RESPONSE OF CHILLI (*Capsicum annuum* L.) TO PLANT GROWTH PROMOTING RHIZOBACTERIA FLUORESCENT PSEUDOMONADS

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DECLARATION

I hereby declare that this thesis entitled "**Response of chilli (*Capsicum annuum* L.) to plant growth promoting rhizobacteria fluorescent pseudomonads**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled "**Response of chilli (*Capsicum annuum* L.) to plant growth promoting rhizobacteria fluorescent pseudomonads**" is a record of research work done independently by Ms. Anu. V. (2001-11-01) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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Anu. V.
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LIST OF ABBREVIATIONS

@	–	At the rate of
%	–	Per cent
°C	–	Degree Celsius
°E	–	Degree East
°N	–	Degree North
BTB	–	Bromo Thiol Blue
CD	–	Critical difference
cfu		Colony forming units
cm	–	Centimetre
cv.	–	Cultivar
DAT	–	Days after transplanting
DMP	–	Dry matter production
et al.	–	And others
Fig.	–	Figure
FYM	–	Farmyard manure
g	–	Gram
GA	–	Gibberellic acid
ha	–	Hectare
i.e.	–	That is
IAA	–	Indole acetic acid
K	–	Potassium
K_2O		Potash
kg	–	Kilogram
mg	–	Milligram
ml		Millilitre
mm	–	Millimetre
N	–	Nitrogen
no.	–	Number
P	–	Phosphorus
P_2O_5		Phosphate
POP	–	Package of Practices Recommendations Crops (KAU, 1996)
q	–	Quintal
RH	–	Relative humidity
Rs.	–	Rupees
spp.	–	Species
t	–	Tonnes
var.	–	Variety
viz.	–	Namely

Dedicated to My
Beloved Ammoomma

INTRODUCTION

1. INTRODUCTION

To meet the full dietary needs of the common man, to eliminate malnutrition and deficiency diseases and to relieve the overstress on cereals, there is greater need for vegetables. India is gifted with varied agroclimatic conditions for growing an array of vegetable crops to combat the present ill balanced diet. Of the 456 million tonnes of vegetables produced in the world, India's share is 59 million tonnes.

The homesteads of Kerala has immense scope for the cultivation of vegetable crops. Most of the vegetables grown in Kerala are seasonal. Within this very short growing period, these crops produce large amounts of dry matter and remove substantial quantities of nutrients from the soil.

Chilli is one of the most important solanaceous vegetables and occupies a prominent place in the dietary habits of the people of South India. It is an indispensable adjunct to the diet of people. Chilli imparts pungency to culinary items and is useful for adding red colour and seasoning. It is a rich source of vitamin C and A in its fresh state.

Being a seasonal vegetable, this crop also removes substantial quantity of nutrients from the soil. The almost complete reliance on inorganic fertilizers in crop production is known to create problems such as deficiencies of plant nutrients, disturbances in soil reaction and specific conductance, decrease in soil life, fall in crop productivity and increase in environmental pollution (Phillips, 1972; Day *et al.*, 1978; Anilakumar *et al.*, 1993; Palaniappan *et al.*, 1995). It is in this context the concept of integrating inorganic and biofertilizers assumes importance as a means to achieve and sustain high productivity in vegetables.

The objective is to achieve high yield through balanced plant nutrition without impairing soil health. The employment of plant beneficial bacteria to increase yield and to reduce the use of inorganics is an attractive development and the potential benefits may be considered (Schmidt, 1979). The beneficial effects of plant growth promoting rhizobacteria (PGPR) are plant growth promotion and biological control under field conditions (Kloepper *et al.*, 1992). It is well established that several PGPR, especially fluorescent pseudomonads spp. produce plant growth promoting substances such as auxins and cytokinins which often lead to certain morphological changes in plants (Brown, 1972) and enhance plant growth. Moreover, fluorescent pseudomonads are known to suppress plant pathogens by various modes of action *viz.*, competition for nutrients and space, antibiosis by production of various antibiotics, siderophores and lytic enzymes (Defago *et al.*, 1990).

The beneficial effects of *Azospirillum* on plant growth is by way of associative nitrogen fixation, capability to produce plant growth hormones and their effect on root morphology (Okon, 1985). *Azospirillum* application has been found to increase the yield of wheat, rice, maize, pearl millet and sorghum by 0-30 per cent over controls.

Bioinoculants are in short supply at the present stage. Therefore the use of inorganic fertilizers has to be continued till the biological sources of nutrients are readily available. However there is ample scope for reducing the excessive dependence on inorganic fertilizers by the use of bioinoculants.

Keeping these views under consideration, the present investigation entitled 'Response of chilli (*Capsicum annuum* L.) to plant growth promoting rhizobacteria, fluorescent pseudomonads' was carried out with the following objectives :

- To evaluate fluorescent pseudomonads isolates for growth promotion and yield in chilli
- To assess the suitability of the best isolate as a biofertilizer either alone or in combination with *Azospirillum*
- To study the economics of the treatments.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The indispensability of NPK application for vegetables is well understood by the farmers. Very often there is excessive use of inorganic fertilizers creating soil fertility hazards and soil health problems. Therefore, in recent years the concept of integrated nutrient management (INM) involving organic manures, bionutrient resources and chemical fertilizers is gaining importance.

Two experiments were carried out at the College of Agriculture, Vellayani during 2002-2003 to evaluate fluorescent pseudomonads isolates for growth promotion and yield in chilli and to assess the suitability of the best isolate as a biofertilizer either alone or in combination with *Azospirillum*. The literature collected pertaining to the above subjects are reviewed hereunder. Wherever sufficient literature is not available on chilli, results of similar experiments on other crops are reviewed.

2.1 EFFECT OF NPK FERTILIZERS

2.1.1 Effect on Growth Characters

Joseph (1982) from his experiments in chilli for two seasons concluded that incremental doses of nitrogen and phosphorus increased plant height and number of branches at all stages of growth whereas potassium had no significant influence on these characters except plant height at the time of final harvest. It was also observed that increased doses of N, P and K increased dry matter production in chilli.

Lakatos (1982) found that increasing NPK levels increase plant height, shoot root ratio and dry matter production in chilli. Significant increase in plant height, number of branches and canopy spread in chilli with increase in NPK application was noted by Dolkova *et al.* (1984). Thomas and Leong (1984) noted that increase in nitrogen application increases the foliar growth in chilli resulting in more canopy spread. According to Zayed *et al.* (1985) increased doses of NPK increased plant height, number of branches and dry matter production in chilli. Prabhakar *et al.* (1987) noticed that nitrogen application at the rate of 90 kg ha^{-1} recorded maximum plant height in chilli. It was also observed that plant height was not influenced by phosphorus fertilization. Similar effects of nitrogen and phosphorus in chilli was noticed by Shukla *et al.* (1987). Belichki (1988) reported an increase in dry matter production with graded doses of NPK upto 320 kg ha^{-1} each. John (1989) observed that plant height, number of branches and shoot root ratio increased with increased doses of nitrogen and phosphorus, but potassium had no significant influence on these characters. According to him, a positive correlation was obtained between nitrogen, phosphorus and potassium application and dry matter production in chilli. Increase in nitrogen application enhanced the cell division and elongation in chilli resulting in more spread of canopy as reported by Ahmed and Tanki (1991).

Sherly (1996) noted significant increase in plant height, number of branches, dry matter production, canopy spread and shoot root ratio in chilli at higher levels of N and K.

2.1.2 Effect on Yield and Yield Attributes

Khan and Suryanarayana (1977) reported that number of days to flowering was reduced from 60 to about 53 and 45 by phosphorus at 45 and 90 kg ha^{-1} respectively. Ramachandran and Subbiah (1981) showed that number of fruits $plant^{-1}$ increased with increasing nitrogen levels upto 120 kg ha^{-1}. Significant increase in number of fruits, setting percentage, 100 fruit weight and fruit yield with increased levels of N, P and K was reported by Joseph (1982).

Subbiah *et al.* (1982) showed that N in combination with K tended to produce more yield in chillies. Dolkova *et al.* (1984) observed that increased NPK application increased fruit production in chilli and the highest yield was reported by the application of 360 kg each of N, P and K ha^{-1}. Joseph and Pillai (1985) reported that highest dry fruit yield in chilli under rainfed condition was observed by the application of 112.50 : 60 : 30 kg NPK ha^{-1}. Rao and Gulshanlal (1986) noted significant increase in number of days to 50 per cent flowering with increased levels of nitrogen upto 150 kg ha^{-1}.

Green chilli yield increased with levels of N upto 90 kg ha^{-1} and P upto 30 kg ha^{-1} (Prabhakar *et al.*, 1987). Shukla *et al.* (1987) reported that number of fruits $plant^{-1}$ was significantly influenced by varying levels of nitrogen. Similar results were noted by Singh and Srivastava (1988), John (1989), Natarajan (1990), Ahmed and Tanki (1991) and Lata and Singh (1993).

Rao *et al.* (1988) reported that highest economic yield of dry chilli pods was obtained with 120 kg N in combination with 50 kg K_2O. According to Shin *et al.* (1988) optimum NPK rate for maximum yield was 23 : 20.2 : 18 kg NPK ha^{-1}. Application of increased dose of nitrogen increased the setting percentage and 100 fruit weight (Goyal *et al.*, 1989 and John, 1989).

Highest fruit yield of 2.6 t ha^{-1} was obtained by application of 120 : 90 : 90 kg ha^{-1} (Nasreen and Islam, 1989). Increase in NPK rates increased the yield in chilli (Surlekov and Rankov, 1989; Subhani *et al.*, 1990; Thiagarajan, 1990; Jayaraman and Balasubramanian, 1991; Kaminwar and Rajagopal, 1993 and Subbiah, 1994). Sherly (1996) also observed increased fruit yield with increase in N and K levels.

2.1.3 Effect on Quality Attributes

Joseph (1982) observed that incremental doses of nitrogen increased the ascorbic acid content of fruits whereas potassium had no significant influence. Thomas and Leong (1984) reported profound effect of nitrogen fertilizers on the ascorbic acid content of fruits. Singh *et al.* (1986) showed that vitamin C content increased with increased levels of nitrogen and the response was linear upto 90 kg ha^{-1}. Application of 87.5 kg nitrogen ha^{-1} recorded maximum ascorbic acid content (Amritalingam, 1988). Contrary to this, Belichki (1988) pointed out that ascorbic acid content of chillies decreased as the application of NPK increased. Mary and Balakrishnan (1990) stated that increase in nitrogen application increased the ascorbic acid of chilli due to enhancement of enzymatic activities for amino acid synthesis. Uddin and Begum (1990) found that nitrogen alone or in combination had negative effect on ascorbic acid content in chilli while phosphorus had positive effect. According to Kaminwar and Rajagopal (1993) application of NPK at the rate of 100 : 75 : 100 kg ha^{-1} recorded the highest ascorbic acid content in chilli.

2.1.4 Effect on Nutrient Uptake

Joseph (1982) observed that total uptake of nitrogen by chilli was significantly increased by increased levels of N, P and K. Similar trends were also noted in the uptake of P and K. To produce an average chilli yield of 3.8 t ha^{-1}, total uptake of NPK by plant was 205, 58 and 445 kg ha^{-1} respectively (Roman, 1982). Rankov *et al.* (1983) found that NPK uptake of chilli was always greater on a light sandy soil. Dolkova *et al.* (1984) observed that for producing 1000 kg fruits, control chilli plants and plants receiving highest NPK removed from soil 6.91 and 6.37 kg ha^{-1} N, 1.89 and 1.63 kg ha^{-1}, P_2O_5 and 7.3 and 6.13 kg ha^{-1}, K_2O ha^{-1} respectively. Rankov and Todorov (1984) noticed that on an average 4.79 kg N, 1.74 kg P_2O_5 and 5.47 kg K_2O were needed for producing one tonne market ripe chilli fruits of early cultivars and 6.08 N, 2.12 kg P_2O_5 and 6.27 kg K_2O ha^{-1} with mid early cultivars. Dolkova *et al.* (1986) found that fruit N content reached permissible level even at lower rates of NPK. According to Hegde (1988) in chilli, N fertilization upto 120 kg ha^{-1}

significantly increased the nutrient uptake by 128, 64 and 76 per cent for N, P and K respectively. John (1989) reported that uptake of N and K by chilli was significantly increased by higher doses of NPK. Russo (1991) observed that the levels of nutrients in leaves and fruits did not respond to fertilizer application. To produce 1 q of dry chilli pods, the nutrient requirement was found to be 1.94, 0.25 and 1.6 kg N, P and K respectively (Kaminwar and Rajagopal, 1993). Subbiah (1994) noted that at 100 per cent of recommended dose of N and P, chilli crop had recorded the highest N, P and K uptake

2.2 EFFECT OF BIOFERTILIZERS

2.2.1 Effect of *Azospirillum*

2.2.1.1 Effect on Growth Characters

Over the past twenty years, in the case of 60-70 per cent of the experiments done world wide, an increase in crop yield due to *Azospirillum* inoculation could be observed. This increase could compensate the increased costs and replace about 30 per cent of nitrogen fertilizers. Application of biofertilizers followed by NPK fertilizers was found to increase yield (Mehrotra and Lehri, 1971; Oblisami *et al.*, 1976).

According to Smith *et al.* (1978) *Azospirillum* inoculation resulted in increased root and shoot growth and biomass accumulation in crop plants. *Azospirillum* has the ability for better root induction in inoculated plants mainly due to the production of plant growth hormones like IAA and GA. As a result of this, such plants are capable of absorbing more and more available nutrients from soil, which in turn result in better establishment of plant seedling and subsequent growth (Tien *et al.*, 1979). Manib *et al.* (1979) reported increased dry weight of tomato plants by 5-12 per cent due to the inoculation of *Azospirillum*. Inoculation with *Azospirillum* increased root length and root dry weight of inoculated plants (Dewan and Rao, 1979). Karthikeyan (1981) reported that *Azospirillum* inoculation increased the plant height and dry matter accumulation in rice. Kapulnik *et al.* (1981) studied the effect of *Azospirillum* inoculation on wheat, sorghum and panicum and observed that inoculation with *Azospirillum brasiliense* resulted in significant increase in plant height in all the three crops. Venkateswarlu and Rao (1983) reported that inoculation with *A. brasiliense* increased the growth, dry matter production and root growth in pearl millet. Use of *Azospirillum* alone produced better growth response equivalent to that of 30 kg N ha^{-1} in rice (Prasad and Singh, 1984). Inoculation of wheat seedlings with *Azospirillum* increased the total shoot and root dry weight and plant height than control treatments (Kapulnik *et al.*, 1985). After a field experiment, Gopalaswamy and Vidyasekharan (1987) confirmed that split application of *Azospirillum* through seed, seedlings and soil increased the plant height. Subramanian (1987) reported that seed and soil application of *Azospirillum* significantly improved seedling height, shoot dry weight and root dry weight in rice. Inoculation significantly improved dry matter production at all the growth stages. Hadas and Okon (1987) reported that there was significant increase in root length (3.5 %), root dry weight (50 %) and total leaf area of 18 days old tomato seedlings due to *Azospirillum* inoculation. A study conducted by Balasubramoni (1988) revealed that the seed and soil treatments of *Azospirillum* were superior to untreated check and *Azospirillum* seed treatment enhanced germination per cent, plant height, root length, root width, days to first flowering, first fruit node and dry matter production in brinjal.

Parvatham *et al.* (1989) pointed out that the inoculation of *Azospirillum* increased the root growth, root volume, plant height, girth and number of leaves of bhindi. Bashan *et al.* (1989) observed that in *Azospirillum* treated brinjal seedlings the plant height was significantly increased from 11.2 to 15.3 mm as compared to uninoculated treatment. There was also significant increase in dry weight of foliage and number of leaves per plant due to *Azospirillum* inoculation. Further there was also significant increase in population of *Azospirillum* (5.4×10^5 cfu g^{-1} of fresh roots) in inoculated treatments. Gallo and Fabri (1990) noted that inoculation of chickpea seedlings with *Azospirillum brasiliense* produced greater root and shoot dry weight than uninoculated plants. Inoculation of *Azospirillum* in cabbage gave significantly higher yield than untreated control (Jeevajothi *et al.*, 1993). Paramaguru and Natarajan (1993) reported increase in plant height, number of primary branches and number of lateral roots in chilli when inoculated with *Azospirillum*. Swarupa (1996) observed significant increase in plant height, stem girth, root length and root weight by inoculation of *Azosprillium brasiliense* in coffee seedlings.

Anitha (1997) reported that growth parameters like height of the plant, number of branches per plant, canopy spread and dry matter production were significantly higher for *Azospirillum* treated chilli plants over untreated plants. Rekha (1999) observed that *Azospirillum* application increased the plant height and number of branches in brinjal during early stages of growth. Seed inoculation of *A. brasiliense* in wheat plants increased the leaf area, total biomass production and grain yield compared to untreated control (Panwar and Singh, 2000). Significant increase in height of chilli plants were observed when treated with *Azospirillum*. These treatments were found to be significantly superior to the uninoculated control which recorded a plant height of 18 cm (Kavitha, 2001).

2.2.1.2 Effect on Yield and Yield Attributes

Chatto *et al.* (1977) observed that in Knolkhol, *Azospirillum* inoculation markedly increased growth, yield and quality attributes over control. Cohen *et al.* (1980) obtained increased yield for a wide range of tropical and temperate crops by *Azospirillum* inoculation. Inoculation of wheat seedlings with *Azospirillum* increased the number of fertile tillers and grain yield than control treatments (Kapulnik *et al.*, 1985).

The mechanism by which plants inoculated with *Azospirillum* derive positive benefits in terms of increased grain yield, plant biomass and nitrogen uptake are attributed to small increase in nitrogen input from biological nitrogen fixation, development and branching of roots, production of plant growth hormones, enhancement on uptake of nutrients, improved water status of plants, increased nitrate reductase activity in plants and production of antibacterial and anti fungal compounds (Okon, 1985).

Azospirillum inoculation was known to increase yield of crops by 5 to 20 per cent with savings of 40 per cent of the recommended dose of nitrogen (Dart, 1986). Amritalingam (1988) observed earliness in first flower appearance and 50 per cent flowering by *Azospirillum* treatment. The treatment increased the number of flowers and fruits plant^{-1} ,fresh and dry weight of pods plant^{-1}, length and girth of pods, number of seeds and weight of seeds pod^{-1} in chilli. A study conducted by Balasubramoni (1988) revealed that yield attributes like number of fruits plant^{-1}, length, girth and weight of fruits were increased by *Azospirillum* seed and soil treatment.

Parvatham *et al.* (1989) reported that *Azospirillum* treatment showed increase in total number of flowers and fruits which may be due to the increased activity of hormones produced by *Azospirillum*.

Govindaswamy *et al.* (1992) observed increase in total grain yield and straw yield of rice due to *Azospirillum* inoculation. Inoculation of *Azospirillum* in cabbage gave significantly higher yield than the untreated control (Jeevajothi *et al.*, 1993).

Raj (1999) observed significantly higher fruit yield (141.3 q ha^{-1}) than control in bhindi by *Azospirillum* inoculation. Rekha (1999) reported that *Azospirillum* inoculation increased the number of flowers and fruits plant^{-1} in brinjal when compared to uninoculated plants.

2.2.1.3 Effect on Quality Attributes

Chatto *et al.* (1977) observed that in knolkhol, *Azospirillum* inoculation markedly increased quality attributes over control. Inoculation with *Azospirillum* increased capsaicin and ascorbic acid content in chilli (Balakrishnan, 1988). *Azospirillum* inoculation has been reported to significantly increase vitamin C content in cabbage, cauliflower and tomato (Subbiah, 1990; Kalyani *et al.*, 1992 and Jeevajothi *et al.*, 1993).

Kumaraswami and Madalageri (1990) pointed out that *Azospirillum* treated tomato plants gave fruits with high total soluble solids (8.46 per cent) and ascorbic acid content (32.91 mg 100 g^{-1} fruit).

Anitha (1997) reported that ascorbic acid content of fruit was higher for *Azospirillum* inoculated plants (95.99 mg 100 g^{-1} fruit) than the control (95.49 mg 100 g^{-1} fruit).

Quality attributes of bhindi fruits *viz.*, ascorbic acid content were significantly higher for *Azospirillum* inoculated plants than control (Raj, 1999).

2.2.1.4 Effect on Nutrient Uptake

Boddey *et al.* (1986) using N-15 labelled $(NH_4)\ SO_4$ as a source of nitrogen fertilizer to wheat plants, observed high quantity of N-15 in *Azospirillum* inoculated plants than in uninoculated plants. Pacovsky *et al.* (1986) observed an increase in P and other nutrient concentration in the foliage of *Azospirillum* inoculated sorghum plants. Sarig *et al.* (1988) reported that *Azospirillum* inoculation enhanced the uptake of NO_3^{2-}, NH_4^+, phosphorus and potassium in plants as compared to uninoculated plants. Parvatham *et al.* (1989) noted better uptake of nitrogen and phosphorus in bhindi due to *Azospirillum* inoculation. Subbiah (1991) observed that soil application of *Azospirillum* to bhindi crop had beneficial effect on nitrogen, phosphorus and potassium uptake as compared to uninoculated plants. Anitha (1997) reported that

Azospirillum inoculation improved nitrogen, phosphorus and potassium uptake in chilli as compared to uninoculated control. Raj (1999) observed that nutrient uptake was favourable influenced by *Azospirillum* inoculation. Potassium uptake was significantly higher in the *Azospirillum* treated plants. Available N status of soil improved with *Azospirillum* inoculation. However, P and K content were not influenced by it. Rekha (1999) pointed out that *Azospirillum* application increased the content and uptake of phosphorus and potassium in bhindi compared to control treatments.

2.2.2 Effect of Fluorescent Pseudomonads

2.2.2.1 Effect on Growth Promotion

Many rhizobacteria, especially fluorescent pseudomonads are known to produce several growth hormones like auxins, cytokinins etc. This leads to certain morphological changes in plants like increased root growth, leaf expansion, shoot growth etc. Enhancement of plant growth by the fluorescent pseudomonads has been attributed to the yellow green fluorescent siderophores produced by them (Kloepper *et al.*, 1980). Some plant growth promoting rhizobacteria such as *P. fluorescens* and *P. aeruginosa* may promote plant growth by secreting plant hormones like Gibberellic acid like substances (Suslow, 1982). Suslow and Schroth (1982) reported that selected strains of fluorescent pseudomonads spp. isolated from rhizosphere and rhizoplane of field grown sugarbeets caused statistically significant yield increase of sugarbeets in field trials when applied as a seed coat formulation. Significant growth increases in seedling weight, root weight and total sucrose yield were also observed. Increases in root weight and total sucrose, averaging 13 per cent above untreated controls were as great as 4.6 and 2.68 t ha^{-1} respectively. Weller (1983) found that introduction of *Pseudomonas fluorescens* 2-79 increased the number of fluorescent pseudomonads in the soil over control soils. The growth response of roots was even more intensive, reaching 166 per cent.

Seed and root inoculation of rhizobacteria promoted plant growth by producing phytohormones like auxins and gibberellins (Loper and Schroth, 1986). Savithry and Gnanamanickam (1987) observed that fluorescent pseudomonads applied peanut plants were 25.74 per cent taller and appeared greener than the non bacterized plants.

Hofte *et al.* (1991) reported that plant growth promoting strains of *P. aeruginosa* 7NSK$_2$ and *P. fluorescens* ANP significantly increased the germination of maize seeds by 60-300 per cent. Defreitas and Germida (1992) also noted that inoculation of winter wheat with fluorescent pseudomonads resulted in increased root growth in growth chamber conditions. Significant increase in yield was also observed for winter wheat inoculated with fluorescent pseudomonads in field conditions.

Bacterization of chickpea and soyabean seeds which a siderophore producing fluorescent pseudomonads RBT-13 resulted in increased seed germination, growth and yield (Dileepkumar and Dube, 1992). Gnanamanickam and Mew (1992) obtained slight increase in grain yield of rice due to seed treatment with strains of *P. fluorescens*. Inoculation of *P. fluorescens* significantly increased seedling emergence rate and total dry weight and length of root and shoot. *P. fluorescens* increased the plant growth of rice and cotton by 25 and 40 per cent respectively when the bacterium was applied to seeds (Lin *et al.*, 1992).

Seed bacterization of rice cv. IR-58, IR-42 and IR-36 with fluorescent pseudomonads resulted in increased root and shoot length and dry weights of roots and shoot (Rosales *et al.*, 1993). Muthamilan (1994) observed increased growth rate of rice plants by seed treatment with *P. fluorescens*. Gupta *et al.* (1995) reported growth promotion of tomato plants by rhizobacteria especially *P. fluorescens*. Luz *et al.*(1998) observed increase in seedling emergence and grain yield of wheat by seed treatment with *P. fluorescens*. Rangeswaran and Prasad (2000) reported increased growth of chickpea seedlings treated with *P. fluorescens*.

