BIO FARMING IN VEGETABLES

I) EFFECT OF BIOFERTILIZERS IN AMARANTH (*Amaranthus tricolor* L.)

By

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DECLARATION

I hereby declare that this thesis entitled " **Bio farming in vegetables - i) Effect of biofertilizers on amaranth (*Amaranthus tricolor* L.)** "is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Vellayani,
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CERTIFICATE

Certified that this thesis entitled " **Bio farming in vegetables - i) Effect of biofertilizers in amaranth (*Amaranthus tricolor* L.)**" is a record of research work done independently by N.S.Niranjana under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to her.

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INTRODUCTION

1. INTRODUCTION

India is basically an agricultural country. Indian sub continent maintains a unique position as far as vegetable cultivation is considered. It can be proud of being the producer of nearly 60 kinds of leafy fruit, and other vegetables. Incidentally India is the largest producer of vegetables next to China in the world.

According to FAO data, the food supply in terms of calorie intake was reported 2021 day^{-1} in 1969-71 and 2204 day^{-1} in 1984-86. The average food availability has not gone up in recent years and hence it is reasonable to conclude that 74 per cent of the rural population in India is taking sub-optimal calorie intake. Against daily recommended intake of 280 g of vegetables, the availability is only 135.82 g day^{-1} (84 k cal) [Ministry of Agriculture, 1994]

Food security has been recognised as a fundamental directive of State policy by Constitution under Article 47 which clearly places on the State, the duty of raising level of nutrition and standard of living of its people and improvement of public health

Leafy vegetables play an important role in supplying valuable nutrients, particularly minerals and vitamins in human diet. Amaranthus, being rich in protein, vitamin A, vitamin C and iron is a popular leafy vegetable. It is capable of producing, several crops in a year making it more acceptable to farmers.

Of the many problems identified in feeding the teeming millions, downtrends in capital formation in agriculture and the unbalanced use of fertilizers are great impedemetic in achieving food self sufficiency and food security in India. Overall management is the basic criterion for the impressive performance of crops. This management is often costly and not affordable by our resource poor farmers. Our strategies should be pro resource poor farmers with minimum use of external inputs, maximum use of natural nutrients present in the ecosystem. The major means have to be technological change. From technical, economical, logistical and environmental considerations the best course is to practise integrated nutrient management. This will harmoniously integrate the use of mineral fertilizers, organics and bio fetilizers. Bio fertilizers are an important component of integrated nutrient management which supplement chemical fertilizer in crop nutrition. They have the added advantage of being of low cost, renewable and non polluting.

In recent years bio-fertilizers *Azospirillum* and Arbuscular Mycorrhizal Fungi (AMF) has given good responses in many horticultural crops. *Azospirillum* is an associative symbiotic nitrogen fixing bacteria having high potential for nitrogen fixation. They are also known to produce growth-promoting substances. Inoculation increased the yield in the range of 5-50 per cent.

The obligate symbiotic omnipresent mycorrhizal association are known to promote growth of cultivated crop under nutrient deficient soil. AMF have been known to increase plant growth through mobilisation of P, Zn, Cu, S and water through greater soil exploration of the hyphae. AMF inoculated plants have also shown significant increase in plant dry weight.

Azospirillum and AMF by virtue of fixing atmospheric nitrogen and greater soil exploration of the hyphae have proved to be promising bioinoculants responsive in vegetable crops. They assure a saving of chemical fertilizer as they supplement nutrients in crop production. The present study included these to note specifically the range of chemical fertilizer it can substitute without loss in yield and quality of the produce. They have also shown advantage of greater bio-mass due to the production of plant growth hormones and better nutrient mobilisation. The study also aimed at quantifying the added advantage which the bioinoculants provided in increasing yield and improving the quality of produce. A suitable leafy vegetable popular to Kerala was selected to note the sustained performance of bioinoculants over the various harvests.

Keeping these views under consideration, the present investigation entitled **"Bio farming in vegetables - i) Effect of biofertilizers in amaranth (*Amaranthus tricolor* L.)"** has been taken up. The objective of the investigation is to find out the effect of bio-fertilizers like *Azospirillum* and AMF on the productivity and quality of amaranthus and to assess the possibility of economising fertilizer by using these bioagents.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

An investigation was conducted in the College of Agriculture , Vellayani during the period from April to September, 1996 to study the influence of biofertilizers *Azospirillum* and AMF on amaranth. The literature collected pertaining to the above subject are reviewed hereunder.

2.1 *Azospirillum*

Nitrogen fixing rhizosphere bacteria *Azospirillum* have beneficial effects on plant growth and yield of many crops of agricultural importance. *Azospirillum* has during the past eighteen years attracted ever increasing scientific interest for several reasons, it can utilise atmospheric nitrogen and contribute to plant nitrogen nutrition, it can improve plant nutrient uptake and contribute the balance of root environment through protection against pathogen, equilibrate nutrient flow and immobilise chemical fertilizers in the soil. They are very versatile in their carbon and nitrogen metabolism and are known to produce phytohormones.

Over the past twenty years in the case of 60-70 per cent of the experiments done world wide, an increase in crop yield due to *Azospirillum* inoculation could be observed. This increase could compensate the inoculation costs and replaced about 30 per cent of nitrogen fertilizers. Application of bacterial fertilizer followed by chemical fertilizer was found to increase yield (Mehorotra and Lehri, 1971; Oblisami *et al.* ,1976). Use of biofertilizer gave 15-62 per cent and 25-30 per cent increase in yield of brinjal and cabbage respectively (Lehri and Mehorotra, 1972). A 65.1 per cent yield hike in cabbage was reported by Conty *et al.*,(1974); Iswaran ,(1975).

Manib *et al.* (1979) reported increased dry weight of tomato plants by 5-12 per cent due to inoculation of *Azospirillum.*

Inoculation gave increased yield in maize (Kapulnik *et al.*, 1983) in fodder sorghum (Govindarajan, 1987), in tomato (Subbiah, 1991, Dhanalakshmi and Pappiah, 1995), in cabbage (Jothi *et al.*, 1993), in mulberry (Reddy *et al.*, 1995) and in bhendi, (Balasubramani and Pappiah, 1995; Rajasekar *et al.*, 1995).

2.1.1 Growth response

Santhanakrishnan and Oblisami,(1980) reported an increase in length of root, root weight and root number when mulberry plants were inoculated with *Azospirillum.* Positive effects of inoculation on various root parameters include, increase in root dry weight and root hair development. Inoculated maize recorded more plant height, vegetative growth, leaf dry weight and number of ears than uninoculated plants (Kapulnik *et al*; 1983).In cereal and non cereals increase in total dry weight, nitrogen content in the shoots and grains, total number of tillers, number of spikes and grain per spike, earlier heading and flowering time, increased grain weight, greater plant height and leaf size and higher germination rate were observed. (Baldani *et al*, 1983; Bashan, 1990; Cohen *et al*, 1980; Fulcheri and Frioni, 1994; Hegazi *et al*, 1983; Pascovsky *et al*, 1985; Yaholom *et al*, 1984; Rai and Guar, 1982). *Azospirillum* with medium and high dose of fertilizer recorded greater yield in wheat (Millet and Feldman, 1984). Govindarajan (1987) reported increased fresh weight of root, shoot and greater plant height when *Azospirillum* was given as seed or soil inoculum. Hadas and Okon (1987) found a significant increase in root length (35 per cent) and root dry weight (50 per cent) and total leaf area in 18 day old *Azospirillum* inoculated tomato seedlings. Sarig *et al*,(1988) observed increase in root length particularly in the root elongation zone and increase in root surface area when given with nitrogen fixing bacterium. Pusa sawani bhendi gave better plant height, plant girth and number of leaves when inoculated with *Azospirillum* (Parvatham *et al*, 1989). Brinjal seedlings recorded increased plant height over control. Dry weight of foliage + leaf number also recorded a higher value (10.4 as against 7.3 without inoculation) (Bashan *et al*, 1989). Lopez *et al* (1993) reported that storage root yield of sweet potato var. UPLSP-2 and Binicol with *Azospirillum* inoculation alone was 48 and 9 per cent higher than the control respectively. In Balincaguing, the largest increment in yield (105 per cent) was obtained when inorganic fertilizer application was combined with inoculation. Increased plant height, number of primary branches per plant, number of lateral roots in chilly was realised when inoculated with *Azospirillum* (Paramaguru and Nataraja, 1993) Treatment of tomato, seedlings with *Azospirillum* gave highest germination percentage, shoot and root length, vigour index, fresh and dry weight. The number of primary and secondary roots were more and they established better in field. Early flowering and highest number of flowers were also obtained (Dhanalakshmi and Pappiah, 1995). Bhendi gave highest yield when *Azospirillum* was given as seed and soil treatment along with 30 kg N per ha, compared to control (Balasubramani and Pappiah, 1995). Rajasekhar *et al* (1995) got better yield in bhendi when plants were treated with *Azospirillum*, FYM and inorganic fertilizers.

2.1.2 Nutrient uptake

Plant inoculation with *Azospirillum* affected the foliage these changes were attributed to positive bacterial effects on mineral uptake by plants. *Azospirillum* enhanced the uptake of NO_3, NH_4, P_2O_4, K^+, Rb^+ in plants (Sarig *et al* 1984). Pacovsky *et al* (1985) observed an increase in P and other nutrient concentration in the foliage of *Azospirillum* inoculated sorghum plants. Boddey *et al.* (1983) using N-15 labelled $(NH_4)_2SO_4$ as a source of nitrogen fertilizer to wheat plants observed higher quantity of N-15 in inoculated than in uninoculated plants. Parvatham *et al*(1989) noted better uptake of N and P due to inoculation.

2.1.3 Growth hormone effects

Azospirillum has the ability for, better root induction in inoculated plants mainly due to the production of hormones like IAA and GA. As a result plants are capable of absorbing more and more available nutrients from soil which in turn results in better establishment of plant seedlings and subsequent growth. Govindan and Purushothaman, 1989; Hubbel *et al.*, 1979;Tien *et al*, 1979). Reddy *et al*, 1995; opined stimulation in plant growth due to inoculation as a result of growth promoting substances.

2.1.4 Economics

Performance of *Azospirillum* was found to be better at lower doses of nitrogen (Wani and Konde, 1986). *Azospirillum* inoculation saved 50 per cent of the recommended nitrogen and increased nitrogen use efficiency in tomato (Subbiah, 1990). Kumaraswamy and Madalageri (1990) also reported similar findings. Subbiah (1991) got saving of fertilizers to the tune of 50 per cent in bhendi when inoculated with bio agent. In tomato, seed and soil treatment of *Azospirillum* decreased nitrogen fertilizer application. Seventy five per cent of recommended dose was sufficient when supplemented with biofertilizer (Dhanalakshmi and Pappiah, 1995).

2.1.5 Quality

Zambre *et al* (1984) reported increased protein content when wheat was inoculated with *Azotobacter* and *Azospirillum* . *Azospirillum* treated plants gave fruits with high TSS (8.46 per cent) and ascorbic and (32.91 mg $100g^{-1}$) (Kumaraswamy and Madalageri, 1990).

Okon and Gonzalez (1994) by evaluating world wide data over the past 20 years on field inoculation experiments with *Azospirillum*, concluded that these bacteria are capable of promoting the yield of agriculturally important crops in different soils and climatic region. The results showed significant increases in yield of the order of 5-30 per cent.

2.2. Arbuscular mycorrhizal fungi (AMF)

By far, the most common mycorrhizal association is from the endomycorrhizae also referred as vesicular arbuscular mycorrhizal (VAM) which produces fungal structures (vesicles and arbuscules) in the cortex region of the root. The arbuscular mycorrhizal fungal association is found in most crop families so far examined, although it may be rare or absent in families such as *Cruciferae, Chenopodiaceae, Junaceae and Cyperaceae* (Barea, 1991). This fungus is an obligate symbiont and have not been cultured in artificial nutrient media.

Since AMF are mostly associated with crop plants they are considered to be important in agriculture. Perhaps the most important factor stimulating interest in mycorrhizae was the growth promoting aspects of AMF fungi. AMF fungi with their extramatrical hyphae increased the absorption of relatively immobile elements in soil such as phosphorus, copper and zinc (Mosse 1957;Haymann and Mosse, 1971). In addition mycorrhizal plants have shown greater tolerance to toxic heavy metals, drought (Sieverding,1983), high soil temperatures, saline soils, adverse pH, transplant shocks and root pathogens especially nematodes and pathogenic soil fungi than non mycorrhizal plants (Jalali,1983).

Several reports are showing the efficiency of AMF in increasing nutrient uptake and growth of plants (Gray and Gerdemann, 1969; Iqbal *et al*; 1978; Jalali and Tareja, 1980; Khan, 1975; Meenakumari and Nair, 1992; Pairunan *et al* 1980; Powell, 1979; Sanni, 1976)

2.2.1 Growth response

Increase in plant shoot and root biomass was noted in tobacco, tomato and maize (Daft and Nicolson, 1969) .Islam (1980) recorded greater dry matter production and early flowering in inoculated cowpea. When tomato plants were grown in pots of P deficient sand inoculated with *Gigaspora margarita* there was significant increase in shoot growth (Fair weather and Parbery, 1982). In an evaluation trial of transplanted chilly to different mycorrhizal fungi, Bagyaraj and Sreeramulu (1982) observed higher growth rate, flowering and yield.

Interaction between onion cultivars and AMF fungi were significant. It gave better yield response (Powell *et al* 1982). Khaliel and Elkhider (1987) reported that *Glomus mossae* inoculated tomato transplants had greater dry weight and higher percentage survival, number of nodes, lateral branches and the number of leaves per plant were almost double in mycorrhizal transplants. Senapati *et al* (1987) noticed increase in plant height and number of seeds per pod in AMF inoculated plants. Plant height and fruit yield was more in bell pepper inoculated with AMF grown in low P soil under water stress (Waterer and Coltmann, 1989). In sweet potato yield increase of 20-26 per cent was noticed due to AMF inoculation (KAU, 1991 a) . Sundaram and Arangarasan,(1995) found 35per cent yield increase in Co-3 variety of tomato when inoculated with *Glomus fasciculatum.*

2.2.2 Nutrient uptake

Significantly high P was found in shoots and roots of AMF inoculated Onion (Gray and Gerdemann, 1969; Hayman and Mosse, 1971). Daft and Nicolson,(1969); Sanni, (1976) observed higher shoot P content in mycorrhizal tomato. Lambert *et al* (1979) reported increased uptake of Zn in mycorrhizal onion and soybean plants. Better P uptake in cowpea was realised by Islam *et al.*, (1980). P uptake was more in onion cultivars inoculated with AMF fungi (Powell *et al.*,1982). *Glomus fasciculatum* increased yield and P and Zn content of chilly plants (Sreeramulu and Bagyaraj, 1986). Khaliel and Elkhider (1987) opined that irrespective of nutrient, the uptake per unit root length was higher in plants inoculated with mycorrhiza. Soil analysis indicated hyphal translocation of potassium also (Kothari *et al*, 1990). Muromotsev *et al* (1990) reported increased P_2O_5 uptake of oats, barley, clover and onion yield by AMF inoculation.

2.2.3 Growth hormone effect

AMF has been reported to produce hormone in plants, resulting in spectacular growth response. (Bagyaraj and Menge,1978)

2.2.4 Economics

Babu *et al* (1988) studied the response of chilly to early inoculation of AMF at different levels of P. Inoculation with *Gigaspora margarita* and 50 per cent of the recommended dose of phosphatic fertilizer gave the same yield as compared to those plants which were non-mycorrhizal, but were supplied with 100 per cent of recommended dose of fertilizer. Sreenivasa *et al*,(1993) concluded that the application rate of P fertilizer could be reduced by 50 per cent if *Capsicum annum* plants were inoculated with an efficient AMF fungi along with application of lower levels of P.This treatment recorded significantly higher leaf area diameter, leaf area and dry weight in cowpea plants than control with higher P level (Pai ,1989). The possibility of saving P fertilizer using AMF in cowpea was reported by Geetha kumari *et al*,(1994).

2.2.5 Quality

Green chillies having higher ascorbic acid content were obtained when plants were inoculated with AMF (Bagyaraj and Sreeramulu, 1982). The quality attributes of tomato namely Vitamin C content and TSS significantly increased over control by inoculation (Sundaram and Arangarasan, 1995)

Mycorrhizal plants show faster growth and greater size. Many of the published growth responses have been spectacular, some gave response of twenty fold or more. Thus the growth responses provide the usual standard for judging, whether inoculation has been a success. Inoculation also gave the advantage of disease protection, better soil structure, drought tolerance etc.

Mycorrhizal fungi and other beneficials like *Azospirillum*, *Azotobacter*, *Rhizobia etc* interact to produce a range of favourable effects that may be difficult to duplicate with chemicals.

2.3.1 Growth response

The growth rate of roots inoculated with *Azospirillum* could influence the mycorrhizal infection (Gerdemann, 1968 and Harley, 1989) Better growth was due to interaction of plant growth substances synthesized by *Azospirillum* and AMF infection. Bagyaraj and Menge (1978) showed that dual inoculation of *Glomus fasciculatum* and *Azotobacter chroococcum* significantly increased the dry weight of tomato plants. The synergistic effect increased growth and nutrition of maize and rye grass by inoculation of AMF and *Azotobacter* (Barea *et al.*, 1983). They gave plants of similar size too. Mixed inoculation of *Azospirillum* and AMF proved better in plants. The growth response was significant (Pacovsky *et al*, 1985; Subba Rao *et al*, 1985). Mohandas (1987) obtained increased leaf area, shoot dry weight and yield in tomato given with AMF and *Azotobacter*. The combined inoculation proved superior in brinjal too (Ramachandra and Rai, 1987)where growth and yield was significantly higher over others. Nagarajan (1989) conducted a study on the combined inoculation of *Azospirillum brasilience* and *Glomus fasciculatum* wherein inoculated mulberry gave increased shoot biomass and leaf weight compared to control. Simultaneous inoculation of tomato plants with *Azotobacter vinelandii* and AMF gave better growth (Azcon, 1989). Dual inoculation of *Azotobacter* and *Glomus mosseae* increased plant height, fresh and dry biomass of leaf in mulberry (Gowda *et al*, 1993). Kumutha *et al.*,

(1993) noticed that combined inoculation of AMF and *Azospirillum* enhanced root and shoot growth, number of leaves and growth of plants. Increased root growth might have favoured better mycorrhizal colonisation. They observed maximum colonisation of 76 per cent in dual inoculated plot. In jute plants the shoot length and root length area almost doubled in dual inoculated plants. The dry weight of shoot and root in such plants were 2-3 times more than single inoculation and in the absence of inoculation (Sharma and Mukherjee,1995). Plants inoculated with both AMF and *Azospirillum* fixed more nitrogen, a higher grain yield was recorded than single inoculated plants.

2.3.2 Nutrient uptake

Maize and rye grass recorded higher N and P contents when given a combination of *Azotobacter* and AMF (Barea *et al.*, 1983) A higher P content in plants was noticed as a result of synergistic action of mixed inoculation (Pacovsky *et al*, 1985; Subba Rao *et al*; 1985). A significant increase in N and P content was observed when supplied with AMF and *Azotobacter* (Mohandas, 1987). Gowda *et al*,(1993) found that the leaf of mulberry had higher P content in dual inoculation treatment using *Azotobacter* and *Glomus mosseae.*

2.3.3 Economics

Balasubramaniam (1989) found that combined application of *Azotobacter*, AMF and inorganic fertilizer gave a saving of 25 per cent mineral N and P. Pacovsky *et al*, (1985) and Subba Rao *et al*, (1985) opined that dual inoculation of *Azospirillum* and AMF could completely replace application of N and P fertilizer.

2.3.4. Quality

Gurubatham *et al* (1989) reported increased bulb yield and quality in onion as judged by TSS and sulphur content when given both *Azospirillum* and AMF.

2.3.5 Farm yard manure (FYM)

The height of bhendi plants increased with the application of manures. A combination of organic and inorganic manure were found better than either of the two. (Chinnaswamy 1963). FYM favourably affected the vegetative mass dry weight, plant height, rate of dry matter increment per unit area (Cerna, 1980; Valsikova and Ivanic, 1982). Subbiah *et al* (1985) reported that the yields of brinjal fruits were significantly influenced by the levels of FYM but not by the levels of fertilizer or by interaction of FYM and inorganic fertilizer. In a trial conducted for three seasons, chilly recorded highest yield with 15t FYM and 175:40:25 Kg NPK/ha in the 3 season tried when compared to FYM alone or inorganic fertilizer alone. Studies conducted in KAU revealed that organic and inorganic fertilizers and their combination had significant influence on vegetative production. A higher rate of N along with FYM induced increased fruit yield in clustered chilly (KAU, 1991). Subbiah and Sundarajan (1993) found that combined application of 12.5t FYM + recommended dose of NPK along with 25 kg zinc sulphate was superior to FYM alone.

2.3.6 Vermicompost

Kala and Krishanmoorthy (1981) reported the role of earthworms in the degradation of organic wastes and in improving the physciochemical properties of soil. Tomati *et al* (1983) reported that earthworm casts were rich in available nutrients. Khanker 1993) reported that vermicompost can be well adopted for vegetable farming and the keeping quality of vegetables were considerably improved after the use of vermicompost as organic manure. Bhawalkar and Bhawalkar (1993) reported that vermicastings, the sustainable effective fertilizer produced through vermiculture, if applied by the farmer at a basal dose of 2.5 t ha^{-1} will trigger the soil biology and the transition from chemical nutrition to bio nutrition is quick and without a significant loss of yield.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation was undertaken to study the effect of bio fertilizers like *Azospirillum* and AMF on the growth, yield and quality of two amaranth cultivars namely Arun and Kannara local. Field experiment was conducted during the month of April-September 1996 at the Instructional farm, College of Agriculture, Vellayani. The details on materials used and methods followed are presented.

3.1 Experimental Site

The Instructional farm, Vellayani is located at 8^0 30' N latitude and 76^0 54'E longitude at an altitude of 29 m above MSL. The experimental area was under mango ginger *[Curcuma amada]* during the previous season.

3.2 Soil

The experimental soil was red sandy loam(Oxisol, vlellayani series). It was acidic in reaction. It recorded a low available N and medium P and K. contents. The initial data on the mechanical and chemical analysis of the soil are given below.

Table 3.1 Soil characteristic of experimental site

A. Mechanical Composition

Parameters	Content in Soil	Method used
Coarse Sand	15%	
Fine Sand	47%	Bouyoucos Hydrometer method
Silt	12%	(Bouyoucos, 1962)
Clay	23%	

B. Chemical Properties

Parameter	Value	Rating	Method
Available N (kg ha^{-1})	215	Low	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P_2O_5 (kg ha^{-1})	62	Medium	Bray extraction and Klett summerson photoelectric colorimeter (Jackson 1973)
Available K_2O(kg ha^{-1})	103	Low	Neutral Normal Ammonium Acetate method (Jackson 1973)

3.3 Climate and season

A humid tropical climate prevails in the experimental site. The data on various weather parameters during the cropping period (April 96-September 96) are given in Appendix I and graphically presented in Fig. 1.

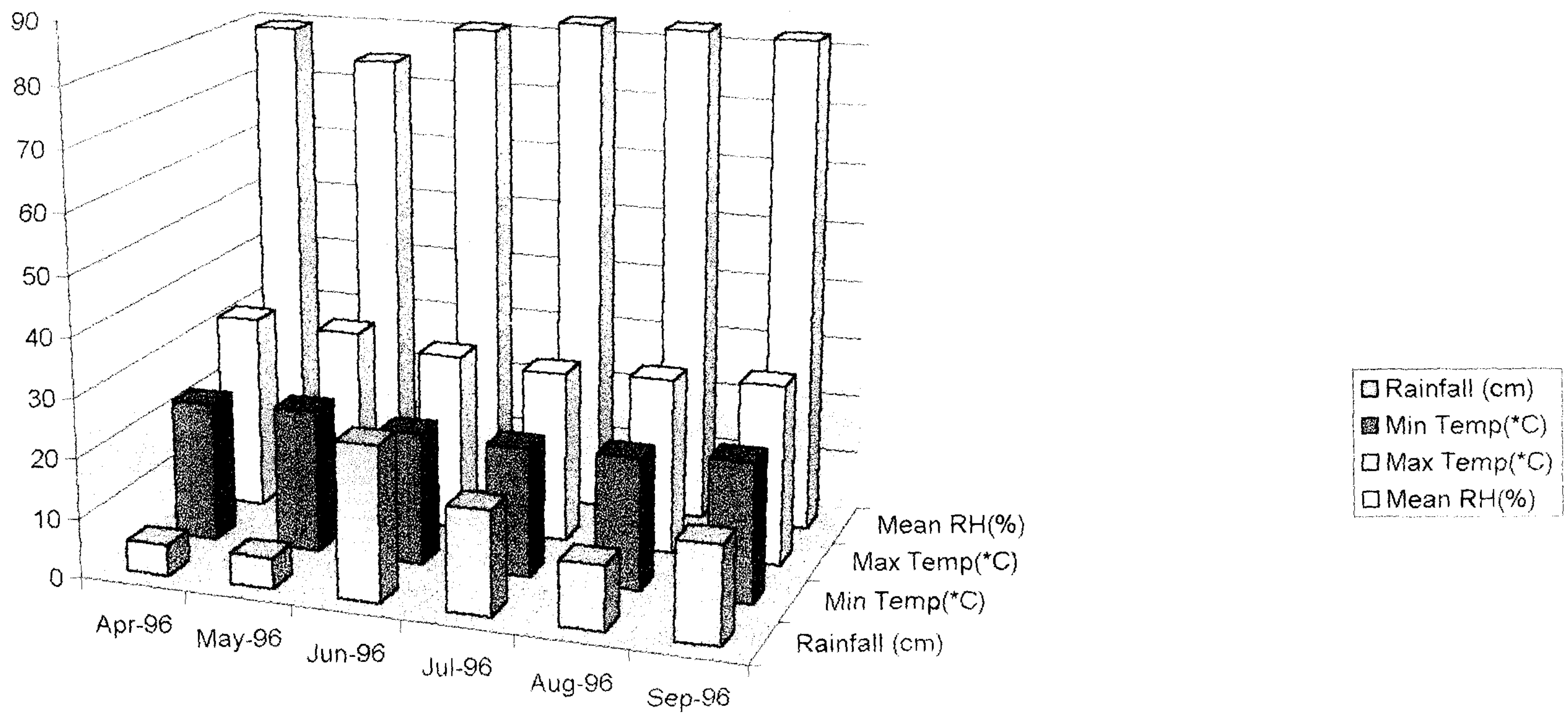
3.4 Varieties

Two popular red amaranthus varieties viz Arun and Kannara local were used for the experiment. (Plate 1 and 2)

3.4.1 Arun

It is a multicut variety with purple leaves evolved by mass selection. It is a photo insensitive variety and is cultivated throughout the year, with an average yield of 210g plant $^{-1}$. The seeds were collected from the Instructional Farm, College of

Fig 1. Weather conditions during the cropping period April 1996- September 1996.



	Apr-96	May-96	Jun-96	Jul-96	Aug-96	Sep-96
Rainfall (cm)	5.1	5.1	25.8	17.3	10.7	16.2
Min Temp(*C)	23.2	23.9	22	21.5	21.8	**23.2**
Max Temp(*C)	32.8	32.2	29.8	28.6	29.3	30.1
Mean RH(%)	79.7	74.9	81.2	83.2	83.1	82.5

Horticulure, Vellanikkara. The variety has a duration of 100 days, growing to a height of about 40cm with a root spread of about 35 cm.(Plates 1 and 2)

3.4.2 Kannara Local

It is a variety evolved by selection. It is a photosensitive variety. The leaves are dull purple in colour. Seeds of the variety were collected from the Instructional Farm, College of Horticulture, Vellanikkara (Plates 1 and 2)

3.5 Manures and fertilizers

3.5.1 Organic manure

Farmyard manure (0.5 per cent N, 0.2 per cent P and 0.5 per cent K), Vermi compost (1.5 per cent N, 0.48 per cent P and 1.80 per cent K) were used .

3.5.2 Chemical fertilizer

Urea (45.8 per cent N), mussuriphos (20.1 per cent P_2O_5) and muriate of potash (60 per cent K_2O) were used as nutrient source in this study.

3.5.3 Biofertilizers

Azospirillum -Culture of *Azospirillum brasilience* maintained in the department of Plant Pathology, College of Agriculture, Vellayani was used.

