EFFICACY OF BIOFERTILIZERS IN TOMATO

(*Solanum lycopersicum* L.)

By

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(2010-12-103)

THESIS

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DECLARATION

I, hereby declare that the thesis entitled **"Efficacy of biofertilizers in tomato (*Solanum lycopersicum* L.)"** 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, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **“Efficacy of biofertilizers in tomato (*Solanum lycopersicum* L.)”** is a record of research work done independently by **Miss Smitha, K. O. (2010-12-03)** under my guidance and supervision and that it has not formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the advisory committee of Miss Smitha, K. O. (2010-12-103) a candidate for the degree of **Master of Science in Horticulture**, with major field in **Olericulture,** agree that the thesis entitled **"Efficacy of biofertilizers in tomato (*Solanum lycopersicum* L.)"** may be submitted by **Miss Smitha, K. O. (2010-12-103)**, in partial fulfillment of the requirement for the degree.

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ABBREVIATIONS

@	At the rate of
^0C	Degree Celsius
AMF	Arbuscular Mycorrhizal Fungi
AZ	*Azospirillum* sp.
cfu	Colony forming units
cm	Centimetre
cm^3	Cubic centimeter
cv	Cultivar
DAT	Days After Transplanting
et al.	Co workers
FR	*Frateuria* sp.
FYM	Farm Yard Manure
GA	Gibberelic Acid
IAA	Indole Acetic Acid
INM	Integrated Nutrient Management
K	Potassium
K_2O	Available Potassium
ml	Milli litre
N	Nitrogen
nm	Nano metre
P	Phosphorus
P_2O_5	Available Phosphorus
PGPR	Plant Growth Promoting Rhizobacteria
ppm	Parts per million
PSB	Phosphate Solubilising Bacteria
$q\ ha^{-1}$	Quintals per hectare
RDF	Rcommended Dose of Fertilizers
RP	Recommended Phosphorus
sp.	Species
$t\ ha^{-1}$	Tonnes per hectare
VAM	Vesicular Arbuscular Mycorrhiza
viz.	Namely

Introduction

1. INTRODUCTION

Vegetables play a pivotal role in Indian agriculture by providing food, nutritional and economic security and more importantly, producing higher returns per unit area and time. They are considered as health capsules, being the main source of vitamins and minerals besides providing other dietary elements like carbohydrates, proteins, fibers, fats and enzymes. They contain significantly higher levels of biologically active components that impart health benefits beyond basic nutrition. Vegetables as a source of antioxidants act as scavengers of free radicals and reduce the risk of cardiovascular diseases.

The vast diversity of land, soil and agroclimatic conditions in India provides unique competitiveness to grow a wide range of vegetable crops. During the last three decades, India has made commendable progres in vegetable production, securing the position of the second largest producer in the world, next to China. In India, vegetables occupy an area of 7.99 million hectare with an annual production of 133.74 million tonnes (NHM, 2010).

Tomato (*Solanum lycopersicum* L.) is one of the most popular and widely grown vegetable crops in the world. The fruits are consumed either as raw or cooked. It can also be processed into various value added products such as juice, ketchup, sauce, paste and puree. Tomato is known for its outstanding nutritive value since it is a rich source of vitamin A, vitamin C, phosphorus, potassium, calcium, magnesium and iron (Rana, 2008). This protective food is also considered as a powerhouse of medicinal properties. It contains lycopene, beta-carotene, flavanoids and vitamin C, which together contribute to the increased antioxidant properties of fresh and processed tomatoes (Gahler *et al*., 2003), which associate the fruit with the low rates of certain types of cancers and cardiovascular diseases on its consumption (Rajoria *et al*., 2010). These factors contribute to the high demand for tomato, making it a high value crop, which can generate much income to farmers. Currently, India produces 12.43 million tonnes of tomato from an area of 0.634 million hectare with a productivity of 19.6 million tonnes per hectare (NHM, 2010).

The present agricultural scenario is waiting for an ever green revolution. Increased demand for food production necessitated the widespread use of pesticides and chemical fertilizers. However, indiscriminate use and faulty practices with chemical inputs jeoparadized the future of intensive agriculture. Chemicalization in agriculture has made it productive, but expensive, more exploiting and resource consuming. Despite the spectacular progress made in production by the use of fertilizers, at present a felt need has emerged for more sustainable and ecofriendly crop production systems. Since vegetables are mostly consumed fresh or partially cooked, safety and quality of vegetables have become increasingly important to the public. Therefore in recent years, sustainable production practices have been recognized as an important tool for ensuring food and nutritional security.

Sustainable agriculture embraces human health, environmental quality and soil health besides production aspects. The pivotal components which provide enroute approach to sustainable farming are biodiversity and ecological balance, integrated pest management, integrated nutrient management, organic farming and use of biofertilizers (Sharma, 2006).

At present, biofertilizers, an indispensable component of sustainable agriculture, are emerging as partial substitutes to chemical fertilizers. These are preparations containing agriculturally important beneficial microorganisms, which add, conserve and mobilize nutrients from nonusable to usable form through biological process (Bahadur *et al.*, 2004). They influence total soil microflora, soil enzyme activity, accelerate decomposition of plant residue and in turn, soil health (Dar *et al*., 2010). They produce growth promoting substances, vitamins and help to maintain soil fertility and suppress the incidence of pathogens (Bagyaraj, 2003). It passess nutritional benefits to the companion as well as succeeding crops.

Biofertilizers being ecological component can act as economical, ecofriendly, low investment requiring, non bulky and alternate plant nutrient source. As a cost effective supplement to chemical fertilizers, biofertilizers can help to economize on the high investment needed for fertilizer use (Pandey and Kumar, 2002). It is imperative to explore the possibility of supplementing chemical fertilizers with organic manures and biofertilizers to maintain high level of soil fertility and crop productivity.

Having considered these aspects, the present investigation was carried out with the following objectives.

- To test the response of tomato in terms of growth, yield and quality to biofertilizers

- To assess whether chemical fertilizers can be minimized or avoided by biofertilizer application so as to pave a way for formulation of organic farming technology

- To investigate the effectiveness of biofertilizers when applied along with chemical fertilizers

Review of Literature

2. REVIEW OF LITERATURE

There are several beneficial microorganisms in the rhizosphere, which can improve soil quality, enhance plant growth and yield, and conserve natural resources for sustainable agricultural production. A number of microorganisms like bacteria, fungi and algae are considered beneficial for agriculture, and used as biofertilizers. They can fix atmospheric nitrogen, solubilize insoluble phosphates and produce growth promoting substances like vitamins and hormones for plants (Yojana, 1992). Biofertilizers are one of the important components of integrated nutrient management, as they are cost effective and renewable source of plant nutrients to supplement the chemical fertilizers for sustainable agriculture.

Biofertilizers are carrier based preparations containing live or latent cells of efficient strains of beneficial microorganisms in a viable state intended for seed, soil or root application with the objective of increasing the number of such micro organisms and accelerating certain microbial processes to augment the extent of availability of nutrients in a form which can be easily assimilated by the plants (Rao, 1995). They facilitate several microbial processes in the soil and thereby enhance the uptake of major nutrients like N, P and K (Rao, 1982). Significant improvement in growth, yield and quality of vegetables with respect to biofertilizer application has been reported in various crops. The most important commercially exploited and widely accepted biofertilizers in vegetables are *Azospirillum, Azotobacter, Rhizobium*, Arbuscular Mycorrhizal Fungi (AMF) and Phosphate Solubilising Bacteria (PSB). *Frateuria aurantia,* a recently introduced potassium mobilizing microorganism is also found to be effective in vegetable cultivation.

Azospirillum is an associative symbiotic nitrogen fixing micro aerophillc bacteria having high potential for N fixation in cereals and also in vegetable crops (Subbiah, 1991). It fixes about 20-25 kg N per ha under ideal conditions, thereby effecting a reduction of 25 per cent in the quantity of N fertilizers required (KAU, 2011). The stimulatory effect exerted by *Azospirillum* has been attributed to several mechanisms including secretion of phytohormones (IAA, gibberellins and cytokinins), biological nitrogen fixation, and enhancement of mineral uptake by plants (Okon and Itzigsohn, 1995). Inoculation with *Azospirillum* sp. mainly changes morphology of roots, by increasing the number of lateral roots and root hairs results in better nutrient uptake and an improved water status enhance plant growth (Bottini *et al*., 2004).

Arbuscular Mycorrhizal Fungi are ubiquitous in nature. They are obligatory symbiotic and colonize the cortical region of the very fine absorbing roots of host plants. Mycorrhizal structures effectively take up phosphorus from lower concentration at which normal plant roots fail. Further, the AM fungi increase the surface area of absorptive system of plant and explore the soil by the external hyphae beyond the root hairs and phosphorus depletion zone. The same mechanism also helps the uptake of nitrogen, potassium, zinc, iron, copper, magnesium and calcium. Apart from nutrient uptake, AM fungi play an important role in the water economy of plants, drought resistance of plants, provide well developed root system to host plants, enhance phytohormone activity especially cytokinin and IAA, increased photosynthesis by reducing stomatal and mesophyll resistance to carbon dioxide and provide salt and heavy metal tolerance to plants. In addition, mycorrhizal association protects the host root from the attack of soil pathogens like *Pythium*, *Phytophthora, Rhizoctonia* and nematodes. AMF association remarkably increases the multiplication rate of other beneficial soil micro organisms. Mycorrhizae play an important role in managing soil stability. The large amount of AMF hyphae in soil serves to bind soil particles together and maintain the stability.

Frateuria aurantia is a gram negative, motile, rod shaped bacterium which belongs to Pseudomonaceae family. It is recently isolated from acidic soils (Curtis *et al.,* 2002) and shows exponential growth under very diverse growth conditions including wide temperature (10-36 ^{0}C) and pH range ($3.5^{-1}1$) (Joyeux *et al.,* 2004; Murugesan, 2008). It mobilizes elementary or mixture of potassium or solubilize the fixed form of potassium into easily absorbable form. It can mobilize K in all types of soil especially in low K content soils. By using *Frateuria* about 50-60 per cent potash fertilizers could be reduced (Chandra *et al*., 2005).

The present investigation deals with the effect of *Azospirillum*, AMF and *Frateuria* in tomato. Reviews related to the effect of these biofertilizers in vegetable crops are given.

2.1. EFFECT OF BIOFERTILIZERS

2.1.1. Effect of biofertilizers on growth characters

In a green house experiment conducted in tomato by Gupta *et al.* (1995), inoculation with *Azospirillum* sp., *Azotobacter chroococcum* and *Pseudomonas fluorescens* significantly increased seedling emergence rate. *A. chroococcum* was most effective in increasing the total dry weight, and root and shoot length, followed by *P. fluorescens* and *Azospirillum* sp. In tomato cv. INCA-17 application of biological product based on *Azospirillium brasilense* Sp-7 at different stages produced significant difference from those just receiving mineral fertilizer. Inoculation increased plant height, shoot diameter, root length and fresh and dry weights of plants. Inoculation at sowing time was the best treatment, giving a positive effect on growth parameters, which resulted in yield increase (Terry *et al.*, 2000). Vasanthakumar (2003) reported that combined inoculation of *Azospirillum* and PSB isolate produced synergistic effect, resulting in increased root length, shoot length, stem girth, number of leaves and number of branches in solanaceous crop plants.

Alfonso and Galan (2006) investigated the effectiveness of the *Glomus clarum and Azospirillum brasilense* co-inoculation in tomato. The treatments comprised inoculation and/or co-inoculation with mycorrhiza and rhizobacteria, under different nitrogen fertilizer dosages. Results showed a positive effect of co-inoculation, as seedlings were 23 percent taller than uninoculated plants. A field experiment conducted to study the effect of dual inoculation of *Glomus fasciculatum* and *Azospirillum* on the growth and yield of tomato var. $L^{-1}5$ in red sandy loam soil of Dharwad. The treatments were compared with uninoculated control at two varying levels of RDF (Recommended Dose of Fertilizer) (115:100:60 kg NPK ha^{-1}). The result revealed that height, number of primary branches and stem girth of the tomato plants were significantly higher than control treatments (Girish, 2006).

According to Kumar *et al.* (2007), among the different biofertilizers *viz. Azotobacter, Azospirillum* and *Phosphobacteria, Azospirillum* gave maximum plant growth, number of primary branches and days taken to first flowering in tomato. Malik and Kumar (2009) observed tomato plants recorded maximum height (73.17 cm) in VAM inoculated plants and is on par with 2/3 rd RDF.

Kandasamy *et al.* (1985) recorded an increase in seedling length in chilli (19.7 cm) and brinjal (14.9 cm) when soil was inoculated with mycorrhiza and phosphobacteria in nursery. Gurumurthy (1994) observed chilli plants inoculated with *Glomus macrocarpum* recorded highest plant height and plant dry weight with an increase in the level of inoculation. Chandraghatgi (1997) reported that the chilli plants recorded higher plant height in treatment inoculated with *G. macrocarpum* and the tomato plants recorded the highest growth parameters in the plants inoculated with *G. fasciculatum*. In a field experiment carried out at TNAU by Naveen *et al*., 2009 in chilli revealed that leaf area index and number of branches per plant (3.07 and 7.00, respectively) were significantly higher in combined application of composted coir pith 25 % + Vermicompost 25 % + Biodigested slurry 25 % + *Azospirillum* + PSB 25%.

Sundaravelu *et al.* (1993) assessed the effect of seed treatment with *Azospirillum* and gibberellic acid on the growth and yield of radish. Application of *Azospirillum* in combination with GA3 induced the vegetative growth at a faster rate. The root length (29.83 cm), diameter (3.97 cm) and weight (55.06 kg per plot) were increased due to *Azospirillum* in combination with GA treatment.

Bhagavantagoudra and Rokhade (2001) reported that in cabbage, application of *Azospirillum* through soil + seedling dipping recorded the highest cabbage yield (41.61t ha^{-1}), which was 33.67 per cent more than that obtained without *Azospirillum* application. Treatment with *Azospirillum* through soil + seedling dipping recorded the highest values for plant spread (46.22 cm), plant height (26.44 cm), number of outer leaves (22.70), leaf area (315.02 cm2), head diameter (13.33 cm), head surface area (577.31 cm2), number of inner leaves per head (41.92) and head weight (687.98 g) over uninoculated treatment.

Maximum leaf area $plant^{-1}$ (917.59 cm2), leaf number per plant (11.24) and weight per plant (150.24g) were obtained in knoll khol by the application of *Azospirillum* @ 2 kg ha^{-1} during kharif season (Chattoo *et al*., 1997).

2.1.2. Effect of biofertilizers on yield and yield attributing characters

Duraisamy *et al.* (1999) studied the effect of fertilizer nitrogen, *Azospirillum* and biofertilizers on yield and nutrition of rainfed tomato. Biofertilizer and coconut coir pith accounted the highest fruit yield (14.68 t ha^{-1}). Labeena (2001) reported that the plant height, fruit weight per plant and diameter of the fruits were higher in mycorrhiza inoculated plants of tomato compared to uninoculated control plants. Sowing tomato seeds inoculated with *Azospirillum* sp. on sterilized substrate significantly increased the fresh and dry weight, shoot height, leaf number and shoot root ratio (Moccia, 2004). *Azospirillum* inoculation on tomato gave 11 per cent yield increase compared to control plant (Alfonso *et al*. 2005). Kannan *et al.* (2006) reported that application of 75 per cent vermicompost in combination with *Azospirillum* resulted the highest yield in tomato. Nursery inoculation of *Azospirillum* and AMF in tomato gave the highest number of fruits per plant (39.00) and maximum yield (37.22 t ha^{-1}) over 100 per cent NPK (Girish, 2006).

Kumar and Sharma (2006) studied the effect of different methods of biofertilzier application in tomato seed production. They used four biofertilzers, namely

Azotobacter, *Azospirillum*, *Pseudomonas* and vesicular arbuscular mycorrhiza (VAM) and application of these biofertilizers were done with three methods *viz.* nursery soil, seedling and field soil treatment, individually and in combinations. The study revealed that *Azotobacter* when applied to nursery, seedling and field soil resulted in maximum values for number of fruits per plant (19.23), fruit yield per plant (1109 g) and per hectare (356.9 q), 1000 seed weight (3.63 g), seed yield per plant (4.58 g) and per hectare (152.70 kg).

According to Terry *et al*. (2006), in tomato the combined application of biofertilizers (*Glomus clarum* + *Azospirillum brasilense*) and bioactive compounds significantly increased yield by $12^{-1}9$ percent (26-29 t ha^{-1}). In tomato the soil application of FYM (50 %) + vermicompost (50 %) + biofertilizer (5 kg ha^{-1} *Azospirillum* + 5 kg ha^{-1} PSB) produced higher seed and fruit yield (475.31 kg and 13.99 t ha^{-1}). The increase in seed yield is due to more number of seeds per fruit (137.18), seed weight per plot (321.40 g), number of fruits per plant (12.61), fruit yield per plant (380.57 g) and fruit yield per plot (9.29 kg) (Patil, 2008).

Gurumurthy (1994) reported that the chilli plants inoculated with *Glomus macrocarpum* recorded the highest total number of green chilli fruits and fruit weight per plant. Chandraghatgi (1997) reported that the highest yield and yield components were recorded in AMF inoculated chilli plants as compared to the uninoculated control plants. Shashidhara (2000) noticed that *Azospirillum* + phosphobacteria recorded higher 1000 seed weight (5.93 g) which was significantly superior over 50 per cent RDF (5.40 g) in chilli.

Field experiments conducted to study the effect of biofertilizers on growth and yield of okra revealed that plants treated with double dose of FYM, *Azospirillum*, AMF and *Frateuria* recorded the highest number of fruits per plant (31.67), fruit yield per plant (544.40 g) and total fruit yield (16.33 t ha^{-1}) than the RDF (Anisa, 2011).

In cabbage, pressmud + VAM recorded the highest values for all parameters studied, i.e. number of outer leaves (13.3), fresh weight of outer leaves (476.67 g), number of inner leaves (31.7), head weight (161.67 g), head length (16.8 cm), head diameter (15.5 cm) and head yield (602.67 q ha^{-1}) (Bahadur *et al*., 2004). Application of vermicompost + seedling inoculation of *Azospirillum* noticed head yield at par with conventional fertilization.

Onion inoculated with *Glomus intraradices* at transplanting improved bulb yield and accelerated maturation (Makus, 2004).

2.1.3. Effect of biofertilizers on quality and nutrient content

Azospirillum treatment recorded the highest TSS of 5.95 and ascorbic acid content of 22.76 mg 100 g^{-1} in tomato (Sengupta *et al.*, 2002). In an experiment conducted by Abou-Aly (2005) reported that inoculation of nitrogen fixer (*Azospirillum lipoferum*) and PSB (*Bacillus megaterium* var. *phosphaticum*) along with *Saccharomyces cerevisiae* increased TSS and vitamin C in tomato fruits. In tomato Kannan *et al.* (2006) observed application of 75 per cent vermicompost in combination with *Azospirillum* resulted in the highest titratable acidity (0.72%), ascorbic acid content (23 mg 100 g^{-1}), total solids (5.4 %), pH (3.9), crude protein content (1.70 %) and lycopene content (3.7 mg 100 g^{-1}), and the lowest nonreducing sugar content (0.37 g 100 g^{-1}). Meerabai *et al.* (2007) reported that *Azospirillum* @ 1 kg ha^{-1} significantly improved the quality of bitter gourd fruits like vitamin C and protein content. Kumar *et al*. (2007) revealed that the quality parameters such as TSS and ascorbic acid contents of tomato were higher in *Azospirillum* inoculated plants. Kumar *et al.* (2010) noticed that AMF inoculation in tomato recorded high ascorbic acid content and acidity content over control. In tomato, Ordookhani *et al*. (2010) reported that combined inoculation of *Pseudomonas putida, Azotobacter chroococcum and Azosprillum lipoferum,* and AMF showed maximum lycopene and antioxidant activity. It also increased the potassium content of fruits. Crude fibre content (0.50 %) was the highest with the application of 50 % FYM + *Azospirillum*.

In brinjal maximum TSS was rescorded for 100 % RDF + *Azotobacter* + *Azospirillum* + PSB (Solanki, 2010).

According to Amor and del Porras (2009), inoculation of *Azospirillum brasilense* increased flavonoids and anthocyanins contents in red chilli fruits under limited N supply. In green chillies, ascorbic acid (289.25 mg 100 g^{-1}), capsaicin (0.86 %), oleoresin (19.02 %) and moisture content (89.58 %) were higher in 100 per cent organic manure (Composted coir pith 25 % + Vermicompost 25 % + Biodigested slurry 25 % + *Azospirillum*-PSB 25 %) (Naveen *et al*., 2009). Ghanti and Sharangi (2009) reported that the total loss of weight up to 60 days (11.5 %), was found minimum when *Azotobacter* + PSB was applied followed by *Azotobacte*r + *Azospirillum* (14.32 %) in onion.

2.1.4. Effect of biofertilizers on nutrient uptake and availability

In tomato, the inoculation of *Azospirillum brasilense* together with AMF species extracted the highest N, P and K (Pulido, 2003). Kannan *et al*. (2005) reported that application of 75 per cent vermicompost with *Azospirillum* recorded maximum organic carbon (0.78 %) over the inorganic source and which was on par with 75 per cent coir pith compost with *Azospirillum* in tomato. Application of *Azospirillum* with 75 per cent vermicompost also recorded the highest available N of 254 kg ha^{-1} over the 100 per cent N as urea (242 kg ha^{-1}).

According to Girish (2006), nitrogen uptake (348.5 mg $plant^{-1}$) was the highest in plants with nursery raised dual inoculation of *Azospirillum* and AMF than uninoculated control (197 mg $plant^{-1}$). Similarly significantly higher P uptake (62.25 mg $plant^{-1}$) was noticed in dual inoculation of *Azospirillum* and AMF compared to control (31.9 mg $plant^{-1}$). Application of the biofertilizers and biological control agents increased the quality and decreased the nitrate content in tomato fruit (Mironova and Marin, 2008). In tomato, seed inoculation and soil application of *Azospirillum*, PSB and methylotrophic bacterial strains alone or under dual inoculation increased the nutrient uptake in the plants compared to uninoculated control plants (Madhaiyan *et al.*, 2010). Ordookhani *et al.* (2010) obtained highest shoot potassium uptake (8.88 %) for the combined inoculation of PGPR and AMF in tomato.

