @ 0.5 % f_1l_1 (Rs.0.61 lakhs ha^{-1}).

During the second crop, significant variation was noticed among the different fertigation levels. Application of 125 % RDF (F_4) (Rs.2.54 lakhs ha^{-1}) showed higher net return. Significant variation was also recorded among the different foliar levels of nutrients. Poly feed @ 0.5 % (L_1) (Rs.2.32 lakhs ha^{-1}) resulted in higher net returns. Significant interaction was also noticed between fertigation and foliar levels of nutrients on net returns. Significantly higher net return was recorded in 125 % RDF + poly feed @ 0.5 % (f_4l_1) (Rs. 2.73 lakhs ha^{-1}) and was on par with f_3l_1.

4.2.8.2 B: C ratio

The data regarding the effects of treatments on B: C ratio under rain shelter is presented in Table 52. During first crop, B: C ratio was significantly higher for fertigation with 100 % RDF (F_3) (2.05) which was on par with F_4. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) (1.98) showed significantly higher B: C ratio. There was significant difference among the interaction of fertigation and foliar levels of nutrients on B: C ratio and was higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (2.35).

Table 52. Effect of fertigation and foliar levels of nutrients on net return and B: C ratio under rain shelter

	Sept-Dec, 2017		May-Aug, 2018	
Treatment	Net return (Rs. Lakhs ha^{-1})	B: C ratio	Net return (Rs. Lakhs ha^{-1})	B: C ratio
Fertigation (F)				
F_1	1.98	1.66	2.15	1.72
F_2	2.00	1.63	2. 22	1.74
F_3	3.16	2.05	3.39	2.12
F_4	2. 83	1.93	3.36	2.11
SE m (±)	0.13	0.04	0.16	0.05
CD(0.05)	0.391	0.131	0.484	0.159
Foliar (L)				
L_1	2.97	1.98	3.21	2.06
L_2	1.96	1.65	2.35	1.78
SE m (±)	0.07	0.023	0.08	0.03
CD(0.05)	0.212	0.071	0.249	0.083
fxl Interaction				
f_1l_1	1.76	1.59	1.91	1.64
f_1l_2	2.19	1.73	2.40	1.80
f_2l_1	2.55	1.85	2.87	1.95
f_2l_2	1.25	1.41	1.56	1.52
f_3l_1	4.07	2.35	4.41	2.46
f_3l_2	2.25	1.74	2.37	1.78
f_4l_1	3.47	2.14	3.64	2.20
f_4l_2	2.18	1.72	3.08	2.02
SE m (±)	0.18	0.06	0.22	0.07
CD(0.05)	0.431	0.144	0.508	0.169

Table 53. Effect of fertigation and foliar levels of nutrients on net return and B: C ratio under open field condition

	Sept-Dec, 2017		May-Aug, 2018	
Treatment	Net return (Rs. Lakhs ha^{-1})	B: C ratio	Net return (Rs. Lakhs ha^{-1})	B: C ratio
Fertigation (F)				
F_1	0.68	1.28	1.43	1.60
F_2	0.90	1.37	1.53	1.63
F_3	1.47	1.60	2.09	1.86
F_4	1.58	1.64	2.54	2.03
SE m (±)	0.093	0.04	0.06	0.03
CD(0.05)	0.289	0.118	0.200	0.081
Foliar (L)				
L_1	1.36	1.56	2.32	1.95
L_2	0.96	1.39	1.47	1.60
SE m (±)	0.074	0.03	0. 05	0.02
CD(0.05)	0.224	0.091	0.138	0.057
fxl Interaction				
f_1l_1	0.61	1.25	1.71	1.71
f_1l_2	0.75	1.31	1.17	1.49
f_2l_1	0.81	1.34	2.24	1.92
f_2l_2	0.99	1.41	0.82	1.34
f_3l_1	1.71	1.70	2.62	2.07
f_3l_2	1.23	1.51	1.55	1.64
f_4l_1	2.32	1.94	2.73	2.11
f_4l_2	0.84	1.34	2.35	1.95
SE m (±)	0.13	0.05	0.09	0.04
CD(0.05)	0.453	0.185	0.280	0.116

During the second crop, B:C ratio was significantly higher for the fertigation with 100 % RDF (F_3) (2.12) which was on par with F_4. Among the foliar levels of nutrients, poly feed @ 0.5 % (L_1) (2.06) showed significantly higher B:C ratio. There was significant difference among the interaction of fertigation and foliar levels of nutrients on B:C ratio and was higher for 100 % RDF + poly feed @ 0.5 % (f_3l_1) (2.46).

The data on the effect of treatments on B: C ratio under open field condition is presented in the Table 53. During the first crop, significant variation was noticed among different fertigation levels. Application of 125 % RDF (F_4) (1.64) showed higher B: C ratio and was on par with F_3. Significant variation was also recorded among the different foliar levels of nutrients. Poly feed @ 0.5 % (L_1) (1.56) resulted in higher B:C ratio. Significant interaction was also noticed between fertigation and foliar levels of nutrients on B: C ratio. Significantly higher B: C ratio was recorded in 125 % RDF + poly feed @ 0.5 % (f_4l_1) (1.94) and the least was for 50 % RDF + poly feed @ 0.5 % f_1l_1 (1.25).

During the second crop, significant variation was noticed among the fertigation levels. Application of 125 % RDF (F_4) (2.03) showed higher B: C ratio. Significant variation was also recorded among the different foliar levels of nutrients. Poly feed @ 0.5 % (L_1) (1.95) resulted in higher B: C ratio. Significant interaction was also noticed between fertigation and foliar levels of nutrients on B: C ratio. Significantly higher B: C ratio was recorded by 125 % RDF + poly feed @ 0.5 % (f_4l_1) (2.11) and was on par with f_3l_1.

DISCUSSION

5. DISCUSSION

An investigation entitled "Agro techniques in bhindi for precision farming" was conducted to standardize the spacing and response of bio inoculants for bhindi under rain shelter and open field conditions and to evaluate the effect of fertigation and foliar nutrition on improving the growth, yield and quality of bhindi and to work out the economics of different cultivation systems. The explanations and understandings conferred after analysis of the important results obtained are discussed in this chapter under the following major sections:

1. Response of spacing and bio inoculants for bhindi under rain shelter and open field condition
2. Effect of fertigation and foliar nutrition on improving growth, yield and quality of bhindi both under rain shelter and open field condition

5.1. RESPONSE OF BHINDI TO VARYING SPACING AND BIO INOCULANTS IN RAIN SHELTER AND OPEN FIELD CONDITIONS

In this experiment, three spacings (60 cm x 30 cm, 60 cm x 45 cm and 60 cm x 60 cm) and three bio inoculant treatments (PGPR mix 1, AMF and no bio inoculant) were compared to select the best spacing and bio inoculant for bhindi cultivation under rain shelter and open field conditions.

5.1.1. Effect of Spacing and Bio inoculants on Growth Characters under Rain shelter and Open Field Conditions

Both under rain shelter and open field conditions, plant height was significantly influenced by plant to plant spacing and bio inoculants and found that closer spacing of 60 cm x 30 cm recorded higher plant height (Fig. 3 and 4). Closer spacing of plants resulted in increased plant population which led to mutual shading and thus increased the competition among plants for light and favoured the plants to grow taller. Similar results of increased plant height with decreased intra - row spacing was observed in bhindi (Agba *et al.,* 2011; Zibelo *et al.*, 2016; Kumar *et al.*, 2016). On the other hand, wider spacing of

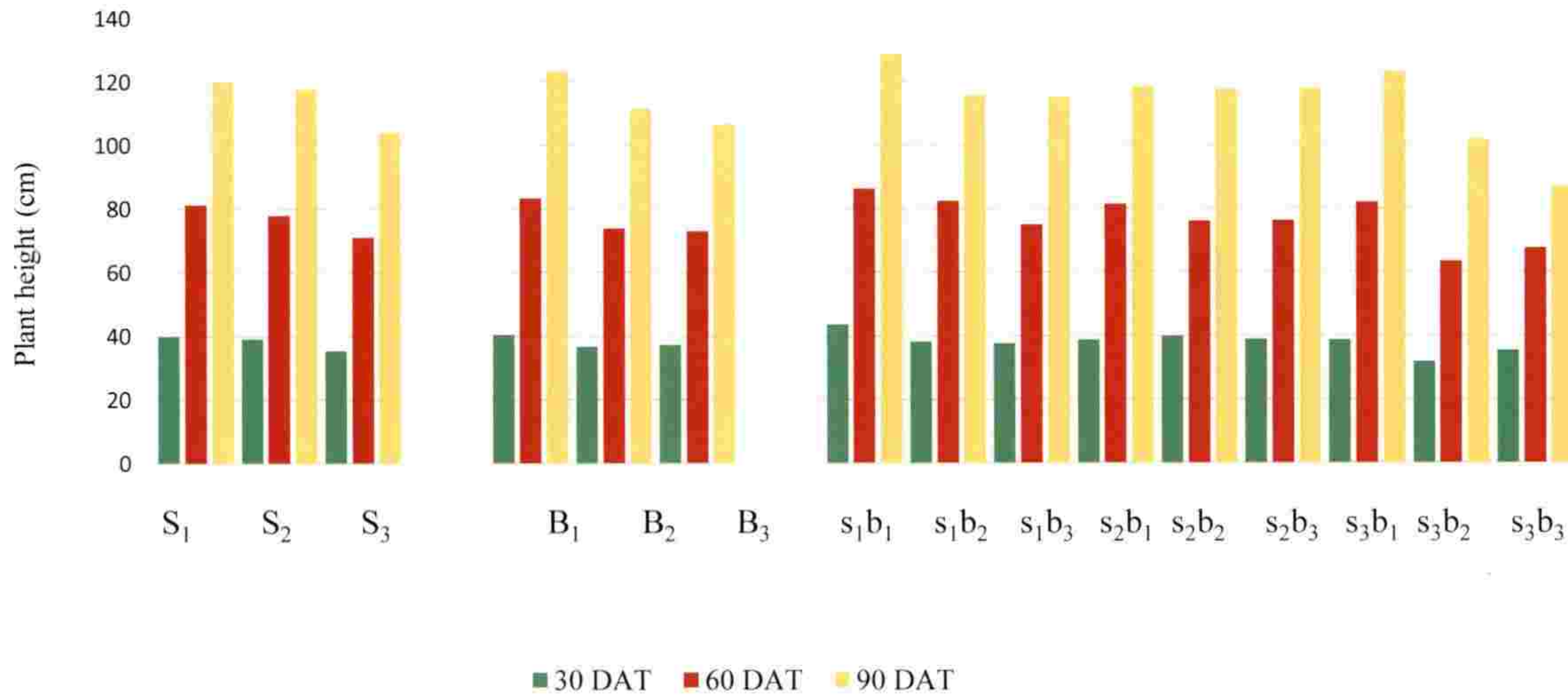

Fig. 3 Effect of spacing and bio inoculants on height of the plant at monthly interval under rain shelter, cm

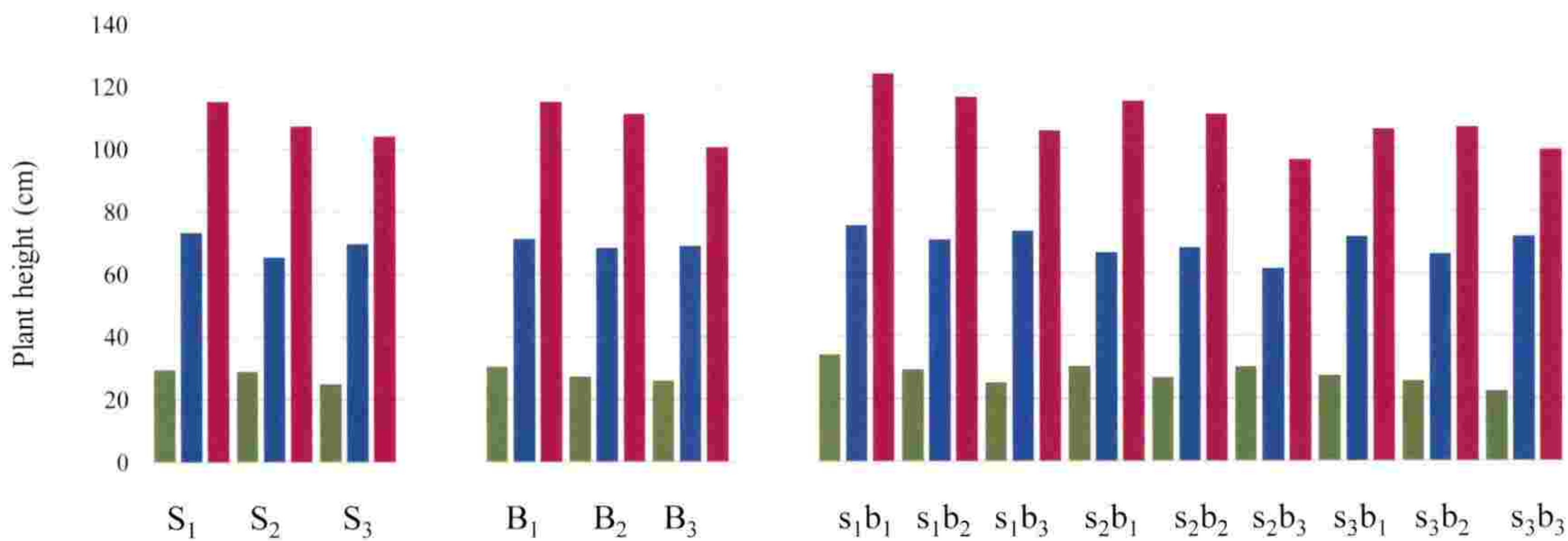

Fig. 4 Effect of spacing and bio inoculants on height of the plant at monthly intervals under open field condition, cm

60 cm x 60 cm showed more number of leaves and branches per plant under both growing conditions as there was minimum competition for light and nutrients among the plants (Ram *et al.*, 2013; Madisa *et al.*, 2015; Shilpa and Bijalwan., 2018). This might have helped the plants to utilize the resources and resulted in increased lateral growth and number of leaves and branches per plant. Similarly, Feleafel and Ghoneim (2005) also reported increased plant density with decreased number of branches and leaves in bhindi.

Under open field condition, LAI was significantly higher for the closer spacing of 60 cm x 30 cm at 60 and 90 DAT under open field condition. In closer spacing, the number of leaves per unit area was high and this might be the reason for higher LAI. Zibelo *et al.* (2016) also reported that the LAI increased as plant population density increased and the higher number of plants per unit area in the narrow spacing compensated for the lower leaf area per plant, resulting in higher LAI. According to Mohammad *et al.* (2012), plant biomass production per unit area of land is directly related to radiation interception. The author also reported higher radiation interception because of higher LAI at higher plant densities resulting in higher biomass and fruit yield in pepper. According to Amanullah *et al.* (2016), LAI is a measure of leafiness per unit ground area and denotes the extent of photosynthetic machinery and so it influences the interception and utilization of solar radiation and consequently growth and yield. Manuel *et al.* (1998) and Cushman *et al.* (2005) reported similar results in bhindi and Streck *et al.* (2014) in cassava.

Under rain shelter, tap root length was found to be significantly higher for wider spacing (60 cm x 60 cm) while under open field condition, a spacing of 60 cm x 45 cm recorded higher tap root length and was on par with 60 cm x 60 cm. Under both growing conditions, root volume was higher for 60 cm x 60 cm. With increasing plant density, light interception per plant decreases, resulting in reduced photosynthesis and biomass accumulation. Similarly, wider spaced plants got more space to develop and therefore, carbon allocated to the roots can be greatly reduced and as a result, the total length of the roots is reduced under high plant density. Similar finding was also reported by Mi *et al.* (2016) in maize who explained that the reduction in total root length was possibly due to the competition for nutrients and water between the roots of the neighbouring plants. Similarly, increased root length with increased spacing was also reported in carrot by Kabir *et al.* (2013).

Among the bio inoculants, PGPR mix 1 reported higher growth characters like plant height, number of leaves and number of branches at all growth stages and tap root length and root volume at harvest under rain shelter and open field condition. As PGPR mix 1 is a consortium of beneficial microorganisms, these microbes colonises plant roots and increase the nutrient availability which resulted in higher plant growth. According to Arora and Dan (2003) these microbes have the ability to mobilize nutritionally important elements from non-usable to usable form through biological processes. Compared to uninoculated plants, increase in shoot and root growth through PGPR application was observed by Habib *et al.* (2015) in bhindi. Similar results of increase in plant growth through the bio fertilizer application were reported by Ez El-Din and Hendawy (2010), and Viji *et al.* (2018).

5.1.2. Effect of Spacing and Bio inoculants on Yield Attributes under Rain shelter and Open Field Condition

Under rain shelter and open field condition, number of flowers and fruits (Fig. 5 and 6) per plant was significantly influenced by spacing. Wider spacing of 60 cm x 60 cm recorded significantly higher number of flowers and fruits under both conditions and was on par with 60 cm x 45 cm for number of fruits under rain shelter condition. There was 28.12 per cent increase in flower number and 23.79 per cent increase in fruit number for 60 cm x 60 cm spacing compared to 60 cm x 30 cm under rain shelter. While under open field condition, 23.11 per cent increase in flower number and 20.06 per cent increase in fruit number was observed for 60 cm x 60 cm spacing compared to 60 cm x 30 cm. Plants with wider spacing had less competition for light and other nutrients which

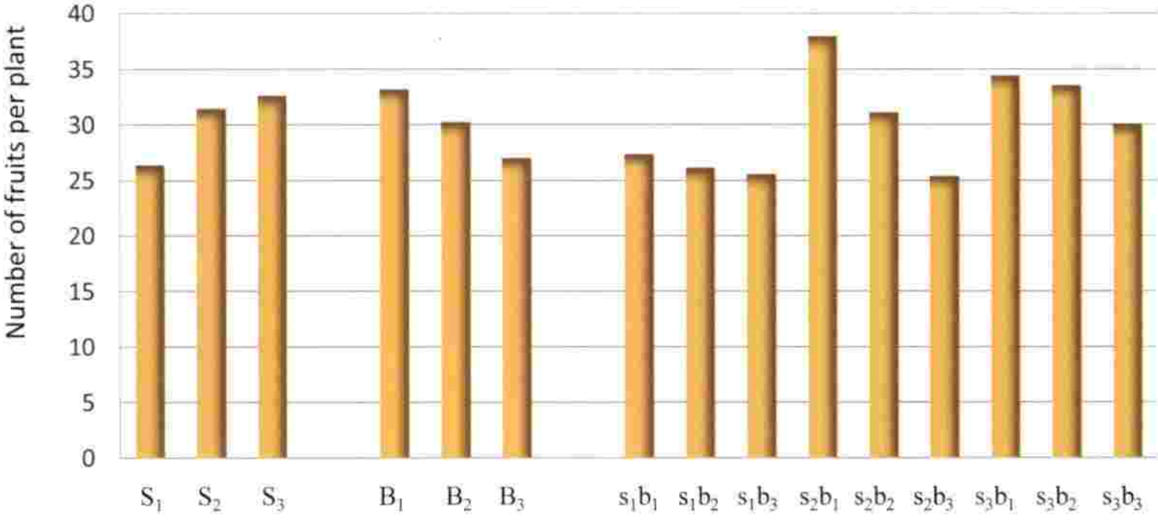

Fig. 5 Effect of spacing and bio inoculants on number of fruits per plant under rain shelter

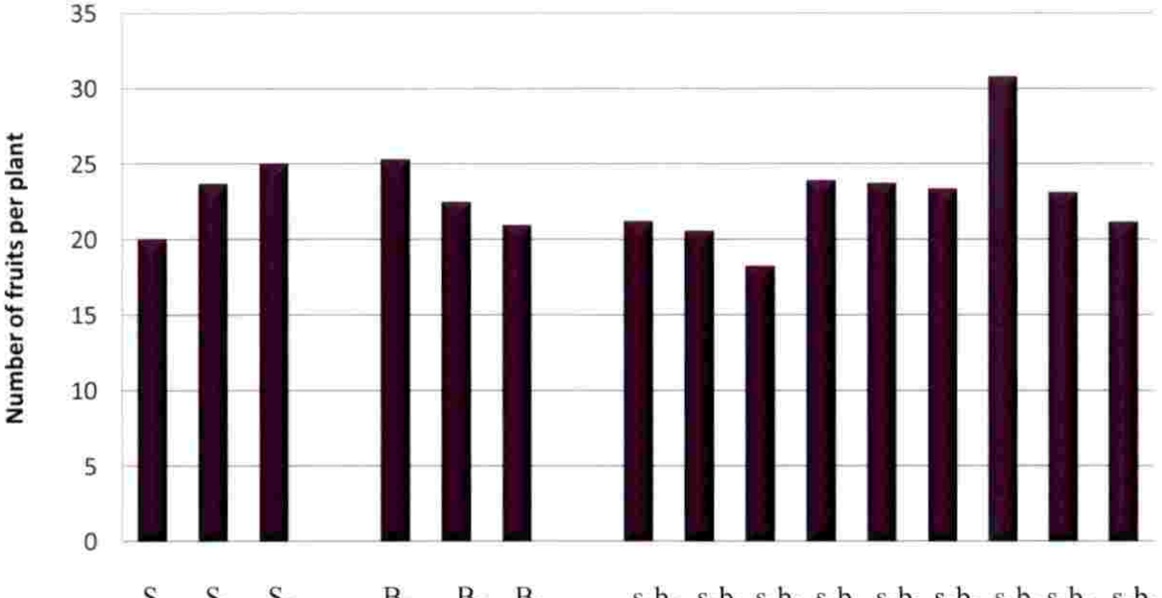

Fig. 6 Effect of spacing and bio inoculants on number of fruits per plant under open field condition

instigated higher lateral growth and more number of branches which resulted in the production of more number of flowers and fruits. Similar results of higher number of flowers and fruits under wider intra row spacing were reported by Ekwu *et al.* (2010) and Jana *et al.* (2010) in bhindi. Fruit setting per cent under open field condition was found significant among spacings and higher value (59.54 %) was found under 60 cm x 45 cm. Widely spaced plants with reduced overlapping from nearby plants resulting in decreased competition for light might have facilitated the utilization of energy for maximum branching and subsequently, the production of a larger leaf area, higher number of fruits per plant and larger fruit size (fruit weight and diameter). This is in line with the findings of Muhammad *et al.* (2001).

Under rain shelter and open field condition, wider spacing of 60 cm x 60 cm recorded higher fruit length and was on par with 60 cm x 45 cm. Increased fruit length for wider spacing might be due to the better utilization of growth factors like space and moisture under lower plant population (Singh, 1996). Similarly higher fruit weight and weight of fruits per plant was also recorded for wider spacing of 60 cm x 60 cm. Wider spacings might have provided better growth and yield attributes which eventually resulted in higher per plant yield. As given by Zibelo *et al.* (2016), the parameters like number of fruits, single fruit weight, and fruit length and diameter were the highest in wider spacing and therefore fruit weight per plant was also the highest for wider spacing. The results of the study was in accordance with Paththinige *et al.* (2008) and Ijoyah *et al.* (2010) who reported decreased fruit length and weight with increased plant density in bhindi. Contrary to this, fruit yield ha^{-1} was found to be higher under narrow spacing of 60 cm x 30 cm both under rain shelter and open field condition. This is due to the higher plant population per unit area. Reduced growth and yield attributes in narrow spacing was compensated by higher plant density. This result is also in line with the results of Talukder *et al.* (2003), Moniruzzaman *et al.* (2007), Agba *et al.* (2011) and Zibelo *et al.* (2016) in bhindi.

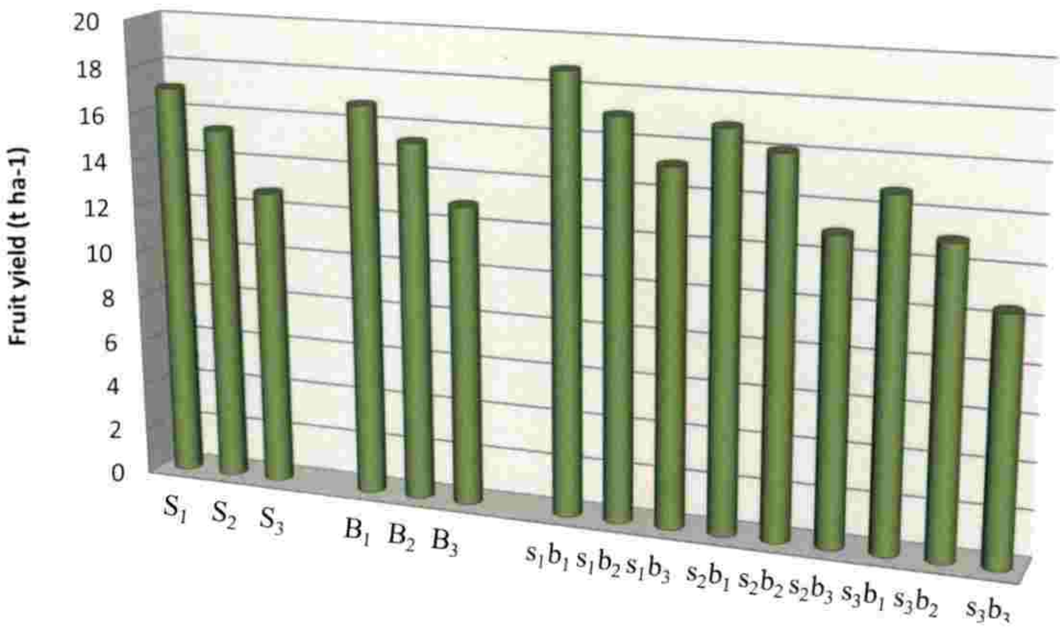

Fig.7 Effect of spacing and bio inoculants on fruit yield ha^{-1} under rain shelter, t ha^{-1}

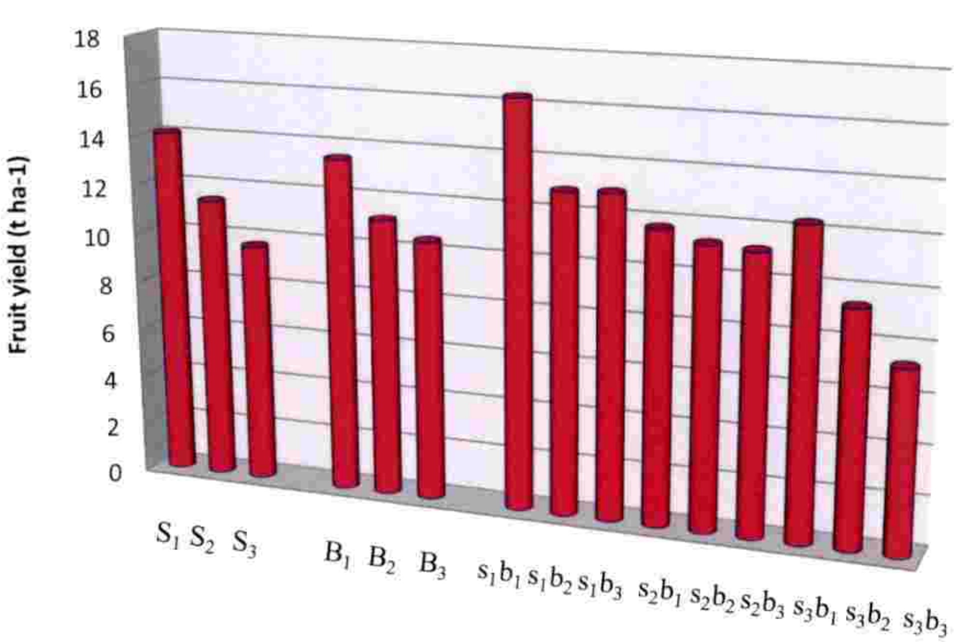

Fig.8 Effect of spacing and bio inoculants on fruit yield ha^{-1} under open field condition, t ha^{-1}

Among the bio inoculants, PGPR mix 1 recorded higher number of flowers per plant, fruit length, single fruit weight, fruit weight per plant and total fruit yield per hectare (Fig.7 and Fig.8) when compared to AMF and no bio inoculant. Beneficial microbes in PGPR mix 1 have the ability to colonize rhizosphere of host plants which helps in enhancing the nutrient uptake and in turn enhanced plant productivity (Glick *et al.*, 2007; Adesemoye *et al.,* 2009). Similar results of augmenting the yield through PGPR application were also documented by Sahin *et al.* (2000) in tomato, Mia *et al.* (2010) in musa and Rafique *et al.* (2018) in bhindi. Weight of fruit was on par with AMF also since the mycorrhizal fungi act as roots as they absorb minerals and nutrients from the rhizosphere soil of the plant and translocate to the aerial parts of the plant which resulted in higher plant growth and yield (Darade, 2015).