Seed bacterization with fluorescent pseudomonads with *P. fluorescens* NBR 11303 increased the germination of chickpea seedlings by 25 per cent and reduced the number of diseased plants by 45 per cent compared to non bacterized controls. Increase in seedling dry weight, shoot length and root length ranged from 16-18 per cent. Significant growth increase in shoot length, dry weight and grain yield, averaging 11.59 per cent, 17.58 per cent and 22.60 per cent respectively over untreated controls were also recorded (Nautiyal, 2000). Gupta *et al.* (2001) observed that rhizobacterial isolates belonging to the genera *Pseudomonas* were found to increase fresh and dry root weight of mungbean by over 50 per cent compared to uninoculated control.

Nadezhkina and Silnova (2001) reported that in nonfertilized soil, the inoculation of *P. fluorescens* increased the grain yield of millets only in years with favourable weather conditions and in fertilized soils *P. fluorescens* significantly increased yield. Rangeswaran *et al.* (2001) reported that there was no significant differences in the shoot and root length of rice among the bioagent treatments, however vigour index was highest in plots treated with a combination of *P.fluorescens* and *P. putida.*

Bullock and Ristaino (2002) observed that the population of fluorescent pseudomonads and enteric bacteria were higher in soils receiving organic amendments than in soils with synthetic fertilizers.

Inoculation of maize with *Pseudomonas fluorescens* PsIA$_{12}$ was found to significantly increase the root and shoot growth of maize grown on loamy sand at 16°C compared to 26°C. Bacterial inoculation also resulted in significantly higher values for plant growth and N, P and K content of plant components in field experiments (Egamberdiyeva *et al.*, 2002).

Hao *et al.* (2002) reported that bacterial growth promotion of strawberry following inoculation in the field was variable and depended on soil, location as well as the isolate.

Heera (2002) noted a 31.54 per cent increase in shoot dry weight and 53.08 per cent increase in root dry weight of rice seedlings TN-1 by the inoculation of *P. fluorescens*. Similarly, length of shoots and roots were significantly increased by the application of talc based formulation of *P. fluorescens* compared to control.

2.2.2.2 Effect on Nutrient Uptake

Hoflish and Kuhn (1996) attributed the increased growth of all cruciferous oil crops when inoculated with fluorescent pseudomonads to improved root development and nutrient uptake. Seed treatment of fibre flax with *P. fluorescens* had improved uptake of phosphorus by shoots and roots and resulted in increased N, P and K content, stem length and fibre yields (Vorobeikov *et al.*, 1996). Bromecombe *et al.* (1999) noticed that *P. fluorescens* inoculated nitrogen rich organic residues enhanced nitrogen uptake of wheat. Silva *et al.* (2000) noted that *P. fluorescens* inoculation increased P uptake in blueberry. According to Tabar *et al.* (2002), inoculation of different strains of fluorescent pseudomonads improved the nutrient uptake in wheat.

2.2.2.3 Effect on Disease Incidence

Strains of fluorescent pseudomonads are the foremost among bio control agents as they improve plant growth by suppressing either major or minor pathogens of plants (Cook and Rovira, 1976).

P. capacia formulated as wettable powder effectively controlled peanut leaf spot (Knudson and Spurr, 1987). Seed treatment with *P. fluorescens* suppressed sheath rot of rice (Sakthivel and Gnanamanickam, 1987). Wei *et al.* (1991) demonstrated the ability of different PGPR strains to decrease the incidence of anthracnose of cucumber.

Fluorescent pseudomonads produces many secondary metabolites with antibiotic activities many of which have been implicated in suppression of soil borne diseases like phenazine-1-carboxylic acid, 2, 4-diacetyl phloroglucanol (DAPG). Oomycin, pyocyanine, pyoluteorin and pyrrolnitrin (Thomoshow and Weller, 1996).

Several pathogens of tomatoes including *P. solani* were inhibited by fluorescent pseudomonads spp (Varshney and Chaube, 1999).

Marnoranjitham *et al.* (2000) observed that *Pseudomonas fluorescens* application greatly reduced pre and post emergence damping off and increased the root length, shoot length and dry matter production of chilli seedlings.

An isolate of fluorescent pseudomonads, P_1 was identified as the best bacterial antagonist against *Rhizoctonia solani* inciting foliar blight disease of Amaranthus (Smitha, 2000).

Seed treatment with *P. aeruginosa* strain CR-54 reduced *R. solani* infection in cucumber and tomato (Gan *et al.*, 2001).

Hegde and Anahosur (2001) also noted the effectiveness of *P. fluorescence* in reducing the fruit rot in chilli by *Colletotrichum capsici*. Gehlot and Purohit (2002) observed that inoculation with *P. fluorescens* reduced the Fusarium wilt disease incidence by 37 per cent in chilli. Ramamoorthy *et al.* (2002) reported that *P. fluorescens* isolate Pf_1 was effective in reducing the damping off incidence in tomato and hot pepper. According to Kureck and Jarosenk-eisel (2003), growth promotion and pathogen inhibiting efficiencies were not directly dependent on the sole ratio of *Pseudomonas* strains to pathogen number in the rhizosphere, but were likely dependent on environmental conditions.

2.2.3 *Effect of Combined Application of Fluorescent Pseudomonads and Azospirillum*

Fayez (1990) reported that combined inoculation of *Azospirillum* and *Pseudomonas* resulted in significant increase in the growth of wheat and barley. Munoz-Garcia and Valdes (1995) observed that inoculation with fluorescent pseudomonads did not affect the *Azospirillum* count in the rhizoplane of maize. Inoculation with the mixture of species promoted maize development at early stages of growth, and 23 per cent and 35.6 per cent increase in shoot and root dry weight, respectively, compared to the control seedlings were observed.

Contrary to these results, Fallik *et al.* (1998) observed that a high concentration of fluorescent pseudomonads (108 cfu g^{-1} sand) diminished the influence of *Azospirillum* on root surface area. Kamble *et al.* (2000) reported that individual inoculation of *Azospirillum* and *Pseudomonas fluorescens* were found to be more effective than combined inoculation in rice.

Marimuthu *et al.* (2002) observed that simultaneous application of formulations of *Azospirillum* and *Pseudomonas fluorescens* resulted in effective control of cotton root rot. Seed and soil application of talc based formulation of *P. fluorescence* alone led to significantly higher amount of colony forming units of *P. fluorescens* at vegetative and flowering stages when compared to coinoculation of both *Azospirillum* and *P. fluorescens* on rhizosphere regions of cotton.

2.3 EFFECT OF CONJOINT USE OF NPK AND BIOFERTILIZERS

2.3.1 Effect of Conjoint Use of NPK Fertilizers and *Azospirillum*

2.3.1.1 Effect on Growth Characters

Bacterization of rice seedlings with *Azospirillum* along with application of 90 kg N ha^{-1} resulted in increase in plant height (Prasad and Singh, 1984).

Wam and Konde (1986) reported that performance of *Azospirillum* was better at lower doses of nitrogen. Balasubramanian and Kumar (1987) revealed that combined application of *Azospirillum* significantly increased the plant dry weight at all fertilizer levels in rice. Gopalaswami *et al.* (1989) revealed that *Azospirillum* application did not increase the plant height significantly over uninoculated control at any nitrogen levels. Subbiah (1991) conducted field experiments to study the effect of *Azospirillum* and fertilizer nitrogen on bhindi and found that 60 per cent of recommended dose of nitrogen was saved by application of *Azospirillum* and it had beneficial effect on bhindi. Paramaguru and Natarajan (1993) suggested that seed treatment and soil application of *Azospirillum* combined with application of 56 kg N ha^{-1} was found to increase plant height, number of primary branches plant^{-1} and number of lateral roots plant^{-1} in chilli under semidry condition.

2.3.1.2 Effect on Yield and Yield Attributes

Subbarao *et al.* (1979) found that inoculation of rice (Pusa 2-21) with *Azospirillum* increased grain yield at 0, 40 and 60 kg nitrogen ha^{-1} in rice. Rao *et al.* (1983) reported that the response of rice to root inoculation with *Azospirillum* resulted in significant increase in grain and straw yield especially at low levels of nitrogen (30 and 40 kg nitrogen ha^{-1}) than at an application rate of 60 kg nitrogen ha^{-1}. The interaction between nitrogen fertilizer and inoculation was not statistically significant. Balasubramanian and Kumar (1987) revealed that combined application of *Azospirillum* was marked by increased yield at all nitrogen levels. Maximum increase in yield was due to *Azospirillum* treatment with 50 per cent nitrogen level which equalled to that with full fertilizer nitrogen. Subbiah (1991) reported than in okra, application of 50 per cent of the recommended dose of nitrogen and soil application of *Azospirillum* has beneficial effect on yield and N use efficiency besides saving upto 50 per cent of recommended nitrogen. Pramaguru and Natarajan (1993) noted that seed treatment with *Azospirillum* along with 56 kg nitrogen gave highest yield in chilli.

Yield increase of 18 per cent was observed by *Azospirillum* inoculation at lower levels of nitrogen, but at higher levels the percentage increase in yield was only 8-9 (Anitha, 1997). Raj (1999) pointed out that the performance of *Azospirillum* in bhindi was better at lower doses of nitrogen *i.e.*, 50 and 100 kg ha^{-1}. Jha and Mishra (1999) could obtain highest tuber yield in sweet potato when 40 kg nitrogen ha^{-1} was supplemented with 10 kg *Azospirillum* ha^{-1} as soil application.

2.3.2 Effect of Conjoint Use of NPK Fertilizers and Fluorescent Pseudomonads

Marschner *et al.* (1999) reported that nitrogen deficiency decreased both plant growth of wheat and root colonization by *Pseudomonas fluorescens* at the root tip. Shabayev and Smolin (1999) observed that *P. fluorescens* inoculation in winter wheat gave increased nitrogen content in grain and straw compared to fertilizers alone. It was also observed that *P. fluorescens* inoculation along with nitrogen fertilizers provided greater grain yield when compared with soil inoculation with PK fertilizers. Application of *P. fluorescens* made it possible to reduce the rate of NPK fertilization by 1.5 times without any loss in yield of root crops (Silva *et al.*,2000). Kumaresn *et al.* (2001) reported that *P. fluorescens* application with 75 per cent recommended level of P_2O_5 as single super phosphate increased the growth and yield of cowpea fodder. Shabayev and Smolin (2002) demonstrated that inoculation of fodder beets with *P. fluorescens* increased the yield of root crops and the uptake of N, P and K also increased along with very low application rates of NPK.

2.3.3 Effect of Conjoint Use of NPK Fertilizers, *Azospirillum* and Fluorescent Pseudomonads

Ali *et al.* (1995) concluded that the use of biofertilizers (*Azospirillum* + *Pseudomonas fluorescens* + Flavobacterium) along with a low input of mineral nitrogen was useful for increasing rice biomass, N uptake and fertilizer N recovery in rice. Amara and Nasr (1995) reported that combined inoculation of nitrogen fixing bacteria (*Azotobacter* and *Azospirillum*) and phosphate dissolving bacteria (*P. fluorescens* and *Bacillus*) + Fe + Mn + Zn gave the highest seed yield per plant in soyabean. Marimuthu *et al.* (2002) observed that application of 100 per cent recommended dose of N and P along with *Azospirillum* and *P. fluorescens* recorded maximum number of sympodial branches and highest seed yield of cotton. Significant synergistic interaction effect was noticed between bioinoculants and inorganic fertilizer application.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation entitled ' Response of chilli (*Capsicum annuum* L.) to plant growth promoting rhizobacteria fluorescent pseudomonads' was taken up at College of Agriculture, Vellayani during July 2002– April 2003. This study was aimed to evaluate the fluorescent pseudomonads isolates for growth promotion and yield in chilli and to assess the suitability of the best isolate as a biofertilizer either alone or in combination with *Azospirillum*. The investigation was programmed as two experiments, a pot culture trial followed by a field study to achieve the objectives envisaged. The details of the site, season and weather conditions, materials used and methods followed are presented in this chapter.

3.1. EXPERIMENT I

EVALUATION OF FLUORESCENT PSEUDOMONADS ISOLATES FOR GROWTH PROMOTION IN CHILLI.

3.1.1. Materials

3.1.1.1 Experimental Site

The experiment was done as a pot culture trial at the Department of Agronomy, College of Agriculture, Vellayani, located at 8.5^0 N latitude and 76.9^0 E latitude at an altitude of 29 m above MSL.

3.1.1.2 Season

The study was carried out during the period from July to November 2002. The data on various weather parameters like rainfall, minimum and maximum temperature, relative humidity and evaporation during the cropping period are given in Appendix I and graphically presented in Fig. 1.

3.1.1.3 Potting Mixture

Potting mixture comprising of equal proportion of red loam soil, sand and cowdung was used as the media for crop growth. The chemical characteristics of

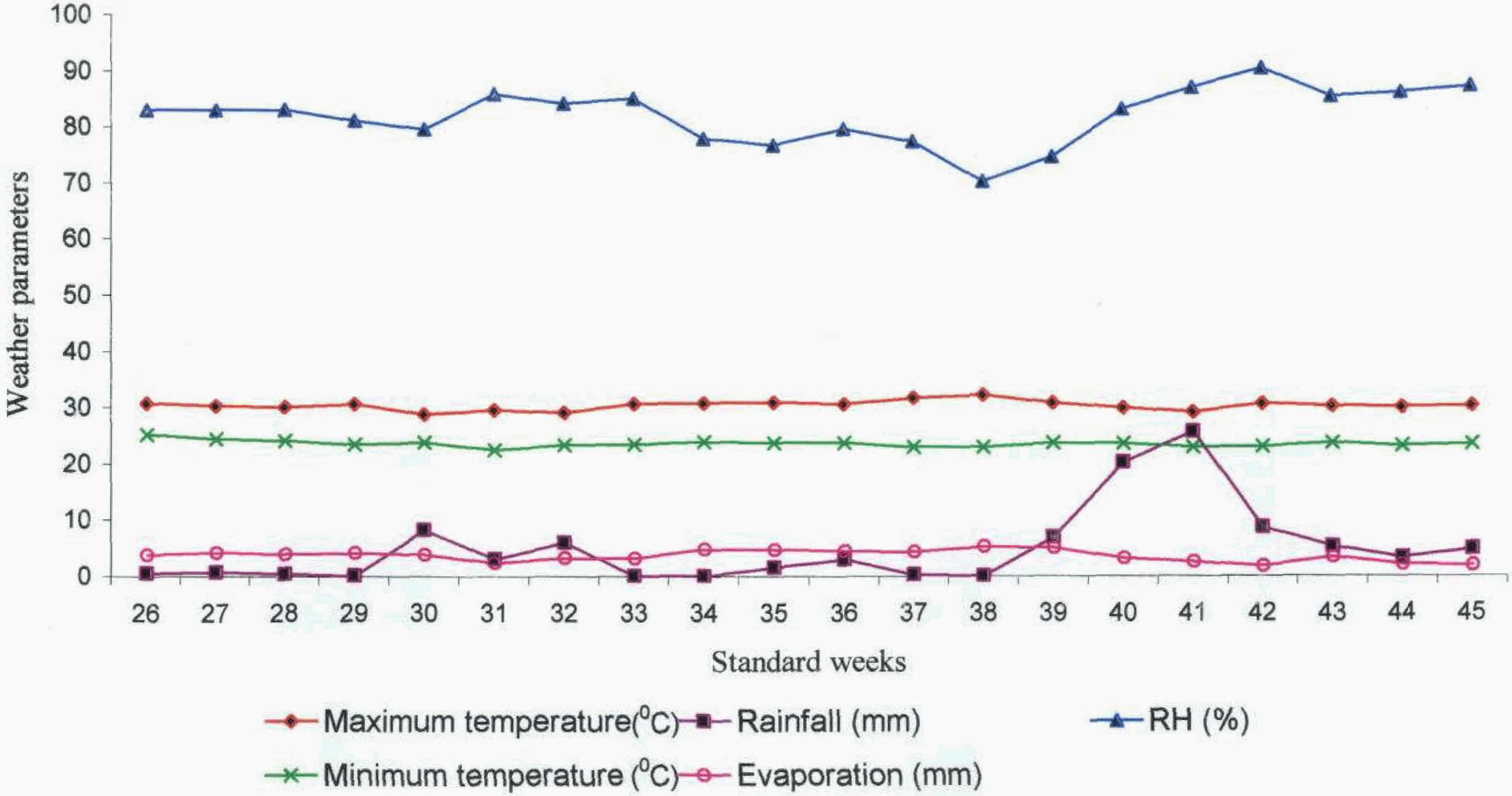


Fig. 1 Weather parameters during the cropping period (July to November 2002)

3.1.1.7 Application of Manures and Fertilizers

The manures and fertilizers were applied as per the package of practice recommendations of Kerala Agricultural University. (KAU, 1996) and the recommended management practices were adopted uniformly for all treatments.

3.1.1.8 Plant Protection

Leaf curl due to mite attack was noticed and Dimethoate was sprayed three times for getting satisfactory control.

3.1.2 Methods

The pot culture trial was laid out in Completely Randomised Design with 4 replications (Fig 2). The details of the layout are given below.

3.1.2.1 Design and Layout

Design	:	CRD
Treatments	:	5
Replications	:	4
Total no. of pots	:	20
Variety	:	Jwalasakhi
Duration	:	120 days

3.1.2.2 Treatments

Five fluorescent pseudomonads isolates obtained from the Department of Plant Pathology, College of Agriculture, Vellayani, were subjected to preliminary screening for growth promotion and yield in chilli.

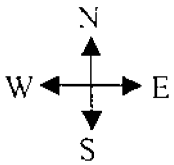
T_1 – Fluorescent pseudomonads isolate 1(P_1)

T_2 – Fluorescent pseudomonads isolate 2(P_5)

T_3 – Fluorescent pseudomonads isolate 3(P_{14})

T_4 – Fluorescent pseudomonads isolate 4(P_{22})

T_5 – Fluorescent pseudomonads isolate 5(KK_{16})



R1	R2	R3	R4
T_3	T_4	T_2	T_1
T_1	T_2	T_1	T_5
T_4	T_5	T_3	T_2
T_2	T_1	T_5	T_4
T_5	T_3	T_4	T_3

Fig. 2 Layout of experiment I

R1 : Replication 1

R2 : Replication 2

R3 : Replication 3

R4 : Replication 4

potting mixture is given in Table 3.1

Table 3.1 Soil characteristics of potting mixture

Parameter	Content kg ha^{-1}	Method
Available N, kg ha^{-1}	247.74	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
Available P_2O_5, kg ha^{-1}	40.32	Bray colorimetric method (Jackson, 1973)
Available K_2O, kg ha^{-1}	97.92	Ammonium acetate method (Jackson, 1973)
Organic Carbon, %	0.48	Walkley and Blacks rapid titration method (Jackson, 1973)
Soil reaction, pH	5.0	pH meter with glass electrode (Jackson, 1973)

3.1.1.4 Variety

The variety used was Jwalasakhi, a newly released high yielding variety of vegetable chilli from Kerala Agricultural University evolved by crossing Vellanotchi, a popular local cultivar of South Kerala with Pusa Jwala.

3.1.1.5 Planting Site

Earthern pots of 25 cm diameter and 30 cm height were used as containers. Pots were filled with potting mixture at the rate of 8 kg pot^{-1} for raising the crop

3.1.1.6 Biofertilizer Application

Talc based formulations of fluorescent pseudomonads isolates were made into thick slurry (250 g in 700 ml) and seedling roots were dipped in the slurry for 20 minutes and transplanted. A foliar spray (2 %) was given 30 days after transplanting

On the basis of growth promotion, yield and disease resistance, best isolates were selected and further tested in the field along with *Azospirillum* and chemical fertilizers.

3.1.3 Observations

Observations were taken on important parameters of growth and yield in chilli. Parameters considered and methods followed are briefly stated below.

3.1.3.1 Observations on Crop

3.1.3.1.1 Crop Growth Characters

3.1.3.1.1.1 Height of Plant at Different Growth Stages

The height of the plant was measured from the base to the growing tip of the plant at 30, 60 and 90 days after planting.

3.1.3.1.1.2 Number of Branches at Different Growth Stages

The total number of primary branches per plant were recorded at 30, 60 and 90 days after planting.

3.1.3.1.1.3 Dry Matter Production at Harvest

Dry matter production of each plant was worked out by recording dry weights of shoots and fruits after oven drying at 70 ± 5^0 C. Drying and weighing were repeated till constant weights were obtained and expressed in g.

3.1.3.1.1.4 Shoot/ Root Ratio

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

3.1.3.1.1.5 Spread of Canopy at Flowering

The canopy spread was measured as the maximum lateral diameter through the main stem of the plant at flowering and expressed in cm.

3.1.3.1.2 Crop Yield Attributes

3.1.3.1.2.1 Days to First Flowering

Total number of days taken for the plant to flower in each treatment was recorded.

3.1.3.1.2.2 Number of Flowers per Plant

The total number of flowers was recorded in each treatment.

3.1.3.1.2.3 Number of Fruits per Plant

The total number of fruits was recorded in each treatment.

3.1.3.1.2.4 Setting Percentage of Fruit

Fruit set was calculated by dividing the total number of fruits formed in the plant with the total number of flowers produced in the same plant and expressed in percentage.

3.1.3.1.2.5 Length and Girth of Fruits

Length of randomly selected 10 fruits were measured and the mean worked out and expressed in cm. Fruits used for measuring length were also used for recording the girth. It was measured at the broadest part of the fruits and expressed in cm.

3.1.3.1.2.6 Hundred Fruit Weight

From each plant, 10 fruits were drawn at random and their fresh weights recorded which was multiplied by 10 to obtain 100 fruit weight.

3.1.3.1.2.7 Ascorbic Acid Content of Fruit

The ascorbic acid content of fruits was estimated by titrimetric method (Gyorgy and Pearson, 1967).

3.1.3.1.2.8 Fruit Yield per Plant

Fruit yield per plant was calculated by summing up the weight of fruits in each plant and expressed in gram.

3.1.3.2 Chemical Analysis

3.1.3.2.1 Soil Analysis

Soil samples were taken from experimental area before and after the experiment. Composite samples were collected from each plot, air dried, powdered and passed through 2 mm sieve and analysed for organic carbon, available N, available P_2O_5 and K_2O as per the standard analytical methods. Available N status of soil was estimated using alkaline potassium permanganate method (Subbiah and Asija, 1956), available P status by bray colorimetric method (Jackson, 1973) and available K status of soil by ammonium acetate method (Jackson, 1973)

3.1.3.2.2 Plant Analysis

3.1.3.2.2.1 NPK Content

Plant samples were analysed for nitrogen, phosphorus and potassium at harvest by adopting standard procedures. The plants were chopped and dried in hot air oven at 70 ± 5^0 C separately till constant weights were achieved. Samples were then sieved through a 0.5 mm mesh in a Willey mill. Nitrogen content was estimated using a microkjeldahl method (Jackson, 1973), phosphorus content using vanadomolybdophosphoric yellow colour method (Jackson, 1973) and potassium content using flame photometer (Piper, 1966)

3.1.3.2.2.2 NPK Uptake

The total uptake of N, P and K were calculated as the product of per cent content of nutrients of the plant samples and dry weight and expressed as g $plant^{-1}$

3.1.3.3 Bacterial Population in the Rhizosphere

Bacterial count for fluorescent pseudomonads in soil samples collected from each treatment were enumerated by serial dilution and plate technique using Kings B medium of following composition (King *et al.*, 1954). A dilution of 10^{-6} was used for plating the rhizosphere soil.

Kings B medium

Peptone – 20.0 g

K_2HPO_4- 1.5 g

$MgSO_4$ – 1.5 g

Glycerol – 10.0 ml

Distilled water – 1000 l

pH – 7.2

Agar – 20 g

3.1.3.4 Scoring for Disease Incidence

Fruit rot

$$\text{Per cent infection} = \frac{\text{Number of fruits infected per plant}}{\text{Total number of fruits per plant}} \times 100$$

3.1.3.5 Economics of Cultivation

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

3.1.3.6 Benefit-Cost Ratio

The benefit-cost ratio was worked out from the cost of cultivation and the returns derived from the treatments.

$$\text{Benefit-Cost ratio} = \frac{\text{Gross returns}}{\text{Cost of cultivation}}$$

3.1.3.7 Statistical Analysis

Data relating to each character were analysed by applying the analysis of variance (ANOVA) as applied to factorial randomised block design (Panse and Sukhatme, 1985) and the significance was tested by F test. The data that do not satisfy the basic assumptions of ANOVA were appropriately transformed and the transformed values were used for analysis of variance.

3.2 EXPERIMENT II

RESPONSE OF CHILLI TO PLANT GROWTH PROMOTING RHIZOBACTERIA FLUORESCENT PSEUDOMONADS, *AZOSPIRILLUM* AND CHEMICAL FERTILIZERS

3.2.1 Materials

3.2.1.1 Experimental Site

The experimental site was the garden lands of the Instructional farm attached to the College of Agriculture, Vellayani, located at 8.5^0 N latitude and 76.9^0 E latitude at an altitude of 29 m above MSL.

3.2.1.2 Soil

The soil of the experimental site was red loam, acidic, low in available N. medium in available phosphorus and low in available potassium. The soil of the experimental site was sandy clay loam belonging to the taxonomical order Oxisol. The important physiochemical properties and pH of the soil are presented in Table 3.2.