Chandraghatagi (1997) reported that chilli and tomato plants responded well to the inoculation of AMF in improving phosphorous uptake as compared to the uninoculated plants. Inoculation of *G. macrocarpum* significantly increased plant P concentration of chilli followed by *G. fasciulatum* and *G. margarita*. However, tomato plants inoculated with *G. fasciculatum* had the highest P concentration followed by *G. macrocarpum* and *G, margarita*.

2.1.5. Effect of biofertilizers on microbial count

Hadas and Okon (1987) reported that the level of *Azospirillum brasilense* colonized in the rhizosphere of tomato plants was 10^4-10^5 cfu per plant per root when 2 weeks old plants were inoculated with 5 x 108 *Azospirillum* cells. An inoculum concentration of 1 x 10^8 to 5 x 10^8 cfu ml^{-1} stimulated the appearance of root hairs.

In an experiment done by Bashan *et al.* (1989) to find the non specific response of non cereal crop to *Azospirillum brasilense* inoculation, it was found that *Azospirillum* inoculation showed a buildup of root population reaching 5.6 x 10^5 cfu g^{-1} fresh weight of root at 18 days after inoculation in tomato, and 5.4 x 10^5 cfu g^{-1} fresh weight of root at 15 days after inoculation on egg plant.

Coupling of AMF (*G. mosseae*) and *Azospirillum lipoferum* significantly increased bacterial, actinomycete and *Azospirillum* counts in the rhizosphere of the tomato plants. While fungal population was significantly dropped. Similarly coupling of both organisms significantly increased sporulation and mycorrhizal infection of tomato plant roots (Shalaby, 2001). Sreenivasa *et al.* (2007) observed maximum micorrhizal spore count in the rhizosphere of tomato plants inoculated with *Glomus fasciculatum.* It was 115.00, 312.50 and 329.16 spores/50 cc soil at 30, 60 and 90 DAT respectively.

A study in *Capsicum chinense* by Constantino *et al.* (2008) reported that populations of *Azospirillum brasilense* ranged from 2.5 x 10^6 to 1.3 x 10^6 cfu g^{-1} soil and was significantly greater than *Azotobacter chroococcum* (10.3 x 10^5 to 2.6 x 10^5 cfu g^{-1} soil). The percentage of colonization of plants inoculated with AMF ranged from 35 to 57 per cent, with the greatest values recorded for the treatment involving single biofertilization by root coating. In chilli, application of composted coir pith 25 % + vermicompost 25 % + biodigested slurry 25 % + *Azospirillum* + PSB 25 % recorded higher population of bacteria, fungi and actinomycetes after harvest of the crop as compared to all other treatments (Naveen *et al*., 2009).

Venkatachalam *et al.* (2009) studied the effect of AM infection in enhancing plant growth. They isolated AM spores from the soil and observed that potatoes and peas showed the highest number of spores (>4000 spores kg^{-1} soil) whereas onion and tomato showed the lowest number of spores (<1300 spores kg^{-1} soil).

Sivaprasad *et al.* (1989) studied the response of cassava and sweet potato intercropped in coconut garden to inoculation of *Glomus fasciculatum*. They observed that *Glomus fasciculatum* inoculated cassava cultivars recorded $88^{-}114$ spores/50 g soil and sweet potato recorded $84^{-}109$ spores/50 g soil.

In an experiment to study the effect of solarisation and VAM on weed density and yield of lettuce, Cimen *et al.* (2010) observed that VAM inoculated treatments gave a higher spore count of 61.18 spores/10 g soil than non micorrhizal one (32.06 spores/10 g soil).

2.1.6. Effect of biofertilizers on economics

In tomato Kamal *et al*. (2008) obtained the highest benefit cost ratio of 2.02 due to application of *Azotobacter* and *Azospirillum*. Murugesan (2008) reported that the liquid formulation of *Frateuria aurantia* formulation when given as soil application recorded a significant increase in growth and yield of brinjal crop as compared to untreated control and saved 50 per cent fertilizer potash.

In onion application of *Azospirillum* + phosphobacteria gave 18.3 per cent increase in yield and saved 25 per cent inorganic fertilizers, thereby reducing cost of cultivation (Kanauja and Narayanan, 2003).

Geethakumari *et al.* (1994) conducted an experiment in phosphorus mycorrhiza interaction in grain cowpea and recorded the possibility of saving P fertilizers using AMF.

Madhavi *et al*. (2008) reported that higher net returns (Rs.1,49,650 ha^{-1}) and benefit cost ratio (2.61) in Indian spinach with application of poultry manure (8 t ha^{-1}), *Azospirillum* (2 kg ha^{-1}) and PSB (2 kg ha^{-1}).

Chandra *et al.* (2005) reported that *Frateuria aurantia* application enhanced yield by 15-25 per cent and there by reduced 50-60 per cent of potash chemical fertilizer cost.

2.2. COMBINED EFFECT OF BIOFERTILIZERS AND FERTILIZERS

2.2.1. Effect of biofertilizers and fertilizers on growth characters

Kumaran *et al.* (1998) reported that in tomato, plant height (75.75 cm), branches per plant (12.23), mean fruit weight (41.05 g) and number of fruits per plant (18.30) were the best with combination of FYM (15 t ha^{-1}), NPK (150:100:50 kg ha^{-1}) along with *Azospirillum* and phosphobacteria. In tomato treatment with 120 kg N ha^{-1} + *Azospirillum* recorded the highest plant height (84.36 and 82.74 cm), number of branches (13.17 and 12.91), fruit diameter (6.75 and 6.45 cm), number of fruits per plant (34.38 and 32.85) and yield per plant (284.38 and 265.81 q) for the first and second year (Sengupta *et al.*, 2002).

Field experiments conducted at Annamalainagar by Anburani and Manivannan (2002) to evaluate the effect of organic manures, different levels of N and P fertilizer and with or without biofertilizers (*Azospirillum* + PSB) on the growth and yield of aubergine cv. Annamalai. Application of FYM + Poultry manure each @ 12.5 t ha^{-1}

along with full dose of NPK + biofertilizers each at 2kg ha^{-1} increased plant height (108.90 cm), number of primary branches (11.66) and number of leaves (94.05), whereas FYM at 25 t ha^{-1} along with 100 per cent NPK + biofertilizers recorded the highest values for stem girth (3.71 cm), number of secondary branches (15.58) and leaf area (68.62 cm2). Anburani *et al*. 2003 reported that application of 25 t FYM ha^{-1} + 100:50:50 kg NPK ha^{-1} + *Azospirillum* + PSB resulted the greatest fruit length (10.77 cm) and fruit girth (10.03 cm) in brinjal.

In brinjal Wange and Kale (2004) reported that inoculation with mixture of *Azotobacter* + *Azospirillum* + 75 kg N per ha significantly improved plant height and number of leaves per plant when compared to the recommended rate of N fertilizer. Kiran (2006) reported that in brinjal significantly higher growth components such as plant height, number of leaves and branches per plant were recorded at 100:100:50 kg NPK ha^{-1} + *Azospirillum* and PSB (root dipping) treatment.

In an experiment conducted by Patel *et al.* (2011), to know the effect of biofertilizers on growth, physiological parameters, yield and quality of brinjal cv. Surati Ravaiya, reported that growth parameters like plant height at 60 DAT and number of branches per plant were found maximum with 100 % RDF + *Azospirillum* + *Azotobacter* + PSB, which was followed by 75 % RDF + *Azospirillum* + *Azotobacter* + PSB.

Sankaranarayanan *et al.* (1995) conducted an experiment on the effect of *Azospirillum* on improved varieties of bhendi. The highest root length (8.12 cm) and plant height (63.99 cm) were obtained with 50 per cent recomended N and *Azospirillum* (2 kg ha^{-1}). Application of 75 % RDF + vermicompost (4 t ha^{-1}) + neem cake (1 t ha^{-1}) + microbial consortium (*Azotobacter* + PSB+ AMF + Trichoderma each @ 2.5 kg ha^{-1}) was recorded maximum plant height at harvest stage (100.50 cm), number of leaves (28.13), number of branches (2.73), leaf area (22.00 cm2) and leaf area index (1.21) as compared to other treatments in okra (Gowda *et al*., 2009). Seed and soil treatment with the application of *Azospirillum* with 30 kg N ha^{-1} recorded the highest plant height (205.2 cm) in bhendi cv. Pusa Sawani (Balasubramanian *et al.*, 1997).

Amrithalingam (1988) observed that soil inoculation of *Azospirillum* along with 50 per cent of recommended dose of nitrogen increased the seedling length and vigour index in chilli. In chilli cultivars local and CA-42 Paramaguru and Natarajan (1993) reported that *Azospirillum* in combination with 75 per cent of recommended nitrogen produced maximum number of primary branches (6.3 and 5.9, respectively).

Application of 75 per cent nitrogen of recommended doses (135 kg ha^{-1}) in combination with *Azotobacter* significantly increased the growth parameters (numbers of unfolded leaf, leaf area and LAI), yield attributes (number of folded leaf, weight and diameter of head) and yield of cabbage (341-66 q ha^{-1}) (Khare and Singh, 2008).

A study by Muneppa *et al.* (2009) in onion reported that application of 100 % RDF + neem cake (1 t ha^{-1}) + *Azotobacter* (5.0 kg ha^{-1}) + PSB (5.0 kg ha^{-1}) + K mobilize (5.0 kg ha^{-1}) recorded significantly the highest plant height, leaf area per plant, leaf area index and absolute growth rate. Study conducted by Ghanti and Sharangi (2009) to find the effect of six combinations of biofertilizers and two chemical fertilizers on onion cv. Sukhsagar revealed that the height of the plant (43.46 cm) with the application of *Azotobacter* + VAM. Application of *Azotobacter* + *Azospirillum* and NPK 100 per cent gave maximum length of bulbs (6.03 cm). The maximum number of scale per bulb (9.81) was counted from NPK 50 per cent. The plants raised under 100 per cent NPK produced the maximum bulb weight of 67.45 g.

Kumaran and Muthuvel (2009) reported that at closest spacing (45 cm × 5 cm) with the application of *Azospirillium* and phosphobacteria each @ 2 kg ha^{-1} along with 60:60:30 kg NPK ha^{-1} + FYM @ 25t ha^{-1} registered the highest plant height (48.5 cm), bulb length (5.7 cm) and shape index (1.1%).

2.2.2. Effect of biofertilizers and fertilizers on yield and yield attributing characters

Terry *et al.* (1995) compared the efficacy of various bacterial inoculum and N-fertilizer treatments in tomato cultivar INCA^{-1}7 in red soil. The treatment with *Azospirillum brasilense* + 75 kg N ha^{-1} resulted in higher fruit yield (24.19 t ha^{-1}) compared to control (23.16 t ha^{-1}). Sendur *et al.* (1998) reported that combination of FYM + 150:100:50 kg NPK ha^{-1} + *Azospirillum* + phosphobacteria produced higher number of fruits per plant and mean fruit weight of tomato as compared to other treatments.

In tomato, Amer *et al.* (2003) reported that the combined application of mineral fertilizers (full and 75 % RDF) and biofertilizers (*Azotobacter, Azospirillum* and *Bacillus megaterium*) significantly increased the vegetative growth and total fruit yield. Natarajan *et al.* (2003) recorded the influence of growing media, irrigation regime, integrated nutrient management and mulching on yield and economics in tomato hybrids under polyhouse condition in which RDF+ biofertilizer as basal registered higher yield per hectare (165 t).

A study conducted at Allahabad Agricultural Institute in tomato revealed that mixed application of biofertilizers, VAM + *Azospirillum* + 75 per cent boron recorded the highest yield of 15.24 t ha^{-1} and at the same time uninoculated boron treatment recorded a minimum yield of 7.81 t/ha (Bhat and Prasad, 2004). The combined application of inorganic fertilizer (120 kg N + 60 kg P ha^{-1}) and *Azospirillum* application significantly improved the yield of tomato (Kumar *et al*., 2007). Kumar *et al.* (2010) carried out a study to find out the response of INM on tomato and reported that inoculation of VAM recorded maximum number of seeds per plant and the highest seed yield.

In brinjal, Anburani and Manivannan (2002) reported that application of FYM (25 t ha^{-1}) + Poultry manure (12.5 t ha^{-1}) and FYM (25 t ha^{-1}) along with full dose of

NPK + *Azospirillum* + PSB recorded the lowest number of days to first flowering and 50 per cent flowering. FYM (25 t ha^{-1}) + 100 % NPK + biofertilizers recorded the highest fruit set (65 %), number of fruits (26.64), fruit yield per plot (62.92 kg) and fruit yield (31.67 t ha^{-1}). Anburani *et al.*, 2003 reported that application of 25 FYM t ha^{-1}+ 100:50:50 kg NPK ha^{-1} + *Azospirillum* + PSB resulted in the highest fruit weight of 54.11 g and fruit yield of 1.43 kg per plant. An experiment to study the effect of fertilizer and biofertilizer on seed yield and quality of brinjal revealed that higher yield components like number of fruits per plant (16.72), fruit weight (145.70 g), 1000 seed weight (6.52 g) and seed yield (445.74 kg ha^{-1}) were recorded at 100:100:50 kg NPK ha^{-1} + *Azospirillum* and PSB treatment (Kiran, 2006).

Jeevansab (2000) recorded significantly higher number of seeds per fruit (194.8), seed weight (1.44 g) per fruit and 100 seed weight (0.75 g) with the application of *Azospirillum* + RDF as compared to 50 per cent RDF (175.8, 1.32 g and 0.72 g, respectively) in capsicum. Field experiment to study the effect of inoculation with biological nitrogen fixers (*Azospirillum* and *Azotobacte*r) on growth and yield of 'Suryamukhi' chilli (*Capsicum annuum* L.) by Talukder and Jana (2009) reported that dual inoculation with the biological nitrogen fixers, 100 per cent recommended dose of N-fertilizer @ 80 kg N ha^{-1} and FYM @ 15 t ha^{-1} recorded maximum yield (7.43 t ha^{-1}). Thamizh and Nanjam (1998) stated the combined application of *Azospirullum*, phosphobacteria and VAM with 75 per cent of recommended NPK (90:90:90 kg/ha) recorded the highest yield (14.96 t ha^{-1}) which was 21 per cent higher than uninoculated control (11.93 t ha^{-1}) in potato.

According to Sankaranarayanan *et al.* (1995), *Azospirillum* + 50 per cent N recorded maximum number of fruits (33.44) and yield per plant (217.14 g) in bhendi. Balasubramani *et al.* (1997) reported that the seed and soil treatment of *Azospirillum* with 75 per cent recommended dose of nitrogen per hectare recorded the highest yield (17.5 t ha^{-1}) of bhendi whereas control registered only 9.6 t ha^{-1}. In okra maximum fruit yield per plant (254.53 g), fruit yield per plot (6.08 g) and fruit yield per ha (14. 07 t) was recorded in treatment with combined application of 75 per cent RDF along with vermicompost (4 t ha^{-1}), Neem cake (1 t ha $^{-1}$) and microbial consortium (*Azotobacter* + PSB + AMF+ Trichoderma each @ 2.5 kg ha^{-1}) (Gowda *et al*., 2009).

Jothi *et al*. (1993) recorded a cabbage yield of 117.2 t ha^{-1} with the application of NPK at 100: 125: 25 kg ha^{-1} + soil inoculation with *Azospirillum* 2 kg ha^{-1}. Maximum head volume (1725 ml3), head size index (279.8), net yield (891.7 kg ha^{-1}) and seed yield (46.404 kg ha^{-1}) were obtained in cabbage plots treated with 60 kg N ha^{-1} combined with *Azospirillum* and *Azotobacter* (Verma *et al*., 1997). Sannigrahi and Borah (2000) obtained the highest yield of cabbage (26.6 t ha^{-1}) with 10t compost + root inoculation of AMF + nitrogen 40 kg + potassium 30 kg ha^{-1}.

Nitrogen application along with *Azospirillum* increased the number and weight of non-wrapper leaves per plant, head length and width, gross and net head weight per plant and yield per ha of cabbage, with the highest values recorded at 60 kg N ha^{-1} (Sharma, 2002). According to Devi *et al.* (2003) head yield (55.82 t ha^{-1}) was the highest with the application of 50 % recommended N + 25 % poultry manure + biofertilizers. Upadhyay (2012) reported that in cabbage, treatments comprising recommended fertilizers package coupled with seedling inoculation in any biofertilizer had relatively higher dry matter in leaves (head), higher number of non-wrapper leaves and head yield (40.81-41.88±1.07 tonnes ha^{-1}).

Gupta and samnotra (2004) reported that in cabbage, application of 90 kg N + *Azospirillum* resulted in the greatest plant height (25.08 cm), number of wrapper leaves (31.33), head diameter (14.63 cm), head weight (1.280 kg), yield (435.22 q ha^{-1}), net income (79,450 rupees per ha) and benefit cost ratio (4.35), and the lowest core length (5 cm). According to Sharma *et al.* (2005), response of different cabbage cultivar *viz*. Pride of India, Golden Acre and Pusa Mukta to *Azotobacter* and *Azospirillum* revealed that Golden Acre was found to be the earliest cultivar, recording the minimum number of days taken to maturity (87.67). Pusa Mukta excelled in respect of net weight of head

(715.23 g) and yield (358.58 q ha^{-1}) over other cultivars. The combined use of N and *Azospirillum* proved the most effective treatment for the enhancement of net weight and yield of cabbage heads.

According to Khan *et al*. (2009), *Azospirillum* + 100 per cent RDF recorded significantly higher curd yield (216.6 q ha^{-1}) in cauliflower as compared to the application of all the other biofertilizer + inorganic fertilizer, but comparable with *Azospirillum* + 75 % N.

Application of 50 % N through urea and 50 % N through vermicompost along with *Azospirillum* resulted in higher availability and uptake of nutrients by knol kohl and thus produce the maximum yield of 37 t ha^{-1} (Shalini *et al.,* 2002).

2.2.3. Effect of biofertilizers and fertilizers on quality and nutrient content

A field experiment was conducted to assess the efficacy of biofertilizers along with chemical fertilizers on tomato. The highest specific gravity (1.07 g cm-3) and juice content (91.21 %) were found in VAM + RDF (Kamal *et al*., 2008). Study conducted by Premsekhar and Rajashree (2009) revealed that *Azospirillum* @ 2 kg ha^{-1} + 75 per cent N + 100 % PK recorded higher TSS of 4.45 ^{0}Brix.

Subbiah (1994) reported that chilli plants treated with 100 per cent RDF (N and P) along with biofertilizers (*Azosprillum* and VAM) recorded the highest P content (0.7 %). Ascorbic acid (136.77 mg $100g^{-1}$), capsaicin (4.17 mg g^{-1}) and oleoresin (8.96 %) in chilli were more when *Azospirillum* and phosphobacteria (each @ 4 kg ha^{-1}) were applied along with inorganic N and P, accounting for an increase of 7.99 per cent, 7.2 per cent and 11.7 per cent respectively over treatment involving only inorganic N and P as reported by Selvaraj (1996).

Study conducted by Nanthakumar and Veeraragavathatham, (1998) concluded that combined application of FYM 12.5 t ha^{-1}, *Azospirillum* and phosphobacteria (2 kg each) + inorganic fertilizers at 75 per cent of the recommended rate of N (75 kg ha^{-1}), P

(37.5 kg ha^{-1}) and 100 per cent of K (30 kg ha^{-1}) increased the keeping quality, improved the general appearance and overall acceptance of the harvested brinjal fruits compared to the ones treated with inorganic fertilizers. Application of 100 % NPK + FYM + *Azospirillum* + PSB gave maximum ascorbic acid, carbohydrate and crude protein in fruits. In brinjal when *Azospirillum* was inoculated @ 1 kg ha^{-1} along with recommended dose of chemical nitrogen, it resulted in significantly higher vitamin C content of 30.21 mg/100g (Kamili *et al*., 2002). Patel *et al*. (2011) reported that TSS of brinjal fruits was found superior when 100 per cent RDF + *Azospirillum* + *Azotobacter* + PSB was applied.

Mahendran and Kumar (1998) studied the effect of biofertilziers on quality parameters of potato and observed that application of two equal split doses of 100 per cent recommended dose of NPK with *Azospirillum* and phosphobacterium increased the ascorbic acid content significantly over control.

Upadhyay (2012) observed that fibre content in cabbage head was improved remarkably with the use of organic manures and biofertilizers. The highest total carotenoid content (0.445 mg 100 g^{-1}) in head was recorded with the use of FYM + PSM. Significantly higher ascorbic acid content (vitamin C) in head was registered with the use of either FYM or pressmud along with PSM or VAM (14.25-15.48±0.33 mg 100 g^{-1}).

Sable and Bhamare (2007) reported that in cauliflower cv. Snowball-16, 75 per cent N along with *Azospirillum* and *Azotobacter* showed significant increase in ascorbic acid (87 mg 100g^{-1}), protein (18.62 %) and total nitrogen content in plants (2.98 %), and compactness of curd (97.39 %).

Ragland *et al.* (1989) studied the effect of bio-fertilizers in onion and found that 75 percent of recommended nitrogen (112.5 kg ha^{-1}) and phosphorous (112.5 kg ha^{-1}) along with *Azospirillum* and VAM recorded significantly higher TSS content as compared to other treatments.

In a study to find the comparative efficiency of organics, inorganics and their combination in Kharif and Rabi, Sarkar (1995) reported that leaf N (2.45 %) and leaf K (4.57 %) were higher during kharif and leaf P (0.33 %) was higher during Rabi in plots treated with 60 kg N and P, 30 kg K along with *Azospirillum* (2 kg ha^{-1}), phosphobacteria (2 kg ha^{-1}), FYM (25 t ha^{-1}) and neem cake (200 kg ha^{-1}) in aggregatum onion cv.Co-4.

2.2.4. Effect of biofertilizers and fertilizers on nutrient uptake and availability

Harikrishna *et al.* (2002) reported that application of FYM 25 t ha^{-1} + 75 % N +100 % P + 100 % K + *Azospirillum brasilense* in tomato resulted in the highest available N (299.9 kg ha^{-1}), P2O5 (44.2 kg ha^{-1}) and K2O (321.9 kg ha^{-1}) in soil.