5.1.3. Effect of Spacing and Bio inoculants on Physiological Parameters and Water Use Efficiency of Bhindi under Rain shelter and Open Field Condition

Comparing the different spacings, the narrow spacing of 60 cm x 30 cm showed higher CGR between 30 and 60 DAT under both growing conditions and it was on par with 60 cm x 45 cm inside rain shelter. Higher CGR in closer spacing can be due to the higher number of plants per unit area. This also explains that since plants are tall and dense enough to utilize all environmental parameters in closer spacing resulted in maximum CGR (Radford, 1967). This result is in close conformity with the findings of Rajput *et al.* (2017) in rice and Islam *et al.* (2002) in pea. In contrast, RGR was influenced by plant spacing and was higher for the wider spacing of 60 cm x 60 cm under rain shelter and open field conditions and was on par with 60 cm x 45 cm under rain shelter. Proper utilization of space and other resources available for crop growth resulted in increased DMP per plant which in turn caused higher RGR. Higher RGR values with lower plant population density were reported by Islam (2002) in mung bean. Total DMP was observed to be higher under the closer spacing of 60 cm x 30 cm due to higher plant population (Fig. 9 and 10). Zajac *et al.* (2005) found a positive

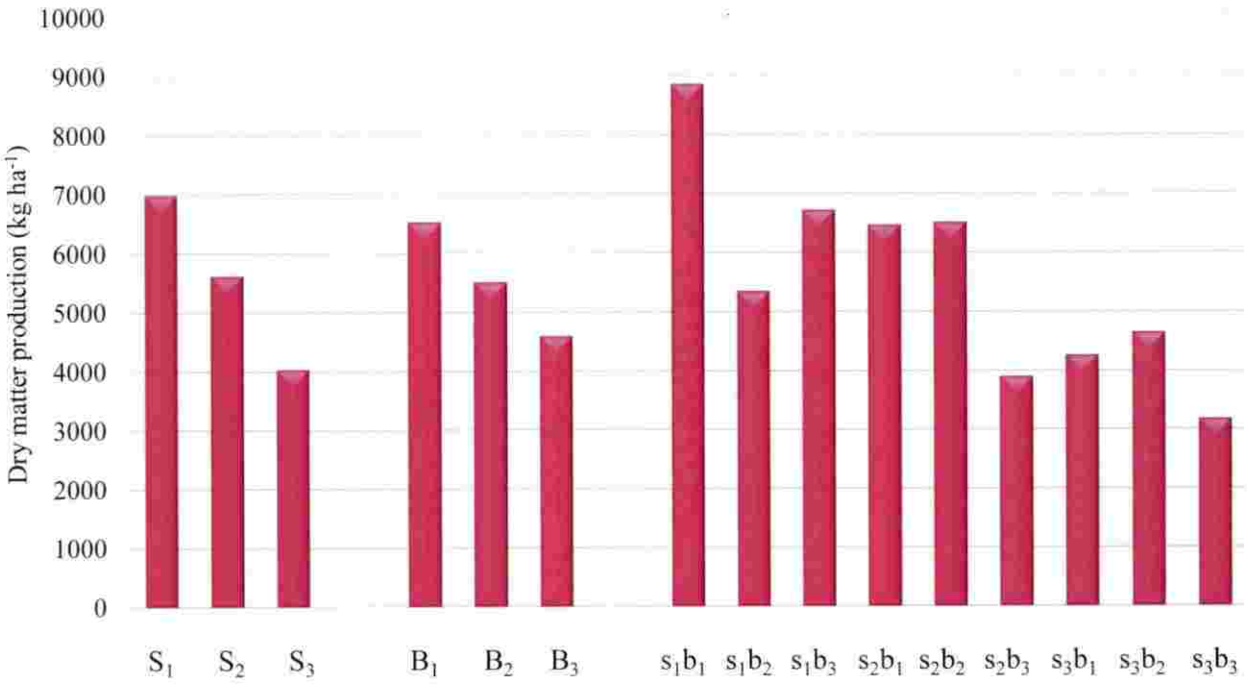

Fig.9 Effect of spacing and bio inoculants on dry matter production at harvest under rain shelter, kg ha^{-1}

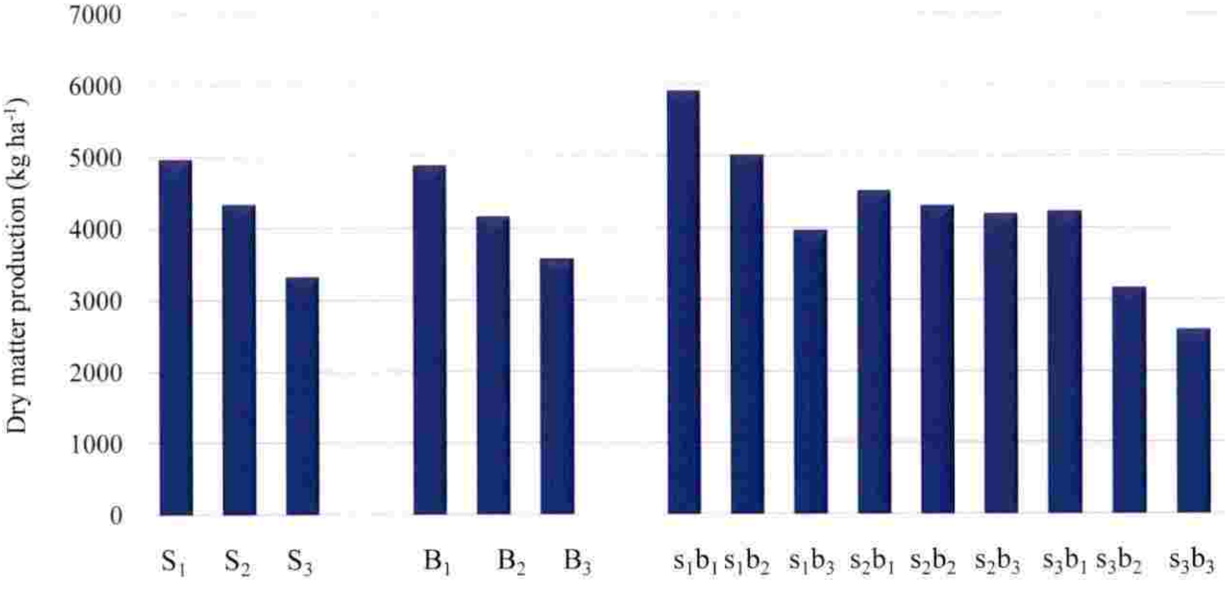

Fig. 10 Effect of spacing and bio inoculants on dry matter production at harvest under open field condition, kg ha^{-1}

relation between dry matter yield and growth indices like CGR. This result was similar to the findings of Agba *et al.* (2011) who stated that the dry matter per plant fraction gets reduced with higher plant population. Also in addition to this, Dutta *et al.* (2015) stated that higher dry matter accumulation was due to the combined effect of higher plant height and LAI in closer spacing.

Under rain shelter and open field conditions, closer spacing of 60 cm x 30 cm resulted in higher WUE due to the higher plant density in narrow spacing which resulted in higher yield. The efficient utilization of applied water can be achieved with closer spacing. According to Wondatir *et al.* (2013), water productivity can be increased by increasing the yield per unit land area. This is in line with the result of Mbarek and Boujelben (2004) who reported higher irrigation WUE with double row planting in tomato in greenhouse. Similarly higher WUE with closer spacing was observed in baby corn (Dutta *et al.*, 2015).

Among the bio inoculants, PGPR mix 1 resulted in higher CGR and RGR under both growing conditions and was on par with AMF under rain shelter. Higher growth rate of PGPR mix 1 treated plants resulted in higher dry matter which in turn resulted in higher CGR and RGR. Zajac *et al.* (2005) found a positive relation between dry matter yield and growth indices like CGR. AMF treatment was comparable with PGPR mix 1 under rain shelter. Similarly, Kumar *et al.* (2015) observed higher CGR in bhindi with AMF application. Total DMP was found to be higher under PGPR mix 1 under both growing condition. The higher growth rate and yield of PGPR mix 1 treated plants resulted in higher DMP. Application of bioferilizers in seeds and soil significantly increased the plant growth parameters and dry matter accumulation in plant parts (Ez El-Din and Hendawy, 2010). WUE was found to be higher in PGPR mix 1 treated plants under both growing conditions. Increased nutrient uptake by plants inoculated with PGPR resulting in better absorption of water and nutrients from the soil (Kloepper *et al.*, 1991) might have helped in producing higher yield and thus higher WUE. Similarly, better WUE could be obtained with PGPR application in combination with 50 per cent of optimum water supply (deficit irrigation) as reported by Le *et al.* (2018) in tomato.

5.1.4. Effect of Spacing and Bio inoculants on Quality of Fruits under Rain shelter and Open Field Conditions

Protein content was found significantly higher under wider spacing (60 cm x 60 cm and 60 cm x 45 cm (1.44 per cent) under rain shelter. Higher nutrient availability for the plants due to wider spacing resulting in higher N uptake and accumulation of photosynthates in sink might have resulted in higher protein content in fruits. In conformation to this, fruit quality of bhindi affected by inter and intra row spacing as noticed by Pathinige *et al.* (2008).

AMF treated plants recorded higher protein content and was on par with PGPR mix 1 treated plants. Better translocation and accumulation of nutrients especially N by bio inoculant treated plants resulted in higher protein content. Shinde and Khanna (2014) observed higher protein levels in mycorrhizal plants compared to non-mycorrhizal plants. This is in line with the findings of Lucy *et al.* (2004) who obtained increased protein content due to the addition of PGPR.

5.1.5. Effect of Spacing and Bio inoculants on Nutrient Uptake and Available Nutrient Status of Soil after Experiment under Rain shelter and Open Field Conditions

Considering the N, P and K uptake by plants under rain shelter and open field condition, closer spacing of 60 cm x 30 cm recorded higher N, P and K uptake. The increased nutrient uptake was attributed to the higher plant density resulting in higher DMP under closer spacing. Analysis of available NPK status of the soil after the experiment revealed that available P and K under rain shelter and available K under open field condition was observed to be higher for wider spacing and might be due to the lower plant population which resulted in lower nutrient uptake and DMP. Bharadwaj *et al.* (2010) also noticed a decrease in available nutrient status under closer spacing due to higher nutrient uptake in bhindi.

Microbial population after the experiment was analysed and found that under rain shelter, significantly higher bacterial population was found for closer spacing of 60 cm x 30 cm and it was on par with 60 cm x 45 cm. Under open field condition, bacteria, fungi and actinomycetes population was reported to be higher for closer spacing of 60 cm x 30 cm. Increased root activity in closer spacing due to higher plant population density might have resulted in higher microbial population in closer spacing. Bulgarelli *et al.* (2013) also reported that rhizospheric niche is a hotspot of ecological richness, with plant roots hosting an enormous array of microbial taxa. In addition to this, narrow plant spacing helped in retaining moisture of soil for longer period, which provided optimal condition for soil microbial communities that helped in nutrient transformation and ultimately improved the nutrient supplying capacity of the soil as advocated by Kumar *et al.* (2013).

Among the bio inoculants, PGPR mix 1 recorded higher N, P and K uptake under rain shelter and N and K uptake under open field conditions. Increased nutrient uptake by plants inoculated with plant-growth promoting bacteria has been attributed to the production of plant growth regulators at the root interface, which stimulated root development and resulted in better absorption of water and nutrients from the soil (Kloepper *et al.*, 1991; Zimmer *et al.*, 1995).

After the experiment, higher available P content was noticed for fields treated with AMF and was on par with PGPR mix 1 under open field condition. Available K status was higher for PGPR mix 1 under both growing conditions and was on par with AMF treatment under rain shelter. Plant growth promoting rhizobacteria promote plant growth directly by their ability to supply nutrients *viz.* N, P, K and essential minerals since PGPR is a consortium of beneficial microbes which solubilises the essential plant nutrients in soil (Gupta *et al.*, 2015). The increase of nutrient P in soil was attributed to increased root colonization by AMF

(Umadevi and Sitaramaiah, 1998). The Vesicular arbuscular mycorrhizal fungi increase the absorption of relatively immobile elements such as P by increasing the absorptive area beyond the root hairs (Darade, 2014).

Microbial count showed significant differences among the treatments. Higher bacterial and actinomycetes population was recorded under PGPR mix 1 treatment and was on par with the AMF treatment. Consortium of beneficial microbes in PGPR mix 1 resulted in higher microbial population in soil. They are environmental friendly renewable sources of nutrients and they activate soil biology and restore soil fertility (Timmusk *et al.* 2017). Higher fungal count was observed under AMF and it was on par with PGPR mix 1 treatment. Plant-root interactions in the rhizosphere may include root– root, root-insect and root-microbe interactions, resulting in the production of more root exudates that ultimately favours maximum microbial population in soil (Bhattacharyya and Jha, 2012).

5.1.6. Effect of Spacing and Bio inoculants on Net Return and B: C ratio under Rain shelter and Open Field Conditions

Under rain shelter and open field condition, net returns and B: C ratio (Fig. 11 and 12) were found higher under 60 cm x 30 cm spacing due to higher yield obtained from closer spacing. An yield increase of 33.15 per cent under rain shelter and 45.05 per cent under open field condition was obtained for 60 cm x 30 cm compared to 60 cm x 60 cm spacing which in turn resulted in higher net return and B: C ratio. Similarly Agba *et al.* (2011) also obtained higher net return and B: C ratio with a plant population of 55,555 plants ha^{-1}. This result is also in accordance with the findings of Paththinige *et al.* (2008) who reported that high planting densities produced shorter fruits with higher consumer preference, which in turn fetch higher market price as compared to the longer fruits from wider densities. He also added that increasing plant density by narrowing the plant spacing, increases the productivity (34.9 %) and profitability (38.6 %) of bhindi.

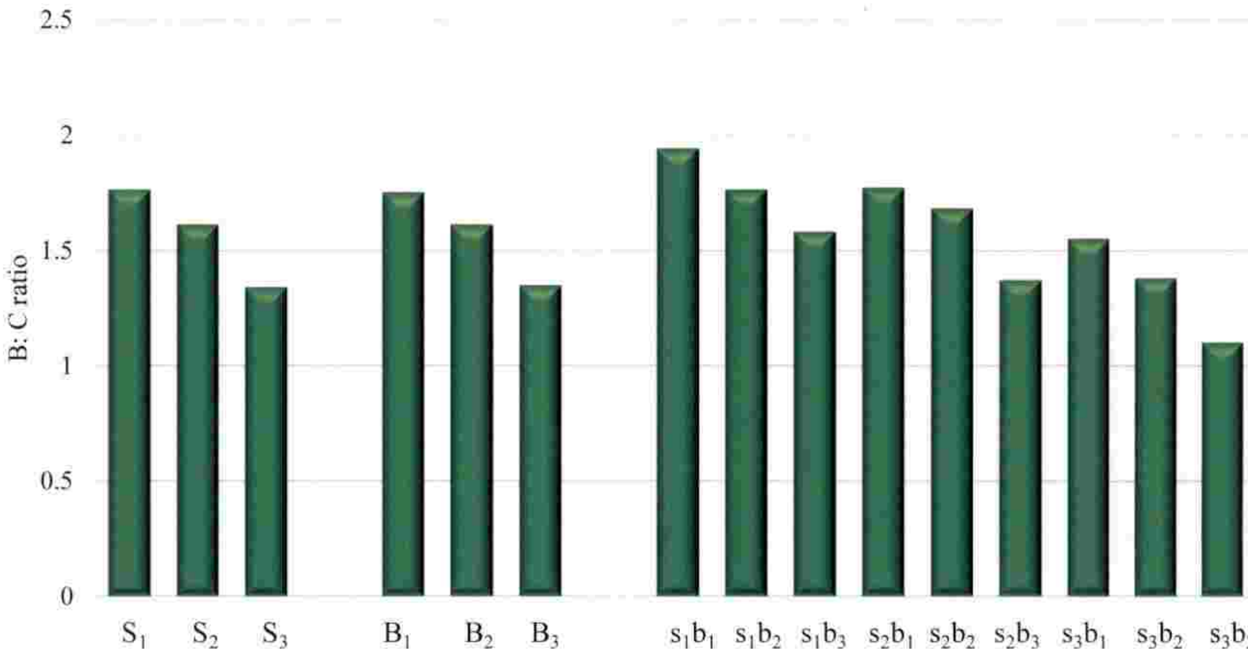

Fig. 11 Effect of spacing and bio inoculants on B: C ratio under rain shelter

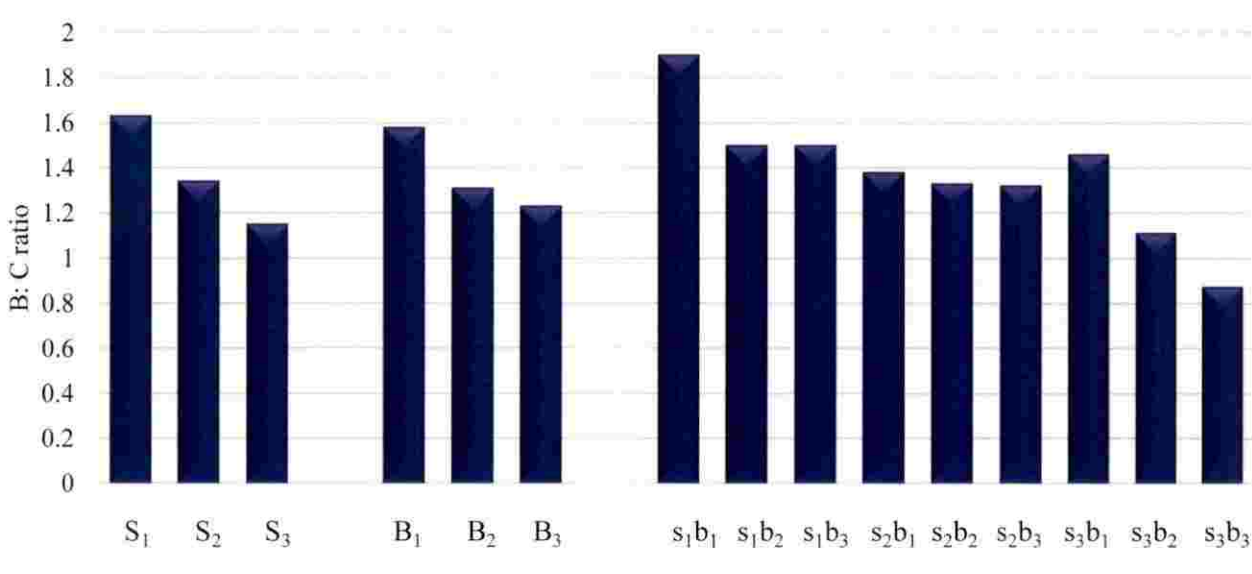

Fig. 12 Effect of spacing and bio inoculants on B: C ratio under open field condition

Among the bio inoculants, net returns and B: C ratio was found superior for PGPR mix 1 due to an yield increase of 30.26 per cent and 28.57 per cent under rain shelter and under open field condition respectively when compared to the treatment without inoculant. High profitability on account of higher yield with PGPR inoculation was reported by Sharma *et al.* (2014). Similarly, results with the use of PGPR seems to be a promising alternative as an amendment for profitable crop production and sustainable recovery of degraded soils (Kausar *et al.*, 2018) in ground nut.

5.2. STANDARDIZATION OF NUTRIENT SCHEDULE FOR BHINDI UNDER RAIN SHELTER AND OPEN FIELD CONDITIONS

Best spacing of 60 cm x 30 cm and best bio inoculant -PGPR mix 1 were selected for the planting of bhindi during the second experiment. Four different fertigation levels and two foliar levels of nutrients were compared in this experiment.

5.2.1. Effect of Fertigation and Foliar Nutrition on Growth Characters under Rain shelter and Open Field Conditions

Under rain shelter, higher plant height was observed for 100 per cent *adhoc* POP recommendation for precision farming (RDF) and it was on par with 125 per cent RDF at 30 and 60 DAT during the first crop and at 30 and 90 DAT during the second crop (Fig. 13 and Fig 14). Under open field condition, 125 per cent RDF recorded higher values for plant height during first crop and was on par with 100 per cent RDF at all the growth stages (Fig. 15 and Fig 16). During the second crop, 125 per cent RDF recorded higher plant height and was on par with 100 per cent RDF at 90 DAT.

The improvement in plant height with increasing fertigation levels might be due to the increased cell division and cell elongation with higher content and uptake of N during the growth period. This is in line with the findings of Singhal *et al.* (2016). The increased plant height of bhindi can also be explained to be a result of uniform availability of major nutrients through fertigation. Also,

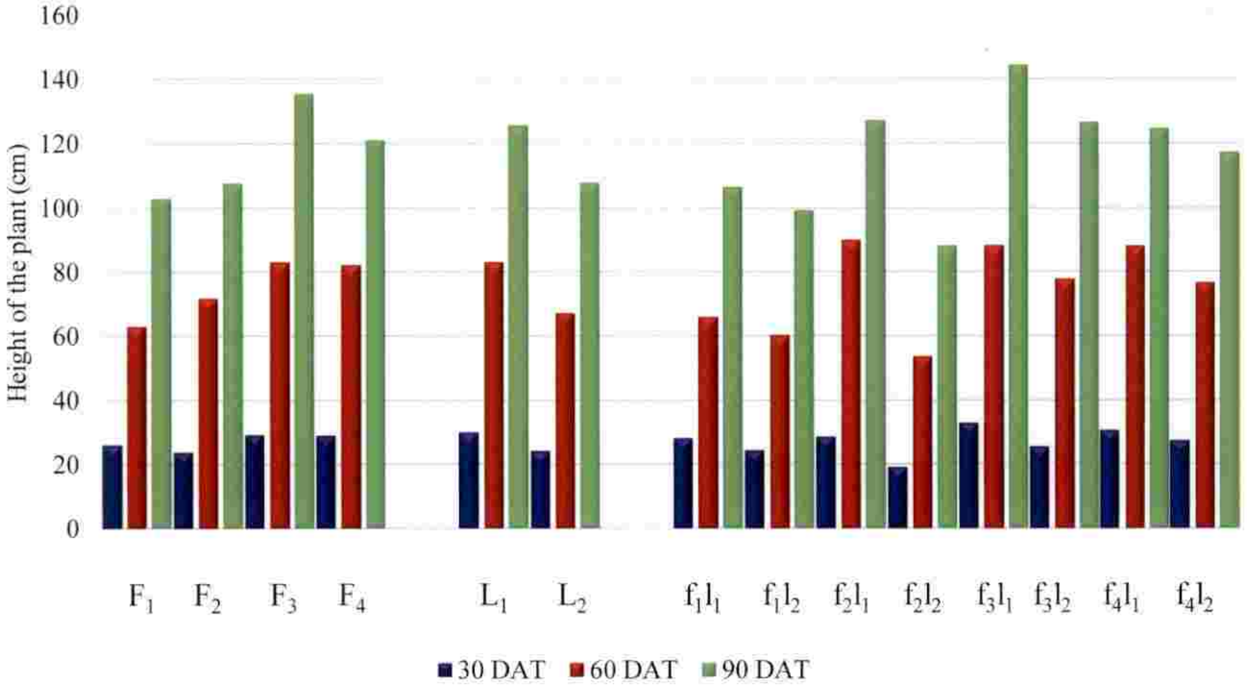

Fig. 13 Effect of fertigation and foliar levels of nutrients on height of the plant during Sept-Dec, 2017 under rain shelter, cm