Table 3.2 Soil characteristics of the experimental site

A. Mechanical composition

Parameter	Content in soil	Method used
Coarse sand, %	15	Bouyoucos hydrometer method (Bouyoucos,1962)
Fine sand, %	48	
Silt, %	12	
Clay, %	23	

B. Chemical composition

Parameter	Content	Method
Available N, kg ha^{-1}	228.79	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
Available P_2O_5, kg ha^{-1}	36.34	Bray colorimetric method (Jackson, 1973)
Available K_2O, kg ha^{-1}	77.95	Ammonium acetate method (Jackson, 1973)
Organic Carbon, %	0.36	Walkley and Blacks rapid titration method (Jackson, 1973)
Soil reaction, pH	5.1	pH meter with glass electrode (Jackson, 1973)

3.2.1.3 Cropping History of the Field

The experimental area was under a bulk crop of chilli before the experiment

3.2.1.4 Season

The field experiment was conducted during the period from 13-12-2002 to 14-04-2003. The data on various weather parameters like rainfall, minimum and maximum temperature, relative humidity and evaporation during the cropping period are given in Appendix II and graphically presented in Fig 3.

3.2.1.5 Variety

The variety used was Jwalasakhi, which was also used in the pot experiment.

The seed material was obtained from the Department of Plant Breeding, College of Agriculture, Vellayani.

3.2.1.6 Cultural Operations

3.2.1.6.1 Nursery

Seeds were sown in well prepared nursery beds of 1.2 m width and 15 cm height with channels around them to facilitate drainage. The seeds were sown on 13-12-2002. The seedlings were irrigated everyday. Hand weeding and plant protection operations were undertaken periodically as per the package of practice recommendations. The seedlings were ready for transplanting in 30 days.

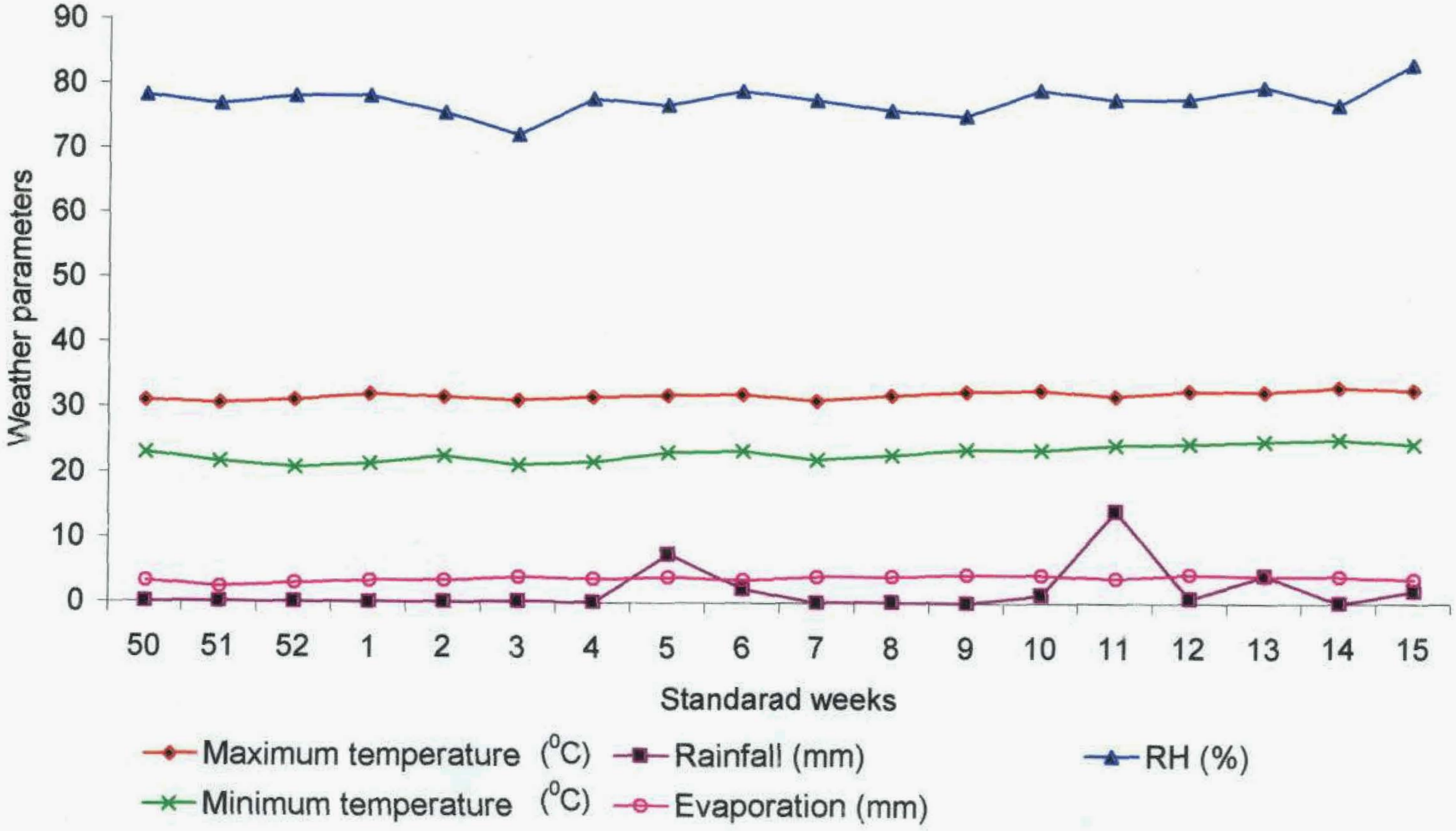


Fig. 3 Weather parameters during the cropping period (December 2002 to April 2003)

3.2.1.6.2 Field Culture

The main field was ploughed, clods broken, cleared of stubbles and plots were laid out with bunds of 30 cm width all round. Individual plots were again dug and perfectly levelled. Ridges and furrows were formed 45 cm apart. Plants were given uniform irrigation. Shade was provided with banana leaves for the first four days after planting.

3.2.1.6.3 Application of Manures and Fertilizers

FYM@ 25tha^{-1} was applied uniformly to all the plots. N, P_2O_5 and K_2O were applied in the form of urea, mussoriphos and muriate of potash at 75 per cent, 100 per cent and 125 per cent of the Package of Practice Recommendations 'Crops' (KAU, 1996) to the respective plots as per the treatment. Entire quantity of P_2O_5 and ½ N and ½ K_2O were given as basal. ¼ N and ¼ K_2O was applied 30 days after transplanting and remaining ¼ N and ¼ K_2O 30 days after the first topdressing.

3.2.1.6.4 Biofertilizer Application

Seedlings were dipped for 20 minutes in a thick slurry of talc based formulations of fluorescent pseudomonads isolates, *Azospirillum* and mixture of *Azospirillum*, and fluorescent pseudomonads in 1:1 proportion according to the treatments. A foliar spray (2 %) with flourescent pseudomonads and *Azospirillum* was given 30 days after transplanting for the respective treatments.

3.2.1.6.5 After Cultivation

Gap filling was done with healthy seedlings. Regular irrigation and weeding were carried out.

3.2.1.6.6 Plant Protection

Leaf curl incidence due to mite attack was noticed and hence Dimethoate was sprayed 4 times, for getting satisfactory fruit and seed yield.

3.2.2 Methods

The field experiment was laid out in Factorial Randomised Block Design with 3 replications (Fig.4). The details of the layout are given below.

3.2.2.1 Design and Layout

Design : Factorial RBD
Number of treatment combinations : 12
Replications : 3
Total no. of plots : 36
Gross plot size :2.7 m x 3.15 m
Net plot size : 2.25 m x 2.7 m
Variety : Jwalasakhi
Duration : 120 days

3.2.2.2 Treatments

A. Levels of fertilizers

F_1 - 75 per cent of the recommended dose of NPK
F_2 - 100 per cent " (POP)
F_3 - 125 per cent "

B. Biofertilizers

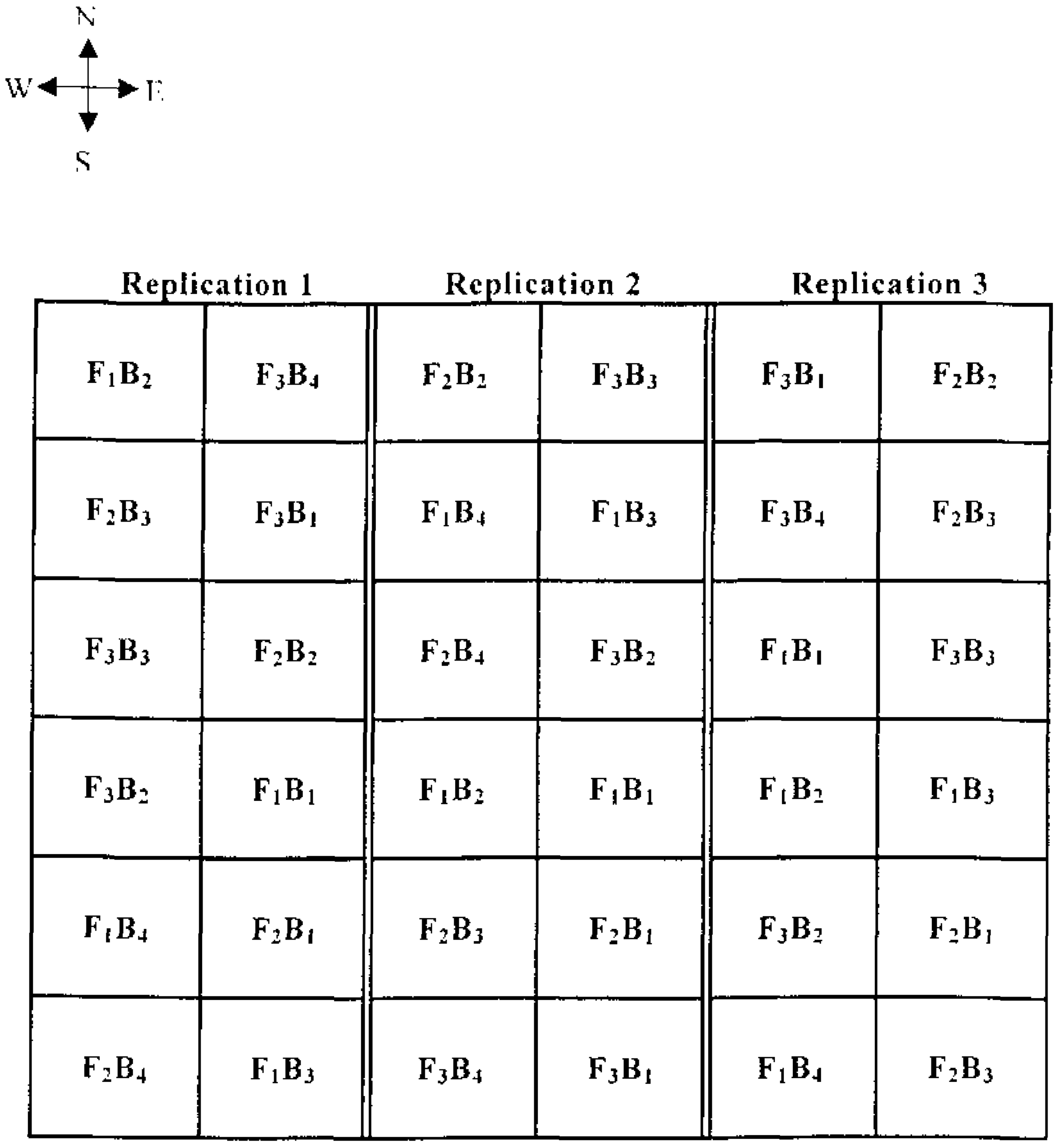
B_1 - Fluorescent pseudomonads isolate
B_2 - *Azospirillum*
B_3 - Fluorescent pseudomonads isolate + *Azospirillum*
B_4 - No biofertilizers

Note : POP recommendation - 75:40:25 kg NPK ha^{-1}

FYM @ 25 t ha^{-1} will be applied uniformly in all the plots

Treatment combinations : (T)

F_1B_1 - 75 per cent of the recommended dose of NPK + Fluorescent pseudomonads isolate



Replication 1		Replication 2		Replication 3	
F_1B_2	F_3B_4	F_2B_2	F_3B_3	F_3B_1	F_2B_2
F_2B_3	F_3B_1	F_1B_4	F_1B_3	F_3B_4	F_2B_3
F_3B_3	F_2B_2	F_2B_4	F_3B_2	F_1B_1	F_3B_3
F_3B_2	F_1B_1	F_1B_2	F_1B_1	F_1B_2	F_1B_3
F_1B_4	F_2B_1	F_2B_3	F_2B_1	F_3B_2	F_2B_1
F_2B_4	F_1B_3	F_3B_4	F_3B_1	F_1B_4	F_2B_3

Fig. 4 Layout of experiment II

F_1B_2 - 75 per cent of the recommended dose of NPK + *Azospirillum*

F_1B_3 - 75 per cent of the recommended dose of NPK + Fluorescent pseudomonads isolate + *Azospirillum*

F_1B_4 - 75 per cent of the recommended dose of NPK + No biofertilizers

F_2B_1 - 100 per cent of the recommended dose of NPK + Fluorescent pseudomonads isolate

F_2B_2 - 100 per cent of the recommended dose of NPK +*Azospirillum*

F_2B_3 - 100 per cent of the recommended dose of NPK + Fluorescent pseudomonads isolate + *Azospirillum*

F_2B_4 - 100 per cent of the recommended dose of NPK + No biofertilizers

F_3B_1 - 125 per cent of the recommended dose of NPK + Fluorescent pseudomonads isolate

F_3B_2 - 125 per cent of the recommended dose of NPK +*Azospirillum*

F_3B_3 - 125 per cent of the recommended dose of NPK + Fluorescent pseudomonads isolate + *Azospirillum*

F_3B_4 - 125 per cent of the recommended dose of NPK + No biofertilizers

3.2.2 Observations

Observations were taken on important parameters associated with growth and yield of chilli. Five plants were selected for the purpose of study in the field experiment. Parameters considered and methods followed are briefly stated below

3.2.2.1 Observations on Crop

3.2.2.1.1 Crop Growth Characters

3.2.2.1.1.1 Height of plant at different growth stages

The height of the plant was measured from the base to the growing tip of the plant at flowering and harvest . For field experiment, this observation was taken from five plants at random in each plot after eliminating border rows. The mean plant heights were worked out and expressed in cm.

3.2.2.1.1.2 Number of Branches at Different Growth Stages

The total number of branches per plant at growth stages *viz.*, flowering and harvest were recorded .

3.2.2.1.1.3 Dry Matter Production at Harvest

Dry matter production of each plant was worked out by recording dry weights of shoots and fruits after oven drying at 70 ± 5^0 C. Drying and weighing were repeated till constant weights were obtained and expressed in g.

3.2.2.1.1.4 Shoot/ Root Ratio

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

3.2.2.1.1.5 Spread of Canopy at Flowering

The canopy spread was measured as the maximum lateral diameter through the main stem of the plant at flowering and expressed in cm.

3.2.2.1.2 Crop Yield Attributes

3.2.2.1.2.1 Time of 50 per cent Flowering

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

3.2.2.1.2.2 Number of Flowers per Plant

Flower production on the observational plants was recorded from the first flower opening till the flower production was ceased.

3.2.2.1.2.3 Number of Fruits

The total number of fruits on the five observational plants was recorded and the average worked out was recorded in each treatment.

3.2.2.1.2.4 Setting Percentage of Fruit

Fruit set was calculated by dividing the total number of fruits formed in the plant with the total number of flowers produced in the same plant and expressed in percentage.

3.2.2.1.2.5 Length and Girth of Fruits

Length of randomly selected 10 fruits were measured and the mean worked out and expressed in cm. Fruits used for measuring length were also used for recording the girth. It was measured at the broadest part of the fruits and expressed in cm.

3.2.3.1.2.6 Hundred fruit weight

From each plot, 100 fruits were drawn at random and their fresh weight recorded and expressed in gram.

3.2.3.1.2.7 Ascorbic Acid Content of Fruit

The ascorbic acid content of fruits was estimated by titrimetric method (Gyorgy and Pearson, 1967)

3.2.3.1.2.8 Fruit Yield per Plant

Fruit yield per plant was calculated by summing up the weight of fruits in each plant and expressed in g

3.2.3.1.2.9 Fruit Yield per Plot

Total yield was calculated by summing up the weights of fruits on all the plants in a plot and expressed as kg ha^{-1}

3.2.3.2 Chemical Analysis

3.2.3.2.1 Soil Analysis

Soil samples were taken from experimental area before and after the experiment. Composite samples were collected from each plot, air dried, powdered and passed through 2 mm sieve and analysed for organic carbon, available N, available P_2O_5 and K_2O as per the standard analytical methods.

Available N status of soil was estimated using alkaline potassium permanganate method (Subbiah and Asija, 1956), available P status by bray colorimetric method (Jackson, 1973) and available K status of soil by ammonium acetate method (Jackson, 1973)

3.2.3.2.2 Plant Analysis

Plant samples were analysed for nitrogen, phosphorus and potassium at harvest by adopting standard procedures. The plants were chopped and dried in air oven at 70 ± 5^0 C till constant weights were achieved. Samples were then passed through a 0.5 mm mesh in a Willey mill. Nitrogen content was estimated using microkjeldahl method (Jackson, 1973) phosphorus content using vanadomolybdophosphoric yellow colour method (Jackson, 1973) and potassium content using flame photometer (Piper, 1966)

3.2.3.2.2.2 NPK Uptake

The total uptake of N, P and K were calculated as the product of per cent content of nutrients of the plant samples and dry weight expressed as kg ha^{-1}

3.2.3.3 Bacterial Population in the Rhizosphere

The population of *Azospirillum* and fluorescent pseudomonads in the rhizosphere soil samples collected from each treatment were enumerated by serial dilution and plate technique using respective medium. For *Azospirillum*, nitrogen free broth of following composition (Baldani and Dobereiner, 1980), and for fluorescent pseudomonads Kings B media (King *et al.*, 1954) were used for enumerating *Azospirillum* and pseudomonads at dilutions of 10^{-5}

Nitrogen Free Semisolid Malate Medium

Malic acid – 5.0 g

K_2HPO_4 – 0.5 g

$MgSO_4.7H_2O$ – 0.2 g

NaCl – 0.1 g

$CaCl_2$ – 0.02 g

Trace element solution – 2 ml

BTB – 2 ml

$FeSO_4$ – 0.05 g

Vitamin solution – 4 ml

KOH – 4 g

Distilled water 1000 ml

Agar 1.75 g

3.2.3.4 Scoring for Disease Incidence

Fruit rot

$$\text{Per cent infection} = \frac{\text{Number of fruits infected per plant}}{\text{Total number of fruits per plant}} \times 100$$

3.2.3.5 Economics of Cultivation

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

3.2.3.6 Benefit-Cost Ratio

The benefit-cost ratio was worked out from the cost of cultivation and the returns derived from the treatments.

$$\text{Benefit-Cost ratio} = \frac{\text{Gross returns}}{\text{Cost of cultivation}}$$

3.2.3.7 Statistical Analysis

Data relating to each character were analysed by applying the analysis of variance (ANOVA) as applied to factorial randomised block design (Panse and Sukhatme, 1985) and the significance was tested by F test In areas where the effects were found to be significant, CD values were calculated by using standard techniques.

RESULTS

4. RESULTS

The present study was undertaken at the College of Agriculture, Vellayani during the period from July 2002 to April 2003. The objectives of the experiments were to evaluate fluorescent pseudomonads isolates for growth promotion and yield in chilli, to assess the suitability of the best isolate as a biofertilizer either alone or in combination with *Azospirillum*, and to work out the economics of production. The data collected were statistically analysed and the results are presented in this chapter.

4.1 EXPERIMENT I

4.1.1 Growth Characters

Data generated on growth characters like plant height, number of branches, canopy spread, dry matter production and shoot root ratio are presented in this section.

4.1.1.1 Plant Height (Table 4.1.1)

The results revealed that plant height was significantly influenced by the different treatments at 30 DAT and 60 DAT. The treatment T_4 (Fluorescent pseudomonads isolate P_{22}) recorded the maximum plant height at all stages of growth *viz.*, 30 DAT, 60 DAT and 90 DAT (28.98, 37.25 and 43.63 cm respectively). At 30 DAT and 60 DAT, T_4 was significantly superior to all other treatments. The plant height at 90 DAT did not show any significant difference among various treatments.

4.1.1.2 Number of Branches (Table 4.1.2)

Among various treatments, application of different fluorescent pseudomonads isolates had significant influence on the number of branches per plant. Treatment T_4 recorded the highest number of branches at different growth stages *viz.*, 30 DAT, 60 DAT and 90 DAT (8.25, 13.25

Table 4.1.1 Effect of fluorescent pseudomonads isolates on plant height, cm

Treatments	30 DAT	60 DAT	90 DAT
T_1 (P_1)	24.95	34.25	40.88
T_2 (P_5)	24.10	34.73	40.83
T_3 (P_{14})	25.63	34.08	43.38
T_4 (P_{22})	28.98	37.25	43.63
T_5 (KK_{16})	25.25	33.28	41.93
F	7.95**	8.99**	2.65^{NS}
CD	2.001	1.762	-

Table 4.1.2 Effect of fluorescent pseudomonads isolates on number of branches

Treatments	30 DAT	60 DAT	90 DAT
T_1 (P_1)	6	9.75	16.25
T_2 (P_5)	5.75	9.75	16.00
T_3 (P_{14})	6.75	11.25	16.50
T_4 (P_{22})	8.25	13.25	18.50
T_5 (KK_{16})	6	9.75	15.25
F	5.11**	7.22**	4.52**
CD	1.362	1.729	1.718

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Plate 1. General view of pot culture trial (Experiment I)

and 18.5 respectively) and was significantly superior to all other treatments.

4.1.1.3 Dry Matter Production at Harvest (Table 4.1.3)

A critical analysis of the data indicated that treatments significantly influenced the dry matter production at harvest. The maximum dry matter production was recorded for treatment T_4 (56.25 g plant^{-1}) which was on par with treatment T_3 and was significantly higher than other treatments. Treatment T_5 (Isolate KK_{16}) recorded the lowest dry matter production (46.73 g plant^{-1}).

4.1.1.4 Shoot Root Ratio (Table 4.1.3)

A perusal of the data revealed that P_{22} isolate of fluorescent pseudomonads (T_4) was the most superior treatment with a shoot root ratio of 4.22 and it was significantly superior to other treatments. The lowest shoot root ratio was noticed for treatment T_5 (3.16).

4.1.1.5 Spread of Canopy (Table 4.1.3)

Analysing the data on the spread of canopy, it was found that maximum canopy spread (38.40 cm) was recorded for treatment T_4 and was significantly superior to other treatments.

4.1.2 Yield and Yield Attributes

4.1.2.1 Days to First Flowering (Table 4.1.4)

The data on the influence of various treatments on days to first flowering showed that the different treatments had no significant influence on this yield attribute.

4.1.2.2 Number of Flowers per Plant (Table 4.1.4)

Number of flowers per plant did not show any significant difference due to treatments. Treatment T_4 recorded the maximum number of flowers (108.00) followed by T_3 (106.00).

4.1.2.3 Number of Fruits per Plant (Table 4.1.4)

A critical review of the data showed that the application of different isolates of fluorescent pseudomonads significantly influenced the number of fruits. The maximum number of fruits (52.75) was noted for the isolate P_1 (T_1) and was on par with P_{22} (50.25). The lowest number of fruits was recorded for treatment T_5 (41.25).

4.1.2.4 Setting Percentage of Fruits (4.1.5)

The data on fruit setting percentage indicated that different treatments did not significantly influence this character. Maximum fruit set was noted for treatment T_4 (55.39 %) followed by T_3 (53.59 %). T_2 (Fluorescent pseudomonads isolate P_5) recorded the lowest fruit setting percentage (46.25 %).

4.1.2.5 Length and Girth of Fruit (Table 4.1.5)

The treatments exerted significant influence on the length and girth of fruits. Maximum length and girth of fruits was observed for T_4 (8.77 cm and 4.46 cm respectively), which was on par with T_3 (8.42 cm and 4.34 cm respectively) and was significantly superior to other treatments.

4.1.2.6 Hundred Fruit Weight (Table 4.1.6)

Hundred fruit weight was significantly influenced by the application of fluorescent pseudomonads isolates. T_4 recorded the maximum value (589.90 g), which was significantly higher than other treatments. The lowest value for 100 fruit weight was observed for treatment T_2 (510.50 g).

4.1.2.7 Ascorbic Acid Content of Fruits (Table 4.1.6)

The results revealed that T_4 registered highest ascorbic acid content (141.02 mg 100 g^{-1}). But the magnitude of variation between different treatments did not touch the level of statistical significance.

