RESPONSE OF OKRA (*Abelmoschus esculentus* (L.) Moench) TO BIOFERTILIZERS

By

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(2009-12-105)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Response of okra (*Abelmoschus esculentus* (L.) Moench) to biofertilizers"** 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 **"Response of okra (*Abelmoschus esculentus* (L.) Moench) to biofertilizers"** is a record of research work done independently by **Miss Anisa N. A.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the advisory committee of **Miss Anisa, N. A. (2009-12-105)** a candidate for the degree of **Master of Science in Horticulture**, with major field in Olericulture, agree that the thesis entitled **"Response of okra (*Abelmoschus esculentus* (L.) Moench) to biofertilizers"** may be submitted by **Miss Anisa, N. A. (2009-12-105),** in partial fulfillment of the requirement for the degree.

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Introduction

1. INTRODUCTION

Vegetables are an indispensable part of human nutrition. The importance of vegetables in human nutrition is well known as it is a rich and comparatively cheaper source of vitamins, minerals, proteins, carbohydrates and roughages. They are important adjunct for maintenance of good health and are beneficial in protecting against many degenerative diseases. They occupy an important place in diversification of agriculture and have played a pivotal role in food and nutritional security of growing population of our country.

India is basically an agricultural country and it maintains a unique position as far as vegetable cultivation is concerned. India is the second largest producer of vegetables after China. In India vegetables occupy an area of 7.99 million ha with an annual production of 133.74 million tonnes (NHM, 2010). Among the wide variety of vegetables cultivated in India, okra is one of the popular and most important vegetable crops which is grown throughout the year. India is the second largest producer of okra with a production of 48.03 lakh tonnes (NHM, 2010). The immature fruits are highly nutritious and are good sources of vitamin A, vitamin B, proteins, carbohydrates, dietary fibres, calcium, phosphorus, iron and iodine (Purseglove, 1968). Besides the nutritional value, increased interest is being bestowed on the economic and therapeutic benefits of okra.

High iodine content of okra fruits helps to control goitre. The leaves are used in preparing medicines which reduce inflammation. Ground powder of its roots provides relief in leucorrhoea backache. Seeds are used for curing chronic dysentery, genito urinary disorders, renal colic problems and fever based weakness. Oil from okra is used in soaps, cosmetic industry and as vanaspathi, while protein is used for cattle feed preparation (Bini, 2003). Crushed seeds are fed to cattle for increasing milk production and the fibre is used in paper and textile industry. They are also used for thickening of soups and gravies because of their high mucilage content. Mucilaginous extract from roots and stem is used as clarifier and also in manufacture of jaggery (Rana, 2008).

Now-a-days a major transition is taking place in the world agriculture scenario. People are aware of the adverse effects of imprudent use of heavy dose of chemical fertilizers on physical and chemical properties of soil. Moreover, the decreasing soil fertility and soil microflaura, increasing vulnerability of crops to pest and diseases, increasing concern for environment safety, and fertilizer use reaching the point of near no response have led to the need for developing an alternative to costlier environmental damaging and energy intensive chemical inputs. Today much attention is given to overcome this situation by popularising the concept of integrated nutrient management (INM).

An integrated approach recognises that soils are the storehouse of most of the plant nutrients essential for plant growth and that, the way in which nutrients are managed will have a major impact on plant growth, soil fertility and agricultural sustainability (Patel *et al.*, 2010). This farming system is productive, profitable, energy and resource conserving, environmentally sound and ensures food safety and quality. INM has emerged as a proven technology which supplements chemical fertilizers with organic manures and biofertilizers in an environmentally benign manner.

In recent years there has been a welcome awareness for eco-friendly products like biofertilizers in improving crop yield through better nutrient supplies. Biofertilizers are preparations containing agriculturally important beneficial microorganisms which add, conserve and mobilise the nutritionally important elements from non-usable to usable form through biological process (Bahadur *et al.*, 2004a). They influence total soil microflaura, soil enzyme activity and in turn soil health (Dar *et al.*, 2010b). They produce growth promoting substances and vitamins and help to maintain soil fertility and suppress the incidence of pathogen and control diseases (Bagyaraj, 2003). 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). These non-conventional sources of nutrients are gaining immense importance as they improve long term sustainability of soil.

Progressive use of biofertilizers offers the best alternative to intensive chemical fertilizers, as unlike chemicals they will remain in soil, multiply and benefit crops and can completely obviate detrimental effects of current agricultural practises in an eco-friendly manner. Therefore 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.

With this point in view the present investigation was done in okra with the following objectives

- To test the efficacy of biofertilizers on growth and yield of okra.
- 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

The beneficial plant microbe interactions in the rhizosphere are the primary determinants of plant health and soil fertility. Very often microorganisms are not as efficient in natural surroundings as one would expect them to be. The lost biological activity in the soil due to excess use of chemical fertilizers can be restored slowly by incorporating artificially multiplied cultures of beneficial microorganisms. The importance of biofertilizers comes in this context.

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 microorganisms and accelerating certain microbial process to augment the extent of availability of nutrients in a form which can be easily assimilated by the plants (Rao, 1995). They play an important role in various chemical transformations in soil and thus influence the availability of major nutrients like N, P and K to plants (Chaurasia, 2008). Significant improvement in growth, yield and quality of vegetables with respect to biofertilizer application has been reported in various crops using *Azospirillum*, *Azotobacter*, *Rhizobium*, Arbuscular Mycorrhizal Fungi (AMF) and Phosphate Solubilising Bacteria (PSB) which are the most important commercially exploited and widely used biofertilizers in vegetables. In addition to these regular biofertilizers, recently potassium mobilizing microorganisms like *Frateuria aurantia* are also introduced.

Azospirillum is an associative symbiotic, micro aerophilic, nitrogen fixing bacteria having high potential for nitrogen fixation. It fixes about 20-25 kg/ha of nitrogen under ideal conditions and thereby effecting a reduction of 25% in the quantity of nitrogenous fertilizers (KAU, 2007). The production of phytohormones like gibberellins, cytokinins (Parvatham *et al.*, 1989) and more specifically the auxins (IAA) has been recognised as an important factor in plant growth promoting ability of *Azospirillum* (Dobbeleare *et al.*, 1999). It has the ability for better root induction. As a result, plants are capable of absorbing more and more available nutrients from soil which results in better establishment of plant and subsequent growth (Govindan and Purushothaman, 1989).

Arbuscular Mycorrhizal Fungi (AMF) are obligate symbiotic fungi associated with agricultural crops which improves the uptake of available phosphorus. AMF with their extramatrical hyphae increases absorption of relatively immobile elements in soil such as P, Cu, Zn (Haymann and Mosse, 1971), N, K, Ca, Mg and Fe (Linderman, 1992). In addition, mycorrhizal plants have shown greater tolerance to toxic heavy metals, drought (Sieverding, 1983), high soil temperature, saline conditions, adverse pH, transplanting shocks and root pathogens especially nematodes and pathogenic soil fungi than non-mycorrhizal plants (Jalali and Tareja, 1980). Colonization of plant roots by AMF can also affect root exudation as Arbuscular Mycorrhizal formation may alter root physiology including root permeability (Sharma and Johri, 2002). They produce growth hormones, improve rhizosphere conditions and alter host physiological and biochemical properties. They synergistically interact with other beneficial microorganisms (Azcon, 1989) and improve soil aggregation (Singh *et al.*, 2010).

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 (3.5-11) (Joyeux *et al.*, 2004; Murugesan, 2008). It mobilizes elementary or mixture of potassium or solubilize the fixed form of potassium into easily absorbable simpler form. It can mobilize K in all types of soil especially in low K content soils. By using *Frateuria* about 50-60 per cent of potash fertilizers could be reduced (Chandra *et al.*, 2005).

The present study deals with the effect of *Azospirillum*, AMF and *Frateuria* on okra. Reviews related to the effect of these biofertilizers in vegetable crops are given. Since *Frateuria* is comparatively a recently isolated microorganism, not much literature is available on it.

2.1. EFFECT OF BIOFERTILIZERS

2.1.1. Effect of biofertilizers on growth characters

Study conducted by Senapathi *et al.* (1987) to find the effect of mycorrhiza on growth characteristics of okra in laterite soils revealed that AMF inoculated bhindi plants gave increased plant height and number of seeds per pod. In an experiment to study the field efficiency of biofertilizers on growth of okra, Nuruzzaman *et al.* (2003) reported that *Azospirillum* + cowdung (5 t/ha) showed significantly higher plant height (132.2 cm) over control (117.7 cm). This treatment also gave the highest root length at 60, 75, 90 and 105 days.

El-Shaikh and Mohammed (2009) reported that VAM inoculated okra plants exceeded uninoculated ones by 5.9 per cent and 3.5 per cent in first and second season for plant height and 16.8 per cent and 14.97 per cent in case of number of branches per plant. Application of *Azospirillum* (2 kg/ha) gave maximum plant height (103.94 cm) compared to control (87.47 cm) in okra cv. Varsha Uphar. It also gave maximum dry weight of fruits (12.4 g) and took less number of days to 50 per cent flowering (40.96) when compared to its control (Dar *et al.*, 2010 b).

In *Azospirillum* treated chilli characteristics like plant height, number of branches/plant, canopy spread and dry matter production were significantly higher over untreated ones (Anitha, 1997). In an experiment to study the presence of arbuscular mycorrhiza on performance of chilli (bell) pepper, it was found that mycorrhizal association induced early flowering and early fruit production (Oyetunji and Osonubi, 2005).

Dual inoculation of *Glomus fasciculatum* and *Azotobacter chroococcum* significantly increased dry weight of tomato plants (Bagyaraj and Menge, 1978).

In an experiment done by Khaliel and Elkhider (1987), tomato when inoculated with *Glomus mossae* had greater dry weight, higher percentage of survival, number of nodes and number of lateral branches. Number of leaves per plant almost doubled in mycorrhizal transplants. Shreenivasa *et al.* (2007) reported that in tomato cv. Pusa Ruby, *Glomus fasciculatum* inoculated plants produced significantly taller plants (86.50 cm) at all stages of growth, which was 43.18 per cent increase over control.

Kandasamy *et al.* (1985) reported that in brinjal cv. MDU 1, an increase of 39.31 per cent and 78.34 per cent over control was noticed in seedling height and dry weight, and in chilli cv. Co 2 seedling height (19.70 cm), dry weight (0.14 mg) and root length (7.90 cm) were maximum due to inoculation of mycorrhiza (500 g/m^2) and phosphobacteria. In a study conducted at KAU in integrated nutrient management in brinjal cv. Swetha, *Azospirillum* inoculation increased number of leaves per plant at all stages except 30 DAT. It also increased number of flowers (7.56) and fruits per plant (5.44) when compared to uninoculated plants (Rekha, 1999).

In an experiment in cassava, where five species of VAM fungi were used, it was reported that *Glomus fasciculatum* and *Glomus etunicatum* inoculated plants significantly increased plant height, and shoot and root dry weight than other *Glomus* species (Sivaprasad *et al.*, 1990). Bacterial culture of *Frateuria aurantia* did not give any significant change in harvest index of sweet potato (Byju and Ray, 2002).

In a study conducted at Mahatma Phule Krishi Vidya Peet, Rahori, it was found that application of *Azospirillum* (12 kg/ha) + PSB + VAM (20 kg/ha) significantly improved growth contributing characters such as number of leaves (54.13) per plant, days for bulb sprouting (27.66) and days for seed harvesting (142.88) in onion cv. Phule Samarth compared to control (Waghmode *et al.*, 2010).

2.1.2. Effect of biofertilizers on yield and yield attributing characters

In okra cv. Pusa Sawani, *Azospirillum* inoculation @ 2.5 kg/ha gave the highest yield of 15.6 t/ha (Parvatham and Vijayan, 1989). Prabhu *et al.* (2002a) reported a yield increase of 9.85 per cent in *Azospirillum* + VAM (1g/hill) inoculated plots over control in okra cv. Parbhani Kranthi. In a study on integrated nutrient management in summer okra, it was found that *Azospirillum* when given as seed treatment (30 g/kg) produced better plant height (117.06 cm) compared to no inoculation (109.19 cm). This also gave 9.7 per cent more green fruits over control. Significantly higher fruit weight (10.97 g) and fruit yield (10.88 t/ha) were also recorded in this treatment (Patel *et al.*, 2009).

In chilli Amritalingam and Balakrishnan (1988) observed earliness in first flower appearance, 50 per cent flowering, number of flowers, number of fruits/plant, fresh and dry weight of pods/plant, length and girth of pods, number of seeds, and weight of seeds/pod by *Azospirillum* treatment. Kumari and Lakshmi (2009) conducted a field experiment during Kharif to know the response of chilli to microbial inoculation with *Azospirillum* isolates. They reported that inoculation of *Azospirillum* increased dry chilli yield (2.7 t/ha) over uninoculated one (2.5 t/ha).

In a study conducted by Edathil *et al.* (1996), tomato seedlings were grown in sterile, phosphorus deficient soil and inoculated with four species of Vesicular Arbuscular Mycorrhizal (VAM) fungi in 15 possible combinations. Mycorrhizal plants exhibited a significantly higher shoot length and biomass than non-mycorrhizal plants.

In an experiment conducted by Naidu *et al.* (2002) in brinjal cv. JB-64, it was found that 20 t poultry manure when applied in conjunction with *Azospirillum* and PSB yielded greater number of fruits (17.96) with higher girth (19.38 cm). Bashan *et al.* (1989) inoculated *Azospirillum brasilense* in seven different crop species and a significant increase in total yield was noticed. The yield increase was 30 per cent in tomato and 23 per cent in eggplant.

Bahadur *et al.* (2004a) reported that in cabbage significant improvement in number of inner leaves (31.70) and head weight (1616.67 g) was observed compared to control (26.30 and 1335 g respectively) when pressmud (10 t/ha) was applied in soil, and seedlings were inoculated with VAM. This treatment also gave significantly higher head yield (602.67 q/ha) which is 22.6 per cent more than control (491.33 q/ha). It also recorded maximum head diameter (15.5 cm). In cabbage, length (23 cm), width (33 cm), gross weight (1.69 kg) and net weight (1.22 kg) of head per plant and yield/ha (40.99 t) were significantly enhanced by *Azospirillum* which was given as seed treatment (0.5 kg/ha), seedling treatment (1 kg/ha) and soil application (5 kg/ha) over no biofertilizer application (Sharma, 2002).

When *Azospirillum* was given as seed (500 g/ha), seedling (2 kg/ha) and soil application (2.5 kg/ha) in Early White Vienna variety of knol khol in Rabi and Kharif seasons, significant increase in weight per bulb (95.57 g and 129.05 g), volume per bulb (102.77 cm^3 and 104.95 cm^3) and yield (289.05 q/ha and 263.78 q/ha) were noticed. The increase in yield was 15.42 per cent and 19.96 per cent over control in both seasons (Chatto *et al.*, 1997). Sundaravelu and Muthukrishnan (1993) reported that in radish cv. Japanese White, *Azospirillum* inoculated seeds (75 g/kg) recorded increased root length (13.94 %), root diameter (8.9 %) and yield (9.93 %) over control.

In a study conducted by Singh (2006), to ascertain the effect of different biofertilizers and biopesticides in combination with organic nutrients on different vegetable based crop rotation involving brinjal, cabbage and radish, it was found that *Azospirillum brasilense* in combination with other organic sources of nutrients gave highest yield in brinjal (158.29 q/ha), cabbage (130.79 q/ha) and radish (90.40 q/ha).

Sivaprasad *et al.* (1989) conducted a study to find the response of different cultivars of cassava and sweet potato to AMF inoculation and found that Ambakadan cultivar of cassava and Kanjangadu local of sweet potato recorded a yield increase of 31.79 per cent and 24 per cent due to VAM inoculation. In cassava, number of tubers per plant was more in AMF applied plots (Saraswathi and Shanmugham, 2006).

In garlic cv. Godavari, Vesicular Arbuscular Mycorrhiza significantly increased the plant height, number of functional leaves, dry matter, fresh and dry weight of bulbs, and N and P uptake by plants. It also increased available P_2O_5 in soil (Wani and Konde, 1998). In an experiment where Yadav *et al.* (2005) inoculated onion cv. RO-1 with *Azospirillum* @ 500 g/ha (seed treatment), 1 kg/ha (seedling dip) and 2 kg/ha (soil application), it gave significantly higher bulb yield of 323.7 q/ha over control (310.9 q/ha).

Nirmala and Vadivel (1999) reported a yield increase of 49.4 per cent in cucumber when inoculated with *Azospirillum* @ 2 kg/ha as soil application. Combined application of *Azospirillum*, phosphobacteria and VAM each @ 2 kg/ha as soil application along with FYM (30 t/ha) increased fruit length (22.41 cm), number of fruits (9.58) and mean tender fruit yield (2053.13 g/vine) for two seasons and in pooled mean analysis in cucumber (Nirmala *et al.*, 1999). A study conducted to assess the effect of various organic manures with and without microbial inoculation in slicing cucumber cv. AAUC-2 revealed that combined inoculation of *Azospirillum* and AMF each @ 2 kg/ha resulted in significant improvement in fruit yield (16.5 t/ha) as compared to uninoculated control (15.75 t/ha) (Raj, 2006).

Prasad *et al.* (2008) reported that application of VAM (*Gigaspora colospora*) @ 100 g/ha significantly increased number of pods/plant (45.46), length of pods (22.48 cm), fresh weight of pods (4.41g), number of seeds/pod (9.34) and pod yield (60.22 q/ha) in cowpea.

Desai *et al.* (2009) reported that in grain amaranth cv. GA-2, there was 15.2 per cent increase in grain yield due to seed inoculation with *Azospirillum* over control. Cimen *et al.* (2010) reported that in Lettuce cv. Yedikule, weight of marketable lettuce (83.12 g), plant height (11.15 cm) and crown width (19.1 cm) were increased by VAM inoculation whereas the control plot gave 69.40 g, 9.86 cm and 17.32 cm respectively.

2.1.3. Effect of biofertilizers on quality and nutrient content

Studies in organic nutrition in okra by Raj (1999) revealed that in bhindi, ascorbic acid content (21.78 mg/100g) and crude protein content (17.73 %) were significantly higher for *Azospirillum* inoculated plants. This increase is attributed to the increased efficiency of *Azospirillum* to fix nitrogen and to secrete growth promoting substances which accelerate synthesis of carbohydrates.

In a study conducted by Amritalingam and Balakrishnan (1988) to find the effect of *Azospirillum*, nitrogen and NAA in chilli, it was found that capsaicin and ascorbic acid content in chilli were increased by *Azospirillum* inoculation. Subbiah (1994) reported that seed (100 g/100g) and soil application (2 kg/ha) of *Azospirillum* + VAM recorded highest N content (4.83 %) in chilli cv. Co-1 and highest P uptake (3.8 kg/ha) in Bellary onion. Anitha (1997) reported higher ascorbic acid content in *Azospirillum* inoculated plants (95.99 mg/100g fruit) than control in chilli. It also improved N, P and K uptake when compared to uninoculated control.

Mycorrhizal inoculation increased concentration of N and P in host tissue in tomato plants (Edathil *et al.*, 1996). Studies conducted by Raut *et al.* (2003) reported that in tomato vitamin C content was the highest (16.5 mg/100g) in plants that received 30 t FYM + 5 kg *Azospirillum*. This treatment enhanced storage life also.

Kandasamy *et al.* (1985) reported that inoculation of mycorrhiza in brinjal resulted in an increase of 30.43 per cent and 43.04 per cent in N and P content over uninoculated control, whereas in chilli the increase in P content was 86.9 per cent. Sreeramulu and Bagyaraj (1986) reported that *Glomus fasciculatum* increased P and Zn content in chilli.

Nelson and Achar (2001) observed that inoculation of *Glomus fasciculatum* in cabbage caused more than two fold increase in nitrogen content, three fold increase in total sugars, four fold increase in starch content and P uptake. A similar trend was also observed in total chlorophyll, carotenoids and soluble protein content.

Nagaraju *et al.* (1999) tested three different VAM fungi to find its efficiency in aggregatum onion. It was found that *Glomus mosseae* infected plants exhibited significant improvement in the contents of chlorophyll, ascorbic acid and pyruvic acid compared to other species, and the difference was significant over uninoculted one.

Meerabai *et al.* (2007) reported that *Azospirillum* @ 1 kg/ha significantly improved quality of bittergourd like vitamin C and protein content.

2.1.4. Effect of biofertilizers on nutrient uptake and availability

Parvatham *et al.* (1989) reported that *Azospirillum* inoculation increased better uptake of N and P in okra cv. Pusa Sawani. This is by improving nitrogen availability in the rhizosphere and by production of enzymatic complex which solubilize unavailable form of phosphorus. In okra, available nutrient status in *Azospirillum* treated plots was higher compared to control. K uptake by plants (30.32 kg/ha) was significantly increased over control (28.57 kg/ha) (Raj, 1999).