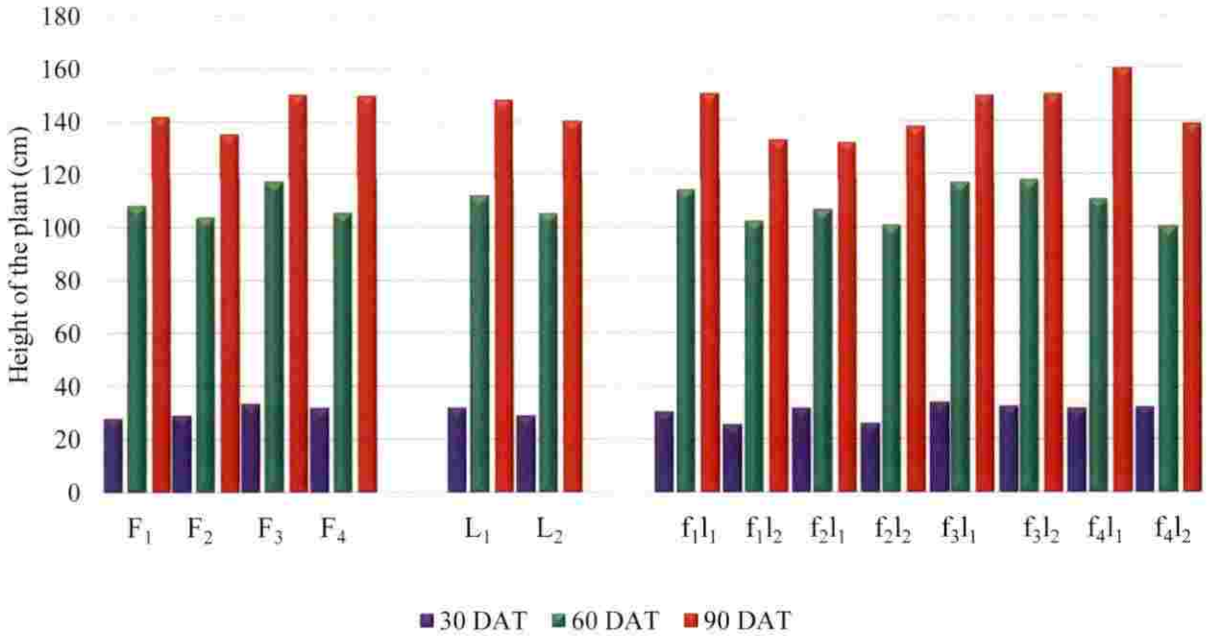

Fig. 14 Effect of fertigation and foliar levels of nutrients on height of the plant during May-Aug, 2018 under rain shelter, cm

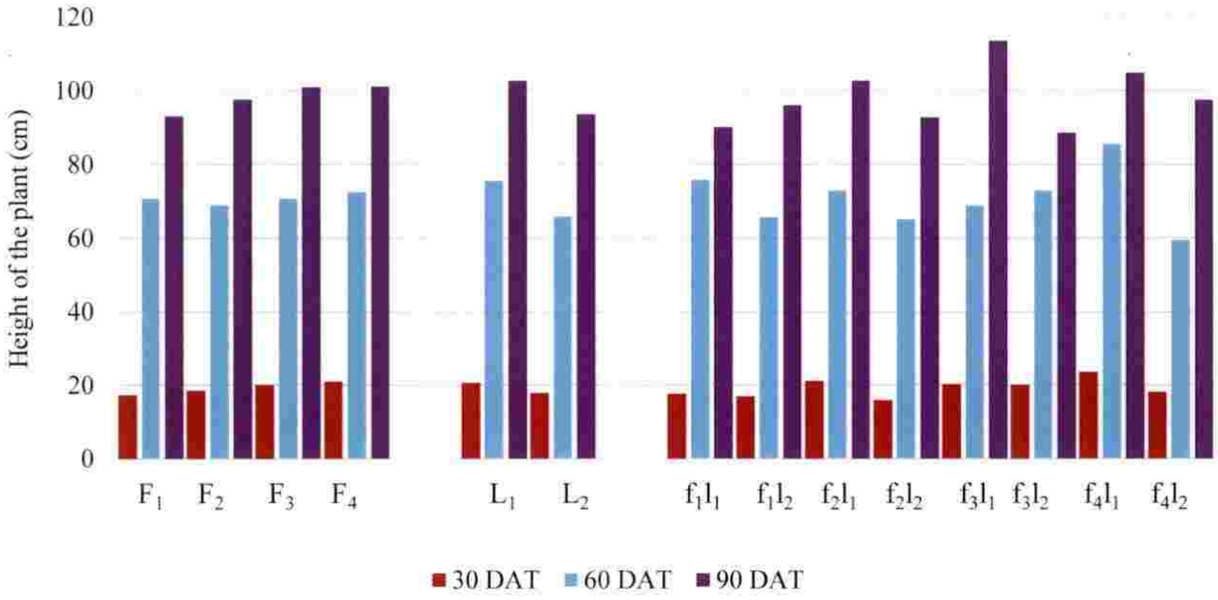

Fig. 15 Effect of fertigation and foliar levels of nutrients on height of the plant during Sept- Dec, 2017 under open field condition, cm

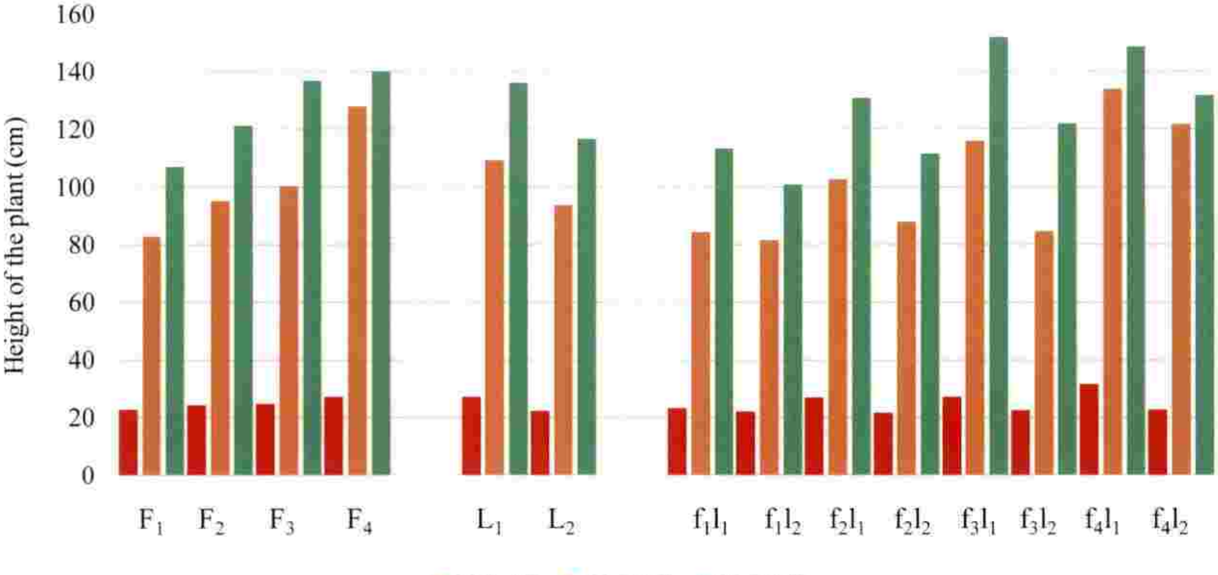

Fig. 16 Effect of fertigation and foliar levels of nutrients on height of the plant during May-Aug, 2018 under open field condition, cm

increased plant height with increase in N availability was observed by Jana *et al.* (2010) and Shanke *et al.* (2003) in bhindi. A similar result of increased height with increased fertigation level was also observed in capsicum (Sanchita *et al.*, 2010). In cucumber also, the highest plant height was obtained for 120 per cent RDF, which was on par with 100 per cent RDF (Pushpendra and Hardaha, 2016).

Under rain shelter, number of leaves was higher for 100 per cent RDF during the first and second crops and was on par with 125 per cent RDF during the second crops at all growth stages. Under open field condition 125 per cent RDF resulted in more number of leaves during both crops. Under rain shelter, number of branches per plant was higher for 100 per cent RDF at 60 DAT during the first crop and at all growth stages during the second crop. This was on par with 125 per cent RDF at 60 and 90 DAT during second crop. Under open field condition, number of branches per plant was higher for 125 per cent RDF at 30 DAT during first crop and at all growth stages for second crop. This was on par with 100 per cent RDF at 30 DAT during both crops. Higher growth obtained in higher fertigation level might be due to increased supply of N, P and K through fertigation to the plant root zone. This fulfils the nutrition demand of the crop which supported maximum absorption of moisture and nutrients by crop that accelerated the plants metabolic activities and reflected in higher cell growth. As per the findings of Ughade *et al.* (2016) the increased level of fertigation lead to increased photosynthetic activities, protein synthesis and assimilate translocation owing to the suitable environmental conditions in protected structure. The higher plant height and leaves by fertigation with 100 per cent RDF was also reported by Nair *et al.* (2017) and Venkadeswaran *et al.* (2014).

Under rain shelter, LAI was found to be higher for 100 per cent RDF at 30 and 60 DAT and was on par with 75 per cent RDF for the first crop. For the second crop, 100 per cent RDF showed higher LAI at 30 and 90 DAT and was on par with 125 per cent RDF. Under open field condition, 125 per cent RDF recorded higher LAI for the first crop at all growth stages and at 30 DAT for the second crop and this was on par with 100 per cent RDF. Higher LAI obtained with higher fertigation level might be due to the supplementation of adequate amount of nutrients through higher dose of fertigation which led to better crop growth, increased plant height and more number of leaves and better leaf development (Sampathkumar and Pandian, 2010). Higher LAI obtained with higher fertigation level of 100 per cent RDF was also reported by Shruti and Aladakatti (2017) in cotton.

Under rain shelter, higher tap root length and root volume was obtained for 100 per cent RDF during the first and second crops. Under open field condition, tap root length was found to be higher for 100 per cent RDF and was on par with 125 per cent RDF during both first and second crops. Root volume was observed to be higher under 125 per cent RDF and was on par with 100 per cent RDF for both first and second crops.

The higher root proliferation was owing to the availability of higher amounts of nutrients for the plants applied with higher quantities of nutrients. This is in conformity with the findings of Raj *et al.* (2013). Similarly, positive response of root characters to higher fertilizer dose producing higher root biomass under favourable moisture and nutrient status was observed by Parthasarathi (1999) in radish.

Among the foliar levels, poly feed at 0.5 per cent at fortnightly intervals resulted in higher plant height over the application of nano NPK at 0.3 per cent at both growing conditions during the first and second crops. Since the poly feed fertilizer contains higher amount of all the primary nutrients (19 per cent N, P and K) compared to the nano NPK (4 % N, P and K) foliar feed, it might have resulted in more nutrient availability and enhanced plant growth. The increased plant height is also due to increased uptake of primary nutrients, and fast movements of photosynthates within the plant system due to foliar application of water soluble fertiliers (Devi and Shanthi, 2013). Similar results were also obtained by

Sundaram and Kanthaswamy (2005), and Venkataraman (2007) in bhindi and Gutte *et al.* (2018) in soybean.

Under rain shelter and open field conditions, number of leaves and LAI for the first crop and second crops were found to be superior for poly feed at 0.5 per cent spray. Higher LAI might be due to the higher uptake and translocation of nutrients that resulted in higher vegetative growth of the plants and thus more number of leaves. This led to higher leaf area and so LAI was higher for the poly feed treated plants. The result is in confirmation with the findings of Sharifi *et al.* (2018) and Manjunatha (2004) in bhindi. Tap root length and root volume were also higher under poly feed at 0.5 per cent spray under both growing conditions for the first and second crops. Higher root growth by the application of poly feed can also be attributed to the higher nutrient content in poly feed and their availability resulted in over all growth of the plant. Foliar nutrients usually penetrate the cuticle of the leaf or stomata, enter the cells rapidly and fulfil the nutrient demand of the growing plant and thus ameliorate nutrient deficiencies and improve the growth of the plant (Devi and Shanthi, 2013).

5.2.2. Effect of Fertigation and Foliar Nutrition on Yield Attributes under Rain shelter and Open Field Conditions

More days for fifty per cent flowering were observed for the lower dose (50 % RDF) of fertigation under rain shelter condition during the first crop. This can be attributed to the prolonged vegetative stage of plants supplied with lower dose of fertigation. This is in line with the result of Pawar *et al.* (2018) in cucumber who reported that lower rate of fertilizers delayed days to fifty per cent flowering.

Number of flowers and fruits per plant was higher for 100 per cent RDF and was on par with 125 per cent RDF under rain shelter (Fig. 17 and 18). Under open field condition, number of flowers per plant was higher for 100 per cent RDF and 75 per cent RDF during the first and second crop respectively and was on par with 100 and 125 per cent RDF. Number of fruits per plant was significant for 125 per cent RDF under both crops and was on par with 100 per cent RDF for

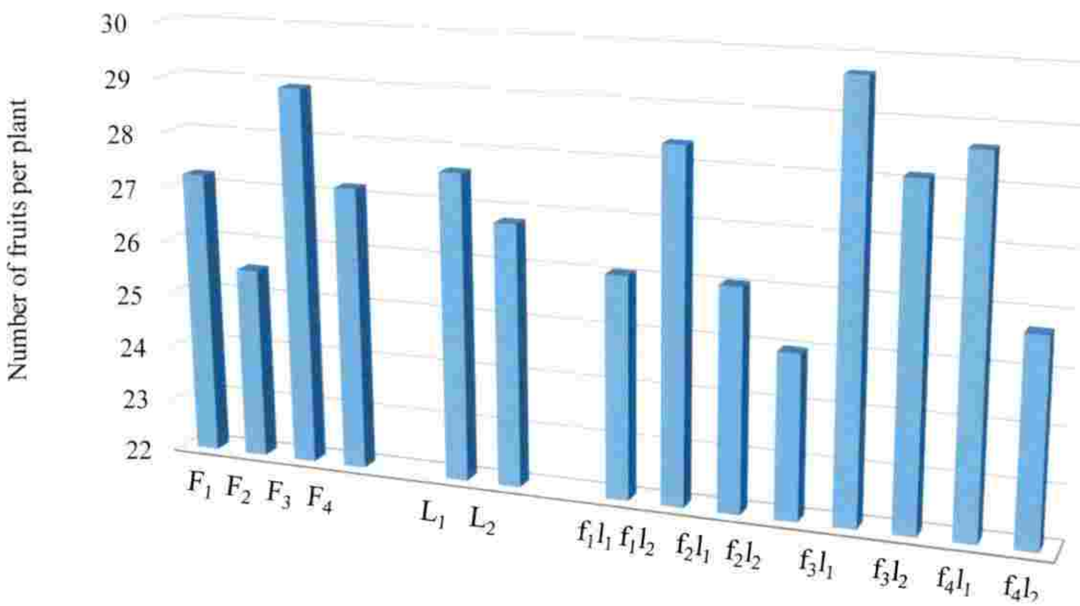

Fig. 17 Effect of fertigation and foliar levels of nutrients on number of fruits per plant during Sept-Dec, 2017 under rain shelter

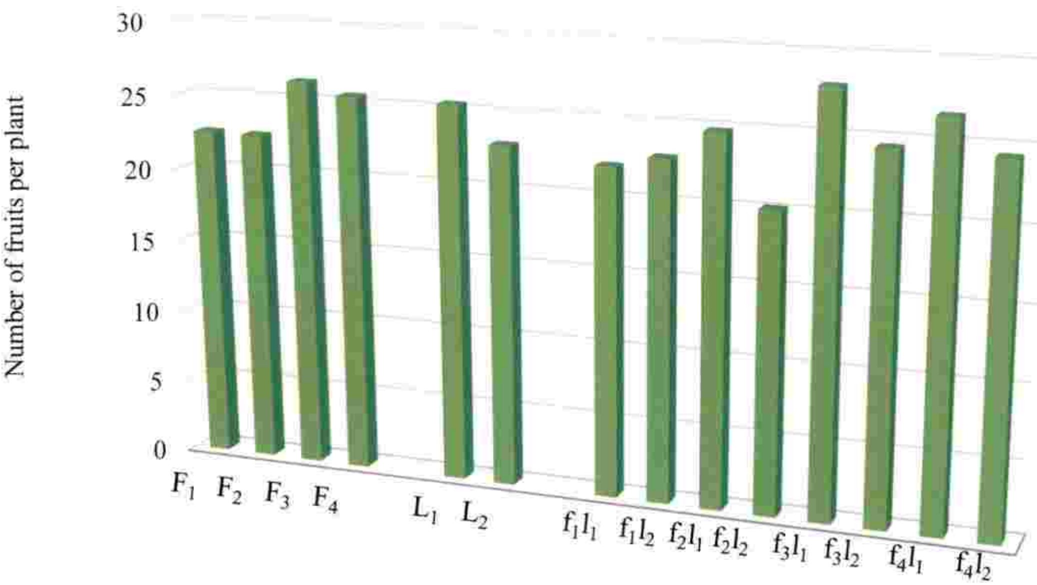

Fig. 18 Effect of fertigation and foliar levels of nutrients on number of fruits per plant during May-Aug, 2018 under rain shelter

the first crop (Fig. 19 and 20). Adequate supply of nutrients and their efficient utilization along with good growing condition resulted in higher number of branches and other growth characters produced more flowers and fruits under higher fertigation level. These results are in accordance with the findings of Kavitha (2007) in tomato.

Under rain shelter, length of fruit was higher for 100 per cent RDF and was on par with 75 per cent RDF during the first and second crops. Weight of fruit was higher under 125 per cent RDF and was on par with 100 per cent RDF during both the crops. Under open field condition, 125 per cent RDF resulted in higher percentage fruit set and length of fruit. Weight of fruit was higher for 125 per cent RDF and was on par with 100 per cent RDF for the first and second crop.

Better fruit characters with higher fertigation dose might be due to optimum availability of water and nutrients without loss of fertilisers and increased photosynthesis. This might also be due to higher nutrient uptake by plant with fertigation at 100 per cent RDF (Pawar *et al.*, 2018).

Under rain shelter, weight of fruit per plant was higher under 100 per cent RDF and it was on par with 125 per cent RDF for both the crops. Under open field condition, 125 per cent RDF resulted in higher weight of fruit per plant and it was on par with 100 per cent RDF during first crop. Maximum weight of fruit, diameter and length of fruit might be due to the enhanced supply of nutrients through increased fertigation level in the vicinity of plant roots which maintained optimum nutrient concentration in the root zone throughout the crop growth period. This helped in increased uptake of moisture and nutrients which resulted in increase in growth attributes and consequent increase in photosynthesis led to more translocation of photosynthates towards reproductive organs (sink) which ultimately increased the yield attributes (Kaur *et al.*, 2019). The present findings are in accordance with Janapriya *et al.* (2010) who found that significantly higher fruit yield under increased fertigation level. Mahendran *et al.* (2011) also observed higher number of fruits per plant, fruit length, fruit girth and fruit weight

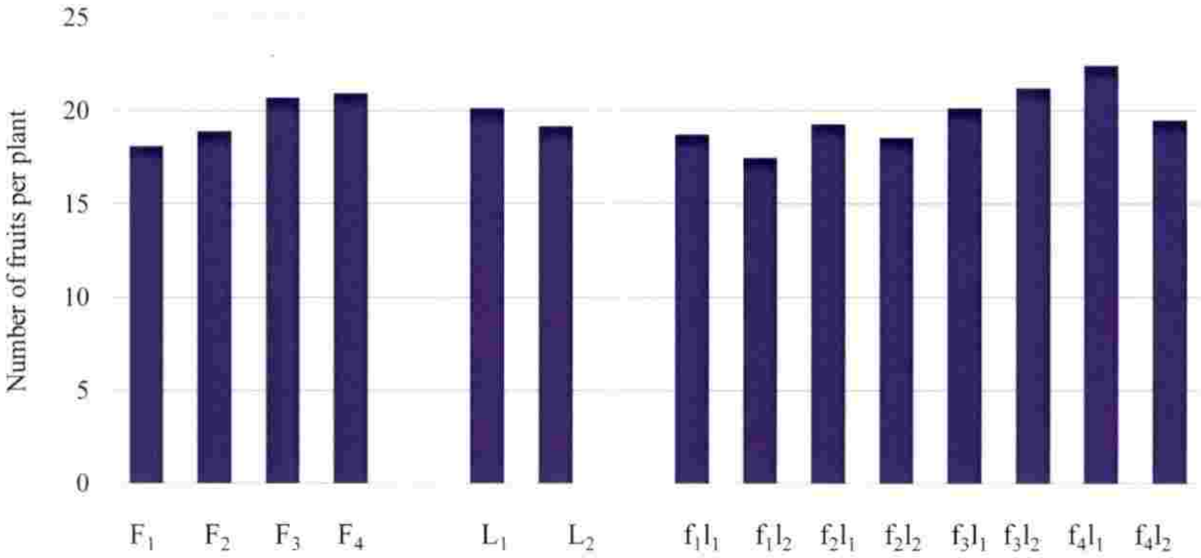

Fig. 19 Effect of fertigation and foliar levels of nutrients on number of fruits per plant during Sept-Dec, 2017 under open field condition

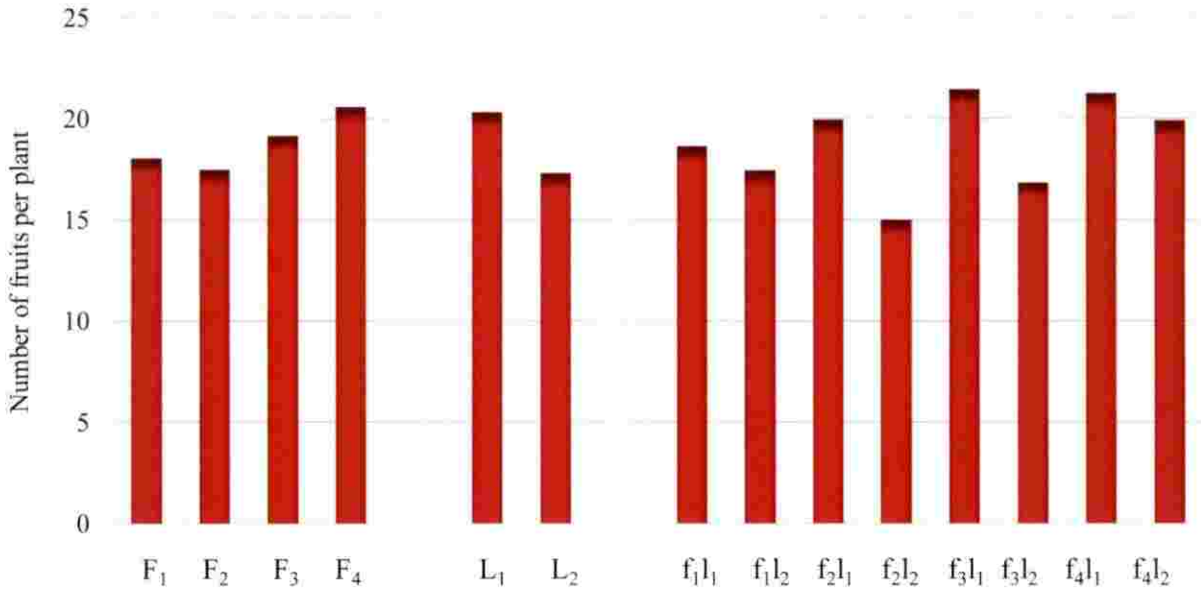

Fig. 20 Effect of fertigation and foliar levels of nutrients on number of fruits per plant during May-Aug, 2018 under open field condition

with the application of 100 per cent NPK fertigation through water soluble fertilizers in bhindi.

Under rain shelter, fruit yield per hectare was higher under 100 per cent RDF and was on par with 125 per cent RDF for the first and second crops (Fig. 21 and Fig. 22). Under open field condition higher fruit yield was recorded for 125 per cent RDF and it was on par with 100 per cent RDF for the first crop (Fig. 23 and 24).

These higher yields were due to better growth and yield parameters like days to flowering, plant height, number of fruits per plant and fruit length. Goswami *et al.* (2015) also reported significant positive correlation of bhindi fruit yield with above mentioned parameters. The increase in numbers of fruits and yield per plant might be due to the supply of more nutrients at critical stages (i.e. flowering and fruit setting) and an abundance of nitrogenous fertilizers for photosynthesis activity which ultimately enhanced the utilization of photosynthates and increased allocation of photosynthates towards the economic part (Singhal *et al.*, 2016). The results of the study confirm that application of 100 per cent of the RDF resulted in the highest yield in bhindi (Varughese *et al.* 2014). The results indicated that the highest irrigation and fertigation levels (100 % Ep and 125% NPK dose) along with plastic mulching produced maximum values of fruit length, fruit girth, fruit weight, number of fruits per plant, number of harvests and the marketable yield in bitter gourd (Abraham *et al.*, 2017).

The number of flowers and fruits per plant under both growing conditions were higher for poly feed at 0.5 per cent spray for both the crops. More uptake and translocation of nutrient resulted in higher availability of nutrients which helped in more retention of flowers which in turn produced more fruits. Length and weight of fruit, weight of fruit per plant and fruit yield ha^{-1} was also superior for poly feed at 0.5 per cent spray than nano NPK under both growing conditions.

Spraying of water soluble fertilizers increase uptake of nutrients and water, resulting in more photosynthesis and enhanced food accumulation in edible parts.