4.1.2.8 Fruit Yield per Plant (Table 4.1.6)

Data pertaining to fruit yield per plant revealed that the highest fruit

Table 4.1.3 Effect of fluorescent pseudomonads isolates on dry matter production, shoot root ratio and canopy spread

Treatments	Dry matter production, g plant^{-1}	Shoot- root ratio	Canopy spread, cm
T_1 (P_1)	49.02	3.40	36.25
T_2 (P_5)	48.99	3.31	36.60
T_3 (P_{14})	54.07	3.56	37.00
T_4 (P_{22})	56.25	4.22	38.40
T_5 (KK_{16})	46.73	3.16	37.10
F	4.10*	8.84**	4.42*
CD	5.915	0.419	1.170

Table 4.1.4 Effect of fluorescent pseudomonads isolates on days to first flowering, number of flowers plant^{-1} and number of fruits plant^{-1}

Treatments	Days to first flowering	No. of flowers plant^{-1}	No. of fruits plant^{-1}
T_1 (P_1)	33.75	105.00	52.75
T_2 (P_5)	35.00	103.25	43.75
T_3 (P_{14})	35.75	106.00	46.5
T_4 (P_{22})	35.25	108.00	50.25
T_5 (KK_{16})	34.25	102.75	41.25
F	1.16^{NS}	0.26^{NS}	5.70**
CD	-	-	5.901

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Table 4.1.5 Effect of fluorescent pseudomonads isolates on fruit setting percentage, length and girth of fruits

Treatments	Setting percentage, per cent	Length of fruit, cm	Girth of fruit, cm
T_1 (P_1)	50.59	7.59	3.88
T_2 (P_5)	46.25	7.57	4.12
T_3 (P_{14})	53.59	8.42	4.34
T_4 (P_{22})	55.39	8.77	4.46
T_5 (KK_{16})	47.94	7.66	4.07
F	1.08^{NS}	5.62**	8.85**
CD	-	0.706	0.232

Table 4.1.6 Effect of fluorescent pseudomonads isolates on 100 fruit weight, ascorbic acid content of fruits, and fruit yield plant^{-1}

Treatments	100 fruit weight, g	Ascorbic acid content, mg 100 g^{-1}	Fruit yield, g plant^{-1}
T_1 (P_1)	522.73	89.74	201.47
T_2 (P_5)	510.50	76.92	159.29
T_3 (P_{14})	527.25	102.56	179.81
T_4 (P_{22})	589.90	141.02	200.71
T_5 (KK_{16})	511.78	102.56	158.84
F	4.72*	2.02^{NS}	8.61**
CD	45.669	-	21.582

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Plate 2. Plants treated with different isolates of fluorescent pseudomonads viz., P_1, P_5, P_{14}, P_{22} and KK_{16}

yield was obtained for treatment T_1 (201.47 g plant^{-1}) which was on par with treatment T_4 (200.71 g plant^{-1}) and was significantly higher than all other treatments. Lowest yield was noted for treatment T_5 (158.84 g plant^{-1}).

4.1.3 Soil Analysis

4.1.3.1 Available Nitrogen Status of Soil (Table 4.1.7)

Available nitrogen status of the soil after the experiment was the highest for treatment T_5 (324.58 kg ha^{-1}) and this was significantly superior to all other treatments. Treatment T_4 recorded lowest available nitrogen in soil (243.04 kg ha^{-1}) and was significantly inferior to other treatments).

4.1.3.2 Available Phosphorus Status of the Soil (Table 4.1.7)

Available phosphorus status of soil was significantly influenced by the different treatments. As in the case of available nitrogen status of the soil, treatment T_5 recorded highest available P status of the soil (60.93 kg ha^{-1}) and was significantly superior to all other treatments except T_2 (56.91 kg ha^{-1}).

4.1.3.3 Available Potassium Status of Soil (Table 4.1.7)

With regard to available K status of the soil the highest value was obtained for treatment T_2 (131.04 kg ha^{-1}) which was significantly superior to all other treatments except T_5 (123.65 kg ha^{-1}).

4.1.3.4 Organic Carbon Status of Soil (Table 4.1.7)

The different treatments had no significant influence on the organic carbon status of the soil.

4.1.4 Plant Analysis

4.1.4.1 Content of Nitrogen, Phosphorus and Potassium

4.1.4.1.1 Nitrogen Content of Plants (Table 4.1.8)

A perusal of the data revealed that plant nitrogen content was significantly influenced by different isolates of fluorescent pseudomonads.

Table 4.1.7 Effect of fluorescent pseudomonades isolates on soil NPK status and organic carbon content

Treatments	N, kg ha^{-1}	P, kg ha^{-1}	K, kg ha^{-1}	Organic carbon, per cent
T_1 (P_1)	286.16	54.73	119.62	0.73
T_2 (P_5)	302.63	56.91	131.04	0.74
T_3 (P_{14})	263.42	52.60	114.24	0.74
T_4 (P_{22})	243.04	46.54	105.50	0.78
T_5 (KK_{16})	324.58	60.93	123.65	0.71
F	26.52**	14.09**	285.61**	1.26 ^{NS}
CD	18.734	4.288	9.613	-

Table 4.1.8 Effect of fluorescent pseudomonads isolates on plant nutrient content, per cent

Treatments	N	P	K
T_1 (P_1)	1.64	0.37	1.79
T_2 (P_5)	1.66	0.30	1.65
T_3 (P_{14})	1.77	0.35	1.62
T_4 (P_{22})	1.88	0.40	2.20
T_5 (KK_{16})	1.61	0.30	1.58
F	20.06**	21.60**	6.66**
CD	0.075	0.030	0.298

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Treatment T_4 had the maximum content of nitrogen in plant sample (1.88 %) and was significantly superior to all other treatments. Here the lowest value (1.61 %) was recorded for treatment T_5.

4.1.4.1.2 **Phosphorous Content of Plants** (Table 4.1.8)

With respect to phosphorous content of plants, T_4 recorded the highest value (0.40 %) and was significantly superior to all other treatments except T_1 (0.37 %).

4.1.4.1.3 **Potassium Content of Plants** (Table 4.1.8)

The data on the K content of plants revealed that the highest potassium content was recorded for treatment T_4 (2.20 %) and was significantly higher than all other treatments.

4.1.4.2 Uptake of Nitrogen, Phosphorus and Potassium

4.1.4.2.1 **Nitrogen Uptake** (Table 4.1.9)

Nitrogen uptake of plants was significantly influenced by various treatments. Highest uptake was noted for treatment T_4 (1.06 g plant^{-1}) which on par with T_3 (0.95 g plant^{-1}) and both these treatments were significantly superior to other treatments.

4.1.4.2.2 **Phosphorus Uptake** (Table 4.1.9)

Phosphorus uptake by plant was profoundly influenced by various treatments. It was noted that treatment T_4 recorded the highest P uptake by plants (0.22 g plant^{-1}) and was significantly higher than other treatments.

4.1.4.2.3 **Potassium Uptake** (Table 4.1.9)

Potassium uptake was markedly influenced by the different treatments. T_4 recorded the highest K uptake (1.24 g plant^{-1}) and was significantly superior to other treatments.

Table 4.1.9 Effect of fluorescent pseudomonads isolates on plant nutrient uptake, g plant^{-1}

Treatments	N	P	K
T_1 (P_1)	0.80	0.18	0.88
T_2 (P_5)	0.81	0.14	0.81
T_3 (P_{14})	0.95	0.19	0.87
T_4 (P_{22})	1.06	0.22	1.24
T_5 (KK_{16})	0.75	0.14	0.74
F	12.80**	23.58**	9.32**
CD	0.106	0.022	0.190

Table 4.1.10 Effect of fluorescent pseudomonads isolates on fluorescent pseudomonads count in the rhizosphere and fruit rot incidence

Treatments	Fluorescent pseudomonads count, cfu g^{-1} x 10^6	Fruit rot incidence, per cent
T_1 (P_1)	24.25	0.35 (1.16)
T_2 (P_5)	21.75	8.15 (3.02)
T_3 (P_{14})	24.00	11.45 (3.53)
T_4 (P_{22})	26.00	9.81 (3.29)
T_5 (KK_{16})	20.75	9.55 (3.25)
F	2.19^{NS}	13.95**
CD	-	0.775

Transformed values $\sqrt{x+1}$ are given in parenthesis
NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Table 4.1.11 Effect of fluorescent pseudomonads on economics of cultivation

Treatments	Net income, Rs plant^{-1}	Benefit-cost ratio
T_1 (P_1)	1.53	2.03
T_2 (P_5)	0.90	1.61
T_3 (P_{14})	1.21	1.81
T_4 (P_{22})	1.52	2.02
T_5 (KK_{16})	0.89	1.60
F	8.61**	8.61**
CD	0.324	0.217

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Plate 3 Plants treated with the best isolates of fluorescent pseudomonads viz., P_{22} and P_1

4.1.5 Bacterial Population in the Rhizosphere (Table 4.1.10)

Data pertaining to the bacterial count in the soil revealed that different treatments had no significant influence on the fluorescent pseudomonads count in the rhizosphere. Maximum count was recorded for treatment T_4 (26.00 x 10^6 cfu g^{-1} soil).

4.1.6 Scoring for Disease Incidence (Table 4.1.10)

The data on disease scoring indicated that fruit rot incidence was minimum for treatment T_1 (0.35 %) and was significantly lower than that in other treatments. Treatment T_3 recorded highest disease incidence (11.45 %) and was significantly higher than others.

4.1.7 Economics of Cultivation

4.1.7.1 Net Returns (Table 4.1.11)

The data showed that among the different fluorescent pseudomonads isolates, maximum net returns (Rs. 1.53 plant^{-1}) was recorded by P_1 which was on par with P_{22} isolate (T_4) of Rs. 1.52 plant^{-1} and it was significantly superior to other treatments.

4.1.7.2 Benefit-Cost Ratio (Table 4.1.11)

With respect to benefit-cost ratio also the same trend as that of net returns was noticed and treatment T_1 recorded the highest benefit-cost ratio of 2.03 and it was on par with T_4 (2.02).

4.2 EXPERIMENT II

4.2.1 Growth Characters

4.2.1.1 Plant Height

A perusal of the data furnished in Tables 4.2.1a and 4.2.1b revealed that at all growth stages, inorganic fertilizers influenced plant height significantly. At 30 DAT, maximum plant height of 26.31 cm was recorded by F_3 (NPK @ 125 per cent of the recommended dose) and was significantly superior to lower levels of nutrients. Similarly at 60 DAT

Table 4.2.1a. Main effect of NPK fertilizers and bio fertilizers on plant height, cm

Treatments	30 DAT	60 DAT	90 DAT
NPK fertilizers			
F_1	23.16	34.47	40.16
F_2	24.07	35.10	42.15
F_3	26.31	36.40	43.27
F	29.09**	34.21**	24.42**
CD	0.853	0.568	0.905
Biofertilizers			
B_1	24.64	35.25	41.88
B_2	24.47	35.29	41.78
B_3	25.73	36.22	43.00
B_4	23.20	34.54	40.77
F	8.94**	8.90**	6.13**
CD	0.985	0.656	1.045

Table 4.2.1b. Interaction effect of NPK fertilizers and biofertilizers on plant height, cm

Treatment combinations	30 DAT	60 DAT	90 DAT
F_1B_1	23.99	34.80	41.53
F_1B_2	24.41	34.79	40.53
F_1B_3	26.50	37.63	42.89
F_1B_4	17.74	30.66	35.69
F_2B_1	24.57	35.20	42.10
F_2B_2	23.82	35.58	42.39
F_2B_3	24.89	35.23	43.50
F_2B_4	23.00	34.37	40.59
F_3B_1	25.36	35.74	42.02
F_3B_2	25.18	35.50	42.41
F_3B_3	25.80	35.79	42.60
F_3B_4	28.87	38.57	46.04
F	20.49**	28.76**	15.11**
CD	1.706	1.137	1.810

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Plate 4 General view of the experimental field (Experiment II)

and at harvest 125 per cent of the recommended dose of NPK was significantly superior to others and recorded the maximum plant height of 36.40 cm and 43.27 cm respectively.

Application of biofertilizers significantly influenced plant height at 30 DAT, 60 DAT and 90 DAT. Combined application of fluorescent pseudomonads and *Azospirillum* (B_3) recorded the maximum plant height at different growth stages *viz.*, 30 DAT, 60 DAT and 90 DAT (25.73 cm, 36.22 cm and 43.00 cm respectively) and it was significantly superior to all other treatments. At all the stages, application of fluorescent pseudomonads (B_1) was found to be on par with *Azospirillum* treated plants (B_2) and both these treatments had significantly higher plant height than B_4 (no biofertilizers).

The interaction between inorganic fertilizers and biofertilizers was significant at all growth stages. At 30 DAT, maximum plant height of 28.87 cm was recorded by F_3B_4 (NPK @ 125 per cent of the recommended dose + no biofertilizers) which was significantly superior to others. At 60 DAT, F_3B_4 produced the maximum plant height (38.57 cm) which was found to be on par with F_1B_3 *viz.*, Fluorescent pseudomonads + *Azospirillum* + 75 per cent of the recommended dose of NPK (37.63 cm) and was significantly superior to all other treatment combinations. Maximum plant height of 46.04 cm at 90 DAT was recorded by F_3B_4 and was significantly higher than others.

4.2.1.2 Number of Branches (Tables 4.2.2a and 4.2.2b)

A critical analysis of the data revealed that levels of NPK fertilizers and biofertilizers significantly influenced the number of branches at 30 DAT and 60 DAT.

At 30 DAT and 60 DAT, highest number of branches was observed for F_3 (8.50 and 12.87 respectively) and was significantly higher than that of plants treated with lower doses of nutrients. F_1 (75 per cent of the recommended dose of NPK) recorded the lowest values (7.38 and 11.45 respectively) and was significantly inferior to others. However, number of

Table 4.2.2a. Main effect of NPK fertilizers and biofertilizers on number of branches

Treatments	30 DAT	60 DAT	90 DAT
NPK fertilizers			
F_1	7.38	11.45	19.52
F_2	8.03	12.08	19.83
F_3	8.50	12.87	22.22
F	15.53**	18.62**	2.77^{NS}
CD	0.405	0.468	-
Biofertilizers			
B_1	8.00	12.07	20.80
B_2	8.00	11.91	20.53
B_3	8.49	13.22	21.60
B_4	7.40	11.33	19.16
F	7.36**	17.38**	0.99^{NS}
CD	0.467	0.540	-

Table 4.2.2b. Interaction effect of NPK fertilizers and biofertilizers on number of branches

Treatment combinations	30 DAT	60 DAT	90 DAT
F_1B_1	7.67	11.47	21.00
F_1B_2	7.60	10.80	19.13
F_1B_3	8.67	14.40	22.87
F_1B_4	5.60	9.13	15.07
F_2B_1	8.33	12.47	20.27
F_2B_2	8.13	12.27	20.47
F_2B_3	8.40	12.47	20.27
F_2B_4	7.27	11.13	18.33
F_3B_1	8.00	12.27	21.13
F_3B_2	8.27	12.67	22.00
F_3B_3	8.40	12.80	21.67
F_3B_4	9.33	13.73	24.07
F	10.28**	17.32**	1.69^{NS}
CD	0.809	0.935	-

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

branches at 90 DAT was not significantly influenced by different levels of fertilizers.

With respect to the application of biofertilizers, combined application of fluorescent pseudomonads and *Azospirillum* (B_3) registered maximum number of branches at 30 DAT, 60 DAT and 90 DAT (8.49, 13.22 and 21.60 respectively). At 30 DAT and 60 DAT, B_3 was found to be significantly superior to all other treatments. However B_2 (*Azospirillum*) and B_1 (Fluorescent pseudomonads) were on par and superior to B_4 (no biofertilizers), which recorded the lowest values (7.40 and 11.33 respectively). Application of biofertilizers did not significantly influence the number of branches at 90 DAT.

Interaction between NPK fertilizers and biofertilizers influenced branching significantly at 30 DAT and 60 DAT. At 30 DAT, F_3B_4 recorded the maximum number of branches (9.33), which was on par with F_1B_3 (75 per cent of the recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum*) and was significantly superior to all other treatments. At 60 DAT also the same trend was noticed and maximum number of branches was recorded by F_1B_3 (14.40), which was on par with F_3B_4 (13.73) and was significantly superior to other treatment combinations. There was no significant difference in the number of branches by interaction of NPK fertilizers and biofertilizers at 90 DAT.

4.2.1.3 Dry Matter Production at Harvest (Tables 4.2.3a and 4.2.3b)

Dry matter production at harvest was significantly influenced by inorganic and biofertilizer inoculation.

With regard to different levels of NPK fertilizers, highest dose of NPK (F_3) produced the maximum dry matter (50.60 g plant^{-1}) and was significantly higher when compared to others. F_1 (75 per cent of the recommended dose of NPK) produced the lowest DMP (46.02 g plant^{-1}) and was significantly inferior to others.

Table 4.2.3a. Main effect of NPK fertilizers and biofertilizers on dry matter production, shoot root ratio and canopy spread

Treatments	Dry matter production, g plant^{-1}	Shoot root ratio	Canopy spread, cm
NPK fertilizers			
F_1	46.02	3.84	35.48
F_2	48.28	4.23	37.70
F_3	50.60	4.55	39.68
F	12.65**	11.18**	15.99**
CD	1.831	0.303	1.494
Biofertilizers			
B_1	48.20	4.25	38.15
B_2	48.07	4.13	38.08
B_3	52.03	4.27	39.32
B_4	44.90	4.18	34.92
F	15.39**	0.26^{NS}	9.64**
CD	2.115	-	1.726

Table 4.2.3b. Interaction effect of NPK fertilizers and biofertilizers on dry matter production, shoot root ratio and canopy spread

Treatment combinations	Dry matter production, g plant^{-1}	Shoot root ratio	Canopy spread, cm
F_1B_1	46.50	4.10	37.54
F_1B_2	46.27	3.94	37.49
F_1B_3	53.73	4.44	39.57
F_1B_4	36.57	2.87	27.31
F_2B_1	53.00	4.29	37.53
F_2B_2	47.87	4.17	37.63
F_2B_3	51.00	4.01	38.49
F_2B_4	41.27	4.46	37.16
F_3B_1	44.10	4.34	39.37
F_3B_2	50.07	4.29	39.13
F_3B_3	51.37	4.36	39.91
F_3B_4	56.87	5.21	40.31
F	23.67**	7.50**	9.29**
CD	3.663	0.606	2.989

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

There was significant increase in dry matter production by biofertilizer inoculation. Fluorescent pseudomonads + *Azospirillum* inoculation (B_3) registered the maximum DMP (52.03 g plant^{-1}) and was significantly higher than B_1 (48.20 g plant^{-1}) and B_2 (48.07 g plant^{-1}) which were on par.

Interaction between inorganic nutrient levels and biofertilizer inoculation was also significant. F_3B_4 recorded maximum DMP of 56.87 g plant^{-1} which was on par with F_1B_3 (53.73 g plant^{-1}). F_1B_4 (75 per cent of the recommended dose of NPK + no biofertilizers) registered the lowest DMP and was significantly inferior to other treatment combinations.

4.2.1.4 Shoot Root Ratio (Tables 4.2.3a and 4.2.3b)

Shoot root ratio was significantly influenced by inorganic nutrient levels. Maximum value for shoot root ratio was noticed for F_3 (4.55) and was significantly higher than the lower doses of nutrients.

Biofertilizer inoculation failed to have any significant influence on the shoot root ratio. However the maximum value was observed for B_3 (4.27).

Interaction effect of NPK fertilizers and biofertilizer was significant. Application of 125 per cent of the recommended dose of NPK without biofertilizers produced maximum shoot root ratio (5.21) and was significantly superior to others.

4.2.1.5 Canopy Spread at Flowering (Tables 4.2.3a and 4.2.3b)

Application of inorganic nutrients significantly increased canopy spread with 125 per cent of the recommended dose of NPK registering significantly higher canopy spread (39.68 cm) than 100 per cent of the recommended dose of NPK (37.70 cm) and 75 per cent of the recommended dose of NPK (35.48 cm).

Inoculation of plants with biofertilizers significantly influenced canopy spread at 60 DAT. Maximum canopy spread (39.32 cm) was noted for fluorescent pseudomonads + *Azospirillum* inoculation which was on par with inoculation of fluorescent pseudomonads (38.15 cm) and *Azospirillum* (38.08 cm) individually and these three treatments were significantly superior to B_4 (no biofertilizers).

Interaction effect of inorganic nutrient levels and biofertilizers on canopy spread was significant. Application of 125 per cent of the recommended dose of NPK + no biofertilizers (F_3B_4) registered maximum canopy spread (40.31 cm) which was on par with all treatment combinations except F_2B_4 (100 per cent of the recommended dose of NPK + no biofertilizers) and F_1B_4 (75 per cent of the recommended dose of NPK + no biofertilizers).

4.2.2 Yield and Yield Attributes

4.2.2.1 Time of 50 per cent Flowering (Tables 4.2.4a and 4.2.4b)

A perusal of the data revealed that the levels of NPK fertilizers had profound influence on the time of 50 per cent flowering. F_3 took the maximum time to flower (36.67 days) and was significantly higher than that at lower levels of nutrients.

Influence of biofertilizer inoculation on time of 50 per cent flowering was not significant. The interaction effect of inorganic nutrient levels and biofertilizers was also not significant.

4.2.2.3 Number of Flowers per Plant (Tables 4.2.4a and 4.2.4b)

The number of flowers per plant shown in Table 4.2.4 indicates that inorganic nutrients influenced this character significantly. Significant variations were noticed among F_3, F_2 and F_1 with F_3 (NPK @ 125 per cent of the recommended dose) recording the highest number of 108.23 which was significantly higher than F_2 (104.27) and F_1 (100.10).

Influence of biofertilizers on number of flowers plant^{-1} was also significant. Highest number of flowers plant^{-1} was recorded for combined application of fluorescent pseudomonads and *Azospirillum* (110.20).

Table 4.2.4a. Main effect of NPK fertilizers and biofertilizers on time of 50 per cent flowering, number of flowers plant^{-1} and number of fruits plant^{-1}

Treatments	Time of 50 per cent flowering, days	Number of flowers plant^{-1}	Number of fruits plant^{-1}
NPK fertilizers			
F_1	32.50	100.10	36.42
F_2	34.83	104.27	38.45
F_3	36.67	108.23	37.63
F	12.49**	12.09**	1.36^{NS}
CD	1.680	3.325	-
Biofertilizers			
B_1	34.44	104.80	39.42
B_2	34.56	103.89	37.96
B_3	35.67	110.20	41.53
B_4	34.00	97.91	31.09
F	1.08^{NS}	13.89**	19.88**
CD	-	3.839	2.881

Table 4.2.4b. Interaction effect of NPK fertilizers and biofertilizers on time of 50 per cent flowering, number of flowers plant^{-1} and number of fruits plant^{-1}

Treatment combinations	Time of 50 per cent flowering, days	Number of flowers plant^{-1}	Number of fruits plant^{-1}
F_1B_1	32.33	102.73	38.00
F_1B_2	32.67	103.47	36.47
F_1B_3	35.00	114.73	49.00
F_1B_4	30.00	79.47	22.20
F_2B_1	36.00	105.47	43.67
F_2B_2	35.00	104.20	41.80
F_2B_3	35.00	110.47	38.67
F_2B_4	33.33	96.93	29.67
F_3B_1	35.00	106.20	36.60
F_3B_2	36.00	104.00	35.60
F_3B_3	37.00	105.40	36.93
F_3B_4	38.67	117.33	41.40
F	2.27^{NS}	19.39**	17.02**
CD	-	6.650	5.000

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Plants which were not treated with biofertilizers (B_4) recorded lowest number of flowers (97.91) and was significantly inferior to other treatments.

Interaction effect of inorganic and biofertilizers on number of flowers was significant. F_3B_4 recorded the maximum number of flowers per plant (117.33) which was on par with F_1B_3 (114.73) and was significantly superior to other treatment combinations. F_1B_4 recorded the lowest number of flowers (79.47).

4.2.2.3 Number of Fruits per Plant (Tables 4.2.4a and 4.2.4b)

The different levels of NPK fertilizers did not show significant influence on the number of fruits $plant^{-1}$.

However biofertilizer inoculation significantly influenced this yield attribute. Maximum number of fruits $plant^{-1}$ (41.53) was noticed for B_3 (Fluorescent pseudomonads + *Azospirillum*) and it was on par with B_1 *viz.*, fluorescent pseudomonads (39.42) Plants which were not inoculated with biofertilizers (B_4) recorded the lowest number of fruits $plant^{-1}$ (31.09).

The interaction between inorganic nutrients and biofertilizers was noticed to be significant. F_1B_3 recorded the maximum number of fruits $plant^{-1}$ (49.00) and was significantly superior to other treatment combinations.

4.2.2.4 Setting Percentage of Fruits (Tables 4.2.5a and 4.2.5b)

Setting percentage of fruits was significantly influenced by NPK fertilizers. F_3 recorded maximum setting percentage (45.11 %) and was on par with F_2 (44.02 %). Lowest level of inorganics (F_1) registered the lowest setting percentage and was significantly inferior to F_3 and F_2.

Biofertilizer application did not significantly affect fruit setting percentage, but the maximum fruit set was noted for fluorescent pseudomonads inoculation (44.96).