Subbiah (1994) reported that in chilli 100 per cent recommended dose of N and P along with biofertilizers (*Azospirillum* + VAM) recorded the highest N, P and K uptake. *Azospirillum* and phosphobacteria combined with inorganic N and P gave a higher level of uptake of N (130.6 kg ha^{-1}), P (23.63 kg ha^{-1}) and K (155.57 kg ha^{-1}) in chilli (Selvaraj, 1996). Sreeja (2003) noticed that in chilli, total uptake of N was significantly increased by the treatment with 3:1 NK ratio and *Azospirillum* inoculation whereas *Azospirillum* along with 2:1 NK ratio recorded maximum P and K uptake. In green chilli, there was increased content of plant nitrogen (84.10 mg kg^{-1}), phosphate (84.42 mg kg^{-1}) and potash (57.46 mg kg^{-1}), leaf chlorophyll (0.204 mg 100 g^{-1}) and residual available soil nitrogen (202.90 kg ha^{-1}), phosphate (67.10 kg ha^{-1}) and potash (70.50 kg ha^{-1}) with dual inoculation with the biological nitrogen fixers (*Azospirillum* and *Azotobacter*) along with full dose of N-fertilizer (Talukder and Jana, 2009; Khan *et al.*, 2012).

Han and Lee (2005) found that co-inoculation of PSB and KSB in combination with direct application of rock P and K materials into the soil resulted in increased N, P and K uptake, photosynthesis and yield of brinjal grown on P and K limited soil.

In cabbage, application of 50 per cent N (urea) + 50 per cent N (vermicompost) + *Azospirillum* resulted in higher uptake of nutrients. Maximum dry matter production was also observed in this treatment (Shalini *et al.*, 2002).

Subbiah (1991) reported that in bhindi cv. CO-2, application of 50 per cent recommended nitrogen and soil application of *Azospirillum* (2 kg ha^{-1}) gave the highest yield of 23.97 t ha^{-1} which was 13.3 percent over control. This also registered the highest value for N uptake (278.2 kg ha^{-1}). This treatment had beneficial effect on nitrogen use efficiency besides saving up to 50 per cent recommended nitrogen in okra. In onion, *Azospirillum* + VAM + 50 kg N + 50 kg P gave the highest bulb N and P uptake as reported by Mengistu and Singh (1999). Nagaraju *et al.* (2000) recorded maximum availability of N (189.4 kg ha^{-1}), P (25.54 kg ha^{-1}) and K (246.21 kg ha^{-1}) in treatments 25 per cent recommended P (RP) + VAM, 100 per cent RP + VAM and 50 per cent RP + VAM in aggregatum onion. Mahanthesh *et al.* (2009) investigated the impact of biofertilizers with levels of NPK on nutrient uptake and yield of onion cv. Bellary red revealed that plants provided with *Azospirillum* + 100 % N PK (125: 50: 125 kg ha^{-1}) showed maximum uptake of N (157.88 kg ha^{-1}), P (73.56 kg ha^{-1}) and K (70.46 kg ha^{-1}).

2.2.5. Effect of biofertilizers and fertilizers on Microbial population

Raji (2002) studied the effect of VAM and different sources and doses of phosphorus on root colonization and rhizosphere count in tomato cv. Shakthi. Maximum spore count of 417.5 spores per 50 g soil was recorded in VAM + FYM + N + 75 per cent mussorie rock phosphate + K. When single super phosphate was applied, maximum spore count of 358.8 spores per 50 g soil was recorded in VAM + FYM + N + 50 per cent single super phosphate + K. The co-inoculation of *Glomus clarum* and *Azospirillum brasilense* along with nitrogen fertilizer stimulated the population of both microorganisms at the rhizosphere of tomato plant (Alfonso and Galan, 2006).

In *Capsicum annuum*, the number of AMF spores recovered from soil decreased with increasing phosphorus fertility. At lower phosphorus (11 µg ml^{-1}) the spore count was 124/100 cm^3 soil whereas, at high phosphorus (44 µg ml^{-1}) it was 611 per 100 cm^3. Arunkumar (1997) reported that in chilli cv. Jwalamukhi, population of *Azospirillum* (13×10^3) and actinomycetes (18×10^4) were significantly high in 100 per cent N + half vermicompost + *Azospirillum* @ 5 kg ha^{-1}. In amaranth 75 per cent N + FYM + *Azospirillum* gave significantly higher number of bacteria (17×10^6) and fungi (13.7×10^4). In a study conducted at KAU, Thrissur, Sreeja (2003) reported that chilli plants treated with *Azospirillum* @ 1 kg ha^{-1} and 2: 1 NK ratio registered maximum mean *Azospirillum* count of 8.33×10^5 cfu g^{-1}.

Effect of VAM and soluble phosphorus on bhindi was studied in phosphorus deficient sandy loam soil by Krishna and Bagyaraj (1982) at varying levels of phosphorus. It was observed that maximum number of spores (448 per 100 ml soil) was recorded when no soluble phosphorus was added.

Tilak and Saxena (2008) conducted a laboratory and field experiments to study the response of onion cv. Pusa Red to inoculation with *Azospirillum brasilense.* It was found that population of *Azospirillum* in endorhizosphere was more in inoculated treatment than uninoculated control. Application of *Azospirillum* along with nitrogen @ 30 kg ha^{-1} and 60 kg ha^{-1} stimulated bacterial counts (1.72×10^8 and 3.21×10^8 per g fresh root weight respectively) whereas at higher levels of N (90 kg ha^{-1}) population was low even in the presence of bacterium.

Shinde and Latake (2009) conducted an experiment in pearl millet to investigate the combined effects of diazotrophs and phosphobacteria on nitrogen, phosphorus and microbial status of soil. The seeds treated with inoculants before sowing and RDF is applied in the field. The maximum population of all bacteria was recorded in composite culture of three diazotrophic (*Acetobacter, Azotobacter, Azospirillum*) and one phosphobacteria (*Bacillus*) in soil at flowering stage and decreased at maturity stage, whereas found minimum in uninoculated control. The maximum population of

Acetobacter, Azotobacter, Azospirillum and Bacillus are 16.84 cfu x 10^5 g^{-1} soil, 17.52 cfu x 10^5 g^{-1} soil 17.64 cfu x 10^5 g^{-1} soil and 15.23 cfu x 10^5 g^{-1} soil respectively.

2.2.6. Effect of biofertilizers and fertilizers on economics

Prasad *et al.* (2002) reported that mixed biofertilizer (VAM + *Azospirillum*) with 75 percent of recommended chemical fertilizer dose was found to be superior over all levels of biofertilizer and chemical fertilizer for growth and yield of tomato. In a study conducted to find the influence of biofertilizers on tomato cv. Co-3, it was found that *Azospirillum* @ 2 kg ha^{-1} + 75 per cent N + 100 % PK recorded the highest yield (43.85 t ha^{-1}) (Premsekhar and Rajashree, 2009).

In a study conducted by Sreeramulu and Bhagyaraj (1986) where four different VAM fungi were inoculated in chilli @ 2 kg per bed, it was found that the yield of *Glomus fasciculatum* inoculated plants at half P (0.52 kg per plot) was more than the plants receiving full P (0.43 kg per plot) suggesting that application of phosphatic fertilizer could be reduced through mycorrhizal inoculation. Application of *Azospirillum* on 40 day old capsicum seedlings cv. California Wonder saved 25 per cent chemical nitrogen (Chatoo *et al.*, 2003). Dual inoculation with the biological nitrogen fixers (*Azotobacter* and *Azospirillum*), 100 per cent recommended dose of N fertilizer @ 80 kg N ha^{-1} and FYM @ 15 t ha^{-1} recorded maximum yield (7.43 t ha^{-1}) and cost:benefit ratio of 1.55 in chilli. Combined application of biofertilizers with chemical fertilizers saved 25 per cent nitrogenous fertilizer in the crop (Talukder and Jana, 2009).

In brinjal, Devi *et al*., (2002) reported that treatment with 50 % N + 25 % poultry manure + biofertilizer resulted in the highest yield (27.57 t ha^{-1}) and benefit: cost ratio (7.72:1). According to Wange and Kale (2004) yield of brinjal when inoculated with mixture of *Azotobacter* + Azospirillum followed by application of 75 kg N ha^{-1} was on par with 100 kg N ha^{-1} *Azotobacter* + *Azospirillum*. So the former treatment saved 25 per cent of N fertilizer. In brinjal the highest cost benefit ratio was obtained for100% RDF+ *Azotobacter* + *Azospirillum* + PSB. (Solanki, 2010).

In cabbage, combination of *Azospirillum* + 60 kg N ha^{-1} recorded the highest benefit: cost ratio of 2.9 (Sharma, 2002). According to Devi *et al.* (2003) in cabbage, benefit cost ratio was the highest (4.30) with the application of 75 % N + biofertilizers. Gupta and Samnotra (2004) reported that in cabbage, application of 90 kg N + *Azospirillum* recorded the highest benefit cost ratio of 4.35 and reduced the N use by 25 per cent. Sood and Vidyasagar (2007) reported that *Azospirillum* reduced the N requirement by up to 20 per cent of the recommended rate in the same crop. Performance of *Azospirillium* and *Azotobactor* had been more efficient in combination with 80 per cent (144 kg N ha^{-1}) of the recommended levels of chemical nitrogen, resulting in a nitrogen economy of 20 per cent without affecting the yield (Bhat *et al.*, 2007) in cabbage.

In an experiment to evaluate the response of cauliflower cv. Snow ball^{-}16 to four biofertilizers. Inoculation of *Azospirillium* along with recommended dose of NPK @ 120: 60: 60 kg ha^{-1} produced maximum average curd weight (1.1 kg) and curd yield (28.2 t ha^{-1}). This treatment also recorded the highest net return (Rs. 53,695 ha^{-1}) and benefit cost ratio (2.23) as reported by Singh and Singh (2005).

Yadav *et al.* (2005) reported that application of 75 kg N ha^{-1} along with *Azospirillium* inoculation fetched the highest net profit per hectare (Rs.31,288) with a benefit cost ratio of 10.0 in onion which is on par with 100 kg N ha^{-1} + *Azospirillium* (Rs. 32,792). Mahanthesh *et al*. (2008) obtained maximum net income of Rs. 56,328 and Rs. 52,135 with maximum B: C ratio of 4.0 and 3.94 from Bellary onion provided with *Azospirillium* + 100 per cent NPK under irrigated and rain fed condition. The control plots registered a maximum net profit of Rs. 30,781 and Rs. 27,725 with B: C ratio of 2.93 and 2.86 respectively.

In cucumber, Prabhu *et al*. (2006) conducted a study on INM in cucumber at TNAU, Coimbatore and concluded that application of 50 per cent RDF + Vermicompost (2 t ha^{-1}) + *Azospirillium* (2 kg ha^{-1}) + phosphobacteria (2 kg ha^{-1}) increased the vine length, earliness in flowering and gave the highest number of fruits

(8.4), yield (32.8 t ha^{-1}) and B: C ratio (2.24). A basal dose of FYM (25 t ha^{-1}) and application of poultry manure to supply the recommended dose of 70 kg N ha^{-1} (on N equivalent basis) in combination with *Azospirillium* @ 1 kg ha^{-1} was the best economic organic nutrient schedule in bitter gourd (Meerabai *et al.*, 2007).

In amaranth, Niranjana (1998) reported that dual inoculation (*Azospirillium* and AMF) along with 75 percent POP gave the highest yield of 144.31 t ha^{-1} which also recorded maximum B: C ratio (9.59) and net returns (Rs. 6, 46,261). This offered considerable economy of fertilizer to the tune of 25 per cent of recommendation and a balanced low cost approach for vegetable cultivation.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation was carried out in the Department of Olericulture, College of Horticulture, Vellanikkara during 2011-2012 with the objective of studying the effect of different biofertilizers on growth, yield and quality in tomato. The materials used and methods adopted for the study are described in this chapter.

3.1. EXPERIMENTAL SITE

3.1.1. Location

The field experiment was laid out in the research farm of Department of Olericulture, located at an altitude of 22.25 m above MSL at 10^{o} 32'N latitude and 76^{o} 16'E longitude.

3.1.2. Climate and soil

The region enjoys a warm humid tropical climate. The site has a well drained laterite loam soil. The data on maximum and minimum rainfall and relative humidity during the entire cropping period, collected from the Meteorological Observatory of College of Horticulture, Vellanikkara and are presented as weekly averages and weekly totals (Appendix I).

3.1.3. Season

The crop was raised from July, 2011 to November, 2011.

3.2. MATERIALS

3.2.1. Variety

Anagha, a bacterial wilt and crack resistant variety of tomato developed by Kerala Agricultural University was selected for the study (Plate 1).

3.2.2. Biofertilizers

Three biofertilizers, viz. *Azospirillum*, AMF and *Frateuria* were used at different combinations along with farm yard manure (FYM) and with or without chemical fertilizers constituted different treatments. Commercial talc formulation of *Azospirillum* and soil based formulation of AMF were purchased from College of Agriculture, Vellayani. Liquid formulation of potassium mobilizer, *Frateuria aurantia*,

Plate 1: Anagha

commercially known as Symbion-K was obtained from T. Stanes and Company, Coimatore (Plate 2).

3.2.3. Organic manures

Farm yard manure containing N, P_2O_5 and K_2O at 1: 0.5 : 1 percentage was used.

3.2.4. Inorganic fertilizers

Urea (46 %), Factamphos (20 % N and 20 % P_2O_5) and Muriate of Potash (60 % K_2O) were used as sources of chemical fertilizers.

3.3. METHODS

3.3.1. Layout and experimental design

The experiment was laid out in Randomised Block Design (RBD) with three replications. The size of plot was 3.0 m x 3.0 m. There were 25 plants in a plot with 5 rows of 5 plants each. Spacing adopted was 60 x 60 cm. The manurial and fertilizer doses were based on the Package of Practices recommendations (KAU, 2011) for tomato. Accordingly, FYM at 25 tonnes and N: P_2O_5: K_2O at 75: 40: 25 kg ha^{-1} were applied.

3.3.2 Treatments

T1 - FYM +*Azospirillum* @ 2 kg ha^{-1}

T2 - FYM + AMF @ 2 kg ha^{-1}

T3 - FYM + *Frateuria* @ 2 kg ha^{-1}

T4 - FYM + *Azospirillum* + AMF each @ 2 kg ha^{-1}

T5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha^{-1}

T6 - FYM + AMF + *Frateuria* each @ 2 kg ha^{-1}

T7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha^{-1}

T8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha^{-1}

T9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T10 - Manures and fertilizers as per POP recommendation (control)

Note: Mulching was provided in all the treatments.

3.4. FIELD EXPERIMENT

3.4.1. Nursery

The nursery was raised in pots of 5 kg capacity, and filled with soil, sand and FYM at the ratio 1:1:1. Seeds were coated with *Azospirillu*m and *Frateuria.* Shade dried seeds were sown in 30 pots. AMF inoculum was mixed with the potting mixture as per package of practice recommendations (KAU, 2011) (Plate 3).

3.4.2. Land preparation and planting

The experimental area was ploughed twice, weeds were removed and the land was levelled before the layout of treatments. Ridges were taken at 60 cm apart, and 30 days old seedlings were transplanted in furrows at a spacing of 60 cm.

3.4.3. Application of biofertilizers

3.4.3.1. Nursery

One third of the recommended rate of biofertilizers were applied in nursery. Seeds were dipped in rice gruel and then coated with *Azospirillum* and *Frateuria.* The seeds were shade dried for 20 minutes and sown in pots. AMF was applied in the pots after mixing with FYM at a ratio of 1:25 (KAU, 2011) (Plate 4).

3.4.3.2. Field

Two third of the biofertilizers were applied at the time of transplanting. Root dipping of the seedlings was followed for inoculation of *Azospirillum* and *Frateuria* (Plate 5). AMF was mixed with FYM in the ratio 1:25 and placed in small pits into which seedlings were transplanted. Mulching was provided in all the treatments (Plate 5).

3.4.4. After cultivation

Hand weeding was done regularly to keep the field free of weeds. Light earthing up was done along with top dressing of fertilizers. Irrigation was done at alternate days. Staking was given to the plants.

3.4.5. Plant protection

Biocontrol agents like *Pseudomonas fluorescens* (10 g l^{-1}) and the botanical Econeem (3 ml l^{-1}) were applied as and when required.

3.4.6 Harvesting

Fruits were harvested at turning stage.

3.5. BIOMETRICAL OBSERVATIONS

For taking observations five plants per plot were tagged and the following observations were recorded.

3.5.1. Growth parameters

3.5.1.1. Days to germination

The number of days from sowing to germination was recorded.

3.5.1.2. Plant height (cm)

The height of five plants was recorded at 15, 30, 45 and 60 DAT and the average was taken. The measurement was done from the base of the stem to the growing tip of the plants.

3.5.1.3. Number of leaves

Number of leaves of five plants per plot was counted at 30, 45 and 60 DAT.

3.5.1.4. Number of branches

Number of branches was counted at 30, 45 and 60 DAT in five plants per plot and the average was taken.

3.5.2. Earliness

3.5.2.1. Days to first flower

The number of days taken from transplanting to opening of the first flower in each plot was recorded.

3.5.2.2. Days to first harvest

The number of days taken from transplanting to first harvest of the fruits in each plot was recorded.

3.5.3. Biometric characteristics of fruit

3.5.3.1. Average fruit weight (g)

Total weight of the fruits from ten plants per plot at second and third harvest was recorded and divided by the total number of fruits to get the average fruit weight.

Plate 2: Biofertilizers

Plate 3: Nursery

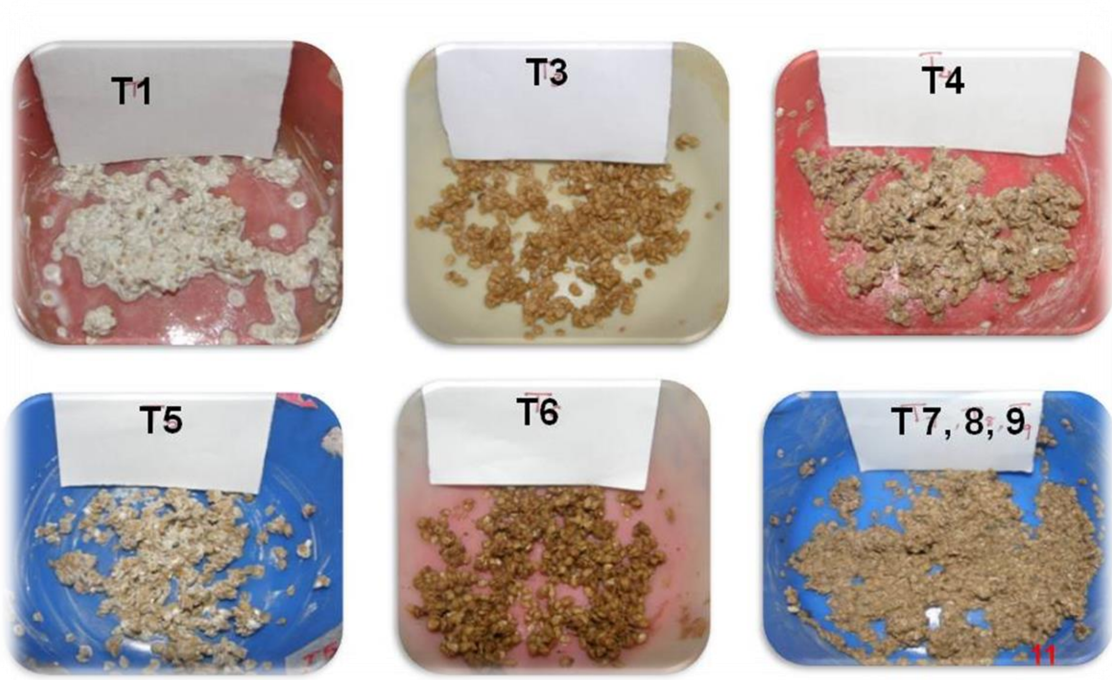


Plate 4: Seed coating of biofertilizers

Plate 5: Seedling dip of biofertilizers

Plate 6: Field view

Plate 7: Mulching

3.5.3.2. Fruit girth (cm)

Five fruits from each observation plant were taken and the diameter of fruits was determined using a thread. The thread was wound around the middle portion of the fruits and the length of the thread was measured on a metre scale. The average girth of five fruits were taken.

3.5.3.3. Fruit volume (cm3)

The volume of five average sized fruits per plot at second and third harvest was recorded using water displacement method by immersing them in one litre measuring jar and average was calculated to get the volume of fruits.

3.5.3.4. Locules per fruit

Locules per fruit were counted from the cross-section of five fruits.

3.5.3.5. Number of seeds per fruit

Number of seeds from five fruits per plot was counted and their average was calculated to get the number of seeds per fruit.

3.5.4. Yield and yield attributes

3.5.4.1. Number of fruits per plant

Total number of fruits from five plants per plot at each harvest was counted and their average was calculated to get the number of fruits per plant. This was then summed up to get the number of fruits per plant.

3.5.4.3. Fruit yield per plant (g)

Weight of fruits from five plants per plot was recorded after each harvest and the average was calculated from the total to get fruit yield per plant.

3.5.4.4. Fruit yield per plot (kg/ 9m2)

Weight of the fruits from each plot after each harvest was recorded and added to get the total yield per plot.

3.5.4.5. Percentage of cracked fruits

The number of cracked fruits among the total fruits was counted and expressed in percentage.

3.5.4.6. Number of harvests

Total number of harvests from each plot was recorded

3.5.4.7. Duration of crop (days)

Time taken for completion of crop for each treatment was recorded separately and expressed as days.

3.5.5. Biochemical characters of fruit

3.5.5.1. Total soluble solids (°Brix)

Total soluble solids was measured using a pocket refractometer and was expressed in degree brix.

3.5.5.2. Ascorbic acid content (mg/100 g)

Ascorbic acid content of fruits at turning stage was estimated by titration with 2,6-dichlorophenol indophenol dye (Sadasivam and Manickam, 1991). The value was expressed as mg 100 g^{-1} fruit.

3.5.5.3. Shelf life (Days)

Harvested fruits from each treatment and replication were kept at room temperature for 20 days under open condition. The keeping quality was assessed as per visual observations.

3.5.6 Chemical analysis

3.5.6.1. Nutrient Analysis of plant

Nutrient analysis was done after the completion of the crop. Representative samples of plant parts were taken from each treatment. It was washed and dried in shade and then oven dried at 80±5°C. The dried samples were ground, mixed and chemically analysed for N, P, K and Ca.

3.5.6.1.1. Nitrogen (%)

Samples (0.2 g) were digested using H_2SO_4 and digestion mixture (K_2SO_4 + $CuSO_4$). The nitrogen content in the samples was estimated using Micro Kjeldahl method (Jackson, 1958).

3.5.6.1.2. Phosphorus (%)

Samples (0.2 g) were digested using diacid mixture of nitric acid and perchloric acid taken in the ratio of 9:4. Finally phosphorus was estimated using Vanadomolybdophosphoric yellow colour method (Jackson, 1958). The intensity of yellow colour was read in the spectrophotometer at 470 nm.