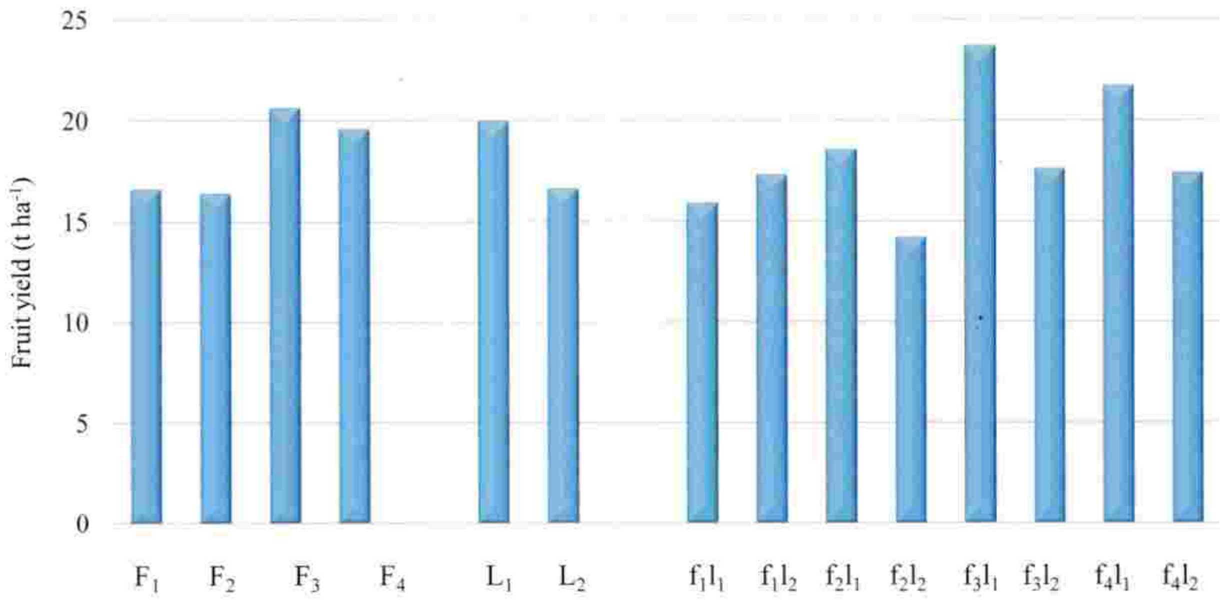

Fig. 21 Effect of fertigation and foliar levels of nutrients on fruit yield ha^{-1} during Sept-Dec, 2017 under rain shelter, t ha^{-1}

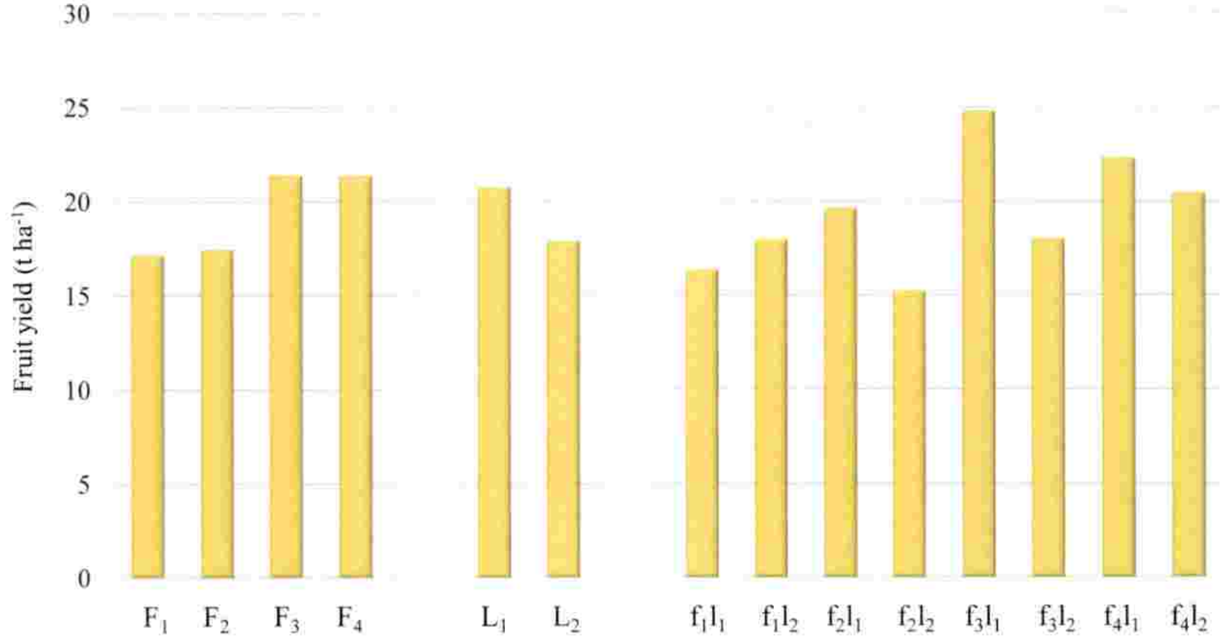

Fig. 22 Effect of fertigation and foliar levels of nutrients on fruit yield ha^{-1} during May-Aug, 2018 under rain shelter, t ha^{-1}

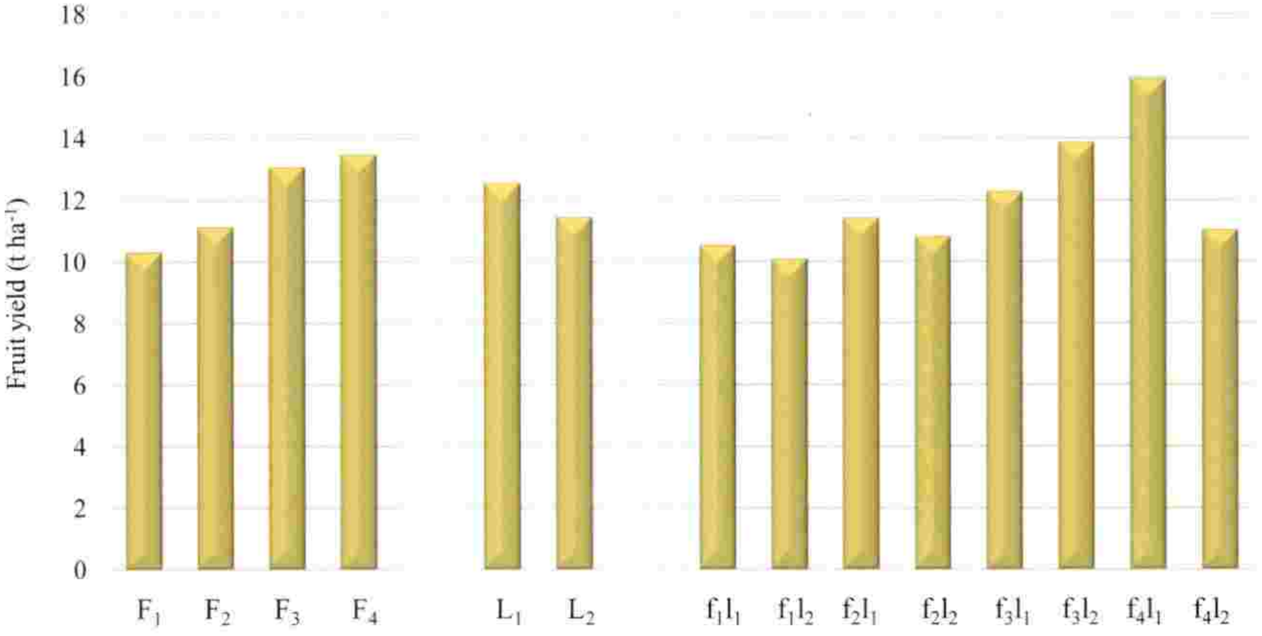

Fig. 23 Effect of fertigation and foliar levels of nutrients on fruit yield ha^{-1} during Sept-Dec, 2017 under open field condition, t ha^{-1}

-

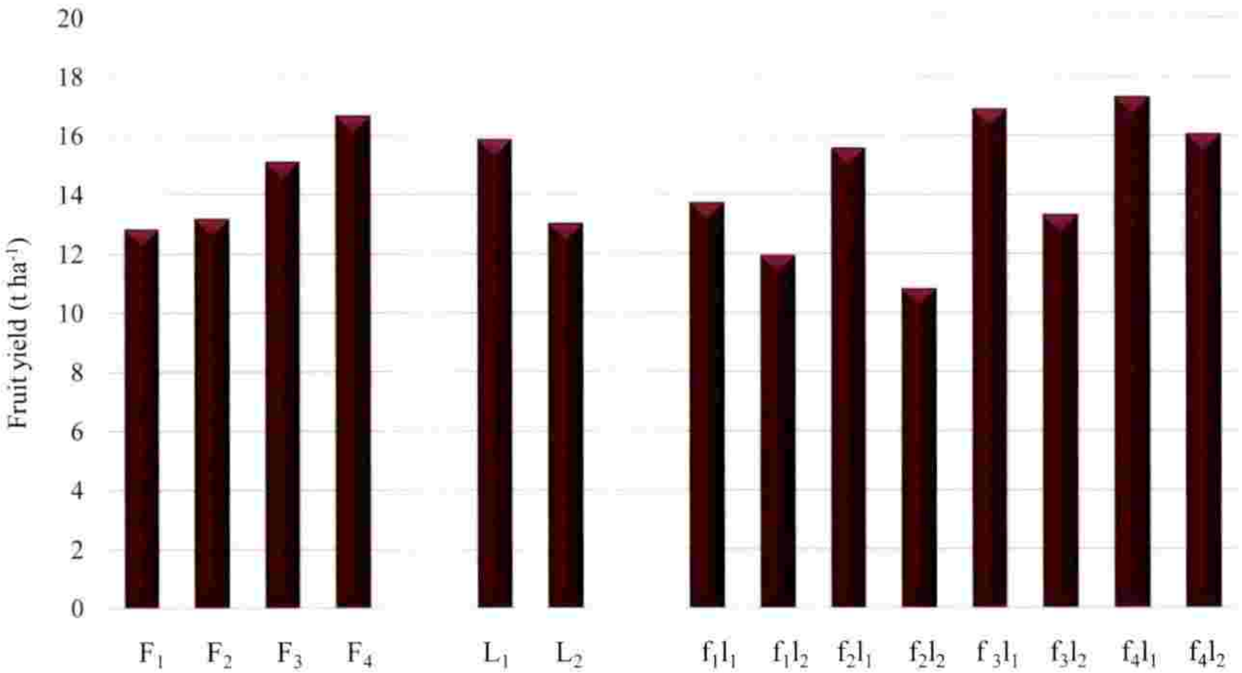

Fig. 24 Effect of fertigation and foliar levels of nutrients on fruit yield ha^{-1} during May-Aug, 2018 under open field condition, t ha^{-1}

The probable reason for increased yield might be due to easy assimilation of nutrients and balance in NPK ratio which affects crop productivity (Batra *et al.*, 2002). Similar results of increased fruit weight and yield per plant was observed by Sundaram and Kanthaswamy (2005). This is in confirmation with the findings of Singhal *et al.* (2016), who observed that foliar feeding through water soluble fertilizers (19:19:19 at 0.5 per cent) in bhindi favourably influenced the plant growth and yield attributes. Gutte *et al.*, (2018) also observed an increase in yield attributes per plant due to application of poly feed foliar fertilizer which increased the number of flowers, seeds and pods per plant in soybean.

5.2.3. Effect of Fertigation and Foliar Nutrition on Physiological Parameters and Water Use Efficiency of Bhindi under Rain shelter and Open Field Conditions

Under rain shelter, higher CGR, RGR and NAR between 30 and 60 DAT was observed for the higher fertigation level of 125 per cent RDF for both crops. This was on par with 100 per cent RDF for CGR and RGR during both the crops. Under open field condition, CGR, was higher for 100 per cent RDF and was on par with 125per cent RDF for both crops. RGR and NAR were found to be higher under 125 per cent RDF and was on par with 100 per cent RDF for the second crop. Higher fertigation doses improved the photosynthate accumulation in sink and also improved the growth which in turn increased the dry matter production resulting in higher CGR, RGR and NAR. Increase in CGR and NAR with increased levels of fertigation with 125 per cent RDF was also noticed by Mohan *et al.* (2000) in Maize. Similar findings were also obtained by Manikandan *et al.* (2015) in pigeonpea and Veeraputhiran (2000) in cotton. Under rain shelter, chlorophyll content was higher for the higher dose of fertigation (125 % RDF) for the first crop and for 100 per cent RDF for the second crop. Under open field condition 125per cent RDF resulted in higher chlorophyll content for the first crop.

Higher dose of fertigation resulted in higher N availability which resulted in improved chlorophyll content in leaves since N is the main component for chlorophyll synthesis. This result is in line with the findings of Meenakshi and Vadivel (2005) in bitter gourd who observed higher chlorophyll content with a fertigation level of 100 per cent RDF. Dry matter production was found to be higher under 100 per cent RDF inside rain shelter for both crops (Fig. 25 and Fig. 26). Under open field condition, 125 per cent RDF recorded higher DMP and was on par with 100 per cent RDF for both crops (Fig. 27 and Fig. 28).

Increase in dry matter is attributable to the favourable water balance and improved nutrient availability in the root zone of the crop under higher level of fertigation. Maximum DMP under higher level of fertigation can be attributed to the production of more number of leaves and effective accumulation of nutrients in plant parts due to more uptake and accumulation of nutrients. Fertigation with 100 per cent RDF recorded higher DMP as a result of higher leaf area and LAI as noticed by Shedeed *et al*. (2009) for tomato.

Water use efficiency was higher for 100 per cent RDF for both the crops and this was on par with 125 per cent RDF for the second crop under rain shelter. Under open field condition 125 per cent RDF was found to be higher for both crops and these were on par with 100 per cent RDF during the first crop.

Higher level of fertigation improved the WUE as yield is improved by the higher doses of fertilizers and its application through emitters to the root zone decreased the nutrient losses. Higher fertigation dose of 125 per cent RDF with drip irrigation resulted in higher WUE was also reported by Pawar *et al*. (2018) in cucumber. Muralidhar (1999) also noticed higher WUE (2.34 kg m^{-3}) with an application of 100 per cent recommended dose of water soluble fertilizers through drip irrigation in capsicum.

Foliar application of poly feed at 0.5 per cent spray resulted in higher CGR, RGR and NAR under both growing conditions for both crops. The increase in dry matter per unit area and unit leaf area was higher for poly feed than nano NPK

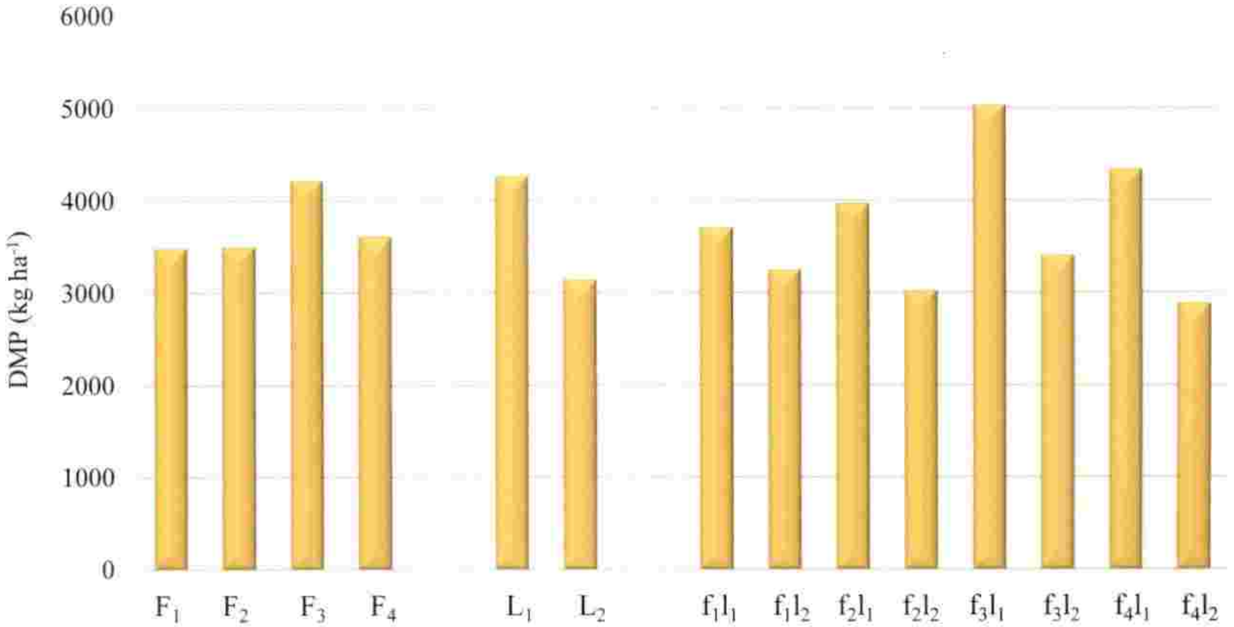

Fig. 25 Effect of fertigation and foliar levels of nutrients on dry matter production at harvest during Sept-Dec, 2017 under rain shelter, kg ha^{-1}

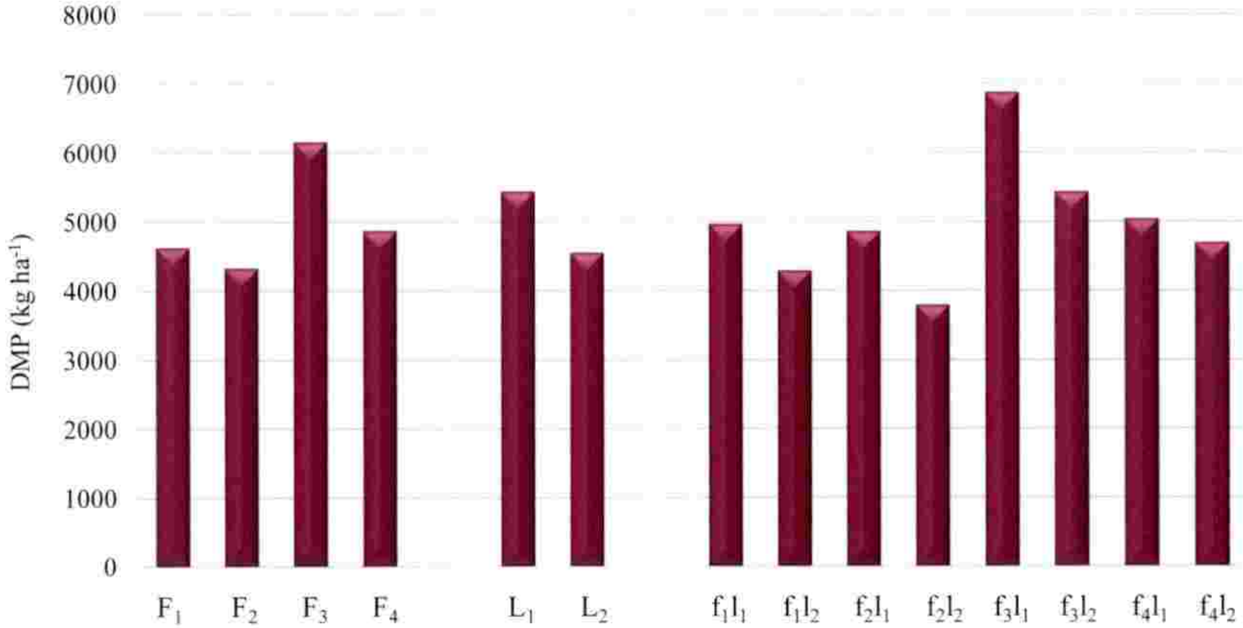

Fig. 26 Effect of fertigation and foliar levels of nutrients on dry matter production at harvest during May-Aug, 2018 under rain shelter, kg ha^{-1}

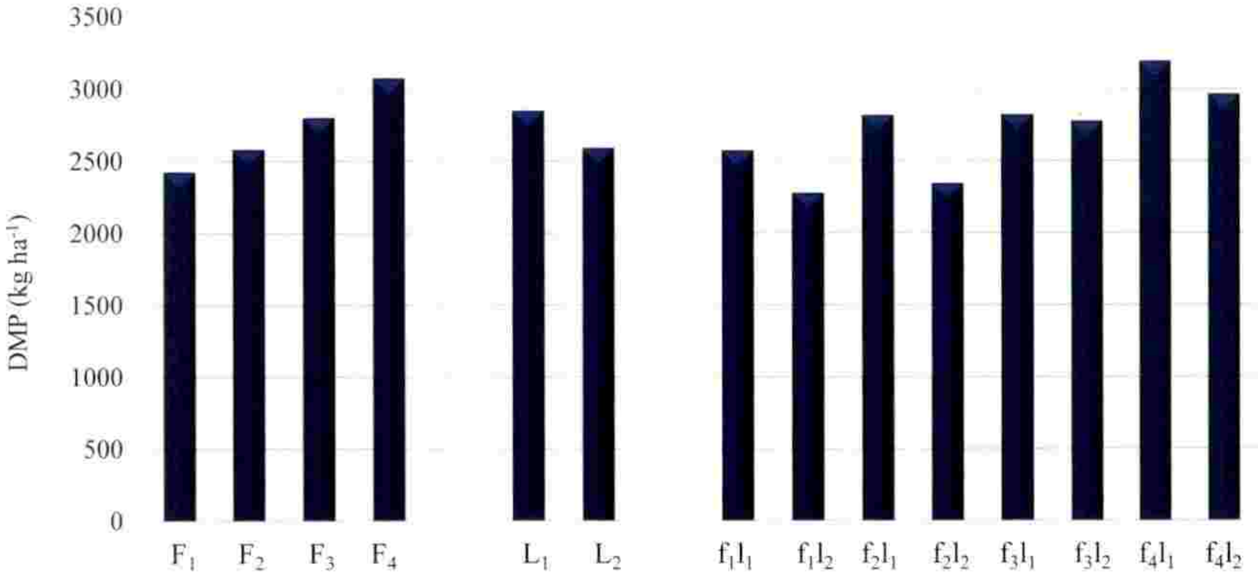

Fig. 27 Effect of fertigation and foliar levels of nutrients on dry matter production at harvest during Sept-Dec, 2017 under open field condition, kg ha^{-1}

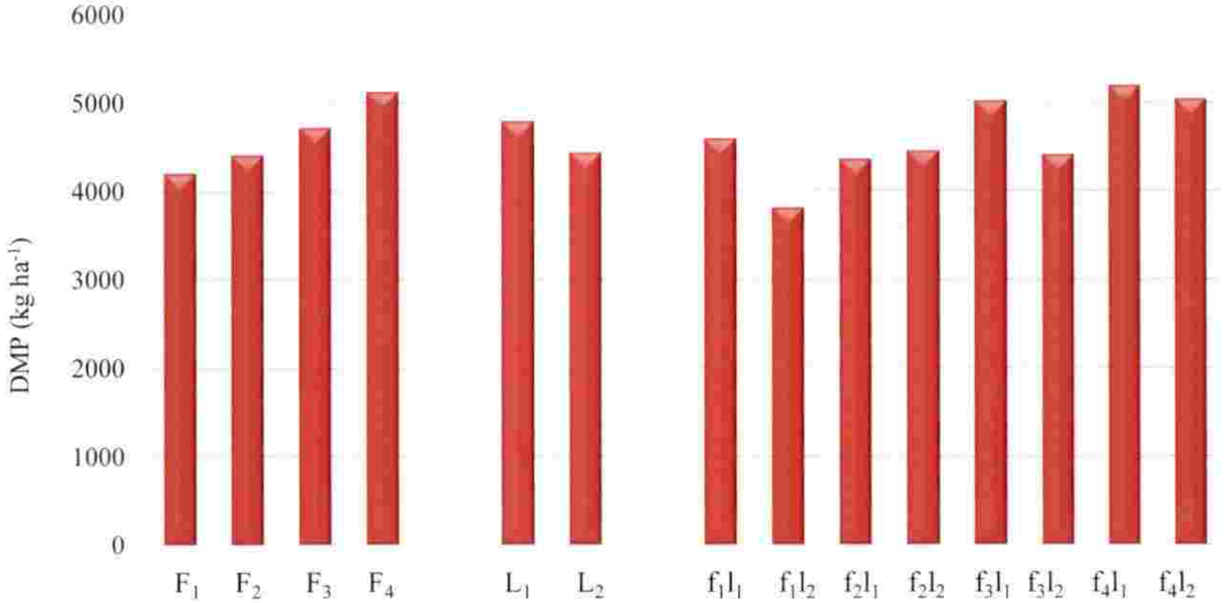

Fig. 28 Effect of fertigation and foliar levels of nutrients on dry matter production at harvest during May-Aug, 2018 under open field condition, kg ha^{-1}

which resulted in higher CGR and NAR. Increased leaf area increased the photosynthesis and more photosynthates resulting in higher NAR. Foliar application of poly feed resulted in increased plant height, number of functional leaves and LAI which are the vital parts of the plant where the photosynthesis takes place and thereby build up more photosynthates, which reflected ultimately on dry matter accumulation (Gutte *et al.*, 2018).

Chlorophyll content at 45 DAT was found to be higher for nano NPK at 0.3 per cent treated plants for both growing conditions. The reason behind this might be the nano size of the nutrient particles, which might have allowed easy absorption of nutrients by the leaves. Also small size of the nutrients allows them to get into the pores of roots and leaves, improve the reactivity and solubility. As N is a major component of chlorophyll formation, easy availability of N on the site of photosynthesis might have resulted in efficient utilization and in turn resulted in higher chlorophyll content in leaves (Barooah and Ahmed, 1983) Similar results of higher chlorophyll content with the application of nano foliar fertilizers has been reported by Mir *et al.* (2015) in forage sorghum; Nadi *et al.* (2013) in faba bean and Ghafari and Razmjoo (2013) in wheat.

Dry matter production was found to be higher under poly feed at 0.5 per cent spray under both conditions. Higher DMP with the application of poly feed might be due to the presence of high nutrient content (19 % NPK) in the fertilizer compared to nano NPK (4 % NPK) which resulted in higher growth and yield of plants. Sharifi *et al.* (2018) explained that increased DMP is due to balanced proportion of macro nutrients in the foliar fertilization which resulted in better crop growth and photosynthetic activity which has lead to better supply of photosynthates ultimately resulting in higher DMP per plant. Similarly, Gutte *et al.*, (2018) also reported higher DMP with the foliar application of polyfeed at 1.0 per cent in soybean. Arun and Jayakumar (2014) explained that the higher DMP with foliar application is due to the positive interference in tissue formation and dry matter weight of cucumber in polyhouse.

5.2.4. Effect of Fertigation and Foliar Nutrition on Quality of Fruits under Rain shelter and Open Field Conditions

Higher shelf life was observed under lower level of fertigation of 50 per cent RDF under both growing condition and was on par with 75 per cent RDF. Higher fertigation results in higher nutrient uptake and improved biochemical processes ultimately resulting in higher protein content in fruits. So easy degeneration of protein molecules and other biochemical components might have resulted in shorter shelf life of bhindi fruits. According to FAO (2004), high N content is often associated with reduced post-harvest-life due to increased susceptibility to mechanical damage, physiological disorders, and decay. The result is in confirmation with the findings of Baser (1986) in potato and Aschcroft and Jones (1993) in tomato.

Under rain shelter, higher protein content was observed with 125 per cent RDF for both crops. Ascorbic acid content was higher under 125 per cent RDF and was on par with 100 per cent RDF during the second crop. Under open field, higher protein content was observed under 125 per cent RDF for both the crops. Ascorbic acid was higher for 125 per cent RDF and was on par with 75 per cent RDF during the second crop. Increased ascorbic acid content might be due to increase in uptake of nutrients especially N which had promoted the synthesis of ascorbic acid. Higher ascorbic is attributed to the enhanced metabolic activity of the plants under frequent fertigation resulting in increased protein synthesis thus, accumulating low fibre as reported earlier by Meenakshi and Vadivel (2006) and Kuppusamy (2008). Higher dose of fertigation resulting in higher ascorbic acid content was also reported by Brahma *et al.* (2010) in capsicum and Tomar and Singhal (2007) in tomato.

Among foliar levels, nano NPK at 0.3 per cent spray resulted in higher ascorbic acid and protein content under both condition. As nano NPK used for the foliar application have been formulated with organic and chelated micro nutrients, trace elements, vitamins, probiotics, seaweed extract and humic acid besides

N, P and K, it might have enhanced the quality of fruits. Unlike roots, the cuticular membranes are permeable to both organic and inorganic ions and undissociated molecules (Franke, 1967) resulting in higher fruit quality.