Table 4.2.5a. Main effect of NPK fertilizers and biofertilizers on setting percentage, length, girth and ascorbic acid content of fruits

Treatments	Setting percentage, per cent	Length of fruit, cm	Girth of fruit, cm	Ascorbic acid, mg 100^{-1} g
NPK fertilizers				
F_1	41.18	8.07	4.20	101.09
F_2	44.02	8.45	4.44	103.28
F_3	45.11	8.75	4.71	98.59
F	4.31*	20.08**	13.07**	0.11^{NS}
CD	2.777	0.216	0.201	-
Biofertilizers				
B_1	44.96	8.33	4.34	97.02
B_2	43.98	8.40	4.40	93.89
B_3	44.20	8.58	4.82	116.02
B_4	40.61	8.38	4.25	97.02
F	2.94^{NS}	1.57^{NS}	9.59**	1.52^{NS}
CD	-	-	0.233	-

Table 4.2.5b. Interaction effect of NPK fertilizers and biofertilizers on setting percentage, length, girth and ascorbic acid content of fruits

Treatment combinations	Setting percentage, per cent	Length of fruit, cm	Girthof fruit, cm	Ascorbic acid, mg 100^{-1} g
F_1B_1	43.64	8.11	4.13	103.29
F_1B_2	41.97	8.14	4.18	103.28
F_1B_3	48.84	8.57	5.02	132.07
F_1B_4	30.28	7.47	3.49	65.72
F_2B_1	48.52	8.30	4.40	112.67
F_2B_2	47.09	8.47	4.40	84.50
F_2B_3	40.40	8.58	4.81	112.68
F_2B_4	40.06	8.43	4.15	103.28
F_3B_1	42.72	8.58	4.50	75.11
F_3B_2	42.89	8.59	4.61	93.89
F_3B_3	43.35	8.60	4.64	103.30
F_3B_4	51.48	9.24	5.11	122.07
F	11.50**	6.30**	8.65**	2.45^{NS}
CD	5.554	0.432	0.403	-

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Interaction between inorganic nutrients and biofertilizer application significantly influenced setting percentage of fruits. F_3B_4 recorded maximum fruit setting percentage (51.48) and was on par with F_1B_3 (48.84), F_2B_1 (48.52) and F_2B_2 (47.09).

4.2.2.5 Length and Girth of Fruits (Tables 4.2.5a and 4.2.5b)

Data on mean length and girth of fruits presented in Table 4.2.5 reveals that F_3 recorded maximum length and girth of fruits (8.75 and 4.71 cm respectively) and was significantly higher than F_2 (8.45 and 4.44 cm respectively) and F_1 (8.07 and 4.20 cm respectively).

With regard to length of fruits, there was no significant difference due to application of biofertilizers. However maximum length was recorded for B_3 (8.58 cm). However, biofertilizer application significantly influenced the girth of fruits and B_3 (4.82 cm) was significantly superior to others.

Interaction effect was significant with regard to length and girth of fruits. Maximum value for length (9.24 cm) was observed for F_3B_4 and was significantly superior to others. Similarly F_3B_4 registered maximum fruit girth (5.11 cm), which was on par with F_1B_3 (5.02 cm) and F_2B_3 (4.81 cm).

4.2.2.6 Hundred Fruit Weight (Tables 4.2.6a and 4.2.6b)

Neither the inorganic fertilizers nor the biofertilizers exerted any significant effect on 100 fruit weight. On the other hand, interaction effect of inorganics and biofertilizers was significant on 100 fruit weight. F_3B_4 (604.39) topped the list of treatment combinations although it was on par with F_1B_3 (600.73). Both these treatments were significantly superior to other treatment combinations.

4.2.2.7 Ascorbic Acid Content of Fruits (Tables 4.2.5a and 4.2.5b)

Application of inorganic and biofertilizers failed to produce any significant influence on the ascorbic acid content of fruits.

Table 4.2.6a. Main effect of NPK fertilizers and biofertilizers on 100 fruit weight and fruit yield

Treatments	100 fruit weight, g	Fruit yield, g plant^{-1}	Fruit yield, t ha^{-1}
NPK fertilizers			
F_1	523.99	137.18	6.75
F_2	524.98	137.24	7.21
F_3	550.85	132.43	6.75
F	3.43^{NS}	1.74^{NS}	2.26^{NS}
CD	-	5.932	-
Biofertilizers			
B_1	526.20	144.84	7.56
B_2	525.65	136.57	7.01
B_3	557.07	150.18	7.76
B_4	524.18	110.89	5.29
F	2.80^{NS}	52.20**	30.95**
CD	-	6.850	0.574

Table 4.2.6b Interaction effect of NPK fertilizers and biofertilizers on 100 fruit weight and fruit yield

Treatment combinations	100 fruit weight, g	Fruit yield g plant^{-1}	Fruit yield, t ha^{-1}
F_1B_1	519.09	147.94	7.63
F_1B_2	516.58	136.44	7.00
F_1B_3	600.73	163.71	8.74
F_1B_4	459.56	100.63	3.65
F_2B_1	520.33	160.25	8.42
F_2B_2	529.02	139.15	7.09
F_2B_3	541.97	146.12	7.55
F_2B_4	508.60	103.45	5.76
F_3B_1	539.17	126.32	6.62
F_3B_2	531.33	134.12	6.94
F_3B_3	528.50	140.70	6.98
F_3B_4	604.39	128.58	6.46
F	7.59**	12.48**	9.52**
CD	46.759	11.865	0.994

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

4.2.2.8 ***Fruit Yield per Plant*** (Tables 4.2.6a and 4.2.6b)

Different levels of NPK fertilizers did not significantly influence the fruit yield plant^{-1}. F_2 (100 per cent of recommended dose of NPK) recorded the highest yield (137.24 g plant^{-1})

Among the biofertilizer treatments, B_3 (Fluorescent pseudomonads + *Azospirillum*) produced the highest yield (150.18 g plant^{-1}), which was on par with B_1 (144.84 g plant^{-1}) and was significantly superior to other treatments. The most inferior treatment was B_4 (110.89 g plant^{-1}).

Interaction effect of NPK fertilizers and biofertilizers was significant. Treatment combination F_1B_3 produced the highest yield (163.71 g plant^{-1}) which was on par with F_2B_1 (160.25 g plant^{-1}) and was significantly superior to all other treatment combinations. F_1B_4 recorded the lowest value (100.63 g plant^{-1}) and was significantly inferior to other treatment combinations.

4.2.2.9 ***Fruit Yield per Hectare*** (Tables 4.2.6a and 4.2.6b)

The data revealed that yield per hectare was not significantly influenced by different levels of NPK fertilizers, whereas biofertilizer inoculation had profound influence on this character.

With regard to biofertilizer application, combined application of fluorescent pseudomonads and *Azospirillum* (B_3) recorded the highest yield ha^{-1} (7.76 t ha^{-1}) which was on par with treatment B_1 (Fluorescent pseudomonads) which produced yield of 7.56 t ha^{-1}.

Interaction effect of inorganics and biofertilizer inoculation was significant with regard to yield per hectare. F_1B_3 *i.e.*, 75 per cent of the recommended dose of NPK along with combined inoculation of fluorescent pseudomonads and *Azospirillum* registered the highest yield (8.74 t ha^{-1}) and was on par with F_2B_1 *i.e.*, NPK @ 100 per cent of the recommended dose along with fluorescent pseudomonads (8.42 t ha^{-1})

Table 4.2.7a. Main effect of NPK fertilizers and biofertilizers on soil NPK status and organic carbon content of soil

Treatments	N, kg ha^{-1}	P, kg ha^{-1}	K, kg ha^{-1}	Organic carbon, per cent
NPK fertilizers				
F$_1$	254.28	46.96	94.30	0.70
F$_2$	264.46	55.45	108.86	0.77
F$_3$	267.55	59.32	118.95	0.80
F	5.09**	5.23**	8.35**	24.67**
CD	8.752	7.866	12.184	0.029
Biofertilizers				
B$_1$	266.57	53.52	106.32	0.75
B$_2$	264.26	51.91	103.64	0.76
B$_3$	264.60	60.88	115.29	0.81
B$_4$	252.97	49.33	104.24	0.71
F	3.01^{NS}	2.41^{NS}	1.19^{NS}	13.82**
CD	-	-	-	0.033

Table 4.2.7b. Interaction effect of NPK fertilizers and biofertilizers on soil NPK status and organic carbon content of soil

Treatment combinations	N, kg ha^{-1}	P, kg ha^{-1}	K, kg ha^{-1}	Organic carbon, per cent
F$_1$B$_1$	262.39	48.40	104.83	0.69
F$_1$B$_2$	257.15	40.82	94.08	0.73
F$_1$B$_3$	247.74	58.28	108.42	0.82
F$_1$B$_4$	249.83	40.32	69.89	0.57
F$_2$B$_1$	267.60	52.75	104.83	0.77
F$_2$B$_2$	270.72	56.84	107.52	0.77
F$_2$B$_3$	266.56	63.33	115.58	0.81
F$_2$B$_4$	252.97	48.89	107.52	0.71
F$_3$B$_1$	269.70	59.42	109.31	0.78
F$_3$B$_2$	264.90	58.07	109.31	0.79
F$_3$B$_3$	279.50	61.02	121.86	0.80
F$_3$B$_4$	256.11	58.77	135.30	0.84
F	1.16^{NS}	0.60^{NS}	2.65*	9.19**
CD	-	-	24.368	0.058

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

4.2.3 Soil Analysis

4.2.3.1 Available Soil Nitrogen (Tables 4.2.7a and 4.2.7b)

Data on available soil nitrogen status revealed that application of inorganic fertilizers had significant influence on this attribute. Maximum available nitrogen in soil was noted for F_3 (267.55 kg ha^{-1}) and it was on par with F_2 (264.46 kg ha^{-1}) and both the treatments were significantly superior to F_1 (254.28 kg ha^{-1}).

There was no significant influence of biofertilizer on available soil nitrogen status. Maximum soil nitrogen status was observed for fluorescent pseudomonads treatment (266.57 kg ha^{-1}).

Interaction effect of inorganic nutrient and biofertilizers failed to produce any significant effect on available soil nitrogen status.

4.2.3.2 Available Phosphorus Status of Soil (Tables 4.2.7a and 4.2.7b)

The results on available phosphorus status of soil reveals that fertilizer application significantly influenced available soil phosphorus status. Highest level of inorganic fertilizer (F_3) was observed to have the highest available phosphorus in soil (59.32 kg ha^{-1}) which was on par with F_2 (55.45 kg ha^{-1}).

There was no significant effect on available soil phosphorus status due to biofertilizer application. Maximum available soil phosphorus was noted for B_3 (60.88 kg ha^{-1}) followed by B_1 (53.52 kg ha^{-1}).

Interaction effect was not significant on soil phosphorus status.

4.2.3.3 Available Potassium Status of Soil (Tables 4.2.7a and 4.2.7b)

Application of NPK fertilizers had significant influence on available K status of soil. F_3 was the most superior treatment with respect to this character which recorded the highest value (118.95 kg ha^{-1}) and it was significantly higher than that registered with F_2 (108.86 kg ha^{-1}) and F_1 (94.30 kg ha^{-1}).

Application of biofertilizers had no significant influence on available K status of soil. B_3 recorded the highest value (115.29 kg ha^{-1}).

Interaction effect of NPK fertilizers and biofertilizers was also significant. The maximum available K status in soil (135.30 kg ha^{-1}) was noted for F_3B_4 which was on par with F_3B_3 (121.86 kg ha^{-1}) and F_2B_3 (115.58 kg ha^{-1}) and was significantly higher than other treatment combinations.

4.2.3.4 Organic Carbon Content (Tables 4.2.7a and 4.2.7b)

Application of NPK fertilizers and biofertilizers significantly influenced organic carbon content of soil. There was significant variation among F_3 (0.80 %), F_2 (0.77 %) and F_1 (0.70 %). F_3 was the most superior for this character and F_1, the most inferior.

With regard to application of biofertilizers, maximum organic carbon content was noted for B_3 (0.81 %) which was significantly higher than B_2 (0.76 %) which was on par with B_1 (0.75 %). B_4 (0.71 %) had the minimum organic carbon content and was significantly inferior to other treatments.

Interaction effect of NPK fertilizers and biofertilizers was also significant. F_3B_4 had the highest organic carbon content (0.84 %) which was on par with F_1B_3 (0.82 %), F_2B_3 (0.81 %), F_3B_3 (0.80 %), F_3B_2 (0.79 %) and F_3B_1 (0.78 %). F_1B_4 recorded the lowest value (0.57 %).

4.2.4 Plant Analysis

4.2.4.1 Content of N, P and K

4.2.4.1.1 Nitrogen Content of Plants (Tables 4.2.8a and 4.2.8b)

A critical analysis of the data revealed that application of NPK fertilizers and biofertilizer inoculation significantly influenced the nitrogen content of plants.

Table 4.2.8a. Main effect of NPK fertilizers and biofertilizers on plant nutrient content, per cent

Treatments	N	P	K
NPK fertilizers			
F_1	1.94	0.29	1.82
F_2	2.05	0.33	2.02
F_3	2.20	0.36	2.27
F	29.72**	11.41**	59.36**
CD	0.007	0.032	0.084
Biofertilizers			
B_1	2.02	0.35	2.05
B_2	2.16	0.31	2.05
B_3	2.20	0.39	2.10
B_4	1.87	0.26	1.94
F	28.54**	16.83**	4.12**
CD	0.081	0.037	0.097

Table 4.2.8b. Interaction effect of NPK fertilizers and biofertilizers on plant nutrient content, per cent

Treatment combinations	N	P	K
F_1B_1	1.90	0.33	1.87
F_1B_2	2.20	0.26	1.88
F_1B_3	2.33	0.41	1.91
F_1B_4	1.31	0.15	1.61
F_2B_1	2.05	0.37	2.04
F_2B_2	2.18	0.36	2.05
F_2B_3	2.09	0.39	2.11
F_2B_4	1.87	0.19	1.86
F_3B_1	2.11	0.33	2.25
F_3B_2	2.09	0.31	2.21
F_3B_3	2.19	0.37	2.28
F_3B_4	2.43	0.45	2.33
F	37.56**	15.58**	2.63*
CD	0.140	0.063	0.168

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Maximum nitrogen content (2.20 %) was noted for F_3 (NPK @ 125 per cent of the recommended dose) which was significantly higher than F_2 (2.05 %) and F_1 (1.94 %).

In the case of biofertilizer inoculation, B_3 recorded the maximum plant nitrogen content (2.20 %) which was found to be on par with B_2 (2.16 %).

None of the interactions had significant influence on this character. F_3B_4 recorded the highest value (2.43 %) which was on par with F_1B_3 (2.33 %) and was significantly superior to other treatment combinations.

4.2.4.1.2 Phosphorus Content of Plants (Tables 4.2.8a and 4.2.8b)

It was observed that both NPK fertilizers and biofertilizers significantly affected phosphorus content of plants.

Significant differences were observed among fertilizer levels and F_3 had significantly higher P content (0.36 %) than others.

Among biofertilizer treated plants, B_3 recorded the maximum value (0.39 %) and this differed significantly with B_1 (0.35 %) and B_2 (0.31 %). B_4 (0.26 %) recorded the lowest value and was significantly inferior to others.

Treatment combinations also exerted significant influence on plant phosphorus content. F_3B_4 recorded the highest plant P content (0.45 %) which was on par with F_1B_3 (0.41 %) and F_2B_3 (0.39 %) and was significantly superior to others.

4.2.4.1.4 Potassium Content of Plants (Tables 4.2.8a and 4.2.8b)

Application of NPK fertilizers and biofertilizers influenced the potassium content of plants significantly. It was found that there was significant variation among F_3 (2.27 %), F_2 (2.02 %) and F_1 (1.82 %). F_3 was the most superior treatment with regard to K content.

With respect to biofertilizer inoculation, B_3 registered maximum

K content in plants (2.10 %) and was on par with B_1 (2.05 %) and B_2 (2.05 %). However B_4 recorded minimum K content (1.94 %) and was significantly inferior to others.

Interaction effect on plant K content was significant with maximum value for F_3B_4 (2.33 %) and it was on par with combinations F_3B_3 (2.28 %), F_3B_1 (2.25 %) and F_3B_2 (2.21 %).

4.2.4.2 Uptake of Nitrogen, Phosphorus and Potassium

4.2.4.2.1 Uptake of Nitrogen (Tables 4.2.9a and 4.2.9b)

It could be observed that NPK fertilizer application significantly influenced nitrogen uptake by plants. Uptake of nitrogen increased significantly with successive increase in nutrient levels and maximum uptake was observed for F_3 (55.30 kg ha^{-1}) and least by F_1 (45.12 kg ha^{-1}).

Among the biofertilizers, fluorescent pseudomonads + *Azospirillum* recorded significantly higher nitrogen uptake (56.63 kg ha^{-1}) compared to that of *Azospirillum* (51.23 kg ha^{-1}), fluorescent pseudomonads (48.05 kg ha^{-1}) and plants which were not treated with biofertilizers (43.29 kg ha^{-1}).

Interaction between inorganic nutrients and biofertilizers was significant and the treatment combination F_3B_4 recorded the highest nitrogen uptake (68.21 kg ha^{-1}) which was significantly higher than others.

4.2.4.2.2 Uptake of Phosphorus (Tables 4.2.9a and 4.2.9b)

There was progressive increase in the uptake of phosphorus due to different inorganic nutrient levels and the difference was significant. F_3 recorded maximum phosphorus uptake of 9.18 kg ha^{-1} and it was significantly superior to lower doses of NPK. F_1 recorded the minimum uptake of 6.83 kg ha^{-1}.

Fluorescent pseudomonads + *Azospirillum* inoculation recorded significantly higher phosphorus uptake (9.97 kg ha^{-1}) than fluorescent pseudomonads applied plants (8.28 kg ha^{-1}) which was on par with that of

Table 4.2.9a. Main effect of NPK fertilizers and biofertilizers on plant nutrient uptake, kg ha^{-1}

Treatments	N	P	K
NPK fertilizers			
F_1	45.12	6.83	41.59
F_2	48.98	8.02	48.26
F_3	55.30	9.18	56.83
F	42.47**	17.33**	76.81**
CD	2.243	0.804	2.478
Biofertilizers			
B_1	48.05	8.28	48.77
B_2	51.23	7.36	48.74
B_3	56.63	9.97	53.83
B_4	43.29	6.42	44.23
F	37.76**	21.47**	15.22**
CD	2.590	0.928	2.861

Table 4.2.9b. Interaction effect of NPK fertilizers and biofertilizers on plant nutrient uptake, kg ha^{-1}

Treatment combinations	N	P	K
F_1B_1	44.65	7.83	43.79
F_1B_2	50.35	5.96	42.90
F_1B_3	61.85	10.76	50.51
F_1B_4	23.62	2.76	29.14
F_2B_1	53.61	9.76	53.37
F_2B_2	51.64	8.50	48.54
F_2B_3	52.63	9.83	53.13
F_2B_4	38.05	3.97	38.01
F_3B_1	45.90	7.26	49.15
F_3B_2	51.70	7.62	54.76
F_3B_3	55.41	9.32	57.87
F_3B_4	68.21	12.53	65.52
F	61.36**	27.87**	21.78**
CD	4.487	1.607	4.956

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

Azospirillum inoculated plants (7.36 kg ha^{-1}). B_4 registered minimum value and was significantly lower than other treatments.

The interaction between inorganic and biofertilizers was significant and F_3B_4 recorded the maximum uptake (12.53 kg ha^{-1}) and was significantly higher than other treatment combinations.

4.2.4.2.3 Uptake of Potassium (Tables 4.2.9a and 4.2.9b)

Application of NPK fertilizers and biofertilizers significantly influenced K uptake by plants.

F_3 recorded maximum potassium uptake by plants (56.83 kg ha^{-1}) and was significantly higher than F_1 and F_2.

With respect to application of biofertilizers, B_3 had maximum K uptake (53.83 kg ha^{-1}) and it significantly varied with B_1 (48.77 kg ha^{-1}) which was on par with B_2 (48.74 kg ha^{-1}). B_4 was significantly inferior to others and recorded the lowest value (44.23 kg ha^{-1}).

Among the various treatment combinations F_3B_4 recorded the highest value (65.52 kg ha^{-1}) and was significantly superior to other treatment combinations. Minimum K uptake was observed for F_1B_4 (29.14 kg ha^{-1}).

4.2.5 Bacterial Count in the Rhizosphere (Tables 4.2.10a and 4.2.10b)

NPK fertilizer application exerted significant influence on the count of fluorescent pseudomonads and *Azospirillum* in the rhizosphere of plants. F_1 (75 per cent of the recommended dose of NPK) registered the highest count of fluorescent pseudomonads (36.50 x 10^5 cfu g^{-1} soil) which was on par with F_2 (36.17 x 10^5 cfu g^{-1} soil). With regard to *Azospirillum* count, 100 per cent of the recommended dose of NPK (F_2) recorded maximum value (7.17 x 10^5 cfu g^{-1} soil) and was on par with 75 per cent of the recommended dose of NPK (6.42 x 10^5 cfu g^{-1} soil). Plants treated with highest dose of fertilizer (F_3) gave the minimum count for both fluorescent pseudomonads and *Azospirillum* (30.75 x 10^5 cfu g^{-1} soil and 5.08 x 10^5 cfu g^{-1} soil respectively).

Table 4.2.10a. Main effect of NPK fertilizers and biofertilizers on bacterial count in the rhizosphere and fruit rot incidence

Treatments	Bacterial count, cfu g^{-1} x 10^5		Fruit rot incidence, per cent
	Pseudomonas	*Azospirillum*	
NPK fertilizers			
F_1	36.50	6.42	14.27
F_2	36.17	7.17	16.44
F_3	30.75	5.08	20.07
F	3.60*	7.89**	21.79**
CD	4.839	1.068	1.784
Biofertilizers			
B_1	40.00	3.00	13.11
B_2	29.11	11.44	16.91
B_3	39.89	7.22	15.59
B_4	28.89	3.22	22.10
F	10.34**	84.37**	27.37**
CD	5.587	1.233	2.061

Table 4.2.10b. Interaction effect of NPK fertilizers and biofertilizers on bacterial count in the rhizosphere and fruit rot incidence

Treatment combinations	Bacterial count, cfu g^{-1} x 10^5		Fruit rot incidence, per cent
	Pseudomonas	*Azospirillum*	
F_1B_1	47.67	3.00	10.34
F_1B_2	27.33	12.00	15.94
F_1B_3	42.67	7.00	12.16
F_1B_4	28.33	3.67	18.65
F_2B_1	42.00	4.00	11.96
F_2B_2	31.00	13.67	14.77
F_2B_3	41.33	7.67	15.74
F_2B_4	30.33	3.33	23.29
F_3B_1	30.33	2.00	17.03
F_3B_2	29.00	8.67	20.02
F_3B_3	35.67	7.00	18.86
F_3B_4	28.00	2.67	24.37
F	1.59^{NS}	2.03^{NS}	1.26^{NS}
CD	-	-	-

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

With respect to biofertilizer inoculation there was significant variation for bacterial count in the rhizosphere. B_1 recorded maximum count for fluorescent pseudomonads (40.00 x 10^5 cfu g^{-1} soil) closely followed by B_3 (39.89 x 10^5 cfu g^{-1} soil) and both these treatments were on par. Lowest value was noted for B_4 (28.89 x 10^5 cfu g^{-1} soil), which was on par with B_2 (29.11 x 10^5 cfu g^{-1} soil).

Azospirillum inoculation (B_2) registered maximum count of *Azospirillum* (11.44 x 10^5 cfu g^{-1} soil) which differed significantly from combined inoculation of fluorescent pseudomonads and *Azospirillum* (7.22 x 10^5 cfu g^{-1} soil).

Interaction effect of NPK fertilizers and biofertilizer was not significant on the count of both fluorescent pseudomonads and *Azospirillum*.

4.2.6 Scoring for Disease Incidence (Tables 4.2.10a and 4.2.10b)

NPK fertilizer application significantly influenced incidence of fruit rot and 125 per cent of the recommended dose of NPK (F_3) registered the highest value (20.07 %) compared to F_2 (16.44 %) and F_1 (14.27 %).

With respect to biofertilizer application, lowest disease incidence was noted for fluorescent pseudomonads (13.11 %) which was significantly lower than others. B_4 (no biofertilizer) recorded maximum fruit rot incidence (22.10 %) and was significantly inferior to *Azospirillum* (16.91 %) and fluorescent pseudomonads + *Azospirillum* treatments (15.59 %).

Interaction effect was not significant on this character.

4.2.7 Economics of Cultivation

4.2.7.1 Net Returns (Tables 4.2.11a and 4.2.11b)

Data presented in Table 4.2.12 revealed that application of NPK fertilizers did not significantly influence net returns. However biofertilizers had significant influence on this.