AMF - Mixed cultures containing *Glomus fasciculatum*, *Glomus etunicatum* and a local culture was used mixed culture containing spores, infected root pieces and infected medium (perlite vermiculite) were collected from pots maintained the department of Plant Pathology, College of Agriculture, Vellayani.

FIELD VIEW OF AMARANTH

PLATE 1

KANNARA LOCAL ARUN

PLATE 2

ARUN KANNARA LOCAL

3.6 Methods cultural operations

3.6.1 Nursery

Garden pots were filled with sterilised potting mixture in the ratio 1sand:1soil:

1 cow dung. These were categorised into four groups.

a. Blank
b. AMF alone
c. *Azospirillum* alone
d. *Azospirillum* and AMF

(a) Blank

Separate pots filled with sterilised potting mixture were sown with variety Arun and Kannara local BHC 10 percent dust was sprinkled at the base of pots. Pots were watered and labelled as B-Arun and B-KL respectively.

(b) AMF alone

The top layer of filled pots were mixed well mixed AMF culture and seeds of both variety were sown separately, BHC 10 percent dust sprinkled at the base and watered.

(c) *Azospirillum* alone

Seeds were soaked in liquid *Azospirillum* cultures for 20 minutes. Each variety, were soaked in separate petridishes. These were dried in shade and sown in separate pots. Liquid culture of *Azospirillum* was sprinkled to surface layer of soil and irrigation was given. BHC was applied at the base of pots.

(d) AMF and *Azospirillum*

Mixed culture of AMF incorporated in the top layer of pot. Further, seeds soaked in *Azospirillum* and dried in shade were sown to AMF inoculated potting mixture. Each variety was planted in pots. Irrigation was given and BHC 10 percent dust sprinkled.

Seedlings were tested at random for infection of AMF (Philips and Hayman, 1970) when they were three weeks old. Uniform seedlings were pulled out from pots for transplanting to the main field.

After one month of planting 10 seedlings were pulled out from each category of pots and the weight of seedlings were recorded.

3.6.2 Field culture

The experimental plots were ploughed, stubbles removed, clods broken and the field was laid out into blocks and plots. Buffer area of 50 cm width was left all around each plot.

3.6.3 Manure and fertiliser

FYM @ 50 kg ha^{-1} was applied uniformly to all plots except in control plots of vermicompost. N, P_2O_5, K_2O in the form of urea, mussoriephos and MOP 25 percent, 50 percent and 75 percent of the recommended dose of chemical fertiliser (50:50:50 kg NPK ha^{-1}) were applied to respective plots as per the treatment. Entire quantity of P_2O_5 and K_2O and ½ N were given as basal, while ½ N was applied after first harvest.

3.6.4 Transplanting

Each category of seedlings were pulled out separately and kept labelled in separate trays. *Azospirillum* alone and AMF + *Azospirillum* inoculated seedlings were dipped in liquid cultures of *Azospirillum* for 20 minutes before transplanting. Further transplanting was carried out according to the layout at a spacing of 30 x 15 cm.

Shade was provided to newly planted area using coconut fronds. Light irrigation was given.

3.6.5 After cultivation

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

3.6.6 Plant protection

Dithane-M-45 0.15 per cent spray in cowdung water suspension was given for leaf blight attack.

3.6.7 Harvesting

First harvest was taken at 30 DAT and subsequent harvests at 15 days interval

3.7 Outline of Technical Programme

3.7.1 Design and layout

Replication	:	2
Plot size (Gross)	:	2.4 x 1.2 m
(Net)	:	1.2 x 1.6 m
Spacing	:	30 x 15 cm

The experiment was laid out in split plot design with 2 replications. The layout plan of the experiment is given in Figure 2.

Fig. 2.

LAYOUT OF THE EXPERIMENTAL PLOT

N

T11	[illegible]	T7	[illegible]	T15	T12
T12	T16	T13	T10	T1	T6
T12	T10	T13	T16	T1	T6
T8	T7	T8	T3	T11	[illegible]
T5	T1	T8	T3	T11	T4

REPLICATION - II

3.7.2 Treatments

Combinations of bio fertilizers and chemical fertilizers + 3 control

A. Main plot treatments

1. Bio fertilizer treatments –3

(i) *Azospirillum*
(ii) AMF
(iii) *Azospirillum* + AMF

2. Chemical fertilizer levels - 4

(i) No fertilizer
(ii) 25 percent of the recommended dose
(iii) 50 percent of the recommended dose
(iv) 75 percent of the recommended dose

B. Sub plot treatments

Varieties - 2
(i) Arun
(ii) Kannara Local

C. Control Treatment

(i) Package of practice recommendations (50 : 50: 50 kg NPK ha^{-1})
(ii) Farm yard manure alone
(iii) Vermicompost

1. *Azospirillum* alone + Arun

2. AMF alone + Arun

3. *Azospirillum* + AMF + Arun

4. *Azospirillum* + 25 percent of the recommended dose + Arun
(12.5:12.5:12.5 kg NPK ha^{-1})

5. AMF + 25 percent of the recommended dose + Arun
(12.5:12.5:12.5 kg NPK ha^{-1})

6. *Azospirillum* + AMF + 25 percent of the recommended dose + Arun
(12.5:12.5:12.5 kg NPK ha^{-1})

7. *Azospirillum* + 50 percent of the recommended dose + Arun
(25:25:25 kg NPK ha^{-1})

8. AMF + 50 percent of the recommended dose + Arun (25:25:25 kg NPK ha^{-1})
9. *Azospirillum* + AMF + 50 percent of the recommended dose + Arun (25:25:25 kg NPK ha^{-1})
10. *Azospirillum* + 75 percent of the recommended dose + Arun (37.5:37.5:37.5 kg NPK ha^{-1})
11. AMF + 75 percent of the recommended dose + Arun (37.5:37.5:37.5 kg NPK ha^{-1})
12. *Azospirillum* + AMF + 75 percent of the recommended dose + Arun (37.5:37.5:37.5 kg NPK ha^{-1})
13. 100 percent of the recommended dose + Arun (50: 50:50 kg NPK ha^{-1})
14. FYM alone + Arun (50 tons ha^{-1})
15. Vermicompost alone + Arun (50 tons ha^{-1})
16. *Azospirillum* alone + Kannara Local
17. AMF alone + Kannara Local
18. *Azospirillum* + AMF + Kannara Local
19. *Azospirillum* + 25 percent of the recommended dose + Kannara Local 12.5:12.5:12.5 kg NPK ha^{-1}
20. AMF + 25 percent of the recommended dose + Kannara Local (12.5:12.5:12.5 kg NPK ha^{-1})
21. *Azospirillum* + AMF + 25 percent of the recommended dose + Kannara Local (2.5:12.5:12.5 kg NPK ha^{-1})
22. *Azospirillum* + 50 percent of the recommended dose + Kannara Local (25:25:25 kg NPK ha^{-1})
23. AMF + 50 percent of the recommended dose + Kannara Local (25:25:25 kg NPK ha^{-1})
24. *Azospirillum* + AMF + 50 percent of the recommended dose + Kannara Local (25:25:25 kg NPK ha^{-1})
25. *Azospirillum* + 75 percent of the recommended dose + Kannara Local (37.5: 37.5:37.5 kg NPK ha^{-1})
26. AMF + 75 percent of the recommended dose + Kannara Local (37.5: 37.5:37.5 kg NPK ha^{-1})

27. *Azospirillum* + AMF + 75 percent of the recommended dose + Kannara Local (37.5: 37.5:37.5 kg NPK ha^{-1})
28. 100 percent of the recommended dose + Kannara Local (50:50:50 kg NPK ha^{-1})
29. FYM alone + Kannara Local (50 tons ha^{-1})
30. Vermicompost alone + Kannara Local (50 tons ha^{-1})

3.8 Observations

Observations were made on important parameters associated with growth, yield and quality of amaranthus. Five plants were selected at random for the purpose of study. Parameters considered and methods followed are briefly described hereunder.

3.8.1 Growth characters

3.8.1.1 Seedling growth rate

Weight of 10 pulled out seedlings were recorded after a month of sowing seeds from each category

3.8.1.2 Height of the plant

The height of the plants were recorded from five randomly selected observational plants at 4 stages of growth viz 15^{th} ,30^{th} , 45^{th} and 60^{th} DAT. The height was measured from the ground level to the topmost leaf bud. Mean values were computed and expressed in cm.

3.8.1.3 Number of leaves

Total no. of leaves in each observational plant was counted and the average recorded for each plant at 4 growth stages, 15^{th}, 30^{th}, 45^{th} and 60^{th} DAT.

3.8.1.4 Number of branches

Total number of branches of observational plants was counted and the mean worked out for each plant at 4 stages of growth viz 15^{th}, 30^{th}, 45^{th} and 60^{th} day of transplant

3.8.1.5 LAI

LAI was measured using LI - 300 leaf area meter at 4 stages of growth of viz 15^{th}, 30^{th}, 45^{th} and 60^{th} day of transplant and expressed in square cm. LAI was worked out using the equation.

$$LAI = \frac{\text{Total leaf area}}{\text{Land area}} \text{.(Watson,1952)}$$

3.8.2 Yield and yield attributes

3.8.2.1 Number of harvests

Number of economic harvests possible for each treatment was recorded

3.8.2.2 Yield harvest^{-1}.

Total weight of leaf and stem portion 10 cm above the ground leaving woody portion were recorded for each plot and expressed in kg ha^{-1}.

3.8.2.3 Total dry matter production

Dry matter production of each plant was obtained by summing up the dry weight of all plant parts at the time of harvest.

3.8.2.4 Total marketable green yield

Total weight of disease and pest free leaf and stem portion. Marketable green yield also excluded the plants which flowered.

3.8.3 Physiological parameters

3.8.3.1 Biomass

Total fresh weight of single plant was recorded at each harvest and from this figure the biomass was found out.

3.8.3.2 RGR

This is rate of increase in dry weight per unit dry weight per unit time expressed as mg day^{-1} was calculated by formula suggested by Blackman, (1919).

$$RGR = \frac{InW_2 - InW_1}{T_2 - T_1}$$

Where W_1 is the dry weight at time t_1

W_2 is the dry weight at time t_2

3.8.3.3 CGR.

This is the rate of increase in dry weight per unit area per unit time. Expressed in mg m^{-2} day^{-1} Hunt (1978).

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} x \frac{1}{p}$$

Where W_1 is the dry weight at time t_1

W_2 is the dry weight at time t_2

p is the ground area

3.8.3.4 NAR

This is rate of increase in dry weight per unit leaf area per unit time expressed in mg cm^{-2} day^{-1} (Willam, 1946)

$$NAR = \frac{(W_2 - W_1)x(\ln l_2 - \ln l_1)}{(t_2 - t_1)x(l_2 - l_1)}$$

Where W_1 is the dry weight at time t_1

W_2 is the dry weight at time t_2

l_1 is the leaf area at time t_1

l_2 is the leaf area at time t_2

3.8.4 Dry matter production and partitioning

Plants left for destructive sampling were cut close to the ground at 15 days interval. Leaves, stem and roots of plants were dried separately in shade, oven dried at 70 ± 5°C till two constant weight were obtained. The weight was averaged and expressed in kg ha^{-1} and in ratio.

3.8.4.1 Leaf stem ratio

Leaf stem ratio was recorded at the stage of harvest as the ratio of dry weight of leaves to the dry weight of stem.

3.8.4.2 Dry weight of leaves + stems

After recording the fresh weight of leaves and stem from each plot, they were first sun dried separately and then in hot air even at 70 ± 5°C for 10 hours till two consecutive weights were obtained. The final weight was averaged and expressed as g $plant^{-1}$

3.8.4.3 Root dry weight

Root masses of observational plants were carefully separated from soil at harvest stage. They were washed with clean water and dried to constant weight at

65°C for 10 hours in hot air oven. From the data obtained, mean value was worked out and expressed as g plant^{-1}.

3.8.5 Leaf quality

3.8.5.1 Moisture content

Plant samples of known fresh weights were first sun dried and then dried to a constant weight in hot air oven at 80°C. From the data, moisture content was worked out and expressed as percentage.

3.8.5.2 Ascorbic acid

Estimated by titrimetric method (Paul Gyorgy and Pearson 1967) and expressed in mg 100g^{-1}

3.8.5.3 Total minerals

Total mineral content expressed as percentage was estimated by A.O.A.C. method (1965)

3.8.5.4 Fibre content

Fibre content of plants was determined by A.O.A.C. method (1975) and expressed as percentage.

3.8.5.5 Oxalate content

From fresh plant samples, oxalate content was determined by method suggested by Abaza *et al.* (1968) and presented as percentage.

3.8.5.6 Protein content

The plant nitrogen values were multiplied by the factor 6.25 to obtain the protein content of plants and the values were expressed as percentage (Simpson *et al.*, 1965).

3.8.5.7 Plant analysis

The plant samples were analysed for nitrogen, phosphorus and potassium at final harvest. The plants were chopped and dried in an air oven at 80 ± 5°C separately till constant weights were obtained. Samples were then ground to pass through 0.5 mm mesh in a Willey mill. The required quantity of samples were then weighed out accurately in a physical balance and analysed.

The nitrogen content in plant was estimated by modified microkjeldahl method (Jackson, 1973) and the uptake of nitrogen was calculated based on the content of this nutrient in plants and the dry matter produced. The phosphorus content in plant was estimated calorimetrically (Jackson, 1973). Based on the phosphorus content in plants and the dry matter produced at harvest, the uptake was worked out. The potassium content in plants was estimated by the flame photometric method in Perkin - Elmer 3030. The uptake of potassium was calculated based on potassium content in plants and dry matter produced

3.8.7 Soil analysis

Soil samples were taken from the experimental area before and after the experiment. The air dried soil samples were analysed for available nitrogen, available phosphorus and available potassium content.

Available nitrogen content was estimated by potassium permanganate method (Subbiah and Asija, 1956). Available phosphorus content was estimated by Bray calorimetric method (Jackson, (1973) and available potash by ammonium acetate method (Jackson, 1973).

3.8.8 Scoring of pest and diseases

3.8.8.1 Scoring of Disease

In order to estimate the percent leaf blight index, initial measurement of leaf blight on amaranths infected with *Rhizoctonia solani* was carried out after one month of transplanting.

Rating Score	Disease percent
0	No disease
1	0-25
2	26-50
3	51-75
4	76-100

After scoring the disease intensity using the above chart, the disease index was computed using the formula

$$D = \frac{\textit{Total}\text{ disease score}}{\textit{Maximum}\text{ score (4) X No. of leaves examined}}$$

Each treatment consisted of 2 replications. Mean of all replications were taken to express disease index of treatment. Finally the value of disease index was multiplied with 100 to obtain percent disease index (Singh 1993).

3.8.9 Benefit-Cost ratio

The economics of cultivation of amaranths were worked out and the net income and benefit cost ratio were calculated a follows

Net income (Rs ha^{-1}) = Gross income - Cost of cultivation

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

3.9 Statistical analysis

Data relating to each character were analysed by applying the analysis of variance technique and significance was tested by F test (Snedecor and Cochran, 1967). In cases where the effects were found to be significant, CD was calculated by using standard technique.

RESULTS

4. RESULTS

An investigation was conducted at the College of Agriculture, Vellayani to assess the effect of bio fertilizers and different levels of fertilizer on two varieties of amaranth during the period from April- September 1996.

4.1 Growth characters

Observations on growth characters like seedling growth rate, plant height, number of leaves and leaf area index were recorded and the results are presented in Tables 1 to 9

4.1.1 Seeding growth rate (Table 1)

Table 1 indicates the variation in seedling growth rate due to various biofertilizers and variety. Application of different biofertilizers had significant influence on the seedling growth rate. *Azospirillum* inoculation performed significantly superior over other bioagents and the control treatment. Varietal difference was not observed with respect to seedling growth rate.

4.1.2 Plant height (Tables 2 and 3)

The mean plant height recorded in centimetres from 15 DAT to 60 DAT are presented in Table 2 and 3. Biofertilizer has influenced the plant height significantly at all growth stages except 30 DAT. At 15 DAT, plant height recorded by *Azospirillum* (16.31 cm) was significantly superior to AMF (12.38 cm) and dual inoculation (12.81 cm), while the latter two were on par. At 30 DAT, the biofertilizer treatments recorded no significant difference. However AMF recorded the highest

Table 1. Seedling growth rate of amaranth as influenced by bio fertilizers and varieties

Treatment	Seedling growth rate
Bio fertilizer	
Azospirillum	31.025
AMF	13.18
Azospirillum + AMF	10.28
Blank	5.01
F	4.86^{S}
SE	2.17
CD	5.012
Variety	
V_1 (Arun)	16.39
V_2 (Kannara Local)	13.35
F	1.31^{NS}
SE	1.54
CD	--

Table 2. Plant height (cms) of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties.

	15 DAT	30 DAT	45 DAT	60 DAT
Bio fertilizer				
A_1 (Azospirillum)	16.31	48.06	47.47	52.75
A_2 (AMF)	12.38	49.34	49.12	62.54
A_3 (Azospirillum+AMF)	12.81	47.87	44.16	63.25
$F_{2,14}$	72.28^{S}	1.08^{NS}	33.69^{S}	100.48^{S}
SE	0.359	0.751	0.615	0.827
CD	0.773	--	1.321	1.778
Levels of chemical fertilizer				
B_1(No Fertilizer)	12.5	44.96	42.87	52.25
B_2 (25 per cent POP)	13.58	45.16	49.19	57.25
B_3 (50 per cent POP)	16.42	51.13	48.20	58.72
B_4 (75 per cent POP)	12.83	52.45	48.39	69.83
$F_{3,14}$	36.91^{S}	40.99^{S}	30.88^{S}	120.41^{S}
SE	0.414	0.866	0.710	0.955
CD	0.889	1.859	1.530	2.051
Varieties				
V_1 (Arun)	14.42	50.87	45.83	58.44
V_2 (Kannara Local)	13.25	50.98	48.00	60.58
$F_{1,14}$	13.24^{S}	14.16^{S}	8.12^{S}	5.13^{S}
SE	0.32	1.359	0.762	0.946
CD	0.671	2.851	1.601	1.994

Table 3. Interaction effect of bio fertilizers, chemical fertilizer levels and varieties on height of the plant (cms) in amaranth.

Treatment		15 DAT	30DAT		45 DAT		60DAT
	Arun	Kannara Local	Mean Val	Arun	Kannara Local	Arun	Kannara Local
Azospirillum(A)	13.00	17.00	41.75	36.38	41.55	38.00	36.50
A+ 25 per cent POP	14.00	14.00	37.00	32.50	54.50	47.00	48.00
A+ 50 per cent POP	21.00	21.00	59.00	57.45	49.00	67.00	58.00
A+ 75 per cent POP	11.50	19.00	54.50	53.95	54.40	64.00	61.50
AMF(V)	13.50	9.50	56.25	57.00	42.80	60.50	69.00
V+ 25 per cent POP	15.00	12.00	49.90	63.25	44.90	61.00	65.00
V+ 50 per cent POP	14.00	12.00	49.00	37.50	46.50	53.30	56.00
V+ 75 per cent POP	12.00	11.00	42.15	48.00	53.00	65.00	70.50
Azospirillum. + AMF	13.50	8.50	37.35	37.00	42.50	53.50	54.00
A+V+ 25 per cent POP	15.50	11.00	48.00	48.00	52.00	63.50	59.00
A+V+ 50 per cent POP	18.50	12.00	47.90	44.90	53.85	58.00	60.00
A+V+ 75 per cent POP	11.50	12.00	58.20	34.00	41.00	70.50	87.50
POP	4.00	3.50	37.90	29.22	29.45	32.00	37.25
FYM	5.00	5.50	35.65	17.25	20.25	20.50	20.50
Vermicompost	3.25	3.75	40.15	23.25	26.25	24.75	31.75
SE	1.18	1.18	5.02	2.81	2.81	3.41	3.41
CD	2.891	2.891	12.299	6.881	6.881	8.354	8.354

value (49.34 cm). AMF was significantly superior to other treatments at 45 DAT. The height recorded by AMF (49.12 cm) was significantly superior to that of *Azospirillum* and dual inoculation. At 60 DAT, dual inoculation of *Azospirillum*+AMF and AMF alone recorded comparable plant heights (63.25 and 62.54 cm respectively) and was significantly superior to *Azospirillum*.

Different levels of chemical fertilizer recorded significant influence on the height of the plant at all growth stages. At 15 DAT, B_3 (50 per cent POP) recorded highest plant height (16.42 cm) and was significantly superior to the plant height recorded at the other three fertilizer levels. At 30 DAT, B_4 (52.45 cm) and B_3 (51.13 cm) were on par and was significantly superior to the lower two levels,B_2 and B_1.At 45 DAT B_2 (49.19 cm), B_3 (48.20 cm) and B_4 (47.39 cm) were on par and were significantly superior to the plant height recorded by no chemical fertilizer treatment, B_1. At 60 DAT B_4 recorded highest plant height (69.83 cm) and was significantly superior to B_3, B_2 and B_1.

The two varieties too differed significantly in plant height. At 15 DAT, variety Arun (14.42cms) was significantly superior to Kannara local. At 30 DAT, both varieties were on par. But at 45 and 60 DAT, Kannara local recorded significantly higher plant height compared to Arun.

Among the three control treatments, FYM was superior to POP and vermicompost at 15 DAT. At 30 DAT, FYM, POP and vermicompost recorded comparable plant heights which was not significantly different. At 45 DAT, POP was significantly superior to FYM and vermicompost for both the varieties. At 60 DAT, the same trend was seen for the variety Kannara local. But, POP was found to be on par with the effect of vermicompost in variety Arun at 60 DAT.

Interaction effect of biofertilizer, fertilizer levels and variety was significant in all stages of growth except at 30 DAT. In variety Arun, at 15 DAT, treatment T_3 (A +50 per cent POP) recorded significantly more plant height (21 cm) compared to all other treatments including the control i.e., FYM (10.5 cm). Next higher plant height (18.5 cm) was recorded by the treatment T_{11} (A+V+50 per cent POP) which was significantly higher than T_2, T_5, T_7 and T_{10} . The treatments T_2, T_5, T_7 and T_{10} were on par. In the case of variety Kannara local also, plant height recorded by T_3 (21 cm) was significantly superior to all the other treatments. Second higher plant height was recorded by T_4 (19 cm).At 30 DAT, interaction effect was not significant. Thus comparing the mean values it was found that treatments T_3 (59 cm), T_{12} (58.2 cm), T_5 (56.25 cm) and T_4 (54.5 cm) recorded comparable plant heights and were significantly superior to all the other treatments. Among the two varieties, Arun variety was found significantly superior to Kannara local at 45 DAT. In Arun variety the treatment T_6 recorded the highest plant height (63.25 cm) where as in variety Kannara local T_2 (54.4 cm), T_4 (54.4 cm), T_{11} (53.85 cm), T_8 (53 cm) and T_{10} (52 cm) were on par and were significantly superior to T_3. At 60 DAT, plant height recorded by T_{12} (A+V+75 per cent POP) was the highest for both Arun and Kannara local (70.5 cm and 87.5 cm respectively)

4.1.3 Number of leaves per plant (Tables 4 and 5)

Total number of fully opened leaves in both varieties were counted at different stages and are presented in Tables 4 and 5.

Table 4. Number of leaves per plant of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties.

	15 DAT	30 DAT	45 DAT	60 DAT
Bio fertilizer				
A_1 (Azospirillum)	19.63	59.75	103.812	110.375
A_2 (AMF)	15.45	53.59	85.375	133.5
A_3 (Azospirillum+AMF)	15.65	50.23	101.93	141.68
$F_{2,14}$	65.02^{S}	9.37^{S}	47.73^{S}	15.38^{S}
SE	0.414	2.23	2.077	5.85
CD	0.882	4.778	4.445	12.550
Levels of chemical fertilizer				
B_1(No Fertilizer)	14.08	53.51	83.416	132.75
B_2 (25 per cent POP)	15.23	51.44	109	81.75
B_3 (50 per cent POP)	19.64	56.83	107.833	151.58
B_4 (75 per cent POP)	18.69	56.24	87.91	148.00
$F_{3,14}$	62.55^{S}	1.87^{NS}	61.23^{S}	45.45^{S}
SE	0.478	2.57	2.39	6.76
CD	1.025	5.519	5.143	14.512
Varieties				
V_1 (Arun)	15.26	52.29	86.66	129.5
V_2 (Kannara Local)	18.55	56.75	107.42	127.54
$F_{1,14}$	30.37^{S}	3.28^{S}	18.53^{S}	0.11^{NS}
SE	0.597	2.45	4.82	6.06
CD	1.255	5.156	10.122	12.608

Table 5. Interaction effect of bio fertilizers, chemical fertilizer levels and varieties on the number of leaves per plant in amaranth.

Treatment	15 DAT		30DAT	45 DAT		60DAT	
	Arun	Kannara Local	Mean Val	Arun	Kannara Local	Arun	Kannara Local
Azospirillum(A)	12.94	19.00	50.25	60.00	141.00	56.00	55.50
A+ 25 per cent POP	15.00	15.55	35.25	61.00	142.50	84.50	66.00
A+ 50 per cent POP	20.50	15.45	84.25	107.00	125.00	227.50	139.50
A+ 75 per cent POP	15.15	28.50	64.25	84.00	110.00	144.00	110.00
AMF(V)	15.40	17.50	57.97	91.00	48.50	202.50	178.00
V+ 25 per cent POP	14.00	20.75	59.67	80.00	103.00	92.50	114.00
V+ 50 per cent POP	10.45	12.00	31.75	76.50	108.00	107.00	86.50
V+ 75 per cent POP	17.00	16.50	64.97	121.00	55.00	161.00	126.50
Azospirillum + AMF	11.70	7.95	52.50	93.00	67.00	174.50	130.00
A+V+ 25 per cent POP	14.80	11.30	59.42	126.00	141.50	63.00	70.50
A+V+ 50 per cent POP	21.75	22.70	54.50	97.00	133.50	146.00	203.00
A+V+ 75 per cent POP	14.50	20.50	34.50	43.50	114.00	95.50	251.00
POP	7.00	8.50	50.67	92.00	78.25	88.00	118.00
FYM	9.00	10.50	35.00	73.50	93.50	51.00	44.00
Vermicompost	6.00	11.50	60.80	106.50	55.00	133.50	156.00
SE	1.17	1.17	6.30	5.87	5.87	16.56	16.56
CD	2.866	2.866	15.435	14.381	14.381	40.572	40.572

Biofertilizer have significant influence on the number of leaves at all growth stages. The number of leaves was maximum for the plants inoculated with *Azospirillum* in the early stages of growth i.e at 15 DAT, 30 DAT and 45 DAT (19.63, 59.75 and 103.81 respectively). At 45 DAT, *Azospirillum* treatment was on par with dual inoculation (101.93) and these two treatments were significantly superior to AMF. But at 60 DAT, a total change was observed. Dual inoculation recorded higher leaf number (141.68) which was on par with AMF (133.5) and was significantly superior to *Azospirillum*.

Number of leaves recorded significant difference by varying levels of chemical fertilizers at all the growth stages except 30 DAT. At 15 DAT, B_3(50 per cent POP) was on par with B_4 (75 per cent POP). The number of leaves was 19.64 and 18.69 respectively. They were significantly superior to B_2 and B_1. At 30 DAT there was no significant difference in the number of leaves due to different fertilizer levels. But at 45 DAT, B_2 (109.00) and B_3 (107.83) were on par and was significantly superior to B_4 and B_1. B_3 maintained its superiority even at 60 DAT (151.58) and was on par with B_4 (148.00).

Number of leaves recorded by Kannara local was significantly superior to variety Arun at 15 and 45 DAT. Interaction effect of biofertilizer, chemical fertilizer and variety was significant at all stages except 30 DAT. In variety Arun, the treatment T_{11} gave highest number of leaves (21.7) at 15 DAT and T_{11} was on par with treatments T_2 (15), T_3 (20.5), T_4 (15.15), T_6 (14), T_8 (17) and T_{10} (14.8) and with all the control treatments. Comparing the mean values at 30 DAT, T_3 recorded higher leaf number (84.25) and was on par with POP and vermicompost which were the best control treatments at this stage.

A perusal of the data on leaf number in variety Arun at 45 DAT revealed that T_{10} (126) and T_8 (121) were on par and significantly superior to T_3 (107), T_5 (91) and T_9 (93). T_{10} was on par with all control treatments which had comparable values of leaf number.

In the case of Kannara local it was found that T_2 (142.5) T_{10} (141.5), T_1 (141), T_{11} (133.5) and T_3 (125) were on par and were significantly superior to T_{12}, T_7, T_6 and T_4 which were on par. T_{12} (A+V+75 per cent POP) was on par with the best control treatments - FYM and POP - in Kannara local at 45 DAT .