5.2.5. Effect of Fertigation and Foliar Nutrition on Uptake of Nutrients, Available Nutrient Status and Microbial Population of Soil after the Experiment under Rain shelter and Open Field Conditions

Uptake of N, P and K was higher under 100 per cent RDF under rain shelter for the first and second crop. Under open field condition, 125 per cent RDF resulted in higher N, P and K uptake under open field condition and was on par with 100 per cent RDF for both crops. Higher N, P and K uptake under high fertigation level might be due to the higher DMP under high fertigation level. Higher uptake resulted under higher fertigation level might be due to the application of fertilizers in small doses at higher frequency (*i.e.* on daily basis) through drip fertigation which could ensure a continuous and stable supply of nutrients to meet the growing demand of hybrid bhindi thus improving nutrient uptake responsible for ultimate increase in productivity (Venkadeswan and Sundaram, 2016). Higher drip irrigation and fertigation helped the plants for better uptake of nutrients and consequently the good growth of plants. Also water soluble fertilizers might have activated the physiological processes for the rapid absorption and utilization of the nutrients for the primary metabolic process (Sahana *et al*, 2018). These results are in confirmation with Honnappa *et al.* (2017) in fenugreek.

Available N, P and K of the soil after the experiment were higher for 100 per cent RDF for the first crop under rain shelter. Under open field condition, higher available N, P and K were recorded higher for 125 per cent RDF and were on par with 100 per cent RDF for first crop. Higher dose of fertigation resulted in higher nutrient availability in soil. The drip fertigation treatments with 100 per cent RDF showed statistically significant higher yield compared to the other drip fertigation treatments. This can be explained by the fact that water and nutrients are supplied directly to the root zone of the crop in drip fertigation. Hence leaching is reduced thereby increasing the availability of nutrients to the plants (Rajasekhar *et al.*, 2017).

Supply of enough water soluble fertilizers through frequent fertigation, and at higher fertigation levels, increased their availability in the soil after the experiment remained high. This is in confirmation with the findings of Sahana (2018) in pole bean. The uptake of nutrients by plant roots was higher since nutrient availability availability to root system was high in the higher dose of fertigation (Rao, 1996).

Microbial population was higher under 125 per cent RDF under rain shelter and open field condition for first and second crop. Higher nutrient availability resulting in higher root activity might be the reason for higher microbial population in soil after the experiment.

Poly feed at 0.5 per cent spray showed higher N, P and K uptake among the foliar application levels under rain shelter. Higher N and P uptake was reported under poly feed at 0.5 per cent spray for the second crop under open field condition. Higher nutrient content in the poly feed (19 % NPK) compared to nano NPK (4 % NPK) resulted in higher nutrient uptake by the plant and nutrient availability in soil. Foliar application of water soluble fertilizers triggered plant response to increased water and nutrient uptake from the soil (Veeramani *et al.*, 2012). Devi and Shanthi (2013) reported that the plant N, P and K uptake increased when the corresponding nutrient was applied at higher levels. The increased accumulation of N, P and K in the plant might be attributed to higher availability of the respective nutrients and more absorptive area which resulted in the highest nutrient accumulation. N, P and K uptake were also increased in the same treatment reported by Venkataraman (2007).

Higher N availability after the experiment was reported under poly feed at 0.5 per cent foliar spray under rain shelter and this can be due to the higher N content in poly feed fertilizer than in nano NPK. The availability of K after the experiment was reported to be higher under nano NPK at 0.3 per cent foliar spray under open field condition and this might be due to the reduced yield in nano NPK treatment compared to poly feed and the nutrient remained unused in soil since fruit yield and available K in soil is directly related to fruit development.

Microbial population was significantly higher under nano NPK at 0.3 per cent spray. As the foliar spray under rain shelter has been formulated with organic and chelated micro nutrients, trace elements, vitamins, probiotics, seaweed extract and humic acid, application of these organic formulation might have resulted in higher microflora. Moreover the presence of probiotics in the formulation can improve the beneficial microbial population in soil.

5.2.6. Effect of Fertigation and Foliar Nutrition on Net Returns and B: C ratio Under Rain shelter and Open Field Conditions

Under rain shelter, the net returns and B: C ratio (Fig. 29 and Fig. 30) was higher under 100 per cent RDF and was on par with 125 per cent RDF for both the crops. Under open field condition, net returns and B: C ratio (Fig. 31 and Fig. 32) was higher under 125 per cent RDF during both the crops and was on par with 100 per cent RDF during the first crop. Under rain shelter, 100 per cent RDF reported a yield increase of 26.02 per cent for the first crop and 24.52 per cent for the second crop compared to lower levels of fertigation.

Under open field condition, an increase of 30.55 per cent for the first crop and 29. 65 per cent for the second crop was recorded from 125 per cent RDF treated plots compared to the lower dose (50 % RDF). This increase in yield under higher fertigation levels resulted in higher net returns and B: C ratio. Similarly, fertigation of 100 per cent RDF resulted in higher net returns and B: C ratio for bhindi as obtained by Rajaraman and Pugalendhi (2013) and Nair *et al.* (2017). All these might have improved the net returns and B: C ratio for bhindi cultivation with higher fertigation.

Foliar application of poly feed at 0.5 per cent spray under rain shelter and open field condition resulted in higher net returns and B: C ratio since the

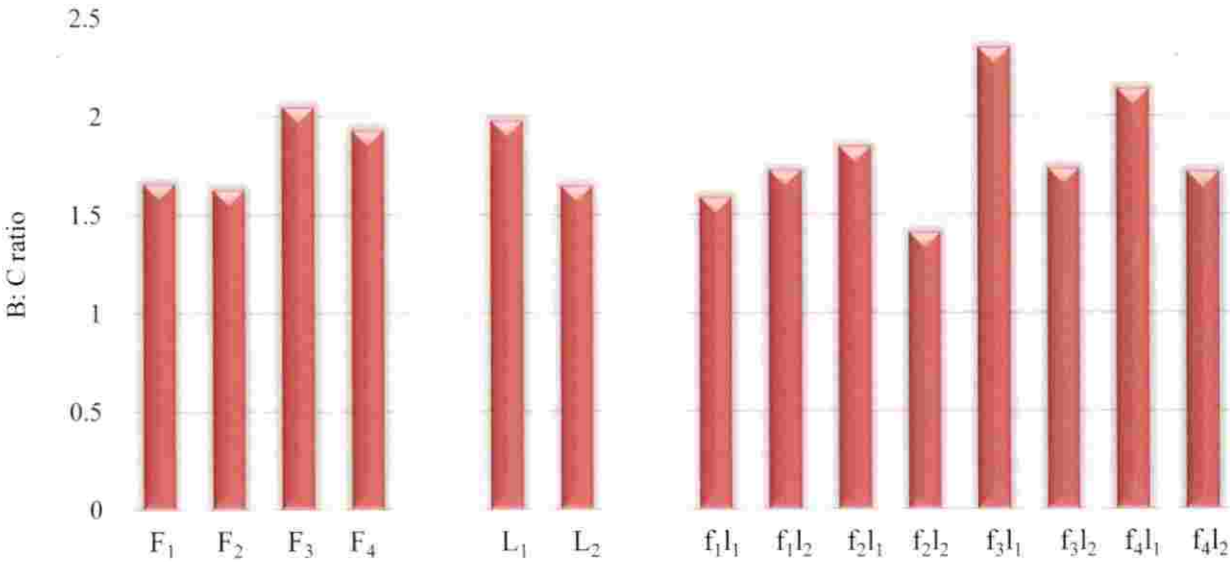

Fig. 29 Effect of fertigation and foliar levels of nutrients on B: C ratio during Sept-Dec, 2017 under rain shelter

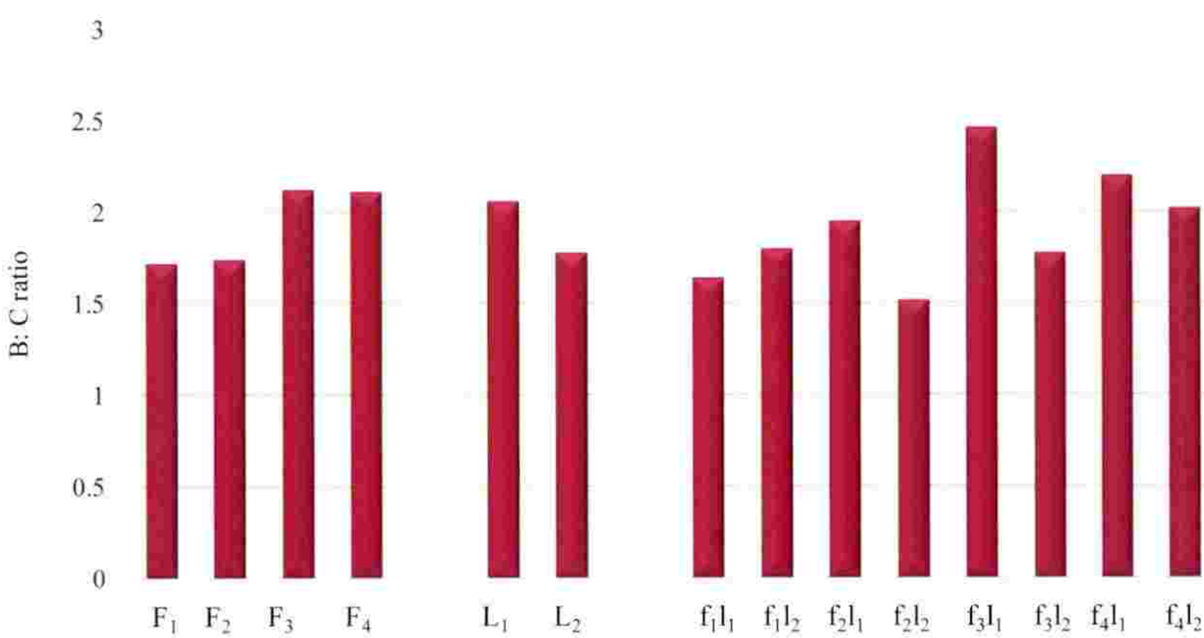

Fig.30. Effect of fertigation and foliar levels of nutrients on B: C ratio during May-Aug, 2018 under rain shelter

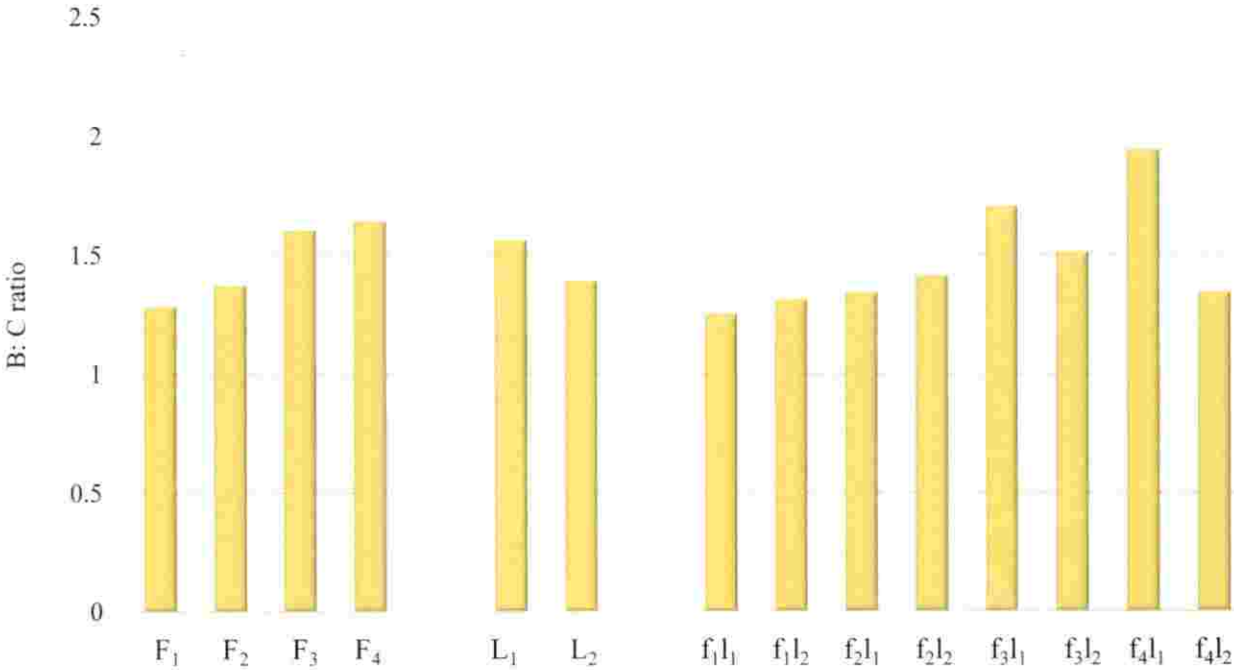

Fig. 31 Effect of fertigation and foliar levels of nutrients on B: C ratio during Sept-Dec, 2017 under open field condition

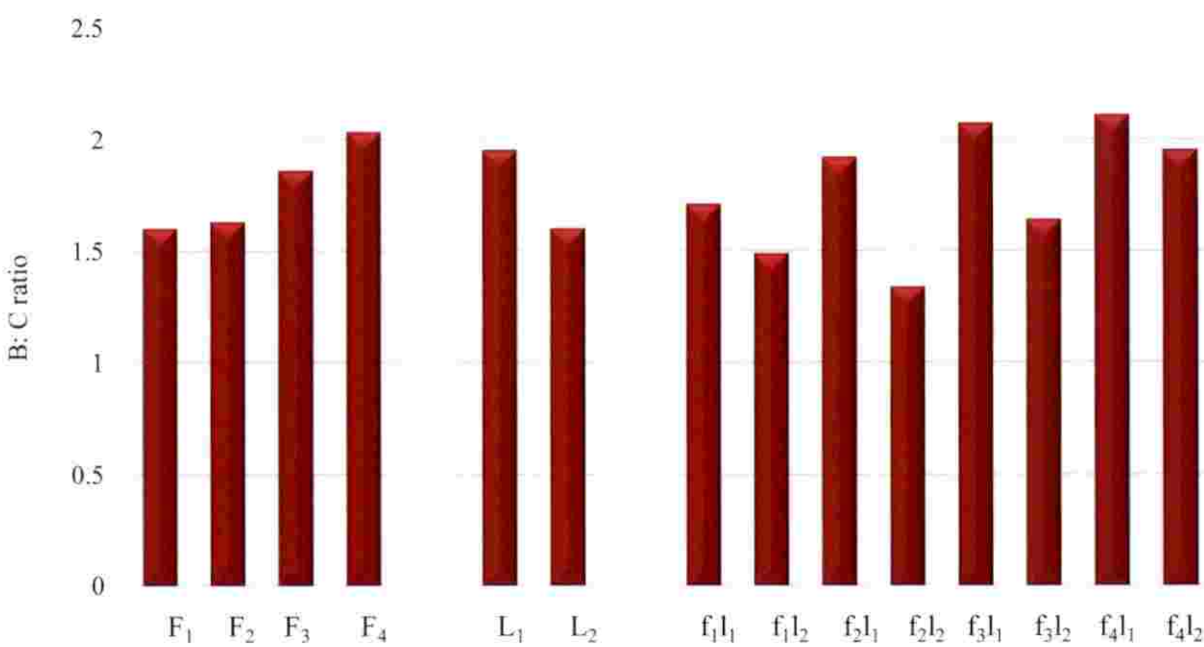

Fig. 32 Effect of fertigation and foliar levels of nutrients on B: C ratio during May-Aug, 2018 under open field condition

treatment produced higher yield than nano NPK at 0.3 per cent application. Similar result of improved monetary returns through the application of poly feed at 0.5 per cent was reported by Singhal *et al.* (2016).

SUMMARY

6. SUMMARY

The present study entitled 'Agro techniques in bhindi for precision farming' was conducted during 2016 to 2019 at the Instructional Farm, College of Agriculture, Vellayani. The objectives were to standardize the spacing and response of bio inoculants for bhindi under rain shelter and open field conditions, to evaluate the effect of fertigation and foliar nutrition on improving growth, yield and quality of bhindi and to work out the economics of different cultivation systems. The salient findings of the study are summarised below.

The first experiment was to standardise the spacing and bio inoculants suitable for the cultivation of bhindi under rain shelter and open field condition. Field experiment was conducted using the variety, Varsha Uphar during May to August, 2017. The treatments consisted of three spacings (S_1 - 60 cm x 30 cm, S_2- 60 cm x 45 cm and S_3 – 60 cm x 60 cm) and three bio inoculant treatments (B_1- Bio inoculant- PGPR mix 1 and B_2 - Bio inoculant - Arbuscular mycorrhizal fungi and B_3 - No Bio inoculant). The experiment was carried out in RBD with three replications.

Both under open field and rain shelter conditions, taller plants were observed for closer spacing of 60 cm x 30 cm at all growth stages. Among bio inoculant treatments, significant variation in height was noticed at 60 DAT and 90 DAT and was higher for the bio inoculant, PGPR mix 1. Under rain shelter, number of leaves at 60 and 90 DAT were significantly higher for the wider spacing, 60 cm x 60 cm. Among bio inoculants, PGPR mix 1 showed significantly higher number of leaves at all stages except at 60 DAT. Under open field condition, significant variation was noticed between three spacing on number of leaves. The spacing, 60 cm x 60 cm showed more number of leaves than other spacings at all the growth stages of crop. Leaf number recorded by PGPR mix 1 was comparable with AMF at 30 and 60 DAT.

Higher number of branches was recorded by wider spacing, 60 cm x 60 cm under both growing conditions. PGPR mix 1 recorded more number of branches among bio inoculants under rain shelter and open field conditions. LAI was found to be significant among spacing only at 60 and 90 DAT under open field conditions. Tap root length and root volume were also found significantly higher at wider spacing (60 cm x 60 cm). PGPR mix 1 resulted in higher tap root length and root volume at harvest among bio inoculants.

Under rain shelter and open field conditions, number of flowers was significantly higher for wider spacing of 60 cm x 60 cm. Among bio inoculants, PGPR mix 1 showed significantly more number of flowers. Number of fruits per plant was found to be significantly higher for 60 cm x 60 cm spacing and was on par with 60 cm x 45 cm under rain shelter condition. Under open field condition also, wider spacing (60 cm x 60 cm) recorded more number of fruits. Bio inoculants also influenced the number of fruits produced by plants. PGPR mix 1 recorded higher and no bio inoculant recorded lower number of fruits under both conditions. Significant difference was found among treatments on their effect on fruit set percentage under open field conditions. 60 cm x 45 cm showed higher fruit set percentage than other spacings and PGPR mix 1 resulted in higher fruit set percentage among bio inoculants.

Fruit length was significantly influenced by spacing and was higher for wider spacing 60 cm x 60 cm which was on par with 60 cm x 45 cm under both growing conditions. PGPR mix 1 recorded higher fruit length among bio inoculants under open field conditions. Weight of fruit was significantly higher for 60cm x 60 cm spacing and PGPR mix 1 among bio inoculants under both conditions. Under both growing conditions, different spacing had significant influence on weight of fruit per plant. 60 cm x 60 cm recorded significantly higher weight of fruit per plant among spacings and among bio inoculants, PGPR mix 1 recorded higher fruit weight per plant. Fruit yield was significantly influenced by spacing and bio inoculant application and was higher for 60 cm x 30 cm spacing and PGPR mix 1 under both growing conditions. Their interaction was also found to be significant under both conditions.

Among the physiological observations, CGR was significantly influenced by spacing and was higher at 60 cm x 30 cm. Among bio inoculants, PGPR mix 1 recorded higher CGR under rain shelter and open field conditions. RGR was found significantly higher for wider spacing, 60 cm x 60 cm. Among bio inoculants, PGPR mix1 was found superior with respect to relative growth rate (RGR) under both conditions. NAR was not influenced by treatments under both conditions.

Among the fruit quality aspects, significant difference was observed for protein content inside rain shelter. Higher protein content was observed under both wider spacings 60 cm x 60 cm and 60 cm x 45 cm. AMF treated plants recorded higher protein content among bio inoculants. Dry matter production was significantly influenced by spacing and was higher for 60 cm x 30 cm due to higher number plants under closer spacing. Among bio inoculants, PGPR mix 1 treated plants produced more dry matter due to the higher growth and yield of plants.

NPK uptake showed an increasing trend with decreased plant to plant spacing. The spacing, 60 cm x 30 cm recorded significantly higher N, P and K uptake by plants. Application of PGPR mix 1 resulted in higher nutrient uptake. Available P status of soil after the experiment was significantly higher for 60 cm x 60 cm spacing under rain shelter. AMF treated soil showed significantly higher available P under open field condition. Available K was significantly higher for 60 cm x 60 cm spacing and PGPR mix 1 under rain shelter and open field condition.

Under rain shelter, different spacing had significant influence on bacterial count. Spacing of 60 cmx 30 cm recorded significantly higher soil bacteria. Among bio inoculants, PGPR mix 1 recorded higher bacterial count and was on par with AMF. Inside rain shelter, spacing had no significant influence on fungal population, but was influenced by bio inoculants. AMF showed higher fungal population which was on par with PGPR mix 1. Under open field condition, fungal population was significantly influenced by spacing and higher fungal population was observed under 60 cm x 30 cm and was on par with 60 cm x 45 cm. AMF showed significantly higher fungal count among different bio inoculant used for seedling inoculation and was on par with PGPR mix 1. Actinomycetes population was influenced by bio inoculants under rain shelter and PGPR mix 1 treatment showed higher population and was on par with AMF treatment. Under open field condition, 60 cm x 30 cm spacing resulted in significantly higher actinomycetes population. PGPR mix 1 showed significantly higher number of actinomycetes among different bio inoculants used for seedling inoculation and was on par with AMF.

Under rain shelter and open field conditions, WUE was significantly higher for the closer spacing of 60 cmx 30 cm. Among bio inoculants, PGPR mix 1 showed significantly higher water use efficiency. Net returns and B: C ratio was also higher at closer spacing of 60 cm x 30 cm and PGPR mix 1 and their interaction under both condition.

The second experiment for standardization of nutrient schedule of bhindi under rain shelter and open field condition was conducted during September to December 2017 and May to August 2018. The best treatments from the first experiment were used for this trial. The trial was laid out in split plot design with five replications. The main plot treatments consisted of four levels of fertigation; 50 per cent *adhoc* POP recommendation for precision farming (F_1), 75 per cent *adhoc* POP recommendation for precision farming (F_2), 100 per cent *adhoc* POP recommendation for precision farming (F_3), 125 per cent *adhoc* POP recommendation for precision farming (F_4) and the sub plot treatments consisted of two foliar levels; poly feed fertilizer (19:19:19 at 0.5 %) (L_1) and nano NPK (4: 4: 4 at 0.3 %) (L_2). The variety used for the experiment was Varsha Uphar.

Growth characters such as plant height, number of leaves, and number of branches, LAI at monthly intervals and tap root length and root volume at harvest were recorded. Under rain shelter, fertigation level of 100 per cent RDF (F_3)

produced the tallest plants at all the growth stages and was on par with 125 per cent RDF (F_4). Under open field, 125 per cent RDF (F_4) recorded significantly higher plant height during all growth stages and was on par with F_3 at all growth stages. Foliar application had significant influence on plant height and was higher for poly feed at 0.5per cent (L_1) during both crops under both growing conditions.

Number of leaves at all growth stages was significantly higher for the fertigation level of 100 per cent RDF (F_3) during both crops under rain shelter. Under open field conditions, significantly more number of leaves was recorded by 125 per cent RDF (F_4) and was on par with F_3. Foliar application had significant influence on the number of leaves and was higher for poly feed at 0.5 per cent (L_1) during both crops under both growing conditions.

Under rain shelter, 100 per cent RDF (F_3) showed significantly higher number of branches at all growth stages. Under open field condition, 125 per cent RDF (F_4) produced more number of branches at all growth stages and was on par with F_3. Foliar application had no significant effect on the number of branches under both growing conditions.

Under rain shelter, significantly higher LAI was recorded for 100 per cent RDF (F_3) and was comparable with F_4. Under open field condition, fertigation showed significant effect on LAI. F_4 recorded higher LAI during all the growth stages. This was on a par with the fertigation, F_3 and F_1 at all the growth stages. Considering the foliar levels, poly feed at 0.5 per cent (L_1) recorded higher LAI than nano NPK (4: 4: 4 at 0.3 %) (L_2) during both crop under both conditions.

Length of tap root under rain shelter and open field condition was found to be higher for 100 per cent RDF (F_3) than other three fertigation levels and was on par with F_4. Among the different foliar levels, poly feed at 0.5 per cent (L_1) resulted in higher tap root length than nano NPK (4: 4: 4 at 0.3 %) (L_2). Root volume was also found to be higher for the fertigation level of 100 per cent RDF (F_3) at harvest under rain shelter. Under open field conditions, higher fertilizer level of 125 per cent RDF (F_4) showed higher root volume. Foliar application had significant influence on the root volume and was higher for poly feed at 0.5 per cent (L_1) under both conditions.

Yield attributes like, days to 50 per cent flowering was also influenced by fertigation levels under rain shelter. Lower dose of fertigation of 50 per cent RDF (F_1) resulted in more days to 50 per cent flowering.

Under rain shelter, number of flowers was significantly higher for higher fertigation level of 100 per cent RDF (F_3) during first crop and 125per cent RDF (F_4) during second crop. Among foliar levels, treatments were found significant and were higher for poly feed at 0.5 per cent (L_1). Under open field condition also, number of flowers was significantly higher for the higher fertigation level. Among foliar levels, treatments were found significant and were higher under poly feed at 0.5 per cent (L_1).

Number of fruits per plant under rain shelter was significantly higher for the fertigation of 100 per cent RDF (F_3) during both crops. Among foliar levels, poly feed at 0.5 per cent (L_1) recorded more number of fruits. Under open field condition, significant variation was noticed between the fertigation levels. Application of 125 per cent RDF (F_4) showed more number of fruits per plant and was on par with 100 per cent RDF (F_3). Significant variation was also recorded among different foliar levels. Poly feed at 0.5 per cent (L_1) resulted in higher number of fruits.

Effects of treatments on fruit set per cent under rain shelter condition revealed that higher fertigation level of 100 per cent RDF (F_3) produced higher fruit set per cent. Under open field condition, 125 per cent RDF (F_4) showed higher fruit setting percentage than other fertigation levels. Foliar application had significant influence on the fruit setting percentage and was higher for poly feed at 0.5 per cent (L_1) than nano NPK (4: 4: 4 at 0.3 %) (L_2).

Fertigation levels had significant influence on length of fruit. Higher dose of 100 per cent RDF (F_3) recorded significantly higher fruit length under both crops. Under open field condition, 125 per cent RDF (F_4) of fertigation level resulted in significantly higher length of fruit. Weight of fruit under rain shelter was higher for the fertigation level of 125 per cent RDF (F_4) and was on par with F_3. Higher fruit weight was observed for the poly feed at 0.5 per cent (L_1) among foliar treatments under open field condition. Under open field condition also, weight of fruit was significantly influenced by fertigation and foliar application. Higher fertigation level of 125 per cent RDF (F_4) recorded significantly higher fruit weight. Poly feed at 0.5 per cent (L_1) recorded significantly higher fruit weight among foliar levels.