3.5.6.1.3. Potassium (%)

From the digested sample as mentioned above, an aliquot was prepared and potassium content was estimated using flame photometer (Jackson, 1958).

3.5.6.1.4. Fruit calcium (%)

Calcium content of fruit was estimated by Atomic Absorption Spectrophotometer (Jackson, 1958).

3.5.6.1.5. Plant uptake of N, P and K (kg ha^{-1})

The total uptake of N, P and K by the plants was calculated as the product of per cent content of nutrients in the plant samples and respective dry weight of plant parts, and expressed in kg/ha.

3.5.6.2. Soil analysis

Soil samples were collected before the experiment, at 45 DAT and at 90 DAT. The air dried samples were analysed to estimate the status of organic carbon, available nitrogen, available phosphorus, available potassium, pH and electrical conductivity using the methods as given in Table 1.

3.5.7. Enumeration of *Azospirillum* and *Frateuria* in the rhizosphere soil

Enumeration of *Azospirillum* and *Frateuria* in rhizosphere soil was carried out before treatment, 45 DAT and at final harvest.

3.5.7.1. Azospirillum* sp. and *Frateuria aurantia

Serial dilution and plate count technique (Johnson and Curl, 1972) was used for enumeration of *Azospirillum* sp. and *Frateuria aurantia* in rhisosphere soil. Modified Okon's media (Appendix II) was used for *Azospirillum* (Lakshmikumari *et al.,* 1980) and Glucose- yeast extract- $CaCO_3$ Agar was used for *Frateuria* (Lisdiyanti *et al.*, 2003) (Appendix III).

Table1: Methods used for soil analysis

Parameter	Method	Reference
Organic carbon (%)	Chromic acid wet digestion method	Walkley and Black (1934)
Available N (kg/ha)	Alkaline permanganate method	Subbiah and Asija (1956)
Available P_2O_5 (kg/ha)	Bray extraction and photoelectric colorimetry	Bray and Kurtz (1945)
Available K_2O (kg/ha)	Neutral normal ammonium acetate method	Jackson, 1958
pH	pH meter	Jackson, 1958
Electrical conductivity (dS/m^{-1})	Conductivity meter	Jackson, 1958

3.6. Incidence of pests and diseases

Observations on the incidence of major pests and diseases recorded. The percentage of pest and disease incidence was calculated using the following formula

$$\text{Percentage of disease incidence} = \frac{\text{No of plants affected by the disease}}{\text{Total no. of plants}} \times 100$$

$$\text{Percentage of pest infestation} = \frac{\text{No of plants affected by the insect}}{\text{Total no. of plants}} \times 100$$

3.7. Economics of cultivation

Economics of production was calculated by including all aspects of cost of cultivation and the income generated from the treatments.

$$\text{B:C ratio} - \frac{\text{Gross Income}}{\text{Total cost of cultivation}}$$

3.8. Statistical analysis

Data relating to each character was analysed by applying the Analysis of Variance (ANOVA) and the means were compared using Duncan's Multiple Range Test (DMRT). MSTATC was used for computation and analysis of data (Panse and Sukhatme, 1978).

Results

4. RESULTS

The experiment on 'Efficacy of biofertilizers in tomato (*Solanum lycopersicum* L.) was conducted at the Department of Olericulture, College of Horticulture, Vellanikkara, Thrissur during 2011- 2012. The tomato variety 'Anagha,' released from Kerala Agricultural University was selected for the study. Commercial formulations of *Azospirillum*, AMF and *Frateuria aurantia* were used in 10 treatment combinations. The control treatment was the POP recommendation of Kerala Agricultural University. The results obtained are presented below after analysing statistically.

4.1. Growth parameters

The results related to growth parameters are given in Table 2 to 5.

4.1.1. Days to germination

The days to germination varied from 4 to 4.6 days but were found to be non-significant between treatments (Table 2).

4.1.2. Height of plant (cm)

Plant height as influenced by different biofertilizers at 15, 30, 45 and 60 DAT is presented in the Table 3.

Plant height at 15, 30, 45 and 60 DAT showed significant differences. At 15 DAT, T9 (FYM + NPK + AZ + AMF + FR) and T7 (FYM + AZ + AMF + FR) showed maximum height (30.66 cm and 30.56 cm). The treatment T8 (FYM + ½ NPK + AZ + AMF + FR) was on par with T9 and T7.

At 30 DAT, plants treated with T9 produced taller plants with 60.77 cm followed by T8 (57.77 cm) and T7 (57.37 cm). Control plants recorded a height of 51.20 cm and were on par with T1 (49.41 cm), T2 (51.35 cm), T4 (50.93 cm), T5 (49.27 cm) and T6 (51.25 cm). The shortest plants were seen in the treatment T3 with 33.22 cm.

Table 2: Effect of treatments on days to germination.

Treatments	**Days to germination**
T_1- FYM + AZ	4.00 [a]
T_2 - FYM +AMF	4.66 [a]
T_3 - FYM +FR	4.00 [a]
T_4 - FYM +AZ+AMF	4.33 [a]
T_5 - FYM +AZ+FR	4.66 [a]
T_6- FYM +AMF+FR	4.66 [a]
T_7- FYM +AZ+AMF+FR	4.00 [a]
T_8- FYM + ½ NPK + AZ + AMF + FR	4.00 [a]
T_9- FYM +NPK+AZ+AMF+FR	4.33 [a]
T_{10}- FYM + NPK (Control)	4.33 [a]

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

Table 3: Effect of treatments on plant height at different growth stages.

Treatments	Plant height (cm)			
	15 DAT	30 DAT	45 DAT	60 DAT
T_1- FYM + AZ	26.46 ^{cd}	49.41 ^{c}	70.40 ^{e}	82.66 ^{e}
T_2 - FYM +AMF	28.26 ^{bc}	51.35 ^{c}	70.82 ^{e}	87.75 ^{cd}
T_3 - FYM +FR	24.13 ^{e}	33.22 ^{d}	65.00 ^{f}	65.06 ^{f}
T_4 - FYM +AZ+AMF	27.26 ^{cd}	50.93 ^{c}	72.85 ^{d}	91.26 ^{b}
T_5 - FYM +AZ+FR	25.86 ^{de}	49.27 ^{c}	64.66 ^{f}	86.67 ^{cd}
T_6- FYM +AMF+FR	25.40 ^{de}	51.25 ^{c}	66.40 ^{f}	86.00 ^{d}
T_7- FYM +AZ+AMF+FR	30.56 ^{a}	57.37 ^{b}	75.50 ^{bc}	92.92 ^{b}
T_8- FYM +1/2NPK+ AZ+AMF+FR	29.33 ^{ab}	57.77 ^{b}	76.56 ^{b}	96.18 ^{a}
T_9- FYM +NPK+AZ+AMF+FR	30.66 ^{a}	60.77 ^{a}	79.20 ^{a}	88.17 ^{c}
T_{10}- FYM + NPK (Control)	26.78 ^{cd}	51.20 ^{c}	74.43 ^{cd}	83.07 ^{e}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

At 45 DAT, T9 (FYM + NPK + AZ + AMF + FR) produced taller plants (79.20 cm) followed by T8 (FYM + ½ NPK + AZ + AMF + FR) with 76.56 cm and were on par with T7 (75.50 cm). Control plants reached a height of 74.43 cm. The lowest plant height was obtained in T6 (66.40 cm), T3 (65.00) and T5 (64.66 cm).

At 60 DAT, a differential response in plant height was noticed among treatments. T8 (FYM + ½ NPK + AZ + AMF + FR) recorded significantly higher plant height of 96.18 cm followed by T7 (FYM + AZ + AMF + FR) and T4 (FYM + AZ + AMF) with 92.92 cm and 91.26 cm respectively. The treatment T3 (FYM + FR) recorded the minimum height (65.06 cm). Control plants recorded a height of 83.07 cm and were on par with T1 (82.66 cm).

4.1.3. Number of leaves

The effect of various treatments on number of leaves at 30, 45 and 60 DAT is given in Table 4.

Leaf number at 30, 45 and 60 DAT showed significant differences. At 30 DAT treatment T9 (FYM + NPK + AZ + AMF + FR) produced maximum number of leaves (15.16). No significant differences were noticed between treatments T2 (FYM + AMF), T8 (FYM + ½ NPK + AZ + AMF + FR), T7 (FYM + AZ + AMF + FR) and T1 (FYM + AZ). The treatment T3 (FYM + FR) produced minimum number of leaves (8.17).

At 45 DAT, T9 (FYM + NPK + AZ + AMF + FR) produced maximum number of leaves (35.08) followed by T7 (FYM + AZ + AMF + FR) with 31.40. No significant difference was noticed between T4 (FYM + AZ + AMF) and T10 (FYM + NPK) and was on par with T8 (FYM + ½ NPK + AZ + AMF + FR).

At 60 DAT also, the plants treated with T9 (FYM + NPK + AZ + AMF + FR) recorded the highest number of leaves (52.58). This was followed by treatments T7 (FYM + AZ + AMF + FR) and T8 (FYM + ½ NPK + AZ + AMF + FR) with values 47.75 and 46.65 respectively. Control plants (45.73) were on par with T7 and T8.

Table 4: Effect of treatments on number of leaves at different growth stages.

Treatments	No. of leaves		
	30 DAT	**45 DAT**	**60 DAT**
T_1- FYM + AZ	12.06 ^{b}	25.33 ^{e}	43.52 ^{cd}
T_2 - FYM +AMF	12.50 ^{b}	25.50 ^{e}	35.00 ^{f}
T_3 - FYM +FR	8.17 ^{e}	20.23 ^{f}	25.35 ^{g}
T_4 - FYM +AZ+AMF	10.26 ^{c}	30.92 ^{bc}	43.68 ^{cd}
T_5 - FYM +AZ+FR	10.55 ^{c}	29.66 ^{c}	42.16 ^{de}
T_6- FYM +AMF+FR	9.23 ^{d}	27.66 ^{d}	39.82 ^{e}
T_7- FYM +AZ+AMF+FR	12.1 ^{b}	31.40 ^{b}	47.75 ^{b}
T_8- FYM +1/2NPK+ AZ+AMF+FR	12.33 ^{b}	29.66 ^{c}	46.65 ^{b}
T_9- FYM +NPK+AZ+AMF+FR	15.16 ^{a}	35.08 ^{a}	52.58 ^{a}
T_{10}- FYM + NPK (Control)	10.55 ^{c}	30.23 ^{bc}	45.73 ^{bc}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

The highest number of leaves was observed in T9 (FYM +NPK+AZ+AMF+FR) and the least was observed in T3 (FYM + FR) in all cases.

4.1.4. Number of branches

The data on the effect of various treatments on the number of branches at 30, 45 and 60 DAT are given in Table 5.

There was significant variation with respect to the number of branches at different growth stages. At 30 DAT, maximum number of branches (5.08) was recorded for T7 (FYM + AZ + AMF + FR). But this was statistically on par with T9 (FYM + NPK + AZ + AMF + FR) (4.40). Control plants (FYM + NPK) produced 3.35 branches and were on par with T8 (FYM + ½ NPK + AZ + AMF + FR) and T6 (FYM + AMF + FR).

At 45 DAT, plants treated with T7 (FYM + AZ + AMF + FR) recorded maximum number of branches (8.78) and this was on par with T4 (FYM + AZ + AMF). Plants which received FYM and *Frateuria* produced the least number of branches (3.56).

At 60 DAT also maximum number of branches was observed in T7 (12.00) (FYM + AZ + AMF + FR). This was followed by T4 (FYM + AZ + AMF) with 11.26 branches. The treatments T6 - FYM + AZ + FR (10.02), T10 - FYM + NPK (9.85), T8 - FYM + ½ NPK + AZ + AMF + FR (9.67) andT9 - FYM + NPK + AZ + AMF + FR (9.42) were on par.

4.2. Earliness of the crop

The data pertaining to various characters relating to earliness are given in Table 6.

Table 5: Effect of treatments on number of branches at different growth stages.

Treatments	Number of branches		
	30 DAT	45 DAT	60 DAT
T_1- FYM + AZ	2.56 ^{cd}	7.06 ^{cd}	8.36 ^{d}
T_2 - FYM +AMF	1.68 ^{e}	5.30 ^{f}	7.28 ^{e}
T_3 - FYM +FR	1.58^{e}	3.56 ^{g}	4.08 ^{f}
T_4 - FYM +AZ+AMF	3.08 ^{bc}	8.08 ^{ab}	11.26 ^{b}
T_5 - FYM +AZ+FR	2.16 ^{de}	6.38 ^{de}	7.63 ^{e}
T_6- FYM +AMF+FR	3.35^{b}	7.46^{bc}	10.02 ^{c}
T_7- FYM +AZ+AMF+FR	5.08^{a}	8.78 ^{a}	12.00 ^{a}
T_8- FYM + ½ NPK+ AZ+AMF+FR	3.42^{b}	7.46 ^{bc}	9.67 ^{c}
T_9- FYM +NPK+AZ+AMF+FR	4.40^{a}	7.63 ^{bc}	9.42 ^{c}
T_{10}- FYM + NPK (Control)	3.35^{b}	5.85 ^{ef}	9.85 ^{c}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

Table 6: Effect of treatments on earliness of the crop

Treatments	Days to first flower opening	Days to first harvest
T_1- FYM + AZ	35.50 [a]	64.00 [b]
T_2 - FYM +AMF	28.83 [e]	60.53 [c]
T_3 - FYM +FR	36.33[a]	68.00 [a]
T_4 - FYM +AZ+AMF	31.83 [cd]	62.83 [b]
T_5 - FYM +AZ+FR	33.33[b]	63.93 [b]
T_6- FYM +AMF+FR	31.66 [d]	68.00 [a]
T_7- FYM +AZ+AMF+FR	28.50 [e]	60.33 [c]
T_8- FYM +1/2NPK+ AZ+AMF+FR	33.16 [b]	64.33 [b]
T_9- FYM +NPK+AZ+AMF+FR	31.50 [d]	60.86 [c]
T_{10}- FYM + NPK (Control)	33.00 [bc]	63.10 [b]

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

4.2.1. Days to first flower opening

There was significant difference between treatments with respect to days to first flower opening. The least number of days taken for flowering was recorded in T7 (FYM + AZ + AMF + FR) with 28.83 days and T2 (FYM + AMF) with 28.83 days. Maximum number of days taken for flowering was noticed for T1 (FYM + AZ) and T3 (FYM + FR) with 35.50 and 36.33 days respectively. The control plants took 33 days for flowering.

4.2.2. Days to first harvest

There was significant difference among treatments with respect to days to first harvest. The treatments T7 (FYM + AZ + AMF + FR), T2 (FYM + AMF) and T9 (FYM + NPK + AZ + AMF + FR) recorded early harvests with 60.33, 60.53 and 60.86 days respectively. T3 - FYM + FR (68.00) and T6 - FYM + AMF + FR (68.00) recorded the maximum days to first harvest.

4.3. Biometric characteristics of fruit

Statistical analysis revealed that there were significant differences among the treatments for the fruit weight**,** volume, girth, flesh thickness and number of seeds. Mean value of various biometrical characteristics of tomato fruits are given in Tables 7 and 8.

4.3.1. Average fruit weight (g)

Average fruit weight showed significant differences among treatments. The highest average fruit weight was obtained in T7 (FYM + AZ + AMF + FR) with 34.15 g. It was followed by T9 (FYM + NPK + AZ + AMF + FR) with 29.93 g and control with 29.70 g. The lowest fruit weight was recorded in T3 (FYM + FR) (24.16 g).

Table 7: Effect of treatments on biometric characteristics of fruits

Treatments	Fruit weight (g)	Fruit girth (cm)	Average fruit volume (cm^3)
T_1- FYM + AZ	26.80 ^{d}	12.32 ^{d}	28.40 ^{e}
T_2 - FYM +AMF	26.26 ^{d}	12.44 ^{d}	28.40 ^{e}
T_3 - FYM +FR	24.16 ^{e}	11.15 ^{e}	26.13 ^{f}
T_4 - FYM +AZ+AMF	29.26 ^{bc}	13.14 ^{bc}	31.43 ^{d}
T_5 - FYM +AZ+FR	28.23 ^{c}	12.87 ^{bcd}	31.23 ^{d}
T_6- FYM +AMF+FR	28.30 ^{c}	12.94 ^{bcd}	29.61 ^{e}
T_7- FYM +AZ+AMF+FR	34.15 ^{a}	15.31 ^{a}	38.20 ^{a}
T_8- FYM + ½ NPK+ AZ+AMF+FR	28.60 ^{c}	12.80 ^{cd}	31.66 ^{cd}
T_9- FYM +NPK+AZ+AMF+FR	29.93 ^{b}	13.54 ^{b}	33.80 ^{b}
T_{10}- FYM + NPK (Control)	29.70 ^{b}	13.16 ^{bc}	33.10 ^{bc}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

Table 8: Effect of treatments on biometric characteristics of fruits

Treatments	Flesh thickness (mm)	Number of locules/fruit	Number of seeds
T_1- FYM + AZ	2.93 ^{d}	4.16 ^{cd}	108.33 ^{d}
T_2 - FYM +AMF	3.43 ^{a}	3.50 ^{e}	97.16 ^{ef}
T_3 - FYM +FR	2.72 ^{e}	2.76 ^{f}	94.78 ^{f}
T_4 - FYM +AZ+AMF	3.12 ^{bc}	4.03 ^{cde}	115.33 ^{c}
T_5 - FYM +AZ+FR	2.89 ^{d}	4.50 ^{bc}	109.50 ^{d}
T_6- FYM +AMF+FR	3.25 ^{b}	3.80 ^{de}	102.50 ^{e}
T_7- FYM +AZ+AMF+FR	3.27 ^{ab}	5.16 ^{a}	136.75 ^{a}
T_8- FYM + ½ NPK+ AZ+AMF+FR	3.19 ^{b}	4.93 ^{ab}	113.23 ^{cd}
T_9- FYM +NPK+AZ+AMF+FR	3.18 ^{b}	5.00 ^{ab}	122.13 ^{b}
T_{10}- FYM + NPK (Control)	2.99 ^{cd}	5.00 ^{ab}	123.30 ^{b}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

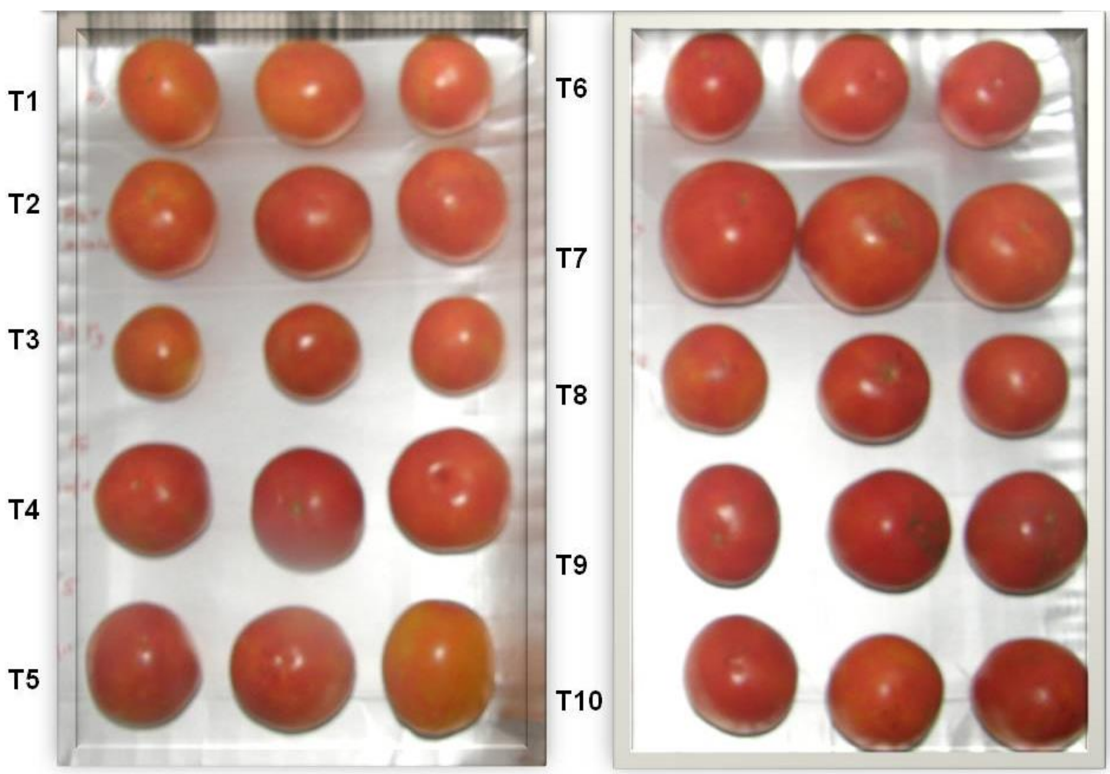


Plate 8: Comparison of fruits harvested from different experimental plots

4.3.2. Average fruit girth (cm)

The treatments differed significantly in case of average fruit girth. The maximum fruit girth was observed in T7 (FYM + AZ + AMF + FR) with 15.31 cm. It was followed by T9 (FYM + NPK + AZ + AMF + FR) with 13.54 cm which was on par with T10 (13.16 cm), T4 (13.14 cm), T6 (12.94 cm) and T5 (12.87 cm). The lowest value of 11.15 cm was noticed in T3 (FYM + FR).

4.3.3. Average fruit volume (cm3)

There was significant difference between treatments with respect to average fruit volume. The maximum fruit volume was noticed in T7 (FYM + AZ + AMF + FR) (38.20 cm3). It was followed by T9 (FYM + NPK + AZ + AMF + FR) with 33.80 cm3 which was on par with T10. The lowest fruit volume was recorded in T3 (FYM + FR) (26.13 cm3).

4.3.4. Flesh thickness (mm)

There were significant differences between treatments with respect to flesh thickness. The maximum flesh thickness was recorded in T2 (FYM + AMF) with 3.43 mm. It was followed by T7 - FYM + AZ + AMF + FR (3.27 mm) which was on par with T6 - FYM + AMF + FR (3.25 mm), T8 - FYM + ½ NPK + AZ + AMF + FR (3.19 mm), T9 - FYM + NPK + AZ + AMF + FR (3.18 mm) and T4 - FYM + AZ + AMF (3.12 mm). The lowest flesh thickness was registered in T3 (FYM + FR) with 2.72 mm.