Ray *et al.* (2005) reported that soil enriched with *Azospirillum* and FYM (15 t/ha) recorded two fold increase of available nitrogen (285.2 kg/ha) over sole application of FYM in okra cv. Pankaj. Jadhav *et al.* (2008) reported maximum total uptake of N (41.29 kg/ha), P (3.99 kg/ha) and K (42.11 kg/ha) in okra fruits due to the use of recommended dose of FYM in combination with *Azospirillum* @ 30 g/kg seed compared to recommended dose of NPK.

Kumari and Lakshmi (2009) reported significant increase in uptake of N (64.83 kg/ha), P (12.2 kg/ha) and K (45.01 kg/ha) by shoot, due to inoculation with *Azospirillum* isolates compared to non-inoculation (52.08 kg/ha, 8.9 kg/ha and 36.5 kg/ha respectively) in chilli.

In a study conducted at IIHR, Bangalore, Mohandas (1987) reported that *Glomus fasciculatum* or *Azotobacter vinelandii* singly or in combination increased plant growth, leaf nitrogen (3.65%) and phosphorus (0.368 ppm) content and yield (11.77 kg/plot) in tomato var. Pusa Ruby. In an experiment done by Shreenivasa *et al.* (2007), *Glomus fasciculatum* colonized tomato plants had higher P uptake amounting to 64.66 per cent increase over healthy check.

In a field experiment conducted in brinjal by Ramarethinam and Chandra (2005), inoculation of potash solubilizing bacteria (*Frateuria aurantia*) significantly increased vegetative characters, yield, nutrient uptake and chlorophyll content compared to treatments with K fertilizer application alone. Potassium mobilising power of *Frateuria aurantia* is high and that K availability could be increased to the magnitude of 5-60 kg/ha by its application as reported by Singh (2007).

Shalini *et al.* (2002) reported that in cabbage, available soil nitrogen was significantly higher in plots receiving organic manures and *Azospirillum* than those in inorganic fertilized plots.

In a work conducted at TNAU, Coimbatore to study the influence of biofertilizers in Bellary onion cv. N-53, it was found that N, P and K content of leaf were significantly enhanced by inoculation of *Azospirillum* and VAM either alone or in combination (Gurubatham, 1989). Laboratory and field experiments conducted to study the response of onion cv. Pusa Red to *Azospirillum* revealed that nitrogen uptake was more in *Azospirillum* inoculated onion (0.77 g/plant) than control (0.28 g/plant) (Tilak and Saxena, 2008).

N and P content in plant parts, N and K uptake, and S and Zn content in soil were significantly improved by microbial inoculation (*Azospirillum* + AMF each @ 2 kg/ha) in slicing cucumber. Microbial inoculation with neem cake produced highest crude protein content whereas *Azospirillum* + AMF along with enriched vermicompost gave the highest calcium content (Raj, 2006).

2.1.5. Effect of biofertilizers on microbial count

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 build-up of root population reaching 5.6×10^5 cfu/g fresh weight of root at 18 days after inoculation in tomato, and 5.4×10^5 cfu/g fresh weight of roots at 15 days after inoculation on eggplant.

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.

Shreenivasa *et al.* (2007) observed maximum mycorrhizal spore count in the rhizosphere of tomato plants inoculated with *Glomus fasciculatum*. It was 115, 312.5 and 329.16 spores/50 cc soil at 30, 60 and 90 DAS.

Population of *Azospirillum brasilense* found in rhizosphere of chilli ranged from 1.3 x 10^6 to 2.4 x 10^6 cfu/g soil and was significantly greater than *Azotobacter* (Constantino *et al.*, 2008).

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 highest number of spores (> 4000 spores/kg soil) whereas onion and tomato showed minimum number of spores (< 1300 spores/kg 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-mycorrhizal one (32.06 spores/10 g soil).

2.1.6. Effect of biofertilizers on economics

Study conducted by Raj (1999) in okra concluded that *Azospirillum* inoculation showed significantly higher fruit yield (141.97 q/ha) than control (129.74 q/ha) and registered a higher profit of Rs. 32,352/ha than control (Rs. 25,059/ha). The B: C ratio was 1.61.

Kamal *et al.* (2008) obtained the highest benefit cost ratio of 2.02 in tomato 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. Based on the observations made, potash mobilization capability of *F. aurantia* in general and in particular in brinjal has been reported on its fitness as a nutrient mobilizer.

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

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

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

Chandra *et al.* (2005) reported that *Frateuria aurantia* application enhanced yield by 15-25 per cent and thereby 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

Effect of VAM and soluble phosphorus on okra cv. Pusa Sawani was studied by Krishna and Bagyaraj (1982) in phosphorus deficient sandy loam soil. They found that root, shoot and total plant dry weight were significantly greater in mycorrhizal plants than in non mycorrhizal controls at all levels of added soluble P. However, significant difference was noticed only upto 100 per cent recommended P. The highest root length, plant height and number of fruits/plant were obtained in okra with 50 per cent recommended N and *Azospirillum* (2 kg/ha). Fruit yield was the greatest (205.91 g/plant) with *Azospirillum* + 75 per cent of the recommended N as reported by Sankaranarayanan *et al.* (1995).

Paramaguru and Natarajan (1993) reported that seed and soil application with *Azospirillum* along with 75 per cent nitrogen gave the highest yield of 2.45

t/ha as against 1.07 t/ha in control without N and *Azospirillum* in chilli cv. Local. This treatment also increased plant height, number of primary branches/plant and number of lateral roots/plant under semi dry condition. Selvaraj (1996) reported that plant height (58.15 cm), number of branches (12.16) and root spread (17.13 cm) were higher in chilli when both *Azospirillum* and phosphobacteria were applied along with inorganic N and P at full recommended dose when compared to full dose of N and P alone.

Field experiments conducted to study the effect of various biofertilizers on tomato cv. Co-3 revealed that the highest number of branches/plant (8.8) significantly taller plants (72.6 cm), higher number of fruits per plant (33.7), higher fruit weight (35.63 g) and higher yield (43.85 t/ha) were recorded in treatment with *Azospirillum* @ 2 kg/ha + 75 per cent N + 100 per cent PK. This treatment also recorded the highest B:C ratio of 3.76 (Premsekhar and Rajashree, 2009).

Application of FYM + poultry manure each @ 12.5 t/ha along with 100 per cent recommended inorganic fertilizers + *Azospirillum* + phosphobacteria each @ 2 kg/ha increased plant height, number of primary branches, leaves and leaf area in brinjal cv. Annamalai (Anburani and Manivannan, 2002). Application of 100:100:50 kg NPK/ha + *Azospirillum* + PSB each @ 125g/ha (root dipping) along with $ZnSO_4$ (0.2%) spray recorded significantly higher plant height (89.47cm), number of branches (32), number of leaves (87), number of fruits (20), fruit yield (27.06 t/ha), number of seeds/fruit (1852), 1000 seed weight (7.9 g), seed yield (633 kg/ha) and seedling dry weight (48.84 mg) over 125:100:50 kg NPK/ha in brinjal (Kiran *et al.*, 2010).

In cauliflower cv. Snowball-16, Bambal *et al.* (1998) reported that significantly maximum yield of 29.64 t/ha was obtained in treatment with 100 per cent N + *Azospirillum* + *Azotobacte*r each @ 250 g/ha. This treatment also gave early curd initiation (66.22 days) and maturity (98.35 days) which was superior to control. Maximum plant height (53.15 cm), leaf width (21.35 cm), leaf size (757.75 cm^2), minimum days taken in curd initiation (25.90) and curd maturity (26.80), maximum length (9.50 cm), width (20.55 cm) and size (195.26 cm^2) of curd, maximum fresh weight of leaves (985.25 g) and maximum average curd weight (874.45 g) were noted by application of ½ NPK + Pressmud @ 5 t/ha + VAM in cauliflower cv. Pusa Snowball K-1 (Chaurasia *et al.*, 2008).

A study conducted in Annamalai, Tamil Nadu, to determine the effect of biofertilizers with inorganic fertilizers on radish revealed that 75 per cent N and P + 100 per cent K + *Azospirillum* + VAM gave maximum shoot length at 25 DAS (30.84 cm) and 45 DAS (35.93 cm) and maximum leaf number at 25 DAS (9.67 cm) and 45 DAS (10.93 cm). It also gave maximum shoot yield (60.9 g), root yield (150 g) and yield per plot (3.31 kg) (Kamalakannan and Manivannan, 2003).

In an experiment conducted at CPRI, Modipuram, application of 37.5 per cent N (organic source) + 62.5 per cent N (inorganics) + *Azospirillum* (5 kg/ha) + VAM (25 kg/ha) improved growth and yield attributes like plant height (74.2 cm) and yield (264.7 q/ha) in potato cv. Kufri Bahar (Singh *et al.*, 2007).

Maximum yield of 62.5 t/ha was obtained in elephant foot yam cv. Gajendra by the application of 75 per cent RDF (through inorganic source) + 25 per cent RDF (through organic source) + AMF (5 kg/ha) + *Azospirillum* (5 kg/ha). Growth characters like plant height (72.29 cm) and canopy spread (73.4 cm) were also higher in this treatment (Patel *et al.*, 2010). It could be concluded that Integrated Nutrient Management is a better option than pure application of chemical fertilizers.

Maximum increase in plant height (17.13 cm) and higher leaf length (21.88 cm) were obtained in aggregatum onion plots treated with 60 kg N, 40 kg P and 30 kg K/ha combined with *Azospirillum* and phosphobacteria each @ 2 kg/ha, FYM (25 t/ha) and neem cake (200 kg/ha) in Kharif season (Sarkar, 1995). Nagaraju *et al*. (2000) reported that the highest mean performance for plant height (44.57 cm), number of leaves (27.68) at harvest and number of bulbs (7) were recorded in aggregatum onion treated with 100 per cent SSP + VAM whereas absolute control registered 29.76 cm and 15.88 for plant height and number of leaves respectively. This treatment also recorded 83.26 per cent and 119.49 per cent increase in bulb diameter and bulb weight over absolute control.

According to Mahanthesh *et al*. (2007) application of *Azospirillum* (500 g/ha) + 100 per cent NPK was the best in improving bulb weight (40.50 g), bulb volume (39.66 ml), neck diameter (1.66 cm), number of rings (9.22) and also ring thickness (1.94 mm) under rainfed condition during Kharif season in Bellary Red onion. Maximum plant height, number of green leaves, neck thickness, shoot girth, bulb diameter, bulb weight and yield was obtained in plants treated with N (75 kg) and *Azospirillum* (400 g per 2000 seedling root) in onion (Singh and Singh, 2007).

In an experiment conducted at Horticulture College and Research Institute, Coimbatore in pumpkin cv. Co-2, it was found that 20 t FYM + 9 kg N + 18 kg P + 24 kg K along with *Azospirillum* and phosphobacteria gave an yield of 16.9 kg (Rabi) and 17.79 kg (Kharif) per plant as against 9.49 kg and 8.68 kg per plant at recommended dose of 12 kg N, 24 kg P and 24 kg K. Other growth characters like the longest vine, the least number of days for first female flower and the highest dry matter production were also recorded in this treatment. (Karuthamani *et al*., 1995).

A field experiment was conducted during Rabi season to study the effect of VAM and PSB along with graded dose of fertilizers on growth and yield of French bean. Results revealed that 75 per cent RDF + VAM @ 2 kg/ha + PSB @ 2.5 kg/ha significantly increased plant height, number of branches, leaf area, dry weight of plants, number of pods per plant, number of seeds per pod, pod length and pod yield (Ramana *et al*., 2010).

Application of *Azospirillum* (2 g/plot) + N (5 kg/ha) recorded significant increase in plant height on 60^{th} day , number of primary and secondary branches and influenced early flowering in coriander cv. CO-2 (Vimala, 1991). In an experiment conducted at Horticultural Farm, Parbhani, Prabhu *et al.* (2002b) obtained the highest shoot: root weight ratio (2.42), leaf weight (16.60 g) and yield/plot (633.33 g) in coriander treated with 25 per cent RDF + FYM (10 t/ha) + *Azospirillum* + PSB.

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

In bhindi var. Pusa Sawani, Balasubramani *et al.* (1997) reported that seed (400 g/ha) and soil application (2 kg/ha) of *Azospirillum* along with application of 30 kg N/ha recorded the highest yield of 17.5 t/ha whereas in control it was 9.6 t/ha. This treatment gave the highest plant height (205.2 cm) and maximum number of fruits per plant (26.4) whereas the control registered only 73.4 cm and 17.3. Jeeva (1997) reported that in bhindi cv. Arka Anamika, pressmud @ 25 t/ha along with 40:50:30 kg NPK/ha and basal application of *Azospirillum* and phosphobacteria each @ 2 kg/ha and 10 per cent coconut milk spray produced the highest yield of 12.11 t/ha which was 46.88 per cent more over application of inorganic fertilizer alone.

Soil inoculation of *Azospirillum* in combination with N (40 kg/ha) gave a yield of 56.33 q/ha which was statistically equivalent to that obtained with 80 kg N/ha (56.78 q/ha) in okra cv. Parbhani Kranti (Ganeshe *et al.*, 1998). Seed treatment with *Azospirillum* (100g/100 g) along with 75 per cent N and full PK resulted in highest number of pods/plant (17.76), average fruit weight (24.46 g), yield of green pods/plant (609.33 g) and crop yield (119.02 q/ha) in okra cv.

VRO-5. This treatment gave 17.51 per cent more yield over control saving 25 per cent of nitrogenous fertilizers (Bahadur and Manohar, 2001).

Wange and Kale (2003) reported that inoculation of *Azospirillum* and *Azotobacter* along with 75 kg N/ha recorded significantly more plant height (33.1 cm), number of fruits (27) and yield (10.8 t/ha) in okra. In bittergourd, the same treatment gave significantly higher number of fruits (33), fruit length (17.9 cm), fruit weight (60.4 g) and yield (11.5 t/ha).

Application of *Azospirillum* (20 g/kg seed) and FYM (15 t/ha) in conjunction with 50 per cent and 100 per cent recommended NPK gave significantly increased fruit yield of 67.21 q/ha and 67.50 q/ha respectively whereas control (FYM alone) gave 51.83 q/ha as reported by Ray *et al.* (2005) in okra. Addition of *Azospirillum* and 50 per cent total nitrogen fertilizer as ammonium sulphate produced heavier pod weight and pod yield in okra. This treatment also gave best nutritional values in okra (Shaheen *et al.*, 2007).

A field experiment conducted to study the nutrient uptake and yield of okra as influenced by integrated plant nutrient supply revealed that, combined use of NPK (100:50:50 kg/ha) along with FYM (10 t/ha) and *Azospirillum* (30 g/kg seed) recorded highest fruit yield of 92.71 q/ha in okra (Jadhav *et al.*, 2008). An investigation was carried out to find out the effect of integrated nutrient management on seed production of okra cv. Varsha Uphar. When *Azospirillum* was applied @ 2 kg/ha in combination with 50 per cent N and P along with 30 kg K/ha, it recorded maximum pod width of 2.20 cm (Dar *et al.*, 2010a).

In tomato the highest yield of 54.32 t/ha was recorded in treatment where recommended dose of FYM and NPK were applied along with *Azospirillum* whereas the treatment with FYM alone recorded only 30.13 t/ha (Harikrishna *et al.*, 2002).

Nanthakumar and Veeraragavatham (2000) reported that combined nutrition of organic fertilizers through 12.5 t/ha of FYM, 2 kg each of *Azospirillum* and phosphobacteria with inorganic fertilizers at 75 per cent recommended dose of N and P and 100 per cent K influenced growth parameters registering the highest yield of 36.48 t/ha in brinjal cv. Palur 1. In an experiment to find the role of *Frateuria* in supplementing potash nutrient to brinjal, Murugesan (2008) reported that treatment involving *Frateuria* + 50 per cent RDF, 75 per cent RDF and 100 per cent RDF recorded significantly higher yield of 28.28 t/ha, 28.34 t/ha and 28.42 t/ha respectively compared to stand alone treatment involving only *Frateuria* and only potash at different proportions of the recommended dose.

The effect of individual factors *viz.* N, P, K and *Azospirillum* and the interactions between them in cabbage revealed that N:P:K @ 100:125:25 kg/ha and soil application of *Azospirillum* (2 kg/ha) was optimum for cabbage to get increased yield of 117.2 t/ha (Jeevajothi *et al.*, 1993). In a field experiment conducted during Rabi to find the effect of biofertilizers in cauliflower, Khan *et al.* (2009b) obtained maximum curd yield (216.6 q/ha) with the application of *Azospirillum* (500 g/ha) + 100 per cent RDF as compared to application of other biofertilizers + inorganic fertilizers. It was 23 per cent more than the recommended dose of fertilizers (control).

Use of 45 kg N/ha in combination with *Azotobacter* and *Azospirillum* increased carrot productivity by 50 per cent over that observed at recommended dose of 60 kg N/ha (Wange, 1996). Vendan and Nanjan (1998) reported that combined application of *Azospirillum*, phosphobacteria and VAM with 75 per cent NPK recorded higher yield of 14.49 t/ha in potato cv. Kufri Jyothi which was 21 per cent over uninoculated control (11.93 t/ha).

Inorder to explore the possibility of improving growth and productivity of *Amorphophallus* by involving INM, Saravaiya *et al.* (2010) conducted an experiment during Kharif in variety Gajendra. They reported that application of

100 per cent RDF + *Azospirillum* (5 kg/ha) + PSB (5 kg/ha) gave the highest corm yield of 55.33 t/ha.

Application of *Azospirillum* as seed (50-100 g/100 g) and soil application (3 kg/ha) + VAM (1 kg/m^2) in combination with 100 per cent recommended dose of N and P registered highest yield of bulb (45.3 q/ha) and total dry matter yield (7.9 q/ha) in Bellary onion NP 53 (Subbiah, 1994). Thilakavathy and Ramaswamy (1999) conducted a study to find the effect of inorganic and biofertilizers in multiplier onion cv. Co-4. The highest yield of 18.37 t/ha was obtained when treated with 45:45:30 kg NPK/ha + *Azospirillum* + phosphobacteria compared to 16.59 t/ha in control.

Santhi *et al.* (2005) conducted a study on the effect of fertility and integrated plant nutrition on aggregatum onion cv. Co-4. Maximum yield (18.84 t/ha) was reported when onion was treated with FYM (25 t/ha) + *Azospirillum* (2 kg/ha) along with NPK @ 90:60:60 kg/ha. A field experiment was carried out for three years during Rabi at ARS, Durgapura to find out the suitable dose of N with and without biofertilizers in onion cv. RO-1 by Yadav *et al.* (2005). It was found that 75 per cent recommended dose of nitrogen along with *Azospirillum* given as seed (500 g/ha), seedling (1 kg/ha) and soil (1 kg/ha) application gave significantly higher bulb yield of 328.4 q/ha.

Seed inoculation of onion using *Azospirillum* (500 g/ha) gave 11.33 per cent increase in mean bulb yield over uninoculated control in Pusa Red variety. Inoculation of *Azospirillum* with 60 kg N/ha brought significant increase in bulb yield over its control (Tilak and Saxena, 2008).

In a study conducted at ARS, Hiriyur, in onion cv. Bellery Red, Mahanthesh *et al.* (2009b) found that plants provided with *Azospirillum* (500 g/ha) + 100 per cent NPK produced highest bulb yield of 232.98 q/ha which was 63 per cent more over control and the highest dry matter production (6287.03 kg/ha) under rainfed condition during Kharif season. Adagale *et al.* (2010) reported that in onion cv. Phule Samrat, number of flower stalk (7.66), number of seeds/umbel (874), number of seeds/bulb (3121), weight of seeds/umbel (3.27g), weight of seeds/bulb (12.8 g) and seed yield/ha (384 kg) were significantly increased with the application of 150:75:75 kg NPK/ha + FYM (20 t/ha) + *Azospirillum* (12.5 kg/ha) + PSB (12.5 kg/ha) + VAM (16 kg/ha).

Study conducted by Sood and Vidyasagar (2008) at Vegetable Research Farm, Himachal Pradesh revealed that treatment with 80 per cent N + *Azospirillum* @ 200 g/kg seed was associated with higher marketable yield (52.71 t/ha) in summer squash cv. Pusa Alankar. In watermelon, Muruganandam and Anburani (2010) reported that application of N @ 75 kg/ha along with *Azospirillum* @ 200 g/kg of seed recorded the highest fruit length (38.65 cm), fruit girth (46.72 cm), fruit weight (5.81g), number of fruits/vine (4.66) and fruit yield/ha (53.64 t/ha).

Prasad *et al.* (2008) reported that application of VAM (100 g/ha), *Rhizobium* culture (250 g/10 kg seed) and P_2O_5 (80 kg/ha) significantly increased yield contributing characters like number of pods/plot (44.32), length of pod (21.08 cm), fruit weight (4.35 g) and yield (63.22 q/ha) in cowpea.