Table 4.2.11a. Main effect of NPK fertilizers and biofertilizers on net returns and benefit-cost ratio

Treatments	Net returns, Rs ha^{-1}	Benefit-Cost ratio
NPK fertilizers		
F_1	29613.86	1.41
F_2	34651.14	1.47
F_3	26053.86	1.35
F	1.59^{NS}	1.15^{NS}
CD	-	-
Biofertilizers		
B_1	39850.66	1.55
B_2	31613.54	1.43
B_3	42834.48	1.59
B_4	6126.46	1.08
F	20.97**	14.72**
CD	3273.119	0.054

Table 4.2.11b. Interaction effect of NPK fertilizers and biofertilizers on net returns and benefit-cost ratio

Treatment combinations	Net returns, Rs ha^{-1}	Benefit-Cost ratio
F_1B_1	42648.52	1.60
F_1B_2	33198.15	1.46
F_1B_3	59328.02	1.82
F_1B_4	-16719.26	0.77
F_2B_1	52825.19	1.72
F_2B_2	32873.08	1.44
F_2B_3	39710.12	1.54
F_2B_4	13196.17	1.18
F_3B_1	24078.27	1.32
F_3B_2	28769.38	1.38
F_3B_3	29465.31	1.39
F_3B_4	21902.46	1.29
F	6.57**	4.73**
CD	5669.210	0.093

NS: Not significant **Significant at 1 per cent level *Significant at 5 per cent level

B_3 recorded the highest net returns (Rs. 42834.48 ha^{-1}) which was on par with B_1 (Rs. 39850.66 ha^{-1}). B_4 was the significantly inferior treatment, which recorded the lowest value (Rs. 6126.46 ha^{-1}).

Interaction effect on net returns was significant. F_1B_3 (75 per cent of the recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum*) recorded maximum net returns (Rs. 59328.02 ha^{-1}) and was significantly superior to other treatment combinations.

4.2.7.2 ***Benefit-Cost Ratio*** (Table 4.2.11)

Application of NPK fertilizers failed to show significant influence on benefit-cost ratio whereas biofertilizers had profound influence on this.

With regard to biofertilizer application, B_3 registered highest benefit-cost ratio (1.59) and was noted to be on par with B_1 (1.55). Lowest value was noted for B_4 (1.08) which was significantly inferior to other treatments.

Among the different treatment combinations, F_1B_3 recorded maximum benefit-cost ratio (1.82) and was significantly higher than other treatment combinations. Lowest value was noted for F_1B_4 (0.77).

DISCUSSION

5. DISCUSSION

In the present investigation entitled 'Response of chilli (*Capsicum annuum* L.) to plant growth promoting rhizobacteria fluorescent pseudomonads', besides evaluating the different isolates of fluorescent pseudomonads, an attempt has been made to ascertain the possibility of partially substituting inorganic fertilizers with biofertilizers with a view to maintain soil health and to increase the net returns.

The results of the investigation are briefly discussed below taking into consideration the previous information available in this subject and the data generated from the study. A critical analysis has been done to elicit possible trends and to draw definite conclusions.

5.1 EXPERIMENT I

5.1.1 Effect of Fluorescent Pseudomonads Isolates on Growth Characters

The pot culture study consisted of testing five different isolates of fluorescent pseudomonads *viz.*, P_1, P_5, P_{14}, P_{22} and KK_{16}.

The results of the experiment showed that various growth characters of chilli were significantly influenced by different treatments. Fluorescent pseudomonads are known to produce several plant growth promoting substances such as vitamins and growth hormones *viz.*, auxins, gibberrelins, cytokinins etc. (Suslow, 1982 and Schippers *et al.*, 1987). These growth hormones can influence the physiological process in plants and can lead to certain morphological changes like increased root growth, leaf expansion, shoot growth etc. With regard to growth characters, treatment T_4 (Fluorescent pseudomonads isolate P_{22}) was significantly superior to others and recorded the highest values for mean plant height at

30 and 60 DAT (28.98 cm and 37.25 cm respectively) and number of branches at 30, 60 and 90 DAT (8.25, 13.25 and 18.5 cm respectively). Maximum canopy spread (38.40 cm) and shoot root ratio (4.22) were also recorded by isolate P_{22} which was significantly superior to others. Isolates producing higher amount of growth hormones like Indole-acetic acid (IAA) that directly affect root growth were found to increase plant vigour and plant growth in chilli (Ramamoorthy and Samiyappan, 2001). Similar results were obtained by Heera (2002) in rice. Isolate P_{22} might have produced higher amount of growth hormones, which might be a factor for increased plant growth in the present study. The increased root growth would have helped the plant to explore more nutrients from the surrounding soil volume thus making more nutrients available to the plant. The increased nutrient content might have increased cell division and cell elongation in plants which might have lead to increased plant height and number of branches. The increased plant height and number of branches have led to a larger canopy spread which enables the plant to tap more solar energy for photosynthesis. In addition to the influence of nutrients, the presence of growth hormones like cytokinins, gibberrelins etc. will be increasing shoot growth. The increased shoot growth might have overtaken corresponding root growth of plants which could be the reason for a higher shoot root ratio. Increased shoot growth with respect to root growth by the application of fluorescent pseudomonads were reported by Savithry and Gnanamanickam (1987) in peanuts.

Maximum drymatter production was noted for treatment T_4 (56.25 g plant^{-1}) which was significantly superior to others except T_3 (Isolate P_{14}). The better vegetative growth helps the plant in capturing more solar radiation and in the synthesis of photosynthates. But the partitioning and translocation of photosynthetic assimilates to the sink by isolate P_{22} might not have excelled that of isolate P_{14} which could be the reason for such performances.

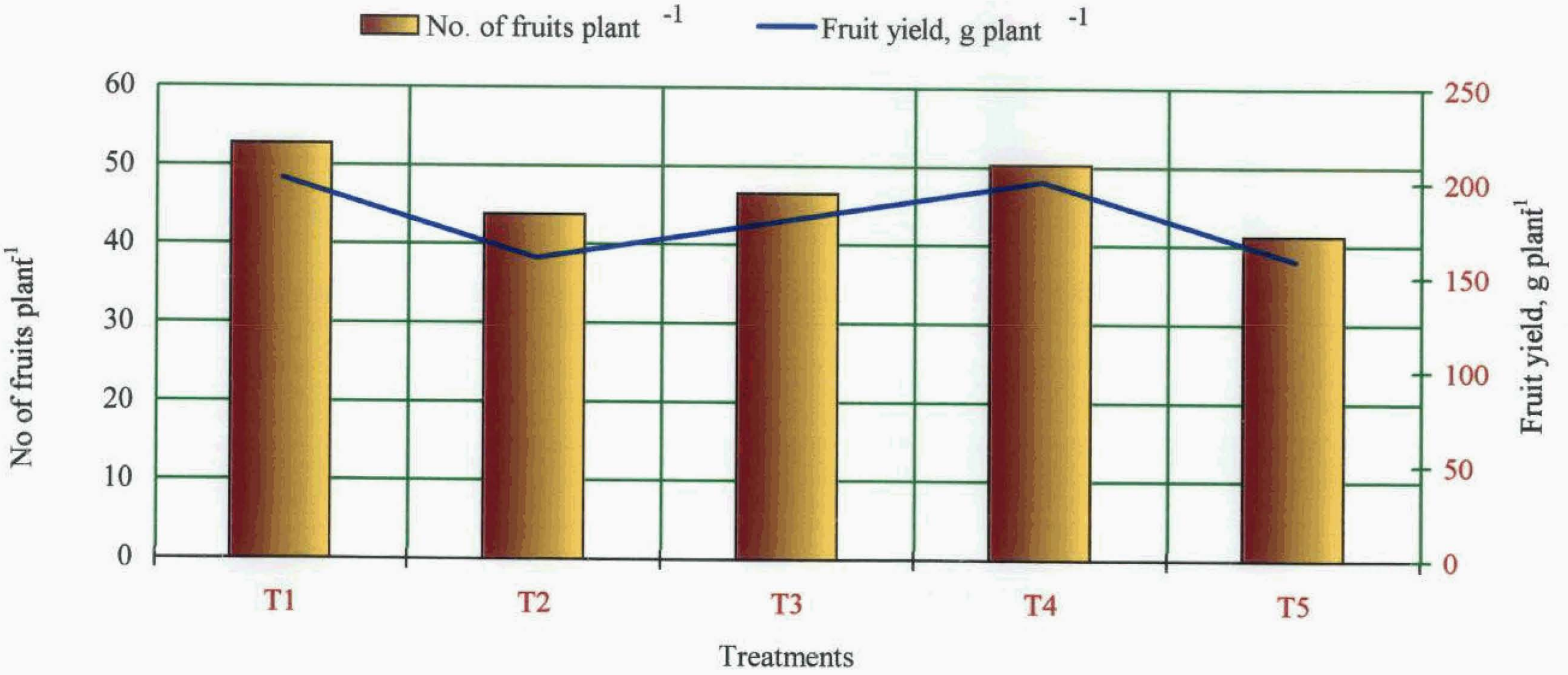


Fig. 5 Effect of fluorescent pseudomonads isolates on number of fruits and fruit yield per plant

5.1.2 Effect of Fluorescent Pseudomonads Isolates on Yield Attributes and Yield

With regard to yield attributing characters, isolate P_{22} recorded maximum length (8.77 cm) and girth (4.46 cm) of fruits and was significantly higher than all other isolates except P_{14}. Isolate P_{22} was significantly superior to others with regard to 100 fruit weight (589.90 g). Also this isolate recorded the maximum number of flowers plant^{-1} (108.00), fruit setting percentage (53.39 %) and ascorbic acid content of fruits (141.02 mg 100^{-1}g) though the effects were not significant. Days to first flowering was also not significantly influenced by the different isolates of fluorescent pseudomonads. With regard to number of marketable fruits plant^{-1} and fruit yield plant^{-1}, isolate P_1 (52.75 and 201.47 g plant^{-1} respectively) and isolate P_{22} (50.25 and 200. 71 g plant^{-1} respectively) were on par. Incidence of fruit rot in isolate P_1 was practically nil which could be the probable reason for higher yields registered for this isolate. Significantly higher disease incidence in isolate P_{14} might have reduced the yield though this was on par with P_{22} for yield attributing characters. Early. plant growth promotion may not be accompanied by significantly higher yields. Early plant vigour may not result in higher plant yields because of problems that occur late in season like pest and disease incidence. These factors may have a levelling effect on the treatments (Schroth and Becker, 1990).

5.1.3 Effect of Fluorescent Pseudomonads Isolates on Plant Nutrient Content, Nutrient Uptake and Available Nutrient Status of Soil

Plant nutrient content and uptake were significantly influenced by the different treatments. Isolate P_{22} had significantly higher N (1.88 %), P (0.4 %) and K contents (2.20 %) of plants than other treatments. Similarly highest N uptake (52.09 kg ha^{-1}), P uptake (10.98 kg ha^{-1}) and K uptake (61.05 kg ha^{-1}) was noted for isolate P_{22}. Increased root development, nitrogen fixation and phosphate solubilisation might have contributed to the increased nutrient content and uptake in plants. Similar results of increased NPK content and uptake by fluorescent pseudomonads were reported by Shabayev and Smolin (2000) in wheat.

Nutrient availability was also significantly influenced by different treatments. Treatment T_5 recorded the highest available nitrogen (324.58 kg ha^{-1}) and phosphorus (52.60 kg ha^{-1}). With regard to available K status of soil, treatment T_2 had the highest value (131.04 kg ha^{-1}) which was on par with that of T_5. The lowest value was recorded for treatment T_4 (isolate P_{22}). The plant treated with isolate P_{22} was able to absorb more nutrients from the surrounding soil which contributed to increased growth, and this might have lead to lower nutrient status of soil whereas T_2 and T_5 which registered the lowest values for growth characters might have absorbed less nutrients from soil and hence could have lead to increased nutrient status in soil after the experiment.

5.1.4 Effect of Fluorescent Pseudomonads Isolates on Disease Incidence and Bacterial Count in the Rhizosphere

Treatment T_1 (isolate P_1) registered significantly lower incidence of fruit rot (0.35 %) compared to other treatments, whereas treatment T_3 (isolate P_{14}) was found to register significantly higher disease incidence (11.45 %). Fluorescent pseudomonads suppress pathogens by various modes of action *viz.*, competition for nutrients and space with pathogens, antibiosis by production of antibiotics, siderophores and phenolic compounds. Also it activates induced systemic resistance against fungal pathogens. Alterations in the level of toxic phenolic compounds might be the reason for difference in disease incidence when inoculated with different isolates of fluorescent pseudomonads (Mondal *et al.*, 2000; Ramamoorthy and Samiyappan, 2001).

There was no significant difference in the count of fluorescent pseudomonads in the rhizosphere due to different treatments. Fluorescent pseudomonads are efficient colonizers of roots and most of these strains

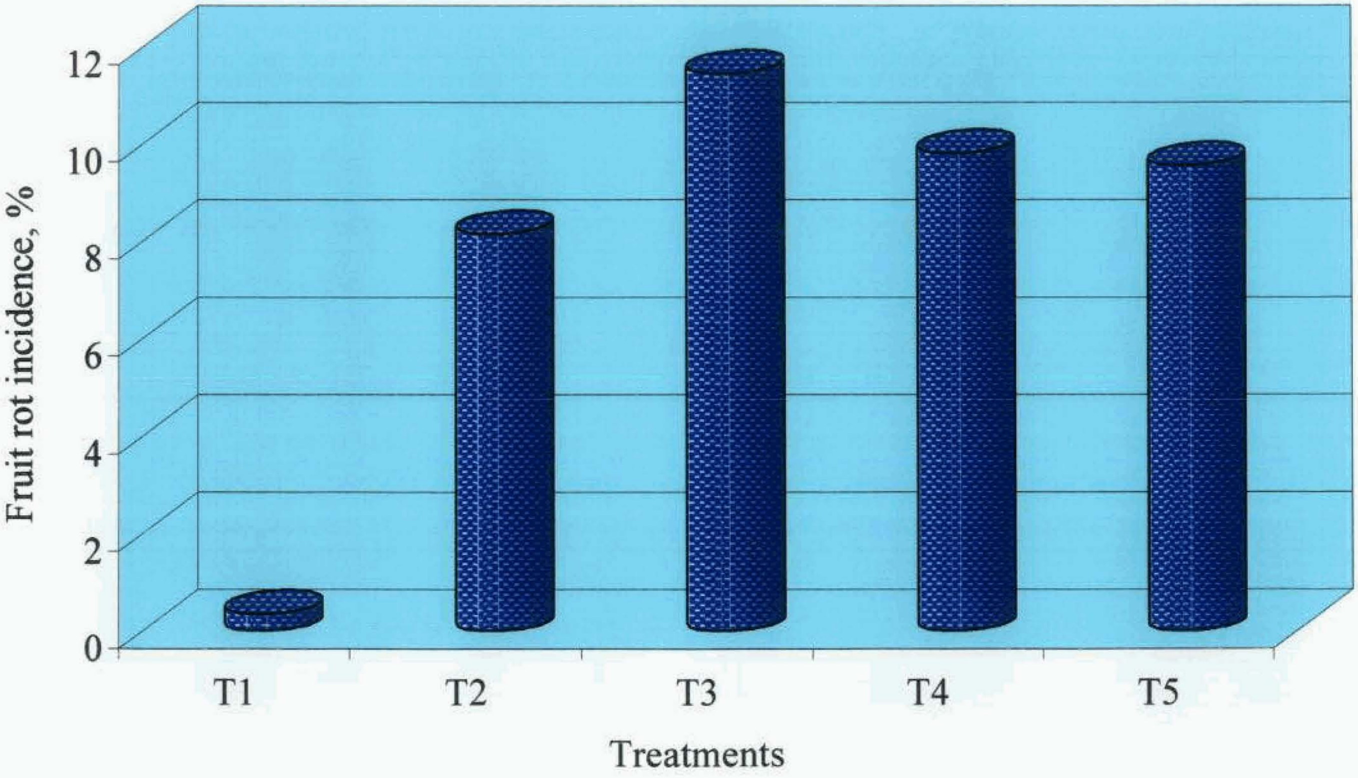


Fig. 6 Effect of fluorescent pseudomonads isolates on fruit rot incidence

are able to utilize organic substrates from root and seed exudates. The different isolates tested might be equally efficient on colonizing roots.

5.1.5 Effect of Fluorescent Pseudomonads Isolates on Economics of Cultivation

With respect to net returns, T_1 (isolate P_1) and T_4 (isolate P_{22}) were on par (Rs 1.53 and Rs 1.52 plant^{-1} respectively). A similar trend was observed for benefit-cost ratio (2.03 and 2.02 respectively for isolates P_1 and P_{22}). The higher net returns of treatments T_1 and T_4 are due to their higher yield and low rates of incidence of fruit rot.

The pot experiment revealed that isolate P_{22} was the best one with regard to growth characters and was significantly superior to other isolates. Though isolate P_{22} was on par with P_{14} with regard to some yield attributing characters, maximum disease incidence was noted for isolate P_{14} finally resulting in its reduced yield and hence this was not promoted for field trial. Isolate P_1 was superior with regard to disease resistance, as it recorded the lowest fruit rot incidence. As far as yield plant^{-1}, net returns and benefit-cost ratios were concerned, isolates P_{22} and P_1 were on par. Hence isolates P_{22} and P_1 were adjudged as the two best isolates for growth promotion, yield and disease control in chilli var. Jwalasakhi. Since P_{22} and P_1 isolates were compatible, dual cultures of these two were used for further field study.

5.2 EXPERIMENT II

5.2.1 Effect of NPK Fertilizers and Biofertilizers on Growth Characters

The field experiment was conducted to have an idea about the effect of different levels of NPK fertilizers, biofertilizers and their interaction. Three different levels of NPK fertilizers were tested *viz.*, 75 per cent (56.3: 30: 18.8 kg ha^{-1}), 100 per cent (75: 40: 25 kg ha^{-1}) and 125 per cent (93.8: 50: 23.5 kg ha^{-1}) of the recommended dose of NPK.

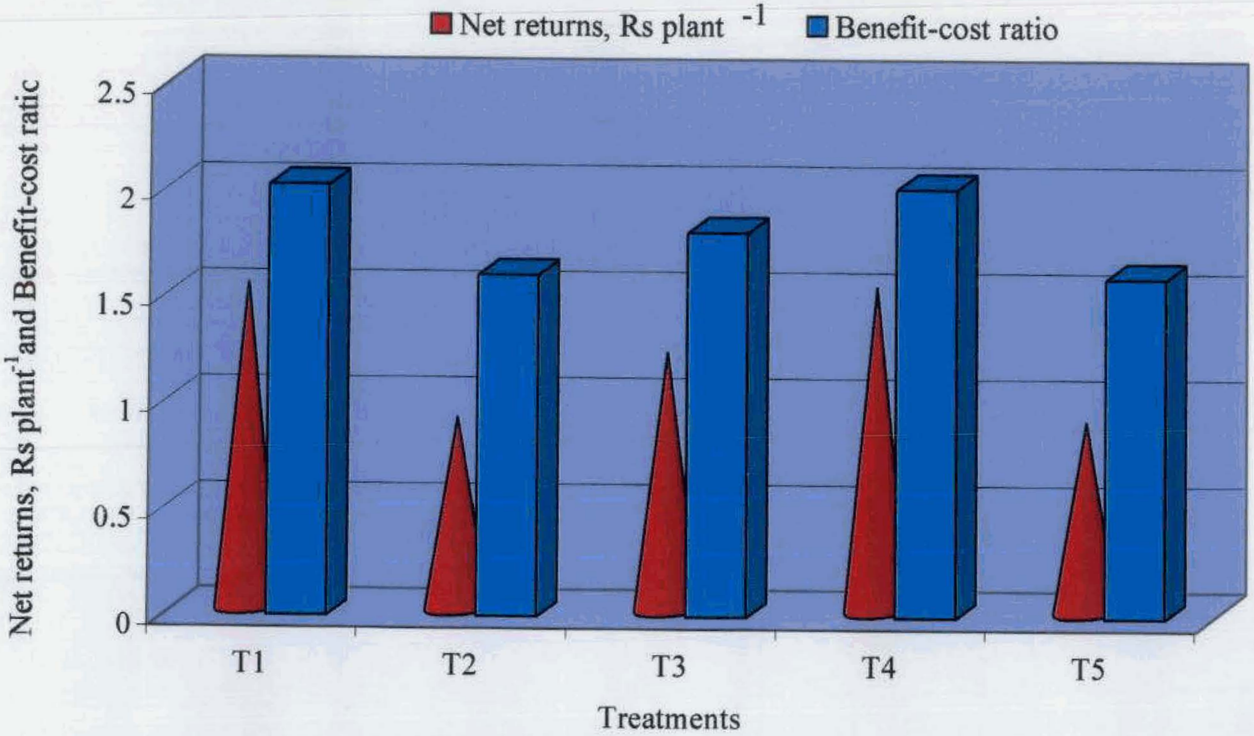


Fig. 7 Effect of fluorescent pseudomonads isolates on net returns and benefit-cost ratio

Nitrogen, phosphorus and potassium are the macronutrients which are highly essential for plant growth. Nitrogen is essential for the synthesis of proteins which plays an important role in plant metabolism. An adequate supply of nitrogen is associated with better vegetative growth. Phosphorus promotes better root growth, which in turn enhances the uptake of nutrients resulting in rapid growth (Tisdale *et al.*, 2002). Potassium is important in the translocation of photosynthates leading to greater CO_2 assimilation and growth (Russel, 1973).

The results of the study showed that NPK fertilizers had significantly influenced plant height at all growth stages and number of branches at 30 and 60 DAT. Highest dose of NPK fertilizers (125 per cent of the recommended dose of NPK) had registered maximum plant height (26.31 cm, 36.40 cm and 43.27 cm respectively) and number of branches (8.50, 12.87 and 22.22 respectively) at 30, 60 and 90 DAT. Increased levels of nutrients increased photosynthetic surface area, resulting in more production, translocation and assimilation of photosynthates, which in turn increased crop growth. Similar results of increase in plant height and branching at higher levels of nutrients have been reported by Joseph (1982), Zayed *et al.* (1985) and John (1989) in chilli. Maximum canopy spread (39.68 cm), shoot root ratio (4.55) and dry matter production (50.60 g plant^{-1}) were recorded by the highest level of nutrients *i.e.*, 125 per cent compared to 100 and 75 per cent of the recommended dose.

The increase in plant height and branching might have resulted in a better canopy spread. Increase in nutrient supply might have enhanced cell division and elongation in chilli resulting in more canopy spread as reported by Ahmed and Tanki (1991). The better canopy spread has helped the plant in tapping more solar radiation to form more photosynthates thus leading to increased shoot root ratio and dry matter production. Similar results have been reported by Lakatos (1982) and Belichki (1988) in chilli.

With regard to biofertilizer application, fluorescent pseudomonads (B_1), *Azospirillum* (B_2), combination of fluorescent pseudomonads and *Azospirillum* (B_3) were compared with no biofertilizer application (B_4). The results revealed that biofertilizer application significantly influenced plant height at all growth stages and the number of branches at 30 and 60 DAT. Both *Azospirillum* and fluorescent pseudomonads are known to influence plant growth by various mechanisms. Production of plant growth promoting substances, suppression of diseases, nitrogen fixation and phosphate solubilization were attributed for plant growth promotion by fluorescent pseudomonads (Pal *et al.*, 1999). Apart from being a nitrogen fixer, *Azospirillum* is also capable of producing plant growth promoting hormones (Okon, 1985). These growth hormones will increase cell division and elongation which may lead to increased growth of plants. The increased root growth helps in enhanced assimiliation of nutrients thus promoting more vegetative growth. Increased plant height by fluorescent pseudomonads were reported earlier by Dileepkumar and Dube (1992). Anitha (1997) pointed out that *Azospirillum* inoculation significantly increased plant height and branching in chilli.

Combined application of fluorescent pseudomonads and *Azospirillum* (B_3) registered maximum plant height at all growth stages (25.73 cm, 36.22 cm and 43.00 cm respectively) and number of branches (8.48, 13.22 and 21.60 respectively) at 30, 60 and 90 DAT. Maximum canopy spread (39.22 cm) was also recorded for combined inoculation (B_3) which was on par with single inoculation of fluorescent pseudomonads *i.e.*, B_1 (38.15 cm) and *Azospirillum* *i.*e., B_2 (38.08 cm). Similarly increased dry matter production was noted for combined inoculation and single inoculation when compared to plants which received no biofertilizers (B_4). Maximum DMP (52.03 g plant^{-1}) was recorded by combined inoculation of fluorescent pseudomonads and *Azospirillum* when compared to other biofertilizer treatments. The increased vegetative growth helps the plant to tap more solar energy for photosynthesis leading to increased dry matter production. Results of enhanced DMP by *Azospirillum* inoculation was reported by Anitha (1997), Synergistic influence of the bacteria might have led to increased dry matter production by the combined inoculation.

Interaction between NPK fertilizers and biofertilizers was significant on growth characters. F_3B_4 (125 per cent of the recommended dose of NPK along with no biofertilizers) and F_1B_3 (75 per cent of the recommended dose along with combined inoculation of fluorescent pseudomonads and *Azospirillum*) were on par as far as plant height at 60 DAT and number of branches at 30 DAT are concerned. This favourable effect of combined inoculation might be due to the nitrogen fixation and growth hormones produced by bacteria. Therefore at 75 per cent level of the recommended dose of NPK fertilizers itself, the plants would have got the amount of nutrients required for their growth due to supplementation of biofertilizer. Also fertilizers at a limited quantity would have increased the availability of root exudates, which might have accelerated the activity of inoculated bacteria resulting in higher nitrogen fixation and secretion of growth promoting substances. A similar trend was noticed for canopy spread. Dry matter production also exhibited a similar trend with F_3B_4 (125 per cent of recommended dose of NPK + no biofertilizers) registering a dry matter production of 56.87 g and F_1B_3 (75 per cent of the recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum*) with 53.73 g plant^{-1} and these two combinations were on par. The amount of dry matter produced by a crop plant depends upon its photosynthetic efficiency (Arnon, 1975). The increase in dry matter production in these treatment combinations is the out come of higher rate of growth and better accumulation of photosynthates owing to enhanced nutrient uptake.