At 60 DAT, the treatment T_3 (A+50 % POP) recorded highest leaf number in variety Arun (227.5) and was significantly superior to the rest of the treatments, but T_3 was on par with vermicompost which was found to be the best control treatment (Table 5). In Kannara local variety, the treatments T_{12} and T_{11} were found best in leaf production (251 and 203 respectively). These two treatments were on par with the control treatments Vermicompost and POP but not with FYM.

4.1.4 Number of branches (Table 6 and 7)

There was significant difference in the number of branches due to application of bio fertilizer. At 15 DAT, *Azospirillum* (4.41) was on par with dual inoculation (4.36) and was significantly superior to AMF (Table 6). At 30 and 45 DAT performance of all bio fertilizers were on par. *Azospirillum*, AMF and dual inoculation recorded number of branches @ 13.91, 13.03, 13.06 for a plant

Table 6. Number of branches per plant of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	15 DAT	30 DAT	45 DAT	60 DAT
Bio fertilizer				
A_1 (Azospirillum)	4.41	13.92	4.88	5.38
A_2 (AMF)	3.51	13.04	5.06	6.75
A_3 (Azospirillum+AMF)	4.37	13.07	5.25	4.50
$F_{2,14}$	12.16^{S}	1.08^{NS}	2.01^{NS}	8.64^{S}
SE	0.24	0.42	0.24	0.22
CD	0.52	--	--	0.46
Levels of chemical fertilizer				
B_1(No Fertilizer)	3.60	14.09	5.17	5.75
B_2 (25 per cent POP)	3.85	13.63	5.92	4.25
B_3 (50 per cent POP)	4.73	13.23	5.58	5.58
B_4 (75 per cent POP)	4.20	12.41	4.83	6.583
$F_{3,14}$	6.41^{S}	8.12^{S}	4.38^{S}	7.89^{S}
SE	0.28	0.48	0.28	0.25
CD	0.60	1.03	0.60	0.54
Varieties				
V_1 (Arun)	3.60	13.14	5.25	5.50
V_2 (Kannara Local)	4.60	13.54	4.88	5.58
$F_{1,14}$	11.36^{S}	1.18^{NS}	1.91^{NS}	2.04^{NS}
SE	0.16	1.10	0.30	0.32
CD	0.333	--	--	--

Table 7. Interaction effect of bio fertilizers, chemical fertilizer levels and varieties on the number of branches per plant in amaranth.

Treatment	15 DAT		30DAT	45 DAT	60DAT	
	Arun	Kannara Local	Mean Val	Mean Val	Arun	Kannara Local
Azospirillum(A)	4.55	5.35	14.00	5.25	3.50	4.00
A+ 25 per cent POP	2.85	3.50	12.70	4.00	6.00	2.00
A+ 50 per cent POP	5.50	6.60	15.70	5.50	7.00	6.50
A+ 75 per cent POP	2.00	4.95	13.10	4.75	6.00	8.00
AMF(V)	2.70	3.00	13.60	5.00	8.50	8.50
V+ 25 per cent POP	2.50	6.45	14.10	5.25	4.00	6.50
V+ 50 per cent POP	3.75	2.75	10.90	5.25	5.00	5.00
V+ 75 per cent POP	3.00	3.90	13.40	4.75	10.00	6.50
Azospirillum + AMF	3.00	3.00	14.60	5.25	5.00	5.00
A+V+ 25 per cent POP	4.00	3.80	14.00	5.50	3.00	4.00
A+V+ 50 per cent POP	4.80	5.00	13.00	6.00	4.50	5.50
A+V+ 75 per cent POP	4.50	6.85	10.60	4.25	3.50	5.50
POP	2.00	2.95	13.50	4.25	6.50	6.00
FYM	1.50	2.00	11.00	5.75	4.00	3.00
Vermicompost	2.80	1.90	12.90	3.50	8.00	5.00
SE	0.68	0.68	1.17	0.68	0.61	0.61
CD	1.666	1.666	2.866	1.666	1.494	1.494

respectively at 30 DAT. At 45 DAT, the values were 4.87, 5.06 and 5.25 respectively. But at 60 DAT, application of AMF recorded maximum number of branches (6.75) and was significantly superior to *Azospirillum* and dual inoculation.

Fertilizer levels had significant influence on the number of branches at all stages of growth. At 15 DAT, B_3 (50 per cent POP) recorded highest number of branches (4.73) and was on par with B_4 (4.2). They were significantly superior to B_2 (3.85) and B_1 (3.6). At 30 DAT, B_1, B_2 and B_3 recorded comparable number of branches having values of 14.09, 13.63 and 13.23 respectively and was significantly superior to B_4. At 45 DAT, B_2 (5.91) and B_3 (5.58) were on par and was significantly superior to B_4 and B_1. However at 60 DAT, B_4 recorded maximum number of branches (6.58) and was significantly superior to B_1 (5.75), B_3 (5.58) and B_2 (4.25).

Significant difference between two amaranthus varieties was noticed only in the very early stages. Kannara local recorded more number of branches compared to Arun variety at 15 DAT. During later stages, the performance of both the varieties were on par (Table 6).

There was no significant difference among control treatments at any stage.

Interaction effect was significant only during the first and the last stage of crop growth (Table 7).

At 15 DAT, in variety Arun, treatments T_3, T_{11}, T_1, T_{12}, T_{10} recorded comparable number of branches and was significantly superior to others and all controls. In Kannara local T_{12} recorded highest branch number (6.85) but it was on par with T_3 (6.6), T_6 (6.4), T_1 (5.35), T_4 (4.95) and T_8 (3.9).

At 30 DAT and 45 DAT, the influence of different treatments on the number of branches was not significant. But at 30 DAT, highest number of branches was recorded by the treatment T_3 (15.70) and at 45 DAT, by the treatment T_{11} (6). At 60 DAT, the treatments T_8 (10), T_5 (8.5), T_3 (7), T_2 (6), T_7 (6), T_7 (6) were on par and were significantly superior to the other treatments. These treatments were on par with POP and vermicompost in variety Arun. In Kannara local all treatments except T_2 was on par. Treatments did not vary significantly with the control treatments.

4.1.5 **Leaf area index** (Tables 8 and 9)

The data on LAI recorded at 15, 30, 45 and 60 DAT are presented in Table 8 and 9. Bio fertilizers significantly increased the leaf area index at 15 and 60 DAT. Dual inoculation recorded higher LAI compared to *Azospirillum* and AMF at 15 and 60 DAT. But the variation among treatments was not significant at 30 and 45 DAT.

Among the four fertilizer levels, the highest level of fertilizer namely B_4 performed significantly superior over the lower levels at 15 DAT. Though it continued to give maximum value at later stages ie., 30 and 45 DAT, the difference was not significant. Varietal difference in LAI was not significant during the growth stages. There was significant difference among control at all stages. Vermicompost was on par with POP and was significantly superior to FYM at 15 DAT in variety Arun. It was significantly superior to the other control treatments at 30 and 45 DAT.

Interaction effect (Table 9) was significant at 15 DAT. Appraisal of the data in variety Arun at 15 DAT indicated maximum value of LAI due to the treatment T_{11} (0.354). But T_{11} was on par with T_{10} (0.282), T_7 (0.262) and vermicompost. However

Table 8. Leaf area index of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	15 DAT	30 DAT	45 DAT	60 DAT
Bio fertilizer				
A_1 (Azospirillum)	0.40	1.96	3.50	3.62
A_2 (AMF)	0.32	1.88	3.65	3.68
A_3 (Azospirillum+AMF)	0.41	1.79	3.84	3.96
$F_{2,14}$	13.07^{S}	1.132^{NS}	1.05^{NS}	8.193^{S}
SE	0.02	0.12	0.24	0.02
CD	0.041	--	--	0.204
Levels of chemical fertilizer				
B_1(No Fertilizer)	0.32	1.73	3.34	3.33
B_2 (25 per cent POP)	0.34	1.80	3.53	3.45
B_3 (50 per cent POP)	0.48	1.75	3.38	3.85
B_4 (75 per cent POP)	0.38	2.23	4.41	4.39
$F_{3,14}$	19.722^{S}	5.994^{S}	6.635^{S}	4.161^{S}
SE	0.02	0.14	0.27	0.11
CD	0.494	0.292	0.592	0.233
Varieties				
V_1 (Arun)	0.37	1.87	3.68	3.84
V_2 (Kannara Local)	0.38	1.88	3.65	3.67
$F_{1,14}$	0.040^{NS}	0.0036^{NS}	0.0082^{NS}	0.872^{NS}
SE	0.04	0.13	0.26	0.18
CD	--	--	--	--

Table 9. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on the leaf area index in amaranth.

Treatment	15 DAT		30DAT	45 DAT
	Arun	Kannara Local	Mean Val	Mean Val
Azospirillum(A)	0.21	0.22	1.32	2.35
A+ 25 per cent POP	0.13	0.15	1.83	3.19
*A+ 50 per cent POP	0.08	0.40	2.13	4.10
A+ 75 per cent POP	0.15	0.25	2.50	4.33
AMF(V)	0.12	0.13	2.44	4.86
V+ 25 per cent POP	0.15	0.19	1.73	3.02
V+ 50 per cent POP	0.26	0.19	1.61	2.83
V+ 75 per cent POP	0.16	0.10	1.72	3.82
Azospirillum. + AMF	0.15	0.13	1.41	2.80
A+V+ 25 per cent POP	0.28	0.10	1.84	4.35
A+V+ 50 per cent POP	0.36	0.19	1.48	3.15
A+V+ 75 per cent POP	0.19	0.30	2.39	5.50
POP	0.21	0.06	1.25	2.80
FYM	0.12	0.11	0.85	2.00
Vermicompost	0.27	0.13	4.20	5.70
SE	0.06	0.06	0.33	0.67
CD	0.073	0.073	0.808	1.641

it was significantly superior to the other two control treatments. In Kannara local variety the performance of treatment T_3 was very good at 15 DAT. T_3 recorded the highest value of LAI (0.40). It was significantly higher than other treatments and all controls. At 30 DAT, the control treatment, vermicompost gave maximum value of 4.2 for LAI, which was significantly superior to other control treatments as well as treatments T_4(2.5), T_5 (2.44), T_{12}(2.39) and T_3 (2.13). At 45 DAT, vermicompost recorded maximum value of 5.7. But it was on par with treatment T_{12}(5.50) and was significantly superior to other control and other treatments. Next higher values of LAI recorded were 4.86, 4.35, 4.33, 4.10 by treatments T_5, T_{10}, T_4 and T_3 respectively.

4.2. Yield attributes

4.2.1. Yield harvest $^{-1}$ (Tables 10 and 11)

The mean values of yield obtained at each harvest starting from 30 DAT and subsequently at 15 days interval is presented in Table 10.

First harvest

Scanning through Table 10, it was found that for first harvest there was no significant difference in yield by the application of different bio fertilizers. Dual inoculation with *Azospirillum* and AMF recorded highest yield during the first harvest (33.58 t ha^{-1}) closely followed by *Azospirillum* alone (33.29 t ha^{-1}) harvest. Difference in yield was not significant by varying the levels of chemical fertilizer.

There was no significant difference among varieties either. Different control treatments didn't elicit any significant difference. Maximum yield among control treatments was for vermicompost. The treatment T_{12} recorded highest yield of 47.91 t

Table 10. Yield per harvest (t ha^{-1})of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	I cut	II cut	III cut	IV cut	V cut
Bio fertilizer					
A_1 (Azospirillum)	33.290	19.038	29.228	13.216	10.791
A_2 (AMF)	30.902	13.829	30.225	13.752	9.826
A_3 (Azospirillum+AMF)	33.580	15.078	33.405	15.331	12.143
$F_{2,14}$	0.811^{NS}	0.867^{NS}	1.124^{NS}	1.127^{NS}	0.893^{NS}
SE	5.482	2.833	5.980	1.735	2.019
CD	---	--	--	--	--
Levels of chemical fertilizer					
B_1(No Fertilizer)	23.588	14.191	21.993	11.809	8.749
B_2 (25 per cent POP)	33.830	15.070	25.974	13.809	10.892
B_3 (50 per cent POP)	36.227	16.865	34.593	14.850	11.006
B_4 (75 per cent POP)	36.723	17.801	41.249	15.930	13.033
$F_{3,14}$	1.114^{NS}	7.017^{S}	0.786^{NS}	0.985^{S}	1.291^{NS}
SE	6.330	3.271	6.905	2.004	2.332
CD	--	0.506	--	--	--
Varieties					
C_1 (Arun)	31.950	13.103	30.050	13.213	10.445
C_2 (Kannara Local)	33.234	18.860	31.855	14.986	11.394
$F_{1,14}$	1.014^{S}	10.384^{S}	0.861^{S}	1.126^{S}	1.145^{S}
SE	3.921	1.786	1.783	1.081	0.580
CD	--	3.753	--	--	--

Table 11. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on yield per harvest (t ha^{-1}) in amaranth

Treatment	Icut	IIcut	IIIcut	IVcut	Vcut
Azospirillum(A)	17.01	11.90	18.26	10.66	6.34
A+ 25 per cent POP	29.81	17.34	18.71	10.00	7.93
A+ 50 per cent POP	47.34	21.18	43.81	17.67	14.71
A+ 75 per cent POP	38.89	25.14	36.07	14.53	13.50
AMF(V)	32.22	15.38	29.89	12.73	10.90
V+ 25 per cent POP	39.37	16.07	28.05	13.50	11.66
V+ 50 per cent POP	28.64	12.43	29.93	12.98	8.64
V+ 75 per cent POP	23.37	11.42	33.02	15.73	8.09
Azospirillum. + AMF	21.53	15.21	17.82	11.98	8.50
A+V+ 25 per cent POP	32.25	11.28	31.14	17.91	13.02
A+V+ 50 per cent POP	32.64	16.93	30.00	13.89	9.62
A+V+ 75 per cent POP	47.91	16.84	54.65	17.03	17.43
POP	18.40	13.99	28.47	11.63	8.63
FYM	18.40	10.71	16.11	10.52	12.74
Vermicompost	19.2	11.21	22.60	13.01	12.12
SE	15.49	8.00	16.91	4.98	5.71
CD	37.999	12.522	41.424	12.021	13.991

ha^{-1} which was 2.49 times the yield of control treatment vermicompost. Except T_1 all other treatments recorded higher yield than all the control treatments. High yield of 47.34t ha^{-1}, 39.37 t ha^{-1} and 38.89 t ha^{-1} was recorded by treatments T_3, T_6 and T_4 respectively.

Second harvest

A significant increase in the yield of amaranthus was noticed with an increase in the dose of chemical fertilizers. The level B_4 (75 per cent POP) recorded highest yield during the second harvest (17.80 t ha^{-1}) and was significantly superior to the lower levels, B_3 (16.865 t ha^{-1}), B_2 (15.070 t ha^{-1}) and B_1(14.191 t ha^{-1}). The yield of variety Kannara local (18.86 t ha^{-1}) was significantly superior to that of variety Arun at 45 DAT. But there was no significant increase in yield by the application of different bioinoculants. The various control treatments too didn't register any significant variation among themselves. Maximum yield was obtained for POP having 13.99 t ha^{-1}. Notable yield was recorded by the treatments, T_4, T_3, T_2, T_{11}, T_{12} having values 25.14, 21.18, 17.34, 16.93, 16.84 t ha^{-1} respectively. Yield of treatment T_4 was 79.6 per cent more than the control ie., POP.

Third harvest

Dual inoculation recorded highest yield of 33.4 t ha^{-1}. But the value was not significantly superior to the application of *Azospirillum* or AMF given alone. The yield of higher levels of chemical fertilizer, B_3 and B_4 was significantly superior to B_2 (25 per cent POP) and B_1 (no chemical fertilizer). Variety Kannara local recorded higher yield compared to Arun, but not significantly different. There was no significant variation among control treatments.

The treatment T_{12} (A+V+ 75 per cent POP) continued to be the best treatment with an yield of 54.65 t ha^{-1} i.e., 91.9 per cent more than the control treatment POP. An increase by 54.13 per cent was recorded by T_3 over POP. T_4 gave 36.07 t ha^{-1}.

Fourth harvest

All bioinoculants recorded comparable yield. Among the different bioinoculants, dual inoculation recorded highest yield (15.33 t ha^{-1}). Though fertilizer levels has no significant influence on yield during the fourth harvest, the highest level B_4 recorded highest yield (15.93 t ha^{-1}). B_3 (14.8 t ha^{-1}) and B_2 (13.8 t ha^{-1}) were on par and was significantly superior to B_1. Variation among varieties was not significant. Variation among control treatments continued to be insignificant. Treatments T_{10}, T_3, T_{12} and T_8 recorded comparable yields ie., 17.91, 17.67, 17.03 and 15.73 t ha^{-1} respectively. The yield of the said treatments was 37.7, 35.7, 34 and 19 per cent more than the control vermicompost (13.01 t ha^{-1}). Among the three control treatments vermicompost recorded highest yield during the fourth harvest.

Fifth harvest

Bioinoculants had no significant influence on fifth harvest in the case of amaranthus. Data presented in Table 11 revealed that dual inoculation recorded a high yield of 12.14 t ha^{-1} compared to the others. Though the highest fertilizer level recorded highest yield of 13 t ha^{-1} during last harvest, it was on par with all lower levels. Performance of variety Arun and Kannara local were on par. Difference among control, between control and treatments were insignificant.

An increase of 36.8 per cent was noted in the yield of the treatment T_{12} over the control FYM (12.74 t ha^{-1}). T_3, T_4 and T_{10} recorded high yield of 14.71, 13.50 and 13.02 t ha^{-1} respectively.

4.2.2 Number of harvests (Tables 12 and 13)

The data on the influence of various treatments on number of harvests are presented in Table 12. The data revealed a significant variation in the number of possible harvests. Dual inoculation with *Azospirillum* and AMF recorded significantly superior response than other two. Dual inoculation gave a possibility up to six cuts.

Higher the level of chemical fertilizer, more was the number of harvests possible. Treatments B_4 (75 per cent POP), B_3 (50 per cent POP) and B_2 (25 per cent POP) enabled 5-6 harvests and was significantly superior to no chemical fertilizer treatment.

Variation among varieties in this attribute was insignificant. The difference among control treatments and between control and treatments in study too was insignificant.

Interaction effect was not significant. Treatments T_{12} (A+V+75 per cent POP) and T_{10} (A+V+25 per cent POP) recorded the possibility of six cuts in amaranthus. Treatments T_{11}, T_4, T_3 and T_9 recorded more than 5 cuts (Table 12).

4.2.3 Total yield (Tables 12 and 13)

Total yield of various treatments are given in Tables 12 and 13. Variation in the total yield of amaranth due to application of different bio-fertilizers did not reach

Table 12. Yield attributes of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	Number of Harvests	Total Yield ($t\ ha^{-1}$)	Marketable Yield ($t\ ha^{-1}$)
Bio fertilizer			
A_1 (Azospirillum)	4.88	105.55	96.73
A_2 (AMF)	4.88	95.90	92.39
A_3 (Azospirillum+AMF)	5.69	109.26	103.32
$F_{2.14}$	12.36^{S}	0.92^{NS}	1.12^{NS}
SE	0.28	12.98	12.28
CD	0.59	--	--
Levels of chemical fertilizer	4.25	80.31	76.08
B_1(No Fertilizer)			
B_2 (25 per cent POP)	5.08	96.07	92.01
B_3 (50 per cent POP)	5.25	113.54	105.01
B_4 (75 per cent POP)	5.50	124.38	116.08
$F_{3.14}$	1.18^{NS}	9.16^{S}	2.01^{NS}
SE	0.32	14.98	14.18
CD	--	32.14	--
Varieties			
C_1 (Arun)	5.08	97.00	93.65
C_2 (Kannara Local)	5.21	110.15	101.30
$F_{1,14}$	1.07^{NS}	11.34^{S}	1.86^{NS}
SE	0.15	5.39	5.14
CD	--	11.32	--

Table 13. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on yield attributes in amaranth.

Treatment	Number of Harvests	Total Yield ($t\ ha^{-1}$)	Marketable Yield ($t\ ha^{-1}$)
Azospirillum(A)	4.50	64.75	61.00
A+ 25 per cent POP	4.25	64.40	60.00
A+ 50 per cent POP	5.25	144.80	127.00
A+ 75 per cent POP	5.50	128.14	118.00
AMF(V)	4.50	101.18	96.25
V+ 25 per cent POP	5.00	98.15	96.37
V+ 50 per cent POP	5.00	92.63	89.16
V+ 75 per cent POP	5.00	91.6	87.77
Azospirillum + AMF	5.25	75.00	71.00
A+V+ 25 per cent POP	6.00	105.12	99.23
A+V+ 50 per cent POP	5.50	103.12	98.71
A+V+ 75 per cent POP	6.00	153.29	144.31
POP	5.00	81.18	54.50
FYM	4.25	68.50	55.00
Vermicompost	4.50	78.13	75.50
SE	0.78	36.61	34.79
CD	0.192	89.692	85.233

the level of significance. Dual inoculation of *Azospirillum* and AMF recorded highest yield of 109.26 t ha^{-1} but its performance was on par with A_1 (*Azospirillum*) and A_2 (AMF). Application of chemical fertilizer significantly increased the total yield of amaranthus. The highest level B_4 recorded highest yield (124.37 t ha^{-1}) and it was on par with the lower two levels, B_3 (113.54 t ha^{-1}) and B_2 (96.06 t ha^{-1}) but significantly superior to no chemical fertilizer treatment B_1(80.31 t ha^{-1}).

Variety Kannara local was significantly superior to Arun in total yield.

There was no significant difference among control treatment. Treatments T_{12} (A+V+75 per cent POP), T_3 (A+50 per cent POP), T_4 (A+75 per cent POP) gave total yield of 153.29, 114.86 and 128.19 t ha^{-1} respectively and was significantly superior to the control treatments. These treatments gave yield of 1.8, 1.7 and 1.5 times more than the control namely POP. The difference was significant. The other treatments which gave high total yield were T_{10} and T_{11} with 105.12 and 103.12 t ha^{-1} respectively.

4.2.4 Marketable green yield (Tables 12 and 13)

The fresh plant parts which has not bolted and which were free from disease and pest infection was recorded as marketable green yield. The data is presented in Tables 12 and 13.

The same trend in total yield was noticed in the case of marketable yield also. Dual inoculation of AMF and *Azospirillum* recorded highest marketable yield (103.32 t ha^{-1}) but the difference among the different bio fertilizers was not significant. A progressive increase in the marketable yield was noticed due to an increase in the fertilizer level but the variation was not significant. Among the different fertilizer levels, the highest level B_4 recorded highest marketable yield (116.08 t ha^{-1}). Varietal difference was also not significant. Variety Kannara local recorded the highest marketable yield (101.3 t ha^{-1}) compared to Arun. Though a variation was noted among control treatments, it was insignificant.

There was significant difference in marketable yield between treatment and control. Treatment T_{12} (A+V+75 per cent POP) recorded highest marketable yield (144.31 t ha^{-1}). It was on par with control vermicompost (75.50t ha^{-1}) and was significantly superior to the other control treatments POP and farm yard manure.

4.2.5 Total dry matter production (Tables 14 and 15)

Data on the total dry matter yield recorded at various stages are presented in Tables 14 and 15.

There was no significant difference among the various bio agents in dry weight of plants at 30 DAT. During the later stages it was noted that treatments involving arbuscular mycorrhizal fungi was significantly superior to *Azospirillum* alone.

At 30 DAT , B_3 (50 per cent POP) and B_2 (25 per cent POP) recorded comparable dry weight and was significantly superior to other levels. But during the later stages B_3 (50 per cent POP) and B_4 (75 per cent POP) were found best.

Kannara local recorded a dry weight of 11.62 g $plant^{-1}$ and was significantly superior to Arun at 30 DAT. Performance of both varieties were on par at 45 DAT.

Table 14. Total dry weight (g plant^{-1})of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	30DAT	45 DAT	60 DAT	75 DAT	90 DAT
Bio fertilizer					
A_1 (Azospirillum)	11.41	15.17	14.334	13.033	12.511
A_2 (AMF)	10.97	16.19	16.126	15.44	15.25
A_3 (Azospirillum +AMF)	10.57	15.52	16.274	15.02	13.44
$F_{2,14}$	1.09 ^{NS}	8.78^{S}	15.66^{S}	44.09^{S}	139.30^{S}
SE	0.438	0.248	0.385	0.274	0.167
CD	--	0.533	0.827	0.588	0.358
Levels of chemical fertilizer					
B_1(No Fertilizer)	10.48	13.35	15.04	13.87	12.85
B_2 (25 per cent POP)	11.65	15.60	14.51	14.64	13.91
B_3 (50 per cent POP)	11.54	16.84	16.397	14.45	14.03
B_4 (75 per cent POP)	10.24	16.71	16.254	15.02	14.13
$F_{3,14}$	8.12^{S}	63.40^{S}	9.015^{S}	6.78^{S}	19.08^{S}
SE	0.505	0.286	0.445	0.316	0.192
CD	1.084	0.615	0.955	0.679	0.413
Varieties					
C_1 (Arun)	10.34	15.83	15.88	14.612	13.82
C_2 (Kannara Local)	11.62	15.42	15.27	14.390	13.64
$F_{1,14}$	9.94 ^{S}	1.04 ^{NS}	12.01^{S}	1.11^{NS}	1.21^{NS}
SE	0.407	0.236	0.260	0.118	0.118
CD	0.856	--	0.547	--	--

Table 15. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on total dry weight (g plant^{-1}) in amaranth.

Treatment	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Azospirillum(A)	3.90	11.58	11.27	12.12	10.60
A+ 25 per cent POP	4.34	15.63	13.20	13.14	12.34
A+ 50 per cent POP	4.07	18.16	17.07	13.25	13.51
A+ 75 per cent POP	3.19	15.31	15.89	13.61	13.58
AMF(V)	3.62	13.74	17.34	14.74	14.94
V+ 25 per cent POP	4.05	16.07	14.83	15.74	15.79
V+ 50 per cent POP	3.49	17.33	15.17	15.44	15.26
V+ 75 per cent POP	2.60	17.59	17.04	15.85	14.91
Azospirillum + AMF	2.38	14.68	16.47	14.77	13.01
A+V+ 25 per cent POP	3.90	15.10	15.56	15.03	13.61
A+V+ 50 per cent POP	3.00	15.03	16.94	14.62	13.24
A+V+ 75 per cent POP	2.69	17.25	16.12	15.62	13.90
POP	6.15	12.50	10.68	9.97	6.45
FYM	6.48	11.15	10.15	7.97	4.63
Vermicompost	8.27	12.29	12.57	8.77	5.62
SE	1.24	0.702	1.09	0.776	0.47
CD	3.038	0.049	2.670	1.908	1.151

At 60 and 75 DAT, variety Arun performed significantly superior to variety Kannara local. The variation among the varieties became insignificant at 90 DAT.

There was significant difference among the control treatments at all stages. Vermi compost was significantly better than other controls i.e., POP and FYM at 30 and 60 DAT. POP was significantly superior to other control treatments at 45, 75 and 90 DAT.

Interaction effect was not significant at any stage of growth. Thus comparing the mean values was found that at 30 DAT application of vermicompost alone out yielded the treatments T_3(A+50 per cent POP), T_1 and T_{10} but it was on par with T_2 (A +25 per cent POP). At 45 DAT, treatments T_3 , T_8, T_7 and T_{12} recorded comparable dry weight and were significantly superior to POP. At 60 DAT, T_5(AMF alone) recorded highest dry weight (17.34 g plant^{-1}) and it was on par with all fertilizers except T_1 and T_2. All control treatments were significantly inferior to other treatments in the study. At 75 DAT, treatments T_8,T_6, T_{12}, T_7, T_5 and T_{11} recorded comparable dry weight and were significantly superior to all control treatments At 90 DAT, treatments with AMF and different chemical fertilizer levels i.e. T_6(V+25 per cent POP), T_7(V+50 per cent POP) and T_8 (V+75 per cent POP) recorded comparable dry weight and were significantly superior to all control treatments.

4.3 Physiological parameters

4.3.1 Biomass (Tables 16 and 17)

Data containing the fresh weight of a single plant recorded at various stages are presented in Tables 16 and 17.