Work done at Annamalai University revealed that application of 56.25 : 22.5 : 45 g NPK/plant + 10 kg FYM/plant + *Azospirillum* and phosphobacteria each @ 2 kg/ha registered highest values for number of inflorescence/plant (54.77), number of flowers/inflorescence (95.23), fruit set (3.9%), fruit length (67.2 cm), fruit girth (4.9 cm), number of fruits (129) and fruit weight (126.8 g) and thereby resulting in higher yield (45.9 t/ha) in drumstick cv. PKM-1 (Rajeswari and Mohideen, 2004).

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

In chilli, combined application of 100 per cent recommended dose of N and P along with biofertilizers (*Azospirillum* + VAM) recorded the highest P content (0.7 %) (Subbiah, 1994). Ascorbic acid (136.77 mg/100g), capsaicin (4.17 mg/g), and oleoresin (8.96 %) in chilli were more when *Azospirillum* (4 kg/ha) and phosphobacteria (4 kg/ha) 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). This treatment also gave higher fruit length (7.94 cm), fruit girth (2.7 cm) and fruit number per plant (78).

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 + recommended dose of fertilizers (Kamal *et al.*, 2008). In a study conducted to find the influence of biofertilizers on tomato cv. Co-3, it was found that *Azospirillum* @ 2 kg/ha + 75 per cent N + 100 per cent PK recorded higher TSS of 4.45^0B. This treatment also recorded 33.7 fruits per plant with an average fruit weight of 35.63 g, highest yield (43.85) and recorded highest cost benefit ratio of 3.76 in tomato (Premsekhar and Rajashree, 2009).

In brinjal when *Azospirillum* was inoculated @ 1 kg/ha along with recommended dose of chemical nitrogen, it resulted in significantly higher vitamin C content of 30.21 mg/100 g (Kamili *et al.*, 2002). Sreeja (2003) reported that chilli plants treated with *Azospirillum* @ 1 kg/ha and 2:1 NK ratio gave significantly higher mean ascorbic acid content of 140.25 mg/100g.

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

In an experiment conducted at Horticultural Research Station, Kodaikanal, Mahendran and Kumar (1998) found that potato treated with two equal split doses of 100 per cent recommended dose of NPK + *Azospirillum* + phosphobacteria increased ascorbic acid (21.27 mg/100g) and protein content (9.19 %) by 2.26 per cent and 1.21 per cent over control. This treatment was found to have maximum tuber yield of 25.87 t/ha which is 23.89 per cent more when compared to control. This also increased dry matter content by 3.6 per cent over 100 per cent recommended dose of NPK alone.

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 was higher (0.33 %) during Rabi in plots treated with 60 kg N and P, 30 kg K along with *Azospirillum* (2 kg/ha), phosphobacteria (2 kg/ha), FYM (25 t/ha) and neem cake (200 kg/ha) in aggregatum onion cv. Co-4. This treatment also gave higher bulb length (4.28 cm and 4.37 cm), bulb girth (9.47 cm and 10.10 cm) and bulb weight (42.8 g and 42.42 g) in Kharif and Rabi respectively.

In a field experiment done at Vegetable Research Farm at IARI in onion cv. Pusa Red, co-inoculation of *Azospirillum* (500 g/ha) + VAM (100 g/ha) + 50 kg N + 25 kg P gave highest TSS (13.11 %). This treatment also resulted in 13.41 per cent and 13.81 per cent increase in soil available P and N compared to initial fertility status as reported by Mengistu and Singh (1999). In an investigation conducted at Vegetable Research Farm, New Delhi, Jha *et al.* (2006) showed marked increase in TSS of onion bulb Pusa Madhavi (13.2^{0}B) in plants treated with *Azospirillum* and VAM along with half N and P. This treatment also showed minimum storage loss.

Kirad *et al.* (2010) got higher values of vitamin A (997.52 IU) in carrots treated with ½ RDF + ½ FYM + *Azospirillum* and phosphobacteria @ 5 kg/ha.

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

Subbiah (1991) reported that in bhindi cv. Co-2, application of 50 per cent recommended nitrogen and soil application of *Azospirillum* (2 kg/ha) gave the highest yield of 23.97 t/ha which was 13.3 per cent over control. This also registered the highest value for N uptake (278.2 kg/ha). This treatment had beneficial effect on nitrogen use efficiency besides saving upto 50 per cent recommended nitrogen in okra.

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), P (23.63 kg/ha) and K (155.57 kg/ha) in chilli (Selvaraj, 1996). In chilli, total uptake of N was significantly increased by treatment with 3:1 NK ratio and *Azospirillum* inoculation, whereas *Azospirillum* along with 2:1 NK ratio recorded maximum P and K uptake (Sreeja, 2003).

Application of FYM (25 t/ha) + 75 per cent N + 100 P and K along with *Azospirillum* resulted in the highest available N (299.9 kg/ha), P_2O_5 (44.2 kg/ha) and K_2O (321.9 kg/ha) in tomato (Harikrishna *et al.*, 2002). 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 egg plant grown on P and K limited soil.

In cabbage, according to Shalini *et al.* (2002) application of 50 per cent N (urea) + 50 per cent N (vermicompost) + *Azospirillum* resulted in higher uptake of nutrients. Maximum growth in terms of increased plant height, number of leaves and dry matter production were also observed in this treatment.

Inoculation of *Azospirillum* and higher dose of fertilizers improved plant uptake of N whereas application of AMF alone or with lower dose of fertilizers enhanced P uptake in amaranth (Niranjana, 1998).

In onion *Azospirillum* + VAM + 50 kg N + 50 kg P gave 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), P (25.54 kg/ha) and K (246.21 kg/ha) in treatments 25 per cent RP + VAM, 100 per cent RP + VAM and 50 per cent RP + VAM in aggregatum onion.

Mahanthesh *et al.* (2009a) reported that *Azospirillum* @ 500 g/ha along with 100 per cent NPK (125:50:125 kg/ha) showed maximum uptake of N (146.16 kg/ha), P (67.45 kg/ha) and K (59.42 kg/ha) in Bellary onion bulb, whereas inoculation of *Azospirillum* alone gave 41.73 kg/ha, 37.72 kg/ha and 36.61 kg/ha respectively.

2.2.5. Effect of biofertilizers and fertilizers on microbial count

Effect of VA mycorrhiza 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 (448/100 ml soil) was recorded when no soluble phosphorus was added.

Davies and Linderman (1991) reported that in *Capsicum annuum*, the number of AMF spores recovered from soil decreased with increasing phosphorus fertility. At lower phosphorus (11 μg/ml) the spore count was 1241/100 cm^3 soil whereas, at high phosphorus (44 μg/ml) it was 611/100 cm^3 soil.

In chilli cv. Jwalamukhi, population of *Azospirillum* (13 x 10^3) and actinomycetes (18 x 10^4) were significantly high in 100 per cent N + half vermicompost + *Azospirillum* @ 5 kg/ha. In amaranth 75 per cent N + FYM + *Azospirillum* gave significantly higher number of bacteria (17 x 10^6) and fungi (13.7 x 10^4) (Arunkumar, 1997).

Raji (2002) studied the effect of VAM and different sources and doses of phosphorus on root colonization and rhizosphere count in tomato cv. Sakthi. Maximum spore count of 417.5 g/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 /50 g soil was recorded in VAM + FYM + N + 50 per cent single super phosphate + K.

In a study conducted at KAU, Thrissur, Sreeja (2003) reported that chilli plants treated with *Azospirillum* @ 1 kg/ha and 2:1 NK ratio registered maximum mean *Azospirillum* count of 8.33 x 10^5 cfu/g.

Laboratory and field experiments were conducted 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 and 60 kg/ha stimulated bacterial counts (1.72 x 10^8 and 3.21 x 10^8 per g fresh root weight respectively) whereas at higher levels of N (90 kg/ha) population was low even in the presence of bacterium (Tilak and Saxena, 2008).

2.2.6. Effect of biofertilizers and fertilizers on economics

Prabhu *et al.* (2002a) reported that treatment combination of 2/3rd recommended dose of fertilizers + *Azospirillum* + VAM (1g/hill) resulted in the highest yield thereby suggesting a possibility of reducing 1/3rd RDF without any detrimental effect on yield of okra cv. Parbhani Kranti.

In a study conducted by Sreeramulu and Bhagyaraj (1986) where four different VAM fungi were inoculated in chilli @ 2 kg/bed, it was found that the yield of *Glomus fasciculatum* inoculated plants at half P (0.52 kg/plot) was more than the plants receiving full P (0.43 kg/plot), suggesting that application of phosphatic fertilizer could be reduced through mycorrhizal inoculation.

Application rate of P fertilizers could be reduced by 50 per cent if *Capsicum annuum* were inoculated with efficient AMF along with the application of lower levels of P (Sreenivasa *et al.*, 1993). *Azospirillum* inoculation registered maximum mean fruit per plant (56.36) in chilli and this treatment gave highest B:C ratio of 2.44 (Sreeja, 2003).

Kamili *et al.* (2002) reported that combination of 75 per cent chemical nitrogen performed better in brinjal. This indicated that 25 per cent chemical nitrogen could be saved without affecting the yield of crop.

Data on three crops (tomato, chillies and brinjal) showed that the use of both inoculants *Azotobacter* and *Azospirillum* in conjunction with 75 per cent recommended nitrogen recorded significant increase in growth characteristics and yield as compared to control. The results indicated that N fixing biofertilizers could reduce the use of inorganic nitrogen by 25-50 per cent in vegetable crops (Khan *et al.*, 2008a).

A study conducted by Sharma (2002) at Horticultural Research Station, Himachal Pradesh found that *Azospirillum* when given as seed treatment (0.5 kg/ha), seedling treatment (1 kg/ha) and soil application (5 kg/ha) along with 60 kg N/ha, it gave the highest head weight (1.58 kg) per plant as well as head weight/ha (52.64 t) which resulted in highest benefit cost ratio (2.9) in cabbage, whereas treatment with *Azospirillum* alone gave a B:C ratio of 0.88.

Experiments were conducted during the Rabi season at Faizabad to evaluate the response of cauliflower cv. Snowball-16 to four biofertilizers. Inoculation of *Azospirillum* along with recommended dose of NPK @ 120:60:60 kg/ha produced maximum average curd weight (1.1 kg) and curd yield (28.2 t/ha). This treatment also recorded the highest net return (Rs. 53,965/ha) and benefit cost ratio (2.23) as reported by Singh and Singh (2005).

Plots treated with 40 kg N and P, 30 kg K along with *Azospirillum* (2 kg/ha), phosphobacteria (2 kg/ha), FYM (25 t/ha) and neem cake (200 kg/ha) recorded the highest net income of Rs. 27, 046/ha with B: C ratio of 1.91 in aggregatum onion as against net income of Rs. 19,051 with B:C ratio of 1.78 which was obtained with recommended dose of fertilizers (Sarkar, 1995).

In an experiment to study the effect of *Glomus* and *Azospirillum* on growth and yield of onion cv. B-780, Navale and Wani (2004) found that application of 75 kg N/ha + *Glomus* (1 kg/m^2) + *Azospirillum* inoculation (200 g as root dip) recorded near about same yield (31.18 t/ha) as recorded by application of 100 kg N/ha along with *Glomus* and *Azospirillum* (31.40 t/ha). This indicated the possibility of saving fertilizer nitrogen to an extent of 25 kg N/ha but also showed 21.57 to 24.15 per cent increase in yield over uninoculated control.

In onion 75 kg N/ha along with *Azospirillum* inoculation fetched the highest net profit per hectare (Rs. 31,288) with a benefit cost ratio of 10.0 which is on par with 100 kg N/ha + *Azospirillum* (Rs. 32,792) (Yadav *et al.*, 2005). 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 *Azospirillum* + 100 per cent NPK under irrigated and rainfed condition. The control plots registered a maximum net profit of Rs. 30,781 and Rs. 27725 with B:C ratio of 2.93 and 2.86.

Prabhu *et al.* (2006) conducted a study on INM in cucumber at TNAU, Coimbatore. It concluded that application of 50 per cent RDF + Vermicompost (2 t/ha) + *Azospirillum* (2 kg/ha) + phosphobacteria (2 kg/ha) increased the vine length, earliness in flowering and gave highest number of fruits (8.4), yield (32.8 t/ha) and B:C ratio (2.24). A basal dose of FYM (25 t/ha) and application of poultry manure to supply the recommended dose of 70 kg N/ha (on N equivalent basis) in combination with *Azospirillum* @ 1 kg/ha was the best economic organic nutrient schedule in bitter gourd (Meerabhai *et al.*, 2007).

In a work conducted at TNAU, Coimbatore, Vimala (1991) reported that *Azospirillum* (2 g/plot) along with normal dose of N (20 kg/ha) gave the highest yield of 926 kg/ha and maximum net profit of Rs. 6458.56/ha in coriander cv. Co-2. This treatment also gave maximum B: C ratio of 2.23.

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

Prabhakar *et al.* (2003) reported that in drumstick cv. PKM-1, application of 50:50:50 kg NPK/ha + biofertilizers (*Azospirillum* + phosphobacteria) @ 2.5 kg/ha with polythene mulch recorded significantly higher number of fruits/plant (104.9), fruit yield per plant (6.29 kg) and fruit yield/ha (10.93 t). This treatment gave significantly higher gross returns (Rs. 163880/ha), net returns (Rs. 141439/ha) and B:C ratio (6.30).

Materials and Methods

3. MATERIALS AND METHODS

The present study was carried out in the Department of Olericulture, College of Horticulture, Vellanikkara during 2010-2011 with an objective to study the response of okra (*Abelmoschus esculentus* (L.) Moench) to biofertilizers.

3.1. EXPERIMENTAL SITE

3.1.1. Location

The experimental site is located at 10^0 32' N latitude, 72^0 16' E longitude and at an altitude of 22.25 m above MSL.

3.1.2. Climate and soil

The area experiences a typical warm humid climate. Data on maximum and minimum temperature, average rainfall, relative humidity and soil temperature during the entire cropping period were collected from meteorological observatory of College of Horticulture, Vellanikkara (Appendix I). The soil of the experimental site is a well drained laterite loam soil and is acidic in reaction.

3.1.3. Season of experiment

The crop was raised from May 2010 to September 2010.

3.2. MATERIALS

3.2.1. Variety

The okra variety Arka Anamika which was developed from IIHR, Bangalore was selected for the study.

3.2.2. Biofertilizers

Commercial formulations of *Azospirillum* and AMF obtained from the College of Agriculture, Vellayani and Symbion-K, a formulation containing *Frateuria aurantia* were used.

3.2.3. Organic Manures

Farm yard manure containing 1 per cent N, 0.5 per cent P_2O_5 and 1 per cent K_2O was used.

3.2.4. Inorganic fertilizers

Urea (46% N), Factomphos (20% N and 20% P) and Muriate of Potash (60% K) were used as sources of chemical fertilizers.

3.3. METHODS

3.3.1. Layout and experimental design

The experiment was laid out in Randomized Block Design (RBD) with three replications (Plate. 1). The size of plot was 3.6 m x 3.6 m. Spacing adopted was 60 x 45 cm. The manurial and fertilizer doses were based on Package of Practices recommendation (KAU, 2007) for bhindi. Accordingly, FYM and NPK were applied @ 12 t/ha and 50:8:25 kg N: P_2O_5: K_2O respectively.

3.3.2. Treatments

Treatment details of the experiment are furnished below (Plate. 2)

T_1 - FYM + *Azospirillum* @ 2 kg/ha

T_2 - FYM + AMF @ 2 kg/ha

T_3 - FYM + *Frateuria* @ 2 kg/ha

T_4 - FYM + *Azospirillum* + AMF each @ 2 kg/ha

T_5 - FYM + *Azospirillum* + *Frateuria* each @ 2 kg/ha

T_6 - FYM + AMF + *Frateuria* each @ 2 kg/ha

T_7 - FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha

T_8 - FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha

T_9 -FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha

Plate 1: Field view of experimental plot

T_{10} - FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha

T_{11} - POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg/ha

T_{12} - *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha

T_{13} - Manures and fertilizers as per POP recommendation (control)

Mulching was provided in all treatments. Upto T_7, FYM was applied as per Package of Practices.

3.4. FIELD EXPERIMENT

3.4.1. Land preparation and sowing

The experimental area was ploughed twice, weeds were removed and the land was levelled before layout. Furrows were taken 60 cm apart and seeds were sown at a spacing of 45 cm. Full dose of FYM, half dose of N, and full dose of P_2O_5 and K_2O of recommended dose were applied as basal dose.

3.4.2. Application of biofertilizers

Azospirillum and Arbuscular Mycorrhizal Fungi (AMF) were applied in the root zone after mixing with dried FYM in the ratio of 1:25. *Frateuria* was mixed with FYM @ 4ml/kg FYM. Mulching was provided in all treatments.

3.4.3. After cultivation

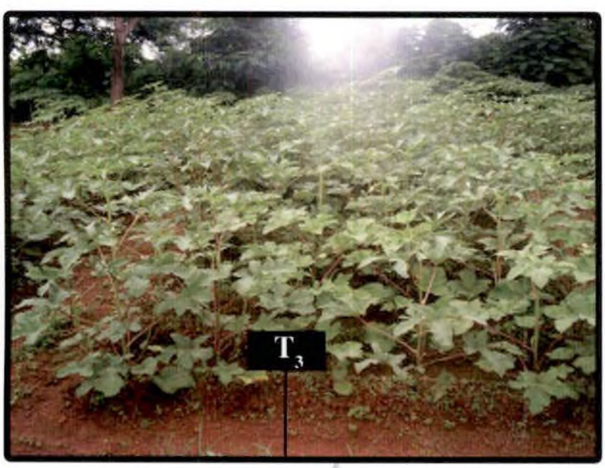
Furrows were hand weeded regularly to keep the field free from weeds. Irrigation was given daily for one week and thereafter it was given once in two days. Light earthing up was done along with the application of remaining half dose of nitrogen at 30 days after sowing (DAS). Mulching was done at 45 DAS.

3.4.4. Plant protection

Biocontrol agents like *Pseudomonas fluorescens* (10 g/l) and botanical *viz.* Econeem (2 ml/l) were applied as and when required.

T_1

T_2



T_3

T_4

Plate 2: Okra plants under different treatments

T_5

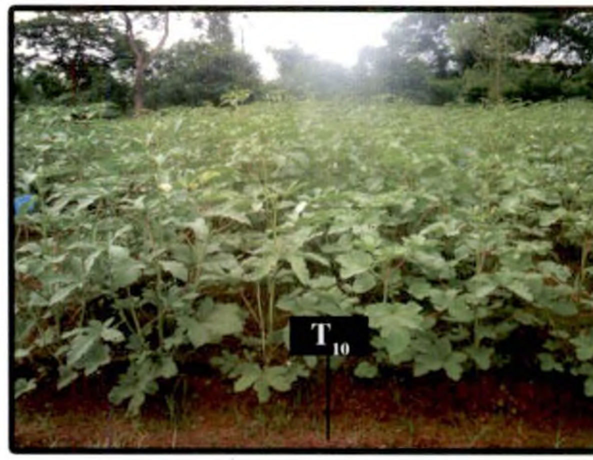
T_6

T_7

T_8

Plate 2: Okra plants under different treatments

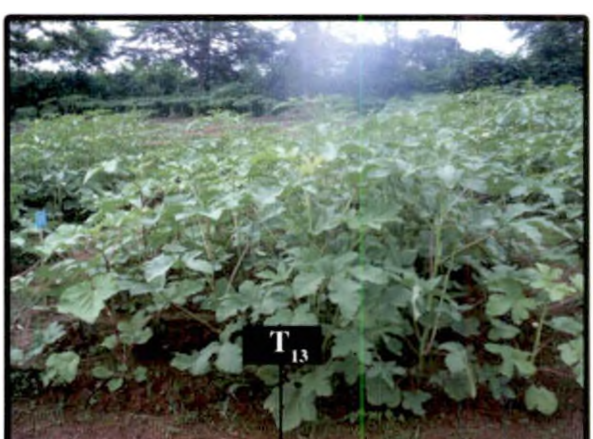
T_9



T_{10}

T_{11}

T_{12}



T_{13}

Plate 2: Okra plants under different treatments

3.4.5. Harvesting

Fruits were harvested at vegetable maturity stage.

3.5. BIOMETRICAL OBSERVATIONS

Biometrical observations were taken from the observational plants from each plot.

3.5.1. Growth parameters

3.5.1.1. Days *to germination*

The number of days taken from sowing to germination was recorded.

3.5.1.2. Height of plant (m)

Height was measured from base to the terminal bud at 40 DAS, 60 DAS, 80 DAS and 100 DAS from selected plants. The mean was worked out and expressed in metres.

3.5.1.3. Number of leaves

Number of leaves was counted at 60 DAS, 80 DAS and 100 DAS from selected plants. The mean was calculated.

3.5.1.4. Number of branches

Number of branches was counted at 60 DAS, 80 DAS and 100 DAS from the selected plants and the mean was worked out.