4.3.5. Number of locules per fruit

The treatments differed significantly in terms of number of locules per fruit. The treatment T7 (FYM + AZ + AMF + FR) recording the maximum locules of 5.16 was on par with T9 - FYM + NPK + AZ + AMF + FR (5.00), T10 - FYM + NPK (5.00) and T8 - FYM + ½ NPK + AZ + AMF + FR (4.93). The treatment T3 (FYM + FR) registered the lowest value of 2.72.

4.3.6. Number of seeds per fruit

Number of seeds per fruit showed significant differences between treatments. The treatment T7 (FYM + AZ + AMF + FR) recorded the maximum seed number of 136.75 followed by T10 - FYM + NPK (123.30) and T9 - FYM + NPK + AZ + AMF + FR (122.13). The minimum number of seeds per fruits was recorded in T3 (FYM + FR) with 94.78 and was on par with T2 - FYM + AMF (97.16).

4.4. Yield characteristics

The data on the effect of various treatments on yield parameters of fruits are given in Tables 9 and 10.

4.4.1. Number of fruits per plant

Number of fruits per plant showed differences among the treatments studied. The treatment T9 (FYM + NPK + AZ + AMF + FR) produced the highest number (28.16) of fruits followed by T8 (FYM + ½ NPK + AZ + AMF + FR) with 24.46 fruits. Control plants produced 22.36 fruits. The lowest number of fruits per plant (11.75) was observed in T3 (FYM + FR) (Plate 9^{-1}1).

4.4.2. Yield per plant (g)

Treatments showed significant differences. The highest yield per plant (814.70 g) was recorded in T9 (FYM + NPK + AZ + AMF + FR). It was followed by T8 - FYM + ½ NPK + AZ + AMF + FR (664.90 g) and control (629.50 g). The lowest yield of 248.00 g was recorded in treatment where FYM and *Frateuria* only applied.

4.4.3. Yield per plot (kg)

There were significant differences between treatments with respect to this character. The maximum yield per plot of 9m2 (18.73 kg) was recorded for plants with treatment T9 (FYM + NPK + AZ + AMF + FR)**.** It was followed by T8 (FYM + ½ NPK

T1

T2

T3

Plate 9: Tomato plants under different treatments

T 4

T 5

T 6

Plate 10: Tomato plants under different treatments

T 7

T 8

T 9

T 10

Plate 11: Tomato plants under different treatments

Table 9: Effect of treatments on yield characteristics.

Treatments	Number of fruits plant $^{-1}$	Fruit yield plant $^{-1}$ (g)	Yield plot $^{-1}$ (kg 9m^{-2})	Yield ha^{-1} t ha^{-1}
T_1- FYM + AZ	15.70 ^{f}	385.91 ^{ef}	8.77 ^{d}	9.64 ^{f}
T_2 - FYM +AMF	14.96 ^{f}	382.13 ^{f}	8.86 ^{d}	9.84 ^{ef}
T_3 - FYM +FR	11.75 ^{g}	248.00 ^{g}	5.69 ^{e}	6.32 ^{g}
T_4 - FYM +AZ+AMF	18.63 ^{d}	519.77 ^{d}	11.94 ^{c}	13.26 ^{d}
T_5 - FYM +AZ+FR	16.00 ^{f}	421.09 ^{e}	9.65 ^{d}	10.72 ^{e}
T_6- FYM +AMF+FR	15.80 ^{f}	392.13 ^{ef}	9.00 ^{d}	10.00 ^{ef}
T_7- FYM +AZ+AMF+FR	17.35 ^{e}	556.66 ^{c}	12.76 ^{c}	14.17 ^{c}
T_8- FYM +1/2NPK+ AZ+AMF+FR	24.46 ^{b}	664.90 ^{b}	15.28 ^{b}	16.95 ^{b}
T_9- FYM +NPK+AZ+AMF+FR	28.16 ^{a}	814.70 ^{a}	18.73 ^{a}	20.80 ^{a}
T_{10}- FYM + NPK (Control)	22.36 ^{c}	629.50 ^{b}	14.47 ^{b}	16.06 ^{b}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

Table 10: Effect of treatments on yield characteristics.

Treatments	Duration of crop (days)	Number of harvests
T_1- FYM + AZ	79.33 [a]	5.10 [a]
T_2 - FYM +AMF	78.66 [a]	5.76 [a]
T_3 - FYM +FR	76.00 [a]	4.10 [a]
T_4 - FYM +AZ+AMF	79.33 [a]	5.40 [a]
T_5 - FYM +AZ+FR	78.33 [a]	5.10 [a]
T_6- FYM +AMF+FR	79.00 [a]	5.20 [a]
T_7- FYM +AZ+AMF+FR	79.66 [a]	5.86 [a]
T_8- FYM +1/2NPK+ AZ+AMF+FR	79.33 [a]	6.1 [a]
T_9- FYM +NPK+AZ+AMF+FR	79.00[a]	5.76 [a]
T_{10}- FYM + NPK (Control)	79.00 [a]	5.86 [a]

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

+ AZ + AMF + FR) (15.28 kg) and there was no significant difference observed between T8 and control. The lowest value (5.69 kg) was obtained for T3 (FYM + FR).

4.4.4. Yield per ha (t ha^{-1})

Analysis of the data on total fruit yield showed significant differences among treatments. The treatment T9 (FYM + NPK + AZ + AMF + FR) produced the highest yield (20.81 t ha^{-1}). It was followed by T8 (FYM + ½ NPK + AZ + AMF + FR) with (16.95 t ha^{-1}) and there was no significant differences observed between T8 and control plants (FYM + NPK) (16.06 t ha^{-1}). The lowest yield of 6.32 t ha^{-1} was recorded in T3 (FYM + FR).

4.4.5. Duration of the crop (days)

There was no significant difference in crop duration between treatments. It ranged from 78.33 to 79.66 days.

4.4.6. Number of harvests

There was no significant difference between the treatments. Number of harvests varied from 4.10 (T3 -FYM + FR) to 6.10 (T8 - FYM + ½ NPK + AZ + AMF + FR).

4.5. Fruit quality parameters

The data depicting the effect of various treatments on quality parameters of fruits are presented in Table 11.

4.5.1. TSS (^{0} Brix)

The highest value of 4.96 ^{o} Brix was recorded for T9 (FYM + NPK + AZ + AMF + FR). The treatment T7 (FYM + AZ + AMF + FR) recorded 4.8 ^{o} Brix which was on par with all other treatments except T3- FYM + FR (4.46 ^{o} Brix), T2 - FYM + AMF (4.40 ^{o} Brix) and T1 - FYM + AZ (4.33 ^{o} Brix).

Table 11: Effect of treatments on fruit quality parameters

Treatments	TSS (^{0} Brix)	Vitamin C (mg 100g $^{-1}$)	Shelf life (days)	Ca (%)
T_1- FYM + AZ	4.33 ^{d}	18.63 ^{c}	11.00 ^{cd}	0.295 ^{d}
T_2 - FYM +AMF	4.40 ^{cd}	21.40 ^{b}	18.66 ^{a}	0.356 ^{a}
T_3 - FYM +FR	4.46 ^{cd}	21.76 ^{b}	6.66 ^{e}	0.273 ^{e}
T_4 - FYM +AZ+AMF	4.66 ^{bc}	21.10 ^{b}	14.00 ^{b}	0.348 ^{ab}
T_5 - FYM +AZ+FR	4.53 ^{bcd}	20.90 ^{bc}	11.33 ^{cd}	0.254 ^{f}
T_6- FYM +AMF+FR	4.66 ^{bc}	22.56 ^{ab}	10.83 ^{d}	0.334 ^{abc}
T_7- FYM +AZ+AMF+FR	4.80 ^{ab}	24.66 ^{a}	12.50 ^{bcd}	0.348 ^{ab}
T_8- FYM +1/2NPK+ AZ+AMF+FR	4.60 ^{bcd}	20.36 ^{bc}	13.50 ^{bc}	0.339 ^{abc}
T_9- FYM +NPK+AZ+AMF+FR	4.96 ^{a}	21.40 ^{b}	12.50 ^{bcd}	0.354 ^{a}
T_{10}- FYM + NPK (Control)	4.60 ^{bcd}	21.40 ^{b}	8.00 ^{e}	0.323 ^{c}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

4.5.2. Vitamin C (mg/100 g)

Significant difference was noticed for vitamin C content of fruits among the treatments. The highest value of 24.66 mg/100 g was observed in T7 (FYM + AZ + AMF + FR) followed by T6 (FYM + AMF + FR) with 22.56 mg/100 g. All other treatments except T1 were on par.

4.5.3. Shelf life (days)

The shelf life of tomato fruits showed significant differences, with treatment T2 (FYM +AMF) recording the maximum days of 18.66 followed by T4 (FYM + AZ + AMF) with 14.00 and was on par with T8 - FYM + ½ NPK + AZ + AMF + FR (13.50), T7- FYM + AZ + AMF + FR (12.50) and T9 - FYM + NPK + AZ + AMF + FR (12.50) were on par. Short shelf life was observed for T3 (FYM + FR) and T10 (FYM + NPK) with 6.66 and 8.00 days respectively.

4.5.4. Calcium content (%)

Statistical analysis of the data regarding the calcium content of tomato fruits indicated that the treatments varied significantly (Table 11). Treatment T2 (FYM + AMF) and T9 (FYM + NPK + AZ + AMF + FR) recorded maximum value for calcium content i.e 0.356 and 0.354 per cent respectively. The treatments T7 (FYM + AZ + AMF + FR) and T8 (FYM + ½ NPK + AZ + AMF + FR) were on par with T2 and T9. The lowest calcium level was noticed in treatment T5 (FYM + AZ + FR) with 0.254 per cent.

4.6. Nutrient analysis of plants

Nitrogen, phosphorus and potassium content of plant parts were separately analysed and are presented in Tables 12 to 14.

Table 12: Effect of treatments on nutrient content of tomato fruits

Treatments	Nutrient content (%)		
	Nitrogen	Phosphorus	Potassium
T_1- FYM + AZ	2.54 ^{fg}	0.256 ^{b}	2.47 ^{e}
T_2 - FYM +AMF	2.63 ^{ef}	0.264 ^{b}	2.79 ^{ab}
T_3 - FYM +FR	2.48 ^{g}	0.194 ^{d}	2.83 ^{a}
T_4 - FYM +AZ+AMF	2.68 ^{de}	0.250 ^{b}	2.57 ^{de}
T_5 - FYM +AZ+FR	2.93 ^{c}	0.246 ^{b}	2.50 ^{de}
T_6- FYM +AMF+FR	2.77 ^{d}	0.195 ^{d}	2.78 ^{ab}
T_7- FYM +AZ+AMF+FR	2.66 ^{de}	0.205 ^{cd}	2.60 ^{cd}
T_8- FYM + ½ NPK+ AZ+AMF+FR	3.27 ^{a}	0.283 ^{a}	2.58 ^{de}
T_9- FYM +NPK+AZ+AMF+FR	3.32 ^{a}	0.246 ^{b}	2.75 ^{ab}
T_{10}- FYM + NPK (Control)	3.08 ^{b}	0.214 ^{c}	2.71 ^{bc}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

4.6.1. Fruit analysis

4.6.1.1. Nitrogen (%)

Significant differences were noticed for nitrogen content of fruits among the treatments. Maximum nitrogen content was observed in T9 (FYM + NPK + AZ + AMF + FR) (3.32 %) and T8 (FYM + ½ NPK + AZ + AMF + FR) (3.27 %). The lowest value was (2.48 %) observed for T3 (FYM + NPK).

4.6.1.2. Phosphorus (%)

Treatments showed significant differences in phosphorus content of fruits. Treatment T8 (FYM + ½ NPK + AZ + AMF + FR) recorded a maximum value of 0.283 per cent. All other treatments except T10 (FYM + NPK), T7 (FYM + AZ + AMF + FR), T6 (FYM + AMF + FR) and T3 (FYM + FR) were on par.

4.6.1.3. Potassium (%)

There was significant difference between treatments with respect to potassium content of fruits. Maximum potassium content of 2.83 per cent was noticed in T3 (FYM +FR). Treatments T2 (FYM + AMF), T6 (FYM + AMF + FR) and T9 (FYM + NPK + AZ + AMF + FR) were on par with T3. The least value 2.77 per cent was recorded in T1 (FYM + AZ).

4.6.2. Leaf analysis

The effect of different treatments on the nutrient content of leaves is depicted in Table 13.

4.6.2.1. Nitrogen (%)

Significant differences were noticed for nitrogen content of leaves among the treatments. Maximum nitrogen content was observed in treatments T7 (FYM + AZ +

Table 13: Effect of treatments on nutrient content of leaves

Treatments	Nutrient content (%)		
	Nitrogen	Phosphorus	Potassium
T_1- FYM + AZ	2.80 [a]	0.206 [d]	2.81 [c]
T_2 - FYM +AMF	2.54 [b]	0.291 [a]	2.09 [f]
T_3 - FYM +FR	2.33 [c]	0.203 [d]	3.00 [b]
T_4 - FYM +AZ+AMF	2.46 [bc]	0.286 [a]	2.77 [c]
T_5 - FYM +AZ+FR	2.16 [d]	0.201 [d]	2.66 [d]
T_6- FYM +AMF+FR	2.45 [bc]	0.239 [c]	2.94 [b]
T_7- FYM +AZ+AMF+FR	2.80 [a]	0.266 [b]	3.03 [ab]
T_8- FYM +1/2NPK+ AZ+AMF+FR	2.35 [c]	0.281 [ab]	2.25 [e]
T_9- FYM +NPK+AZ+AMF+FR	2.88 [a]	0.292 [a]	3.11 [a]
T_{10}- FYM + NPK (Control)	2.13 [d]	0.277 [ab]	2.79 [c]

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

AMF + FR) (2.88 %), T9 (FYM + NPK + AZ + AMF + FR) (2.80 %), and T1 (FYM + AZ) (2.80 %). The lowest value was observed for T5 (2.16 %) and control (2.13%).

4.6.2.2. Phosphorus (%)

Treatments showed significant difference in phosphorus content of leaves. Treatment T9 (FYM + NPK + AZ + AMF + FR), T2 (FYM + AMF) and T4 (FYM + AZ + AMF) and recorded the highest value of 0.292, 0.291 and 0.286 per cent respectively. The treatments T8 (0.281%) and T10 (0.277%) were on par with the above treatments.

4.6.2.3. Potassium (%)

Treatment showed significant differences in potassium content of leaves. Maximum potassium content was noticed in T9 (FYM + NPK + AZ + AMF + FR) with 3.11 per cent. Treatment T7 (3.03 %) was on par with T9 (3.11) and T3 (3.00%).

4.6.3. Plant uptake of N, P2O5 and K_2O (kg ha^{-1})

The data indicated that there was significant variation between treatments with respect to nutrient uptake (Table 14).

Maximum uptake of nitrogen was recorded in T9 (FYM + NPK + AZ + AMF + FR) with 61.56 kg ha^{-1}. This was followed by T8 (FYM + ½ NPK + AZ + AMF + FR and T10 (FYM + NPK) with nitrogen contents of 46.76 kg ha^{-1} and 47.17 kg ha^{-1} respectively. Lowest value was recorded for T3 (17.77 kg ha^{-1}).

In the case of phosphorus uptake, the treatments varied significantly. Treatment T9 (FYM + NPK + AZ + AMF + FR) gave significantly higher value of 5.38 kg ha^{-1}. This was followed by T8 (FYM + ½ NPK + AZ + AMF + FR) with 4.68 kg ha^{-1}. The lowest uptake (1.59 kg ha^{-1}) was observed in T3 (FYM + FR).

With respect to potassium uptake, T9 (FYM + NPK + AZ + AMF + FR) recorded the maximum value of 59.26 kg ha^{-1}. It was followed by T7 (FYM + AZ +

Table 14: Effect of treatments on plant uptake of N, P_2O_5 and K_2O

Treatments	Uptake of N (kg ha^{-1})	Uptake of (P_2O_5 kg ha^{-1})	Uptake of (K_2O kg ha^{-1})
T_1- FYM + AZ	34.87 ^{d}	3.01 ^{e}	36.03 ^{d}
T_2 - FYM +AMF	29.37 ^{e}	3.23 ^{d}	28.53 ^{f}
T_3 - FYM +FR	17.77 ^{f}	1.59 ^{g}	23.43 ^{g}
T_4 - FYM +AZ+AMF	35.85 ^{d}	3.89 ^{c}	40.95 ^{c}
T_5 - FYM +AZ+FR	30.00 ^{e}	2.65 ^{f}	32.63 ^{e}
T_6- FYM +AMF+FR	30.85 ^{e}	2.68 ^{f}	35.55 ^{d}
T_7- FYM +AZ+AMF+FR	39.30 ^{c}	3.88 ^{c}	45.82 ^{b}
T_8- FYM +1/2NPK+ AZ+AMF+FR	46.76 ^{b}	4.68 ^{b}	40.70 ^{c}
T_9- FYM +NPK+AZ+AMF+FR	61.56 ^{a}	5.38 ^{a}	59.26 ^{a}
T_{10}- FYM + NPK (Control)	47.17 ^{b}	4.01 ^{c}	45.30 ^{b}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

AMF + FR) and T10 (FYM + NPK) with 45.82 kg ha^{-1} and 45.30 kg ha^{-1} respectively. The least value 23.43 was found in T3 (FYM + FR).

4.7. Soil analysis

Soil parameters *viz.*, organic carbon, available nitrogen, available phosphorus, available potassium, pH and electrical conductivity were recorded before the experiment, at 45 DAT and 80 DAT (Tables 15^{-1}7).

4.7.1. Organic carbon (%)

The initial value of organic carbon in the soil was 0.57 %. At 45 DAT the higher value (0.89 %) was observed in T3 (FYM +FR), T4 (FYM + AZ + AMF), T5 (FYM + AZ + FR), T9 (FYM + AZ + AMF + FR) and T10 (FYM + NPK). It was followed by T6, T8 and T2. The lowest value of 0.69 % observed for T7 (FYM + AZ + AMF + FR) which was on par with T1 (FYM + AZ) (0.70 %).

At 80 DAT, the treatments did not differ significantly (Table 15).

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

Significant variation was observed among different treatments with respect to the available nitrogen status of the soil at 45 DAT and 80 DAT (Table 15). At pre-planting stage, it was 84.53 kg ha^{-1}.

The highest value of available nitrogen (182.33 kg ha^{-1}) at 45 DAT was recorded in T9 (FYM + NPK + AZ + AMF + FR) which was nonsignificantly superior over T10 (FYM + NPK) and T8 (FYM + ½ NPK + AZ + AMF + FR).

At 80 DAT also, T9 (FYM +NPK+ AZ+AMF+FR) recorded highest available nitrogen (260.66 kg ha^{-1}). In both cases the lowest value was obtained in T3 (FYM + FR).

Table 15: Effect of treatments on soil parameters

Treatments	Organic Carbon (%)		Available N (kg ha^{-1})	
	45 DAT	80 DAT	45 DAT	80 DAT
T_1- FYM + AZ	0.70^{c}	0.92^{a}	159.66^{b}	189.33^{d}
T_2 - FYM +AMF	0.79^{b}	0.90^{a}	158.33^{b}	169.33^{f}
T_3 - FYM +FR	0.89^{a}	0.94^{a}	120.00^{d}	127.00^{g}
T_4 - FYM +AZ+AMF	0.89^{a}	0.87^{a}	153.00^{bc}	173.66^{ef}
T_5 - FYM +AZ+FR	0.89^{a}	0.92^{a}	146.33^{c}	189.33^{d}
T_6- FYM +AMF+FR	0.81^{b}	0.94^{a}	156.66^{b}	181.66^{de}
T_7- FYM +AZ+AMF+FR	0.69^{c}	0.87^{a}	159.66^{b}	234.33^{b}
T_8- FYM + ½ NPK+ AZ+AMF+FR	0.81^{b}	0.94^{a}	174.00^{a}	224.66^{b}
T_9- FYM +NPK+AZ+AMF+FR	0.88^{a}	0.95^{a}	182.33^{a}	260.66^{a}
T_{10}- FYM + NPK (Control)	0.87^{a}	0.92^{a}	174.66^{a}	210.00^{c}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

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

There was significant difference in available phosphorus at 45 and 80 DAT (Table 16). From the initial value (24.78 kg ha^{-1}) it increased up to 61.33 kg ha^{-1} in T9 (FYM + NPK + AZ + AMF + FR). At 45 DAT, the treatment T9 was significantly superior to all other treatment followed by T8 (56.33 kg ha^{-1}). The least value was recorded for T3 (28.41 kg ha^{-1}) and T5 (28.08 kg ha^{-1}).

At 80 DAT also the highest value of available phosphorus (59.01 kg ha^{-1}) was observed in T9 (FYM + NPK + AZ + AMF + FR) followed by T8 (FYM + ½ NPK + AZ + AMF + FR). In both cases the lowest value was observed in T3 with 22.42 kg ha^{-1}.

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

As in the case of available nitrogen and phosphorus, available potassium status of soil also increased from the initial value of 130.24 kg/ha. At 45 DAT it was the highest in T3 (FYM + FR) which recorded 178.74 kg/ha followed by T5 (FYM +AZ + FR) (175.88 kg ha^{-1}). The lowest value of 161.24 kg/ha was recorded in T2 (FYM + AMF).

At 80 DAT, highest available potassium was recorded in T3 (275.44 kg ha^{-1}). All other treatments were on par with T3.

4.7.5. pH

The initial pH reading was 5.36. It increased up to 6.63 at 45 DAT and 6.69 at 80 DAT. There was no significant variation between the treatments (Table 17).

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

There was no significant variation between the treatments at 45DAT and 80 DAT. The initial EC reading was 0.039 dS/ m. At 45 DAT the value varied between 0.010 dS/ m to 0.027 dS/m and at 80 DAT the value varied between 0.007 dS/ m to 0.025 dS/ m.