Table 16. Biomass (g $plant^{-1}$) of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	Icut	IIcut	IIIcut	IVcut
Bio fertilizer				
A_1 (Azospirillum)	150.570	191.125	179.375	104.625
A_2 (AMF)	157.813	168.688	155.000	97.625
A_3 (Azospirillum+AMF)	210.500	190.563	230.000	104.375
$F_{2,14}$	1.09^{NS}	0.91^{NS}	1.11^{NS}	0.98^{NS}
SE	26.712	21.3409	38.2278	21.9711
CD	--	--	--	--
Levels of chemical fertilizer				
B_1(No Fertilizer)	147.500	161.500	122.500	83.917
B_2 (25 per cent POP)	180.583	173.667	140.833	92.917
B_3 (50 per cent POP)	155.917	189.583	226.667	120.833
B_4 (75 per cent POP)	208.083	209.083	262.500	111.167
$F_{3,14}$	1.32^{NS}	1.21^{NS}	6.42^{S}	1.23^{NS}
SE	30.844	24.6423	44.1417	25.3700
CD	--	--	94.684	--
Varieties				
C_1 (Arun)	179.625	179.875	190.833	99.875
C_2 (Kannara Local)	166.417	187.042	185.417	104.542
$F_{1,14}$	1.62^{NS}	1.72^{NS}	1.14^{NS}	0.98^{NS}
SE	15.642	17.744	16.0424	11.6851
CD	--	--	--	--

Table 17. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on biomass (g $plant^{-1}$) in amaranth.

Treatment	Icut	IIcut	IIIcut	IVcut
Azospirillum(A)	72.25	112.50	65.00	73.75
A+ 25 per cent POP	162.00	168.50	127.50	61.25
A+ 50 per cent POP	156.25	265.00	235.00	170
A+ 75 per cent POP	212.50	218.50	240.00	113.50
AMF(V)	192.50	203.50	172.50	90.50
V+ 25 per cent POP	157.25	147.50	122.50	110.00
V+ 50 per cent POP	136.75	155.00	155.00	107.50
V+ 75 per cent POP	144.75	169.00	170.00	82.50
Azospirillum + AMF	177.75	168.50	130.00	87.50
A+V+ 25 per cent POP	222.50	205.00	172.50	107.50
A+V+ 50 per cent POP	174.75	149.00	290.00	85.00
A+V+ 75 per cent POP	267.00	240.00	377.50	137.50
POP	196.75	184.00	262.50	88.50
FYM	80.75	94.00	70.00	65.00
Vermicompost	267.50	297.50	102.5	54.50
SE	75.50	60.35	55.56	62.13
CD	--	--	--	--

At 30 DAT A_3 (Dual inoculation with *Azospirillum* and AMF) recorded significantly higher biomass compared to A_1 (*Azospirillum*) and A_2 (AMF).Biomass did not vary significantly with varying levels of chemical fertilizer. The highest level B_4 recorded highest biomass (g plant^{-1})

There was no significant difference in the biomass yield among the two varieties, Arun and Kannara local.

The difference among control treatments was significant. Vermicompost gave a higher biomass of 267.50g plant^{-1} which is about 5 times higher than FYM. Treatment T_{12} (A+V+75 per cent POP) gave high fresh weight of 267 g plant^{-1}, a value very close to the best control treatment namely vermicompost. T_{10}, T_4, T_5, recorded 222.50, 212.50, 192.50 g plant^{-1} respectively. T_{13} (POP) gave biomass yield of 196.75 g plant^{-1}.

Variation among single plant weight recorded at 45 DAT was insignificant for different biofertilizer treatments. Varying levels of chemical fertilizer did not register a significant variation. In biomass production varietal performance was on par. But there was significant difference among control treatments. Vermicompost continued the same trend with high value of 297.5 g plant^{-1}. The fresh weight under POP was 184 g plant^{-1}. Treatments T_3, T_{12} and T_4 recorded 265, 240 and 218.50 g plant^{-1} respectively. These treatments recorded high values.

At 60 DAT, there was no significant difference among treatments namely *Azospirillum*, AMF and dual inoculation. The higher levels of fertilizer i.e., 50 per cent and 75 per cent registered significant difference in fresh plant weight at 60 DAT.

The highest level B_4 registered 262.5 g plant^{-1} which was on par with B_3 (50 per cent POP) (226.66 g plant^{-1}) and was significantly superior to B_2 and B_1. There was no significant difference among two varieties. Difference among control and treatments was also insignificant. A high biomass of 377.5 g plant^{-1} was noted for the treatment T_{12} at 60 DAT, almost twice the plant weight recorded by the best control namely POP (262.5 g plant^{-1})

At 75 DAT, biomass was not significantly influenced by biofertilizer treatments, fertilizer levels and varieties. The higher values were recorded by treatments with *Azospirillum* and dual inoculation (104.62 and 104.37 g plant^{-1} respectively). Like wise B_3 and B_4 gave higher values (120.83 and 111.16 g plant^{-1}) over B_2 and B_1 . Among the various treatments T_3(170.00 g plant^{-1}), T_{12}(137.50 g plant^{-1}), T_4(113.50 g plant^{-1}) and T_6(110.00 g plant^{-1}) were notable.

4.3.2 **Root dry weight** (Tables 18 and 19)

Dry weight of roots did not vary significantly with application of *Azospirillum*, AMF or dual inoculation at 30, 45 and 75 DAT. At 60 DAT, dual inoculation by *Azospirillum* and AMF and AMF alone were on par and was significantly superior to application of *Azospirillum* alone. Application of chemical fertilizer significantly increased the root dry weight in amaranth. Higher dose of chemical fertilizer gave higher root dry weight. At stages 30, 45, 60, 75 DAT, B_4 i.e. (75 per cent POP) was significantly superior to no fertilizer application. Varieties Arun and Kannara local were on par at 30 and 75 DAT. Variety Arun was significantly superior to Kannara local at 45 and 60 DAT.

Table 18. Root dry weight (g plant^{-1}) of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	30 DAT	45 DAT	60 DAT	75 DAT
Bio fertilizer				
A_1 (Azospirillum)	3.37	3.82	4.00	4.25
A_2 (AMF)	3.47	4.88	5.34	5.45
A_3 (Azospirillum +AMF)	3.77	5.01	5.43	5.17
$F_{2,14}$	0.75^{NS}	24.99^{S}	67.35^{S}	38.59^{S}
SE	0.33	0.19	0.13	0.14
CD	0.71	0.40	0.30	0.31
Levels of chemical fertilizer				
B_1(No Fertilizer)	3.11	3.91	4.24	4.44
B_2 (25 per cent POP)	3.15	4.68	5.12	5.20
B_3 (50 per cent POP)	3.68	4.64	4.98	4.92
B_4 (75 per cent POP)	4.21	5.06	5.35	5.28
$F_{3,14}$	3.65^{S}	9.94^{S}	18.26^{S}	10.41^{S}
SE	0.38	0.21	0.16	0.17
CD	0.83	0.46	0.34	0.36
Varieties				
C_1 (Arun)	3.62	4.78	5.11	4.94
C_2 (Kannara Local)	3.45	4.36	4.74	4.97
$F_{1,14}$	0.64^{NS}	6.39^{S}	5.44^{S}	0.07^{NS}
SE	0.22	0.17	0.16	0.12
CD	0.461	0.363	0.333	0.256

Table 19. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on root dry weight (g $plant^{-1}$) in amaranth.

Treatment	30 DAT	45 DAT	60 DAT	75 DAT
Azospirillum(A)	1.78	2.01	2.14	2.84
A+ 25 per cent POP	3.73	4.18	4.37	4.33
A+ 50 per cent POP	3.59	4.23	4.45	4.60
A+ 75 per cent POP	4.38	4.83	5.04	5.16
AMF(V)	3.62	4.72	5.16	5.36
V+ 25 per cent POP	3.36	5.06	5.53	5.78
V+ 50 per cent POP	3.41	4.70	5.24	5.12
V+ 75 per cent POP	3.47	5.06	5.39	5.59
Azospirillum + AMF	3.90	5.00	5.41	5.11
A+V+ 25 per cent POP	2.35	4.78	5.46	5.47
A+V+ 50 per cent POP	4.02	4.96	5.25	4.98
A+V+ 75 per cent POP	4.76	5.28	5.60	5.12
POP	1.68	2.40	2.17	2.85
FYM	2.24	3.20	3.03	3.17
Vermicompost	2.75	3.45	3.80	3.62
SE	0.94	0.52	0.39	0.41
CD	2.301	1.281	0.952	0.992

There was no significant difference among control treatments at 30, 45 and 75 DAT. At 60 DAT, vermicompost was significantly superior to POP. Maximum value of root dry weight was recorded by the treatment T_{12} at 30, 45, 60 DAT (4.76, 5.28 and 5.6 g plant^{-1} respectively). At 30 DAT, T_{12} was on par with all treatments except T_1 and T_{10}. At 45 DAT, T_{12} was on par with all treatments except T_1 and was significantly superior to all the control treatments. At 60 DAT, all treatments except T_1, T_2, T_3 were on par and were significantly superior to the best control namely vermicompost. At 75 DAT, T_6 recorded maximum dry weight of root (5.78 g plant^{-1}) and was significantly more than all the control treatments and treatments T_1 and T_2.

4.3.3 Stem dry weight (Tables 20 and 21)

Data on stem dry weight at different stages are presented in Tables 20 and 21. Biofertilizer treatment had significant influence on the stem dry weight of amaranthus at all growth stages except 60DAT. During early stages i.e.30 and 45DAT, single inoculation of either *Azospirillum* and AMF recorded comparable stem dry weights and was significantly superior to dual inoculation. But during later stages of growth i.e., at 75 DAT, inoculation of AMF alone and dual inoculation treatments were on par and was significantly superior to *Azospirillum* inoculation.

Among the four different fertilizer levels, the higher two levels, B_3 and B_4 recorded highest yield at all stages except in the early stage ie., 30 DAT, B_4 recorded a higher stem dry weight of 6.328, 5.75 and 4.89 g plant^{-1} at 45, 60 and 75 DAT respectively. Variation among control treatments was insignificant at all stages except 45 DAT, wherein POP was superior significantly.

Table 20. Stem dry weight (g plant^{-1}) of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	30DAT	45 DAT	60 DAT	75 DAT
Bio fertilizer				
A_1 (Azospirillum)	3.88	5.81	4.95	4.42
A_2 (AMF)	3.44	5.97	5.12	4.87
A_3 (Azospirillum +AMF)	2.99	5.31	5.08	4.83
$F_{2,14}$	8.394^{S}	10.567^{S}	0.733^{NS}	18.816^{S}
SE	0.22	0.15	0.15	0.08
CD	0.46	0.32	--	0.17
Levels of chemical fertilizer				
B_1(No Fertilizer)	3.30	4.70	5.12	4.60
B_2 (25 per cent POP)	4.10	5.48	4.53	4.60
B_3 (50 per cent POP)	3.52	6.25	5.38	4.74
B_4 (75 per cent POP)	2.83	6.33	5.15	4.89
$F_{3,14}$	8.909^{S}	39.23^{S}	9.088^{S}	4.34^{S}
SE	0.25	0.17	0.17	0.09
CD	0.53	0.37	0.37	0.20
Varieties				
C_1 (Arun)	3.07	5.71	5.11	4.77
C_2 (Kannara Local)	3.80	5.68	4.99	4.65
$F_{1,14}$	34.295^{S}	0.865^{NS}	0.672^{NS}	2.125^{NS}
SE	0.13	0.14	0.14	0.08
CD	0.261	--	--	--

Table 21. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on stem dry weight (g $plant^{-1}$) in amaranth.

Treatment	30 DAT	45 DAT	60 DAT	75 DAT
Azospirillum(A)	3.90	4.75	4.53	4.67
A+ 25 per cent POP	4.34	6.20	4.21	4.30
A+ 50 per cent POP	4.07	7.22	5.73	4.39
A+ 75 per cent POP	3.20	5.05	5.20	4.29
AMF(V)	3.63	4.82	5.82	4.44
V+ 25 per cent POP	4.05	5.49	4.52	4.77
V+ 50 per cent POP	3.49	6.60	4.71	5.06
V+ 75 per cent POP	2.60	6.92	5.36	5.2
Azospirillum + AMF	2.38	4.53	4.95	4.68
A+V+ 25 per cent POP	3.90	4.76	4.85	4.69
A+V+ 50 per cent POP	3.01	4.93	5.59	4.76
A+V+ 75 per cent POP	2.69	6.99	4.9	5.17
POP	2.08	5.30	3.75	2.87
FYM	2.25	4.00	3.00	3.17
Vermicompost	2.43	4.82	3.72	3.62
SE	0.42	0.61	0.42	0.23
CD	1.031	1.492	1.025	0.543

Kannara local gave significantly higher results over variety Arun at 30 DAT. At 30 DAT, treatment inoculation of *Azospirillum* gave highest value of stem dry weight. T_2 (A+25 per cent POP) and T_3(A+50 per cent POP) gave dry weight 4.34 and 4.09 g plant^{-1} respectively. These were significantly superior to all the control treatments. At 45 DAT, maximum stem dry weight was for the treatment T_3 (7.22 g plant^{-1}) closely followed by treatments T_{12} (6.99 g plant^{-1}) and T_8 (6.92 g plant^{-1}) and these three were significantly more than the control treatments. At 60 DAT, T_5 recorded highest value (5.82 g plant^{-1}) and it was on par with T_3, T_{11}, T_8, T_4, T_9, T_{12} and T_{10}. All the treatments varied significantly over the control treatments. At 75 DAT, maximum stem dry weight was for the treatment T_8 (5.2 g plant^{-1}). It was on par with all treatments except T_2, T_3, T_4 and T_5. All these treatments were significantly superior to all the control treatments.

4.3.4 Leaf dry weight (Tables 22 and 23)

Biofertilizer application significantly influenced leaf dry weight only at 45 and 75 DAT. At 45 DAT, *Azospirillum* recorded highest leaf dry weight (5.55 g plant^{-1}) and it was on par with AMF and these two were significantly superior to dual inoculation. At 75 DAT, AMF (5.12 g plant^{-1}) was on par with dual inoculation (5.02 g plant^{-1}) and was significantly superior to *Azospirillum.* Fertilizer levels had significant influence on leaf dry weight only upto 60 DAT. The level B_3 (50 per cent POP) recorded highest leaf dry weight at 30, 45 and 60 DAT (4.34, 5.95, 6.03 g plant^{-1} respectively).

The difference in leaf dry weight between Arun and Kannara local were significant only at 30 and 75 DAT. In all other stages these two varieties were on par.

Table 22. Leaf dry weight (g plant^{-1}) of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	30DAT	45 DAT	60 DAT	75 DAT
Bio fertilizer				
A_1 (Azospirillum)	4.16	5.55	5.38	4.36
A_2 (AMF)	4.06	5.34	5.67	5.12
A_3 (Azospirillum +AMF)	3.81	5.20	5.77	5.02
$F_{2,14}$	0.686^{NS}	4.800^{S}	1.076^{NS}	17.42^{S}
SE	0.30	0.11	0.27	0.14
CD	--	0.24	--	0.30
Levels of chemical fertilizer				
B_1(No Fertilizer)	4.08	4.74	5.69	4.84
B_2 (25 per cent POP)	4.41	5.44	4.86	4.85
B_3 (50 per cent POP)	4.35	5.95	6.03	4.80
B_4 (75 per cent POP)	3.21	5.33	5.85	4.86
$F_{3,14}$	4.993^{S}	28.85^{S}	5.468^{S}	0.061^{NS}
SE	0.35	0.13	0.31	0.16
CD	0.75	0.28	0.67	--
Varieties				
C_1 (Arun)	3.65	5.34	5.67	4.90
C_2 (Kannara Local)	4.37	5.40	5.55	4.77
$F_{1,14}$	18.64^{S}	0.097^{NS}	0.866^{NS}	4.178^{S}
SE	0.17	0.18	0.12	0.07
CD	0.35	--	--	0.14

Table 23. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on leaf dry weight (g $plant^{-1}$)

Treatment	30 DAT	45 DAT	60 DAT	75 DAT
Azospirillum(A)	4.27	4.82	4.55	4.59
A+ 25 per cent POP	4.10	5.25	4.51	4.48
A+ 50 per cent POP	4.63	6.70	6.83	4.21
A+ 75 per cent POP	3.62	5.40	5.60	4.16
AMF(V)	4.17	4.25	6.41	4.93
V+ 25 per cent POP	4.41	5.52	4.82	5.19
V+ 50 per cent POP	4.35	6.02	5.17	5.25
V+ 75 per cent POP	3.31	5.54	6.28	5.10
Azospirillum + AMF	3.29	5.13	6.10	4.98
A+V+ 25 per cent POP	4.71	5.05	5.24	4.86
A+V+ 50 per cent POP	4.05	5.13	6.09	4.97
A+V+ 75 per cent POP	2.18	4.97	5.61	5.30
POP	2.32	4.70	4.17	3.34
FYM	1.97	3.90	3.57	2.27
Vermicompost	2.90	3.90	4.8	2.50
SE	0.86	0.32	0.77	0.39
CD	2.10	0.78	1.87	0.97

At 30 DAT Kannara local recorded the highest value whereas in the later stages Arun registered the highest value.

There was no significant difference among control treatments at 30, 60 and 75 DAT. At 45 DAT, POP was significantly superior to other two control treatments.

T_{10} (A+V+25 per cent POP) gave maximum dry weight of leaves at 30 DAT (4.72 g plant^{-1}). Though it was on par with vermicompost it was significantly superior to other control treatments and T_{12}. T_3 had maximum value (6.70 plant^{-1}) at 45 DAT. It was on par with T_7 and was significantly superior to all the control treatments and rest of the treatments in the study. T_3 continued to give maximum dry weight (6.83 g plant^{-1}) at 60 DAT. It was on par with T_9, T_8, T_{11}, T_{12}, T_4' T_{10} and T_7 but it was significantly more than all control treatments. T_{12} recorded maximum value of 5.3 g plant^{-1} for the dry weight at 75 DAT. This value was significantly more than all the control treatments.

4.3.5 Leaf-stem ratio (Tables 24 and 25)

It is evident from Table 24 that there was marked variation in the leaf-stem ratio due to application of different bioinoculants and chemical fertilizers at 30 and 45 DAT. *Azospirillum* recorded significantly higher leaf stem ratio (1.84) over others at 30 DAT. At 45 DAT, though dual inoculation gave maximum leaf stem ratio (1.02), it was on par with *Azospirillum*. Variation in leaf-stem ratio was insignificant due to biofertilizer and chemical fertilizer at 60 DAT. Treatment having no chemical fertilizer gave significant L:S ratio at early stages. Variation among varieties was found to be insignificant. Vermicompost recorded highest L:S ratio. But it was on par with POP at all stages. At 30 DAT T_9 (A+V) recorded highest leaf-stem ratio (1.61)

Table 24. Leaf stem ratio of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	30DAT	45 DAT	60 DAT
Bio fertilizer			
A_1 (Azospirillum)	1.84	0.97	1.08
A_2 (AMF)	1.21	0.90	1.11
A_3 (Azospirillum +AMF)	1.32	1.02	1.14
$F_{2,14}$	7.22^{S}	8.53^{S}	1.22^{NS}
SE	0.06	0.03	0.06
CD	0.13	0.07	--
Levels of chemical fertilizer			
B_1(No Fertilizer)	1.31	1.01	1.11
B_2 (25 per cent POP)	1.09	1.01	1.08
B_3 (50 per cent POP)	1.26	0.96	1.12
B_4 (75 per cent POP)	1.15	0.87	1.14
$F_{3,14}$	7.98^{S}	6.87^{S}	1.89^{NS}
SE	0.07	0.04	0.78
CD	1.15	0.08	--
Varieties			
C_1 (Arun)	1.23	0.97	1.11
C_2 (Kannara Local)	1.17	0.962	1.112
$F_{1,4}$	1.15^{NS}	1.23^{NS}	1.42^{NS}
SE	0.05	0.036	0.031
CD	--	--	--

Table 25. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on leaf : stem ratio

Treatment	30 DAT	45 DAT	60 DAT
Azospirillum(A)	1.11	1.01	0.99
A+ 25 per cent POP	0.97	0.86	1.07
A+ 50 per cent POP	1.12	0.93	1.12
A+ 75 per cent POP	1.13	0.07	1.08
AMF(V)	1.19	0.88	1.10
V+ 25 per cent POP	1.09	1.00	1.06
V+ 50 per cent POP	1.25	0.91	1.18
V+ 75 per cent POP	1.27	0.80	1.17
Azosp. + AMF	1.61	1.14	1.23
A+V+ 25 per cent POP	1.20	1.17	1.08
A+V+ 50 per cent POP	1.40	1.03	1.08
A+V+ 75 per cent POP	1.01	0.72	1.13
POP	1.14	1.04	1.10
FYM	0.87	0.79	1.18
Vermicompost	1.16	1.12	1.30
SE	0.17	0.09	0.17
CD	0.044	0.222	0.424

and was significantly superior to other treatments and all the controls. T_{11} (A+V+50 per cent POP) gave notable value of 1.4. At 45 DAT T_{10} (A+V+25 per cent POP) recorded maximum value (1.17) but it was on par with T_9 and control treatments vermicompost and POP. T_9 recorded highest L:S ratio (1.23) even at 60 DAT.

4.3.6 Relative growth rate (RGR) (Tables 26 and 27)

RGR varied significantly by the application of different biofertilizers (Table 26) *Azospirillum* gave significantly higher value for RGR over other two treatments at 45 DAT. It was on par with AMF inoculation and significantly superior to dual inoculation at 60 DAT. Varying levels of chemical fertilizer significantly influenced RGR. No fertilizer application was on par with 25 per cent POP (B_2). B_1 and B_2 were significantly superior to B_3 and B_4 at 45 DAT, while at 60 DAT B_2, B_3 and B_4 were on par and significantly superior to B_1. Though Kannara local was significantly superior to Arun at 45 DAT, it was on par with Arun at 60 DAT. T_1(A) recorded highest value of RGR (-4.9 mg day^{-1}) at 45 DAT (Table 27). It was significantly superior to all the control T_1 was on par with T_5 and T_2. At 60 DAT T_2 recorded highest RGR (5.00 mg day^{-1}). T_2 was significantly superior to the control POP.

4.3.7 Crop growth rate (CGR) (Tables 26 and 27)

As in the case of RGR at 45 DAT, *Azospirillum* was significantly superior over A_2 and A_3 (Table 26). But at 60 DAT A_1 and A_2 were on par and significantly superior to A_3

There was significant difference due to varying fertilizer levels at both stages. At 45 DAT B_1 and B_2 were on par and was significantly superior to B_3 and B_4. At 60

Table 26. RGR, CGR and NAR of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

Treatments	RGR mg day^{-1}		CGR mg m^{-2}day^{-1}		NAR mg cm^{-2}day^{-1}	
	45 DAT	60 DAT	45 DAT	60 DAT	45 DAT	60 DAT
Bio fertilizer						
A_1 (Azospirillum)	-4.19	0.84	-0.27	0.06	0.05	-0.007
A_2 (AMF)	-5.95	0.02	-0.38	0.005	0.65	-0.0045
A_3 (Azospirillum +AMF)	-5.7	-0.69	-0.35	-0.05	0.06	-0.0106
$F_{2.14}$	12.31^{S}	9.35^{S}	8.41^{S}	6.17^{S}	1.64^{NS}	6.79^{S}
SE	0.55	0.41	0.035	0.031	--	0.003
CD	1.25	0.8	0.75	0.075	--	0.008
Levels of chemical fertilizer						
B_1(No Fertilizer)	-3.6	-1.56	-0.21	-0.012	0.045	0.015
B_2 (25 per cent POP)	-4.37	1.07	-0.29	0.08	0.0505	0.011
B_3 (50 per cent POP)	-5.75	0.41	-0.39	0.03	0.07	0.002
B_4 (75 per cent POP)	-7.39	0.3	-0.47	0.027	0.07	0.002
$F_{2.14}$	9.12^{S}	7.52^{S}	6.87^{S}	6.49^{S}	8.14^{S}	5.44^{S}
SE	0.65	0.47	0.04	0.036	0.008	0.004
CD	1.95	1.00	0.9	0.075	0.018	0.009
Varieties						
C_1 (Arun)	-6.2	-0.05	-0.9	-0.003	0.0205	-0.0002
C_2 (Kannara Local)	-4.35	0.16	-0.28	0.011	0.0495	-0.0003
$F_{2.14}$	11.29^{S}	1.01^{NS}	6.84^{S}	4.82^{S}	5.65^{S}	1.17^{NS}
SE	0.55	0.4	0.031	0.026	0.01	0.004
CD	0.151	--	0.756	0.051	0.021	0.008

Table 27. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on RGR, CGR and NAR in amaranth

Treatment	RGR mg day^{-1}		CGR mg $m^{-2}day^{-1}$		NAR mg $cm^{-2}day^{-1}$	
	45 DAT	60DAT	45 DAT	60 DAT	45 DAT	60 DAT
Azospirillum(A)	-4.9	0.7	-0.24	0.0462	0.08	-0.0046
A+ 25 per cent POP	-7.45	5	-0.5	0.3759	0.09	-0.0522
A+ 50 per cent POP	-11.5	1.9	-0.85	0.162	0.145	-0.0091
A+ 75 per cent POP	-9	-1.06	-0.6	-0.0865	0.09	0.0098
AMF(V)	-5.4	-6.75	-3.5	-0.5335	0.44	0.094
V+ 25 per cent POP	-9.2	2.2	-0.6	0.175	0.12	-0.022
V+ 50 per cent POP	-13.5	3.9	-0.9	0.319	0.17	-0.048
V+ 75 per cent POP	-19	0.8	-1.2	0.081	0.205	-0.0145
Azospirillum + AMF	-11	-3.3	-0.65	-0.264	0.14	0.0456
A+V+ 25 per cent POP	-9.5	-0.85	-0.61	-0.067	0.09	0.0069
A+V+ 50 per cent POP	-9	-3.35	-8.85	-0.2825	0.12	0.0045
A+V+ 75 per cent POP	-15.7	2.04	-1.05	0.165	0.125	-0.0128
POP	-20.7	4.83	-0.95	0.28	0.24	-0.045
FYM	-15.8	3.45	-0.69	0.135	0.225	-0.025
Vermicompost	-11.5	2.05	-0.6	0.1	0.05	0.004
SE	0.1048	0.072	0.0065	0.0056	0.0021	0.0006
CD	--	--	--	--	--	--

DAT, B_2 and B_3 were on par. There was significant difference among varieties. Kannara local recorded significantly greater CGR at both stages over variety Arun. Treatments which recorded highest CGR at 45 DAT was T_1 (-0.24 mg $m^{-2}day^{-1}$) and it was significantly superior to all treatments and control. At 60 DAT , T_2 recorded highest CGR (0.37 mg m^{-2} day^{-1}) it was on par with POP. Treatment T_7 also recorded CGR on par with POP.

4.3.8 Net assimilation rate (NAR) (Tables 26 and 27)

Variation in NAR due to various bio agents was insignificant at 45 DAT. But at 60 DAT *Azospirillum* was significantly superior to A_2 and A_3.

Variation in NAR was significant at different fertilizer levels at 45 and 60 DAT. At 45 DAT, B_3 and B_4 were on par and significantly superior to B_2 and B_1. At 60 DAT B_2, B_3 and B_4 were on par. Though Kannara local was superior to variety Arun at 45 DAT, it was on par with Arun at 60 DAT. At 45 DAT POP gave highest NAR (0.24 mg cm^{-2} day^{-1}). Though T_8 recorded (0.20 mg cm^{-2} day^{-1}) it was significantly inferior to the control treatments. At 60 DAT, T_5 (0.094 mg cm^{-2} day^{-1}) was significantly superior to all treatments as well as control. T_9 (0.045 mg cm^{-2} day^{-1}) and T_{11} (0.045 mg cm^{-2} day^{-1}) also recorded high NAR and were significantly superior to other treatments and control.