3.5.1.5. Chlorophyll content

The relative chlorophyll content of leaves was measured using Soil and Plant Analysis Development (SPAD) meter (Konica Minolta) at 70 DAS. Ten mature leaves were selected for taking observation. The mean was noted and expressed in SPAD units.

3.5.1.5. Total dry matter production (g/plant)

Plant samples were collected after final harvest. It was dried in shade and oven dried at 80±5^{0}C to a constant weight. The dry weight was taken and expressed in g/plant.

3.5.2. Earliness of the crop

3.5.2.1. Days to first flower opening

Number of days taken from sowing to opening of first flower in each plot was recorded.

3.5.2.2. Node at which first flower appears

The node at which the first flower appeared was recorded from the selected plants.

3.5.2.3. Days to first harvest

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

3.5.3. Biometrical characteristics of fruit

3.5.3.1. Fruit weight (g)

Weight of fruits from 5th to 15th harvest was recorded from the selected plants and their mean was worked out.

3.5.3.2. Fruit length (cm)

Length of fruits from 5th to 15th harvest was recorded from the selected plants and their mean was calculated.

3.5.3.3. Fruit girth (cm)

Girth of fruits from 5th to 15th harvest was recorded from the middle of the fruit. The mean was worked out.

3.5.3.4. Number of seeds per fruit

Number of seeds from randomly selected fruits was counted and their mean was taken.

3.5.4.1. Yield characteristics

3.5.4.1. Number of fruits per plant

Total number of fruits from the selected plants at each harvest was counted and the mean was calculated.

3.5.4.2. Fruit yield per plant (g)

Weight of fruits from the selected plants was recorded and the mean was calculated to get the fruit yield per plant.

3.5.4.3. Total fruit yield (t/ha)

Weight of fruits from each plot after harvest was recorded and added to get the fruit yield per plot and converted to t/ha.

3.5.4.5. Number of harvests

Total number of harvests from each plot was recorded.

3.5.4.6. Duration of crop (days)

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

3.5.5. Fruit quality parameters

3.5.5.1. Vitamin C content (mg/100 g)

Vitamin C content of fruit at vegetable harvest stage was estimated by titration with 2, 6 - dichlorophenol indophenol dye (Sadasivam and Manickam, 1997). From the fresh sample, 5 g was weighed and extracted in 4 per cent oxalic acid using a mortar and pestle and made upto 100 ml. From the extract 5 ml was pipetted out, 10 ml of 4 per cent oxalic acid was added and titrated against the dye. Ascorbic acid content of the fresh sample was calculated from the titrated value and was expressed as mg per 100g of fresh fruit.

3.5.5.2. Beta carotene content (μg/100g)

Beta carotene was estimated by the method of A. O. A. C (1970) using saturated n-butanol. Dried sample (5 g) was taken in a 125 ml glass flask and 50 ml water saturated n-butanol was added. The flask was stoppered tightly and kept overnight, shook well for one minute and kept overnight, protected from sunlight. Supernatant was decanted and 0.5 ml of it was pipetted out. It was diluted with 10 ml of water saturated n-butanol and the colour intensity was read in spectrophotometer at 435.8 nm.

3.5.5.3. Crude protein content (%)

The percentage of crude protein (dry weight basis) was calculated by multiplying the per cent of nitrogen in the fruit by the factor 6.25 (Simpson *et al.*, 1965) and expressed as percentage.

3.5.5.4. Shelf life (days)

Harvested fruits from each treatment and replication were kept at room temperature for seven 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 oven dried at 80 ± 5^0C. The dried samples were ground, mixed and chemically analysed for N, P, K, Ca, Mg, Fe and Zn.

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 a flame photometer (Jackson, 1958).

3.5.6.1.4. Secondary and micronutrients (%)

Secondary nutrients (Calcium and Magnesium) and micronutrients (Zinc and Iron) were estimated by Atomic Absorption Spectrophotometer (Jackson, 1958).

3.5.6.1.5. Plant uptake of N, P and K (kg/ha)

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 50 DAS and at 100 DAS. The air dried samples were chemically 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.

Table 1: 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)	Conductivity meter	Jackson (1958)

3.5.7. Enumeration of *Azospirillum*, AMF and *Frateuria* in rhizosphere soil

Enumeration of *Azospirillum*, AMF and *Frateuria* in the rhizosphere was carried out before treatment application 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* and *Frateuria* in rhizosphere 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).

3.5.7.2. Arbuscular Mycorrhizal Fungi

The total spore count of AMF from rhizosphere soil was counted by wet sieving and decanting method (Gerdeman and Nicolson, 1963).

In a beaker, 10 g of sieved soil sample was taken and 1000 ml of water was added. It was agitated vigorously till the heavier particles settled down. The supernatant was poured gradually through a series of sieves (1000μ, 425 μ, 250 μ, 105μ and 45 μ) arranged in descending order of their size. The 105μ and 45μ sieves were washed gently with water and transferred along with spores to a filter paper marked with quadrants and observed under the stereo-microscope (200 X). The AMF spores were counted in each quadrant and expressed as total number per 10 g soil.

3.6. Incidence of pests and diseases

Observations on the incidence of pests and diseases were recorded for mosaic, and shoot and fruit borer. The percentage of pest and disease incidence was calculated using the following formula.

$$\text{Percentage of shoot and fruit borer infestation} = \frac{\text{Number of fruits affected by fruit and shoot borer}}{\text{Total number of plants}} \times 100$$

$$\text{Percentage of mosaic infection} = \frac{\text{Number of plants affected by mosaic}}{\text{Total number of plants}} \times 100$$

3.7. Economics of cultivation

Economics of production was worked out by including all aspects of cost of cultivation and the income derived 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 'Response of okra to biofertilizers' was conducted at the Department of Olericulture, College of Horticulture, Vellanikkara, Thrissur during 2010-2011. The okra variety Arka Anamika was selected for the study. Commercial formulation of *Azospirillum*, AMF and *Frateuria aurantia* were used in thirteen treatment combinations. The control treatment was the POP recommendation of Kerala Agricultural University. The results obtained are presented below.

4.1. Growth parameters

Data related to growth parameters are given in Table 2 to 6.

4.1.1. Days to germination

Days to germination ranged from 4 to 6 days. Maximum days taken for germination (6 days) was recorded in T_{13} (Manures and fertilizers as per POP recommendation) (Table 2).

4.1.2. Height of plant (m)

Plant height as influenced by different biofertilizers at 40, 60, 80 and 100 DAS are presented in Table 3.

No significant variation was noticed between treatments at 40 DAS and 60 DAS. It ranged from 0.31 m to 0.43 m and 0.79 m to 1.13 m at 40 DAS and 60 DAS respectively. At 80 DAS, T_{11} (POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg/ha) recorded the maximum height of 1.95 m and the treatments T_{10}, T_7, T_8, T_3, T_2, T_{13}, T_9 and T_1 were on par.

At 100 DAS, a differential response in height was noticed among treatments. T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded significantly higher plant height of 2.19 m

Table 2: Effect of treatments on days to germination

Treatments	Days to germination
T_1	4.00 [a]
T_2	4.00 [a]
T_3	4.00 [a]
T_4	4.67 [a]
T_5	4.67 [a]
T_6	5.33 [a]
T_7	5.33 [a]
T_8	4.67 [a]
T_9	4.00 [a]
T_{10}	4.00 [a]
T_{11}	5.33 [a]
T_{12}	4.67 [a]
T_{13}	6.00 [a]

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

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

Treatments	Height of plant (m)			
	40 DAS	60 DAS	80 DAS	100 DAS
T_1	0.31 [a]	0.96 [a]	1.69 [abc]	1.96 [abc]
T_2	0.37 [a]	1.07 [a]	1.74 [abc]	1.97 [abc]
T_3	0.35 [a]	1.00 [a]	1.79 [abc]	1.84 [c]
T_4	0.35 [a]	1.03 [a]	1.68 [bc]	1.84 [c]
T_5	0.34 [a]	1.03 [a]	1.63 [bc]	1.78 [c]
T_6	0.35 [a]	0.81 [a]	1.67 [bc]	1.92 [bc]
T_7	0.35 [a]	1.02 [a]	1.84 [ab]	2.12 [ab]
T_8	0.39 [a]	1.13 [a]	1.81 [ab]	2.15 [ab]
T_9	0.37 [a]	1.03 [a]	1.71 [abc]	1.92 [bc]
T_{10}	0.37 [a]	1.04 [a]	1.88 [ab]	2.19 [a]
T_{11}	0.43 [a]	1.11 [a]	1.95 [a]	2.12 [ab]
T_{12}	0.31 [a]	0.79 [a]	1.53 [c]	1.86 [c]
T_{13}	0.33 [a]	1.08 [a]	1.72 [abc]	1.95 [abc]

Treatment means having similar alphabets in superscript do not differ significantly
DAS – Days after sowing

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

and T_5 (FYM + *Azospirillum* + *Frateuria* each @ 2 kg/ha) recorded the minimum height (1.78 m). Treatments T_8, T_7, T_{11}, T_2, T_{13} and T_1 were on par with T_{10}.

4.1.3. Number of leaves

Data on the effect of various treatments on number of leaves at 60 DAS, 80 DAS and 100 DAS are given in Table 4.

Leaf number at 60, 80 and 100 DAS showed significant differences. At 60 DAS, treatment T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) showed maximum number of leaves (37.67). All the treatments except T_1, T_3 and T_{12} were on par.

At 80 DAS, T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest leaf number (54.33). At 100 DAS, also maximum leaves (50.33) were observed in T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and the treatments T_{10}, T_7, T_9, T_{11}, T_6 and T_5 were on par. The least number of leaves was observed in T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) at all stages.

4.1.4. Number of branches

Number of branches was found to be non-significant at all stages of growth (Table 5). It ranged from 3.33 to 4.67 at 100 DAS.

4.1.5. Chlorophyll content

The relative chlorophyll content of different treatments at 70 DAS is given in Table 6. There was significant variation with respect to relative chlorophyll content of leaves. It was maximum (48.73 SPAD units) in T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and the treatments T_5, T_2, T_{10}, T_1, T_3, T_{11}, T_6 and T_{12} were on par. The minimum value (40.73 SPAD units) was observed in T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha).

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

Treatments	Number of leaves		
	60 DAS	80 DAS	100 DAS
T_1	27.67 ^{b}	40.00 ^{bc}	34.67 ^{bc}
T_2	31.33 ^{ab}	41.00 ^{abc}	35.67 ^{bc}
T_3	27.00 ^{b}	41.67 ^{abc}	36.67 ^{bc}
T_4	28.67 ^{ab}	42.00 ^{abc}	36.33 ^{bc}
T_5	28.67 ^{ab}	45.00 ^{abc}	39.00 ^{abc}
T_6	30.67 ^{ab}	46.00 ^{abc}	41.00 ^{abc}
T_7	32.33 ^{ab}	42.00 ^{abc}	43.33 ^{abc}
T_8	37.67 ^{a}	54.33 ^{a}	50.33 ^{a}
T_9	37.67 ^{a}	49.00 ^{abc}	43.33 ^{abc}
T_{10}	30.67 ^{ab}	50.33 ^{ab}	45.67 ^{ab}
T_{11}	33.00 ^{ab}	45.00 ^{abc}	43.33 ^{abc}
T_{12}	23.33 ^{b}	36.33 ^{c}	31.67 ^{c}
T_{13}	30.33 ^{ab}	41.00 ^{abc}	36.67 ^{bc}

Treatment means having similar alphabets in superscript do not differ significantly
DAS – Days after sowing

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

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

Treatments	Number of branches		
	60 DAS	80 DAS	100 DAS
T_1	2.67 [a]	2.67 [a]	3.33 [a]
T_2	3.33 [a]	3.33 [a]	3.33 [a]
T_3	2.67 [a]	2.67 [a]	3.67 [a]
T_4	2.67 [a]	3.33 [a]	3.67 [a]
T_5	3.33 [a]	3.33 [a]	4.00 [a]
T_6	3.00 [a]	3.33 [a]	3.33 [a]
T_7	3.00 [a]	3.33 [a]	4.00 [a]
T_8	3.33 [a]	3.33 [a]	4.33 [a]
T_9	3.00 [a]	3.33 [a]	4.67 [a]
T_{10}	3.33 [a]	3.33 [a]	4.00 [a]
T_{11}	3.00 [a]	3.33 [a]	3.67 [a]
T_{12}	2.33 [a]	2.67 [a]	3.67 [a]
T_{13}	2.67 [a]	3.33 [a]	3.33 [a]

Treatment means having similar alphabets in superscript do not differ significantly
DAS – Days after sowing

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

4.1.6. Total dry matter production (g/plant)

The total dry matter production at final harvest showed significant difference (Table 6). Treatments T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded the highest value of 350.50 g/plant and 345.49 g/plant respectively significantly differed from all other treatments. The lowest value of 230.39 g/plant was observed in T_3 (FYM + *Frateuria* @ 2 kg/ha).

4.2. Earliness of the crop

Data pertaining to various characters related to earliness are presented in Table 7.

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 T_6 (FYM + AMF + *Frateuria* each @ 2 kg/ha) *i.e* 39.67 days and all the treatments except T_4 and T_{12} were on par. T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) recorded maximum days (42.67 days) for first flower opening.

4.2.2. Node at which first flower appeared

There was no significant difference with respect to the node at which first flower appeared. It ranged from 4.0 (T_2, T_6 and T_9) to 5.0 (T_4, T_7, T_8 and T_{12}).

4.2.3. Days to first harvest

First harvest (46.33 days) was recorded early in T_6 (FYM + AMF + *Frateuria* each @ 2 kg/ha) and all the treatments except T_2 and T_3 were on par. T_3 (FYM + *Frateuria* @ 2 kg/ha) recorded the maximum days to first harvest (53.67 days).

Table 6: Effect of treatments on chlorophyll content and total dry matter production

Treatments	Chlorophyll content (SPAD units)	Total dry matter production (g/plant)
T_1	45.65 ^{ab}	254.81 ^{e}
T_2	46.71 ^{ab}	263.61 ^{e}
T_3	45.61 ^{ab}	230.39 ^{f}
T_4	40.73 ^{c}	272.63 ^{e}
T_5	47.71 ^{ab}	315.71 ^{bc}
T_6	44.42 ^{abc}	290.44 ^{d}
T_7	43.40 ^{bc}	319.39 ^{bc}
T_8	48.73 ^{a}	350.50 ^{a}
T_9	43.12 ^{bc}	323.69 ^{b}
T_{10}	45.71 ^{ab}	345.49 ^{a}
T_{11}	44.48 ^{abc}	318.55 ^{bc}
T_{12}	44.13 ^{abc}	258.54 ^{e}
T_{13}	43.95 ^{bc}	302.24 ^{cd}

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

Table 7: Effect of treatments on earliness of the crop

Treatments	Days to first flower opening	Node at which first flower appeared	Days to first harvest
T_1	40.33 ^{ab}	4.33 ^{a}	51.00 ^{ab}
T_2	41.00 ^{ab}	4.00 ^{a}	53.00 ^{c}
T_3	41.67 ^{ab}	4.67 ^{a}	53.67 ^{c}
T_4	42.67 ^{c}	5.00 ^{a}	52.33 ^{ab}
T_5	41.00 ^{ab}	4.33 ^{a}	47.67 ^{ab}
T_6	39.67 ^{a}	4.00 ^{a}	46.33 ^{a}
T_7	41.00 ^{ab}	5.00 ^{a}	51.67 ^{ab}
T_8	41.67 ^{ab}	5.00 ^{a}	49.67 ^{ab}
T_9	41.67 ^{ab}	4.00 ^{a}	50.33 ^{ab}
T_{10}	41.00 ^{ab}	4.33 ^{a}	50.33 ^{ab}
T_{11}	41.33 ^{ab}	4.33 ^{a}	49.67 ^{ab}
T_{12}	42.67 ^{c}	5.00 ^{a}	51.00 ^{ab}
T_{13}	41.00 ^{ab}	4.33 ^{a}	51.00 ^{ab}

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

4.3. Biometrical characteristics of fruit

Analysis of variance showed that there was significant difference among the treatments for the characters fruit weight, fruit length and fruit girth (Plate. 3). Mean of various biometrical characteristics of okra fruits are given in Table 8.

4.3.1. Fruit weight (g)

Treatments differed significantly in terms of fruit weight. The highest value of 19.80 g was observed in T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha). It was on par with T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha), T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_{11} (POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg/ha). The lowest value was observed in T_{12} (15.00 cm) where *Azospirillum*, AMF and *Frateuria* were applied each @ 2 kg/ha.

4.3.2. Fruit length (cm)

The data on fruit length revealed significant differences among the treatments studied. Maximum fruit length of 19.17 cm was observed in T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and the treatments T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) were on par with T_{10}

4.3.3. Fruit girth (cm)

There were significant differences between treatments with respect to fruit girth. Maximum girth (6.17 cm) was obtained in T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and all the treatments except T_{12} were on par. T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) registered the lowest value of 5.73 cm.

Table 8: Effect of treatments on biometrical characteristics of fruits

Treatments	Fruit weight (g)	Fruit length (cm)	Fruit girth (cm)	Number of seeds
T_1	16.80 ^{cd}	16.53 ^{b}	5.87 ^{ab}	77.44 ^{ab}
T_2	17.00 ^{bcd}	16.33 ^{b}	5.93 ^{ab}	66.89 ^{b}
T_3	17.13 ^{bcd}	16.60 ^{b}	6.00 ^{ab}	67.33 ^{b}
T_4	17.47 ^{bc}	17.20 ^{b}	6.07 ^{ab}	77.55 ^{ab}
T_5	17.47 ^{bc}	17.13 ^{b}	6.07 ^{ab}	77.89 ^{ab}
T_6	17.27 ^{bcd}	17.20 ^{b}	5.87 ^{ab}	76.67 ^{ab}
T_7	17.88 ^{abc}	17.73 ^{ab}	6.13 ^{a}	76.56 ^{ab}
T_8	19.80 ^{a}	19.07 ^{a}	6.17 ^{a}	82.89 ^{a}
T_9	17.27 ^{bcd}	16.93 ^{b}	6.07 ^{ab}	67.11 ^{b}
T_{10}	19.40 ^{ab}	19.17 ^{a}	6.13 ^{a}	80.33 ^{a}
T_{11}	17.87 ^{abc}	17.47 ^{b}	6.07 ^{ab}	71.67 ^{ab}
T_{12}	15.00 ^{d}	16.73 ^{b}	5.73 ^{b}	70.67 ^{ab}
T_{13}	17.13 ^{bcd}	16.87 ^{b}	6.07 ^{ab}	71.00 ^{ab}

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

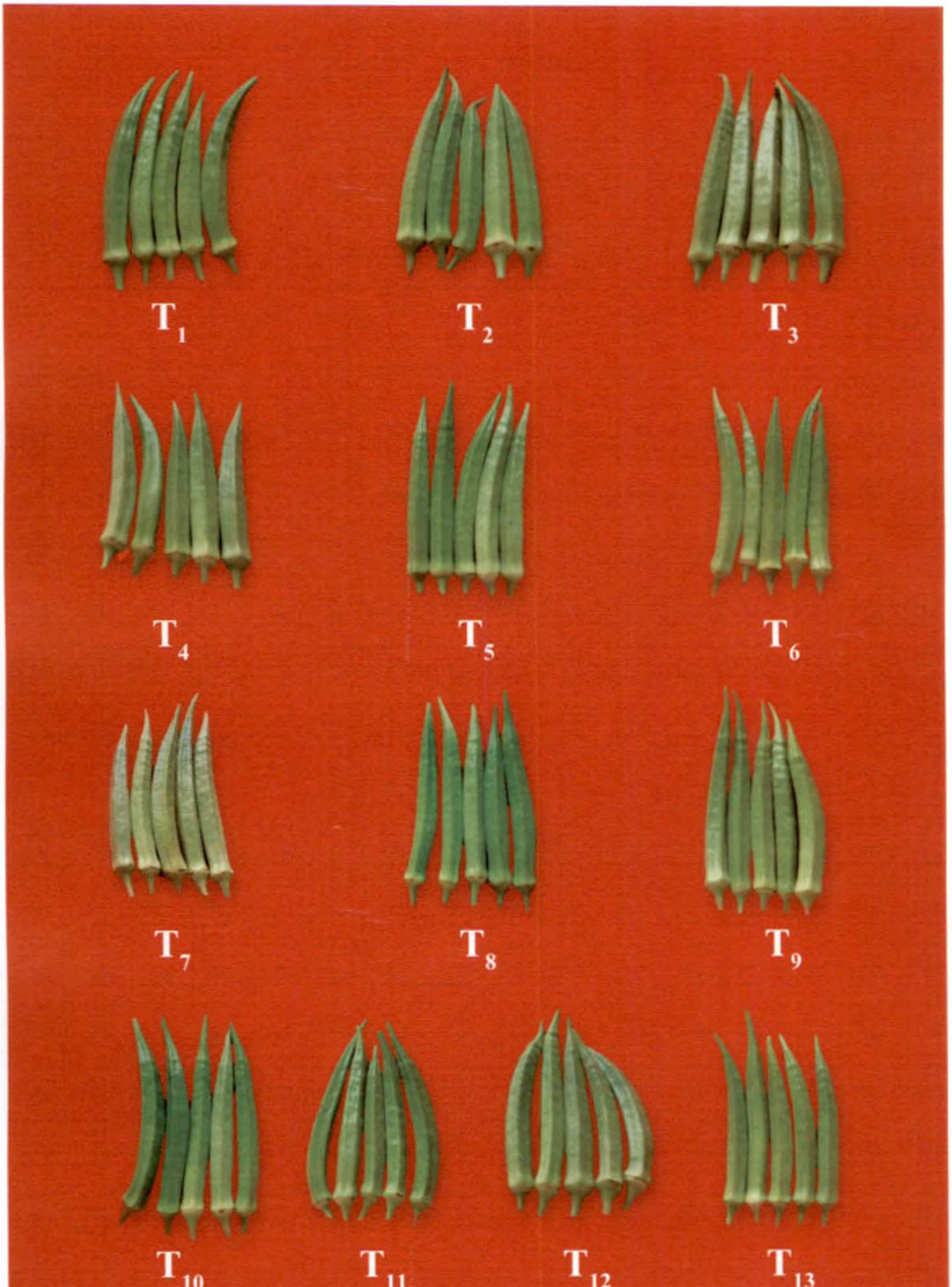


Plate 3: Comparison of fruits harvested from different experimental plots

4.3.4. Number of seeds per fruit

Number of seed per fruit showed significant differences between treatments with T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recording the maximum seed number of 82.89 and all the treatments except T_2, T_3 and T_9 were on par.