5.2.2 Effect of NPK Fertilizers and Biofertilizers on Yield Attributes and Yield

The different levels of NPK fertilizers had profound influence on the yield and yield attributing characters. The highest level of nutrients *i.e.*, 125 per cent of the recommended dose of nutrients (93.8 : 50: 23.5 kg ha^{-1}) took significantly longer time to flower. Increased level of nutrients especially nitrogen might have prolonged the vegetative growth and delayed maturity. Similar increase in the time of 50 per cent flowering with increase in nutrients was noted in chilli by John (1989). Maximum number of flowers plant^{-1} (108.23) was also produced by this treatment. Increase in nutrients would have increased photosynthetic surface area leading to more production, translocation and assimilation of photosynthates to flower primordial points. This is in conformity with the findings observed by Dolkova *et al.* (1984) in chilli. This treatment also recorded maximum setting percentage (45.11) and was on par with 100 per cent of the recommended dose of NPK (75: 40:25 kg ha^{-1}) which registered a setting percentage of 44.02. Similarly the highest level of nutrients recorded the maximum length and girth of fruits (8.75 and 4.71 cm respectively) and was significantly higher than lower doses. Translocation of a larger quantity of photosynthates to the fruits might have resulted in the higher mean girth and length of fruits due to higher levels of applied NPK fertilizers. However, 100 fruit weight and ascorbic acid content of fruits were not significantly influenced by NPK fertilizer levels. Similarly the number of marketable fruits plant^{-1} and fruit yield were not significantly influenced by different levels of NPK fertilizers. Though yield attributing characters like number of flowers, mean length and girth of fruits were significantly higher at higher doses of NPK fertilizers, the substantially higher percentage disease incidence of fruit rot disease has lowered the number of marketable fruits and fruit yield resulting in the non significant performance of different fertilizer levels.

Biofertilizer inoculation significantly influenced most of the yield attributing characters and yield. Combined inoculation of fluorescent pseudomonads and *Azospirillum* was significantly superior to other treatments for the number of flowers plant^{-1} (110.20). Compared to control (no biofertilizers), combined inoculation produced 12.55 per cent

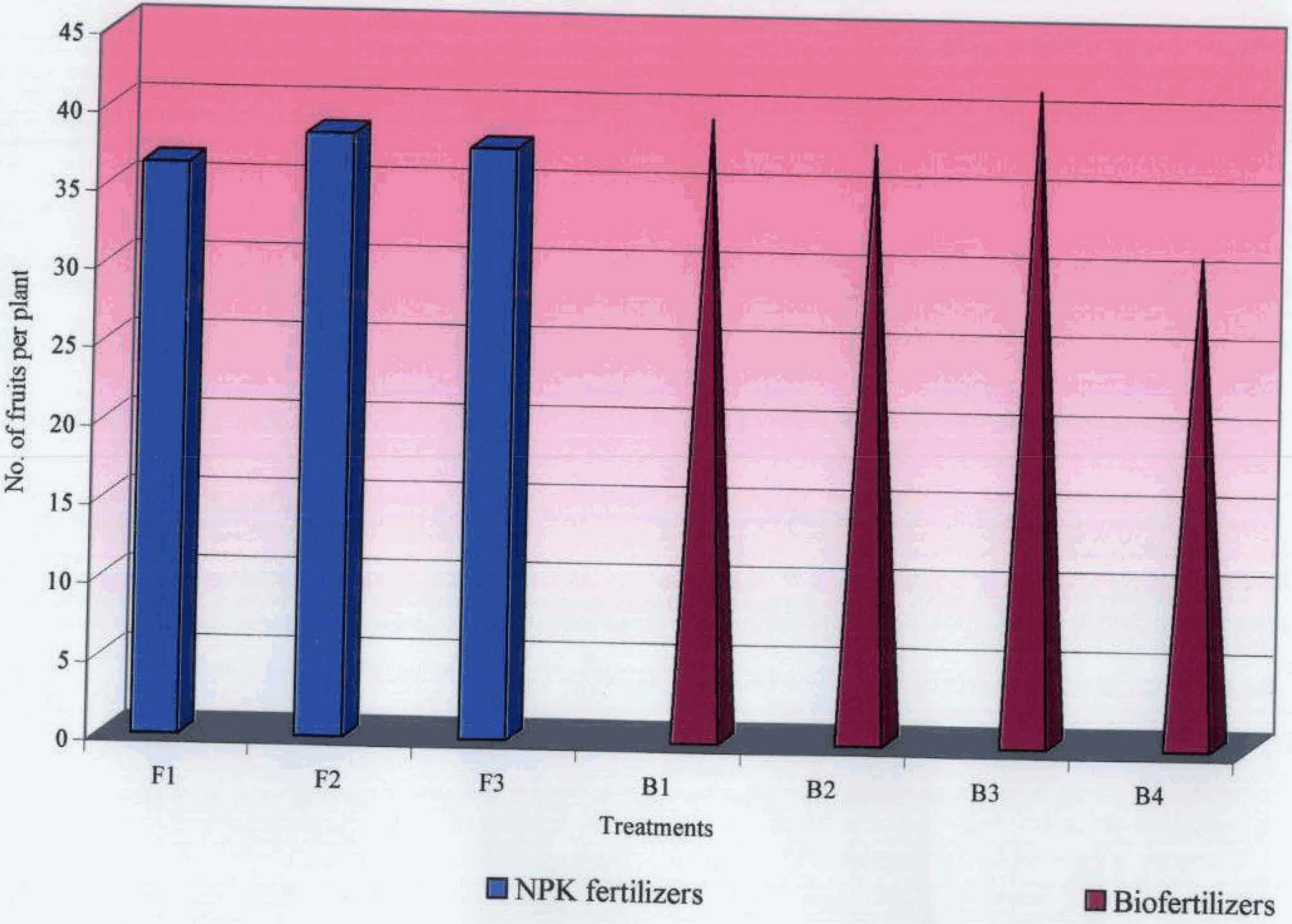


Fig 8. Main effect of NPK fertilizers and biofertilizers on number of fruits per plant

more number of flowers plant^{-1}. The increased vegetative growth might have led to more production and translocation of photosynthetic assimilates to the growing points resulting in the production of more number of flowers plant^{-1}. B_3 (combined inoculation of fluorescent pseudomonads and *Azospirillum*) took maximum days to flower (36.67 days) though the effects were not significant. Effects on length of fruits and 100 fruit weight were also not significant, though combined inoculation recorded maximum values (8.58 cm and 557.07 g respectively). Combined inoculation produced significantly higher fruit girth (4.82 cm). The better partitioning of assimilates to fruit might have contributed to this effect. With regard to number of marketable fruits plant^{-1}, fruit yield plant^{-1} and yield ha^{-1}, combined inoculation (41.53,150.18 g plant^{-1} and 7.76 t ha^{-1} respectively) was on par with fluorescent pseudomonads inoculation (39.42,144.84 g plant^{-1} and 7.56 t ha^{-1} respectively). The better performance of fluorescent pseudomonads isolates with regard to disease control and growth promotion might have resulted in this treatment being on par with combined inoculation with respect to marketable fruit number and fruit yield. Similar results on increased yield by fluorescent pseudomonads inoculation was reported by Karpagavalli *et al.* (2001) in rice and Ramamoorthy and Samiyappan (2001) in chilli. The results show that there was 33.58 per cent increase in fruit number and 46.69 per cent increase in yield ha^{-1} by the combined inoculation of fluorescent pseudomonads and *Azospirillum* when compared to control. The synergistic effect exerted by *Azospirillum* and fluorescent pseudomonads could be the possible reason for the better performance of combined inoculation of fluorescent pseudomonads and *Azospirillum* with regard to fruit number and fruit yield.

Interaction effect of NPK fertilizers and biofertilizers on number of flowers plant^{-1} were found to be significant. The treatment combination F_3B_4 (125 per cent of recommended dose of NPK + no biofertilizers) and F_1B_3 (75 per cent of recommended dose of NPK + Fluorescent

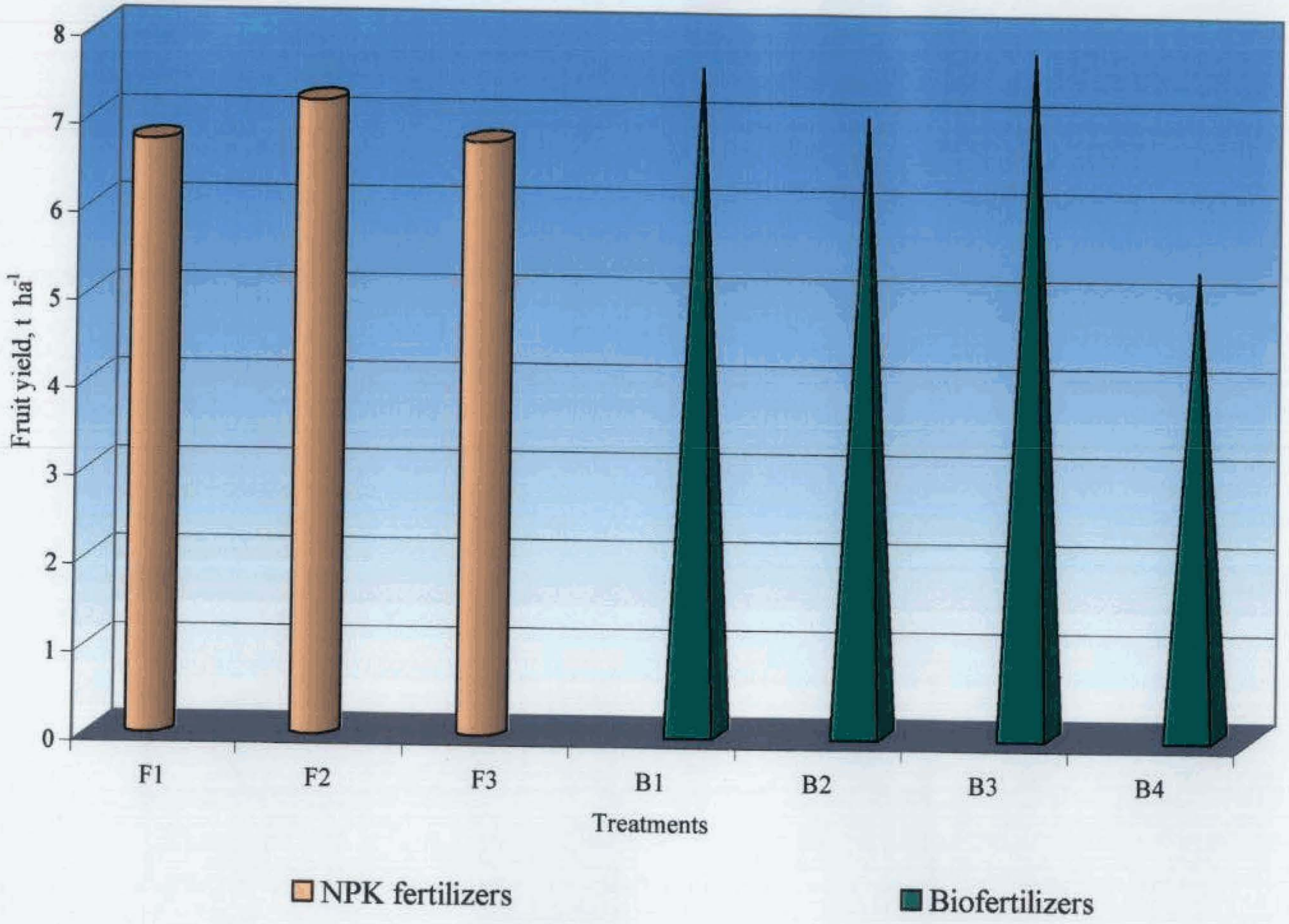


Fig 9. Main effect of NPK fertilizers and biofertilizers on fruit yield per hectare

pseudomonads + *Azospirillum*) were found to be on par (117.33 and 114.73 respectively). At the lower dose of NPK fertilizers itself, biofertilizers might have made the nutrients available to plant resulting in better production and translocation of photosynthetic assimilates to growing points like flower primordia. Similar effect was also observed for hundred fruit weight. With respect to fruit set, F_3B_4 *i.e.* 125 per cent recommended dose of NPK + no biofertilizers (51.48 %), F_1B_3 *viz.*, 75 per cent recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum* (48.48 %), F_2B_1 *viz.*, 100 per cent of the recommended dose of NPK +Fluorescent pseudomonads (48.52 %) and F_2B_2 100 per cent of the recommended dose of NPK + *Azospirillum* were on par. As far as fruit girth is concerned, F_3B_4 was found to be on par with F_1B_3 and F_2B_3 again projecting the significant influence of lower doses of NPK fertilizers (75 per cent) and combined inoculation of fluorescent pseudomonads and *Azospirillum*. However with respect to number of marketable fruits plant^{-1} F_1B_3 (49.00) was significantly superior.

Regarding fruit yield plant^{-1} and ha^{-1}, maximum values were recorded for F_1B_3 (163.71 g plant^{-1} and 8.74 t ha-1 respectively) and it was found to be on par with F_2B_1 (160.25 g plant^{-1}, and 8.42 t ha^{-1} respectively). The results indicated that at lower doses of NPK fertilizers (56.3: 30: 18.8 kg ha^{-1}) itself the plant was able to realize its potential yield when biofertilizers *viz.*, fluorescent pseudomonads and *Azospirillum* were applied conjointly. Similar favourable influence of conjoint application of biofertilizers and lower dose of NPK fertilizers on crop yield were reported earlier by several workers (Thamburaj, 1991; Singh and Sharma, 1993; Subbiah, 1994; Anitha, 1997; Raj, 1999; Shabayev and Smolin, 2002).

5.2.3 Effect of NPK Fertilizers and Biofertilizers on Plant Nutrient Content, Uptake and Nutrient Status of Soil

Significantly higher nitrogen (2.20 %), phosphorus (0.36 %) and potassium (2.27 %) content of plants were noted for 125 per cent recommended dose of NPK ha^{-1}. A similar trend was also observed for nutrient uptake. The increased NPK content and uptake might be due to the better absorption of plant nutrients from the rhizosphere soil. Increased phosphorus application might have induced better root growth facilitating more absorption of nutrients from soil. Similar results of higher nutrient content and uptake at higher levels of applied fertilizers were reported by Dolkova *et al.* (1986) and John (1989). With regard to post harvest soil nutrient status, available K in soil increased significantly at higher levels of applied NPK fertilizers. Significant difference in N and P status of soil after harvest is noticed only upto medium level of NPK fertilizers tried *i.e.*, F_2. . Similar results were obtained by John (1989) Enhanced available N status of soil at higher levels of applied NPK fertilizers might be due to its residual effect over a uniform dose of FYM of 25 t ha^{-1}. There was significant increase in organic carbon content at successive higher levels of NPK fertilizers and maximum value was noted at F_3 *viz.*, 125 per cent of the recommended dose of NPK (0.80 %). Inorganic compounds serve as source of nitrogen for microorganism and hence application of inorganic compounds increases the population of microorganisms. These microorganisms assimilate CO_2 from the atmosphere for their energy requirement (Alexander, 1977). This might be the reason for the increased organic carbon content of soil.

In the case of biofertilizer inoculation, maximum plant nitrogen content (2.20 %) was reported for combined inoculation (B_3), which was on par with *Azospirillum* B_2 (2.16 %). *Azospirillum* is a nitrogen fixing bacteria and this might have contributed to enhanced nitrogen content (Wani, 1990). Phosphorus content of plants increased significantly with biofertilizer application. Plants treated with combined inoculation registered significantly high P content (0.39 %) in plants. Potassium content in plants was also significantly influenced by biofertilizer application. Combined inoculation of fluorescent pseudomonads and *Azospirillum* produced maximum K content (2.10 %), which was on par

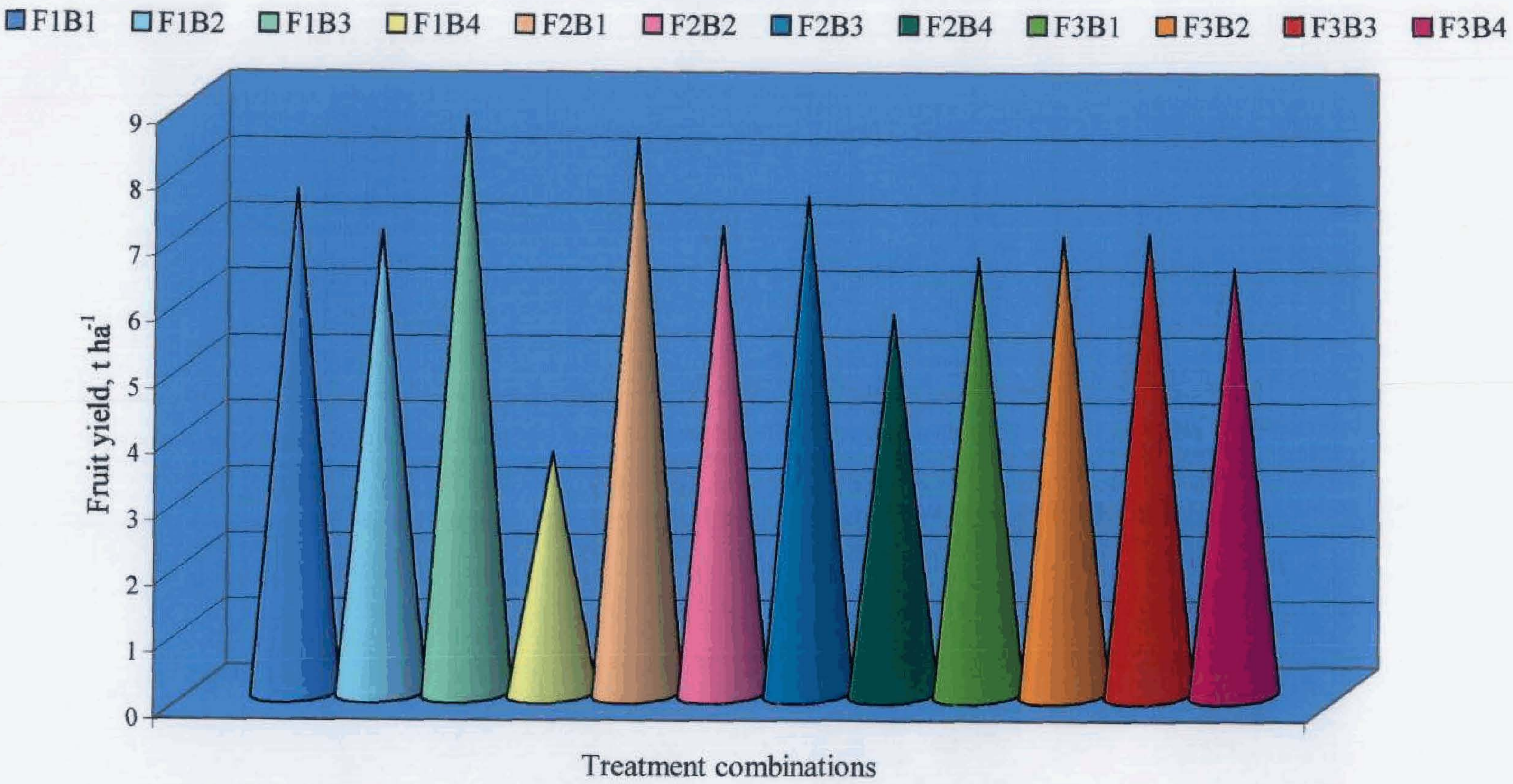


Fig. 10 Interaction effect of NPK fertilizers and biofertilizers on fruit yield per hectare

with single inoculation of fluorescent pseduomonads (2.05 %) and *Azospirillum* (2.05 %). Similar results of increased nutrient content by fluorescent pseudomonads inoculation were reported by Egamberdiyeva *et al.* (2002). Subbiah (1991) reported increased nutrient content in plants treated with *Azospirillum* inoculation. Combined inoculation registered maximum uptake for nitrogen (56.63 kg ha^{-1}) phosphorus (9.97 kg ha^{-1}) and potassium (53.83 kg ha^{-1}). The better performances of combined inoculation might be due to the synergistic effect of the biofertilizers. However biofertilizer application did not significantly influence available nutrient status of soil. Significantly higher organic carbon content was noted for combined inoculation (0.81 %) compared to other treatments.

Interaction effect on plant nutrient content and uptake was also significant. With respect to plant nitrogen content F_3B_4 (2.43 %) was on par with F_1B_3 *viz.*, NPK @ 75 per cent of the recommended dose + Fluorescent pseudomonads + *Azospirillum* (2.33 %). As far as plant phosphorus content is concerned, F_3B_4 *viz.*, NPK @ 125 per cent of the recommended dose + no biofertilizers (0.45 %) was on par with F_1B_3 and F_2B_3 (0.41 and 0.39 per cent respectively), thus emphasizing the favourable effect of combined application of fluorescent pseudomonads and *Azospirillum* along with lower doses of NPK fertilizers *i.e.*, 75 per cent). Maximum plant K content was noted for 125 per cent POP + no biofertilizers. Significantly higher N uptake (68.21 kg ha^{-1}), P uptake (12.53 kg ha^{-1}) and K uptake (65.52 kg ha^{-1}) was noticed for 125 per cent of the recommended dose of NPK + no biofertilizers. Interaction effect failed to produce any significant influence on available N and P status of soil. Significantly higher K status of soil was noted for F_3B_4 *viz.*, NPK @ 125 per cent of the recommended dose + no biofertilizers and it was on par with F_3B_3 and F_2B_3.

5.2.4 Effect of NPK Fertilizers and Biofertilizers on Bacterial Count in the Rhizosphere and Disease Incidence

A perusal of the data on bacterial count in the rhizosphere which indicates the soil health revealed that highest dose of NPK fertilizers *i.e.*, 125 per cent of the recommended dose gave significantly lower count for both fluorescent pseudomonads and *Azospirillum* (30.75 x 10^5 cfu g^{-1} soil and 5.08 x 10^5 cfu g^{-1} soil). However at lower levels of NPK fertilizers *viz.*, 75 per cent and 100 per cent of the recommended dose, there was considerable increase in the bacterial count. Lower bacterial count at highest inorganic nutrient level might be due to changes in soil P^H and high osmotic potential resulting in partial and temporary sterilization of soil (Tisdale *et al.*, 2002).

Fruit rot incidence was the maximum (20.07 %) at 125 per cent of recommended dose of NPK and this was significantly higher than that recorded at lower levels *viz.*, 100 per cent and 75 per cent of the recommended dose. Lesser pseudomonads count on the rhizosphere might have contributed to higher disease incidence.

For biofertilizer application maximum count for fluorescent pseudomonads (40.00 x 10^5 cfu^{-1} g soil) was noted for single inoculation of fluorescent pseudomonads and was on par with combined inoculation. (39.89 x 10^5 cfu g^{-1}soil) indicating that fluorescent pseudomonads and *Azospirillum* are compatible. Maximum count of *Azospirillum* was noticed for *Azospirillum* inoculation (11.44 x 10^5 cfu g^{-1} soil).