4.4 Leaf quality

4.4.1 Moisture content (Tables 28 and 29)

Moisture content in percentage is given in Table 27. Highest value for moisture content was recorded for dual inoculation (85.43 per cent), but it was on par with inoculation with *Azospirillum* and AMF alone. All the levels of chemical

Table 28. Leaf quality parameters of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	Moisture Content (Percent)	Vitamin (mg $100g^{-1}$)	Fibre Content (Percent)	Oxalate (Percent)	Protein (Percent)	Mineral (Percent)
Bio fertilizer						
A_1 (Azospirillum)	84.938	66.750	10.213	-5.063	23.363	13.65
A_2 (AMF)	84.500	67.813	10.595	-4.971	22.405	13.66
A_3(Azospirillum +AMF)	85.438	68.875	10.226	-5.036	22.398	13.71
$F_{2,14}$	0.92^{NS}	1.47^{NS}	7.83^{S}	2.20^{NS}	1.18^{NS}	2.48^{NS}
SE	0.600	0.867	0.1095	-0.035	0.497	0.081
CD	--	--	0.2349	--	--	--
Levels of chemical fertilizer	84.33	68.667	10.487	5.072	21.509	13.30
B_1(No Fertilizer)						
B_2 (25 per cent POP)	83.75	69.667	10.418	5.008	21.471	13.75
B_3 (50 per cent POP)	85.08	66.330	10.384	5.033	23.620	13.85
B_4 (75 per cent POP)	86.66	80.00	10.090	4.980	24.288	13.81
$F_{3,14}$	6.64^{S}	8.30^{S}	14.58^{S}	0.78^{NS}	6.45^{NS}	7.27^{S}
SE	0.692	1.001	0.1264	0.410	0.574	0.0944
CD	1.486	2.149	0.2173	--	1.233	0.2025
Varieties						
C_1 (Arun)	84.708	68.208	10.348	5.201	22.69	13.679
C_2 (Kannara Local)	85.208	67.417	10.342	4.845	22.75	13.679
$F_{1,14}$	3.84^{NS}	1.27^{NS}	2.51^{NS}	29.60^{S}	1.87^{NS}	1.30^{NS}
SE	0.572	0.501	0.0991	0.065	0.434	0.686
CD	--	--	--	0.137	--	--

Table 29. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on leaf quality parameters

Treatment	Moisture Content (Percent)	Vitamin mg $100g^{-1}$		Fibre Content (Percent)	Oxalate (Percent)	Protein (Percent)	Mineral (Percent)
		Arun	KL				
Azospirillum(A)	84.00	67.50	67.50	10.29	5.137	22.60	13.15
A+ 25 per cent POP	83.00	69.50	69.50	10.28	4.920	23.23	13.80
A+ 50 per cent POP	85.50	68.00	63.50	10.26	5.130	23.84	13.90
A+ 75 per cent POP	87.25	67.00	62.00	10.00	5.050	24.66	13.72
AMF(V)	85.00	69.50	66.50	10.86	5.090	20.48	13.30
V+ 25 per cent POP	84.25	69.00	68.00	10.56	5.040	20.69	13.75
V+ 50 per cent POP	84.00	65.50	68.50	10.48	4.860	22.98	13.72
V+ 75 per cent POP	84.75	66.50	69.00	10.47	4.880	23.78	13.72
Azosp. + AMF	84.00	70.00	71.50	10.30	4.980	21.44	13.40
A+V+ 25 per cent POP	84.00	72.00	70.00	10.40	5.050	22.97	13.70
A+V+ 50 per cent POP	85.75	70.00	65.50	10.40	5.100	23.23	13.80
A+V+ 75 per cent POP	88.00	67.50	67.50	9.79	5.000	24.17	13.90
POP	85.50	64.50	63.50	10.50	5.300	25.69	13.85
FYM	84.00	63.00	63.50	11.26	5.060	17.32	13.30
Vermicompost	85.00	65.00	64.50	11.46	4.860	19.42	13.50
SE	1.69	2.45	2.45	0.308	0.100	1.408	0.2313
CD	--	--	--	--	--	3.44	0.566

fertilizer performed on par. However, the highest value of 86.66 per cent was recorded for B_4 (75 per cent POP). There was no significant difference among moisture content among varieties Arun and Kannara local. Variation among control treatments was insignificant. Treatment T_{12} (A+V+75 per cent POP) gave maximum value for moisture content (88 per cent), it was on par with all the control treatments as well as with other treatments. A high value of 87.25 per cent was reported for the moisture content by T_4 (A+75 per cent POP).

4.4.2 Ascorbic acid

Vitamin C content in the leafy vegetable is an important quality parameter and is given in Table 27. Ascorbic acid content was maximum (68.87mg $100g^{-1}$) for dual inoculation, though not significant. The effect of different levels of chemical fertilizers were also on par. The varieties didn't vary significantly. Variation among the control treatment was not significant. But there was interaction effect. Thus comparing mean of varieties separately for ascorbic acid content, it was found that treatment T_{10} (72mg $100g^{-1}$) was significantly superior to all the control treatments and was on par with all treatments except T_7. T_9 recorded highest value for ascorbic acid content (71.5mg $100g^{-1}$) in variety Kannara local. It was significantly superior to all the control treatments and other treatments except T_3 and T_2 in the case of Kannara local.

4.4.3 Fibre content

Variation in fibre content was significant due to biofertilizer application (Table 27). A_2 (AMF) recorded a value of 10.59 per cent which was significantly more than A_1 and A_3.B_1 and B_2 were on par and recorded 10.48 per cent and 10.41

per cent of fibre content respectively. They were significantly greater than B_3 (10.38 per cent) and B_4 (10.09 per cent). Varieties did not register any significant difference. Vermicompost recorded significantly higher fibre content than POP. T_{12} (A+V+75 per cent POP) recorded fibre content of 9.79 per cent, which was significantly lower than control, FYM and vermicompost, but on par with POP. It was on par with all treatments except T_5 (10.86 per cent) and T_6 (10.48 per cent).

4.4.4 Oxalate content

Data on oxalate content is presented in Table 28. Biofertilizers significantly influenced oxalate content in amaranth. Application of *Azospirillum* recorded high oxalate content (5.06per cent), and was on par with dual inoculation (5.03per cent) and was significantly more than AMF. Fertilizer levels also had significant influence on oxalate content. It was noted that application of fertilizers significantly influenced the oxalate content. B_4 (75 per cent POP) recorded oxalate content of 4.9 per cent, a value significantly lower than B_1 (5.072per cent) and on par with B_2 and B_3.

Variety Arun recorded significantly higher oxalate content than Kannara local. There was significant variation in the content of oxalate among control treatments. Vermicompost recorded a low value of 4.86, which was on par with FYM, but significantly lower than POP. There was no interaction effect. Treatment T_7 recorded lowest oxalate content (4.86 per cent). But it was on par with all treatments except T_1 and T_3. It was significantly lower than the control POP too.

4.4.5 Protein content

A perusal of the data on protein content (Table 28) revealed that there was no significant variation among treatments with biofertilizers. Maximum value of protein content was reported by application of *Azospirillum* (23.36 per cent). Protein content was found to increase with increasing levels of chemical fertilizer B_4 (75 per cent POP) gave maximum value (24.2 per cent) and was on par with B_3 (23.62 per cent). B_4 was significantly superior to B_2 (21.47 per cent) and B_1 (21.5 per cent). Content of protein did not vary significantly among varieties. Maximum value of protein content was recorded for POP (25.69 per cent) and it was significantly superior to other controls and treatments T_5, T_6 and T_9. Treatments T_4, T_{12}, T_8 recorded high values of protein comparable with POP

4.4.6 Total minerals

The variation in total minerals due to different bio agents and varieties was insignificant (Table 28).Higher levels of chemical fertilizers gave significantly higher level of total minerals than no fertilizer application.Though POP recorded maximum mineral content, the difference was not significant. T_{12} (A+V+75 per cent POP) and T_3 (A+50 per cent POP) gave maximum total mineral content (13.9 per cent) which was significantly superior to the control FYM (13.3 per cent), treatments T_1 and T_5.

4.5.1 Final NPK status of soil (Table 30 and 31)

Soil samples analysed after the experiment to assess the available nutrient status of soil at different bio fertilizers, fertilizer levels and varieties are presented in tables 30 and 31.

Table 30. Soil NPK status (kg ha^{-1}) as influenced by bio fertilizers, chemical fertilizer levels and varieties

	N	P	K
Bio fertilizer			
A_1 (Azospirillum)	363.64	118.82	123.18
A_2 (AMF)	399.35	84.87	121.75
A_3 (Azospirillum +AMF)	429.62	101.16	95.56
$F_{2,14}$	12.28^{S}	32.66^{S}	103.09^{S}
SE	13.32	4.20	2.16
CD	28.58	9.010	4.64
Levels of chemical fertilizer			
B_1(No Fertilizer)	388.70	77.58	89.25
B_2 (25 per cent POP)	388.03	82.13	91.66
B_3 (50 per cent POP)	405.82	113.15	123.91
B_4 (75 per cent POP)	407.59	133.60	149.16
$F_{3,14}$	2.18^{NS}	59.84^{S}	260.62^{S}
SE	15.39	4.85	2.50
CD	--	10.491	5.36
Varieties			
C_1 (Arun)	394.47	105.67	113.70
C_2 (Kannara Local)	400.59	97.56	113.29
$F_{1,14}$	2.40^{NS}	1.85^{NS}	1.45^{NS}
SE	8.46	5.85	13.22
CD	--	--	--

Table 31. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on soil NPK status (kg ha^{-1})

Treatment	N	P	K
Azospirillum(A)	361.16	57.52	90.25
A+ 25 per cent POP	323.18	120.40	99.75
A+ 50 per cent POP	389.55	150.30	135.25
A+ 75 per cent POP	380.66	147.02	167.25
AMF(V)	357.12	76.00	61.25
V+ 25 per cent POP	428.35	67.50	75.25
V+ 50 per cent POP	406.12	72.50	83.00
V+ 75 per cent POP	405.20	123.50	218.75
Azospirillum. + AMF	402.31	58.50	56.75
A+V+ 25 per cent POP	412.60	51.67	92.75
A+V+ 50 per cent POP	421.79	119.90	61.25
A+V+ 75 per cent POP	436.32	124.50	110.00
POP	350.00	126.50	189.75
FYM	342.15	56.87	82.50
Vermicompost	346.25	70.00	84.25
SE	37.60	11.88	5.76
CD	92.12	29.02	14.11

With respect to the nitrogen content in the soil, dual inoculation was significantly superior to A_2 and A_1. Soil nitrogen status in the treatment with dual inoculation was 429.62 Kg ha^{-1}. Though higher levels of fertilizer recorded more soil nitrogen, the variation did not reach the level of significance. Varieties performed on par in the content of residual N in the soil. T_{12} gave maximum soil N. It was comparable with all treatments except T_2 and the control FYM.

There was significant difference in soil phosphorus after the experiment when different biofertilizers were used. Application of *Azospirillum* gave significantly more residual P over application of AMF and dual inoculation. Soil P increased with increasing level of fertilizer. There was no significant difference among varieties. Maximum residual P was recorded in plots inoculated with *Azospirillum* along with 50 per cent POP, closely followed by treatments (T_4) ie A+75 per cent POP.

Biofertilizers had significant influence in the available potassium content in soil. A_1 (123.18 Kg ha^{-1}) was on par with A_2 (121.75 Kg ha^{-1}) and they were significantly superior to A_3. Fertilizer levels also had significant influence on available K content in soil. B_4 having soil K of 149.16 Kg ha^{-1} was significantly superior to the rest. The varieties Arun and Kannara local were on par in this aspect. POP had significantly higher soil K than others. Treatment T_8 (*AMF* with 75 per cent POP) recorded maximum soil K of 218.75 Kg ha^{-1}. It was significantly superior to all the treatments as well as control.

4.6.1 Plant uptake of nutrients

Plant uptake of major nutrients are presented in Tables 32 and 33.

Table 32. Plant nutrient uptake (kg ha^{-1}) of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties

	Nitrogen	Phosphorus	Potassium
Bio fertilizer			
A_1 (Azospirillum)	197.203	21.43	109.105
A_2 (AMF)	170.956	31.25	109.41
A_3 (Azospirillum +AMF)	193.23	21.63	113.26
$F_{2,14}$	1.86^{NS}	200.91^{S}	0.90^{NS}
SE	26.39	0.560	3.662
CD	--	1.201	--
Levels of chemical fertilizer			
B_1(No Fertilizer)	153.03	24.68	106.193
B_2 (25 per cent POP)	168.02	24.92	108.783
B_3 (50 per cent POP)	207.129	25.41	112.381
B_4 (75 per cent POP)	220.33	24.07	115.02
$F_{3,14}$	2.47^{NS}	2.99^{NS}	1.92^{NS}
SE	30.47	0.646	4.22
CD	--	--	--
Varieties			
C_1 (Arun)	183.77	24.60	109.42
C_2 (Kannara Local)	190.48	24.94	111.76
$F_{1,14}$	0.87^{NS}	1.94^{NS}	19.18^{S}
SE	7.00	0.257	0.981
CD	--	--	2.063

Table 33. Interaction effect of bio fertilizers, chemical fertilizer levels and variety on plant nutrient uptake(kg ha^{-1})

Treatment	Nitrogen kg ha^{-1}	Phosphorous kg ha^{-1}	Potassium kg ha^{-1}
Azospirillum(A)	128.70	17.80	100.50
A+ 25 per cent POP	150.00	19.90	103.70
A+ 50 per cent POP	267.50	25.70	118.50
A+ 75 per cent POP	242.50	22.26	113.49
AMF(V)	199.60	33.19	110.54
V+ 25 per cent POP	177.11	32.44	110.36
V+ 50 per cent POP	153.80	29.90	106.28
V+ 75 per cent POP	153.25	29.43	110.46
Azospirillum + AMF	130.75	23.06	107.50
A+V+ 25 per cent POP	176.90	22.37	112.20
A+V+ 50 per cent POP	200.00	20.59	112.26
A+V+ 75 per cent POP	265.25	20.52	121.10
POP	192.40	17.37	108.90
FYM	153.00	16.80	100.75
Vermicompost	150.21	19.03	103.70
SE	24.20	3.40	0.89
CD	1.50	7.24	1.90

Application of *Azospirillum*, AMF and dual inoculation were on par with regard to uptake of nitrogen by the plant. But the highest value of 197.2 kg ha^{-1} was recorded for the treatment *Azospirillum*. The highest dose of chemical fertilizer namely B_4, B_3 and B_2 recorded highest N uptake (220.33 kg ha^{-1}) and was on par with levels B_3 and B_2 was significantly superior to B_1. Variety Arun and Kannara local did not vary significantly. There was significant difference among control treatments. POP was significantly superior to FYM but on par with Vermicompost. Treatment T_3 (A+50 per cent POP) gave maximum value of 267.5 kg ha^{-1}. T_3 was however, on par with T_{12} (265.25 kg ha^{-1}) and T_4 (242.5 kg ha^{-1}). T_3 and T_{12} was significantly superior to the best control treatment namely POP.

AMF inoculated plants gave significantly more phosphorus content than those inoculated with *Azospirillum* and dual inoculation. There was no significant difference among the different fertilizer levels. B_3 recorded highest value of 25.41 kg ha^{-1}. Performance of Arun and Kannara local were on par. There was no significant difference among the control treatments. Interaction effect was insignificant.T_5 (AMF) recorded maximum P uptake of 33.19 kg ha^{-1}. But it was on par with T_6 (32.44 kg ha^{-1}), T_2 (29.9 kg ha) $^{-1}$ and T_3 (29.43 kg ha^{-1}). It was significantly superior to all other treatments as well as the control. The uptake values were almost two times the value of control treatments.

Significant difference was not obtained for plant K uptake by the application of different biofertilizers and with varied fertilizer levels. Performance of varieties were also on par. POP was significantly superior to vermicompost and FYM.

Interaction effect was insignificant. T_{12} (A+V+75 per cent POP) gave highest K uptake value of 121.10 kg ha^{-1}, which was significantly superior to the rest and the best control. Next best treatment was T_3 (118.5 kg ha^{-1}), which was also significantly superior to all treatments except T_{12}. It was significantly better than control too.

4.7.1 Benefit cost ratio

Economic of cultivation is given in Table 34. When biofertilizer was given alone, maximum benefit cost ratio was recorded for AMF inoculation (6.46).

As the level of chemical fertilizer increased, benefit cost ratio gradually increased for dual inoculation treatments. But it declined for AMF inoculation. For *Azospirillum*, it showed a increase upto 50 per cent level of POP and then declined.

Among the control treatments, highest benefit cost ratio was for FYM ie. 3.71. POP closely followed with 3.61.

Benefit cost ratio was maximum for treatment T_{12} (A+V+75 per cent POP) recording a value of 9.59. Benefit cost ratio in the decreasing order from 8.48, 7.48, 6.65 to 6.59 were noted for treatments T_3, T_4, T_{10}, T_{11} respectively.

4.8.1 Scoring of pest and diseases

Incidence of pest was negligible during the period of cultivation. Minor incidence of leaf webber attack was effectively controlled by mechanical measures of hand picking.

One of the main problems faced was incidence of leaf blight disease during rainy periods. At the initial stage, a scoring was conducted and the results are

Table 34. Economics of Cultivation

Treatment	Additional Cost (Rs)	Total Cost (Rs)	Mktable Yield (tonnes)	Gross Return (Rs)	Net Return (Rs)	Net return per rupee Invested	B:C Ratio
Azospirillum alone	20	74020	61	305000	230980	3.12	4.12
A+25 per cent	554.73	74555	60	300000	225445	3.02	4.02
A+50 per cent	882.94	74883	127	635000	560117	7.48	8.48
A+75 per cent	1211.15	75211	118	590000	514789	6.84	7.84
AMFalone	28	74028	96.2	481000	406972	5.5	6.5
V+25 per cent	562.73	74563	96.3	481500	406937	5.46	6.46
V+50 per cent	890.94	74891	89.1	445500	370609	4.95	5.95
V+75 per cent	1219.15	75219	87.7	438500	363281	4.83	5.83
A+V	48	74020	71	355000	280980	3.8	4.8
A+V+25 per cent	582.71	74583	99.2	496000	421417	5.65	6.65
A+V+50 per cent	910.94	74911	98.7	493500	418589	5.59	6.59
A+V+75 per cent	1239.5	75240	144.3	721500	646261	8.59	9.59
100 per centPOP	1519.34	75519	54.5	272500	196981	2.61	3.61
FYM		74000	55	275000	201000	2.71	3.71
Vermicompost		150000	75.5	377500	227500	1.51	2.51

Note : 1 tonne of FYM Rs 390 Wage Rate Rs 105/day

1 tonne of Vermicompost Rs 3000
1 kg Urea (46 per cent N) Rs 3.80
1 kg R P (24 per cent P) Rs 2.20
1 kg MOP (60 per cent K) Rs 3.80

presented in Tables 35 and 36. AMF recorded minimum incidence of disease among biofertilizer treatments. It was on par with *Azospirillum* and significantly superior to dual inoculation.

The higher the levels of chemical fertilizer, higher was the infection rate. Treatments B_1 and B_2 recorded significantly less disease score compared to B_3 and B_4. There was no significant difference among varieties. There was significant difference among control. POP recorded maximum disease incidence. Treatments which recorded low infection (<50 per cent) were T_1 (27.5per cent), T_5 (28per cent), T_6 (30per cent) and T_2 (44.75per cent).

Table 35. Disease score (per cent) of amaranth as influenced by bio fertilizers, chemical fertilizer levels and varieties on disease score

	Disease Score (%)
Bio fertilizer	
A_1 (Azospirillum)	49.75
A_2 (AMF)	44.75
A_3 (Azospirillum +AMF)	64.56
$F_{2,14}$	7.82^{S}
SE	4.714
CD	10.110
Levels of chemical fertilizer	
B_1(No Fertilizer)	40.33
B_2 (25 per cent POP)	43.25
B_3 (50 per cent POP)	62.75
B_4 (75 per cent POP)	65.75
$F_{3,14}$	4.89^{S}
SE	5.44
CD	11.67
Varieties	
C_1 (Arun)	53.75
C_2 (Kannara Local)	52.29
$F_{1,14}$	1.12^{NS}
SE	4.65
CD	--

Table 36. Interaction effect of bio fertilizers, chemical fertilizer level and varieties on disease score (percent) in amaranth

Treatment Number	Treatment	Disease Score (%)
T1	Azospirillum(A)	27.50
T2	A+ 25 per cent POP	44.75
T3	A+ 50 per cent POP	62.75
T4	A+ 75 per cent POP	64.00
T5	AMF(V)	28.00
T6	V+ 25 per cent POP	30.75
T7	V+ 50 per cent POP	64.50
T8	V+ 75 per cent POP	55.75
T9	Azospirillum + AMF	65.50
T10	A+V+ 25 per cent POP	54.25
T11	A+V+ 50 per cent POP	61.00
T12	A+V+ 75 per cent POP	77.50
T13	POP	76.25
T14	FYM	28.75
T15	Vermicompost	22.75
	SE	13.33
	CD	32.658

DISCUSSION

5. DISCUSSION

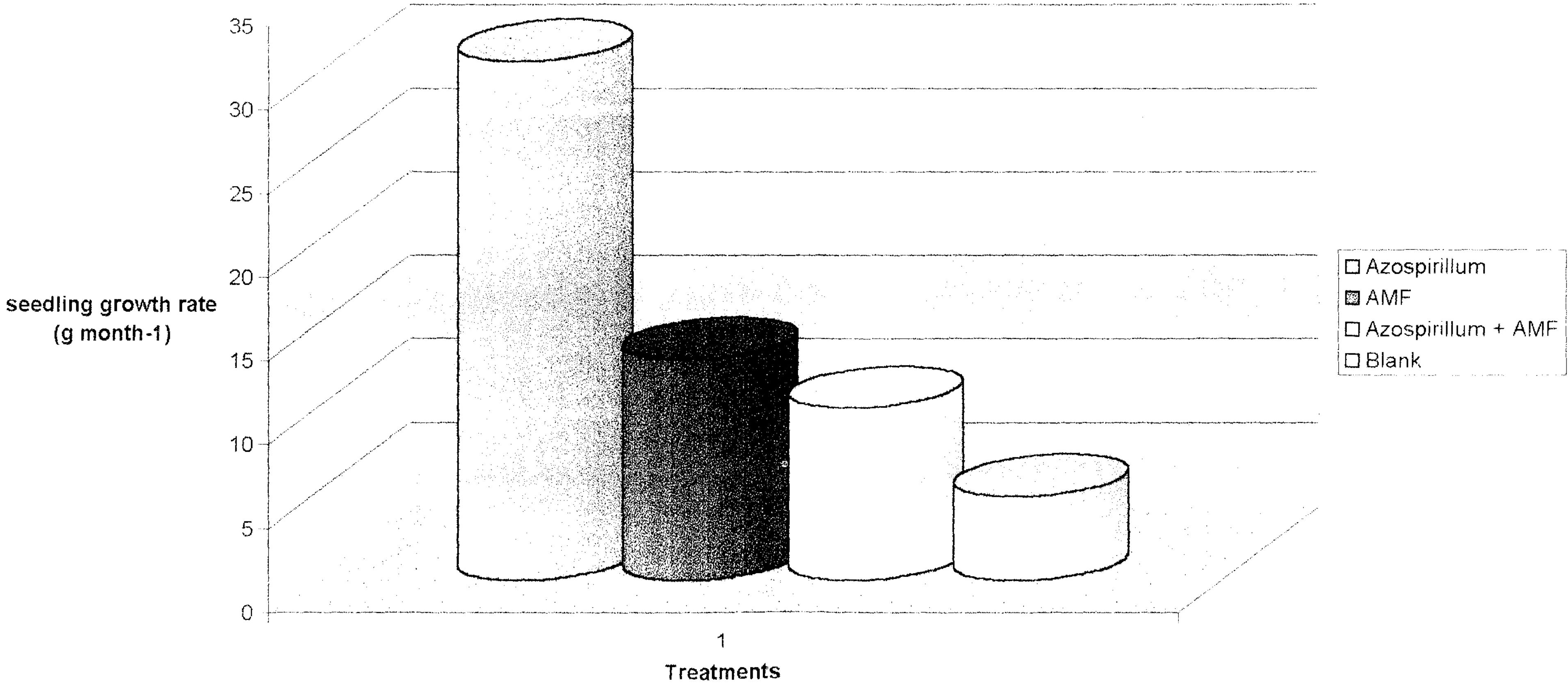
Vegetable cultivation in our state is carried out on commercial scale mostly by the application of chemical fertilizers and organic manure. Bio-fertilizer have not gained popularity in this regards. Bio-fertilizers are known to effectively supplement chemical fertilizers. *Azospirillum,* AMF and their combination have been reported to have spectacular growth responses. A study was undertaken to assess the impact of these bio-fertilizers in amaranth. The growth, yield and quality of amaranth and economics of its cultivation due to the inclusion of bioagent were studied. It was also compared with three checks namely, POP recommendation and two organic treatments (FYM alone and vermicompost alone). As one of the objective was to study the extent of substitution of chemical fertilizer by biofertilizer, various levels of chemical fertilizer were tried along with different biofertilizers. Scientific reports also have revealed that certain varieties of crop to have shown more response to certain agronomic treatments. In the present study two popular amaranth varieties namely Kannara local and Arun were tried to note their comparative performance due to integrated fertilizer application.

The data collected on various growth characters, yield and yield attributes, leaf quality, nutrient uptake, soil nutrient status, benefit cost ratio and disease score were analysed statistically and the results are discussed in this chapter

5.1 Growth characters

Results presented in Table 1 and Fig. 3.revealed that *Azospirillum* had specific influence on the seedling growth rate of amaranth (fig 3) where in the growth

Fig. 3. Effect of biofertilizers on seedling growth rate of amaranth



rate was more than six times that of control treatment while seedling growth rate in AMF and dual inoculated plants were respectively 2.6 and 2 times more than control treatment. This clearly showed the advantages of application of biofertilizer in nursery stage to get better seedlings. Dhanalakshmi and Pappiah (1995) have reported more number of roots, better root and shoot length, vigour index , fresh and dry weight in *Azospirillum* inoculated tomato seedlings.

Azospirillum has the ability for better root induction which is attributed to the production of hormones like IAA and GA. This explains the better morphological characters and growth in inoculated plants (Govindan and Purushothaman, 1989; Hubbel, 1979; Tien et al; 1979). It can be deciphered from the Table 2 that *Azospirillum* inoculation significantly increased the plant height over other treatments and control in early stages i.e. 15 DAT. *Azospirillum* along with 50 per cent of recommended dose (T_3) gave consistently greater plant height at all stages in both varieties. The performance of biofertilizer with 75 per cent POP also showed a favourable trend throughout. Similar results were noticed in bhendi (Kapulnik, 1981; Parvatham *et al.*, 1989) and in chilly (Paramaguru and Natarajan, 1993).

At 30 DAT, there was no significant difference in plant height due to various bioinoculants. However AMF gave maximum value (49.34 cm). The stimulation of plant height by AMF is well established (Schultz, 1979). At 45 DAT, increase in plant height due to arbuscular mycorrhizal fungi was significant. Arbuscular mycorrhizal inoculation has reported better plant height in bhendi (Senapati et al, 1987). T_6 (V+25 per cent POP) have given fairly good performance in variety Arun throughout and in Kannara local at 60 DAT.