4.4. Yield characteristics

Data related to yield characteristics are furnished in Table 9.

4.4.1. Number of fruits per plant

Analysis of data on the number of fruits per plant showed significant differences among the treatments. The treatment T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) produced the highest number of fruits (31.67) and the treatments T_{10}, T_7, T_9, T_5 and T_{11} were on par. All other treatments had significantly lower fruits when compared to T_8. The lowest number of fruits per plant (20.00) was observed in T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

4.4.2. Fruit yield per plant (g)

The data on fruit yield per plant showed significant differences among treatments. The highest yield per plant was recorded in T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) (544.40 g) and the treatments T_{10}, T_9, T_7, T_{11} and T_5 were on par. The lowest yield of 302.13 g was recorded in T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

4.4.3. Total fruit yield (t/ha)

There were significant differences between treatments with respect to total fruit yield. T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the maximum value (16.33 t/ha) and T_{10}, T_7, T_9, T_5, T_4 and T_{11} were on par. The lowest value (9.64 t/ha) was obtained in T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

Table 9: Effect of treatments on yield characteristics

Treatments	Number of fruits per plant	Yield per plant (g)	Total fruit yield (t/ha)	Number of harvests	Duration of crop (days)
T_1	20.27 ^{c}	318.20 ^{c}	11.06 ^{cd}	20.33 ^{a}	106.00 ^{a}
T_2	22.27 ^{bc}	353.67 ^{bc}	11.14 ^{cd}	20.33 ^{a}	106.00 ^{a}
T_3	22.47 ^{bc}	367.93 ^{bc}	11.22 ^{cd}	18.33 ^{a}	100.67 ^{a}
T_4	22.13 ^{bc}	358.53 ^{bc}	12.88 ^{abcd}	20.33 ^{a}	106.00 ^{a}
T_5	25.93 ^{abc}	407.27 ^{abc}	13.68 ^{abcd}	20.33 ^{a}	106.00 ^{a}
T_6	20.53 ^{c}	320.13 ^{c}	11.69 ^{bcd}	21.33 ^{a}	106.00 ^{a}
T_7	27.80 ^{abc}	425.80 ^{abc}	14.54 ^{abc}	22.00 ^{a}	110.00 ^{a}
T_8	31.67 ^{a}	544.40 ^{a}	16.33 ^{a}	21.67 ^{a}	110.00 ^{a}
T_9	26.40 ^{abc}	431.47 ^{abc}	14.34 ^{abc}	21.00 ^{a}	107.67 ^{a}
T_{10}	29.60 ^{ab}	488.73 ^{ab}	15.52 ^{ab}	21.33 ^{a}	110.00 ^{a}
T_{11}	24.93 ^{abc}	408.47 ^{abc}	12.67 ^{abcd}	21.00 ^{a}	104.67 ^{a}
T_{12}	20.00 ^{c}	302.13 ^{c}	9.64 ^{d}	19.33 ^{a}	103.67 ^{a}
T_{13}	22.00 ^{bc}	360.53 ^{bc}	11.75 ^{bcd}	19.33 ^{a}	100.67 ^{a}

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

4.4.5. Number of harvests

There was no significant difference in number of harvests between treatments. Number of harvests ranged from 18.33 (T_3-FYM + *Frateuria* @ 2 kg/ha) to 22 (T_7- FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

4.4.6. Duration of crop (days)

Crop duration ranged from 100.67 days (T_3 and T_{13}) to 110 days (T_7, T_8 and T_{10}). All the treatments were on par.

4.5. Fruit quality parameters

Data depicting the effect of various treatments on quality parameters of fruits are presented in Table 10.

4.5.1. Vitamin C content (mg/100g)

There was no significant variation between the treatments. Vitamin C content varied from 11.29 mg/100 g (T_1, T_5, T_7, T_{10} and T_{12}) to 16.95 mg/100g (T_6).

4.5.2. Beta carotene content (µg/100g)

The treatments differed significantly in case of beta carotene content of fruits. The highest value of 94.33 µg/100g was recorded in T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and was highly significant. The lowest value (53.89 µg/100g) was recorded in T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

4.5.3. Crude protein content (%)

Significant difference was noticed for crude protein content of fruits among the treatments. The highest value (19.19 %) was observed in T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and all the treatments except T_2, T_3, T_4 and T_{12} were on par.

Table 10: Effect of treatments on fruit quality parameters

Treatments	Fruit quality parameters			
	Vitamin C (mg/100g)	β Carotene (μg/100g)	Crude protein (%)	Shelf life (days)
T_1	11.29 [a]	72.59 [d]	18.14 [ab]	5.33 [bc]
T_2	12.71 [a]	79.58 [c]	13.94 [c]	5.33 [bc]
T_3	15.53 [a]	57.89 [fg]	15.45 [bc]	4.00 [d]
T_4	14.12 [a]	88.62 [b]	15.52 [bc]	6.00 [ab]
T_5	11.29 [a]	84.78 [b]	16.10 [abc]	6.00 [ab]
T_6	16.95 [a]	57.20 [fg]	18.32 [ab]	6.00 [ab]
T_7	11.29 [a]	72.34 [d]	18.96 [a]	6.67 [a]
T_8	15.54 [a]	59.52 [f]	19.08 [a]	6.67 [a]
T_9	12.71 [a]	53.89 [g]	19.19 [a]	6.33 [ab]
T_{10}	11.29 [a]	94.33 [a]	18.96 [a]	6.00 [ab]
T_{11}	15.54 [a]	58.63 [fg]	19.02 [a]	5.33 [bc]
T_{12}	11.29 [a]	70.84 [d]	15.69 [bc]	5.00 [c]
T_{13}	15.54 [a]	65.58 [e]	18.55 [ab]	5.00 [c]

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

4.5.4. Shelf life (days)

Shelf life of okra fruits showed significant differences, with treatment T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recording the maximum days of 6.67 and the treatments T_9, T_4, T_5, T_6 and T_{10} were on par. The least shelf life (4.00 days) was observed in T_3 (FYM + *Frateuria* @ 2 kg/ha).

4.6. Nutrient analysis of plants

4.6.1. Fruit analysis

4.6.1.1. Nitrogen (%)

Treatments showed significant differences in nitrogen content of fruits (Table 11). Maximum nitrogen content (3.07 %) was observed in T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha). All the treatments except T_2, T_3, T_4 and T_{12} were on par. The lowest nitrogen content was recorded in T_2 (2.23 %).

4.6.1.2. Phosphorus (%)

Statistical analysis of data revealed that the treatments varied significantly with regard to phosphorus content (Table 11). Treatment T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded a maximum value of 0.17 %. All the treatments except T_{10}, T_{11}, T_{12} and T_{13} were on par. The least value (0.12 %) was recorded in T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

4.6.1.3. Potassium (%)

Significant differences were noticed for potassium content of fruits among the treatments. Maximum potassium content was observed in T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recording a value of 1.28 % and the treatments T_{11} (POP + *Azospirillum* + AMF + *Frateuria*

Table 11: Effect of treatments on nutrient content of okra fruit

Treatments	Nutrient content (%)		
	Nitrogen	Phosphorus	Potassium
T_1	2.90 [ab]	0.16 [a]	1.08 [cd]
T_2	2.23 [c]	0.16 [a]	1.17 [cd]
T_3	2.47 [bc]	0.16 [a]	1.12 [c]
T_4	2.48 [bc]	0.16 [a]	1.02 [d]
T_5	2.58 [abc]	0.16 [a]	1.05 [cd]
T_6	2.93 [ab]	0.16 [a]	1.14 [bc]
T_7	3.03 [a]	0.15 [a]	1.10 [cd]
T_8	3.05 [a]	0.16 [a]	1.12 [c]
T_9	3.07 [a]	0.17 [a]	1.21 [ab]
T_{10}	3.03 [a]	0.13 [b]	1.28 [a]
T_{11}	3.04 [a]	0.14 [b]	1.22 [ab]
T_{12}	2.51 [bc]	0.12 [b]	1.08 [cd]
T_{13}	2.97 [ab]	0.14 [b]	1.02 [d]

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

each @ 2 kg/ha) and T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) were on par. Treatment T_4 (FYM + *Azospirillum* + AMF) and control (T_{13}) showed the least value of 1.02 % (Table 11).

4.6.1.4. Secondary and micronutrients

The data regarding the calcium and magnesium content of fruits indicated that there was no significant variation between the treatments. Calcium content ranged from 0.33 % (T_3) to 0.45 % (T_8). Magnesium content in fruit varied from 0.030 % (T_2 and T_5) to 0.032 % (T_3, T_7, T_8, T_9, T_{12} and T_{13}).

There was no significant variation in zinc content of fruits (Table 12). It ranged from 0.007 % (T_2, T_{10} and T_{12}) to 0.011% (T_3 and T_4). Treatments differed significantly in iron content of fruits. Treatment T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) recorded the highest value (0.050 %) followed by T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recording 0.048 % which were on par and statistically superior to other treatments. The least value (0.001 %) was observed in T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

4.6.2. Leaf analysis

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

4.6.2.1. Nitrogen (%)

Nitrogen content of leaves did not differ significantly. It ranged from 2.37 % (T_{12}-*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) to 3.08 % (T_4-FYM + *Azospirillum* + AMF each @ 2 kg/ha).

4.6.2.2. Phosphorus (%)

Phosphorus content of leaves varied significantly with T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recording the highest value of

Table 12: Effect of treatments on secondary and micronutrient content of okra fruits

Treatments	Calcium (%)	Magnesium (%)	Zinc (%)	Iron (%)
T_1	0.37 [a]	0.031 [a]	0.009 [a]	0.022 [b]
T_2	0.39 [a]	0.030 [a]	0.007 [a]	0.016 [bc]
T_3	0.33 [a]	0.032 [a]	0.011 [a]	0.007 [bc]
T_4	0.37 [a]	0.031 [a]	0.011 [a]	0.050 [a]
T_5	0.36 [a]	0.030 [a]	0.010 [a]	0.007 [bc]
T_6	0.38 [a]	0.031 [a]	0.009 [a]	0.003 [bc]
T_7	0.42 [a]	0.032 [a]	0.009 [a]	0.007 [bc]
T_8	0.45 [a]	0.032 [a]	0.009 [a]	0.003 [bc]
T_9	0.40 [a]	0.032 [a]	0.009 [a]	0.001 [c]
T_{10}	0.37 [a]	0.031 [a]	0.007 [a]	0.048 [a]
T_{11}	0.42 [a]	0.031 [a]	0.008 [a]	0.002 [c]
T_{12}	0.39 [a]	0.032 [a]	0.007 [a]	0.005 [bc]
T_{13}	0.40 [a]	0.032 [a]	0.008 [a]	0.010 [bc]

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

0.20 % and all the treatments except T_3, T_4, T_5 and T_{13} were on par. T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) recorded the lowest value of 0.13 %.

4.6.2.3. Potassium (%)

There was significant difference between treatments with respect to potassium content of leaves. Treatment T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_{11} (POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest value of 0.87 % and was on par with T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 0.85 %. As in case of phosphorus content the lowest value of potassium (0.54 %) was also recorded in T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha).

4.6.3. Plant uptake of N, P and K (kg/ha)

Results showed that there was significant variation between treatments with respect to nutrient uptake (Table 14).

Maximum uptake of nitrogen was recorded in T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recording 212.92 kg/ha and the treatments T_9, T_8, T_7, T_{11}, T_{13}, T_4, T_6, T_3 and T_1 were on par. Minimum uptake (123.54 kg/ha) was observed in T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

With respect to phosphorus uptake, the treatments varied significantly. T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) gave significantly higher value of 38.09 kg/ha. The lowest phosphorus uptake of 20.15 kg/ha was found in T_{12} (*Azospirillum* + AMF + *Frateuria*).

In the case of potassium uptake, T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the maximum value of 150.26 kg/ha and 150.25 kg/ha respectively which were on par with T_9 (FYM (as per POP) + ½

Table 13: Effect of treatments on nutrient content of leaves

Treatments	Nutrient content (%)		
	Nitrogen	Phosphorus	Potassium
T_1	2.84 [a]	0.16 [abc]	0.71 [c]
T_2	2.44 [a]	0.18 [ab]	0.76 [c]
T_3	3.06 [a]	0.15 [bc]	0.55 [de]
T_4	3.08 [a]	0.13 [c]	0.54 [e]
T_5	3.05 [a]	0.15 [bc]	0.71 [c]
T_6	2.81 [a]	0.18 [ab]	0.76 [c]
T_7	2.66 [a]	0.20 [a]	0.87 [a]
T_8	2.56 [a]	0.16 [abc]	0.78 [bc]
T_9	2.67 [a]	0.18 [ab]	0.78 [bc]
T_{10}	2.87 [a]	0.17 [abc]	0.85 [ab]
T_{11}	2.54 [a]	0.18 [ab]	0.87 [a]
T_{12}	2.37 [a]	0.16 [abc]	0.61 [d]
T_{13}	2.87 [a]	0.15 [bc]	0.71 [c]

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

Table 14: Effect of treatments on plant uptake of N, P and K

Treatments	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)
T_1	158.85 ^{abcd}	23.40 ^{fgh}	129.87 ^{d}
T_2	136.59 ^{bcd}	25.90 ^{defg}	118.25 ^{e}
T_3	163.38 ^{abcd}	22.41 ^{gh}	58.72 ^{h}
T_4	176.80 ^{abcd}	27.32 ^{def}	107.65 ^{f}
T_5	131.91 ^{cd}	29.38 ^{cde}	132.33 ^{d}
T_6	175.93 ^{abcd}	28.78 ^{de}	141.94 ^{bc}
T_7	183.51 ^{abc}	38.09 ^{a}	150.25 ^{a}
T_8	190.52 ^{ab}	33.57 ^{bc}	144.31 ^{b}
T_9	201.87 ^{a}	30.13 ^{bcd}	146.52 ^{ab}
T_{10}	212.92 ^{a}	33.93 ^{b}	150.26 ^{a}
T_{11}	182.56 ^{abc}	28.81 ^{de}	142.92 ^{bc}
T_{12}	123.54 ^{d}	20.15 ^{h}	94.37 ^{g}
T_{13}	181.15 ^{ab}	25.32 ^{efg}	137.96 ^{c}

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

(NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 146.52 kg/ha. The least value (58.72 kg/ha) was observed in T_3 (FYM + *Frateuria* @ 2 kg/ha).

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 50 DAS and 100 DAS (Table 15 to 17).

4.7.1. Organic carbon (%)

There was significant difference in soil organic carbon at 50 DAS (Table 15). From the initial value of 0.41 % it increased upto 0.54 % (T_4) at 50 DAS. T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) was significantly superior to all treatments except T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) (0.49 %) which was on par. The least value (0.35 %) was recorded in T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

Organic carbon recorded at 100 DAS showed significant difference. The highest value (0.65 %) was recorded in T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) and T_1, T_5, T_{10} and T_{11} were on par. The least value (0.43 %) was recorded in T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha). Generally, an increasing trend can be noticed in organic carbon content at various stages.

4.7.2. Available nitrogen (kg/ha)

Significant variation existed among different treatments with respect to the available nitrogen status of soil at 50 DAS and 100 DAS (Table 15). At pre-planting stage, it was 115.66 kg/ha. The highest value of available nitrogen (211.00 kg/ha) at 50 DAS was recorded in T_{11} (POP + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which was on par with T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 196.67 kg/ha, and at 100 DAS also T_{11} (297.00 kg/ha) recorded significantly higher nitrogen content. T_{12} recorded the least value at both stages of observation.

Table 15: Effect of treatments on soil parameters

Treatment	Organic carbon (%)		Available nitrogen (kg/ha)	
	50 DAS	100 DAS	50 DAS	100 DAS
T_1	0.48^{bc}	0.64^{a}	127.67^{cd}	163.00^{e}
T_2	0.47^{bcd}	0.50^{cd}	128.67^{cd}	144.33^{f}
T_3	0.44^{bcde}	0.50^{cd}	140.00^{c}	141.67^{f}
T_4	0.54^{a}	0.65^{a}	163.00^{b}	214.33^{cd}
T_5	0.44^{bcde}	0.64^{a}	121.00^{d}	136.00^{f}
T_6	0.43^{cde}	0.45^{de}	137.33^{cd}	142.67^{f}
T_7	0.42^{de}	0.56^{bc}	126.33^{cd}	142.67^{f}
T_8	0.48^{bc}	0.56^{bc}	136.67^{cd}	202.67^{d}
T_9	0.43^{cde}	0.44^{e}	162.00^{b}	202.67^{d}
T_{10}	0.49^{ab}	0.61^{ab}	196.67^{a}	246.33^{b}
T_{11}	0.48^{bc}	0.59^{ab}	211.00^{a}	297.00^{a}
T_{12}	0.35^{f}	0.43^{e}	120.67^{d}	130.67^{f}
T_{13}	0.39^{ef}	0.46^{de}	159.33^{b}	224.33^{c}
Initial value	0.41		115.66	

Treatment means having similar alphabets in superscript do not differ significantly
DAS – Days after sowing

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

4.7.3. Available P_2O_5 (kg/ha)

Regarding the available P_2O_5 in soil, the initial value was 36.59 kg/ha. At the post experimental stage, significant variations were observed among the treatments (Table 16). Treatments T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 106.28 kg/ha and 100.04 kg/ha respectively differed significantly from all other treatments and were on par at 50 DAS.

At 100 DAS, T_{11} (POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg/ha) showed maximum value of 88.57 kg/ha and was significantly different from other treatments. The least value of 43.86 kg/ha was noted in T_1 (FYM + *Azospirillum* @ 2 kg/ha).

4.7.4. Available K_2O (kg/ha)

As in the case of available nitrogen and P_2O_5, available K_2O status of soil also increased from the initial value of 63.16 kg/ha. At 50 DAS it was the highest in T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 89.17 kg/ha followed by T_{11} (POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg/ha) (88.95 kg/ha) which was on par. The lowest value of 69.89 kg/ha was recorded in T_{12} (*Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

At 100 DAS the highest value of K_2O (131.26 kg/ha) was observed in T_3 (FYM + *Frateuria* @ 2 kg/ha) and the treatments T_9, T_{10}, T_5, T_8, T_{13}, T_2, T_6 and T_1 were on par. T_{11} (POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg/ha) recorded the least value of 90.14 kg/ha (Table 16).