The least disease incidence was noted for fluorescent pseudomonads treated plants. This might be due to the antifungal compounds produced by fluorescent pseudomonads. Fluorescent pseudomonads suppress pathogens by various modes of action namely competition for nutrients and space, by antibiosis and by inducing systemic resistance. Hegde and Anahosur (2001) also noted the effectiveness of *P. fluorescens* in reducing fruit rot in chilli. Similar results of biological control by inoculation with

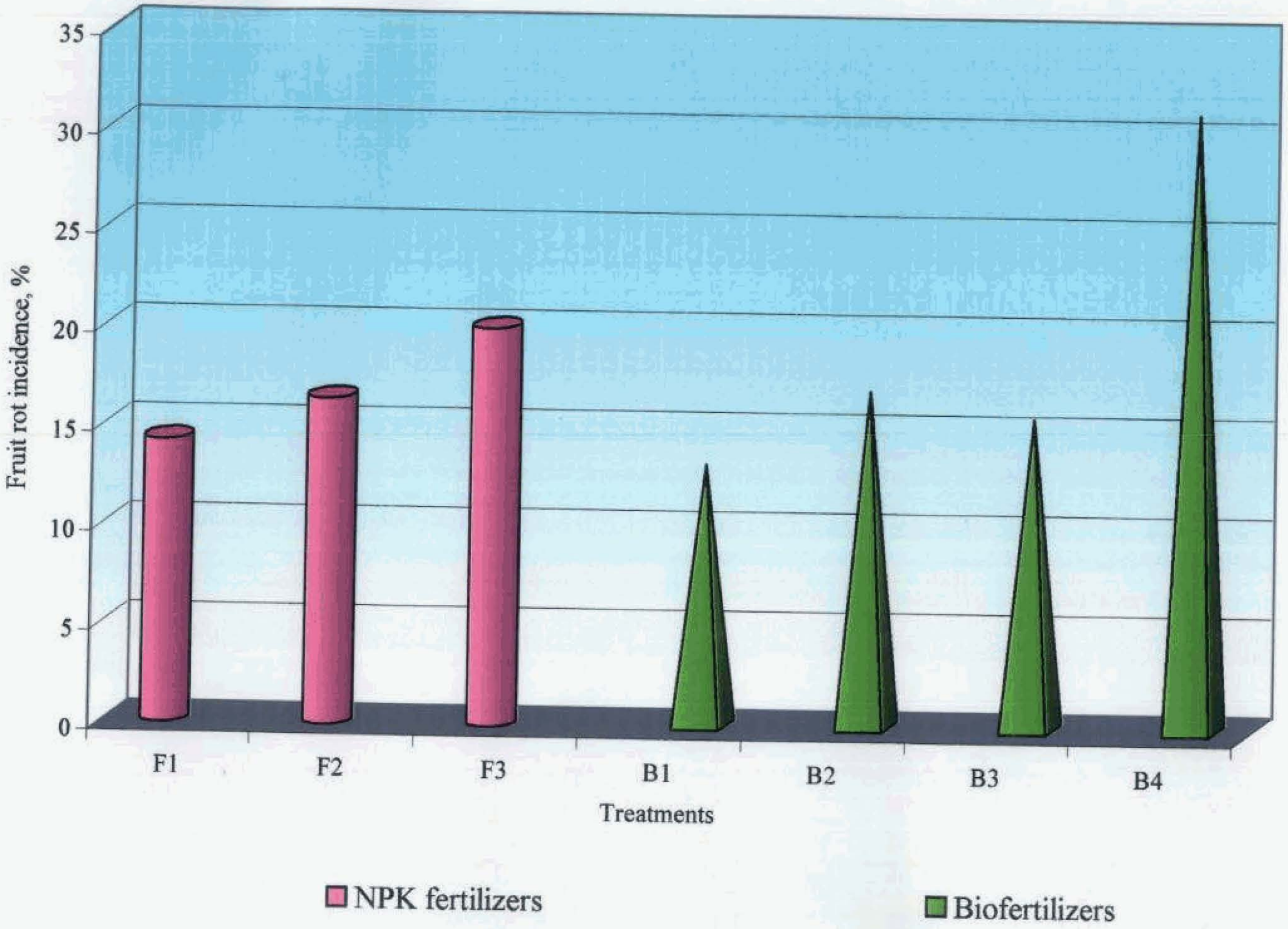


Fig 11. Main effect of NPK fertilizers and biofertilizers on fruit rot incidence

fluorescent pseudomonads were reported by Thomoshow and Weller (1996), Gnanamanickam *et al.*(1999), Ramamoorthy and Samiyappan (2001) and Vidyasekharan *et al.* (2001). Interaction effect was not significant on these characters.

5.2.5 Effect of NPK Fertilizers and Biofertilizers on Economics of Cultivation

A critical analysis of the data indicated that different levels of NPK fertilizers did not show significant influence on net returns and benefit-cost ratio.

However, biofertilizer application markedly influenced net returns and benefit-cost ratio. Maximum net returns (Rs 42834.48 ha^{-1}) and benefit-cost ratio (1.59) was obtained for combined inoculation and was on par with fluorescent pseudomonads inoculation (Rs 39850.66 ha^{-1} and 1.55 respectively). Biofertilizers are cost effective source of nutrients for obtaining increased yield and hence net returns and benefit-cost ratio were significantly higher for biofertilizers compared to control.

Combined application of fluorescent pseudomonads and *Azospirillum* along with 75 per cent of the recommended dose of NPK had significantly higher benefit-cost ratio (1.82) and net returns (Rs. 59328.02 ha^{-1}), when compared to other treatment combinations. Compared to Package of Practices recommendation (F_2B_4 *i.e.*, 100 per cent recommended dose of NPK with no biofertilizers) increase in net returns ha^{-1} for this treatment combination was Rs 46131.85 ha^{-1} Apart from increasing yield significantly, 25 per cent saving in the total quantity of NPK fertilizers also might have contributed to this increased net returns. The favourable significant influence of biofertilizers in enhancing crop yield at lower doses of NPK fertilizers emphasizes the need for integrating inorganic fertilizers and biofertilizers.

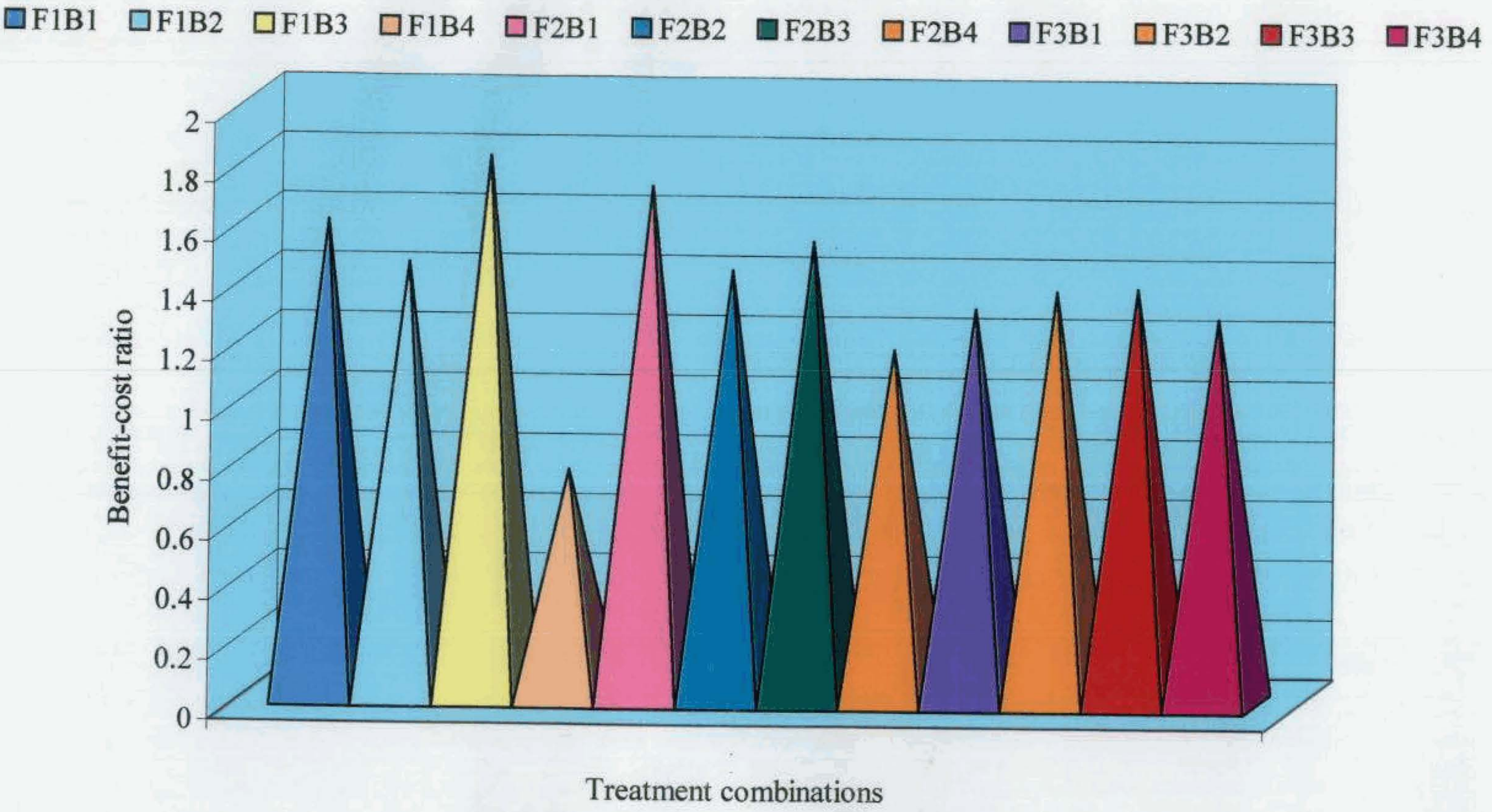


Fig. 12 Interaction effect of NPK fertilizers and biofertilizers on benefit-cost ratio

Data on fruit yield and economics of the treatment combinations elicited the favourable effect of 75 per cent of recommended dose of NPK along with combined inoculation of fluorescent pseudomonads and *Azospirillum* (F_1B_3) which registered a fruit yield, net profit and benefit-cost ratio of 8.74 t ha^{-1}, Rs. 59328.02 ha^{-1} and 1.82 respectively. Hence this combination could be recommended for profitable chilli cultivation in the state

SUMMARY

6. SUMMARY

The study entitled 'Response of chilli (*Capsicum annuum* L.) to plant growth promoting rhizobacteria fluorescent pseudomonads' has been programmed and carried out as two experiments *viz*., a pot culture trial and a field study at the College of Agriculture, Vellayani. The salient results emanating from the study are summarised in this chapter.

6.1 EXPERIMENT I

The pot culture study was programmed to evaluate fluorescent pseudomonads isolates for growth promotion and yield in chilli and was carried out during the period from July to November 2002. The investigation was laid out in completely randomised design with four replications. The treatments consisted of five different isolates of fluorescent pseudomonads *i.e.*, P_1, P_5, P_{14}, P_{22} and KK_{16}.

The different isolates exerted significant influence on various growth and yield attributes of chilli. The results revealed that plants treated with isolate P_{22} had significantly higher plant height, number of branches, shoot root ratio and canopy spread. Dry matter production was also significantly influenced by the treatments and isolate P_{22} was on par with P_{14}.

Analysing the data on yield attributes, isolate P_{22} was found to be significantly superior to all other isolates except P_{14} with regard to length and girth of fruits. Significantly higher 100 fruit weight was observed for isolate P_{22}. There was no marked difference among the different isolates for the days to first flowering, number of flowers plant^{-1} and ascorbic acid content of fruits.

Highest values for number of marketable fruits and fruit yield were obtained for isolate P_1 (52.75 and 201.47 g plant^{-1}repectively) which was on par with P_{22} (50.25 and 200.71 g plant^{-1} respectively).

Application of fluorescent pseudomonads isolate P_{22} recorded significantly higher N, P and K content (1.88 %, 0.40 % and 2.20 % respectively). Uptake of phosphorus and potassium were also significantly higher for isolate P_{22} compared to other isolates. Nitrogen uptake was maximum for isolate P_{22} but was on par with P_{14}. Available nitrogen and phosphorus status of the soil after the experiment was markedly higher for isolate KK_{16}. Higher potassium status was noted for isolate P_5 which was on par with KK_{16}.

The different treatments failed to exert any significant influence on bacterial count in the rhizosphere. As far as disease incidence was concerned, isolate P_1 was identified as the most superior one. Considering economics of treatments, isolate P_1 recorded the maximum net returns

(Rs 1.53 plant^{-1}) and benefit-cost ratio (2.03) and was on par with P_{22}. (Rs 1.52 plant^{-1} and 2.02 respectively)

Isolate P_{22} was the most superior one considering the growth characters. Though the data on yield attributing characters revealed that isolate P_{22} was on par with isolate P_{14}, maximum disease incidence was observed for isolate P_{14}. As far as marketable fruit yield and economics are concerned, isolates P_{22} and P_1 were found to be on par. Thus a dual culture of isolates P_{22} and P_1 was selected for further field study.

6.2 EXPERIMENT II

The field study has been carried out at the Instructional Farm, Vellayani during December 2002 to April 2003. The main objectives of the investigation were to assess the suitability of the best isolate of fluorescent pseudomonads as a biofertilizer either alone or in combination with *Azospirillum* along with different doses of NPK fertilizers on growth and productivity of the vegetable chilli variety Jwalasakhi. The study was laid out in factorial randomised block design with three replications. The treatments consisted of combinations of three different levels of NPK *viz.*, 75 per cent (56.3 : 30 : 18.8 kg ha^{-1}), 100 per cent (75 : 40 : 25 kg ha^{1}) and 125 per cent (93.8 : 50 : 23.5 kg ha^{-1}) of the recommended dose of NPK as per Package of Practice Recommendations and four biofertilizer treatments (Fluorescent pseudomonads, *Azospirillum*, Fluorescent pseudomonads + *Azospirillum*, no biofertilizers). The results of the investigation are summarised below.

The effect of various treatments on growth characters was observed to be significant. Plant height increased significantly with increasing levels of NPK fertilizers at all stages of growth. Significant increase was also observed for number of branches at 30 and 60 DAT, dry matter production at harvest, shoot root ratio and canopy spread.

Biofertilizer inoculation also significantly influenced the various growth characters. Combined inoculation of fluorescent pseudomonads and *Azospirillum* recorded significantly higher plant height at all growth stages, number of branches at 30 and 60 DAT, canopy spread, shoot root ratio and dry matter production.

Interaction of NPK fertilizers and biofertilizers also significantly influenced growth characters. Application of 75 per cent of the recommended dose of NPK along with combined application of fluorescent pseudomonads and *Azospirillum* was on par with 125 per cent of the recommended dose of NPK + no biofertilizers with respect to plant height at 60 DAT, number of branches at 30 and 60 DAT and dry matter production at harvest. All the treatment combinations involving biofertilizers were on par with 125 per cent of the recommended dose of NPK without biofertilizers as far as canopy spread was concerned.

Yield attributing characters and yield were also significantly influenced by different levels of NPK. Significant increase was observed in the number of days for 50 per cent flowering, number of flowers, length, girth and setting percentage of fruits with graded doses of NPK fertilizers. Application of NPK did not significantly influence the 100 fruit weight and ascorbic acid content of fruits. Fruit yield plant^{-1} and yield ha^{-1} were also not influenced by various levels of NPK.

Biofertilizer application also had profound influence on these characters. Among the yield attributing characters, number of flowers plant^{-1} was significantly higher for combined inoculation of fluorescent pseudomonads and *Azospirillum* (B_3). Regarding number of fruits plant^{-1}, fruit yield per plant and yield per hectare, combined inoculation of fluorescent pseudomonads and *Azospirillum* (41.53, 150.18 g plant^{-1} and 7.76 t ha^{-1} respectively) was on par with fluorescent pseudomonads application (39.42, 144.84 g plant^{-1} and 7.56 t ha^{-1} respectively). Application of biofertilizers failed to produce significant influence on time of 50 per cent flowering, fruit setting percentage, 100 fruit weight, length, girth, and ascorbic acid content of fruits.

As far as treatment combinations are concerned, application of 75 per cent of the recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum* was on par with 125 per cent of the recommended dose of NPK + no biofertilizers for number of flowers plant^{-1}. Similar results were also obtained for 100 fruit weight.

Interaction effect was not significant for the days for 50 per cent flowering and ascorbic acid content. With regard to setting percentage, 75 per cent of the recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum*, 100 per cent of the recommended dose of NPK + Fluorescent pseudomonads and 100 per cent of the recommended dose of NPK + *Azospirillum* were on par with 125 per cent of the recommended dose of NPK + no biofertilizers. Significantly higher fruit length was observed for 125 per cent of the recommended dose of NPK + no biofertilizers.

With regard to number of marketable fruits plant^{-1}, 75 per cent of the recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum* recorded significantly higher values (49.00) compared to other combinations. Regarding fruit yield plant^{-1} and yield hectare^{-1} also, 75 per cent of the recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum* registered maximum values (163.71 g plant^{-1} and 8.74 t ha^{-1} respectively) and was on par with NPK @ 100 per cent of the recommended dose + Fluorescent pseudomonads inoculation (160.25 g plant^{-1} and 8.42 t ha^{-1} respectively).

Among various levels of NPK fertilizers tested, plants treated with higher level of inorganic nutrients had significantly higher NPK content of plants. Similar trend was also observed in nutrient uptake. Soil nitrogen and phosphorus status was significant in plots receiving nutrients upto medium level. Available potassium and organic carbon content of soil increased with graded doses of NPK fertilizers.

Biofertilizer inoculation also had marked influence on plant nutrient content and uptake. Significantly higher plant nitrogen content was observed for fluorescent pseudomonads + *Azospirillum* inoculation which was on par with *Azospirillum* treatment. Phosphorus content of plants was the highest with combined inoculation. Significantly higher potassium content in plants was observed for all biofertilizers compared to no biofertilizer treatment. Biofertilizer inoculation had no significant influence on the post experiment available NPK status of soil. Combined inoculation of biofertilizers registered the highest organic carbon content of soil.

Regarding treatment combinations, 75 per cent of the recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum* recorded plant nitrogen content of 2.33 per cent and was on par with 125 per cent of recommended dose of NPK without biofertilizers (2.43 %). Regarding plant phosphorus content, application of 75 per cent of the recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum* and 100 per cent of the recommended dose of NPK + Fluorescent pseudomonads · *Azospirillum* were on par with 125 per cent of the recommended dose of NPK + no biofertilizers. Significantly higher plant potassium content was noted for 125 per cent of the recommended dose of NPK + no biofertilizers and was on par with 125 per cent recommended dose of NPK along with combined inoculation and single inoculation of fluorescent pseudomonads and *Azospirillum*. Plant nutrient uptake was significantly higher for 125 per cent of the recommended dose of NPK + no biofertilizers.

Data on bacterial count in the rhizosphere which is an indicator of soil health, points out that microbial count was significantly lower at the highest dose of NPK *viz.*, 125 per cent of the recommended dose. At lower levels of NPK fertilizers, there was considerable increase in microbial counts. Biofertilizer inoculation significantly increased bacterial count in the rhizosphere which emphasizes the importance of bioinoculants in maintaining soil health.

Fruit rot incidence increased significantly with increasing levels of NPK fertilizers. 125 per cent of the recommended dose of NPK fertilizers was found to be significantly inferior and NPK @ 75 per cent of the recommended dose registered significantly lower values for this character. Among the biofertilizers tested, application of fluorescent pseudomonads recorded significantly lower fruit rot incidence whereas no biofertilizer treatment registered significantly higher values for disease incidence.

Economic analysis revealed that net returns and benefit-cost ratio were not influenced by different levels of NPK. For biofertilizer treatments, combined inoculation of fluorescent pseudomonads and *Azospirillum* turned to be the best treatment recording the highest net returns (Rs. 42834.48 ha^{-1}) and benefit-cost ratio (1.59) and was on par with application of fluorescent pseudomonads (Rs 39850.66 ha^{-1} and 1.55 respectively).

Among the treatment combinations, application of 75 per cent of the recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum* recorded the highest net returns (Rs. 59328.02 ha^{-1}) and benefit-cost ratio (1.82) and was proved to be the most economically viable treatment combination.

The present investigation revealed that an integrated application of lower doses of NPK fertilizers (75 per cent of the recommended dose) and biofertilizers *viz.,* fluorescent pseudomonads and *Azospirillum* was beneficial for economising the production of chilli. Application of biofertilizers also proved to be the best for maintaining soil health by increasing the microbial count in the rhizosphere. The efficiency of biofertilizers especially fluorescent pseudomonads in controlling disease incidence emphasises the need for integrating biofertilizers with inorganic fertilizers.

Future line of work

Considering the beneficial effects of integrated application of inorganic and biofertilizers on soil and plant health as well as on crop growth and yield, it would be appropriate to focus studies on integrated nutrient management (INM) involving NPK fertilizers, biofertilizers and organic manures. Vermicompost, which is a cheap source of organic manure will be a better combination with fluorescent pseudomonads and NPK fertilizers and its effect on other vegetable crops and cropping systems also needs investigation. This can augment vegetable production in Kerala with increased emphasis on sustainable agriculture.

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*Original not seen

RESPONSE OF CHILLI (*Capsicum annuum* L.) TO PLANT GROWTH PROMOTING RHIZOBACTERIA FLUORESCENT PSEUDOMONADS

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Abstract of the
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8. ABSTRACT

The research project entitled 'Response of chilli (*Capsicum annuum* L.) to plant growth promoting rhizobacteria fluorescent pseudomonads' was carried out as two investigations *viz.*, a pot culture trial and a field study at the College of Agriculture, Vellayani, during July 2002 to April 2003. The study was conducted on chilli cultivar, Jwalasakhi. The pot culture study was aimed at evaluation of fluorescent pseudomonads isolates for growth promotion and yield in chilli. The treatments consisted of five different isolates of fluorescent pseudomonads (P_1, P_5, P_{14}, P_{22} and KK_{16}). The trial was laid out in completely randomised design with four replications.

Among the five isolates tested, isolate P_{22} was adjudged as the best one for growth promotion and P_1 for disease resistance. As far as yield and economics are concerned, these two isolates were found to be on par. Thus a dual culture of isolate P_{22} and P_1 was selected for further field study.

The objective of the field study was to assess the suitability of the best isolate of fluorescent pseudomonads as a biofertilizer either alone or in combination with *Azospirillum* along with different doses of NPK fertilizers on growth and productivity of chilli. The field study was laid out in factorial randomised block design with three replications. The different treatments included three different levels of NPK (75 per cent (56.3 : 30 : 18.8 kg ha^{-1}), 100 per cent (75 : 40 : 25 kg ha^{-1}) and 125 per cent (93.8 : 50 : 23.5 kg ha^{-1}) of the recommended dose of NPK as per POP) and four biofertilizer treatments (Fluorescent pseudomonads, *Azospirillum*, Fluorescent pseudomonads + *Azospirillum* and no biofertilizers). The abstract of the result is furnished below.

All the growth characters increased significantly with graded doses of NPK. Combined inoculation of fluorescent pseudomonads and *Azospirillum* was the most superior one among biofertilizer treatments. Similar trend was also observed for yield attributing characters. However with regard to marketable fruit yield, all the levels of NPK fertilizers tested were statistically on par. With respect to biofertilizer application, combined inoculation (7.75 t ha^{-1}) was on par with fluorescent pseudomonads application (7.56 t ha^{-1}). Compared to control of no biofertilizer treatment, Fluorescent pseudomonads + *Azospirillum* increased fruit yield by 46.69 per cent. Among the treatment combinations, 75 per cent of the recommended dose of NPK (56.3 : 30 : 18.8 kg ha^{-1}) + Fluorescent pseudomonads + *Azospirillum* produced significantly higher yield (8.74 t ha^{-1}) and ensured a saving of 25 per cent of recommended dose of NPK. 100 per cent POP + Fluorescent pseudomonads application was on par with this treatment.

At 125 per cent of the recommended dose of NPK (93.8 : 50 : 23.5 kg ha^{1}) microbial count in the rhizosphere was significantly lower and fruit rot incidence was significantly higher. Biofertilizer application significantly increased microbial count and reduced disease incidence. 75 per cent of recommended dose of NPK + Fluorescent pseudomonads + *Azospirillum* was rated as the most economically viable treatment combination, with a net profit and benefit-cost ratio of Rs. 59328 ha^{-1} and 1.82 respectively.

APPENDICES

APPENDIX I

Weather parameters during the cropping period
(July 2002 to November 2002)

Standard weeks	Maximum temperature, °C	Minimum temperature, °C	Rainfall, mm	RH, %	Evaporation, mm
26	30.80	25.17	0.54	83.00	3.80
27	30.39	24.49	0.73	82.93	4.30
28	30.17	24.14	0.43	83.07	3.97
29	30.63	23.44	0.09	81.14	4.13
30	28.86	23.84	8.23	79.57	3.87
31	29.56	22.50	3.10	85.86	2.40
32	29.19	23.36	6.03	84.14	3.27
33	30.66	23.43	0.00	85.00	3.17
34	30.81	23.94	0.00	77.86	4.76
35	30.84	23.69	1.51	76.64	4.73
36	30.53	23.66	2.93	79.50	4.46
37	31.67	22.91	0.19	77.29	4.26
38	32.16	22.93	0.00	70.14	5.20
39	30.77	23.74	6.87	74.57	5.04
40	29.91	23.53	20.14	83.07	3.19
41	29.11	22.89	25.67	86.93	2.56
42	30.63	23.06	8.67	90.36	1.74
43	30.26	23.71	5.20	85.36	3.43
44	30.03	23.17	3.30	86.00	2.10
45	30.23	23.50	4.81	87.07	1.89

APPENDIX II

Weather parameters during the cropping period
(December 2002 to April 2003)

Standard weeks	Maximum temperature, °C	Minimum temperature, °C	Rainfall, mm	RH, %	Evaporation, mm
50	31.04	0.00	78.21	22.99	3.20
51	30.57	0.00	76.86	21.64	2.39
52	31.13	0.00	78.14	20.77	2.91
1	32.01	0.00	78.14	21.29	3.37
2	31.63	0.00	75.57	22.53	3.34
3	31.16	0.23	72.21	21.11	3.89
4	31.59	0.00	77.79	21.57	3.64
5	31.94	7.43	76.79	23.06	3.92
6	32.06	2.16	79.00	23.34	3.49
7	31.16	0.00	77.64	21.97	3.97
8	31.94	0.19	76.14	22.83	4.11
9	32.54	0.00	75.21	23.70	4.41
10	32.77	1.24	79.29	23.59	4.29
11	31.93	14.14	77.79	24.37	3.79
12	32.63	0.64	77.86	24.57	4.37
13	32.53	4.29	79.71	24.91	4.17
14	33.24	0.01	77.00	25.24	4.14
15	32.87	2.00	83.21	24.56	3.76