Fig 4. Effect of biofertilizers and chemical fertilizer levels on plant height in amaranth variety Arun

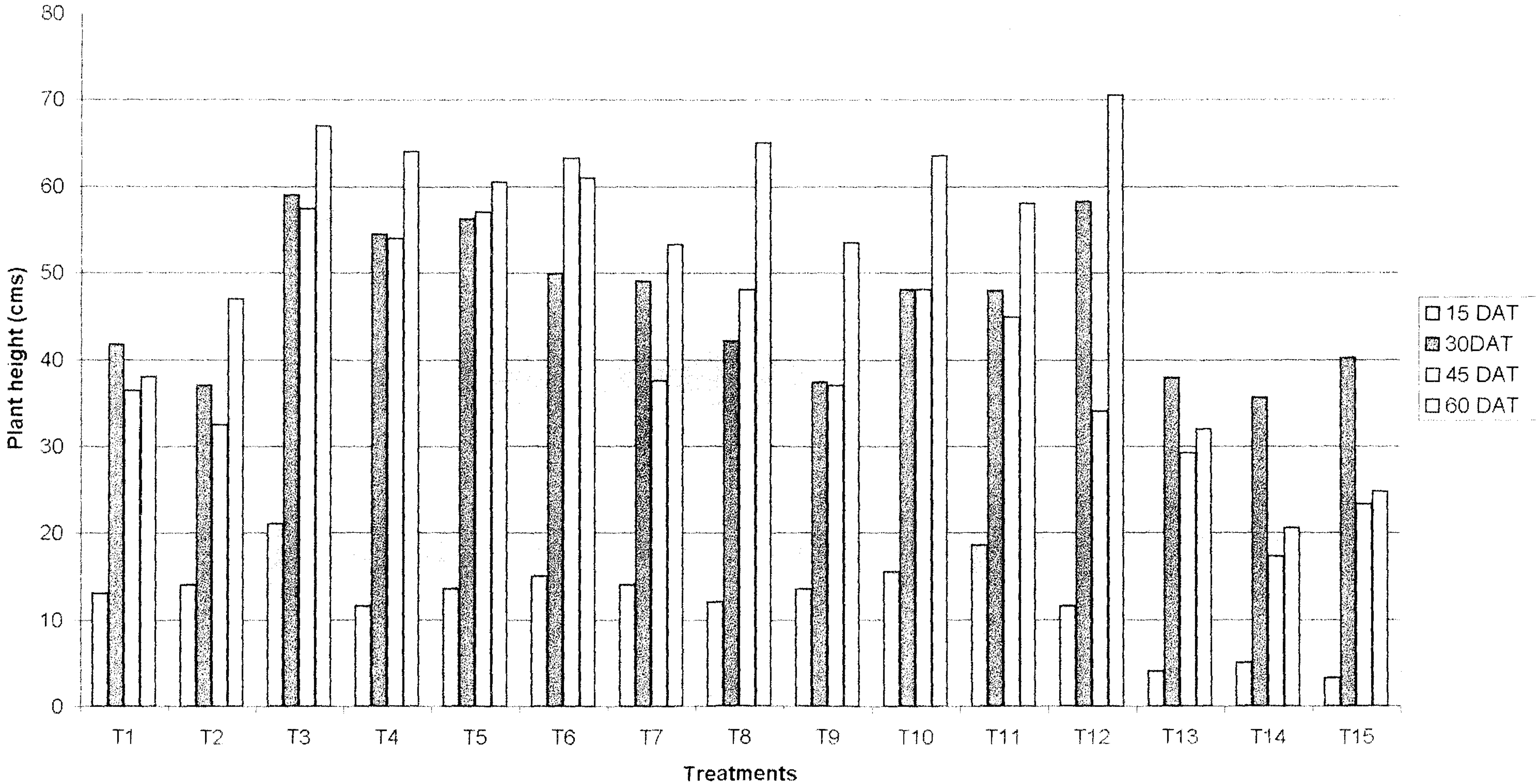
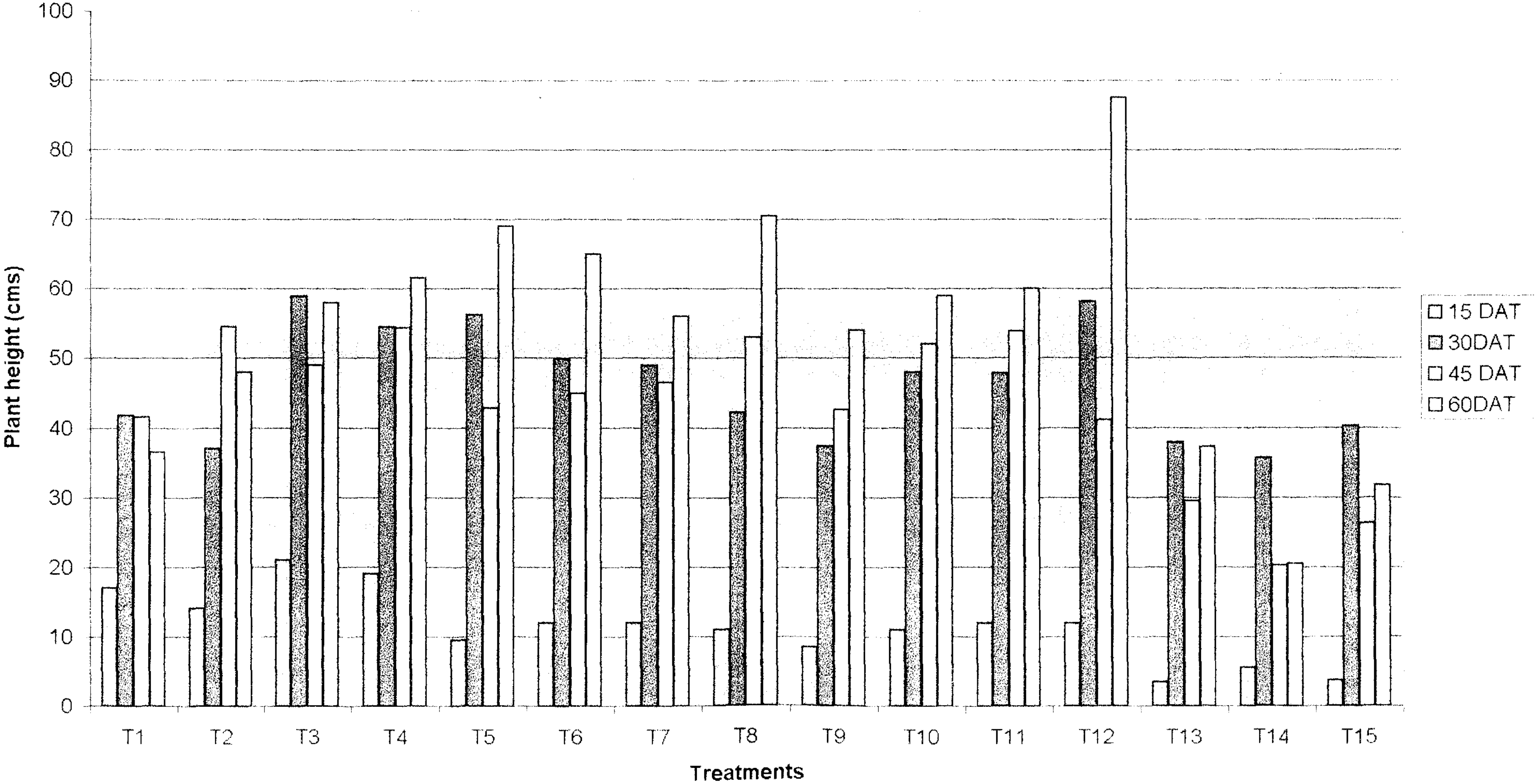


Fig. 5. Effect of biofertilizers and chemical fertilizer levels on plant height in amaranth variety kannara local



Dual inoculation of *Azospirillum* and AMF with 75 per cent POP gave highest plant height for both varieties at 60 DAT (Fig. 4 and 5). But it was on par with control treatments. Synergistic effect of arbuscular fungi along with *Azotobacter* has given highest plant height in mulberry (Gowda *et al.*, 1993). Even double increase in morphological characters was reported by dual inoculation in jute (Sharma and Mukherjee, 1995). (A+V+50 per cent POP) increased shoot length in both varieties in the early stages i.e. 15, 30 and 45 DAT.

At almost all growth stages 50 per cent level of POP and higher doses increased the value for plant height. Similar increase in plant height due to fertilizer application have been reported by Bressani *et al.,* (1987), Singh *et al.* (1985). Exception to this increasing trend was noted only at 45 DAT, where in maximum plant height was at 25 per cent level.

Though Arun showed significantly higher plant height at 15 DAT, Kannara local was taller than Arun at all later stages.

Among the three controls POP gave high value in plant height.

Azospirillum inoculation recorded increased leaf number at almost all stages. This result is in agreement with the findings of Parvatham *et al.*, (1989) in bhendi. *Azospirillum* with 50 per cent POP was found to be very responsive in variety Arun throughout the growth stages and in Kannara local at 45 DAT. Thus a saving of 50 per cent chemical fertiliser was realised, when biofertiliser was supplemented. (A+75 per cent POP) gave maximum number of leaves at 15 DAT for both varieties. An increasing trend was noted in this character with increasing level of nitrogen.

Fig. 6. Effect of biofertilizersand chemical fertilizer levels on number of leaves in amaranth variety Arun

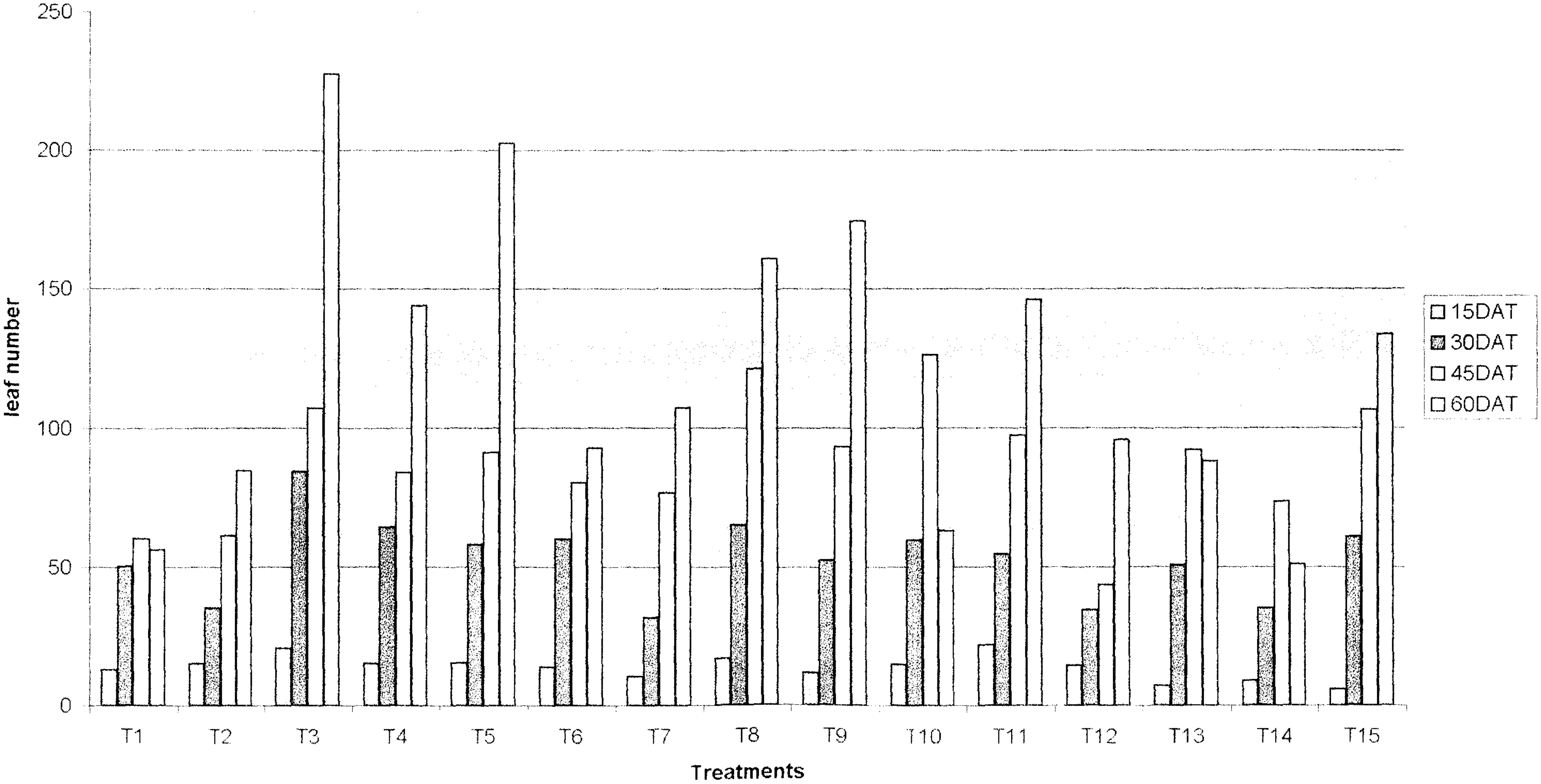
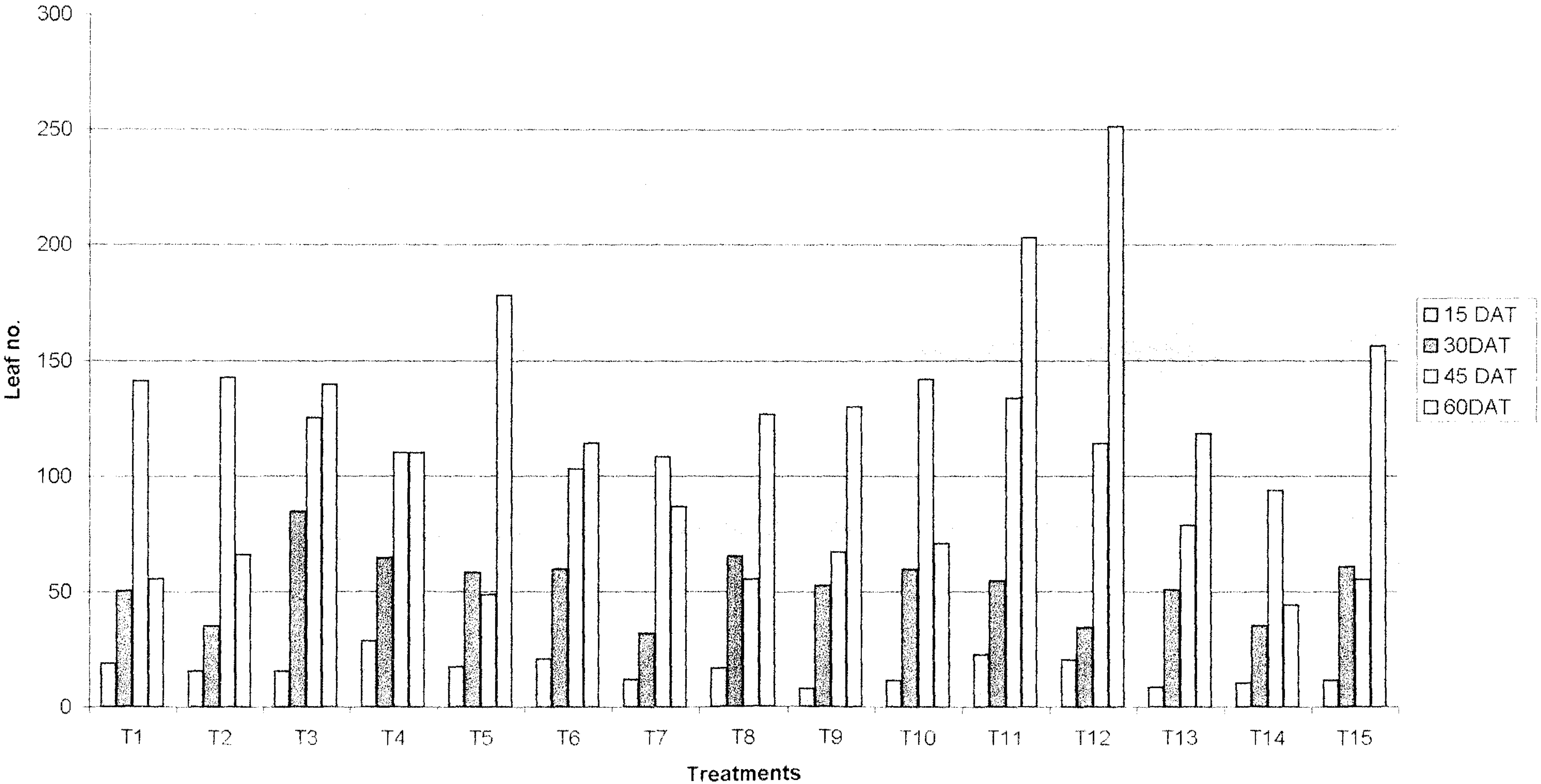


Fig. 7. Effect of biofertilizers and chemical fertilizer levels on number of leaves in amaranth variety kannara local



Nitrogen is the key nutrient for better vegetative growth and so higher levels would have promoted plants to produce more number of leaves. This is in accordance with the findings of Nawawi *et al.*, (1985) in amaranthus.

Though arbuscular mycorrhizal fungi was less effective to *Azospirillum* and dual inoculation in production of leaves at early stages, it was very effective at 60 DAT. Application of arbuscular mycorrhizal fungi alone was fairly responsive in variety Arun through out the study. It gave a good response in Kannara local at 60 DAT. VAM with 75 per cent POP gave maximum number of leaves in Arun at 45 DAT.(Fig. 6). Khaliel and Elkhider (1987) have obtained double the number of leaves in tomato transplants inoculated with AMF.

Dual inoculation though inferior to *Azospirillum* in early stages, gave best results at later stages of growth. Dual inoculation with 50 per cent POP was one of the treatment which was best in early stages in both the varieties. Thereafter it gave good results in variety Kannara local. Maximum number of leaves in Kannara local was recorded by the treatment dual inoculation with 75 per cent POP at 30 and 60 DAT. It gave good results even at 45 DAT. (Fig. 7).

The 50 percent level of POP recommendation gave notable values for number of leaves at all stages of growth. The height of plant (Table 2) and number of branches (Table 6) were also more for this treatment. This might have given the plant more number of leaves.

Kannara local recorded significantly more number of leaves at 15 and 45 DAT.

Fig. 8. Effect of biofertilizersandchemical fertilizer levels onthe number of branches in amaranth variety Arun.

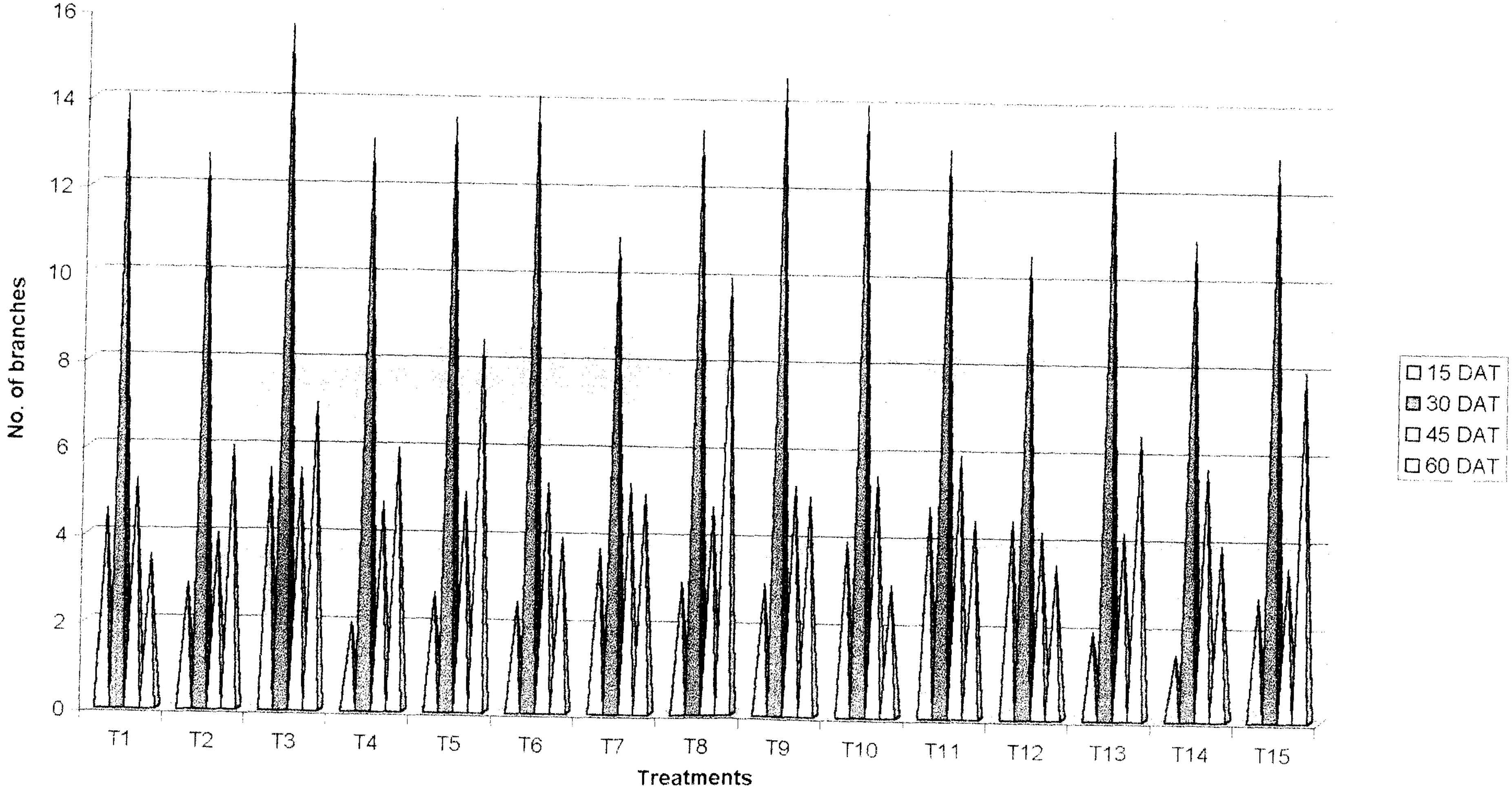
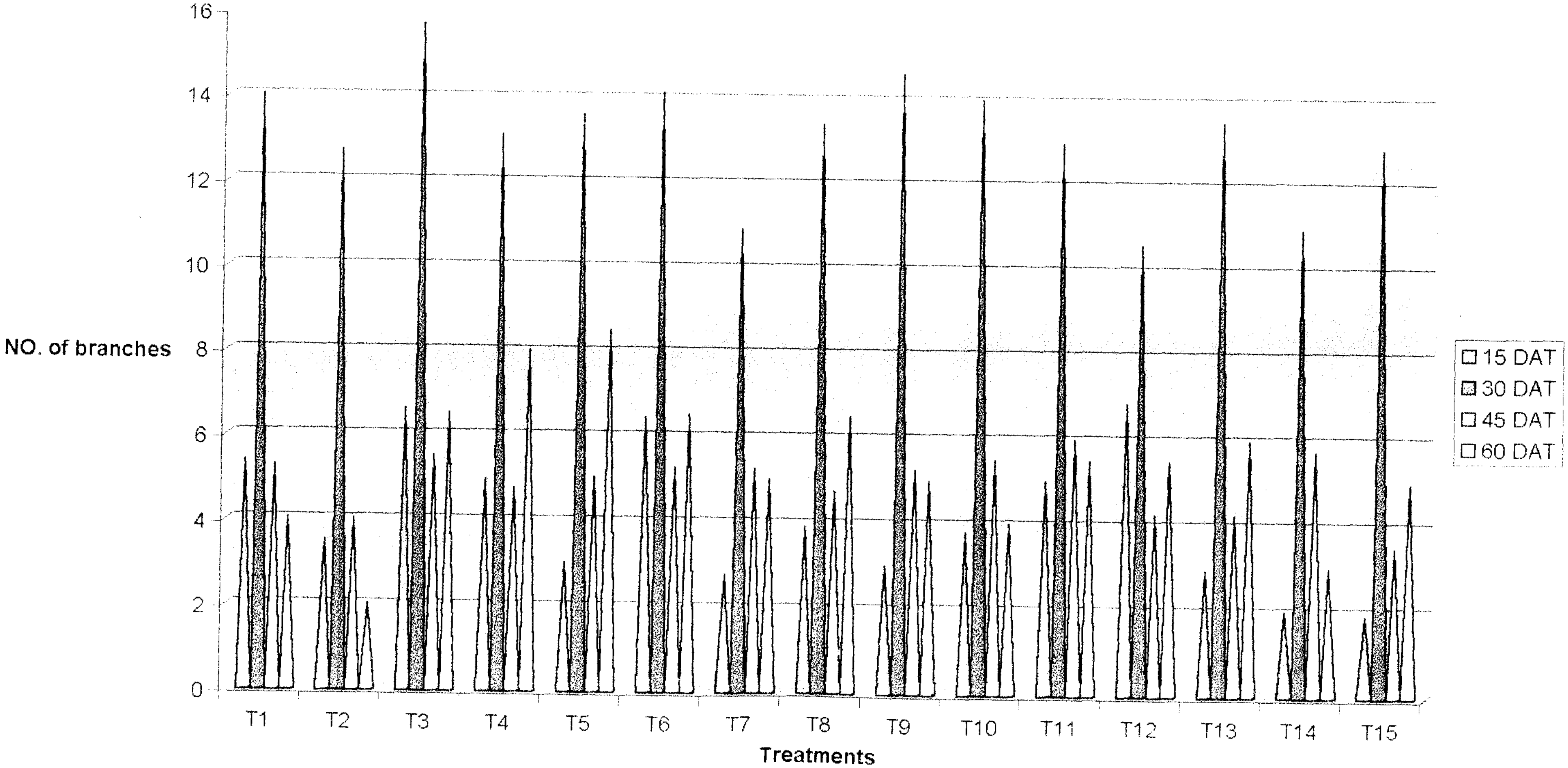


Fig. 9. Effect of biofertilizers and chemical fertilizer levels on the no. of branches in amaranth variety kannara local



Data presented in Table 6 revealed that application of *Azospirillum* recorded significantly higher values over AMF in the number of branches in the early stages. Paramaguru and Natarajan (1993) reported similar results in Chilli. (A+50 per cent POP) performed well throughout the study in both varieties (Fig. 8 and 9). Higher number of branches due to this treatment might have resulted in more number of leaves too.

AMF was found to be significantly superior at 60 DAT. At 15 DAT, it was inferior to other two biofertiliser treatments. It was on par with others at 30 and 45 DAT. Inoculation of AMF alone gave good performance in both the varieties at later stages i.e. at 60 DAT. The treatment (AMF+75 per cent POP) gave maximum number of branches in Arun at 60 DAT.

Dual inoculation was significantly inferior to sole application of *Azospirillum* and AMF after 2 months of transplanting. (A+AMF) faired well throughout. (A+AMF+50 per cent POP) gave good performance in both varieties throughout. (A+AMF+75 per cent POP) recorded maximum number of branches at 15 DAT, though it was inferior in next two stages. It faired well in Kannara local at 60 DAT.

Application of chemical fertilizer was significant only at 15, 45 and 60 DAT for number of branches. But At 45 DAT, 25 percent level was found best.

Kannara local had significantly more number of branches than variety Arun at 15 DAT. (Fig. 8 and 9)

Azospirillum recorded high LAI at 15 and 30 DAT. Hadas and Okon (1987) reported greater LAI in *Azospirillum* inoculated tomato seedlings. (A+50 per cent

POP) gave maximum LAI in Kannara local at 15 DAT. At 45 DAT, *Azospirillum* with 75 per cent POP faired well among treatments (Table 9). Plants subjected to *Azospirillum* inoculation might have been able to obtain more nitrogen from associated biological nitrogen fixation for growth and development, in addition to the applied nitrogen as reported by Miranda and Boddey (1987).

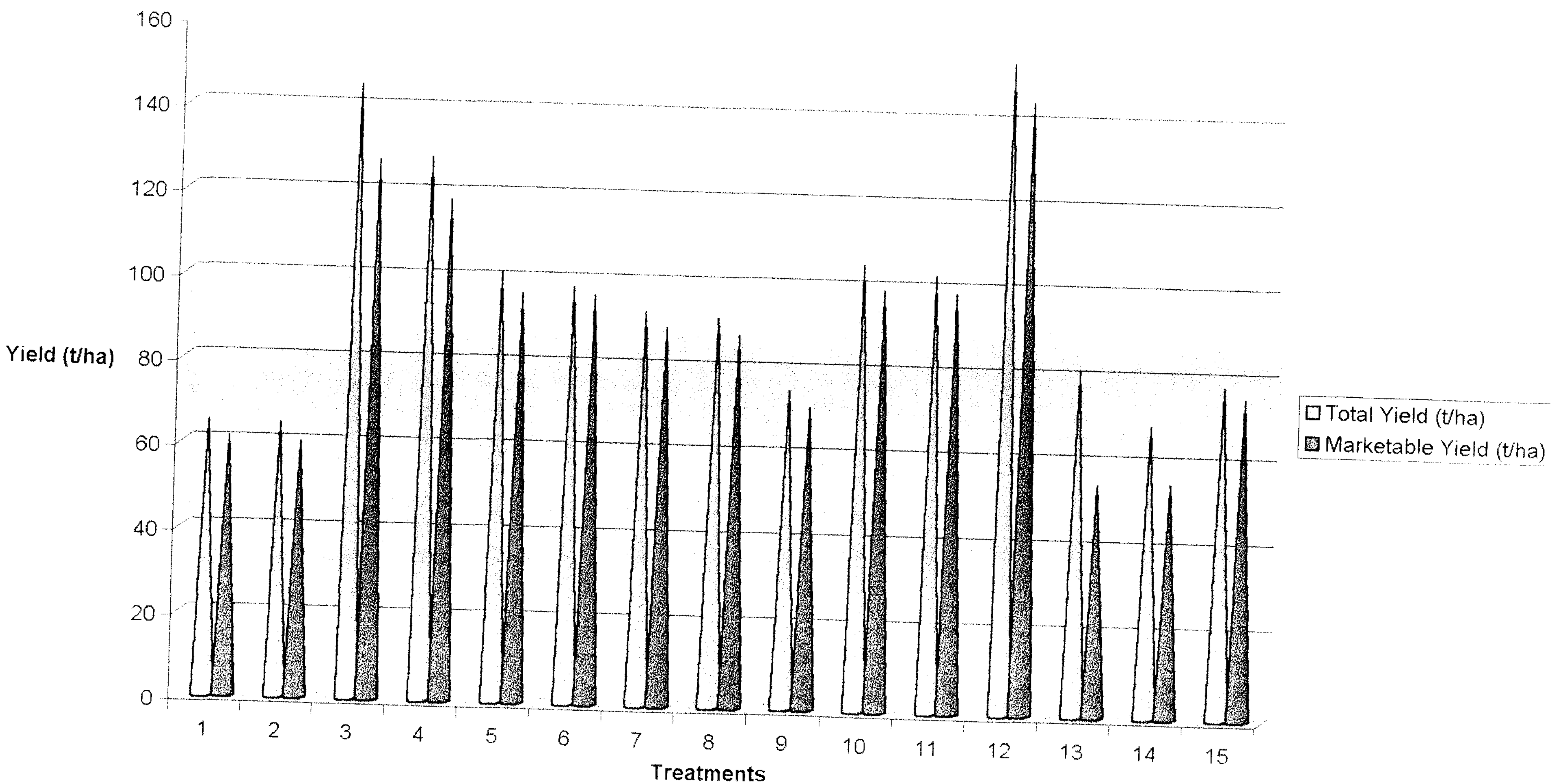
Dual inoculation gave best performance at 45 and 60 DAT. (A+AMF+50 per cent POP) gave maximum LAI in variety Arun at 15 DAT. Treatment, A+AMF+25 per cent and A+AMF+75 per cent were among good treatments.