Table 16: Effect of treatments on soil parameters

Treatment	P_2O_5 (kg/ha)		K_2O (kg/ha)	
	50 DAS	100 DAS	50 DAS	100 DAS
T_1	56.08 ^{c}	43.86 ^{e}	80.89 ^{b}	99.58 ^{abc}
T_2	88.01 ^{b}	55.04 ^{cd}	70.78 ^{de}	119.82 ^{abc}
T_3	47.77 ^{cde}	53.04 ^{cd}	80.68 ^{bc}	131.26 ^{a}
T_4	46.38 ^{cde}	50.57 ^{cde}	73.64 ^{d}	95.09 ^{bc}
T_5	55.04 ^{c}	50.01 ^{cde}	71.68 ^{de}	122.95 ^{abc}
T_6	44.14 ^{de}	52.80 ^{cd}	73.90 ^{d}	105.57 ^{abc}
T_7	100.04 ^{a}	56.20 ^{cd}	70.78 ^{de}	97.87 ^{bc}
T_8	106.28 ^{a}	78.23 ^{b}	70.03 ^{e}	116.54 ^{abc}
T_9	41.35 ^{e}	50.01 ^{cde}	72.89 ^{de}	124.49 ^{ab}
T_{10}	53.92 ^{cd}	58.11 ^{c}	89.17 ^{a}	124.36 ^{ab}
T_{11}	43.58 ^{de}	88.57 ^{a}	88.95 ^{a}	90.14 ^{c}
T_{12}	47.22 ^{cde}	48.05 ^{de}	69.89 ^{e}	92.68 ^{bc}
T_{13}	55.88 ^{c}	49.17 ^{de}	77.59 ^{c}	111.58 ^{abc}
Initial value	36.59		63.16	

Treatment means having similar alphabets in superscript do not differ significantly
DAS – Days after sowing

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

4.7.5. pH

The initial value of pH was 4.13. At 50 DAS the highest value (5.00) was observed in T_3 (FYM + *Frateuria* @ 2 kg/ha). All the treatments except T_2, T_5, T_9, T_{10} and T_{13} were on par. Significantly higher pH was recorded at 100 DAS in T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) (5.47) and T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) (5.30) which were on par. The minimum value was observed in T_{13} (Manures and fertilizers as per POP recommendation) recording 4.80 (Table 17).

4.7.6. Electrical conductivity (dS/m)

EC values varied significantly at 50 and 100 DAS (Table 17). The pre-experimental value was 0.053 dS/m. At 50 DAS T_1 (FYM + *Azospirillum* @ 2 kg/ha) recorded significantly higher value of 0.090 dS/m followed by T_{11} (0.077 dS/m), T_2 (0.073 dS/m) and T_3 (0.073 dS/m) which were on par (Table 17). The least value of 0.030 dS/m was observed in T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha).

There was significant difference between the treatments at 100 DAS. T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded significantly higher value of 0.147 dS/m whereas the least value (0.053 dS/m) was observed in T_1 (FYM + *Azospirillum* @ 2 kg/ha).

4.8. Enumeration of *Azospirillum*, AMF and *Frateuria* in rhizosphere soil

The effect of different treatments on population of *Azospirillum*, AMF and *Frateuria* is given in Table 18 and Plate. 4. Considerable variation was noticed among the treatments.

Table 17: Effect of treatments on soil parameters

Treatments	pH		EC (dSm^{-1})	
	50 DAS	100 DAS	50 DAS	100 DAS
T_1	4.83^{ab}	4.90^{c}	0.090^{a}	0.053^{f}
T_2	4.77^{b}	5.00^{bc}	0.073^{ab}	0.067^{ef}
T_3	5.00^{a}	5.00^{bc}	0.073^{ab}	0.093^{cd}
T_4	4.80^{ab}	4.97^{bc}	0.030^{e}	0.077^{de}
T_5	4.67^{b}	4.93^{c}	0.050^{cd}	0.073^{e}
T_6	4.80^{ab}	5.03^{bc}	0.060^{bc}	0.083^{de}
T_7	4.80^{ab}	4.87^{c}	0.047^{cde}	0.083^{de}
T_8	4.87^{ab}	5.03^{bc}	0.040^{de}	0.067^{ef}
T_9	4.77^{b}	5.47^{a}	0.037^{de}	0.147^{a}
T_{10}	4.77^{b}	5.30^{ab}	0.053^{cd}	0.123^{b}
T_{11}	4.80^{ab}	4.90^{c}	0.077^{ab}	0.103^{c}
T_{12}	4.87^{ab}	4.87^{c}	0.047^{cde}	0.077^{de}
T_{13}	4.70^{b}	4.80^{c}	0.047^{cde}	0.080^{de}
Initial value	4.13		0.053	

Treatment means having similar alphabets in superscript do not differ significantly
DAS – Days after sowing

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

4.8.1. *Azospirillum* (cfu/g soil)

Azospirillum population showed significant difference between treatments. The initial count of *Azospirillum* was 3.17 x 10^6 cfu/g of soil. After completion of crop it was the highest in T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which was 45.50 x 10^6 cfu/g. It was on par with T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 43.00 x 10^6 cfu/g and 40.00 x 10^6 cfu/g.

4.8.2. Arbuscular Mycorrhizal Fungi (spores/10 g soil)

There was no significant difference between treatments with respect to spore count of AMF. The initial value was 3 spores/10 g soil. T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) recorded the highest spore count of 31.00 spores/10 g followed by T_8 ((FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 30.50 spores/10 g. The least value (14.50 spores/10 g) was recorded in T_3 (FYM + *Frateuria*) and T_5 (FYM + *Azospirillum* + *Frateuria* each @ 2 kg/ha).

4.8.3. *Frateuria* (cfu/g soil)

The count of *Frateuria* showed significant difference and it increased from the initial population of 4.5 x 10^6 cfu/g to 37 x 10^6 cfu/g in T_5 (FYM + *Azospirillum* + *Frateuria* each @ 2 kg/ha) which recorded the maximum population. It was followed by T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) (32.00 x 10^6 cfu/g). The minimum population of 4.00 x 10^6 cfu/g soil was observed in T_4 (FYM + *Azospirillum* + AMF).

4.9. Incidence of pests and diseases

There were minor incidence of Yellow Vein Mosaic, and shoot and fruit borer attack at later stages of growth (Table 19). The pest incidence ranged from

Table 18: Effect of treatments on population of *Azospirillum*, AMF and *Frateuria* in rhizosphere soil at final harvest

Treatments	*Azospirillum* ($x10^6$ cfu/g soil)	Spore count of AMF (in 10 g soil)	*Frateuria* ($x10^6$ cfu/g soil)
T_1	14.50 (3.85^b)	17.50^a	9.00 (3.08^{bc})
T_2	9.00 (3.06^b)	23.50^a	8.00 (2.69^c)
T_3	9.00 (3.07^b)	14.50^a	17.50 (4.23^{abc})
T_4	12.50 (3.58^b)	31.00^a	4.00 (2.11^c)
T_5	10.00 (3.14^b)	14.50^a	37.00 (6.11^a)
T_6	6.00 (2.41^b)	24.00^a	15.50 (4.00^{abc})
T_7	15.00 (3.88^b)	18.50^a	12.00 (3.53^{abc})
T_8	45.50 (6.72^a)	30.50^a	32.00 (5.67^{ab})
T_9	40.00 (6.36^a)	27.50^a	15.50 (3.84^{abc})
T_{10}	43.00 (6.59^a)	28.00^a	10.00 (3.21^{bc})
T_{11}	12.00 (3.52^b)	26.50^a	14.50 (3.28^{bc})
T_{12}	10.50 (3.27^b)	26.00^a	9.50 (3.07^{bc})
T_{13}	4.50 (2.21^b)	20.00^a	5.00 (2.15^c)
Initial value	3.17	3.00	4.5

Treatment means having similar alphabets in superscript do not differ significantly
Values given in parenthesis are square root transformed values

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

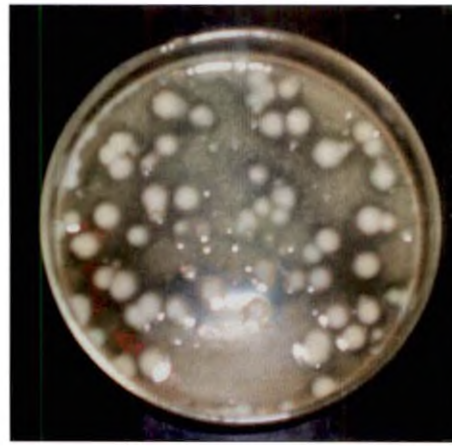
T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

Colonies of *Azospirillum* in modified Okon's medium



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

AMF spore observed under stereo-microscope (200x)

Plate 4: Enumeration of inoculated microbes in rhizosphere soil at final harvest

Table 19: Effect of treatments on pests and disease incidence

Treatments	Shoot and fruit borer infestation (%)	Mosaic infection (%)
T_1	17.66 [a]	28.16 [a]
T_2	16.31 [a]	27.61 [a]
T_3	17.68 [a]	27.42 [a]
T_4	17.58 [a]	28.35 [a]
T_5	17.93 [a]	27.50 [a]
T_6	17.68 [a]	26.99 [a]
T_7	17.21 [a]	25.67 [a]
T_8	18.45 [a]	26.91 [a]
T_9	17.82 [a]	26.86 [a]
T_{10}	18.06 [a]	26.05 [a]
T_{11}	17.85 [a]	26.74 [a]
T_{12}	17.32 [a]	24.79 [a]
T_{13}	17.15 [a]	28.38 [a]

Treatment means having similar alphabets in superscript do not differ significantly

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha

T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha

T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha

T_{13} - POP recommendation (control)

16.31 % to 18.45 % whereas the disease incidence ranged from 24.79 % to 28.38 %. The treatments did not differ significantly.

4.10. Economics of cultivation

The treatment T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest B:C ratio of 2.49 (Table 20). It was followed by T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded a B:C ratio of 2.42. The least value was recorded in T_{12} (1.71).

Table 20: Effect of treatments on economics of cultivation

Treatments	B: C ratio
T_1	1.82
T_2	1.84
T_3	1.85
T_4	2.12
T_5	2.19
T_6	1.91
T_7	2.37
T_8	2.49
T_9	2.23
T_{10}	2.42
T_{11}	1.97
T_{12}	1.71
T_{13}	1.83

T_1 - FYM + *Azo* @ 2 kg/ha, T_2 - FYM + AMF @ 2 kg/ha, T_3 - FYM + *Frat* @ 2 kg/ha
T_4 - FYM + *Azo* + AMF each @ 2 kg/ha, T_5 - FYM + *Azo* + *Frat* each @ 2 kg/ha
T_6 - FYM + AMF + *Frat* each @ 2 kg/ha, T_7 - FYM + *Azo* + AMF + *Frat* each @ 2 kg/ha
T_8 - FYM (double) + *Azo* + AMF + *Frat* each @ 2 kg/ha
T_9 - FYM (POP) + ½ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha
T_{10} - FYM (POP) + ¾ (NPK) + *Azo* + AMF + *Frat* each @ 2 kg/ha
T_{11} - POP + *Azo* + AMF + *Frat* each @ 2 kg/ha
T_{12} - *Azo* + AMF + *Frat* each @ 2 kg/ha
T_{13} - POP recommendation (control)

Discussion

5. DISCUSSION

Integrated nutrient management is assuming a greater importance in maintaining soil health as well as productivity. Neither organic manures alone nor exclusive application of chemical fertilizers could achieve the yield sustainability at a higher order under modern farming, where the nutrient turn over in the soil plant system is quite high. Under such a situation, microorganisms offer a good alternative or supportive technological tool to replenish the depleted nutrients, and are found to be quite a promising component of INM which in turn helps in better nutrient absorption by plants. A judicious combined strategy of using organic, inorganic and biofertilizers will be effective in bridging the existing wide gap between the nutrient removal and addition, ensuring sustainable crop productivity and soil health by balanced nutrient proportion and also in supplementing a part of chemical fertilizer requirement of the crop. In the present investigation, the effect of three biofertilizers *viz.*, *Azospirillum*, AMF and *Frateuria* on okra was studied. The treatments were compared with the control (KAU POP recommendation) and the results obtained are discussed below.

5.1. Growth parameters

Plant height is considered to be an important factor to judge the vigour of the plant. It is an essential pre-requisite for high yield. Treatment effect on plant height was not noticed initially, but with the advancement of growth of the crop, the differences were apparent (Fig.1). Combined application of all the three biofertilizers along with FYM and full dose of NPK (T_{11}) recorded the maximum height (1.95 m) at 80 DAS, whereas at final stage, application of all the three biofertilizers along with FYM and ¾ NPK (T_{10}) recorded the maximum height of 2.19 m. This is in accordance with the findings of Ramana *et al.* (2010) in french bean. Similar results of increased plant height were obtained by Balasubramani *et al.* (1997) in bhindi, Wange and Kale (2003) in okra and bittergourd, Singh and

Singh (2007) in onion and Premsekhar and Rajasree (2009) in tomato, when 75 per cent of recommended nitrogen was applied along with biofertilizers.

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 nutrients leading to increased foliage, enhanced chlorophyll content and carbohydrates, and increased activity of hormones produced by biofertilizers.

Increase in height due to *Azospirillum* may be on account of its direct role in nitrogen fixation, increased nitrogenase activity (Govindarajan and Thangaraju, 2001) and also due to production of phytohormones like IAA, gibberellin and cytokinin like substances (Veeraraghavathatham *et al*., 1988; Pandey and Kumar, 1989) which might have led to enhanced cell division and cell elongation resulting in better root development, increased uptake of nutrients and moisture which ultimately led to better growth.

According to Singh *et al*. (2010), AMF increased 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 improved water uptake. The enhanced availability of nutrients along with production of some growth promoting substances (Sreenivasa, 1994) might have caused cell multiplication leading to increased height. In addition *Frateuria* supplied potassium, which has a major role in activation of enzymes involved in plant growth.

Leaves are the major site of photosynthesis and act as a major source for the sink. Leaf production in general is determined by both environment and nutrition. Significant variation in leaf number was observed at 60 DAS, 80 DAS and 100 DAS (Fig. 2). At all these stages T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the maximum leaf number. The increase in leaf number due to the use of all biofertilizers can be attributed to better growing conditions that prevailed in the vicinity of root zone which helped plants to absorb

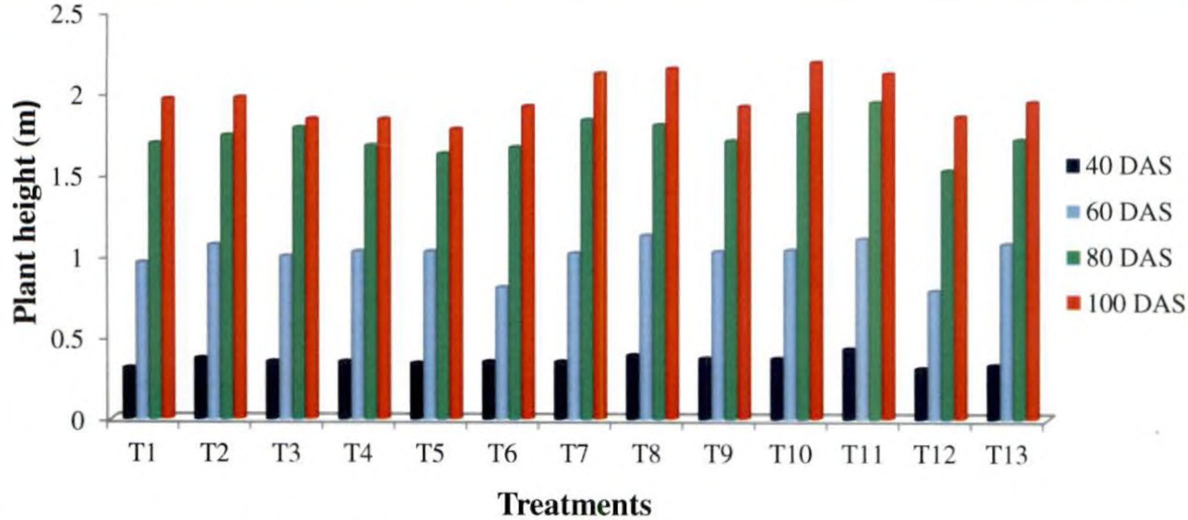


Fig.1: Effect of treatments on plant height at different growth stages

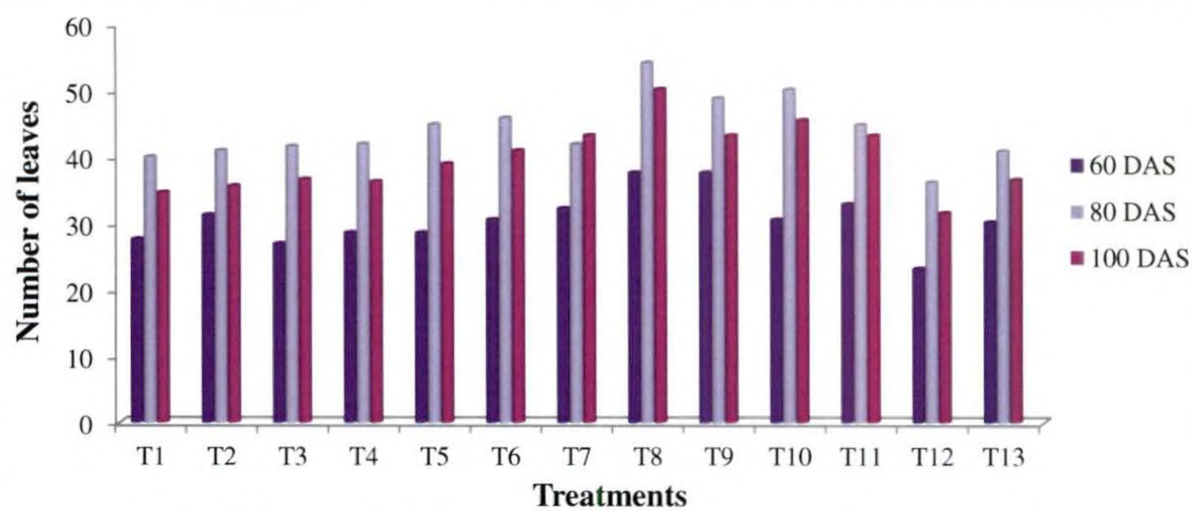


Fig.2: Effect of treatments on number of leaves at different growth stages

more water and nutrients from the soil. In addition, FYM has optimum C:N which on decomposition by microorganisms releases nutrient ions in usable form such as ammonium, nitrates, sulphates, phosphates and make them available to plants. This increase in the mineral constituent of soil might have exerted more number of leaves, since nitrogen is the chief constituent of amino acid and co-enzyme of biological importance.

Creus *et al.* (2005) reported that *Azospirillum* produced nitric oxide which has a direct role in lateral root development of plants. This increased translocation of nutrients especially nitrogen that is essential for formation of protoplasm might have led to increased cell division and cell enlargement ultimately resulting in increased production of leaves (Maynard *et al.*, 1962; Karuthamani *et al.*, 1995). Higher cytokinin activity in the shoot has been found in AMF inoculated plants (Baas and Kuiper, 1989). Cytokinins are known to promote leaf growth by cell division and cell expansion (Vanstanden and Davey, 1979), and it is possible that cytokinin might have played a role in alteration of shoot morphology resulting in higher leaf number.

The relative chlorophyll content showed significant differences between treatments. It was maximum in T_8 (48.73 SPAD units) where FYM was applied in double dose along with *Azospirillum*, AMF and *Frateuria* which was 10.87 per cent more than control (T_{13}). The increased chlorophyll content of leaves in T_8 might have led to increased photosynthates which in turn produced better growth characters.

Nitrogen is the major constituent of chlorophyll and increased nitrogen fixation by *Azospirillum* might have increased chlorophyll content (Sharma, 2002; Patel *et al.*, 2009). In addition, organic manures and AMF might have provided micronutrients such as Mn, Zn, Fe and Cu in an optimum level (Haymann and Mosse, 1971; Linderman, 1992; Prabhu *et al.*, 2006). Zinc and iron are involved in chlorophyll synthesis (Kiran *et al.*, 2010). The increased chlorophyll content by AMF is reported to be due to its activity in prevention of chlorophyll degradation

(Allen, 1981). Therefore, application of organic manures and biofertilizers might have helped in increased plant metabolic activity by supplying important micronutrients in the early crop growth phase which inturn encouraged better chlorophyll content. Nelson and Achar (2001) and Ganeshan and Mahadevan (1994) also reported increased total chlorophyll content in *Glomus fasciculatum* inoculated cabbage and cassava.

Significant differences were noticed between treatments with respect to total dry matter production. T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) significantly differed from all other treatments with a value of 350.50 g/plant and 345.49 g/plant respectively and they were on par. It was 15.97 per cent and 14.31 per cent more than control. This result is contradictory to the findings of Kamili *et al.* (2002) in brinjal where significant increase in dry matter content was observed with increasing level of chemical nitrogen. 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. Better vegetative growth and yield attributes could have resulted in production of more fresh weight and dry weight.

In general, it can be noted that addition of biofertilizers along with double dose of FYM, and combined application of organic, inorganic and biofertilizers increased availability of nutrients on a long term basis resulting in a favourable effect on growth parameters.

5.2. Earliness of the crop

Earliness is considered as a genetically controlled trait. However, environmental factors, cultural practises and nutrition of plants can also influence it to an appreciable extent.

Days to first flowering showed significant variation between treatments. Dual inoculation of AMF and *Frateuria* along with FYM (T_6) produced flowers much earlier (39.67 days) than other treatments. Among the major nutrients, phosphorus plays a vital role in imparting earliness (Anburani and Manivannan, 2002). Increased phosphorus and potassium through the activity of AMF and *Frateuria* resulting in activation of bioactive substances in plants might have helped to produce more photosynthates and cytokinin. Due to the translocation of this synthesised 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; Anburani and Manivannan, 2002). This might have induced flowering stimulus, thus effecting in early initiation of flower bud. Oyetunji and Osonubi (2005) and Chaurasia *et al.* (2008) also observed early flowering and curd initiation in mycorrhiza inoculated chilli and cauliflower.