Table 16: Effect of treatments on soil parameters

Treatments	Available P_2O_5 (kg ha^{-1})		Available K_2O (kg ha^{-1})	
	45 DAT	80 DAT	45 DAT	80 DAT
T_1- FYM + AZ	32.66^{f}	29.48^{gh}	166.56^{de}	244.24^{b}
T_2 - FYM +AMF	45.94^{d}	39.42^{d}	161.24^{f}	255.90^{b}
T_3 - FYM +FR	28.41^{g}	22.42^{h}	178.74^{a}	275.44^{a}
T_4 - FYM +AZ+AMF	32.99^{f}	35.34^{e}	164.54^{ef}	255.66^{b}
T_5 - FYM +AZ+FR	57.08^{g}	35.34^{h}	175.88^{ab}	206.46^{ab}
T_6- FYM +AMF+FR	28.54^{fg}	32.35^{f}	167.58^{de}	229.68^{ab}
T_7- FYM +AZ+AMF+FR	52.49^{c}	43.45^{c}	166.56^{de}	219.90^{ab}
T_8- FYM + ½ NPK+ AZ+AMF+FR	56.33^{b}	53.92^{b}	170.34^{cd}	227.24^{ab}
T_9- FYM +NPK+AZ+AMF+FR	61.33^{a}	59.01^{a}	172.82^{bc}	226.10^{ab}
T_{10}- FYM + NPK (Control)	37.83^{e}	31.34^{fg}	169.18^{cde}	218.02^{ab}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

Table 17: Effect of treatments on soil parameters

Treatments	pH		EC (dS m^{-1})	
	45 DAT	80 DAT	45 DAT	80 DAT
T_1- FYM + AZ	6.53 [a]	6.47 [a]	0.015 [a]	0.007 [a]
T_2 - FYM +AMF	6.40 [a]	6.23 [a]	0.024 [a]	0.018 [a]
T_3 - FYM +FR	6.29 [a]	6.60 [a]	0.011 [a]	0.016 [a]
T_4 - FYM +AZ+AMF	6.57 [a]	6.50 [a]	0.013 [a]	0.010 [a]
T_5 - FYM +AZ+FR	6.63 [a]	6.69 [a]	0.010 [a]	0.008 [a]
T_6- FYM +AMF+FR	6.50 [a]	6.50 [a]	0.027 [a]	0.014 [a]
T_7- FYM +AZ+AMF+FR	6.38 [a]	6.41 [a]	0.018 [a]	0.008 [a]
T_8- FYM +1/2NPK+ AZ+AMF+FR	6.52 [a]	6.69 [a]	0.014 [a]	0.019 [a]
T_9- FYM +NPK+AZ+AMF+FR	6.47 [a]	6.43 [a]	0.015 [a]	0.025 [a]
T_{10}- FYM + NPK (Control)	6.45 [a]	6.55 [a]	0.015 [a]	0.017 [a]

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

4.8. Enumeration of inoculated microbes

The effect of different treatments on population of *Azospirillum* and *Frateuria* is given in Table 18. Considerable variation was noticed among the treatments.

4.8.1. *Azospirillum* sp (cfu g^{-1} soil)

The *Azospirillum* count showed significant differences between treatments. At 45 DAT, it increased from the initial population of 0.25 x 10^6 cfu g^{-1} to 26.93 x 10^6 cfu g^{-1} in T8 (FYM + ½ NPK + AZ + AMF + FR) which recorded the maximum population. It was followed by T9 (FYM + NPK + AZ + AMF + FR) which recorded (24.43 x 10^6 cfu g^{-1}). Minimum population was recorded in control plots (3.93 x 10^6 cfu g^{-1}).

At 80 DAT, population started to decrease. However, maximum population obtained was 17.10 x 10^6 cfu g^{-1} which is in T8 (FYM + ½ NPK + AZ + AMF + FR). It was followed by T9 (FYM + NPK + AZ + AMF + FR) (15.36 x 10^6 cfu g^{-1}). Treatments T2 (3.83 x 10^6 cfu g^{-1}), T3 (5.26 x 10^6 cfu g^{-1}), T6 (5.43 x 10^6 cfu g^{-1}) and T10 (4.66 x 10^6 cfu g^{-1}) recorded the lowest population.

4.8.1. *Frateuria aurantia* (cfu g^{-1} soil)

Frateuria aurantia population showed significant variation between treatments. The initial count of *Frateuria* was 0.32 x 10^6 cfu g^{-1} of soil. At 45 DAT, T8 (FYM + ½ NPK + AZ + AMF + FR) recorded the highest population of 24.70 x 10^6 cfu g^{-1} followed by 20.80 x 10^6 cfu g^{-1} in T3 (FYM + FR). The lowest population (3.93 x 10^6 cfu g^{-1}) was recorded in T4 (FYM + AZ + AMF) and was on par with T10 (FYM + NPK), T2 (FYM + AMF) and T1 (FYM + AZ).

At 80 DAT, T5 (FYM + AZ + FR) recorded the maximum population of 17.76 x 10^6 cfu g^{-1}. It was on par with T3 (FYM + FR), T9 (FYM + NPK + AZ + AMF + FR) and T8 (FYM + ½ NPK + AZ + AMF + FR). The lowest population of 4.50 x 10^6 cfu g^{-1} was noticed in T2 (FYM + AMF). It was on par with T10, T4 and T1.

Table 18: Effect of treatments on population of *Azospirillum* and *Frateuria* at different growth stages

Treatments	*Azospirillum* (x 10^6 cfu g^{-1} soil)		*Frateuria* (x 10^6 cfu g^{-1} soil)	
	45 DAT	80 DAT	45 DAT	80 DAT
T_1- FYM + AZ	18.56^{c}	11.83^{de}	6.33^{e}	5.16^{c}
T_2 - FYM +AMF	6.33^{f}	3.83^{f}	5.16^{e}	4.50^{c}
T_3 - FYM +FR	6.26^{f}	5.26^{f}	20.80^{b}	16.83^{a}
T_4 - FYM +AZ+AMF	13.63^{e}	12.73^{cd}	3.93^{e}	5.00^{c}
T_5 - FYM +AZ+FR	15.33^{de}	14.30^{bc}	17.66^{c}	17.76^{a}
T_6- FYM +AMF+FR	6.30^{f}	5.43^{f}	17.20^{c}	12.76^{b}
T_7- FYM +AZ+AMF+FR	16.86^{cd}	10.43^{e}	12.83^{d}	12.50^{b}
T_8- FYM +1/2NPK+ AZ+AMF+FR	26.93^{a}	17.10^{a}	24.70^{a}	15.83^{a}
T_9- FYM +NPK+AZ+AMF+FR	24.43^{b}	15.36^{ab}	19.86^{bc}	16.66^{a}
T_{10}- FYM + NPK (Control)	3.93^{g}	4.66^{f}	5.00^{e}	4.83^{c}

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

4.9. Incidence of pests and diseases

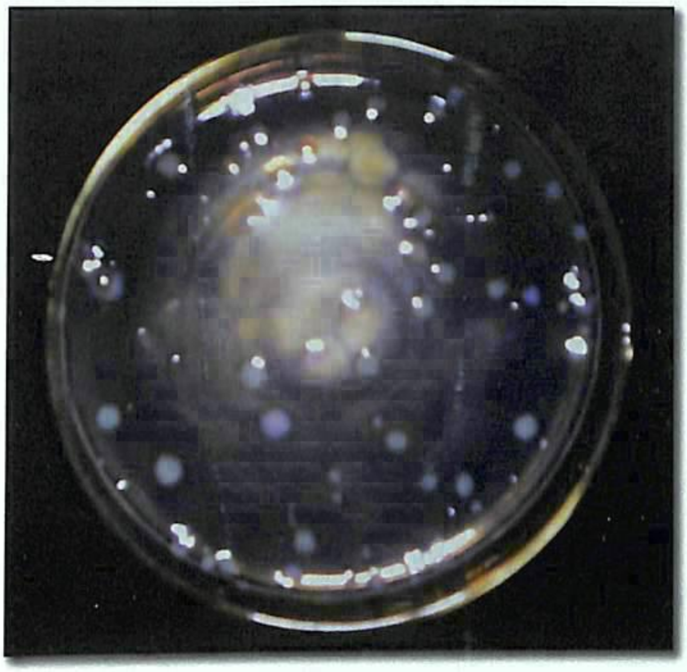
There were minor incidences of tomato spotted wilt virus (TSWV), leaf curl, bacterial wilt and damping off. TSWV incidence ranged from 4.00 to 9.33 per cent. Leaf curlvirus incidence and bacterial wilt recorded the maximum of 9.33 and 2.66 per cent respectively. In the case of damping off, maximum incidence was 12.00 per cent. All the treatments were prone to the attack of disease.

4.10. Percentage of cracked fruits (%)

Significant difference was observed for fruit cracking among the treatments (Table 20). Minimum percentage was recorded in T9 (FYM + NPK + AZ + AMF + FR) with 0.613 per cent. Maximum percentage was recorded in T5 (FYM + AZ + FR) with 2.47 per cent followed by T4 (FYM + AZ + AMF) (2.26 %).

4.11. Economics of cultivation

The highest B:C ratio of 1.76 was recorded for T9 (FYM + NPK + AZ + AMF + FR) followed by T8 (FYM + ½ NPK + AZ + AMF + FR) which recorded a B:C ratio of 1.45. The treatment T3 (FYM + FR) recorded the least value of 0.58.



Colonies of *Azospirillum* in modified Okon's medium

Colonies of *Frateuria* in Glucose- Yeast extract- $CaCO_3$ - Agar medium

Plate 12: Enumeration of inoculated microbes in rhizosphere soil

Table 19: Effect of treatments on disease incidence

Treatments	TSWV (%)	Leaf curl (%)	Bacterial wilt (%)	Damping off (%)
T_1- FYM + AZ	6.66 [a]	8.00 [a]	2.66 [a]	12.00 [a]
T_2 - FYM +AMF	4.00 [a]	6.66 [a]	2.66 [a]	4.00 [a]
T_3 - FYM +FR	6.66 [a]	6.00 [a]	2.33 [a]	12.33 [a]
T_4 - FYM +AZ+AMF	8.00 [a]	6.66 [a]	1.33 [a]	6.66 [a]
T_5 - FYM +AZ+FR	5.33 [a]	6.66 [a]	1.33 [a]	9.33 [a]
T_6- FYM +AMF+FR	4.00 [a]	9.33 [a]	1.33 [a]	6.66 [a]
T_7- FYM +AZ+AMF+FR	6.00 [a]	5.33 [a]	1.33 [a]	6.66 [a]
T_8- FYM + ½ NPK+ AZ+AMF+FR	4.00 [a]	5.33 [a]	1.33 [a]	9.33 [a]
T_9- FYM +NPK+AZ+AMF+FR	9.33 [a]	8.00 [a]	1.33 [a]	8.00 [a]
T_{10}- FYM + NPK (Control)	9.33 [a]	4.00 [a]	1.33 [a]	9.33 [a]

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

Table 20: Effect of treatments on fruit cracking

Treatments	Cracked fruit (%)
T_1- FYM + AZ	0.860 [bc]
T_2 - FYM +AMF	1.17 [abc]
T_3 - FYM +FR	1.22 [abc]
T_4 - FYM +AZ+AMF	2.26 [ab]
T_5 - FYM +AZ+FR	2.47 [a]
T_6- FYM +AMF+FR	1.79 [abc]
T_7- FYM +AZ+AMF+FR	1.62 [abc]
T_8- FYM +1/2NPK+ AZ+AMF+FR	0.860 [bc]
T_9- FYM +NPK+AZ+AMF+FR	0.613 [c]
T_{10}- FYM + NPK (Control)	2.01 [abc]

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

Table 21: Effect of treatments on economics of cultivation

Treatments	B:C ratio
T_1- FYM + AZ	1.00
T_2 - FYM +AMF	0.92
T_3 - FYM +FR	0.58
T_4 - FYM +AZ+AMF	1.21
T_5 - FYM +AZ+FR	0.88
T_6- FYM +AMF+FR	0.96
T_7- FYM +AZ+AMF+FR	1.28
T_8- FYM +1/2NPK+ AZ+AMF+FR	1.45
T_9- FYM +NPK+AZ+AMF+FR	1.76
T_{10}- FYM + NPK	1.40

Values represent average of three replications

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM +*Azospirillum* @ 2 kg ha $^{-1}$

T_2 - FYM + AMF @ 2 kg ha $^{-1}$

T_3 - FYM + *Frateuria* @ 2 kg ha $^{-1}$

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg ha $^{-1}$

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg ha $^{-1}$

T_6 - FYM + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_8 - FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$

T_9- POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}

T_{10} - Manures and fertilizers as per POP recommendation (control)

Discussion

5. DISCUSSION

A major transition is taking place in the world agriculture scenario because of the increased concern on the sustainability of modern agricultural practices. People are aware of the adverse effects of imprudent use of chemical fertilizers and pesticides on physical and chemical properties of soil. Other points of concern include the decreasing soil fertility and soil microflaura, increasing vulnerability of crops to pest and diseases, and growing concern for environment safety. At present, much attention is given to overcome this situation by popularizing the concept of integrated nutrient management. In the present investigation, the effect of three biofertilizers *viz. Azospirillum,* AMF and *Frateuria* on tomato was studied.

5.1. Growth parameters

Significant difference in plant height, number of leaves and number of branches due to treatments was noticed.

The plant height, considered to be an important factor to judge the vigour was found increased to a significant level with the application of biofertilizers (Fig. 1). Treatment effect on plant height was observed at 15, 30, 45 and 60 DAT. In the early stage, combined application of all the three biofertilizers along with FYM and full dose of NPK (T9) and all the three biofertilizers along with FYM (T7) recorded the maximum plant height of 30.66 cm and 30.56 cm. Combined application of all the three biofertilizers along with FYM and full dose of NPK (T9) produced taller plants at 30 (60.77 cm) and 45 DAT (79.20 cm). Whereas at final stage, application of all the three biofertilizers along with FYM and ½ NPK (T8) recorded the maximum height of 96.18 cm. Premsekhar and Rajasree (2009) in tomato, Singh and Singh (2007) in onion and Anisa (2011) in okra reported increased plant height when 75 per cent recommended nitrogen was applied along with biofertilizers.

Enhanced availability of nutrients along with production of some growth promoting substances might have caused cell multiplication leading to increased height (Sreenivasa, 1994). Significant increase in growth parameters due to increase in fertilizer levels could be attributed to the availability of more nitrogenous compounds to the plant from organic and inorganic sources. This might have increased the uptake of nutrient leading to increased foliage, enhanced chlorophyll content and carbohydrate, and increased activity of hormones produced by biofertilizers.

The maximum height in T8 might be due to maximum population of biofertilizers in T8 (Table 18). According to Govindarajan and Thangaraju (2001) increase in height due to *Azospirillum* can be attributed to its direct role in nitrogen fixation, increased nitrogenase activity and also due to production of phytohormones like IAA, gibberellins and cytokinin like substances (Veeraraghavathatham *et al.*, 1988). N is the chief constituent of protein, essential for the formation of protoplasm, which leads to cell enlargement, cell division and ultimately resulting in increased plant growth.

AMF increases the soil volume explored by roots for nutrient absorption and enhanced efficiency of nutrient absorption especially phosphorus, which is an important component of ATP, and it also improves water uptake (Singh *et al.*, 2010). Conversion of more photosynthetic product into protoplasm results better vegetative growth and height.

Among several morphological characters associated with yield, the maintenance of functional leaves is primarily important as it is the site of assimilate production. Leaf production, in general, is determined by both environment and nutrition. Treatment effect on number of leaves differed significantly at 30, 45 and 60 DAT (Fig. 2). Combined application of all the three biofertilizers along with FYM and full dose of NPK (T9) produced maximum number of leaves at all stages of growth. The increase in leaf number on account of all biofertilizers can be attributed to better growing

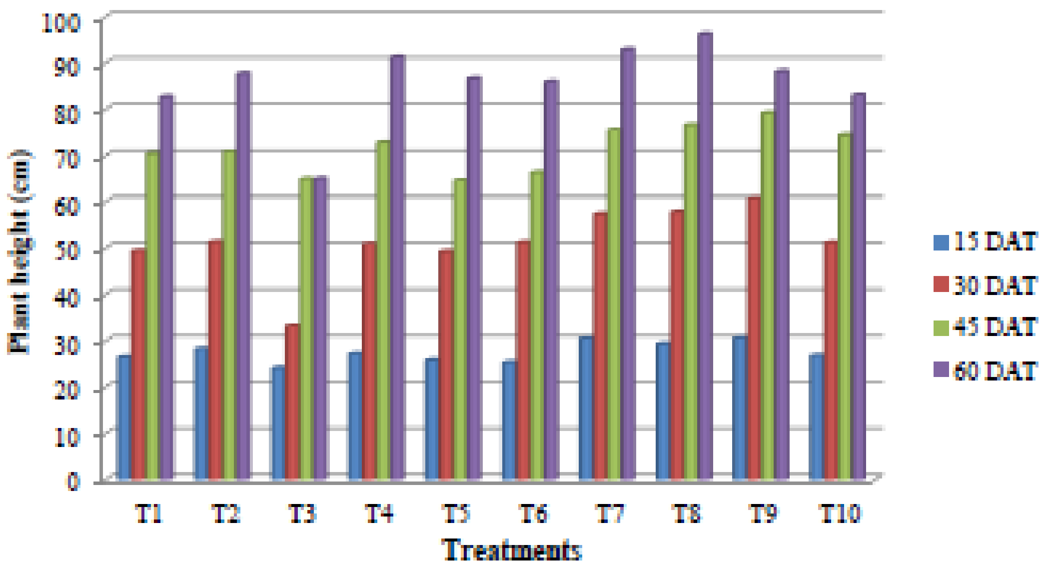


Fig. 1: Effect of treatments on plant height at different growth stages

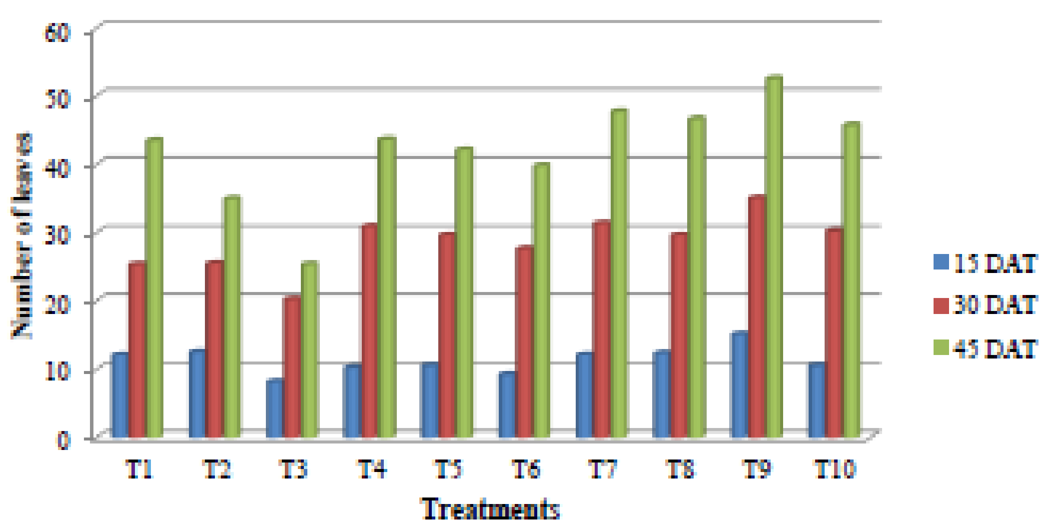


Fig. 2: Effect of treatments on number of leaves at different growth stages

conditions that prevailed in the vicinity of root zone which helped plants to absorb more water and nutrients from the soil.

Number of branches increased significantly due to the application of biofertilizers (Fig. 3). The number of branches per plant is of considerable importance and it has positive association with yield. Significant variation in number of branches was observed at 30, 45 and 60 DAT. At all these stages, application of all the three biofertilizers along with FYM (T7) recorded the maximum number of branches, 5.08 at 30 DAT, 8.78 at 45 DAT and 12.00 at 60 DAT. The change in branching habit may possibly be due to stimulation of breaking up of apical dominance, thereby changing the auxin balance which is the controlling factor (Rademacher, 1991). Hinson and Hanson (1962) have also reported that certain amount of control on apical dominance could invariably result in accelerated development of axillary buds into new branches.

5.2. Earliness

Earliness in flowering and fruiting is an indication of early transformation of plants to reproductive phase (Das and Rabha, 1999) and it is considered as a desirable character which helps the farmers to market the produce early in the season thereby fetching premium price.

Early flowering of tomato was reported to be affected by environmental, cultural or genetic factors among which light, temperature, nutrition, hormonal effect and water supply play significant roles (Kinet and Peet, 1997). In the present study days to first flower opening showed significant difference between treatments. Combined application of all the three biofertilizers along with FYM (T7) and single inoculation of AMF + FYM (T2) produced flowers much earlier (28.50 and 28.88 days respectively) than other treatments. Days to first harvest was also influenced by biofertilizer application. Combined application of all the biofertilizers along with FYM (T7), FYM and AMF (T2) and all the biofertilizers together with FYM and full dose of NPK (T9) recorded early harvests with almost 60 days respectively (Fig. 4).