It was seen that number of leaves and LAI increased with increase in level of fertiliser. There are reports of increased LAI as a result of extra protein synthesis due to increased nitrogen availability which promoted leaves to grow larger (George T., 1984; Jayakrishna K., 1986).

Application of higher levels of fertilizer increased LAI. This is evident from the data showing number of leaves (Table 4 and 5). Performance of varieties were on par. The control treatment vermicompost recorded notable LAI.

5.2 Yield and yield attributes

An appraisal of Table 12 indicated that dual inoculation registered more number of harvests than others. Among growth characters, number of branches were maximum for treatments involving dual inoculation at early stages. This treatment recorded maximum plant height and number of leaves at later stages of growth (Table 5). The stimulatory effect of *Azospirillum* due to the production of plant growth regulators and nitrogen fixing potential combined with excellent root system due to dual inoculation might have permitted prolonged harvest. AMF is known for greater soil exploration and improving nutrient uptake. Higher fertilizer levels permitted more number of harvests in amaranthus. Nitrogen promotes vegetative growth. In amaranthus where leaf and shoot portions are the economic plant parts, better fertilization gave better growth and yield. There was no significant difference among varieties. Maximum number of harvests was recorded for dual inoculation with 75 per cent POP. Number of harvests decreased with decreasing level of fertilizer in the case of dual inoculation. The synergistic effect of dual inoculation was evident in yield harvest^{-1}. Dual inoculation was significantly superior over other treatments at first and third harvests and gave maximum value in fifth cut. The positive effects of *Azospirillum* evident in early stages and AMF in later stages gave definite advantage to the crop. Improved nutrition, stimulatory effect due to IAA and GA might have promoted more vegetative growth at almost all harvests, giving increased cut weights (Table 12) when bio agents were given simultaneously. It is in corroborance with the results of Nagarajan(1989). Kumutha *et al.*, (1993) opined that *Azospirillum* enchanced root and shoot growth, number of leaves and growth of plants. Increased root growth might have favoured better mycorrhizal colonization. Dual inoculation gave significantly high root dry weight, plant height and number of leaves in this study too at later stages. So yield was found consistent to the growth character. Fertilizer levels had significant influence on leaf yield at later stages of growth. This was not evident in early stages due to consistent rain. The higher yield at higher nutrient level may be due to better plant height, more number of leaves and branches. Amaranthus being a leafy vegetable, the utility of primary nutrient element (NPK) in balanced proportion in recommended quantities is the prime and effective fig 10. Effect of biofertilizers and chemical fertilizer levels on the total yield and marketable yield of amaranth



way for boosting leaf production. The favourable influence of nitrogen on yield attributing characters can also be ascribed to the increased availability and uptake of nutrients required for the growth and development of plants. Significant increase in the yield of vegetative parts as a result of higher nitrogen levels was observed by several workers like in cabbage (Peck ,1981); in amaranth (Singh 1984).

Among the control treatments vermicompost gave good yield at first cut, but in second cut, POP was the best control (Plate 3 and 4).

Dual inoculation along with 75 per cent POP, *Azospirillum* along with 50 per cent POP and 75 per cent POP were found to be the best treatment at each harvest and in total yield. (Fig. 10) (Plate 5 to 10).

There was significant difference among treatments and control only at first harvest. Dual inoculation with 75 per cent POP and *Azospirillum* were the best treatments. Dual inoculation along with 75 per cent level of recommended chemical fertilizer and *Azospirillum* with 50 per cent level of recommended dose promised a considerable saving of chemical fertilizer. Better root system, nutrient uptake and activity of plant growth regulators gave better yield of the treatments. Since there was heavy rain soon after first harvest of the crop, the plants were subjected to flooding and hence there was incidence of leaf blight disease. So altogether the performance of the crop was poor. Though there was no significant variation among the treatments, *Azospirillum* with 75 per cent POP gave maximum value. The ability of *Azospirillum* for showing better growth mainly due to activities of plant growth regulators (Tien *et al.,* 1979) might have helped it to yield better than others. The performance of the crop improved in the next harvest. Dual inoculation with 75 per

PERFORMANCE OF AMARANTH VARIETIES OVER THE VARIOUS CONTROL TREATMENTS

PLATE 3

VARIETY ARUN

PLATE 4

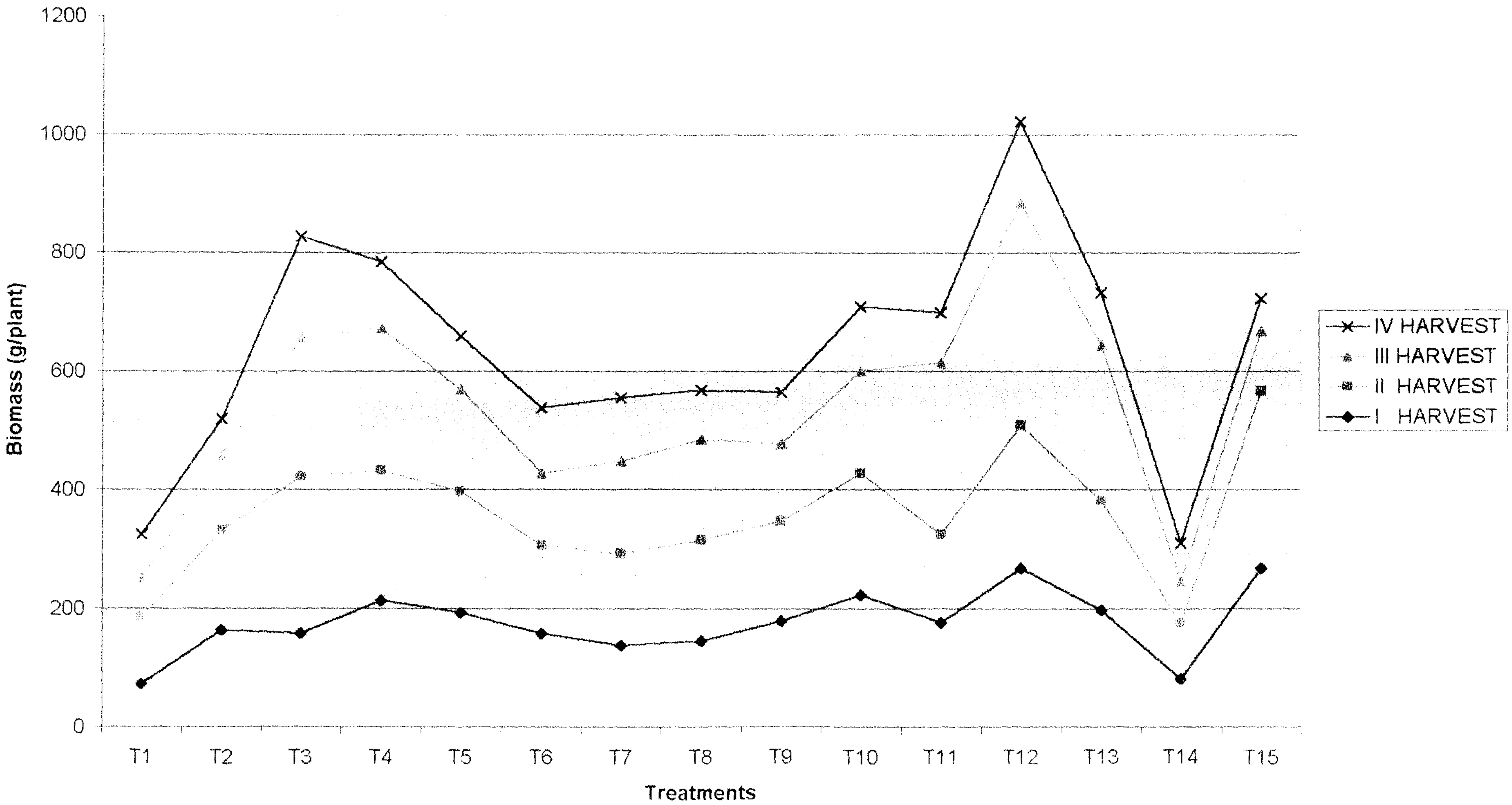
VARIETY KANNARA LOCAL

cent POP recorded an yield of about twice that of the best control namely POP recommendation. Economy in fertilizer application is evident even at third harvest. A crop of amaranthus grown for commercial purpose is economical only till third harvest and thereafter its fiber content increases and flushes lose its tenderness which reduces the market preference. Some of the treatments still showed good performance, especially dual inoculation with 25 per cent POP and 75 per cent POP, *Azospirillum* with 50 per cent POP and AMF with 75 per cent POP. But the improvement in yield was not significant over the control. Yield decreased after 90 days of transplant. But the treatment, dual inoculation with 75 per cent POP still gave 34.86 t ha^{-1} and *Azospirillum* with 50 per cent POP (29.51 t ha^{-1}).

A perusal of the data shown in Table 12, Fig. 10, revealed that in all the harvests and total yield, the best treatments were dual inoculation with 75 and 25 per cent POP, *Azospirillum* with 75 and 50 per cent POP. In general it was seen that biofertilizer inoculation and 50-75 per cent dose of the chemical fertilizer gave significantly superior yield or on par with package of practice recommendation. Variety Kannara local was significantly superior to Arun in total yield $harvest^{-1}$.

Scrutiny of the dry weight presented in Table 14 revealed that *Azospirillum* performed best at first two harvests. But as time progressed the better results were noted in treatments having AMF inoculation and dual inoculation. In commercial cultivation where in amaranthus is grown as single cut crop or when two cuts are taken, inoculation of *Azospirillum* alone gives good results. But in homesteads where plants are maintained for long and many cuts are taken, inoculation with AMF or dual inoculation is desirable. *Azospirillum* inoculation reported greater dry weight in pearl millet (Smith *et al.,* 1978). Tien *et al.,* (1979) opined that *Azospirillum* produced plant growth hormones in pure culture which in turn was responsible for growth response. Hubbel *et al.,* (1979) was also of the view that better plant growth in *Azospirillum* inoculated plant was due to nitrogen fixation and hormones produced by the bacteria. Increased dry weight of brinjal was reported by Bashan *et al.,* (1989) and in tomato (Dhanalekshmi and Pappiah, 1995). Saif and Khan (1977) reported increased dry matter production in AMF inoculated barley. AMF inoculated tomato transplants had greater dry weight (Khaliel and Elkhider, 1987) AMF inoculation has known to increase root biomass (Draft and Nicolson, 1969) and better nutrient uptake (Gray and Gerdemann, 1969; Swaminathan and Verma, 1977). Ability of AMF to overcome water stress by extending hyphae to bypass the dry zone has also been reported (Cooper,1984). All these might have contributed to greater dry weight. Though at early stages 25 per cent and 50 per cent POP were significantly superior, at later stages higher fertilizer level recorded more dry weight. Photosynthesis is the basic process for the build up of organic substances by the plants. The quantity of dry matter production will, therefore depend on the effectiveness of photosynthesis of the crop and further more on crops whose vital activities are functioning efficiently (Arnon, 1975). The LAI recorded (Table 9) also showed similar pattern. Greater leaf area allowed more photosynthesis. Kannara local reported significantly higher dry weight at early stages. Though it was on par in the next stages, variety Arun performed superior to Kannara local in the later stages. Among the control treatments vermicompost recorded higher values for dry weight at 30, 45 and 60 DAT and there after POP was found better. *Azospirillum* with 50 per cent POP gave maximum dry weight upto third harvest, and subsequently *AMF* gained prominence. In the next

Fig. 11. Effect of bio fertilizers and chemical fertilizer levels on the biomass of amaranth



stage *AMF* alone was best, while at 90 DAT, AMF along with 75 per cent dose was the best. The yield harvest^{-1} (Table 10) and total yield (Table 12) of the treatment was also high. *Azospirillum* gave a saving upto 50 per cent chemical fertilizer.

Dual inoculation and higher levels of chemical fertilizer gave maximum marketable yield. Though disease score (Table 35) gave high value both for dual inoculation with 50 as well as 75 per cent POP, it did not adversely affect market yield. This may be because of the high total yield (Table 12) of treatment which were about two times the yield recorded by POP. Kannara local had the problem of early bolting. So eventhough it was superior to variety Arun in total yield, it was on par with Arun in marketable yield. Vermicompost recorded notable marketable yield as it had very low incidence of leaf blight disease (Plates 11 and 12). POP recorded less marketable yield as it was more prone to *Rhizoctonia solani* (Plate 17 and 18). Dual inoculation along with 75 per cent POP and *Azospirillum* along with 50 and 75 per cent POP gave maximum marketable yield (Fig. 10, Plate 5 to 10).

5.3 Physiological parameters

Data on the physiological parameters of amaranth showed that dual inoculation recorded maximum biomass at almost all stages, but variation was not significant at any stage.(Table 16). Subba Rao *et al.,* (1979) reported that application of *Azospirillum* promoted root growth and more nitrogen fixation in plants which helped in increasing the biomass yield. Several researchers showed that *AMF* enhances plant growth as a result of improved mineral nutrition of the host plant and this has been confirmed with the use of isotopic traces (Barea, 1991). AMF are of particular importance for plant acquisition of phosphorus and other nutrients which are

PERFORMANCE OF AMARANTH VARIETIES INOCULATED WITH AMF AT DIFFERENT FERTILIZER LEVELS

PLATE 5

VARIETY ARUN

PLATE 6

VARIETY KANNARA LOCAL

PERFORMANCE OF AMARANTH VARIETIES
INOCULATED WITH *AZOSPIRILLUM* AT DIFFERENT FERTILIZER LEVEL

PLATE 7

VARIETY ARUN

PLATE 8

VARIETY KANNARA LOCAL

PERFORMANCE OF AMARANTH VARIETIES GIVEN DUAL INOCULATION AT DIFFERENT FERTILIZER LEVELS

PLATE 9

VARIETY ARUN

PLATE 10

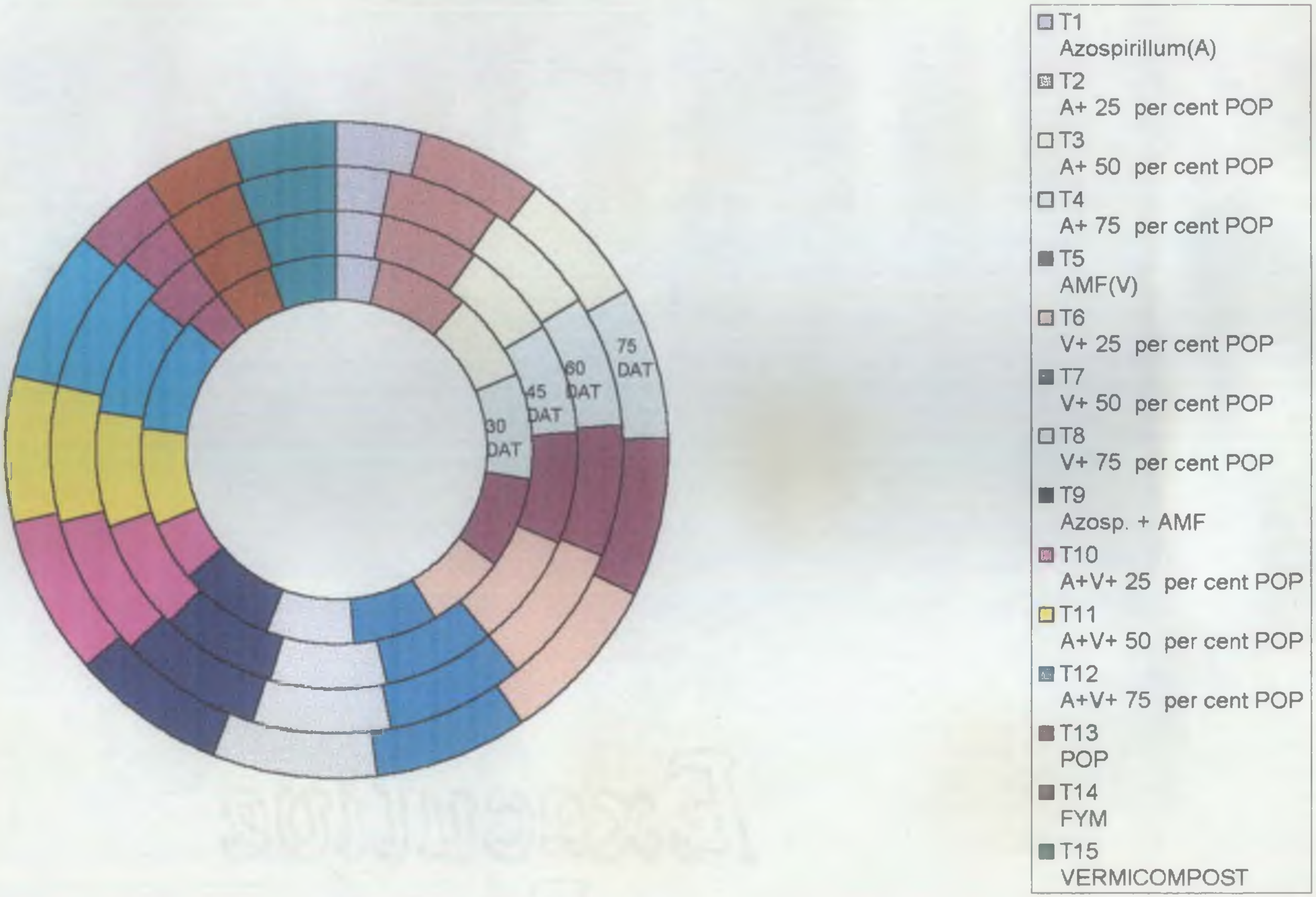
VARIETY KANNARA LOCAL

immobile in soil (Johnson *et al.*, 1993). Synergism due to dual inoculation might have resulted in consistently greater biomass of the treatment. Higher fertilizer levels always recorded higher weight of fresh plant but the variation was significant only at 60 DAT. Higher fertilizer level have reported better plant height, number of leaves (Tables 2 and 4) which have contributed to higher biomass. This is evident in yield studies too.

The two varieties performed on par in recording fresh weight immediately after harvest. The control treatment vermicompost recorded maximum biomass at early stages. This confirms the findings of Kale and Bano (1988). Bhawalkar and Bhawalkar (1993) reported better soil biology and better nutrition due to vermicompost. Dual inoculation with 75 per cent POP was the best treatment.(Fig. 11) *Azospirillum* with 50 and 75 per cent POP also recorded high biomass (Govindarajan, 1987). Jayaraman and Ramiah, (1986) have reported similar findings in forage crops.

Performance of dual inoculation of *Azospirillum* and AMF was good throughout the experiment in dry weight of the roots. Though *Azospirillum* gave good results after a month of transplanting, inoculation with mycorrhizae faired well in the later stages. After 2 months of tranplanting inoculation with AMF along with 25 per cent of dose of POP and 75 per cent dose of POP gave good results. The combined inoculation of *Azospirillum* and AMF increased root biomass (Nagarajan *et al.*, 1989) It is reported that growth substances produced by *Azospirillum* are continuously released from root surface into minor rhizosphere where *Azospirillum* grows with photosynthates supplied by autotropic host (Patriquin and Dobereiner,

Fig. 12. Effect of bio fertilizers and chemical fertilizer levels on the root dry weight of amaranth



1978, Diem and Dommergue, 1980). The growth regulators may affect the growth rate of the root (Thimann, 1972). The growth rate of roots inoculated with *Azospirillum* would influence the mycorrhizal infection (Gerdemann, 1968 and Harley, 1989). Kumutha *et al.,* (1993) noticed that inoculation of *AMF* in combination with *Azospirillum* enhanced shoot and root growth. The increase in root growth might have favoured the AMF colonization. Mycorrhizal occurrence in crop plants stimulated more of root proliferation (Bagyaraj and Manjunath, 1980). Osnubi (1994) reported that the total root length and root dry weight of maize was significantly increased by mycorrhizal infection. It was seen from the data that dry weight of roots per plant increased at higher levels of fertilization.(Fig. 12) Increased growth of top portion (Table 3, 5 and 7) due to fertilizer application have resulted in extensive root development and spread which might have resulted in higher root dry weight per plant.

It can be observed from the Table 22 that there was significant difference in leaf dry weight only at 45, 75 and 90 DAT. Though *Azospirillum* recorded highest dry weight, it was on par with AMF at 45 DAT. But at 75 and 90DAT, AMF gave significantly superior performance. Thus AMF faired well throughout. Geetha kumari *et al.,* (1990) reported that the number of leaves hill^{-1} of Ragi was positively influenced by mycorrhizal inoculation. Lu and Koide (1994) observed that in general mycorrhizal plants had greater leaf area, leaf weight and also more number of leaves. Tinker (1975) observed that mycorrhizal plants showed a marked increase in chlorophyll content of leaves when compared to uninoculated control. Higher pigment content might have resulted in more efficient tapping of solar energy for production of organic substances which resulted in greater dry weight.

Fig. 13. Effect of bio fertilizers and chemical fertilizer levels on the stem dry weight of amaranth at various stages

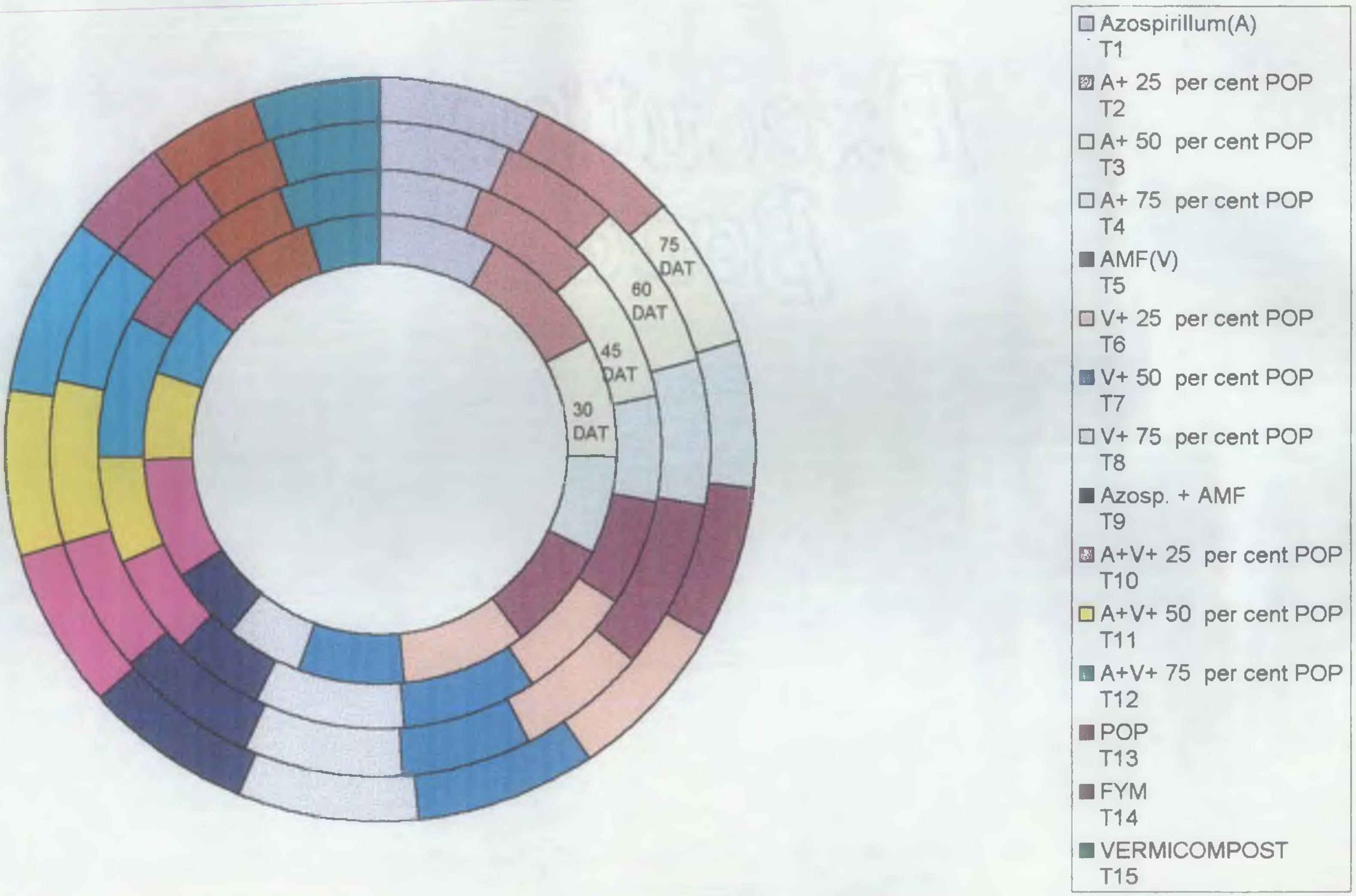
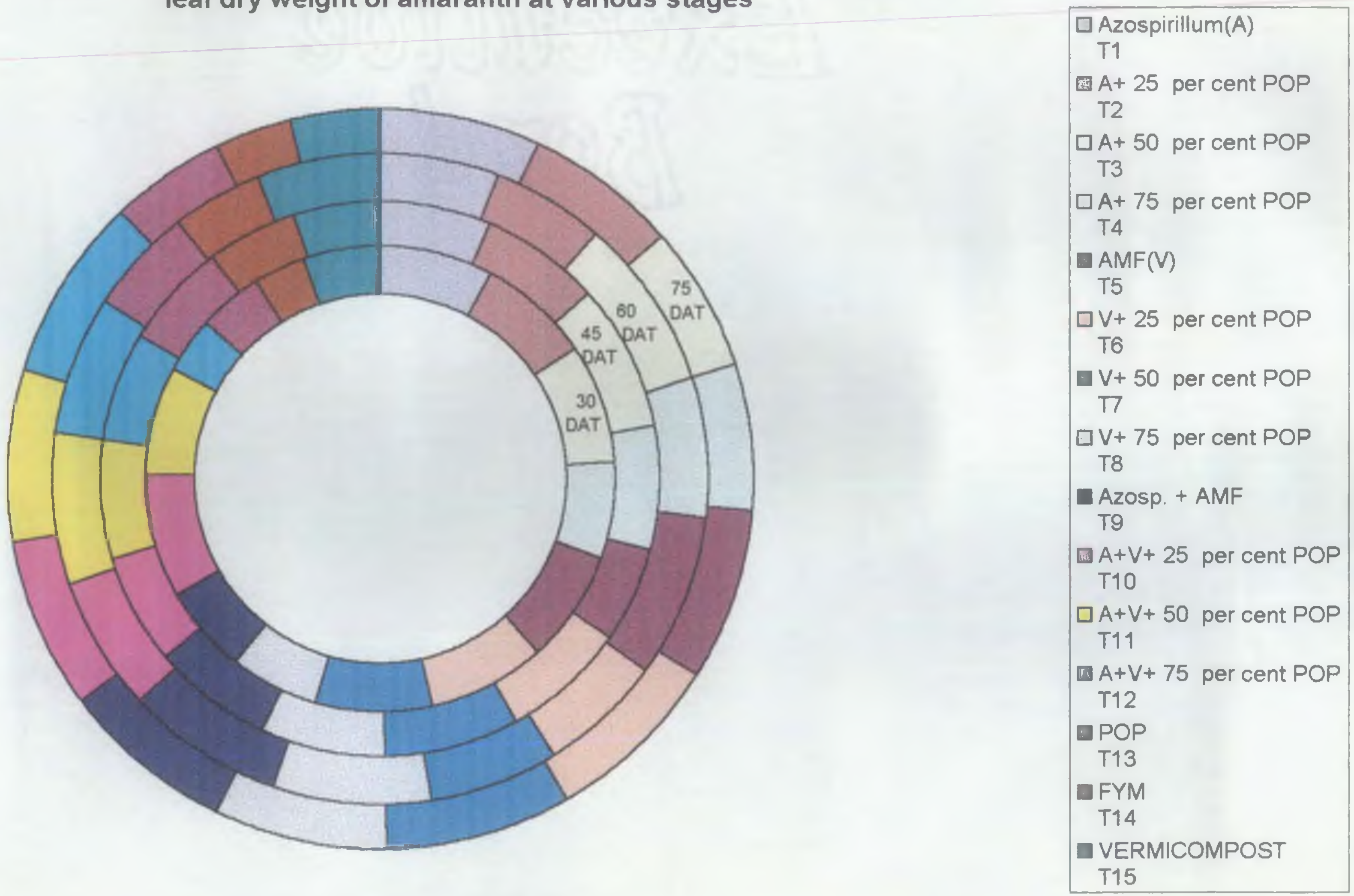


Fig. 14. Effect of bio fertilizers and chemical fertilizer levels on the leaf dry weight of amaranth at various stages



The 50 per cent level of POP was found significantly superior at one and a half month from the date of transplanting. This might be because of the better performance of bioinoculant at lower fertilizer levels. But with time, when crop has utilized nutrients for biomass production higher levels of chemical fertilizer gained the level of significance. Dual inoculation along with 25 per cent POP was found to be the best treatment . The positive effect of AMF in recording high leaf dry weight is discussed. Combination of inorganics with *Azospirillum* gave higher leaf production and expansion (Watanabe and Lin 1984), more dry matter production due to increased number of leaves and LAI (Karthikeyan, 1981).