Weight of fruit per plant under rain shelter was found to be higher for 100 per cent RDF (F_3) and was on par with 125 per cent RDF (F_4). Among foliar levels, poly feed at 0.5 per cent (L_1) showed higher fruit weight per plant. Under open field condition, higher dose of 125 per cent RDF (F_4) fertigation level resulted in significantly higher weight of fruit per plant and was on par with 100 per cent RDF (F_3). Foliar levels had significant influence on weight of fruit per plant. Poly feed at 0.5 per cent showed significantly higher fruit weight per plant among different foliar levels.

Fruit yield under rain shelter was significantly influenced by fertigation and foliar levels. Among fertigation levels, 100 per cent RDF (F_3) recorded significantly higher fruit yield and was on par with F_4. Fruit yield was found to be significantly higher for poly feed at 0.5 per cent (L_1) among foliar levels. Under open field condition, fertigation level of 125 per cent RDF (F_4) produced significantly higher fruit yield and was on par with 100 per cent RDF (F_3). Foliar levels had significant influence on yield. Higher fruit yield was recorded for the poly feed at 0.5 per cent (L_1).

Crop growth rate was significantly higher for the higher fertigation level of 125 per cent RDF (F_4) and was on par with 100 per cent RDF (F_3). Under open field condition also, higher level of fertigation resulted in higher CGR. Significant variation was also recorded among the different foliar levels. Poly feed at 0.5 per cent (L_1) resulted in higher CGR under both growing conditions

Under rain shelter and open field conditions, RGR was found to be higher for the higher level of fertigation of 125 per cent RDF (F_4) and was on par with 100 per cent RDF (F_3). Among the foliar levels, poly feed at 0.5 per cent (L_1) showed significantly higher RGR. Similarly, NAR was also found significant among fertigation levels and was higher for higher level of 125 per cent RDF. Foliar application of poly feed at 0.5 per cent (L_1) recorded significantly higher NAR at both conditions.

Chlorophyll content of leaves at 45 DAT under rain shelter and open field conditions was significantly influenced by fertigation levels and was higher for higher level (125 % RDF) of fertigation. Significant effect on foliar application was found on chlorophyll content and was higher for nano NPK at 0.3 per cent (L_2) under both conditions.

Different fertigation levels had significant influence on dry matter production. Under rain shelter, 100 per cent RDF (F_3) recorded significantly higher DMP than other fertigation levels. Under open field condition, 125 per cent RDF (F_4) resulted in significantly higher dry matter and was on par with 100 per cent RDF (F_3). Among the foliar levels, poly feed at 0.5 per cent (L_1) showed significantly higher DMP under both growing conditions.

Fertigation levels had significant influence on shelf life of bhindi under both growing conditons. Lower level of 50 per cent RDF (F_1) fertigation resulted in higher shelf life and was on par with F_2. Considering the ascorbic acid content of bhindi fruits, higher level of fertigation of 125 per cent RDF (F_4) showed significantly higher ascorbic acid under rain shelter and open field condition. Among the foliar levels, higher ascorbic acid was recorded for nano NPK at 0.3 per cent (L_2). Protein content of bhindi fruits was also influenced by fertigation levels and was higher for 125 per cent RDF (F_4). Nano NPK at 0.3 per cent (L_2)

227

foliar application resulted in higher protein content under both growing conditions.

Fertigation levels had significant influence on N, P and K uptake by plants. The fertigation level of 100 per cent RDF (F_3) recorded significantly higher N, P and K uptake under rain shelter and 125 per cent RDF (F_4) recorded higher N, P and K uptake under open field conditions. Foliar level of poly feed at 0.5 per cent (L_1) application resulted in higher N, P and K uptake under both growing conditions.

Similarly, fertigation levels had significant influence on available N, P and K status in soil after the experiment under both growing conditions. Available N and K was significantly higher for higher level of fertigation (125 % RDF (F_4)) under both conditions. Available P was significantly higher for 100 per cent RDF (F_3) under both growing conditions. Foliar application of poly feed at 0.5 per cent (L_1) resulted in higher available N after experiment under rain shelter and available K under open field conditions.

Higher fertigation level of 125 per cent RDF (F_4) resulted in higher microbial (bacteria, fungi and actinomycetes) count under both conditions. Foliar application with nano NPK at 0.3 per cent (L_2) resulted in higher microbial count inside rain shelter. Water use efficiency was significantly higher for 100 per cent RDF (F_3) under rain shelter and 125 per cent RDF (F_4) under open field conditions. Among foliar levels, poly feed at 0.5 per cent (L_1) showed significantly higher WUE under both growing conditions.

Under rain shelter, net returns and B: C ratio was significantly higher for the fertigation level of 100 per cent RDF (F_3) and was on par with 125 per cent RDF (F_4). Among foliar levels, poly feed at 0.5 per cent (L_1) resulted in significantly higher net return and B: C ratio. Under open field condition significant variation was noticed between fertigation levels on net returns and B: C ratio. The fertigation level of 125 per cent RDF (F_4) showed higher net return and B: C ratio and was on par with F_3. Significant variation was also

228

recorded among the different foliar levels. Poly feed at 0.5 per cent (L_1) resulted in higher net return and B:C ratio under both growing conditions.

The study revealed that growing bhindi at a spacing of 60 cm x 30 cm and seedling inoculation with PGPR mix 1 resulted in higher yield and profit under rain shelter and open field condition. Nutrient scheduling of 98: 25: 136 kg NPK ha^{-1} (100 % *Adhoc* POP recommendation) along with foliar application of poly feed (19:19:19) at 0.5 per cent at fortnightly interval enhanced growth, yield and profit under rain shelter condition. Fertilizer dose of 122: 31: 170 kg NPK ha^{-1} (125 per cent *Adhoc* POP recommendation) or 98: 25: 136 kg NPK ha^{-1} (100 % *Adhoc* POP recommendation) with foliar application of poly feed (19:19:19) at fortnightly interval is beneficial for open field condition. Application of 125 per cent *Adhoc* POP recommendation along with foliar spray of nano NPK at 0.3 per cent at fortnightly interval improved the fruit quality under both conditions.

Future line of work

- Standardization of spacing of various vegetables under rain shelter condition
- Fertigation trials using nano fertilizers in various growing environments
- Standardization of concentration of nano formulation for foliar application in major vegetable crops
- Trials on soil application of nano fertlizers.

REFERENCES

REFERENCES

Aziz, A. H. M. M., Hasaneen, M. N. A., and Omar, A. 2016. Nano chitosan-NPK fertilizer enhances the growth and productivity of wheat plants grown in sandy soil. *Spanish J. Agric. Res.* 14(1): 902.

Abdul, K. S. 1999. Effects of plant spacing and fertilizer levels on the growth and yield of okra. *Iraqi J. Agric. Sci.* 4: 77-89.

Abraham, R. K., Sarathi, M. P., and Manna, D. C. 2017. Yield performance and profitability of bitter gourd cultivation as influenced by drip irrigation, fertigation and plastic mulching. *Int. J. Curr. Microbiol. App. Sci.* 6(10): 638-645.

Adesemoye, A. O. and Kloepper, J. W. 2009. Plant-microbes interactions in enhanced fertilizer use efficiency. *Appl. Microbiol. Biotech.* 85:1–12.

Adesemoye, A. O., Torbert, H. A., and Kloepper, J. W. 2009. Plant growth-promoting rhizobacteria allow reduced application rates of chemical fertilizers. *Microbiol Ecol.* 58:921-929.

Agba, O. A., Mbah, B. N., Asiegbu, J. E., and Adinya, I. B. 2011. Effects of spacing on the growth and yield of Okra (*Abelmochus esculentus* L. Moench) in Obubra cross river state. *Global J. Agric. Sci.* 10(1): 57-1.

Ajirloo, A. R., Shaaban, M., and Motlagh, Z. R. 2015. Effect of K nano-fertilizer and N bio-fertilizer on yield and yield components of tomato (*Lycopersicon esculentum* L.). *Int. J. Adv. Biol. Biom. Res.* 3 (1): 138-143.

Akanbi, W. B., Togun, A. O., Adediran, J. A., and Ilupeju, E. A. O. 2010. Growth, dry matter and fruit yields components of okra under organic and inorganic sources of nutrients. *Am. Eurasian J. Sustain. Agric.* 4(1): 1-13.

Akande, M. O., Oluwatoyinbo, F. I., Adediran, J. A., Buari, K. W., and Yusuf, I. O. 2003. Soil amendments affect the release of P from rock phosphate and yield of okra. *Veg. Crop Prod.* 9(2): 3-9.

Ali, A. 1999. Response of okra (*Abelmoschus esculentus* L. Moench) to phosphorus and spacing. M. Sc. Thesis, University of Agriculture, Faisalabad. 141p.

Ali, M. M., Sani, M. N. H., Arifunnahar, M., Aminuzzaman, F. M., and Mridha, M. A. U. 2018. Influence of arbuscular mycorrhizal fungi on growth, nutrient uptake and disease suppression of some selected vegetable crops. *Azarian J. Agric.* 6(5): 190-196.

Al-Kaisi, M. M. and Yin, X. 2003. Effects of nitrogen rate, irrigation rate, and plant population on corn yield and water use efficiency. *Agron. J.* 95: 1475-1482.

Amanullah., Inamullah., Shah, Z., Khalil, S. K. 2016. Phosphorus and zinc interaction influence leaf area index in fine versus coarse rice (*Oryza sativa* L.) genotypes in North-West Pakistan. *J. Plant Stress Physiol.* 2: 1-8.

Amjad, M., Anjum, M. A., and Ali, A. 2001. Effect of phosphorus and planting density on seed production in okra (*Abelmoschus esculentus* L. Moench. *J. Agri. Biol.* 3(4): 380-383.

Anburani, A. 2018. Influence of water soluble fertilizers on growth in brinjal hybrid (*Solanum melongena* L.). *J. Plant Stress Physiol.* 4: 01-03.

Arora, S. and Dan, S. 2003. Biofertilizers for sustainable agriculture. *Kisan wld.* 31: 35-37.

Arun, S. and Jayakumar, R. 2014. Influence of nutrient management systems on yield attributes of cucumber (*Cucumis sativus* L. var Beit Alpha) cultivated in polyhouse conditions. *Trends Biosci.* 7(21): 3450-3452.

Ashcroft, W. J. and Jones, K. H. 1993. Response of processing tomatoes to application of nitrogen and potassium. In: Barrow, N. J. (ed.), *Plant Nutrition from Genetic Engineering to Field Practice.* Proceedings of the 12th International Plant Nutrition Colloquium, Dordrecht, the Netherlands, pp 581-584.

Ayoob, M., Aziz, I., and Jite, P. K. 2011. Interaction effects of Arbuscular mycorrhizal fungi and different phosphate levels on growth performance of *Catharanthus roseus* L. *Notulae Scientia Biologic.* 3(3): 75-79.

Badr, M. A. and Abou El-Yazied, A. A. 2007. Effect of fertigation frequency from subsurface drip irrigation on tomato yield grown on sandy soil. *Aust. J. Basic Appl. Sci.* 1(3): 279-285.

Barooah, S. and Ahmed, A. Z. 1983. Effect of NPK fertilizers on growth, development and yield of tomato. In: *Proceedings of national seminar on the production technology of tomato and chillies*, Coimbatore. pp 54-56.

Baser, T. K. 1986. Uptake of N, P and K by potato tubers and keeping quality of tubers when stored in cold storage as influenced by different levels of NPK fertilization. *Environ. Ecol.* 4: 640-651.

Batra, V. K., Singh, V., and Singh, B. 2002. Response of brinjal to foliar feeding of water soluble fertilizers. *Proceedings of the international conference on vegetables*, November 2002, 11-14, Bangalore, pp 149-157.

Batsmanova, L. M., Gonchar, L. M., Taran N. Y., and Okanenko A. A. 2013. Using a colloidal solution of metal nanoparticles as micronutrient fertilizer for cereals. *Proceedings of the International Conference on Nanomaterials: Applications and Properties*. pp. 178-192

Battilani, A., Plauborg, F. L., and Hansen, S. 2008. Nitrogen uptake and nitrogen use efficiency of fertigated potatoes. *Acta Hortic.* 792: 61-68.

Bhardwaj, S. K., Kaushal, R and Yoginder, S. 2010. Effect of conjoint use of enriched compost and chemical fertilizers on the yield and nutrient uptake in pea (*Pisum sativum* L.) under mid-hill conditions. *Himachal J. Agric. Res.* 36 (1): 101-104.

Bhattacharya, P. N. and Jha, D. K. 2012. Plant growth-promoting rhizobacteria (PGPR) emergence in agriculture. *Wld. J. Microbiol. Biotech.* 28: 1327-1350.

Birbal, Nehra, B. K. and Malik, Y. S. 1995. Effect of spacing and nitrogen on fruit yield of okra (*Abelmoschus esculentus* L.) cv. Varsha Uphar. *Haryana Agric. J. Res.* 25: 47-51.

Blackman, V. H. 1919. The compound interest law and plant growth. *Annals of Botany,* 33:353–360.

Bouyoucos, C. J. 1962. Hydrometer method improved for making particle size analysis of soil. *Agron. J.* 54(4): 464-465.

Bradford, M. M. 1976. A rapid and sensitive method for the quantitation of microgram quantitites of protein utilizing the principle of protein-dye binding. *Analyt. Biochem.* 72: 248-254.

Brahma, S., Phookan, D. B., Barua, P., and Saikia, L. 2010. Effect of drip-fertigation on performance of tomato under Assam conditions. *Indian J. Hortic.* 67(1): 56-60.

Bulgarelli, D., Schlaeppi, K., Spaepen, S., Van Themaat E. V. L., and Schulze-Lefert P. 2013. Structure and functions of the bacterial microbiota of plants. *Ann. Rev. Plant Biol.* 64: 807-838.

Celline, H. A., Bake, I. D., and Futuless, K. N. 2015. Effects of weeding regime and inter-row spacing on the growth and pod yield of okra [*Abelmoschus esculentus* (L.) Moench]. *J. Agric. Sci.* 13: 95-100.

Chaurasia, S. N. S., Singh, K. P. and Rai, M. 2005. Effect of foliar application of water soluble fertilizers on growth, yield, and quality of tomato (*Lycopersicon esculentum* L.). *Sri Lankan J. Agric. Sci.* 42: 66 – 70.

Chawla, J. K. and Narda, N. K. 2006. Growth dynamics of potato as influenced by trickle fertigation options. *J. Res. Punjab Agric. Univ.* 43(1): 63-68.

Christo, E. I. and Onuh. M. O. 2005. Influence of plant spacing on the growth and yield of okra (*Abelmuschus esculentus* L. Meonch). In: *Proceedings of the 39th Conference of the Agricultural Society of Nigeria,* (ASN`05), Benin, pp: 51-53.

Cushman, K., Olczyk, T., and Klassen. W. 2005. Plant population affects growth and yield of okra (*Abelmoschus esculentus*) in South Florida, USA. *Proc. Int'l. Soc. Trop. Hort.* 48: 54-56.

Darade, M. S. 2014. Effect of VAM fungi on enhancement of Phosphorus in Okra. *Int. J. Life Sci.* 2 (2): 187-189.

Darade, M. S. 2015. Effect of inoculation of VAM fungi on enhancement of biomass and yield in okra. *Int. J. Innovative Sci. Eng. Technol.* 2(8): 859-865.

Davarpanaha, S., Tehranifara, A., Davarynejada, G., Abadíab, J., and Khorasani, R. 2016. Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (*Punica granatum* cv. Ardestani) fruit yield and quality. *Scientia Hortic.* 210: 57-64.

Desai, and Ketan D. 2011. Effect of spacing and growth retardant methods on growth, yield and quality of okra [*Abelmoschus esculentus* (L.) Moench] cv. Gujarat Okra-2, Ph D thesis, Navsari Agricultural University, Navsari, 180p.

Devi, D. N. and Shanthi, A. 2013. Effect of foliar spray of water soluble fertilizer on growth and NPK uptake of chilli hybrid (*Capsicum annuum* L.), *Asian J. Hortic.* 8(1): 222-225.

Djurovka, M. V., Markovic, Z., Ilin, S. Jevtic (Eds.) and Lazic, B. 1997. The effect of nitrogen fertilizer on the drymatter content and mineral elements in radish. *Acta Hortic.* pp.462

Donald, C. M. 1962. In search of yield. *J. Aus. Inst. Agric. Sci.* 28: 171-178.

Dutta, D. Mudi, D. D., and Thentu, T. L. 2015. Effect of irrigation levels and planting geometry on growth, cob yield and water use efficiency of baby corn (*Zea mays* l.). *J. Crop Weed,* 11(2):105-110.

Ekwu, L. G. and Nwokwu, G.N. 2012. Effect of plant spacing and planting date on the growth and yield of okra. *Int J. Agric. Rural Dev.* 15 (2): 1041 - 1048.

Ekwu, L. G., Nwokwu, G. N., and Chiazor, E. O. 2010. Effect of time of mulching and plant spacing on the growth and yield of okra in Abakaliki agro ecological zone. *Int. J. and Rural Dev.* 13(2): 70-5.

El-Aal F. S. A., Shaheen, A. M., Ahmed, A. A., and Mahmoud, A. R. 2010. Effect of foliar application of urea and amino acids mixtures as antioxidants on growth, yield and characteristics of squash. *Res. J. Agric. Biol. Sci.* 6: 583-588.

El-Waraky, Y. B. 2014. Effect of sowing date, plant density and phosphorus fertilization on seed yield of okra. *Alexandria J. Agric. Res.* 59(1): 27-41.

Din, E. A. A. and Hendawy, S. F. 2010. Effect of dry yeast and compost tea on growth and oil content of Borago officinalis plant. *Res. J. Agric. Biol. Sci.* 6: 424-430.

Fageria, M. S., Arya, P. S., Kumar, J., and Singh, A. K., 1992. Effect of sowing dates and nitrogen levels an growth and seed yield of okra. *Veg. Sci.* 19(1): 25-29.

FAO [Food and Agriculture Organization]. 2004. Rome, Italy. Available: http:www.apps.fao.org.[9-June-2018]

FAO [Food and Agriculture Organization]. 2010. FAO Statistics. Food and Agriculture Organization, Rome, Italy. Available: http://www.fao.org/faostat/en [12-March-2019]

Feleafel, M. N. and Ghoneim, I. M. 2005. Effect of plant density and nitrogen fertilizion on vegetative growth, seed yield and quality of okra plants. *J. Agric. Env. Sci. Alex. Univ.* 4(2): 24-35.

Firoz, Z. A., Islam, M. A. Mohiuddin, M., and Rahman, M. M. 2007. Yield and yield attributes of okra as influenced by planting time and plant spacing in hill slope condition. *Prog. Agric.* 18(2): 67-73.

Franke, W. 1967. Mechanisms of foliar penetration of solutions. *Ann. Rev. Plant Physiol.* 18(1): 281-300.

Froggett, S. 2009. Nanotechnology and agricultural trade. In: *Proceedings of OECD Conference on the potential environmental benefits of nanotechnology*, Fostering safe innovation-led growth, USA. https://www.oecd.org/science/ nanosafety/44029039.pdf [14 Jan. 2019].

Garcia, J. A. L., Probanza, A., Ramos, B., Palomino, M. R. and Manero F. J. G. 2004. Effect of inoculation of *Bacillus licheniformis* on tomato and pepper. *Agron. J.* 24: 169-176.

Ghafari, H. and Razmjoo, J. 2013. Effect of foliar application of nano-iron oxidase, iron chelate and iron sulphate rates on yield and quality of wheat. *Int. J. Agron. Plant Prod.* 4: 2997-3003.

Glick, B. R., Todorovic, B., Czarny, J., Cheng, Z., Duan, J., and Mc Conkey, B. 2007. Promotion of plant growth by bacterial ACC deaminase. *Crit. Rev. Plant Sci.* 26: 227–242.

GoI [Government of India]. 2017. *PFDC research findings on fertigation, National committee on plasticulture applications in horticulture (NCPAH)*. Precision farming development centres research findings on fertigation techniques. Patel, N. (ed.), Indian Agricultural Research Institute, New Delhi, 245p.

Gokul, A. A. J. and Hakkim, A. V. M. 2016. Comparative evaluation of naturally ventilated polyhouse and rain shelter on the performance of cowpea. *Int. J. Eng. Sci. Computing* 6(6): 8037-8039.

Goswami., Aakansha., Sharma., Anubhuti, and Singh, B. 2015. Correlation co-efficient analysis for yield attributes in okra (*Abelmoschus esculentus*) using line X tester analysis. *Indian J. Agric. Sci.* 85(1): 137-43.

Gowda, M. C. B., Krishnappa, K. S., Gowda, M. C., and Puttaraju, T. B. 2002. Effect of NPK levels on dry matter, nutrient accumulation and uptake of nutrients in okra. *S. Indian Hort.* 50(4/6): 543-549.

Gupta, A. 1990. Response of spring planted okra to varying of irrigation and plant spacing. *Veg. Sci.* 17: 16-19.

Gupta, A. J., Ahmad, M. F., and Bhat, F. N. 2010a. Studies on yield, quality, water and fertilizer use efficiency of capsicum under drip irrigation and fertigation. *Indian J. Hort.* 67(2): 213-218.

Gupta, A. J., Ahmed, N., Bhat, F. N. and Chattoo, M. A. 2010b. Production of hybrid tomato for higher income under drip irrigation and fertigation in Kashmir valley. *Indian J. Hort.* 67(1): 127-131.

Gupta, G., Parihar, S. S., Ahirwar, N. K., Snehi S. K., and Singh, V. 2015. Plant growth promoting rhizobacteria (PGPR): current and future prospects for development of sustainable agriculture. *J. Microbiol. Biochem. Technol.* 7(2): 96-102.

Gutte, A. V., Karanjikar, P. N., Takankhar, V. G., and Asunewad, A. 2018. Effect of foliar fertilizer application on growth and yield of soybean (*Glycine max* (L.) Merill) under rainfed condition. *Int. J. Curr. Microbiol. App.Sci.* 6: 2203-2207.

Habib, S. H., Kausar, H., and Saud, H. 2015. Plant growth-promoting rhizobacteria enhance salinity stress tolerance in okra through ROS-scavenging enzymes. *Bio Med. Res. Int.* 1-10.

Honnappa, A., Harisha, C. B., and Singh, R. 2017. Precision irrigation and fertigation for higher productivity and water use efficiency in fenugreek (*Trigonella foenum-graecum* L.) in semi arid conditions of Rajasthan. *Bioscan,* 12(1): 591-594

Hossain, M. O., Salam, M. A., Islam, M. S., and Masud, M. A. T. 1999. Yield and quality of okra (BARI Dherosh) seed as influenced by time of sowing and plant spacing. *Bangladesh J. Seed Sci. Technol.* 3(1-2): 83-87.

Hunt. 1978. *Plant Growth Analysis*. The institute Biology's studies in Biology. Edward Arnold (Pub.) Ltd. London, UK. 96p.

Ibeawuchi, I. I., Obiefuna, J. C. and Ofoli, M. C. 2005. Effects of row spacing on yield and yield components of okra (*Abelmoshus esculentus*) and groundnut (*Arachis hypogea*). *J. Agron.* 4(4): 304-307.

Ijoyah, M. O., Unah, P. O., and Fanen, F. T. 2010. Response of okra (*Abelmoschus esculentus* L. Moench) to intra row spacing in Makurdi, Nigeria. *Agric. Biol. J. N. Am.* 1(6): 1328-1332.

INIC [Iran Nanotechnology Initiative Council]. 2014. First nano-organic iron chelated fertilizer invented in Iran. Available: http://www.iran review. org/content/ Documents/Iranians Researchers Produce Nano Organic Fertilizer.html [21 Jan 2019].

Islam, M. N., Haque M. M. and Hamid, A. 2006. Planting arrangement and population density effects on the physiological attributes and productivity of maize–bush bean intercropping systems. *Bangladesh J. Agril. Res.* 31(3): 353-364.

Islam, M. S., Rahman, M. A, Salam, M. A., Masum, A. S. M. H., and Rahman, M. H. 2002. Growth of vegetable pod yield of edible podded pea as influenced by sowing time and plant density. *Online J. Biol. Sci.* 2(10): 706-709.

Islam, M., Saha, S., Hasanuzzaman, Akand, M. D., and Rahim, A. M. D. 2011. Effect of spacing on the growth and yield of sweet pepper (*Capsicum annuum* L.). *J. Cent. Eur. Agric.* 12(2): 328-335.

Jackson, M. L. 1973. *Soil chemical analysis*. Prentice Hall of India Pvt. Ltd, New Delhi, 192p.

Jana, J. C., Guha, S. and Chatterjee, R. 2010. Effect of planting geometry and nitrogen levels on crop growth, fruit yield and quality in okra grown during early winter in Terai zone of West Bengal. *J. Hort. Sci.* 5(1): 30-33.

Janapriya, S., Palanisamy, D., and Ranghaswami, M. V. 2010. Soilless media and fertigation for naturally ventilated polyhouse production of cucumber (*Cucumis sativus* L.) cv Green Long. *Int. J. Agric. Environ. Biotech.* 3(2): 199-205.

Jayakumar, M., Surendran, U., and Manickasundaram, P. 2015. Drip fertigation program on growth, crop productivity, water, and fertilizer-use efficiency of Bt cotton in semiarid tropical region of India. *Commun. Soil Sci. Plant Anal.* 46 (3): 293-304.

Job, M., Singh, V. K., and Dinmani. 2018. Study of water and nutrients requirement through drip irrigation in Okra. *J. Pharmacognosy Phytochem*. 1: 3172-3176.

Kabir, A., Ali, A., Waliullah, M. H. Rahman, M. M. M. U., and Rashid, A. 2013. Effect of spacing and sowing time on growth and yield of carrot (*Daucus carrota* L.). *Int. J. Sustain. Agric.* 5 (1): 29-36.

Kanauja, S. P. and Narayanan, R. 2003. biofertilizers for sustainable vegetable production. *Intensive Agric*. 41: 15-17.

Karla, A. 2003. Organic cultivation of medicinal and aromatic plants. A hope for sustainability and quality enhancement. *J. Org. Prod. Med. Aromat. Dye yielding plants (MADPs)*, 6: 198-199.

Karpagam, R., Kannan, M., Natarajan S., and Srinivasan, K. 2004. Studies on the efficacy of foliar feeding of water soluble fertilizers on growth parameters and yield of brinjal hybrid COBH. *S. Indian Hortic*. 52(1-6): 139-142.