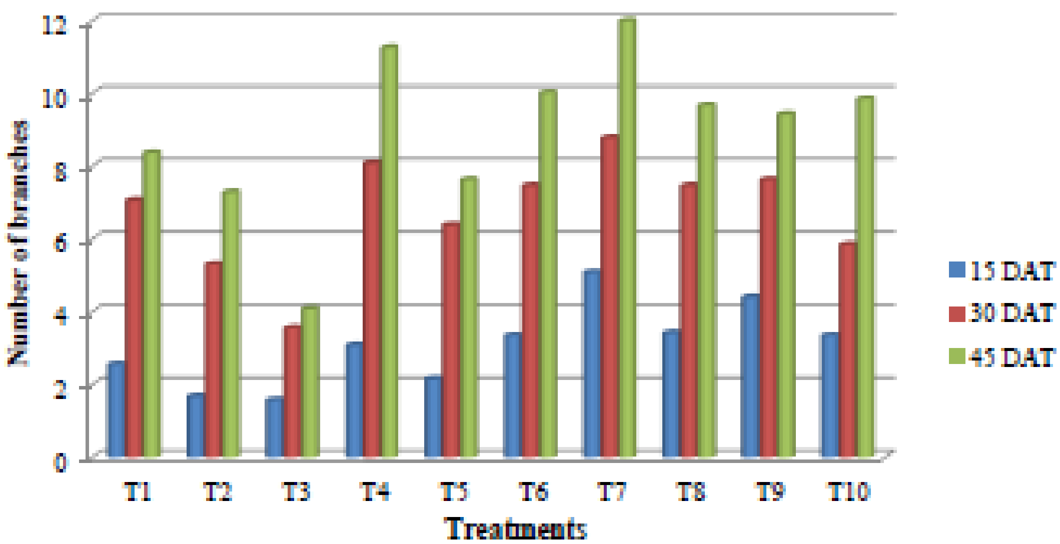


Fig. 3: Effect of treatments on number of branches at different growth stages

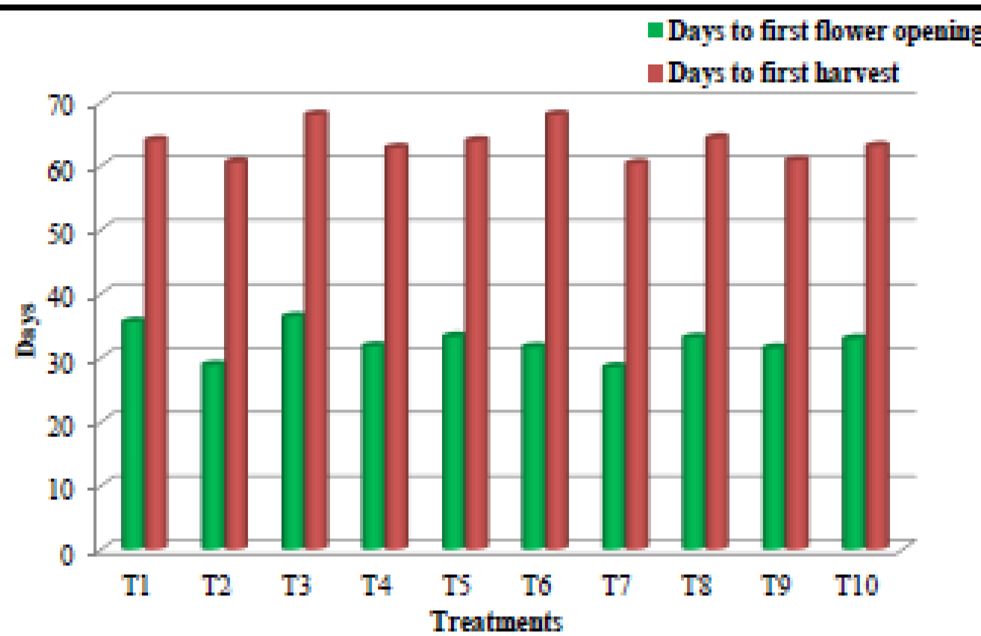


Fig. 4: Effect of treatments on earliness of the crop

Among the major nutrients, phosphorus plays a vital role in imparting earliness. Increased phosphorus uptake and secretion of various hormones by AMF may have resulted in early development of reproductive parts (Anburani and Manivannan, 2002). Increased uptake of major nutrients by all the treatments with three biofertilizers resulting in activation of bioactive substances in plants might have helped to produce more photosynthates and cytokinin. Due to the translocation of this synthesized cytokinin, more available phosphorus through xylem vessels and accumulation of these in axillary bud might have favoured the plants to enter into reproductive phase (Amritalingam and Balakrishnan, 1988). This in turn might have induced flowering stimulus, thus effecting in early initiation of flower bud. Oyetunji and Osonubi (2005) observed early flowering in chilli and Chaurasia *et al.* (2008) observed early curd initiation in cauliflower when they were inoculated with AMF.

Early maturity of fruits can be attributed to the increased uptake of nutrients in the plants leading to enhanced photosynthesis there by synthesis of carbohydrate and increased activity of hormones produced by biofertilizers. By accelerating photosynthesis and rapid translocation of these photosynthates, biofertilizers might have created a source-sink relation which resulted in early harvest.

5.3 Biometric characteristics of fruit

Biometric characteristics of fruit include fruit weight**,** volume, girth, flesh thickness, locule number and number of seeds. All these characteristics varied significantly between treatments.

Combined application of all the biofertilizers each @ 2 kg ha^{-1} along with FYM (T7) recorded maximum fruit weight (34.15 g), fruit girth (15.31 cm) and fruit volume (38.20 cm3) (Fig.5). Anisa (2011) while experimenting with okra with FYM (25 t ha^{-1}) + *Azospirillum* + AMF + *Frateuria aurantia* recorded the highest fruit weight and fruit girth.

In tomato large size fruits are preferred and increase in fruit weight, girth and volume may be the output of increased photosynthetic efficiency, which resulted in accumulation of carbohydrate leading to formation of larger and heavier fruits (Sharma, 1995). Better biochemical properties in T7 can be attributed to better plant stand and direct contribution of biofertilizers in improving the fertility of soil because of microbial activity. Application of FYM might have helped soil to improve nutrient status, water holding capacity, physical, chemical and biological properties, which in turn helped in better absorption by plants and resulting in better biochemical properties.

FYM also provided room for better establishment of inoculated microorganism along with accumulation of excess humus content (Hayworth *et al.*, 1996). Increased size may be due to the presence of growth promoting seed regulatory substances, cytokinins etc., which physiologically influenced the activity of a number of enzymes which leding to increased cell metabolism enzymatic activity which in turn changed the biochemical composition of fruit (Subbaiah, 1991).

The maximum flesh thickness was recorded when AMF applied along with FYM (T2) with 3.43 mm (Table 8). It was followed by T7 - FYM + AZ + AMF + FR (3.27 mm).

The number of locules per fruit varied significantly between treatments (Table 8). Application of all the three biofertilizers each @ 2 kg ha^{-1} along with FYM (T7) recording the maximum locules of 5.16 which was on par with combined application of 50 percent (T8) and 100 percent (T9) inorganic fertilizer along with all the three biofertilizer and control. Sawhney and Dabbs (1978) reported that the number of locules per fruit of GA3 treated plants was greater than the untreated plants which indicate that GA3 has influence on number of locules in tomato. Biofertilizers also produce several growth promoting substances including gibberellic acid and this might

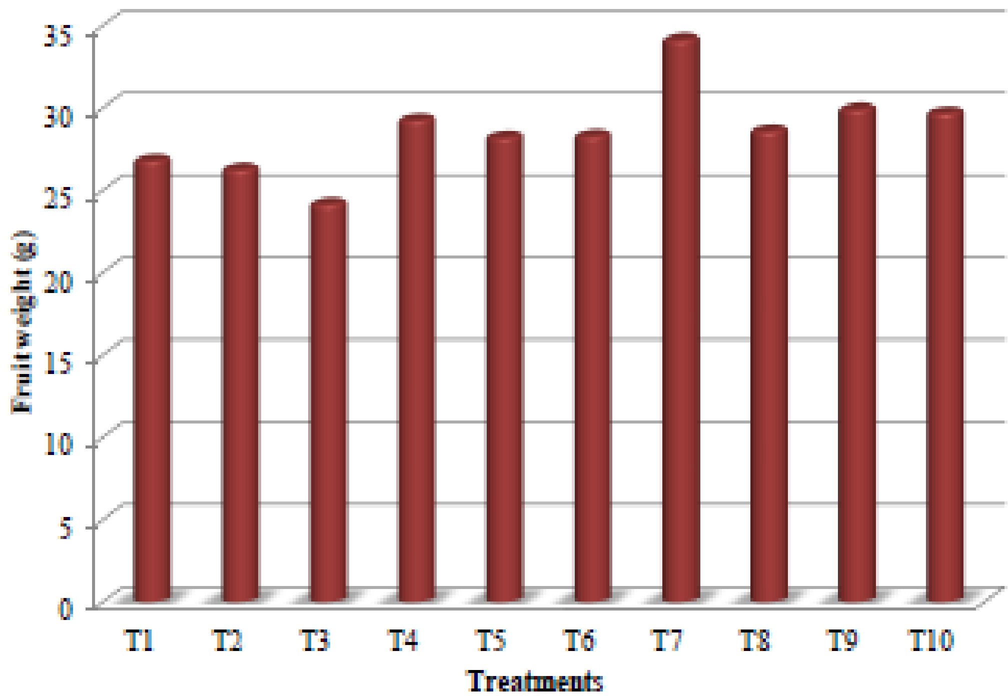


Fig.5: Effect of treatments on fruit weight

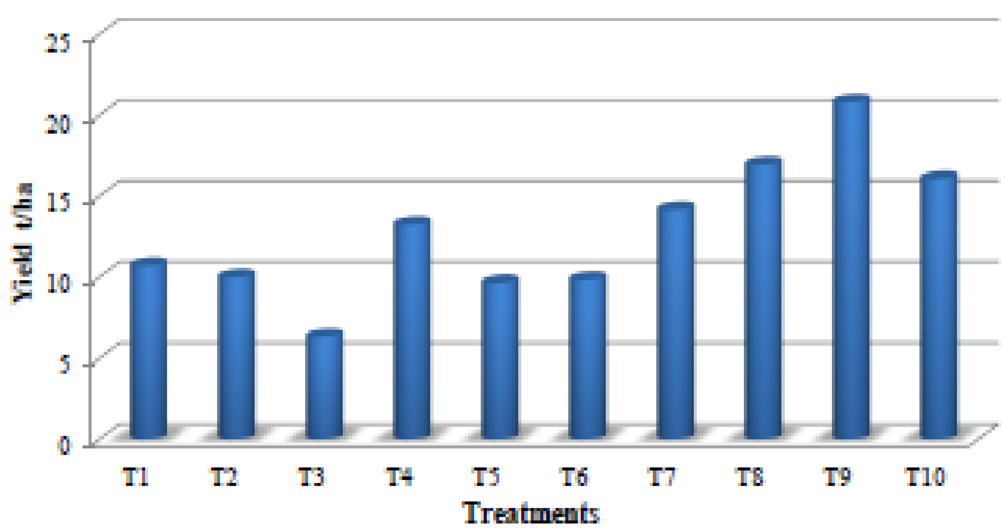


Fig.6: Effect of treatments on t/ha

have resulted in change in locule number. On the other hand, more number of ovary locules, result in large sized fruits (Li, 1990).

Significant differences were noticed between treatments with respect to number of seeds per fruit (Table 8) and the highest value (136.75) was obtained for T7 (FYM + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg ha^{-1}). Similar results were obtained by Kumar and Sharma (2006) in tomato and Patil (2008) in *Capsicum*. The increase in seed yield may be due to the better source sink relationship and better performance of growth parameters. Therefore, it can be attributed to the increased growth attributes and direct role of biofertilizer in nitrogen fixation, production of phytohormones like substances and increased uptake of nutrients might have contributed for the development of fruit and seed yield in this treatment (Bindiya *et al.*, 2006). Synergestic effect of organic source of nutrients and bifertilizers might have enhanced photosynthetic activity and accumulation of carbohydrates, which in turn was translocated in large amount in the seeds resulting in higher seed number.

5.4. Yield characteristics

Yield is the ultimate manifestation of morphological, physiological, biochemical processes and growth parameters, and it depends on how efficiently plants trap and convert solar energy and nutrients. Improvement in yield can be realized in two ways i.e. by allowing existing varieties to grow better in their environment or by altering the relative proportion of different plant parts so as to increase the yield of economically important parts (Humphries, 1969).

Number of fruits per plant showed significant variation among the treatments (Table 9). Combined application of all the biofertilizers along with full dose of NPK (T9) produced the highest number (28.16) of fruits per plant which was 20.60 per cent more than control. Sendur *et al.* (1998) in tomato, Anburani and Manivannan (2002) and Kiran (2006) in brinjal obtained favorable results with represent to number of fruits per plant when biofertilizers were inoculated along with 100 per cent RDF.

Inoculation of biofertilizers might have augmented the uptake of N, P and K which in turn favourably increased photosynthesis and better accumulation of food deposits in plant. Apart from nutrients, growth regulators produced by the inoculated microbes may have induced stimulus for the production of more truss.

The treatments showed significant differences (Fig.6) and combined application of all the biofertilizers along with full dose of NPK (T9) produced the highest fruit yield per plant with 814.70 g followed by half NPK (T8) (664.90 g) and control plants (629.50 g). The treatment T9 produced 29.40 per cent more fruit yield than the control. In the case of yield per hectare, T9 produced 20.81 t ha^{-1} which was 22.84 per cent higher than the control followed by T8 (16.95 t ha^{-1}) and control (16.06 t ha^{-1}). Anburani and Manivannan (2002) and Kiran, (2006) in brijal, Talukder and Jana (2009) in chilli reported almost similar results.

Combined application of inorganic fertilizers in combination with biofertilizers and FYM (T9) might have attributed to better synthesis of metabolites which helped in enhancing uptake of nutrients by plants. It also improved the growth of plants in terms of plant height, more number of leaves, branches and inflorescence which had positive significant co- relation with yield. Application of FYM might have created better soil condition due to higher rate of multiplication of inoculated microbes leading to enrichment and mobilization of bound nutrients and improvement in soil aggregation. (Nirmala and Vadivel, 1999) FYM provides micro and macro nutrients, increase water holding capacity and improves aeration for better root formation (Kirad *et al.*, 2010). All these might have made quick mobilization and availability of nutrients which could have resulted in increased plant height, number of leaves, branches, inflorescence and photosynthetic rate ultimately resulting in higher yield.

5.5. Fruit quality parameters

Quality of the produce is very important since it decides the market demand and price. Balanced nutrient supply is necessary not only for obtaining higher and regular

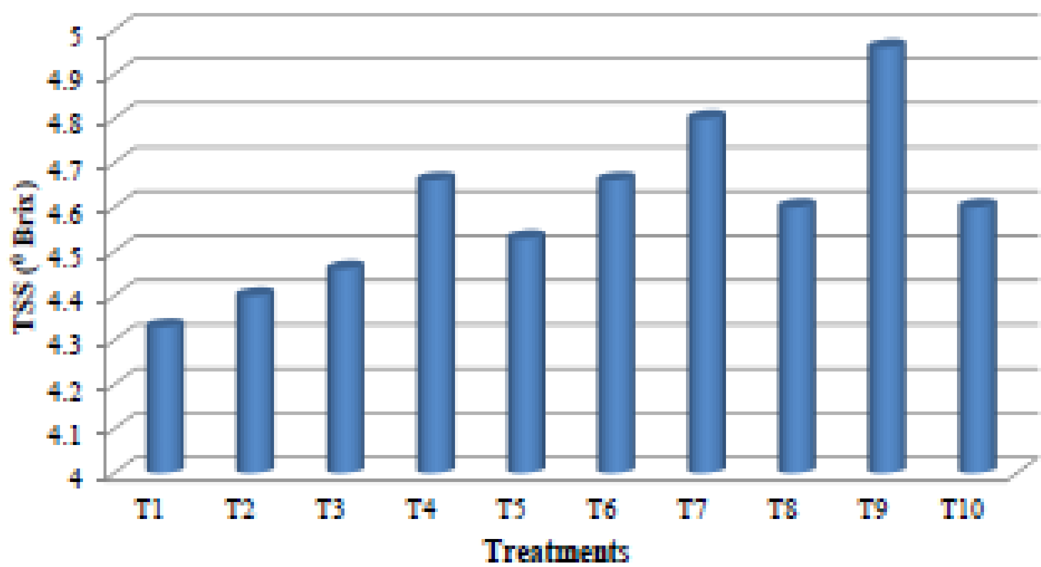


Fig. 7: Effect of treatments on TSS of fruit

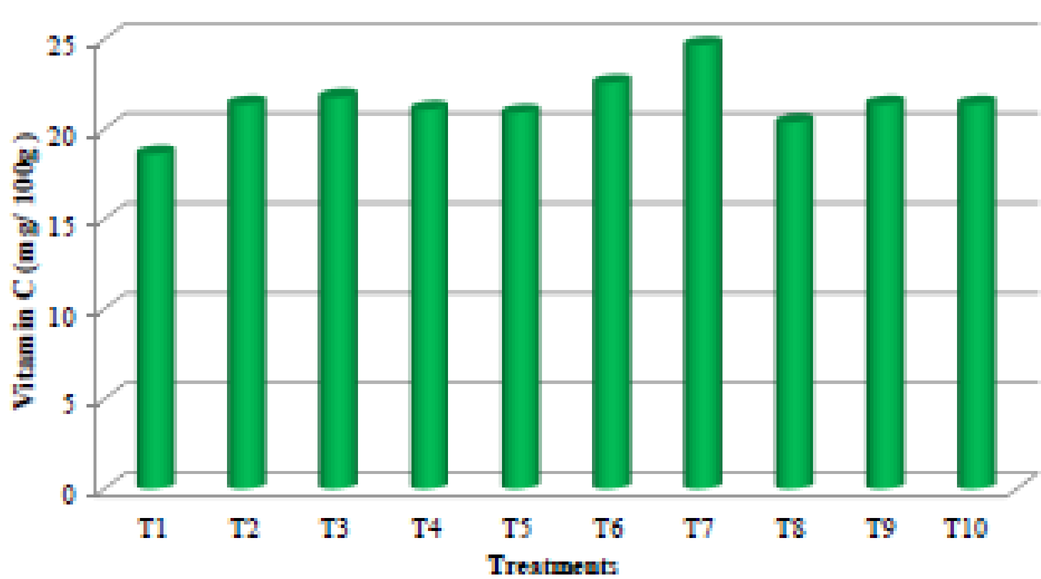


Fig.8: Effect of treatments on vitamin C content

yield but also for increasing quality of the produce. Increasing fruit quality increases the post harvest life of the product and thereby increases the yield indirectly.

TSS is an important quality parameter in the case of processing tomato. It showed significant variation between treatments (Table 11; Fig. 7). The highest value of 4.96 ^{o} Brix was recorded for combined application of all the biofertilizers along with full dose of NPK (T9) followed by T7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$). Patel *et al*. (2011) in brinjal reported favourable effect of biofertilizers on fruit quality. Increased TSS content may be due to the accelerated photosynthetic efficiency and translocation of photosynthates from leaves to fruits. Increased photosynthetic rate and increased efficiency of microbial inoculants to fix atmospheric nitrogen, mobilization and solubilization of nutrients from soil and secrete growth promoting substances which alter the physiological process like synthesis of carbohydrate and sugars (Chatoo *et al*., 1997). This could have resulted in increased TSS in treatment T9.

Significantly higher vitamin C content of 24.66 mg/100g was noticed in T7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$) (Fig. 8). Biofertilizers physiologically influence the activity of number of enzymes which increase cell metabolism and enzymatic activity which in turn change the biochemical composition of fruit. The enhanced absorption of nitrogen and its direct participation in protein synthesis was reported by Subbaiah (1994) in amaranthus. Growth promoting substances could have accelerated synthesis of carbohydrate, resulting in increase in vitamin C content which is a sugar acid (Kamili *et al*., 2002).

On the basis of micronutrient analysis of fruits, application of FYM + AMF (T2) and FYM + NPK + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha^{-1} (T9) recorded the highest value for fruit calcium content (0.356 % and 0.354 % respectively).

Shelf life of tomato fruits also showed significant differences with treatment T2 (FYM + AMF) recording the maximum shelf life of days of 18.66 followed by T4

(FYM + *Azospirillum* + AMF) and the lowest by T3 (FYM + *Frateuria*) and T10 (control). Ganeshe *et al*. (1998) reported that the longest shelf life was recorded in biofertilizer inoculated okra. Calcium plays a fundamental role in plant membrane stability, cell wall stabilization, and cell integrity (Hirschi, 2004). Increased Ca levels have been shown to reduce respiration and ethylene production rates in a variety of fruit crops including tomato (Garcia *et al*., 1995). The increased availability of calcium in T2 might have improved storability and keeping quality.

5.6. Nutrient analysis of plant

Nutrient content of plant parts showed that there was significant variation due to treatment effect (Table $12^{-1}4$).

Maximum nitrogen content of fruits was observed in combined application of all the biofertilizers along with full dose of NPK (T9) with 3.32 per cent and half dose of NPK along with all the three biofertilizers (T8) with 3.27 per cent. In the case of leaf analysis, higher nitrogen content was observed in treatments, combined application of all the biofertilizers along with full dose of NPK (T9) with 2.88 per cent, T7 and T1 with 2.80 per cent. Talukder and Jana (2009) and Khan *et al*., (2012) reported similar trends in green chilli. The increase in nitrogen content of fruits can be attributed to the multiplication of *Azospirillum* and their atmospheric nitrogen fixation there by increasing the nutrient uptake thus registering higher nitrogen content. AMF might have increased the nitrogen content due to increased nitrate reductase activity (Oliver *et al*., 1983) which breaks down organic nutrients (Sherif and Sanni, 1976). In addition, mycorrhizal fungi extract nitrogen from soil by its absorbing surface.

Phosphorus content of fruits showed significant differences. Combined application of all the three biofertilzers along with FYM and inorganic (½ NPK) fertilizers (T8) gave higher phosphorus content of 0.283 per cent. Treatments showed significant differences in phosphorus content of leaves. The treatment, combined application of all the biofertilizers along with full dose of NPK (T9), FYM and AMF

(T2) and T4 (FYM + *Azospirillum* + AMF) recorded the maximum value of 0.292 per cent.

Maximum fruit potassium content of 2.83 per cent was noticed in plants which received FYM and *Frateuria* (T3). The treatment T9 recorded maximum leaf potassium content of 3.11 per cent.

Uptake data of nitrogen, phosphorus and potassium by different plant parts give some indication of the fertility status of the soil and also the yield potential of crop. Significant differences were noticed in nitrogen, phosphorus and potassium uptake of plants (Fig. 9).

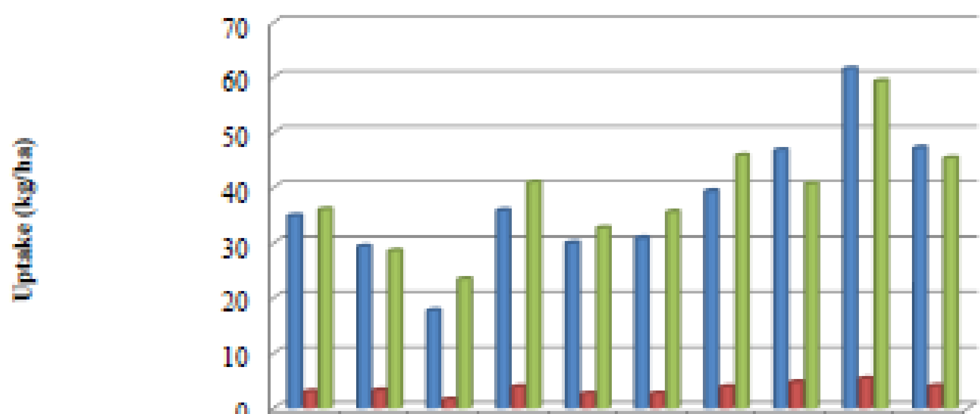
Combined application of biofertilizers along with full dose of inorganic fertilizers (T9) recorded the maximum uptake of nitrogen (61.56 kg ha^{-1}), phosphorus (5.38 kg ha^{-1}) and potassium (59.26 kg ha^{-1}) (Table 14).