Days to first harvest showed significant differences between treatments. Early harvest was obtained in T_6 (46.33 days) when AMF and *Frateuria* were applied along with FYM. The early harvest in T_6 might be due to the synergistic effect of biofertilizers on hormones which induce early flowering and maturity (Chaurasia *et al.*, 2008). By accelerating photosynthesis and rapid translocation of these photosynthates, biofertilizers might have created a conducive source sink relation which resulted in early harvest.

Therefore, it can be inferred from Table 7 that with regard to earliness of the crop, application of FYM along with AMF and *Frateuria* performed better than other treatments.

5.3. Biometrical characteristics of fruit

It can be observed that T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest fruit weight (19.80 g) and fruit girth (6.17 cm) compared to control (Table 8). It was followed by T_{10} where FYM, inorganic (¾ NPK) fertilizers and all the three biofertilizers were applied.

Better biometrical properties in T_8 and T_{10} 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 biometrical properties. FYM also provided room for better establishment of inoculated microorganism along with accumulation of excess humus content (Hayworth *et al.*, 1996). Conjoint application of FYM, inorganic fertilizers and biofertilizers might have acted complementary and supplementary to each other and resulted in adequate and slow, but steady supply of nutrients. Similar results were obtained by Bahadur and Manohar (2001) in okra and Wange and Kale (2003) in bittergourd, when biofertilizers were applied along with 75 per cent nitrogen.

Seed yield depends upon the production of photosynthates and their distribution among various plant parts. In the present investigation, the number of seeds per fruit showed significant variation between the treatments with T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recording higher values of 82.89 and 80.33 respectively. It was 16.74 per cent and 13.14 per cent more than control. Similar results were obtained by Ramana *et al.* (2010) in French bean.

The synergistic effect of optimum rate of integrated source of nutrients with biofertilizers 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 (Desai *et al.*, 2009). Similarly, higher seed content in the present study can be attributed to the increased amount of nutrients which enhanced the formation of plant metabolites that helped to build the plant tissues which affected pod length and consequently number of seeds per pod. In addition, increased phosphorus availability also might have helped in setting and development of seeds.

5.4. Yield characteristics

Yield is the manifestation of morphological, physiological, biochemical and growth parameters and is considered to be the result from the trapping and conversion of solar energy.

Number of fruits per plant showed significant differences among the treatments and it ranged from 20.00 to 31.67. The highest number of fruits per plants (31.67) was recorded in the treatment where double dose of FYM was applied along with *Azospirillum*, AMF and *Frateuria* (T_8) which was 43.95 per cent more than control. T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) also recorded a comparatively higher fruit number (29.60). Similar results were obtained by Bahadur and Manohar (2001) in okra, Wange and Kale (2003) in okra and bittergourd and Premsekhar and Rajasree (2009) in tomato, when biofertilizers were inoculated along with 75 per cent nitrogen.

Better availability of nutrients at vital growth period, greater synthesis of carbohydrates, their proper translocation and improved water status of plants might have enabled the plant to put up better growth with profuse flowering combined with high fruit set, thus resulting in higher number of fruits per plants (Dar *et al.*, 2010b). Moreover, addition of biofertilizers might have increased various endogenous hormonal levels which in turn enhanced pollen germination and tube growth (Prabhu *et al.*, 2006). Supply of nutrients might have increased the production, translocation and accumulation of photosynthates to growing points. This might have stimulated the plants to produce productive flowers ultimately resulting in increased yield and more number of fruits per plant.

Significant differences were noticed with respect to fruit yield (Fig. 3 and 4). Combined application of all the three biofertilizers along with double dose of FYM (T_8) recorded the highest fruit yield per plant (544.40 g) and total fruit yield (16.33 t/ha). It was 50.99 per cent and 38.97 per cent more than control. Here also

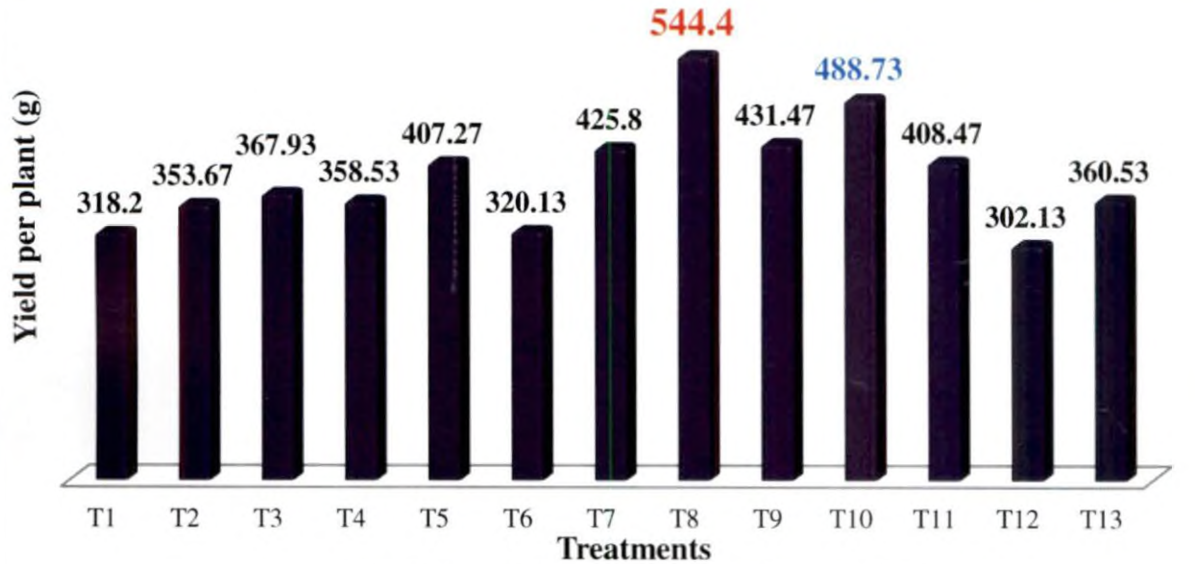


Fig.3: Effect of treatments on yield per plant

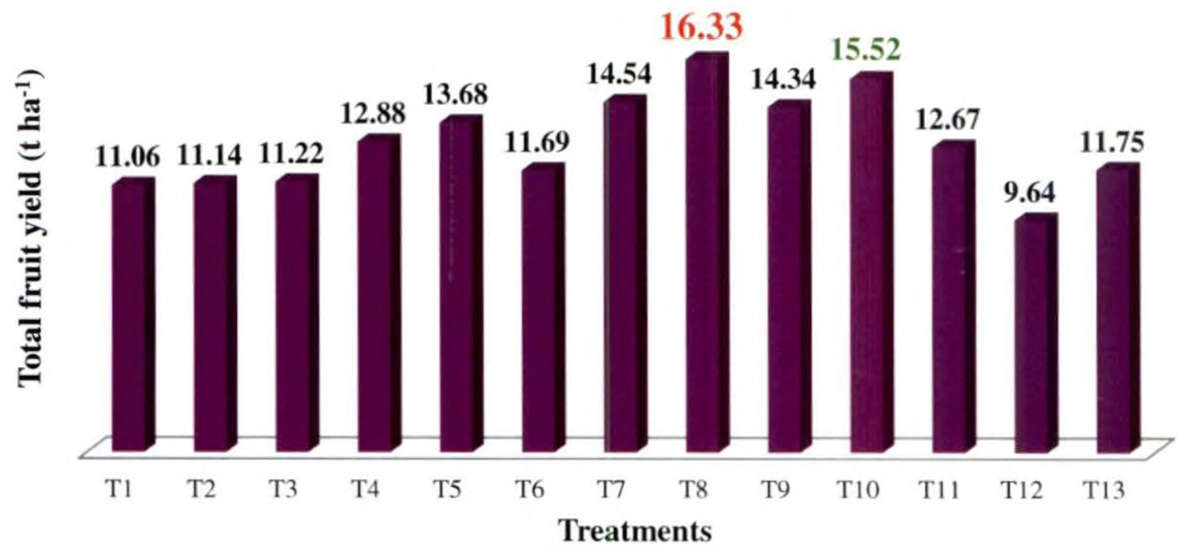


Fig.4: Effect of treatments on total fruit yield

application of FYM, inorganic (¾ NPK) fertilizers and biofertilizers (T_{10}) recorded 35.56 per cent more fruit yield per plant (488.73 g) and 32.08 per cent more total fruit yield (15.52 t/ha) than control. It could be observed that activity of biofertilizers in promoting fruit yield was more pronounced when it was enriched with double dose of FYM, and the more so, when it was further supplemented with lower dose of chemical fertilizers. This suggests that recommended dose of FYM and NPK could be replaced with double dose of FYM along with all the three biofertilizers. It also suggests that application of all the three biofertilizers along with judicious application of inorganic fertilizers and FYM could save 25 per cent of inorganic fertilizers. Similar results were obtained by Karuthamani (1995) in pumpkin, Vendan and Nanjan (1998) in potato, Thilakavathy and Ramaswamy (1999) in multiplier onion, Nanthakumar and Veeraraghavathatham (2000) in brinjal, Kamalakannan and Manivannan (2003) in radish, Patel *et al.* (2010) in elephant foot yam and Ramana *et al.* (2010) in French bean when biofertilizers were applied along with 75 per cent of nitrogenous and phosphatic fertilizers.

Yield improvement could be related to better growth of plants in terms of plant height and number of leaves which had positive significant co-relation with yield. Application of double dose of FYM might have created better soil condition due to higher rate of multiplication of inoculated microbes leading to enrichment and mobilisation of bound nutrients and improvement in soil aggregation. FYM provides macro and micro nutrients, increase water holding capacity and improves aeration for better root formation (Nirmala and Vadivel, 1999; Kirad *et al.*, 2010). Decomposition of FYM increased solubility of nutrients by forming humic complex which are easily assimilated by plants (Jasrotia and Sharma, 1998). All these might have made quick mobilisation and availability of nutrients which could have resulted in increased plant height, number of leaves and photosynthetic rate. This could have resulted in increased yield attributes like fruit weight, fruit length and number of fruits ultimately resulting in higher yield.

The higher yield also observed in T_{10} where FYM, inorganic (¾ NPK) fertilizers and biofertilizers were applied might be due to the supply of additional nutrients as well as improvement in physical and biological properties of soil by organics and inorganics. Active and rapid multiplication of microorganisms in rhizosphere creating a favourable condition for nutrient availability and uptake, secretion of hormones like IAA, cytokinin, vitamin B_{12}, GA (Bahadur and Manohar, 2001; Devi *et al.*, 2002) and supply of antibacterial and antifungal compounds (Sood and Vidyasagar, 2008) and micronutrients might have favoured growth and yield.

Response of *Azospirillum* was better at lower dose of nitrogen (Summer, 1990; Wani and Konde, 1986). It might have increased the number of cells as well as elongation of individual cells and better translocation of soluble ions (Muruganandam and Anburani, 2010). AMF mobilises nutrients from beyond the depletion zone around root (Kandasamy *et al.*, 1985) and improves availability and uptake of nutrients and also produce growth promoting substances (Sreenivasa, 1994). Better crop due to all these factors might have helped in increasing photosynthetic rate and more physiological and biochemical activities which in turn resulted in increased yield and yield components.

The reduced yield components in control plot can be attributed to inadequate translocation of nutrients by plants from vegetative parts to fruits and limited capacity of plants to utilise greater amounts of nutrients supplied through inorganic fertilizers beyond a certain optimum point (Patel *et al.*, 2009).

5.5. Fruit quality parameters

Quality is an important parameter which ultimately decides the demand and price in the market. Balanced nutrient supply is necessary not only for obtaining higher and regular yield but also for increasing quality of the produce. Increasing quality and minimising post-harvest losses will go a long way in increasing production indirectly.

Significantly higher beta carotene content of 94.33 μg/100 g was observed in T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which was 43.84 per cent more than control. Organic amendments are known to increase availability and uptake of micronutrients and vitamins in vegetables. The increased availability and uptake of nutrients particularly micronutrients may be the reason for improved carotenoid content (Chaurasia *et al.*, 2008).

Crude protein content also showed significant variation and the treatments where all the three biofertilizers were applied recorded higher values. This might be attributed to the increased utilization of nitrogen, phosphorus and potassium due to organic acids produced during decomposition and as well as inducing chelating effects on micronutrients which probably enhanced availability of N, P, K and also solubilise the available micronutrient (Bairwa *et al.*, 2009). This increased availability, uptake, assimilation and translocation of nutrients by biological activity of inoculated microorganism might have resulted in increased crude protein content.

Physiological loss in weight during storage occurs continuously due to moisture loss causing the fruits to lose their freshness. In the present study, shelf life of fruits showed good response when biofertilizers were used in combination with FYM (T_7 and T_8) which recorded 6.67 days. It was followed by T_6 (FYM + AMF + *Frateuria* each @ 2 kg/ha) and T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 6.33 days. Potassium plays a major role in increasing shelf life by maintaining turgor pressure and lowering the activity of enzymes which break down carbohydrates. The increased availability of phosphorus might have improved storability since phosphorus is also known to improve keeping quality (Tiruneh, 1999). Application of biofertilizers might have reduced respiration which in turn resulted in higher storage life. Those grown under inorganic fertilizes (T_{13}) might have accelerated the catabolism of fruit and thus possible higher respiration resulting in lower shelf life (Mulani *et al.*, 2007). Therefore, improvement in shelf life by biofertilizer application could be due to their nutritional, stimulatory and therapeutic behaviour (Chatoo *et al.*, 2007).

5.6. Nutrient analysis of plants

Data pertaining to the nutrient content of plant presented in Tables 11-13 indicated that there was significant influence by various treatments over control.

Nitrogen content in fruit was found to be higher in treatments where all the three biofertilizers were used along with FYM (T_7, T_8, T_9, T_{10} and T_{11}) and all were higher than control (T_{13}) whereas there was no significant difference in nitrogen content of leaf. The increase in nitrogen content of fruits can be attributed to the multiplication of *Azospirillum* and their atmospheric nitrogen fixation thereby 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 biofertilizers along with FYM and inorganic (½ NPK) fertilizers (T_9) gave higher phosphorus content (0.17 %) than control. It was on par with other treatments where biofertilizers alone were applied along with FYM. In leaves T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest value of 0.20 per cent. Differences in phosphorus content were prominent at lower levels of added phosphorus. This can be attributed to the high affinity of mycorrhizal roots to phosphorus compared to non mycorrhizal roots while at high levels of added phosphorus the affinity for phosphorus was similar in mycorrhizal and non-mycorrhizal plants (Cress *et al.*, 1979). The additional absorbing surface provided by the external hyphae of mycorrhizal fungi enhances the ability of plants to retrieve phosphates (Marschner and Dell, 1994).

There were significant differences in potassium content of plants. The maximum potassium content in fruit was found in T_{10} (1.28 %) where FYM, *Azospirillum*, AMF and *Frateuria* were applied along with ¾ NPK. It can be observed that all the treatments where FYM, inorganic fertilizers and biofertilizers were applied were on par. Potassium content of leaves was found to be the highest in T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) and T_{11} (POP + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 0.87 per cent.

Iron content of fruits showed significant difference with T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) showing higher content of 0.050 per cent which was on par with T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 0.048 per cent.

Nitrogen, phosphorus and potassium uptake, their distribution and removal have important bearing on crop yield and quality. Uptake of nitrogen, phosphorus and potassium by different plant parts gives an indication of the fertility status of soil and also yield potential of crop. Significant differences were noticed in nitrogen, phosphorus and potassium uptake of plants.

Maximum nitrogen uptake was found in T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) followed by T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 212.92 kg/ha and 201.87 kg/ha respectively. Application of inorganic fertilizers in combination with biofertilizers might have attributed to better synthesis of metabolites which helped in enhancing uptake of nutrients by plants. *Azospirillum* being a root colonizer has close contact with plant roots. It can soften middle lamella through the action of pectinolytic enzymes thus enhancing the mineral absorption surface of cortex cells. In addition, increase in root hairs and lateral roots which are capable of absorbing more and more nutrients from soil might have increased nitrogen uptake (Govindan and Purushothaman, 1989;

Singh *et al.*, 1997). AMF have also been found to increase symbiotic nitrogen fixation and enhance nitrogen uptake (Beaulah *et al.*, 2004).

Significantly higher uptake of phosphorus was obtained in T_7 (38.09 kg/ha) when FYM was applied along with *Azospirillum*, AMF and *Frateuria*. It was 50.43 per cent more than control. The increased phosphorus uptake could be due to the combined action of all the three biofertilizers in the presence of FYM. The FYM acted as a source of energy to microorganism. These microorganisms effectively transform the organic form of nutrients to inorganic form which are easily taken up by the plants. Increased phosphorus uptake could be due to the action of AMF which extends its hyphae, mobilize phosphorus and translocate to plants (Abbott and Robson, 1982). AMF increased effective absorption surface of host root by promoting growth of root external mycelium beyond root zone and in turn increased soil volume to be exploited for phosphorus uptake. Thus it shortens the distance that nutrients must diffuse through soil to the roots (Hattingh *et al.*, 1973; Rhodes and Gerdemann, 1975). *Azospirillum* is also reported to increase phosphorus uptake by producing enzymic complexes which solubilize the unavailable form of phosphorus and render them available (Pacovsky, 1985; Prabhu *et al.*, 2006).

The highest potassium uptake was recorded in T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 150.26 kg/ha followed by T_7 and T_9 recording 150.25 kg/ha and 146.52 kg/ha which were on par. The increased potassium uptake might be due to the action of *Frateuria* which was stimulated in the presence of inorganic fertilizers. Similar findings were reported by Murugesan (2008) using *Frateuria* in brinjal. Increase in potassium uptake might be due to inoculation with *Azospirillum* also (Prabhu *et al.*, 2006). Favourable effect on potassium uptake due to *Azospirillum* inoculation could be attributed to the enhanced mineral and water uptake (Laura *et al.*, 1994; Kumari and Lakshmi, 2009). Synergistic relation between nitrogen and potassium has been reported by Subbiah (1994).

In general it can be noted that higher uptake of nutrients was observed in treatments which recorded higher dry matter content and nutrient content. It can be observed that plants inoculated with all the three biofertilizers, FYM, with and without inorganic fertilizers showed better uptake of nutrients than dual inoculation or sole inoculation. A stimulated growth under inorganic nutrient application might have resulted in better biological activity of the microorganism and could have resulted in better proliferation of root system, better availability of nutrients which resulted in increased intake efficiency of plants.

5.7. Soil analysis

Soil fertility is one of the principle key to crop productivity. Organic manures and biofertilizers are known to influence the physical and chemical properties of the soil and activate soil biologically, thus restoring natural fertility. Some of the important properties of the soil like organic carbon, available nitrogen, available P_2O_5, available K_2O, pH and electrical conductivity have been assessed.

In the present study, organic carbon content of soil increased significantly following the addition of different biofertilizers. It can be observed that T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) recorded the highest value at 50 DAS (0.54 %) and 100 DAS (0.65 %) which was 38.46 per cent and 41.3 per cent more than control. The least carbon content was observed in T_{12} where biofertilizers were applied without FYM.

It can be observed that FYM and biofertilizers along with higher dose of inorganic fertilizers (T_{11}) increased the available nitrogen status of soil over control (Table 15). It was 211 kg/ha at 50 DAS and 297 kg/ha at 100 DAS and was 32.43 per cent and 32.39 per cent more than control. This might be due to improved nitrogen fixation by *Azospirillum* which in turn increased nitrogen availability in soil. Similar results were obtained by Jha *et al.* (2006) when

Azospirillum and AMF were inoculated to onion along with half dose of nitrogen and phosphorus.

Application of double dose of FYM (T_8) and single dose of FYM (T_7) along with all the three biofertilizers recorded the highest available P_2O_5 content in soil recording 106.28 kg/ha and 100.04 kg/ha respectively at 50 DAS and were on par. It was 90.19 per cent and 79.03 per cent more than control. P_2O_5 availability in soil increased with the application of FYM due to increased decomposition of FYM. At 100 DAS, T_{11} (POP + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) showed significantly higher P_2O_5 content of 88.57 kg/ha which was 80.13 per cent more than control.