KAU [Kerala Agricultural University]. 2011. *The Adhoc Package of Practices Recommendation for Organic Farming,* Kerala Agricultural University, Thrissur, 209p.

Kaur, A., Raturi, H. C. Kachwaya, D. S. Singh, S. K., and Singh, T. 2019. Effect of fertigation on growth and fruit yield of cucumber (*Cucumis sativus* L.) grown under open ventilated polyhouse condition. *J. Pharmacognosy and Phytochem***.** 24: 202-204

Kausar, R., Choudhary, M. I., Akram, M. I., Rehman, R. A. U., Ma, A., Khalid, M. A. U. R., Zubair, M., and Alvi, S. 2018. Response of groundnut

(*Arachis hypogaea* L.) to plant growth promoting Rhizobacteria in degraded soils. *Afr. J. Agric. Res*. 13(17): 904-910.

Kavitha, M., Natarajan, S., Pugalendhi, L., and Meenakshi, N. 2007. Yield and quality of tomato under shade and open conditions. *Res. Crops* 8(3): 651-655.

Kaya, C., Higgs, D., Kirnak, H., and Tas, I. 2003. Mycorrhizal colonization improves fruit yield and water use efficiency in watermelon (*Citrullus lanatus* Thunb.) grown under well-watered and water stressed conditions. *Plant Soil* 253: 287-292.

Kimura, K., Tanakamaru, S., and Ariyoshi, M. 1982. Studies on plant response to rainfall. Effect of rainfall on leaf expansion. *J. Agric. Meteorol.* 38: 295-301.

Kloepper, W., Zablotowick, R. M. Tipping, E. M. and Lifshitz, R. 1991. Plant growth promotion mediated by bacterial rhizosphere colonizers. Keister, D. L. and Cregan, P. B (eds.), *The Rhizosphere and Plant Growth*, Kluwer Academic Publishers, Dordrecht, Netherlands. 315-326.

Kolota E., M. and Osinska. 2001. Effciency of foliar nutrition of field vegetables grown at different nitrogen rates. *Acta Hortic*. 563: 87-91.

Kumar, A., Choudhary, A. K., and Suri, V. K. 2015. Influence of AM fungi and applied phosphorus on growth indices, production efficiency, phosphorus use efficiency and fruit succulence in okra (*Abelmoschus esculentus*)–pea (*Pisum sativum*) cropping system in an acid Alfisol. *Indian J. Agric. Sci.* 85 (8): 1030-1037

Kumar, S., Imtyaz, M., and Kumar. A. 2007. Effects of differential soil moisture and nutrient regimes on post harvest attributes of onion (*Allium cepa* L.). *Scientia Hortic.* 112: 121-129.

Kumar, T., Kumar, M., Singh, M. K., Kumar, V., Kumar, A., Kumar, S., and Singh, B. 2013. Impact of integrated nutrient management (INM) on growth and economic yield of okra. *Ann. Hortic.* 6(1): 107-114.

Kumar, V., Dhankhar, S. K., Vilas, C. A., Kathwal, R., and Yadav, N. 2016. Effect of spacing, fertilizers and varieties on growth and yield parameters of okra (*Abelmoschus esculantus* (L.) Moench) *J. Appl. Nat. Sci.* 8(3): 1388-1392.

Kuppusamy, M. 2008. Studies on the comparative performance of farm yard manure and vermicompost on yield and quality of okra [*Abelmoschus esculentus* (L.) Moench]. M. Sc. (Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore. 139p.

Le, A. T., Pék, Z., Takács, S., Neményi, A and Helyes, L. 2018. The effect of plant growth-promoting rhizobacteria on yield, water use efficiency and brix degree of processing tomato. *Plant Soil Environ.* 64: 523–529.

Leithy, S., Gaballah, M. S., Gomaa, A. M. 2009. Associative impact of bio and organic fertilizers on geranium plants grown under saline conditions. *Int. J. Acad. Res.* 1(1): 17-23.

Lenin, M., Selvakumar, G., Thamizhiniyan, P. and Rajendiran, R. 2010. Growth and biochemical changes of vegetable seedlings induced by arbuscular mycorrhizal fungus. *J. Exp. Sci.* 1(4): 27-31.

Lucy, M., Reed, E. and Glick, B. R. 2004. Applications of free living plant growth-promoting rhizobacteria. *Antonie van Leeuwenhoek*, 86: 1-25.

Madisa, M. E., Mathowal, T., Mpofu, C., and Oganne, T. A. 2015. Effects of plant spacing on the growth, yield and yield components of okra (*Abelmoschus esculentus* L.) in Botswana. *Am. J. Exp. Agric.* 6(1): 7-14.

Mahendran, P. P., Arulkumar, D., Gurusamy, A., and Kumar, V. 2009. Performance of nutrient sources and its levels on hybrid okra under drip fertigation system. Tamil Nadu Agricultural University, Coimbatore. Available: www.irncid.org/GetFileArticles.aspx. FilePrm 5384_19202.pdf [7 March 2019].

Mahendran, P. P., Arulkumar, D., Gurusamy, A., and Kumar, V. 2011. Performance of nutrient sources and its levels on hybrid bhendi under drip fertigation system. In: *Innovation in technology and management of micro-irrigation for crop production enhancement*. 8th International micro-irrigation congress under 21st International Congress on Irrigation and Drianage, 16-21 October 2011, Tehran, Iran.

Malerba, M. and Cerana, R. 2016. Chitosan effects on plant systems. *Int. J. Mol. Sci.* 17: 996-1001.

Manikandan, S., vasubramaniam, K. S and Geetha, R. 2015. Influence of drip fertigation on resultant seed quality in main and ratoon crops of pigeon pea (*Cajanus cajan* L.) cv. VBN3. *Int. J. Sci. Res.* 5(3): 315-320.

Manjunatha, G. 2004. Effect foliar nutrition of water soluble fertilizers in bhendi (*Abelmoschus esculentus*) hybrid. M. Sc. (Hort.) thesis, Tamil Nadu Agricultural University, Coimbatore. 142p.

Manuel, C., Palada, M., and Stafford, A. 1998. Planting density affects growth and yield of bush okra. Agricultural Experiment Station, University of the Virgin Islands. *Proceedings of the Caribean Food Crops Soc.*, 34th annual meeting.www.hort.purdue.edu/newcrop/proceedings1999/v4-388.html. [17 Jan, 2019].

Martin J. P. 1950. Use of acid, rosebengal and streptomycin in the plate method for estimating soil fungi. *Soil Sci*. 69: 215.

Martinez, V. O., Jorquera, M. A., Crowley, D. E., Gajardo, G., and Mor, M. L. 2010. Mechanisms and practical considerations involved in plant growth promotion by rhizobacteria. *J. Soil Sci. Plant Nutr.* 10(3): 293-319.

242

Masaki. T. 1987. Vegetable cultivation under the plastic rain shelter. *Japan Agric. Res. Q.* 20(3): 180-184.

Maurya, R. P., Bailey, J. A. and Chandler, J. A. 2013. Impact of plant spacing and picking interval on the growth, fruit quality and yield of okra (*Abelmoschus esculentus* (L.) Moench). *Am. J. Agric. For.* 1(4): 48-54.

Mbarek, K. B. and Boujelben, A. 2004. Behavior of tomato (*Lycopercicum esculentum* Mill.) and red pepper (*Capsicum annuum* L.) crops under greenhouse conditions conducted in single and twin rows. *Tropicultura*, 22 (3): 97–103

Meena, R. K., Tiwari, R. C., Meena, V. D., Charpota, J. L., and Meena, A. K. 2017. Effect of irrigation management and plant population on the performance of summer baby corn (*Zea mays* L.). *Int. J. Curr. Microbiol. App. Sci.* 6(7): 2274-2282.

Meenakshi, N. 2002. Growth and productivity of hybrid bitter gourd (*Momordica charantia* L.) cv. CoBgoH-1 under different macro and micronutrient fertigation levels. Ph. D. (Hort.) Thesis, Tamil Nadu Agricultural University, Coimbatore, 275p.

Meenakshi, N. and Vadivel, E. 2005. Effect of various levels of macro and micro nutrient fertigation on physiological attributes and biochemical characteristics in bitter gourd (*Momordica charantia* L.). *Prog. Hortic.* 37 (1): 48-55.

Megharaja, K. M. 2000. Studies on the effect of growing conditions and growth regulators on growth and productivity of hybrid capsicum cv. Indra. M. Sc. (Ag.) Thesis, University Agricultural Science , Bangalore, 78p.

Mehta, S. 2017. Effect of integrated use of nano and non nano fertilizers on quality and productivity of wheat (*Triticum aestivum* l.). M. Sc. (Ag.)

Thesis, Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir, 73p.

Violante, M. H. G., Jimenez, O. O., Dendooven, L, Soto, M. G., Castafieda, G. J., Davies Jr and Portugal, O. V. 2006. Arbuscular mycorrhizal fungi enhance fruit growth and quality of chile ancho (*Capsicum annuum* L.) cv. San Luis plants exposed to drought. ***Mycorrhiza***, 16: 261-267.

Mi, G., Chen, F., Yuan, L., and Zhang, F. 2016. Ideotype root system architecture for maize to achieve high yield and resource use efficiency in intensive cropping system. *Adv. Agron*. 139: 73-97.

Mia, M. A., Baset, Z. H., Shamsuddin, Z., Wahab, M. and Marziah. 2010. Effect of plant growth promoting rhizobacterial (PGPR) inoculation on growth and nitrogen incorporation of tissue-cultured musa plantlets under nitrogen-free hydroponics condition. *Aust. J. Crop Sci*. 4: 85-90.

Mir, S. Sirousehr, A. and Shiramohammadi, E. 2015. Effect of nano and biological fertilizers on carbohydrate and chlorophyll content of forage sorghum. *Int. J. Biosci.* 6(4): 157-164.

Mohammad, H., Aroiee, H., Ameri, A, and Fatemi, H. 2012. Effect of plant density and nitrogen fertilizer on growth, yield and fruit quality of sweet pepper (*Capsicum annuum* L.). University of Mashhad, Islamic Republic of Iran. Availble: http://www.academicjournals.org/AJAR. [23 Jan 2019].

Mohan, M. M., Luxmi, N. S., and Ibrahim, S. N. 2000. Chlorophyll stability index (CSI): its impact on salt tolerance in rice. *Int. Rice Res. Notes,* 25: 38-39.

Mondani, F., Khanisaeid, K., Honarmand, H. and Saeidi, M. 2019. Evaluating effects of plant growth promoting rhizobacteria on the radiation use efficiency and yield of soybean (*Glycine max*) under water deficit stress condition. *Agric. Water Manag.* 231: 707-713.

Moniruzzaman, M., Uddin, M. Z. and Choudhury, A. K. 2007. Response of okra seed crop to sowing time and plant spacing in south eastern hilly region of Bangladesh. *Bangladesh J. Agric. Res.* 32(3): 393-402.

Mouneke, C. O. and Asiegbu, J. E. 1997. Effect of okra planting desity and spatial; arrangement in intercrop with maize on the growth and yield of the component species. *Agron. Crop Sci.* 179: 2201-2207.

Muhammad, A., Aminifard, A. and Ahmed, A. 2001. Effect of phosphorus and planting density on seed production in okra (*Abelmoschus esculentus* L. Moench). *Int. J. Agric. Biol.* 22(3):12-16.

Muralidhar, A. P. 1999. Effect of fertigation with normal and water soluble fertilizers compared to drip and furrow system in capsicum- maize-sunflower sequence. Ph. D. Thesis, University of Agricultural Sciences, Bangalore, 227p.

Mushayabasa, T., Kona, D. and Gama, R. 2014. Yield and fruit quality of okra (*Abelmoschus esculentus* L. Moench) in response to plant density. *Int. J. Biosci.* 5(1): 449-454.

Naderi, M., Danesh, S. A. A., and Naderi, R. 2011. Application of nano technology in the optimization of formulation of chemical fertilizers. *Iran J. Nanotech.* 12: 16-23.

Nadiya, N., Kurien, E. K., Mathew, E. K. and Varughese, A. 2013. Impact of fertigation and drip system layout in performance of chilli (*Capsicum annuum*). *Int. J. Eng. Res. Dev.* 7: 85-88.

Nair, A. K., Hebbar, S. S., Prabhakar, M., and Rajeshwari, R. S. 2017. Growth and yield performance of okra (*Abelmoschus esculentus* (L.) Moench.) in relation to fertigation using different rates and sources of fertilizers. *Int. J. Curr. Microbiol. App. Sci.* 6(8): 137-143.

Nair, R., Varghese, S. H., Nair, B. G., Maekawa, T., Yoshida, Y., and Kumar, D. S. 2010. Nano particulate material delivery to plants. *Plant Sci.* 179: 154-163.

Nanthakumar, S. and Veeraraghavathatham, D. 2000. Effect of integrated nutrient management on yield and growth parameters and yield of brinjal (*Solanum melongena* L.) cv. PLR-1. *S. Indian Hortic.* 48(1-6): 31-35.

Narayanan, K., Dubey, P., Sharma, D., Katre, V. T., Tiwari, S. P. and Mishra, A. 2012. Effect of soil and foliar application of nutrients on growth and yield in tomato (*Lycopersicon esculentum* Mill.). *J. Hortic. Sci.* 7(1): 101-103.

Narda, N. K. and Chawla, J. K. 2002. A simple nitrate sub-model for trickle irrigated potatoes. *Irri. Drain.* 51: 361-371.

Narda, N. K. and Lubana, P. P. S. 2002. Studies on growth dynamics and yield of trickle fertigated okra. *J. Res. Agric. Univ.* 39 : 272-276.

Nayak, H., Sahoo, D., Swain, S. C., Jena, B. Paramjita, D., and Bisoyi, B. S. 2018. Influence of fertigation doses and mulching on yield attributing characters and post-harvest shelf life of pointed gourd (*Trichosanthes dioica* Roxb.). *Int. J. Curr. Microbiol. App. Sci.* 7(4): 3212-3220.

Novoselov, V. S. 1960. A closed volumeter for plant root systems. *Physiol. Rastenii*, 7: 243-244.

Nzikou, J. M., Tsieri, M. M., Matouba, E., Ouamba, J. M., Kapser, C., Parmentier, M., *et al.* 2006. Study on gumbo seed grown in Congo brazzaville for its food and industrial applications. *Afr. J. Biotech.* 5: 2469-2475.

O'Connell, P. F. 1992. Sustainable agriculture, a valid alternative. *Outlook Agric.* 21: 5-12.

Okon, I. E. 2014. Growth response of okra [*Abelmoschus esculentus* (L.) Moench] to arbuscular mycorrhizal fungus inoculation in sterile and non-sterile soil. *Int. J. Res Humanities Arts Literature*, 2: 31-38.

Ordookhani, K., Khavazi, K., Moezzi, A., and Rejali, F. 2010. Influence of PGPR and AMF on antioxidant activity, lycopene and potassium contents in tomato. *Afr. J. Agric Res*. 5(10): 1108-1116.

Palanisamy, V., Vanangamudi, K., Joyaroj, T., and Karivarattaraju, T. V. 1986. Influence of data of sowing and spacing on seed quality in bhindi. *S. Indian Hortic*. 34(1) : 23-25.

Parthasarathi, K. S., Krishnappa, M., Gowda, N. C., Reddy, S. and Anjanappa, M. 1999. Growth and yield of certain radish varieties to varying level of fertility. *Karnataka J. Agric. Sci*. 12(1-4): 148-153.

Paththinige, S. S., Upashantha, P. S. G., Ranaweera, B. R. M. and Fonseka, R. M. 2008. Effect of plant spacing on yield and fruit characteristics of okra (*Abelmoschus esculentus*). *Trop. Agric. Res*. 20: 336-342.

Pawar, D. P., Bhakar, S. R., Lakhawat, S. S., Kothari, M. and Patil, V. 2018. Interactive impact of irrigation and fertigation level on growth and yield attributes of cucumber under naturally ventilated polyhouse. *Int. J. Curr. Microbiol. App. Sci*. 7(6): 2604-2612.

Prasad, T. N. V. K. V., Sudhakar, P., Sreenivasulu, Y., Latha, P., Munaswamy, V., Raja Reddy, K., Sreeprasad, T. S., Sajanlal, P. R., and Pradeep, T. 2012. Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. *J. Plant Nutr*. 35: 905-927.

Premsekhar, M. and. Rajashree, V. 2009. Performance of hybrid tomato as influenced by foliar feeding of water soluble fertilizers: *Am.-Eurasian J. Sustain. Agric*. 3(1): 33-36

Pushpendra, S. and Hardaha, M. K. 2016. Effect of fertigation levels on growth, quality and yield of polyhouse cucumber (*Cucumis sativus*). *Int. J. Agric. Sci.* 8 (43): 1863-1866.

Radford, P. J. 1967. Growth analysis formula, their use and abuse. *Crop Sci.* 7: 171-175.

Rafique, M., Riaz, A., Anjum, A., Qureshi, M. A. and Mujeeb, F. 2018. Role of bioinoculants for improving growth and yield of okra (*Abelmoshus esculentus*). *Univ. J. Agric. Res.* 6(3): 105-112.

Rahman, M. A. 2005. Effect of spacing and different levels of nitrogen on the growth and yield of okra. M. Sc. (Horti.) thesis, Bangladesh Agriculture University, Mymensingh. 77p.

Raikova, O. P., Panichkin, L. A., and Raikova, N. N. 2006. Studies on the effect of ultrafine metal powders produced by different methods on plant growth and development. In: *Nanotechnologies and Information Technologies in the 21st Century*. Proceedings of the International Scientific and Practical Conference, Moscow, Russia, pp. 108-111.

Raj, A. F. S., Muthukrishnan, P., and Ayyadurai, P. 2013. Root characters of maize as influenced by drip fertigation levels. *Am. J. Plant Sci.* 4: 340-348.

Rajaraman,G and Pugalendhi, L. 2013. Potential impact of spacing and fertilizer levels on the flowering, productivity and economic viability of hybrid bhendi (*Abelmoschus esculentus* L. Moench) under drip fertigation system. *Am. J. Plant Sci.* 04 (09): 1784-1789.

Rajasekar, M., Nandhini, U. D., Swaminathan, V., and Balakrishnan, K. 2017. Impact of mulching and fertigation on growth and yield of grafted brinjal (*Solanum melongena* L.) under drip irrigation system *Int. J. Chem. Stud.* 5(3): 163-166.

Rajput, A., Rajput, S. S. and Jha, G. 2017. Physiological parameters leaf area index, crop growth rate, relative growth rate and net assimilation rate of different varieties of rice grown under different planting geometries and depths in SRI. *Int. J. Pure Appl. Biosci.* 5(1): 362-367.

Ram, H., Khan, M. M. and Singh, P. K. 2013. Effect of spacing and cultivars on growth and yield of okra [*Abelmoschus esculentus* (L.) Moench]. *Asian J. Hortic.* 8(2) : 507-511.

Rana, R. S., Krishna, D., and Verma, I. M. 2005. Fertigation studies in hybrid tomato (*Lycopersicon esculentum* Mill.). *Ann. Agric. Biol. Res.* 10(1): 87-90.

Rao, C. S. 1996. Fertigation- Applying fertilizers through drip irrigation systems. In: *Proceedings of All India Seminar on Modern Irrigation Techniques*, 14 November, 2002, Bangalore, Karnataka, 135p.

Rekha, K. B. and Mahavishnan, K. 2008. Drip fertigation in vegetable crops with emphasis on ladies finger (*Abelmoschus esculentus* (L.) Moench) - A review. *Agric. Rev.* 29: 298-305.

Richardson, A. E. 2001. Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. *Aust. J. Plant Physiol.* 28: 897-906.

Rodriguez, H. and Fraga, R. 1999. Phosphate solubilizing bacteria and their role in plant growth promotion. *Biotech. Adv.* 17: 319-339.

Sadasivam, S and Manickam, A. 1992. *Biochemical Methods.* New Age International (P) Limited, Publishers, New Delhi, India, 105p.

Sahana, P. N., Adivappar, S. V., Girijesh, G. K. and Ganapathi, M. 2018. Effect of fertigation, mulching and micronutrients on the soil and leaf nutrient contents of pole bean (*Phaseolus vulgaris* L.) under polyhouse. *Int. J. Chem. Stud.* 6(4): 457-460.

Sahin, F., Kotan, R., Demirci, E. and Miller, S. A. 2000. Domates ve biber bakteriyel leke hastalığı ile biyolojik savasta actigard ve bazi antagonistlerin etkinligi. *Atatürk Univ. J. Agric. Faculty*. 31: 11-16.

Saimbhi, M. S., Jasiwal, S. P., Nandpuri, K. S. and Kaur, G. 1975. Effect of phorate and N on plant growth, seed yield and chemical composition of okra. *Indian J. Agric. Sci.* 43: 930-933.

Sampathkumar, V. and Pandian, B. J. 2010. Effect of fertigation frequencies and levels on growth and yield of maize. *Madras Agric. J.* 97 (7-9): 245-248.

Sanchita, B., Luchon, S., Pankaj, B., Tridi, P. and Bhaskarjyothi 2010. Studies on effect of fertigation with different levels of N and K fertilizers on growth, yield and economics of early season capsicum under cover. *Veg. Sci.* 37(2): 160-163.

Sasani, G. V., Patel, C. K., Patel, R. N., Patel, N. H. and Patel, S. H. 2006. Efficient use of water and fertilizers through drip fertigation in potato. *Potato J.* 33(3-4): 131-133.

Savitha, B. K., Paramaguru, P. and Pugalendhi, L. 2010. Effect of drip fertigation on growth and yield of onion. *Indian J. Hortic.* 67: 334-336.

Shaha, P. K., Aditya, D. K. and Sharfuddin, A. F. M. 1989. Effects of plant spacing and picking interval on the growth and yield of okra cv. Pusa Sawani. *Bangladesh Hort.* 17(2) : 0-14.

Shams, A. S., Abd El-Rahman, H. M. and El-Ramady, H. R. 2013. Evaluation of integrated nutrient management practices for lettuce production under drip irrigation system. *J Appl. Sci. Res.* 9 (3): 2223-2231.

Shanke, B. R., Jadao., Ghawade, S. M. and Mahorkar V.K. 2003. Effect of different level of N and P on growth and seed yield of okra (Var. Parbhani Kranti.), under Akola condition. *Orissa J. Hort.* 31 (1): 123-124.

Sharafzadeh, S. 2012. Effects of PGPR on growth and nutrients uptake of tomato. *Int. J. Adv. Eng. Technol.* 2(1): 27-31.

Sharifi, S. K., Lalitha, B. S., Qasimullah, R., Kumar, P. G. K., and Manjanagouda, S. S. 2018. Effect of foliar application of water soluble fertilizer on growth and yield of soybean (*Glycine max* L. Merrill). *Int. J. Pure App. Biosci.* 6(5): 766-770.

Sharma, A., Sharma, R. P., Sharma, G. D., Sankhyan, N. K., and Sharma, M. 2014. Integrated nutrient supply system for cauliflower-french bean-okra cropping sequence in humid temperate zone of North-Western Himalayas. *Indian J. Hortic.* 71(2): 211-216.

Sharma, P. and Kaushal, A. 2015. Economics of growing okra under drip fertigation. *Indian J. Sci Technol.* 8(35):28-31.

Shedeed, S. I., Zaghloul, S. M., and Yassen, A. A. 2009. Effect of method and rate of fertilizer application under drip irrigation on yield and nutrient uptake by tomato. *Ozean J. Appl. Sci.* 2(2): 139-147.

Shilpa and Bijalwan, P. 2018. Effect of plant architecture on seed yield and quality of okra [*Abelmoschus esculentus* (L.) Moench]- a review. *Int. J. Curr. Microbiol. App. Sci.* 7(02): 3794-3802.

Shinde, B. P. and Khanna, M. 2014. Impact of AM fungi on biochemical changes in potato plants. *Int. J. Curr. Microbiol. App. Sci.* 3(7): 1018-1027.

Shinde, J. B., Malunjkar, B. D., Raut, R. S., Patil, P. D. and Thawal, D. W. 2010. Response of cucumber to fertigation under drip irrigation system. *Bioinfolet,* 7(2): 161-164.

Shruti, M. Y. and Aladakatti, Y. R. 2017. Effect of drip irrigation and fertigation on yield, economics and water use efficiency of intra-hirsutum Bt cotton. *J. Farm Sci.* 30 (2): 185-189.

Siddique, K. H. M., Walton, G. H., and Seymour, M. 1993. A comparison of seed yields of winter grain legumes in Western Australia. *Aus. J. Exp. Agric.* 33(7): 915-922.

Silber, A., Xu, G., Levkovitch, I. Soriano, S. Bilu, A., and Wallach. R. 2003. High fertigation frequency: the effects on uptake of nutrients, water and plant growth. *Plant Soil* 253: 467-477.

Singh, A. K., Chandra, P. and Srivastava, R. 2010. Response of micro-irrigation and fertigation on high-value vegetable crops under control conditions. *Indian J. Hortic.* 67 (3): 418-420.

Singh, B. P. 1996. Effect of row and plant spacing on yield and yield components of okra. *Indian J. Agron.* 35: 439-441.

Singh, R., Asrey, R., and Nangare, D. D. 2003. Studies on the performance of tomato and capsicum under medium cost greenhouse *Proceedings of All India Seminar on potential and prospects for protective cultivation*, Institute of Engineers, Ahmednagar, December 12-13, pp158-161.

Singhal, V. K., Patel, G. G., Bambhaneeya, S., Patel, D. H., and Saras, P. K. 2016. Effect of foliar application of water soluble fertilizers in okra. *Res. Environ. Life Sci.* 9(3): 297-299.

Snedecor, G. W. and Cochran, W. G. 1980. *Statistical Methods*. (7th Ed.) Ames, Iowa: State Univ. Press, 465p.

Sollapur, D. L. and Hiremath, S. M. 2017. Effects of planting geometry and fertilizer levels on growth and yield of hybrid brinjal. *Int. J. Agric. Sci.* 13(1): 97-100.

Srinivas, K. and Hedge, D. M. 1984. Growth analysis of capsicum (*Capscicum annuum* L.) cultivars in relation to plant spacing. *Singapore J. Primary Ind.* 12: 152-158.

Stanhill, G. 1987. Water use efficiency. *Adv. Agron.* 10: 3953-85..

Starnes, W. J. and Hardley, H. H. 1965. Chlorophyll content of various strains of soybean, *Glycine max. Crop Sci.* 5: 9-11.

Stoffella, P. J. and Bryan, H. H. 1988. Plant population influences growth and yields of bell pepper. *J. Am. Soci. Hortic. Sci.* 113: 835-839.