Subbiah (1994) reported that in chilli 100 per cent recommended dose of N and P along with biofertilizers (*Azospirillum* + VAM) recorded the highest N, P_2O_5 and K_2O uptake. Selvaraj (1996) also obtained higher N, P_2O_5 and K2O uptake with similar treatments.

5.7. Soil analysis

Soil fertility is a complex quality of soil that is closest to plant nutrient management. It combines several soil properties like biological, chemical and physical and all of these properties are affected directly or indirectly by manures, fertilizers and biofertilizers.

Application of FYM increased the per cent of organic carbon in all the treated soil irrespective of the treatment and the maximum (0.89 %) increase was noticed when FYM applied along with *Azospirillum* + AMF (T4) which was at 45 DAT. At 80 DAT, it again increased to 0.95 percent which was in T9.



	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Uptake of N (kg/ha)	34.87	29.37	17.77	35.85	30	30.85	39.3	46.76	61.56	47.17
Uptake of P (kg /ha)	3.01	3.23	1.59	3.89	2.65	2.68	3.88	4.68	5.38	4.01
Uptake of K kg/ha	36.03	28.53	23.43	40.95	32.63	35.55	45.82	40.7	59.26	45.3

Fig.9: Effect of treatments on plant uptake of N, P_2O_5 and K_2O

Application of FYM, full dose of NPK and all the three biofertilizer (T9) together recorded the maximum value of available nitrogen (182.33 kg ha^{-1}) at 45 DAT which was on par with control (FYM + NPK) and T8 (FYM + ½ NPK + *Azospirillum* + AMF + *Frateuria*). The treatment T9 recorded the highest value of available nitrogen (260.66 kg ha^{-1}) at 80 DAT also.

Talukder and Jana (2009) reported that in chilli residual available soil nitrogen (202.90 kg ha^{-1}), phosphate (67.10 kg ha^{-1}) and potash (70.50 kg ha^{-1}) were maximum in case of inoculation with the biological nitrogen fixers (*Azospirillum* and *Azotobacter*) along with full dose of N-fertilizer. Khan *et al*., (2012) also supported the same result in brinjal.

Application of FYM, full dose of NPK and all the three biofertilizer (T9) recorded the highest soil available phosphorus content recording 61.33 kg ha^{-1} (45 DAT) and 59.01 kg ha^{-1}(80 DAT). In soil, P_2O_5 availability increased with the application of FYM due to increased decomposition of organic matter.

Significant difference in available K_2O content was noticed between treatments. Available potassium status of soil also increased from the initial value of 130.24 kg ha^{-1}. At 45 DAT it was the highest in T3 (FYM + *Frateuria*) which recorded 178.74 kg ha^{-1} followed by T5 (FYM +*Azospirillum* + *Frateuria)* (175.88 kg ha^{-1}). At 80 DAT also T3 recorded highest value of 275.44 kg ha^{-1}. Similar finding was reported by Anisa (2011), when *Frateuria* applied along with FYM in okra. The increase in K_2O content in T3 might be due to the solubilisation of potash by secretion of some organic acids like succinic acid by *Frateuria.*

5.8. Enumeration of *Azospirillum* sp and *Frateuria aurantia* in rhizosphere soil

Application of FYM + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg ha $^{-1}$ (T8) increased the population of *Azospirillum* from the initial count of 0.25 x 10^6 cfu g^{-1} soil to 26.93 x 10^6 cfu g^{-1} soil at 45 DAT. The population gradually decreased to 17.10 x 10^6 cfu g^{-1}soil in the same treatment at 80 DAT (Fig.10).

A similar trend was observed in the case of *Frateuria* also. The initial population recorded was 0.32 x 10^6 cfu g^{-1} of soil. At 45 DAT, FYM + AZ + FR (T5) recorded the highest population of 24.70 x 10^6 cfu g^{-1} soil which decreased to 17.76 x 10^6 cfu g^{-1} soil at harvesting stage (Fig.11).

The biofertilizer population data in general revealed that the population trend was increased up to flowering stage (45 DAT) and decreased thereafter at harvesting stage of the crop (80 DAT). These results are supported by the findings of Shinde and Latake (2009) in pearl millet. They reported that the population of *Azospirillum* sp. at flag leaf stage was 16.11cfu x 105 g^{-1} soil and increased to 17.03 cfu x 105 g^{-1} soil during flowering stage. At harvest stage it deceased to 15.94 cfu x 105 g^{-1} soil.

One of the most important factors responsible for rhizosphere effect is the availability of a great variety of organic substances at the root region by way of root exudates. The exudation rates were generally lower at seedling stage, increased until flowering but decreased at maturity (Aulakh, 2001). Application of organic amendments has positive significant effect on fungal and bacterial population, it also improved the physicochemical properties of the soil which is instrumental in providing a suitable habitat for the soil microorganisms (Das and Dkhar, 2010). In the present investigation, it can be observed that maximum population of inoculated microbes was in 50 per cent dose of fertilizer than 100 per cent. According to Dong *et al.* (2008), application of nitrogen @ 90-180 kg ha^{-1} increased the amount of microbes in wheat rhizosphere, with the peak appeared at 180 kg N ha^{-1}. Further increase in N dose (270 kg ha^{-1}) decreased the population of microbes.

5.9. Percentage of cracked fruits

Fruit cracking showed significant difference among the treatments. Maximum percentage was recorded in combined inoculation of *Azospirillum* and *Frateuria* (T5) with 2.47 per cent. Minimum percentage (0.613 %) recorded in combined application of all the biofertilizers together with full dose of inorganic fertilizers and FYM (Table 20).

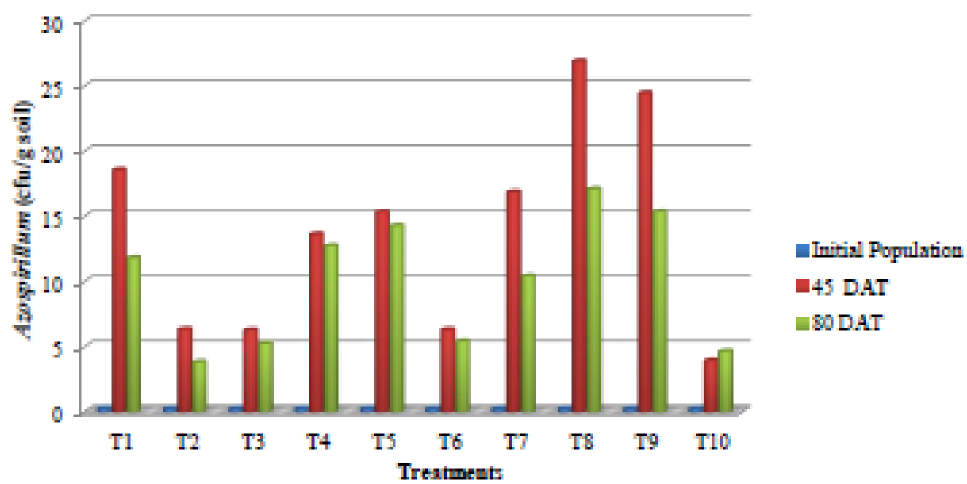


Fig.10: Effect of treatments on population of *Azospirillum* sp. at different growth stages

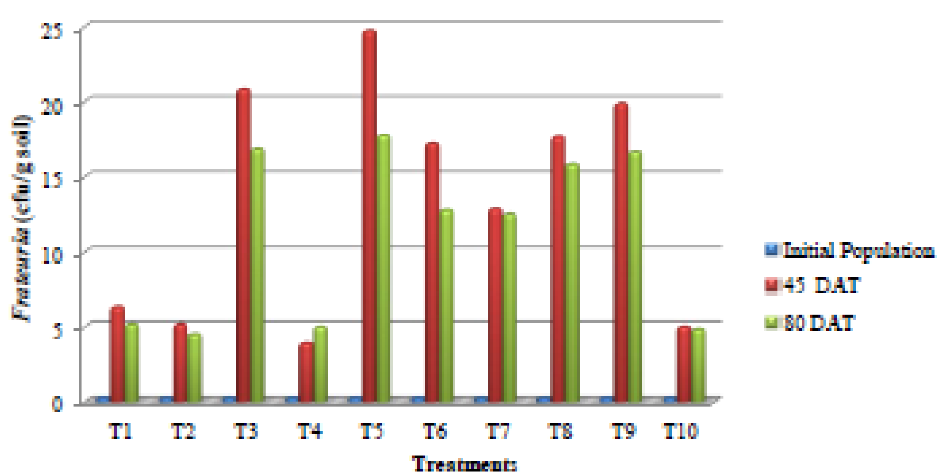


Fig.11: Effect of treatments on population of *Frateuria aurantia* at different growth stages

The development of tomato fruit cracking is related to variations in tension forces on the fruit surface caused by various climatic and cultural factors during the period when the epidermis loses its elasticity (Simon 1978; Jobin-Lawler *et al*. 2002). Inside the cell, calcium linked to pectic acids of the middle lamellae is responsible for maintaining cell wall and tissue rigidity (Marschner 1995). The treatment T5 showed significantly lower level of Ca content in fruit. This further shows that low calcium pectate in fruit leads to fruit cracking in tomato.

5.10. Economics of cultivation

Profitability is the ultimate goal in any crop production. It can be observed from the Table 21 that treatment where all the three biofertilizers were applied recorded a higher maximum benefit : cost ratio and the maximum B:C ratio of 1.76 was obtained in T9 in which combination of all the three bifertilizers and full dose of inorganic fertilizers were applied (Fig.12). The treatment T8 (FYM, *Azospirillum*, AMF and *Frateuria* along with half NPK) recorded a B:C ratio of 1.45 which is comparable with the B:C ratio of control (1.40). This suggests that upto 50 per cent chemical fertilizer can be reduced by the combind application of organic, inorganic and biofertilizers. Similar results were obtained by Sreeramulu and Bhagyaraj (1986) in chilli, Devi *et al*. (2002) in brinjal Kamili *et al*. (2002), Talukder and Jana (2009) in chilli.

In the present study, application of biofertilizers along with present recommended package of practices gave 22.84 per cent increased yield with the highest B:C ratio. It is also possible to achieve 50 per cent economy in the use of chemical fertilizers by adopting integrated nutrient management technology for cultivation of tomato.

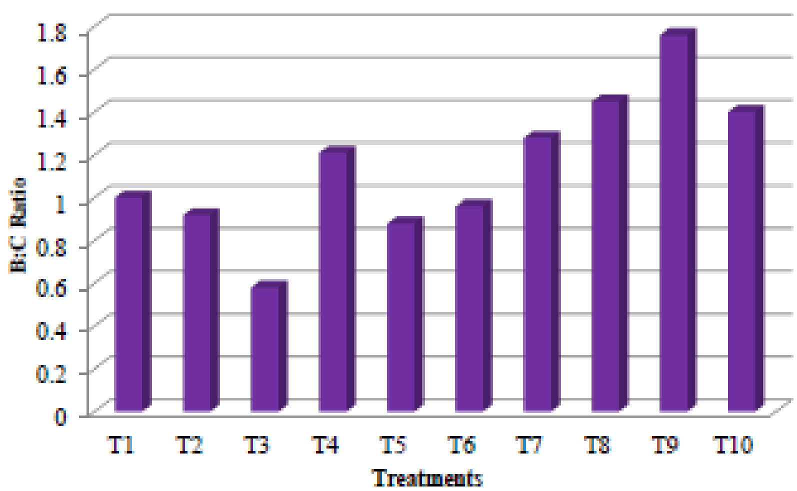


Fig.12: Effect of treatments on economics of cultivation

Future line of work

In continuation of the present investigation the following future lines of work are suggested for further research**:**

- Test the effectiveness of biofertilizers with other organic manures
- Integrate with precision farming and polyhouse cultivation
- Repeat the experiment for more seasons and more vegetables
- Develop an integrated nutrient package for vegetable crops.

Summary

6. SUMMARY

The present investigation on "Efficacy of biofertilizers in tomato (*Solanum lycopersicum* L.)" was carried out in the Department of Olericulture, College of Horticuture, Vellanikkara, during 2011-2012, to explore the effects of biofertilizers on growth, yield and quality of tomato cv. Anagha. The salient findings of the study are summarized below.

1. Growth parameters like height of plant, number of leaves and number of branches were found to be significantly affected by different treatments. The treatment T8 (FYM + ½ NPK + AZ + AMF + FR) recorded significantly higher plant height of 96.18 cm at 60 DAT. More number of leaves were observed in T9 (FYM + NPK + AZ + AMF + FR) at all the growth stages. In the case of number of branches, T7 (FYM + AZ + AMF + FR) produced the highest number of branches at 30, 45 and 60 DAT.

2. The earliest flowering was recorded in plants inoculated with all the three biofertilizers along with FYM (T7) and individual application of FYM along with AMF (T2). The treatments T7, T2 and T9 recorded early harvests.

3. Significant differences among the treatments were observed for biometric characteristics of fruits viz; fruit weight, volume, girth, flesh thickness, number of locules and number of seeds per fruit. The treatment T7 recorded the maximum fruit weight (34.15 g), fruit volume (38.20 cm3), fruit girth (15.31 cm) and number of seeds per fruit (136.75). The highest flesh thickness (3.43 mm) was recorded in T2 (FYM + AMF). The treatment T7 (FYM + AZ + AMF + FR) recorded the maximum numbers of locules (5.16) per fruit and it was on par with T9 (5.00), T10 (5.00) and T8 (4.93).

4. Among the yield characteristics, integrated application of FYM, full dose of inorganic fertilizers and biofertilizers (T9) recorded the highest number of fruits per plant (28.16), fruit yield per plant (814.70 g) and total fruit yield (20.81 t ha^{-1}). There was no significant difference between treatments for crop duration and number of harvests.

5. Total soluble solids of tomato fruit was the highest (4.96 ^{o} Brix) in treatment T9 where FYM, inorganic fertilizers (full NPK) and biofertilizers were applied. The treatment T7, where FYM and all the three biofertilizers were applied, recorded the highest vitamin C (24.66 mg 100 g^{-1}) content. Shelf life (18.66 days) of fruits was more in plants treated with FYM and AMF (T2). The treatments T2 (FYM + AMF) and T9 (FYM + NPK + AZ + AMF + FR) recorded maximum value for calcium content i.e 0.356 and 0.354 per cent respectively.

6. Significant differences were noticed in nutrient content of fruits among the treatments. Maximum nitrogen content was observed in T9 (FYM + NPK + AZ + AMF + FR) (3.32 %). The treatment T8 (FYM + ½ NPK + AZ + AMF + FR) recorded the highest value of phosphorus (0.283 %). The maximum potassium content of 2.83 per cent was noticed in T3 (FYM +FR). With respect to nutrient content of leaves, maximum nitrogen content was observed in treatments T7 (2.88 %), T9 (2.80 %), and T1 (2.80 %). The treatment T9, T2 and T4 recorded the maximum value of phosphorus content (0.292 %). The highest potassium content was noticed in T9 (FYM + NPK + AZ + AMF + FR) (3.11 %).

7. Nutrient uptake of plants varied significantly between treatments. Combined application of biofertilizers along with full dose of inorganic fertilizers (T9) recorded the highest uptake of nitrogen (61.56 kg ha^{-1}), phosphorus (5.38 kg ha^{-1}) and potassium (59.26 kg ha^{-1}).

8. Soil analysis revealed that, organic carbon content of soil increased at 45 and 60 DAT in all the treatments. Application of FYM, full dose of NPK and all the three biofertilizers (T9) together recorded the maximum value of available nitrogen and phosphorus in soil. With respect to available potassium, application of FYM and *Frateuria* (T3) recorded higher value at 45 and 80 DAT. There was no significant difference observed in soil EC and pH due to treatments.

9. Population of *Azospirillum* and *Frateuria* in rhizosphere was the highest in the treatments comprising of application of all the three biofertilizers along with FYM and ½ NPK (T8).

10. Economics of cultivation revealed that, application of *Azospirillum*, AMF or *Frateuria* alone was not effective. Among the treatments with only two biofertilizers, the treatment with *Azospirillum* and AMF (T4) was better than the other two combinations (T5 and T6). A combination of all the three biofertilizers (T7) was more effective than a combination of any two biofertilizers (T4, T5 and T6) alone.

11. Combined application of all the three biofertilizers along with full dose of chemical fertilizers produced maximum yield and the highest B:C ratio.

12. Combined application of all the three biofertilizers along with half the dose of NPK (T8) produced the same effect as that of present POP recommendations of KAU (T10), indicating that half the dose of chemical fertilizers can be substituted by biofertilizers.

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Appendices

APPENDIX I

Weather data collected from meteorological observatory of College of Horticulture, Vellanikkara (09-07-2011 to 15-11-2011)

Standard week	Maximum temperature (^{0} C)	Minimum temperature (^{0} C)	Maximum relative humidity (%)	Minimum relative humidity (%)	Sunshine (hrs)	Average rainfall (mm)
28	30.4	23.5	92.4	75	3	10.4
29	27.9	22.7	95	87	0.4	36.9
30	28.4	22.6	96	83	0.7	21.9
31	28.9	22.6	96	81	1.1	13.6
32	28.3	22.6	97	86	0.6	45.3
33	29.6	22.6	96	80	2.8	17.2
34	30.0	23.3	95	73	2.1	4.8
35	29.8	22.9	95	73	4.0	11.1
36	28.9	22.9	95	85	0.5	44.9
37	29.8	23.0	95	80	3.3	17.7
38	29.2	23.1	96	77	3.5	18.6
39	30.2	23.1	94	71	5.4	4.6
40	31.9	23.3	91	62	9.0	0.0
41	32.5	23.0	91	56	9.6	0.0
42	32.3	24.0	92	68	4.7	4.3
43	32.4	23.3	93	68	5.3	14.7
44	31.0	23.6	87	71	4.6	10.1
45	31.8	23.3	89	65	5.3	27.9
46	31.9	21.2	83	51	8.5	2.3
47	32.2	23.0	73	46	9.2	0.0

APPENDIX - II

Nutrient composition of Modified Okon's medium (Okon et al., 1977) as modified by Lakshmikumari et al. (1980)

Agar	15.00 g
K_2HPO_4	6.00 g
KH_2PO_4	4.00 g
Magnesium sulphate	0.20 g
Calcium chloride	0.02 g
Sodium chloride	0.10 g
Maleic acid	1.00 g
Sodium hydroxide	5.00 g
Yeast extract	3.00 g
Sodium molybdate	0.05 g
Manganese sulphate	0.001 g
Boric acid	0.001 g
Cuprous nitrate	0.0004 g
Zinc sulphate	0.002 g
Ferric chloride	0.002 g
Distilled water	1000 ml
Bromothimol blue	2.00 ml

APPENDIX – III

Nutrient composition of Glucose-Yeast extract-$CaCO_3$ Agar

(Lisdiyanti *et al*., 2003)

Glucose	20.0 g
Yeast extract	8.0 g
Peptone	5.0 g
Ethanol	5.0 ml
CaCO3	3.0 g
Agar	15.0 g
Distilled water	1000 ml

Abstract of the thesis

EFFICACY OF BIOFERTILIZERS IN TOMATO

(*Solanum lycopersicum* L.)

By

SMITHA, K. O.

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ABSTRACT OF THE THESIS

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DEPARTMENT OF OLERICULTURE

COLLEGE OF HORTICULTURE

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KERALA, INDIA.

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ABSTRACT

An experiment was carried to study the response of biofertilizers (*Azospirillum*, AMF and *Frateuria* each @ 2 kg ha $^{-1}$) on growth, yield and quality of tomato at Department of Olericulture, College of Horticulture, Vellanikkara during 2011-12. Anagha, a bacterial wilt and crack resistant variety of tomato developed by Kerala Agricultural University was selected for the study. The experiment was laid out in Randomised Block Design with 10 treatments and 3 replications. The treatments included inoculation of anyone of the biofertilizer along with FYM (T1, T2, T3), inoculation of any two along with FYM (T4, T5, T6), inoculation of all the three biofertilizers along with FYM (T7), inoculation of all the three biofertilizers along with FYM and inorganic (½ and full dose) fertilizers (T8, T9) and control (T10 KAU POP).

The study revealed that integrated application of farm yard manure, full dose of inorganic fertilizers and biofertilizers (T9) exhibited superiority in terms of plant height and number of leaves. The number of branches was maximum when all the three biofertilizers were applied along with FYM (T7). The earliest flowering was recorded in plants inoculated with all the three biofertilizers along with FYM (T7) and individual application of FYM along with AMF (T2). The treatments T7, T2 and T9 recorded early harvests. The treatment T7 recorded the maximum fruit weight (34.15 g), fruit volume (38.20 cm3), fruit girth (15.31 cm) and number of seeds per fruit (136.75). It was followed by the treatment T9. The flesh thickness was maximum in T2 (3.43 mm) followed by T7 (3.27 mm).

Integrated application of FYM, full dose of inorganic fertilizers and biofertilizers (T9) recorded the highest number of fruits per plant (28.16), fruit yield per plant (814.70 g) and total fruit yield (20.81 t ha^{-1}).

Total soluble solids of tomato fruit was the highest in treatment T9 where FYM, inorganic fertilizers (full NPK) and biofertilizers were applied. The treatment T7, where FYM and all the three biofertilizers were applied, recorded the highest vitamin C (24.66

mg/100 g) content. Shelf life (18.66 days) of fruits was more in plants treated with FYM and AMF (T2). Higher uptake of nutrients was observed in integrated application of full dose of NPK and FYM along with all the three biofertilizers (T9).

Application of biofertilizers improved available N, P2O5 and K2O contents in soil. The population of *Azospirillum*, AMF and *Frateuria* in the rhizosphere was also enhanced by the use of biofertilizers and was maximum in integrated application of FYM, ½ NPK and biofertilizers (T8).

Regarding the economics of cultivation, the highest B:C ratio of 1.76 was recorded when full dose of NPK was applied along with all the three biofertilizers and FYM (T9). It was followed by the treatment T8 and T10 which recorded a B:C ratio of 1.45 and 1.40 respectively.

From the study it can be concluded that inoculation of biofertilizers enhanced the growth, yield and quality of tomato. The available nutrient status, microbial population and health of soil were also improved by biofertilizer application. Overall assessment indicated that integrated application of all the three biofertilizers and FYM along with full dose of chemical fertilizer was the best for better growth, yield and soil health. The second best performance was obtained when FYM, inorganic fertilizers (½ NPK) and biofertilizers were applied, signifying that a reduction of 50 per cent chemical fertilizers is possible by using biofertilizers. Application of FYM and all the three biofertilizers together improved the biometric characters like weight, volume and girth of fruits.