Significant differences in available K_2O content were noticed between treatments. At 50 DAS, T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest value of 89.17 kg/ha followed by T_{11} (POP + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 88.95 kg/ha. At 100 DAS, T_3 (FYM + *Frateuria* @ 2 kg/ha) recorded the highest value of 131.26 kg/ha. It can be inferred from Table 16 that there was a gradual increase in available K_2O content over the period of observation. The increased K_2O content in T_3 might be due to the solubilisation of potash by secretion of some organic acids like succinic acid by bacteria.

pH is one of the important soil property that affects the availability of nutrients. pH was significantly affected by various treatments. At 50 DAS, T_3 (FYM + *Frateuria* @ 2 kg/ha) recorded the highest value of 5.0 while at post experimental stage T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest value of 5.47 which is 13.95 per cent more than control. Application of chemical fertilizers alone recorded a lower pH while addition of FYM, biofertilizers and chemical fertilizers recorded variable increase in values. It is in conformity with the findings of Ray *et al.* (2005). It can be observed that pH of all the treatments is in acidic range and addition of biofertilizers was not able to change the acidity of soil even though a slight increase was observed from the initial value (4.13).

Electrical conductivity of soil showed significant differences between treatments. At 50 DAS, T_1 (FYM + *Azospirillum* @ 2 kg/ha) recorded the highest value of 0.090 dS/m which was 91.49 per cent more than control. At 100 DAS, T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) showed a significantly higher EC value of 0.147 dS/m which was 83.75 per cent more than control.

5.8. Enumeration of *Azospirillum*, AMF and *Frateuria* in rhizosphere soil

It could be observed that addition of biofertilizers had a positive effect on population of *Azospirillum*, AMF and *Frateuria*.

Azospirillum count at the final harvest was the highest in T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) with 45.50 x 10^6 cfu/g soil followed by T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 43.00 x 10^6 cfu/g soil (Fig. 5). Application of double dose of FYM might have increased the activity of *Azospirillum*. This increased microbial population might have led to better nutrient availability to plants and have resulted in better growth and yield parameters in T_8 and T_{10}.

All the treatments enhanced the spore count of AMF from the initial values of 3 spores/10 g soil. After the completion of crop, T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) recorded the highest spore count of 31 spores/10 g soil even though there was no significant difference between treatments (Fig. 6). It was followed by T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) which recorded 30.50 spores /10 g soil respectively.

Application of FYM + *Azospirillum* + *Frateuria* each @ 2 kg/ha (T_5) recorded the highest population of *Frateuria* (37 x 10^6 cfu/g soil) at final harvest. T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) also showed superiority over other treatments with a count of 32.00 x 10^6 cfu/g soil. The control (T_{13}) recorded the least count of 5.00 x 10^6 cfu/g soil (Fig. 5).

5.9. Incidence of pests and diseases

Some minor incidence of mosaic, and shoot and fruit borer infestation were noticed at later stages of growth. But it was not significant.

5.10. Economics of cultivation

It can be observed from table 20 that treatments where all the three biofertilizers were applied recorded a higher maximum benefit: cost ratio and the maximum B:C ratio was obtained in T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha). Even though, the cost was higher in T_8, the higher yield obtained in this treatment was able to overcome the high cost and gave the highest B:C ratio of 2.49. T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) also recorded higher B: C ratio of 2.42 (Fig. 7). This suggests that either the POP recommendation could be replaced by double FYM, *Azospirillum*, AMF and *Frateuria* or a reduction of 25 per cent chemical fertilizers is possible with the application of FYM, *Azospirillum*, AMF and *Frateuria*. Similar results were obtained by Kamili *et al.* (2002) in brinjal, Yadav *et al.* (2005) in onion, Premsekhar and Rajasree (2009) in tomato, when biofertilizers were inoculated with 75 per cent of nitrogenous fertilizers.

Summing up the discussion, it can be concluded that it is possible to achieve 25 per cent economy in the use of chemical fertilizers by adopting integrated nutrient management technology for cultivation of okra. Moreover, application of increased dose of FYM along with biofertilizers helped to improve the survival of

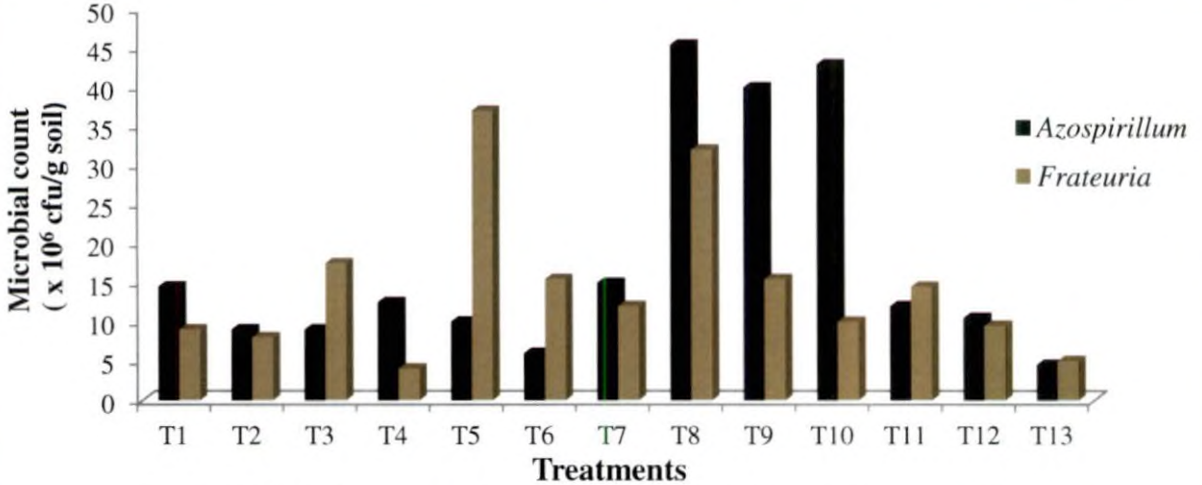


Fig.5: Effect of treatments on population of *Azospirillum* and *Frateuria* in rhizosphere soil

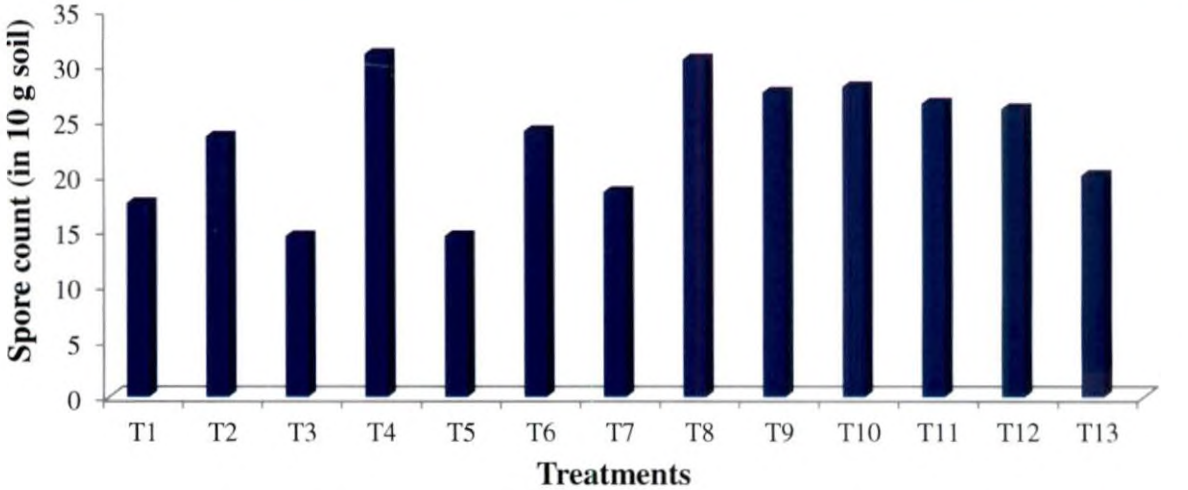


Fig.6: Effect of treatments on spore count of AMF in rhizosphere soil

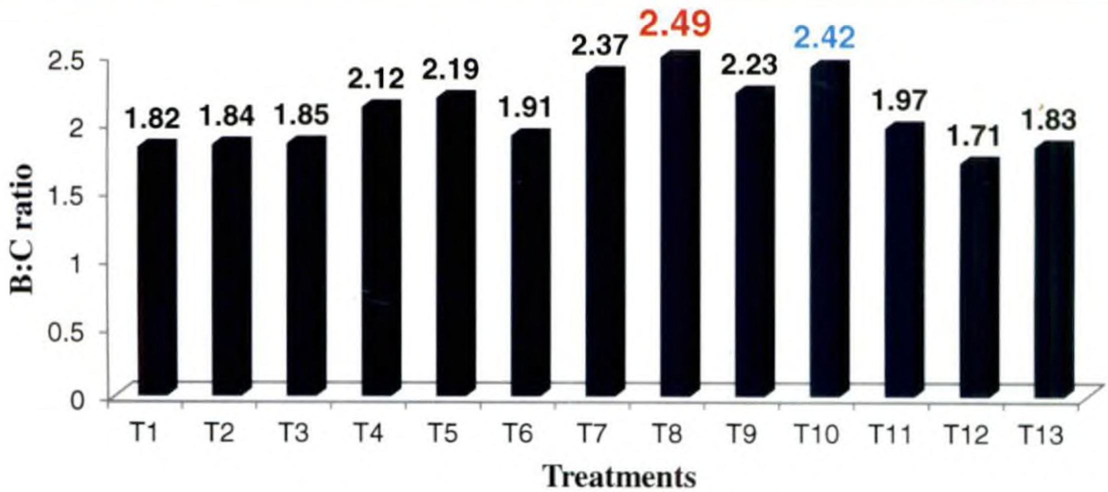


Fig. 7: Effect of treatments on economics of cultivation

different microorganisms which ultimately resulted in improved growth and yield parameters.

Future line of work:

Nutrient requirement of vegetables is very high due to their short duration and it cannot be supplied by biofertilizers alone. Therefore the focus should be to explore the possibility of supplementing chemical fertilizers with biofertilizers and organic manures for sustaining soil fertility and vegetable production. But the lack of consistent and significant crop response under field condition is a huge problem. Variation in the performance of biofertilizers may be due to various environmental and soil factors that may affect the growth of plants. Therefore, future research must take into consideration the prevailing soil conditions and should try to formulate an integrated nutrient package for vegetable cultivation after repeated experiments so that it will give uniform and convincing results. Biofertilizers can be integrated along with other organic manures and organic preparations like panchagavya, dasagavya and amritapani so that, a synergistic action of the microbes present in both the biofertilizers and these preparations will help to boost up production. The research should be extended to other economically important vegetable crops in order to find their response to biofertilizers which will help to reduce the fertilizer consumption.

Summary

6. SUMMARY

The present investigation on "Response of okra (*Abelmoschus esculentus* (L.) Moench) to biofertilizers" was carried out in the Department of Olericulture, College of Horticulture, Vellanikkara during May 2010 to September 2010, to study the effect of biofertilizers on growth, yield and quality of okra cv. Arka Anamika. The results obtained from the study are summarized below.

- Growth parameters like height of plant and number of leaves were found to be significantly affected by different treatments. Maximum plant height was recorded in T_{11} (POP + *Azospirillum* + AMF + *Frateuria* @ 2 kg/ha) at 80 DAS and T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) at 100 DAS. T_8 recorded the maximum number of leaves at 60 DAS, 80 DAS and 100 DAS. There was no significant variation with respect to number of branches.

- The relative chlorophyll content of leaves was also influenced by the application of biofertilizers. Double dose of FYM along with all the three biofertilizers (T_8) recorded the highest relative chlorophyll content.

- Treatment T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest total dry matter production followed by T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

- With respect to earliness, application of FYM along with AMF and *Frateuria* (T_6) recorded the least number of days to first flower opening and first harvest. No significant variation was noticed with respect to the node at which first flower appeared.

- Among the biometrical characteristics of fruits, fruit size, fruit weight, fruit girth and number of seeds were significantly affected by different treatments. T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest value. In all these parameters T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) also showed superiority next to T_8.

- Regarding the yield characteristics, combined application of all the three biofertilizers along with double dose of FYM (T_8) recorded significantly higher values for maximum number of fruits, fruit yield per plant and total fruit yield followed by T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha). No significant variation was noticed with respect to the number of harvests and duration of crop.

- The highest β carotene content of fruit was recorded in T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) whereas T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest crude protein content. There was no significant variation with respect to vitamin C content. Treatments where biofertilizers were applied along with FYM (T_7 and T_8) recorded the maximum shelf life.

- Nutrient content of fruits revealed that T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest nitrogen and phosphorus content whereas T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the highest potassium content. With respect to nutrient content of leaf T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) gave the highest value for nitrogen content whereas T_7 (FYM + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) showed maximum phosphorus content. Potassium content of leaves was maximum in T_7 and T_{10}.

- Nutrient uptake by plants varied significantly between treatments. Combined application of FYM, inorganic (¾) fertilizers and biofertilizers (T_{10}) recorded the maximum uptake of *nitrogen and potassium* whereas maximum uptake of phosphorus was observed in treatment where all the three biofertilizers were applied along with FYM (T_7).

- Integrated nutrient management significantly increased the available nutrient content of soil as compared to that of POP recommendation. T_4 (FYM + *Azospirillum* + AMF each @ 2 kg/ha) recorded the maximum organic carbon content. Soil analysis revealed the superiority of T_{11} (POP + *Azospirillum* + AMF + *Frateuria* @ 2 kg/ha) in terms of available nitrogen. Available P_2O_5 content of soil was highest in T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) at 50 DAS and T_{11} (POP + *Azospirillu*m + AMF + *Frateuria* each @ 2 kg/ha) at 100 DAS, whereas available K_2O content was highest in T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) at 50 DAS and T_3 (FYM + *Frateuria* @ 2 kg/ha) at 100 DAS.

- Application of organic manures, inorganic fertilizers and biofertilizers favourably influenced soil chemical properties like pH and electrical conductivity. Treatment T_3 (FYM + *Frateuria* @ 2 kg/ha) recorded the highest pH at 50 DAS, whereas T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the maximum value at 100 DAS. Treatment T_1 (FYM + *Azospirillum* @ 2 kg/ha) and T_9 (FYM (as per POP) + ½ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) recorded the maximum electrical conductivity at 50 DAS and 100 DAS respectively.

- Population of *Azospirillum* in rhizosphere soil was highest in T_8 (FYM (double dose) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha) whereas the highest population of *Frateuria* was recorded in T_5 (FYM + *Azospirillum* + *Frateuria* each @ 2 kg/ha). Spore count of AMF was found highest in T_4 (FYM + *Azospirillum* + AMF + each @ 2 kg/ha.

- Maximum B: C ratio was recorded in T_8 where all the biofertilizers were applied along with double dose of FYM. It was followed by T_{10} (FYM (as per POP) + ¾ (NPK) + *Azospirillum* + AMF + *Frateuria* each @ 2 kg/ha).

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* Originals not seen

Appendices

APPENDIX I

Weather data collected from meteorological observatory of College of Horticulture, Vellanikkara

(May 14/05/2010 to 16/09/2010)

Standard week	Maximum temperature (^0C)	Minimum temperature (^0C)	Average rainfall (mm)	Maximum humidity (%)	Minimum humidity (%)	Soil temperature (^0C)					
						Morning			Evening		
						5cm	10cm	20cm	5cm	10cm	20cm
20	33.4	25.4	4.6	92	69	29.4	29.7	31.4	38.2	36.0	32.2
21	31.7	25.7	2.1	93	72	28.5	28.6	30.1	36.4	34.5	32.3
22	32.7	25.1	7.8	93	66	28.9	29.2	30.8	37.6	35.3	32.1
23	31.4	24.2	2.3	93	79	27.7	28.0	30.0	33.2	32.6	30.3
24	28.1	23.3	45.3	97	89	26.0	26.1	27.5	29.4	28.6	27.5
25	30.8	23.9	20.7	94	67	27.5	27.5	29.0	33.7	31.9	29.9
26	30.2	23.1	28.6	96	76	26.6	26.8	28.3	31.9	30.3	29.0
27	28.6	22.8	26.6	96	82	26.2	26.4	27.9	31.1	29.5	28.3
28	31.2	24.0	4.7	95	72	28.0	28.0	29.2	34.5	32.1	29.9
29	27.8	23.0	23.9	97	84	26.6	26.6	27.7	29.8	28.4	22.8

30	29.6	22.3	14.8	95	81	26.8	26.8	27.0	30.8	29.4	28.2
31	28.6	22.3	19.2	96	74	25.8	26.0	27.1	31.8	29.6	28.0
32	30.6	24.1	4.4	95	73	26.9	26.9	28.1	34.8	32.1	29.1
33	29.5	23.0	6.2	94	79	26.2	26.3	27.6	33.3	31.1	28.9
34	28.7	23.3	1.9	94	83	26.4	26.4	27.3	31.0	29.2	28.0
35	28.6	22.8	9.1	95	76	26.0	26.1	26.9	32.0	29.8	27.8
36	29.9	23.1	5.6	94	73	23.1	26.8	27.7	33.0	30.7	28.6
37	29.8	23.2	21.2	96	72	23.2	26.7	27.7	33.7	31.5	20.6

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	6.00g
KH_2PO_4	4.00 g
Magnesium sulphate	0.20 g
Calcium chloride	0.02 g
Sodium chloride	0.10 g
Ammonium chloride	1.00 g
Maleic acid	5.00 g
Sodium hydroxide	3.00 g
Yeast extract	0.05 g
Sodium molybdate	0.002 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	20.0g
Yeast extract	8.0 g
Peptone	5.0 g
Ethanol	5.0 ml
$CaCO_3$	3.0 g
Agar	15.0 g
Distilled water	1000 ml

Abstract of the Thesis

RESPONSE OF OKRA (*Abelmoschus esculentus* (L.) Moench) TO BIOFERTILIZERS

By

ANISA N. A.
(2009 - 12 - 105)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Horticulture

Faculty of Agriculture
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ABSTRACT

An investigation on the effect of biofertilizers on growth and yield of okra was carried out in the Department of Olericulture, College of Horticulture, Vellanikkara during 2010-11. Okra variety Arka Anamika was used for the study. The experiment was laid out in Randomised Block Design with thirteen treatments and three replications. The biofertilizers (*Azospirillum*, Arbuscular Mycorrhizal Fungi and *Frateuria*) were applied @ 2 kg/ha. The treatments included sole inoculation of biofertilizers along with FYM (T_1, T_2, T_3), dual inoculation along with FYM (T_4, T_5, T_6), inoculation of all the three biofertilizers along with FYM, applied as single dose (T_7) and double dose (T_8), inoculation of all the three biofertilizers along with FYM and inorganic (½, ¾, full dose) fertilizers (T_9, T_{10}, T_{11}), application of all the three biofertilizers without FYM (T_{12}) and control (T_{13}- KAU POP).

The study revealed that the treatment where *Azospirillum*, AMF and *Frateuria* were inoculated along with double dose of FYM (T_8) and the treatment where all the three biofertilizers were applied along with FYM and ¾ NPK (T_{10}) exhibited superiority in terms of growth parameters. The relative chlorophyll content (48.73 SPAD Units) and total dry matter production (350.50 g/plant) were the highest in plants supplied with double dose of FYM along with biofertilizers.

The earliest flowering (39.67 days) and harvesting (46.33 days) were recorded in plants inoculated with AMF and *Frateuria* along with FYM (T_6). The treatment T_8 (double dose of FYM along with *Azospirillum*, AMF and *Frateuria*) recorded the maximum fruit weight (19.80 g), fruit girth (6.17 cm) and number of seeds per fruit (82.89). It was followed by the treatment T_{10} (FYM, inorganic fertilizers (¾) and biofertilizers).

Plants treated with double dose of FYM, *Azospirillum*, AMF and *Frateuria* (T_8) recorded the highest number of fruits per plant (31.67), fruit yield per plant

(544.40 g) and total fruit yield (16.33 $t ha^{-1}$). It was followed by integrated application of FYM, inorganic fertilizers (¾) and biofertilizers (T_{10}).

The crude protein content of okra fruit was higher in treatments where all the three biofertilizers were applied. The treatment T_{10} where FYM, inorganic fertilizers (¾) and biofertilizers were applied, recorded the highest beta carotene content (94.33 µg/100g). Shelf life (6.67 days) was more in plants treated with all the three biofertilizers and FYM (T_7 and T_8). Higher nutrient content and uptake was observed in treatments where all the three biofertilizers were applied.

Application of biofertilizers resulted in improvement of soil parameters like organic carbon, available N, P_2O_5 and K_2O, pH and electrical conductivity. The population of *Azospirillum*, AMF and *Frateuria* in the rhizosphere was also enhanced by the use of biofertilizers.

Regarding the economics of cultivation the highest B:C ratio of 2.49 was recorded in T_8, where double dose of FYM was applied along with all the three biofertilizers. It was followed by the treatment T_{10} which recorded a B:C ratio of 2.42.

It can be concluded that inoculation of biofertilizers enhanced the growth, yield and quality of okra. The available nutrient status and health of the soil was also improved by biofertilizer application. Overall assessment indicated that combined application of all the three biofertilizers along with double dose of FYM was the best, with respect to growth and yield. The second best performance was obtained when FYM, inorganic fertilizers (¾) and biofertilizers were applied signifying that a reduction of 25 per cent chemical fertilizers is possible by using biofertilizers.