Streck, N. A., Pinheiro, D. G., Zanon, A. J., Gabriel, L. F., Rocha, T. S. M., de Souza, A. T., and da Silva, M. R. 2014. Effect of plant spacing on growth, development and yield of cassava in a subtropical environment. *Bragantia* 73(4): 407-415.

Subbiah, B. V. and Asija, C. L. 1956. A rapid procedure for the estimation of available N in soils. *Curr. Sci.* 25: 259-260.

Subramanian, K. S., Manikandan, A., Thirunavukkarasu, M. and Rahale, C. S. 2015. Nano-fertilizers for balanced crop nutrition. *Nano technol. Food Agric.* 5: 69-80.

Sundaram, V. and Kanthaswamy. V. 2005. Response of okra to foliar feeding of water soluble fertilizers. *Veg. Sci.* 32 : 92-93.

Talukder, M. A. H., Mannaf, M. A., Alam, M. K., Salam, M. A., and Amin, M. M. U. 2003. Influence of sowing time, plant spacing and picking interval on the growth and yield of okra. *Pak. J. Biol. Sci.* 6(18): 1626-1630.

Thakur, J., Kumar, P. and Mohit. 2018. Studies on conjoint application of nutrient sources and PGPR on growth, yield, quality and economics of cauliflower (*Brassica oleracea* var. botrytis L.). *J. Plant Nutr.* 41(14): 1862-1867.

Timmusk, S., Behers, L., Muthoni, J., Muraya, A. and Aronsson. A. 2017. Perspectives and challenges of microbial application for crop improvement. *Front Plant Sci.* 8: 49-55.

Timonin, M. I. 1940. The interaction of higher plants and micro-organisms, Study of microbial population of rhizosphere in relation to resistance of plants to soil borne diseases. *Canad. J. Res.* 18: 444-456.

Tiwari, K. N., Mal, P. K., Singh, A. and Chattopadhyay, A. 1998. Response of okra to drip irrigation under mulch and non mulch conditions. *Agric. Water Manag.* 38: 91-102.

Tomar, I. S. and Singhal, H. C. 2007. Effect of varying levels of nitrogen and different dates of planting on fruit quality of rabi tomato. *JNKVV. Res. J.* 41(2): 219-223.

Tumbare, A. D. and Bhoite, S. U. 2002. Effects of solid soluble fertilizer applied through fertigation on growth and yield of chilli (*Capsicum annuum*). *Indian J. Agric. Sci.* 72(2): 109-111.

Tumbare, A. D. and Nikam, D. R. 2004. Effect of planting and fertigation on growth and yield of green chilli (*Capsicum annuum*). *Indian J. Agric. Sci.* 74(5): 242-245.

Turk, M. A., Tawaha, A. M. and El-shatnawi, M. K. J. 2003. Reponse of lentil (*Lens culinaris* medk) to plant density, sowing date and phosphorus fertilization. *J. Agric. Crop Sci.* 189: 1-6.

Ughade, S. R., Tumbare, A. D., and Surve, U. S. 2016. Fertigation scheduling to summer tomato (*Solanum lycopersicum* L.) under protected cultivation. 11(1): 321-325.

Umadevi, G. and Sitaramaiah, K. 1998. Effect of super-phosphate and rock phosphate as source of phosphorus in combination with endomycorrhizal fungi on growth and chemical composition of blackgram. *J. Mycol. Plant Pathol.* 28(2): 154-160.

Van, N. S., Minh, D. H., and Anh, N. D. 2013 Study on chitosan nanoparticles on biophysical characteristics and growth of Robusta coffee in green house. *Biocatalysis Agric. Biotech*. (2): 289-29.

Varughese, A., Menon, J. S. and Mathew, E. K. 2014. Effect of fertigation levels and drip system layout on performance of okra under plastic mulch. *J. Agric. Engg*. 51(4): 28-32.

Veeramani, P., Subrahmaniyan, K., and Ganesaraja, V. 2012. Organic manure management on groundnut-A review. *J Agric. Res.* 1: 238-243.

Veeraputhiran, R. 2000. Drip fertigation studies in hybrid cotton. Ph.D. Thesis, TNAU, Coimbatore. 255p.

Venkadeswaran, E. and Sundaram, V. 2016. Nutrient uptake of hybrid okra (*Abelmoschus esculentus* (L.) Moench) under drip fertigation. *Indian J. Agric. Res*. 50 (3): 226-231.

Venkadeswaran, E., Sundaram, V. and Sankar, R. 2014. Influence of trickle fertigation on yield and quality of hybrid okra [*Abelmoschus esculentus* (L.) Moench]. *Asian J. Hortic.* 9(2) : 285-290.

Venkataraman, R. 2007. Response of okra [*Abelmoschus esculentus* (L.) Moench] to foliar feeding of water soluble fertilizers. M. Sc. (Hort.) thesis. PAJANCOA and RI, Karaikal 75p.

Vijayakumar, G., Tamilmani, D. and Selvaraj, P. K. 2010. Irrigation and fertigation scheduling under drip irrigation in brinjal crop. *Indian J. Bioresour. Manag.* 1: 72-76.

Viji, V., Balakumbahan R., Lakshmanan, V. R. Poorniammal. and Naik, E. K. 2018. Effect of liquid bioinoculants and inorganic source of nutrients on biomass production and quality of annual moringa (*Moringa oleifera* Lam.) var. PKM – 1. *Int. J. Curr. Microbiol. App. Sci.* 7(06): 699-706.

Warner, H. 2003. Plant spacing and row arrangement affects processing tomato yield.www.omafra.gov.on.ca/english/crops/hort/news/hortmatt/2003/02hrt 03. [2 July 2019]

Watson, D. J. 1947. Comparative physiological studies in the growth of field crops. Variation in net assimilation rate and leaf area between species and varieties, and within and between years. *Ann. Bot.* 11*:* 41–76.

Whitehead, W. F. and Singh, B. P. 2000. Yield, time of maximum CO_2 exchange rate, and Leaf-area Index of 'Clemson Spineless' Okra are affected by within-row spacing. *Hortic. sci*. 35(5): 849–852.

Williams, R. F. 1946. The physiology of plant growth with special reference to the concept of net assimilation rate. *Ann. Bot.* 10: 41-72.

Wondatir, S., Belay, Z. and Desta, G. 2013. Effect of drip lateral spacing and irrigation regime on yield, irrigation water use efficiency and net return of tomato and onion production in the Kobo Girrana valley of Ethiopia. In: Wolde Mekuria. (ed). *Rainwater Management For Resilient Livelihoods In Ethiopia*. Proceedings of the Nile Basin Development Challenge science meeting, Addis Ababa, 9–10 July 2013. NBDC Technical Report 5. Nairobi, Kenya: International Livestock Research Institute.

Yadav, S. K. and Dhankhar, B. S. 1999. Performance of Varsha Uphar cultivar of okra [*Abelmoschus esculentus* (L.) Moench] as affected by the sowing dates and plant geometry. *Veg. Sci.* 26(2): 180-182.

Yoshida, S., Forno, D. A., Cock, J. H. and Gomez, K. A. 1976. *Laboratory Manual for Physiological Studies of Rice* (3rd Ed), IRRI, Philippines, 61p.

Youssef, M. M. A. and Eissa, M. F. M. 2014. Biofertilizers and their role in management of plant parasitic nematodes.-A review. *J. Biotech. Pharma. Res.* 5(1): 001-006.

Zajac, T., Grzesiak, S., Kulig, B. and Polacek, M. 2005. The estimation of productivity and yield of linseed (*Linum usitatissimum* L.) using the growth analysis. *Acta Physiol Plant*. 27: 549-558.

Zibelo, H., Witsadik, K. and Sharma, J. J. 2016. Effect of inter and intra-row spacing on growth and yield of okra [*Abelmoschus esculentus* (L.) Moench] at Humera, Northern Ethiopia *J. Biol. Agric. Health care* 6(3): 45-54.

Zimmer, W., Kloos, K., Hundeshagen, B., Neiderau, E. and Bothe, H. 1995. Auxin biosynthesis and denitrification in plant growth promotion bacteria. In: Fendrik, J., De Gallo, M., Vandeleyden, J., Zamoroczy, M., (eds.), Azospirillum VI and Related Microorganisms. *Ecol. Sci*. 37: 120-141.

APPENDIX

Appendix- I

Composition of media for microbial enumeration

1. Enumeration of Bacteria

Media: Nutrient Agar

Composition:

1. Peptone - 5 g
2. NaCl - 5 g
3. Beef Extract - 3 g
4. Agar - 20 g
5. pH - 7.0
6. Distilled water - 1000 ml

2. Enumeration of Fungi

Media: Rose Bengal Agar

Composition:

1. Glucose - 3.0 g
2. $MgSO_4$ - 0.2 g
3. KH_2PO_4 - 0.9g
4. Rose Bengal - 0.5 g
5. Streptomycin - 0.25 g
6. Agar - 20 g
7. Distilled water - 1000 ml

3. Enumeration of Actinomycetes

Media: Kenknight's Agar

Composition:

1. Dextrose - 1.0 g
2. KH_2PO_4 - 0.1 g
3. $NaNO_3$ - 0.1 g
4. KCl - 0.1 g
5. $MgSO_4$ - 0.1 g
6. Agar - 15 g
7. Distilled water - 1000 ml

Appendix- II

Weather data in open field during the cropping period

Weekly averages (1/5/2017- 1/8/2018)

Standard week	Mean temperature (°C)	Average relative humidity (%)	Total rainfall (mm)	Average light intensity (K. lux)
18	30.1	80.5	20	112.5
19	29.7	81.4	10.8	102.3
20	30	81.9	77.3	95.4
21	29.5	83.1	4.2	115.4
22	27.9	90.9	189.9	75.4
23	27.7	89.8	36.7	89.2
24	28.5	83.6	11.3	98.7
25	28.3	84.2	18.9	95.4
26	27.4	90.6	143.8	87.5
27	28.1	83.5	12.7	103.4
28	27.9	84.1	12.7	94.5
29	27.9	84.7	22.1	94.2
30	28.6	81.9	7.2	124.3
31	28.7	84.9	18.5	115.7
32	27.9	84.2	21.4	103.5
33	27.9	86.3	30.5	89
34	27.6	86.2	18.6	105.2
35	27.9	82.7	114.9	85.1
36	28.5	84.7	30.6	102.4
37	27.8	85.1	93.3	97.5

38	27.4	88	55.8	90.7
39	28.3	86.4	63.2	87.2
40	28.4	85.2	68.6	110.7
41	28.1	89.4	48.1	97.6
42	27.7	92.4	21.7	109.7
43	28	90.5	21	110.3
44	27.7	90.7	104.4	77.7
45	27.5	90.9	0	124.6
46	27.9	84.2	0	128.4
47	27.5	87.4	45.3	97.5
48	26	94.6	205.9	65.7
49	27.3	86.3	9.4	108.3
50	27.8	87	0.9	125.4
51	28	84.2	0	105.4
52	28.2	83.7	0	125.5
18	30.4	77.9	2	115.2
19	29.4	82.3	47.3	92.1
20	28.5	82.1	109.2	84.1
21	28.5	86.3	64.1	90.5
22	28.3	86.9	68	92.4
23	27.6	91.2	126.6	87.4
24	28.1	87.2	63.5	94.2
25	27.8	88.1	57	101.4
26	27.9	85.4	25.2	103.8
27	28.1	81	10.2	134.3

28	26.3	89.6	69.3	94.2
29	27	85.1	56.3	94.5
30	27.5	81.3	13.1	97.9
31	26.7	85.6	136.2	78.4
32	26.8	88.1	107.3	97.4
33	25.8	92.4	205.2	84.2
34	27.5	83	2.8	117.4
35	28.2	80.5	0	124.1

Weather data inside rain shelter during the cropping period

Weekly averages (1/5/2017- 1/8/2018)

Standard week	Mean temperature (°C)	Average relative humidity (%)	Average light intensity (K. lux
18	33	68	56
19	30.75	61.75	52.3
20	32.75	61.75	45.4
21	31.5	59.5	65.4
22	29	68	45.4
23	31.875	59.875	49.2
24	32.5	60.5	48.7
25	31.5	59.5	45.4
26	31.75	59.75	37.5
27	30.75	74.75	73.4
28	30.5	58.5	54.5
29	30.25	58.25	54.2
30	30.75	68.75	64.3
31	34	62	65.7
32	32	60	53.5
33	30.5	58.5	49
34	31.25	69.25	55.2
35	32.75	61.75	35.1
36	32.5	71.5	52.4
37	32.5	61.5	47.5

38	29	57	40.7
39	32.25	61.25	37.2
40	29.5	77.5	60.7
41	30.25	58.25	47.6
42	30.25	67.25	59.7
43	34	68	60.3
44	30.5	58.5	37.7
45	29	57	54.6
46	28.9	73.9	68.4
47	28	56	47.5
48	27.35	55.35	35.7
49	31	70	58.3
50	30.25	72.25	65.4
51	31.5	69.5	55.4
52	31	69	65.5
18	29.75	71.75	55.2
19	31.5	59.5	42.1
20	30.25	58.25	34.1
21	30.75	58.75	40.5
22	30.5	58.5	42.4
23	30.75	58.75	37.4
24	31.75	59.75	44.2
25	33	61	51.4
26	32.5	68.5	53.8
27	31.75	67.75	84.3

28	30.75	61.75	44.2
29	32.5	60.5	44.5
30	32	65	47.9
31	29.25	60.25	38.4
32	30	62	47.4
33	28	63	34.2
34	32	72	57.4
35	33.5	71.5	64.1

Appendix -III

Cost of cultivation of bhindi grown under rain shelter and open field condition for one season

Components	Rain shelter (Rs.)	Open field (Rs.)
Structure and cladding materials	49,999	-
Drip	20,000	20,000
Mulching	19,200	19,200
Machine power	7,200	7,200
Manures	2,500	2,500
Fertilizers	5,708	5,708
Seeds	12,750	12,750
Labour	1,46,550	1,73750
Total	2,60,907	2,41,108

- Structure (including drip irrigation) Rs. 800 per m^2 for life span of 15 years
- Mulching sheet for a life span of 5 years

AGRO TECHNIQUES IN BHINDI FOR PRECISION FARMING

BY

AMMU PUNNOOSE

(2016-21-018)

ABSTRACT

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY IN AGRICULTURE

FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM – 695522
KERALA, INDIA

2019

ABSTRACT

The investigation entitled "Agro techniques in bhindi for precision farming" was conducted during 2016 to 2019 at the Instructional Farm, College of Agriculture, Vellayani. The objectives were to standardize the spacing and response of bio inoculants for bhindi under rain shelter and open field conditions and to evaluate the effect of fertigation and foliar nutrition on improving the growth, yield and quality of bhindi and to work out the economics of different cultivation systems.

The first experiment was to standardise the spacing and bio inoculants suitable for the cultivation of bhindi under rain shelter and open field conditions. A field experiment was conducted using the variety Varsha Uphar, during May to August- 2017. The treatments consisted of three spacings (S_1 - 60 cm x 30 cm, S_2- 60 cm x 45 cm and S_3 - 60 cm x 60 cm) as first factor and three bio inoculant treatments (B_1- Bio inoculant- PGPR mix 1, B_2 - Bio inoculant - Arbuscular mycorrhizal fungi, B_3 - No Bio inoculant) as second factor. The experiment was carried out in RBD with three replications.

Under both open and rain shelter conditions, taller plants were obtained with closer spacing of 60 cm x 30 cm whereas, numbers of leaves and branches per plant, tap root length and root volume were significantly higher at wider spacing (60 cm x 60 cm). Among the bio inoculants, application of PGPR mix 1 resulted in significantly taller plants, more number of leaves and branches at all growth stages and longer tap root and root volume at final harvest. LAI was found to be significant among spacings at 60 and 90 DAT under open field condition. Yield attributes like number of flowers and fruits per plant, length of fruit, weight of fruit and weight of fruits per plant were found to be significantly higher at 60 cm x 60 cm and inoculation with PGPR mix 1. Wider spacing of 60 cm x 60 cm along with PGPR mix 1 was found to be superior to the other combinations with respect to growth and yield attributes. Fruit yield was significantly influenced by spacing and bio inoculant application and was higher at 60 cm x 30 cm (17.03 t ha^{-1} under rain shelter and 14.07 t ha^{-1} under open field condition) and PGPR mix 1 (16.83 t ha^{-1} under rain shelter and 13.50 t ha^{-1} under open field condition). Their interaction was also found to be significant

(18.78 t ha^{-1} under rain shelter and 16.36 t ha^{-1} under open field condition) under both conditions. Dry matter production was significantly higher for 60 cm x 30 cm spacing and PGPR mix 1. Crop growth rate (CGR) was significantly higher at 60 cm x 30 cm and PGPR mix 1 under rain shelter and open field condition. Among the spacings, 60 cm x 60 cm and among bio inoculants, PGPR mix 1 were found superior with respect to relative growth rate (RGR) under both conditions. Among the fruit quality aspects, significant difference was observed for protein content inside rain shelter. NPK uptake showed an increasing trend with decreased plant to plant spacing. Application of PGPR mix 1 resulted in higher nutrient uptake. Available P status of soil after the experiment was significantly higher for 60 cm x 60 cm spacing under rain shelter. AMF treated soil showed significantly higher available P under open field condition. Available K was significantly higher for 60 cm x 60 cm spacing and PGPR mix 1 under rain shelter and open field condition. Higher bacterial and actinomycetes population were found in 60 cm x 30 cm spacing and PGPR mix 1 under both conditions. Higher fungal population was observed in AMF treated soil. Significantly higher water use efficiency was observed with 60 cm x 30 cm spacing and PGPR mix 1 and their interaction under rain shelter and open field condition. Net return and B: C ratio were also higher at 60 cm x 30 cm spacing (B: C ratio of 1.76 under rain shelter and 1.63 under open field) and PGPR mix1 (B: C ratio of 1.75 under rain shelter and 1.58 under open field) and their interaction under both condition (B: C ratio of 1.94 under rain shelter and 1.90 under open field). The first experiment revealed that growing bhindi at a spacing of 60 cm x 30 cm along with seedling inoculation with PGPR mix 1 resulted higher yield, and profit under rain shelter and open field condition

The second experiment for standardization of nutrient schedule of bhindi under rain shelter and open field condition was conducted during September to December, 2017 and May to August, 2018. The best treatments from the first experiment were used for this trial. The trial was laid out in split plot design with five replications. The main plot treatments consisted of four levels of fertigation; 50 % *adhoc* POP recommendation for precision farming (F_1), 75 % *adhoc* POP recommendation for precision farming (F_2), 100 % *adhoc* POP recommendation for precision farming (F_3), 125 % *adhoc* POP recommendation for precision farming (F_4) and the sub plot treatments consisted of two foliar levels; poly feed fertilizer (19:19:19 at 0.5 %) (L_1) and nano NPK (4: 4: 4 at 0.3 %) (L_2). The variety used for the experiment was Varsha Uphar.

Growth characters such as plant height, number of leaves per plant, number of branches per plant, LAI at monthly intervals, tap root length and root volume at harvest were significantly higher for the fertigation level F_3 and foliar application of L_1 under rain shelter, and F_4 and L_1 under open field condition. Yield attributes *viz*., number of flowers and fruits per plant, fruit set percentage, length of fruit, fruit weight, total fruit weight per plant, and yield per hectare were higher for the fertigation level of F_3 and was on par with F_4 and foliar level of L_1 under rain shelter. Under open field condition, regarding yield attributes, fertigation level of F_4 was on par with F_3 and foliar level of L_1 was significantly higher than L_2. Considering the interaction, under rain shelter, $f_3 l_1$ recorded higher fruit yield per hectare and under open field condition, interaction of $f_4 l_1$ was on par with f_3l_1. CGR, RGR and NAR recorded by F_4 and F_3 were comparable and among the foliar levels, L_1 was found to be significantly higher under both conditions. Under both growing conditions, higher chlorophyll content was observed under the fertigation level F_4. Chlorophyll content was significantly higher with L_2. Under rain shelter, F_3 and L_1 recorded higher dry matter production. Under open field condition, the highest dry matter production was recorded by F_4 was on par with F_3 among the fertigation levels and L_1 among the foliar levels. Fruit quality parameters were significantly higher at F_4 and L_2 under both conditions. Higher NPK uptake was found for F_3 and F_4 under rain shelter and open field condition respectively. Available nutrients in the soil after the experiment showed an increasing trend with increasing fertigation levels under both conditions. Higher fertigation level (F_4) resulted in higher microbial count under both conditions. Foliar level with L_2 resulted in higher microbial count inside rain shelter. Higher water use efficiency was recorded for F_3 and L_1 under rain shelter and F_4 and L_1 under open field condition. Highest net return and B: C ratio was obtained for F_3 (B: C ratio of 2.05 during Sept-Dec, 2017 and 2.12 during May- Aug, 2018) and was on par with F_4 (B: C ratio of 1.93 during Sept –Dec, 2017 and 2.11 during May – Aug, 2018) among the fertigation levels under rain shelter. Under open field condition, F_4 (B: C ratio of 1.64 during Sept -Dec, 2017 and 2.03 during May- Aug, 2018) was on par with F_3 (B: C ratio of 1. 60 during Sept –Dec, 2017). Among the foliar levels, L_1 recorded the highest B: C ratio under both growing conditions.

The study revealed that growing bhindi at a spacing of 60 cm x 30 cm and seedling inoculation with PGPR mix 1 resulted in higher yield and profit under rain shelter and open field conditions. Nutrient scheduling of 98: 25: 136 kg NPK ha^{-1} (100 % *Adhoc* POP recommendation) along with foliar application of poly feed (19:19:19) at 0.5 % at fortnightly intervals enhanced the growth, yield and profit under rain shelter condition. Fertilizer dose of 122: 31: 170 kg NPK ha^{-1} (125 % *Adhoc* POP recommendation) or 98: 25: 136 kg NPK ha^{-1} (100 % *Adhoc* POP recommendation) with foliar application of poly feed (19:19:19) at 0.5 % at fortnightly intervals was beneficial for open field condition. Application of 125 % *Adhoc* POP recommendation along with foliar spray of nano NPK at 0.3 % at fortnightly intervals improved the fruit quality under both conditions.

സംഗ്രഹം

"വെണ്ടയിലെ കൃത്യത കൃഷിയിലുള്ള കാർഷിക സാങ്കേതിക വിദ്യകൾ " എന്ന വിഷയത്തെ ആസ്പദമാക്കി ഒരു ഗവേഷക പഠനം വെള്ളായണി കാർഷിക കോളേജിൽ 2016 - 2019 കാലയളവിൽ നടത്തുകയുണ്ടായി. കൃത്യത കൃഷിയിൽ വെണ്ടയുടെ നടീൽ അകലം സ്ഥിരീകരിക്കുക, ജൈവ ഇനോകുലങ്ങളുടെ സ്വാധീനം മഴമറയിലും തുറന്ന കൃഷി രീതിയിലും കണ്ടെത്തുക, ജലം വഴിയുള്ള വളപ്രയോഗം (ഫെർട്ടിഗേഷൻ), മൂലകങ്ങൾ ഇലകളിൽ നനച്ചു നൽകുന്ന രീതി (ഫോളിയർ) എന്നിവയ്ക്ക് വെണ്ടയുടെ വളർച്ചയിലും വിളവിനുമുള്ള സ്വാധീനം വിശകലനം ചെയ്യുക, ആദായം കണ്ടെത്തുക തുടങ്ങിയവയായിരുന്നു പ്രധാന പഠന ലക്ഷ്യങ്ങൾ.

ആദ്യ വിള പരീക്ഷണം 'വർഷ ഉപഹാർ' എന്ന വെണ്ട ഇനത്തിൽ മൂന്ന് തരം നടീൽ അകലങ്ങളും (60 x 30 സെ.മി, 60 x 45 സെ.മി, 60 x 60 സെ.മി) മൂന്ന് തരം ജൈവ ഇനോകുലങ്ങളും (പി. ജി. പി.ആർ. മിക്സ്- 1 , എ). എം. എഫ്, ജൈവ ഇനോകുലം ഇല്ല) ഉപയോഗിച്ച് നടത്തുക ഉണ്ടായി. രണ്ടാമത്തെ പരീക്ഷണത്തിൽ മഴമറയിലും തുറന്ന കൃഷിരീതിയിലും വെണ്ടയുടെ പോഷക രീതി ക്രമപ്പെടുത്തുക എന്നതായിരുന്നു ലക്ഷ്യം.

പഠനത്തിൽ നിന്ന് വെണ്ടയെ 60 x 30 സെ.മി അകലത്തിൽ നടുന്നതും പി. ജി. പി.ആർ. മിക്സ്- 1 ഉപയോഗിക്കുന്നതും ഉയർന്ന വിളവും ലാഭവും നൽകുമെന്ന് തെളിഞ്ഞു. ഹെക്ടറിൽ 98 : 25 :136 കിലോ ഗ്രാം നൈട്രജൻ, ഫോസ്ഫറസ്, പൊട്ടാസിയം എന്നിവ നൽകുന്നതോടൊപ്പം 14 ദിവസത്തെ ഇടവേളയിൽ 0.5

ശതമാനം പോളിഫീഡ് (19 : 19 : 19) ഇലകളിൽ നനച്ചു കൊടുക്കുന്നതും മഴമറയിലെ കൃഷിക്ക് ഏറ്റവും അനുയോജ്യമാണെന്ന് കണ്ടെത്തി. ഹെക്ടറിൽ 122 : 31 : 170 കിലോ ഗ്രാം അല്ലെങ്കിൽ 98 : 25 :136 കിലോ ഗ്രാം നൈട്രജൻ, ഫോസ്ഫറസ്, പൊട്ടാസിയം എന്നിവ നൽകുന്നതോടൊപ്പം 14 ദിവസത്തെ ഇടവേളകളിൽ 0.5 ശതമാനം പോളിഫീഡ് (19 : 19 : 19) ഇലകളിൽ നനച്ചു കൊടുക്കുന്നതും തുറന്ന കൃഷിരീതിയിൽ ഉത്തമമാണെന്ന് വ്യക്തമായി. 125 % നിശ്ചയിക്കപ്പെട്ട പാക്കേജ് കൃഷിരീതിയോടൊപ്പം നാനോ നൈട്രജൻ, ഫോസ്ഫറസ്, പൊട്ടാസിയം 0.3 ശതമാനം 14 ദിവസത്തെ ഇടവേളയിൽ നൽകുന്നത് വെണ്ടയ്ക്കയുടെ ഗുണത്തിന് നല്ലതാണെന്നും കണ്ടെത്തി.

KERALA AGRICULTURAL UNIVERSITY
CENTRAL LIBRARY
174741