Treatments involving AMF gave good results in increasing stem dry weight.(Table 20; Fig.13). 25 per cent level of POP gave notably good results at early stage. But later on higher levels of inorganic fertilizer gave higher response. In general very good results with treatment *Azospirillum* +50 per cent POP till 2 months from date of transplanting was noticed. *Azospirillum* increased the growth due to phytohormonal effect (Zimmer *et. al,* 1988) AMF with 25 per cent POP was found best at later stages after 60 days. Mycorrhizal plants performed better in infertile soils compared to non-mycorrhizal plants. This was studied in crops like corn, onion, clover, potato and strawberry (Sanders and Tinkers, 1971; Hayman and Mosse, 1972; Hughes *et al.,* 1979; Powell, 1979; Swaminathan and Verma, 1977). This effect was more evident in the present study wherein as top dressing stopped, only AMF faired well. Bagyaraj and Manjunath (1980) reported significant increase in root and shoot weight of cotton, cowpea and finger millet plants inoculated with *Glomus fasciculatum.* All the treatments in the present study was superior to all the control treatments at later stages. Kannara local gave significantly high leaf and stem dry weight during the early stages.

Examination of the data on net assimilation rate in amaranthus (Table 26) indicated that single inoculation with AMF and dual inoculation with AMF and *Azospirillum* significantly increased the NAR of amaranth. Dual inoculation gave significantly higher NAR at later stages, over other two biofertilizers given alone. This is clearly evident from the data on dry weight (Table 13) and leaf area index (Table 8) where dual inoculation gave good performance. Sharma and Mittra (1990) reported the beneficial effect of azospirillum in increasing the leaf growth. Greater dry matter production due to *Azospirillum* inoculation was reported by Karthikeyan, (1981). AMF inoculation was known to produce about twice dry matter (Gerdemann, 1965). Greater leaf area (Geethakumari *et al.,* 1990) might have acted in a complimentary manner in the plant.

At early stages higher fertilizer levels increased NAR significantly. But at later stages there was no influence on the addition of chemical fertilizer. NAR did not vary significantly between varieties. Highest NAR was recorded for the treatment. AMF with 75 per cent POP at early stage, but the treatment AMF alone gave highest value at later stage.

Bioinoculant *Azospirillum* gave significantly higher value for RGR over other treatments at early stage.(Table 26). At later stage it was on par with AMF and significantly superior to dual inoculation. *Azospirillum* is known to promote root hair development and branching (Kapulnik *et al.,*, 1983). Rao *et al.,* (1987) and Hegde and Dwivedi (1994) emphasised the phenomenon of nitrogen fixation by *Azospirillum* with improvement in the uptake of N, P and K. All these factors which are congenial for promoting growth might have increased RGR due to inoculation with *Azospirillum*. Lower levels of fertilizer was significant over higher levels in increasing RGR at early stage, while it was higher levels of inorganics which gave good performance at later stage. Kannara local was significantly superior to Arun during early stage, but the two varieties were on par in the later stages.

The treatment *Azospirillum* application alone performed best at early stage. *Azospirillum* along with 25 per cent POP gave maximum RGR at later stages. This result clearly showed the economy possible by the use of biofertilizer. The trend noted in RGR repeated in CGR too. *Azospirillum* was significantly superior to application of AMF alone and dual application at early stage. It performed on par with AMF at later stages. The 25 per cent level of fertilizer performed significantly superior throughout. CGR did not vary significantly among varieties. *Azospirillum* alone and *Azospirillum* with 25 per cent POP recorded highest CGR at early and later stages respectively.

Azospirillum gave highest leaf stem ratio during the early stages. Reason can be attributed to increased leaf number (Table 4) and leaf dry weight (Table 22). Thereafter dual inoculation recorded highest leaf stem ratio. This may be due to better LAI (Table 9) and NAR (Table 26) recorded by dual inoculation which gave greater leaf dry weight.

Lower levels of fertilizer performed well. There was no significant difference among varieties. It is interesting to note that vermicompost had high L:S ratio at all stages but it was comparable with POP. Stephens *et al.*, (1994) obtained significant increase in foliar concentration of N, P, K, Ca, Cu and Na and they attributed the enhancement to increased availability and uptake of nutrients from the soil. This might have contributed to higher ratio of leaf over stem in amaranthus. Dual inoculation alone, performed best at 30 and 60DAT. At 45 DAT dual inoculation with 25 per cent POP performed best.

5.4 Leaf quality

It can be deciphered from Table 28 and Fig. 15 that dual inoculation recorded higher moisture content but the difference was not significant. Higher moisture content was reported with higher level of chemical fertilizer. This finding is in corroborance with the work of Schuphan (1971) in spinach. There was no significant variation in moisture content among varieties. Dual inoculation with 75 per cent POP recorded maximum water content (88 per cent), about 4 per cent more than the control treatments.

Protein content of the leaves did not vary significantly due to various biofertilizer treatment. But higher levels of inorganic fertilizer had significant influence in the protein content. (Table 28, Fig. 16). Nitrogenous fertilizers are the major source of nitrogen to crop plants. Nitrogen thus obtained is metabolised via ammonium ions into glutamic acid. Carbon skeletons (Carbohydrates) provided by photosynthesis are incorporated in this process of amino acid synthesis. Glutamic acid is further converted to other amino acids which are stored as proteins. As noted by Capriel and Ashcroft, (1972) protein content increased with increasing levels of Nitrogen. There was no significant difference in protein content among varieties. POP recorded highest protein content. But it was comparable with all combinations

Fig. 15. Effect of bio fertilizers and chemical fertilizer levels on the moisture content of amaranth

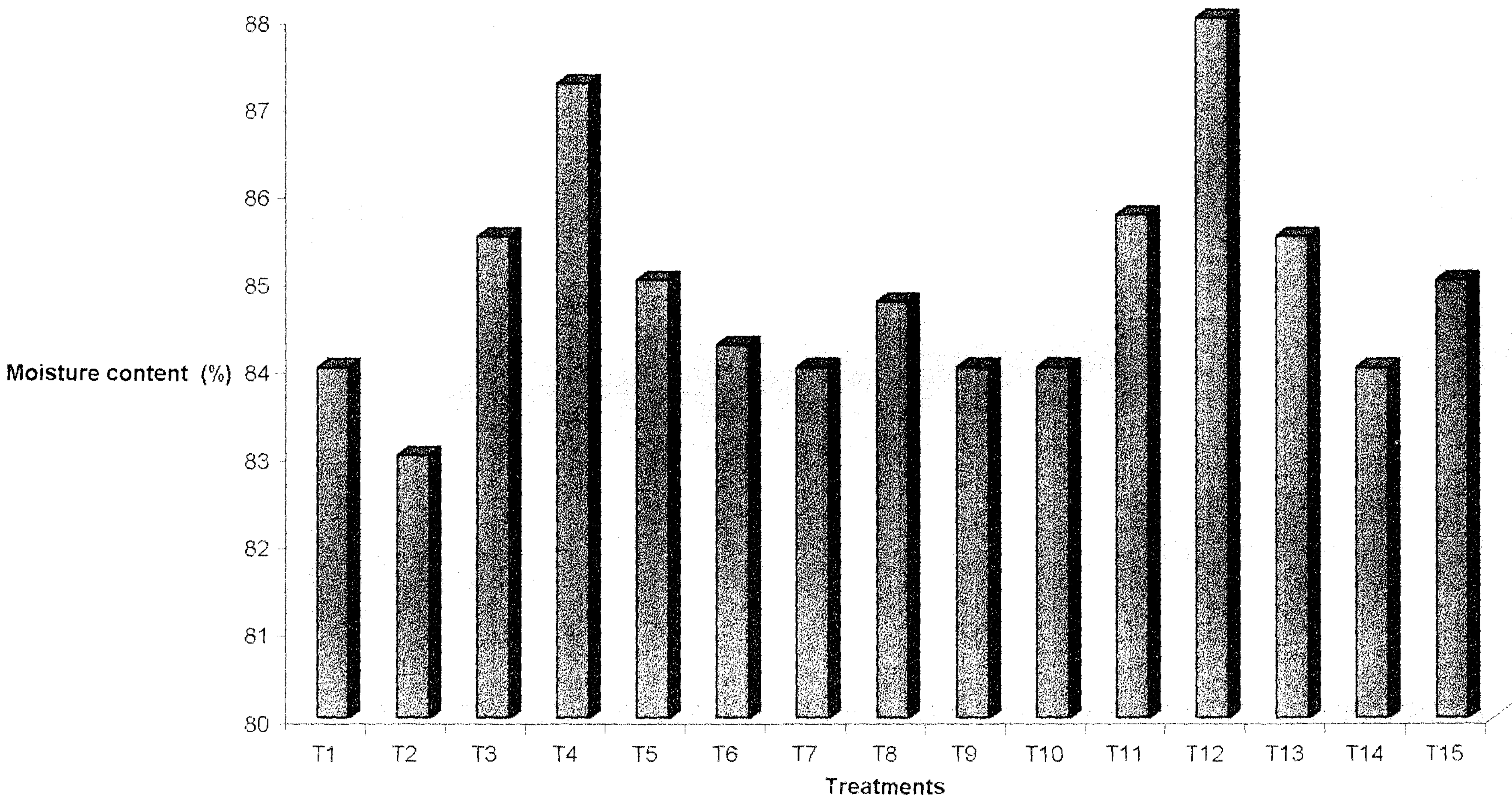


Fig. 16. Effect of bio fertilizers and chemical fertilizer levels on the protein content of amaranth

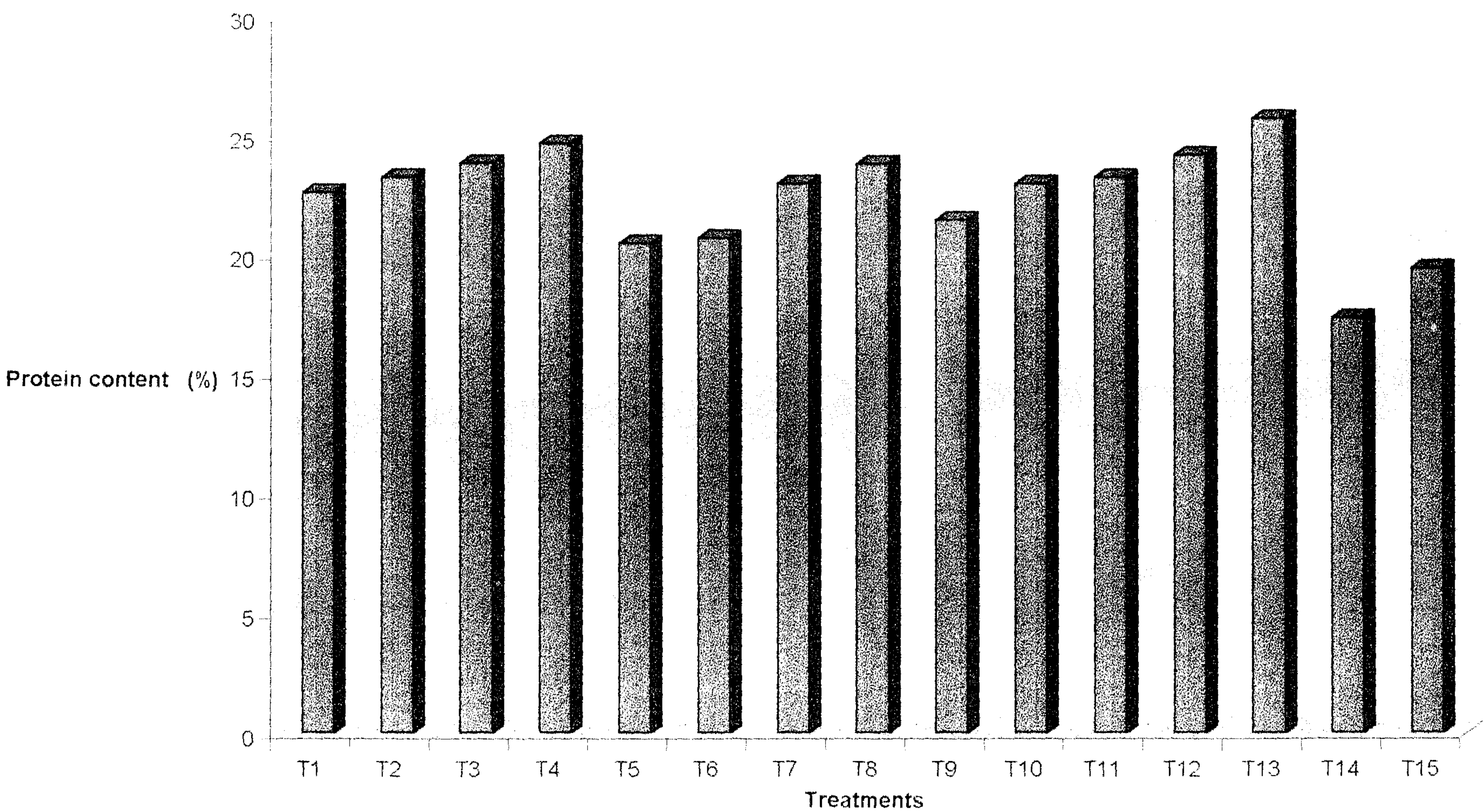


Fig. 17. Effect of bio fertilizers and chemical fertilizer levels on the fibre content of amaranth

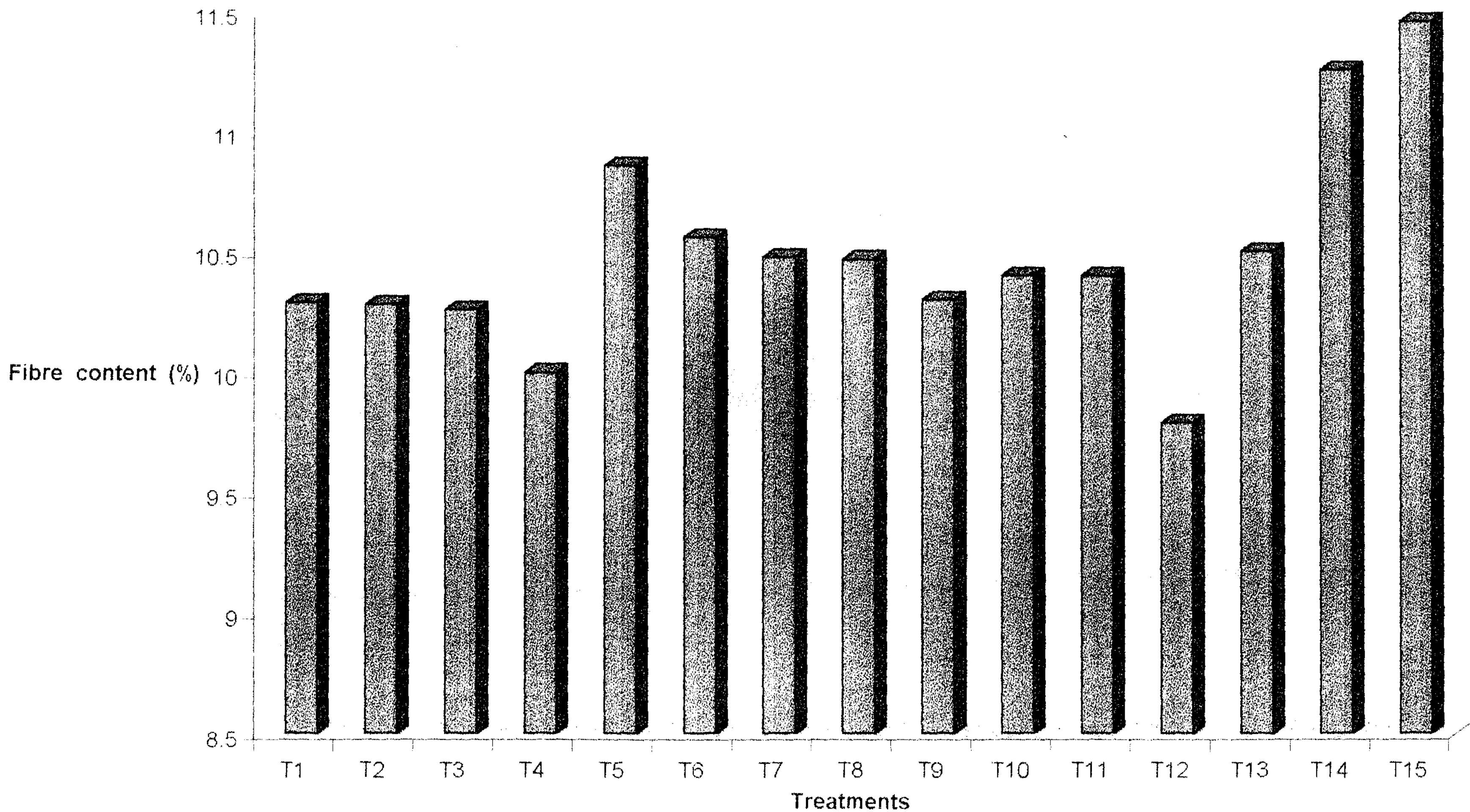
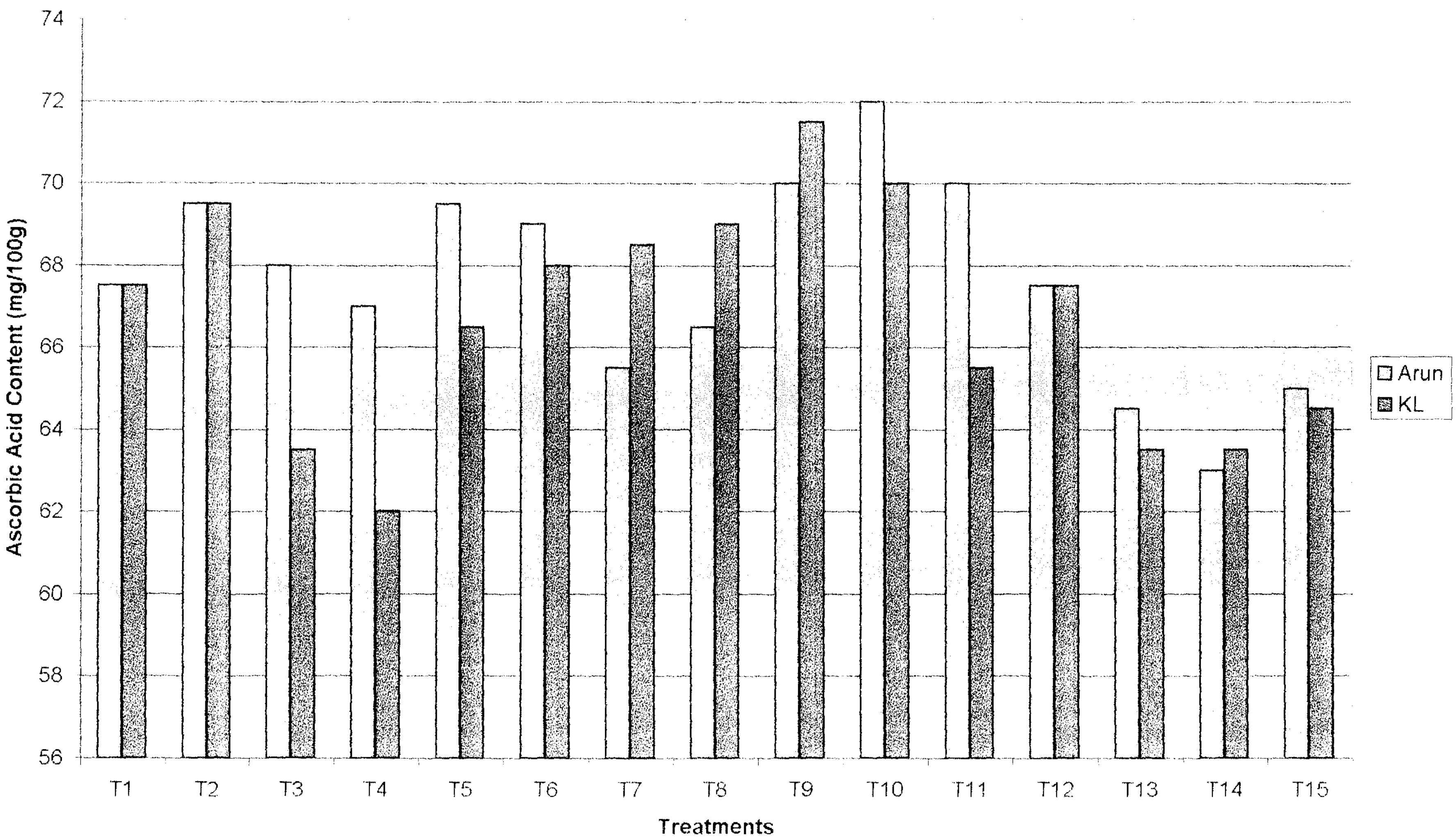


Fig. 18. Effect of bio fertilizers and chemical fertilizer levels on the ascrobic acid content of amaranth



of biofertilizer and 75 per cent POP. Though these treatments were on par with POP, it was significantly superior to other organic controls. Smith *et al.*, (1976) and Singh *et al.*, (1980) reported increased crude protein content due to *Azospirillum* inoculation.

Fibre content did not vary significantly with different biofertilizers and among varieties. Application of fertilizers had significant influence on the fibre content. Fertilizers at higher level decreased the fibre content, as inorganic nutrients increased succulence Mani and Ramanathan (1981) found that bhendi fruits had lower fibre content due to addition of more nitrogen. A decrease in fibre content with increased levels of nitrogen was reported by Pillai (1986) in guinea grass. *Azospirillum* with 75 per cent level gave minimum fibre content. Fibre content recorded by the treatment was less than 5 per cent of that recorded by control POP and 14 per cent less than that recorded by vermicompost. (Fig. 17)

It is seen that ascorbic acid was not significantly influenced by different biofertilizer or varieties. (Table 28) As the levels of inorganic fertilizer decreased, ascorbic acid content showed an increasing trend. A significantly higher value of ascorbic acid, about 5 per cent more was reported for ¼ POP and no chemical fertilizer compared to higher levels. This is in accordance with works of (Phebe, 1998) in snakeguord. Maximum ascorbic acid content among control for both varieties was obtained for vermicompost. Dual inoculation excluding chemical fertilizer and with 25 per cent POP gave maximum content of vitamin C for both the varieties. The ascorbic content was 10 per cent more than in control vermicompost (Fig. 18)

Fig. 19. Effect of bio fertilizers and chemical fertilizer levels on the mineral content of amaranth

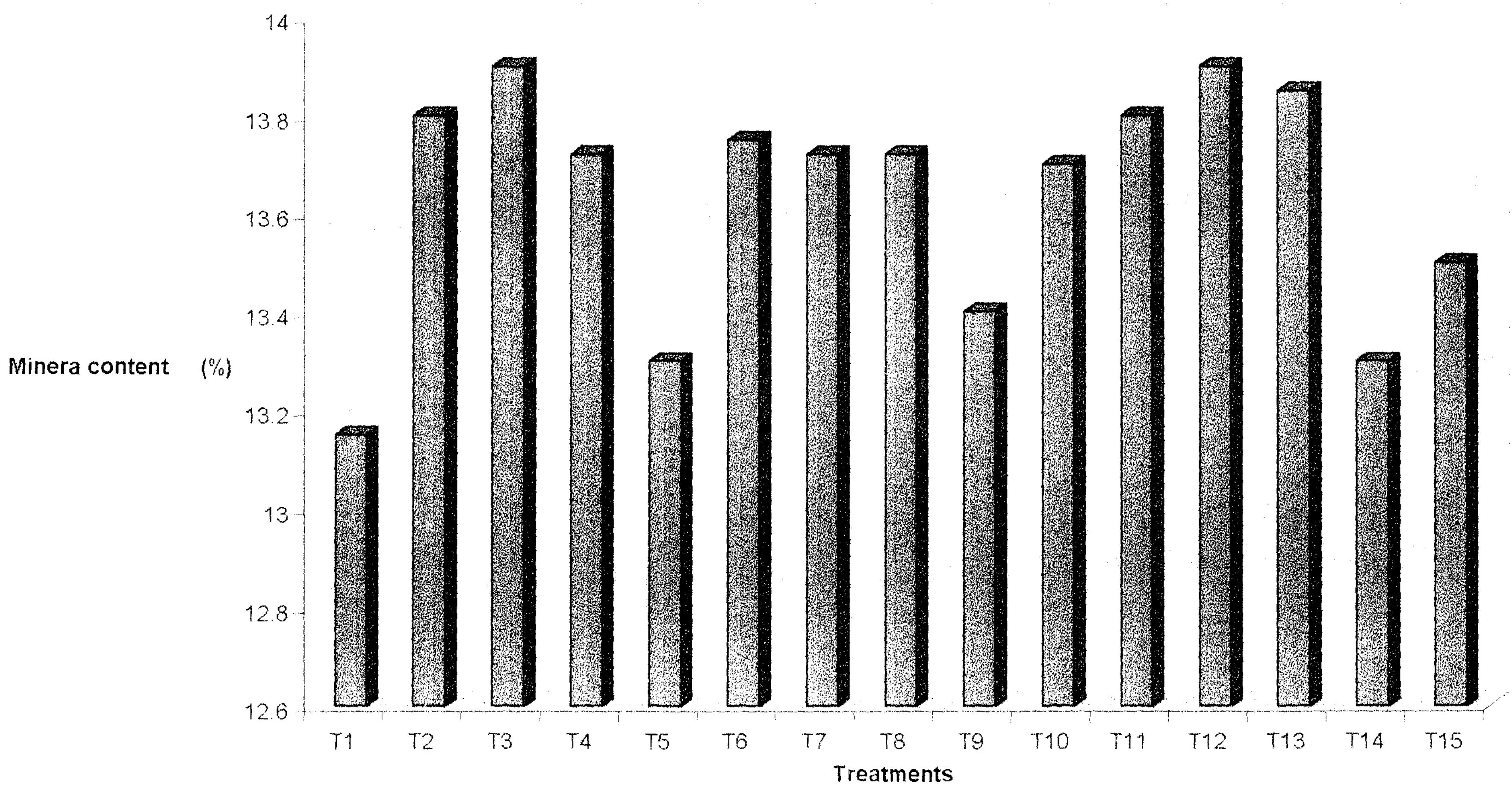
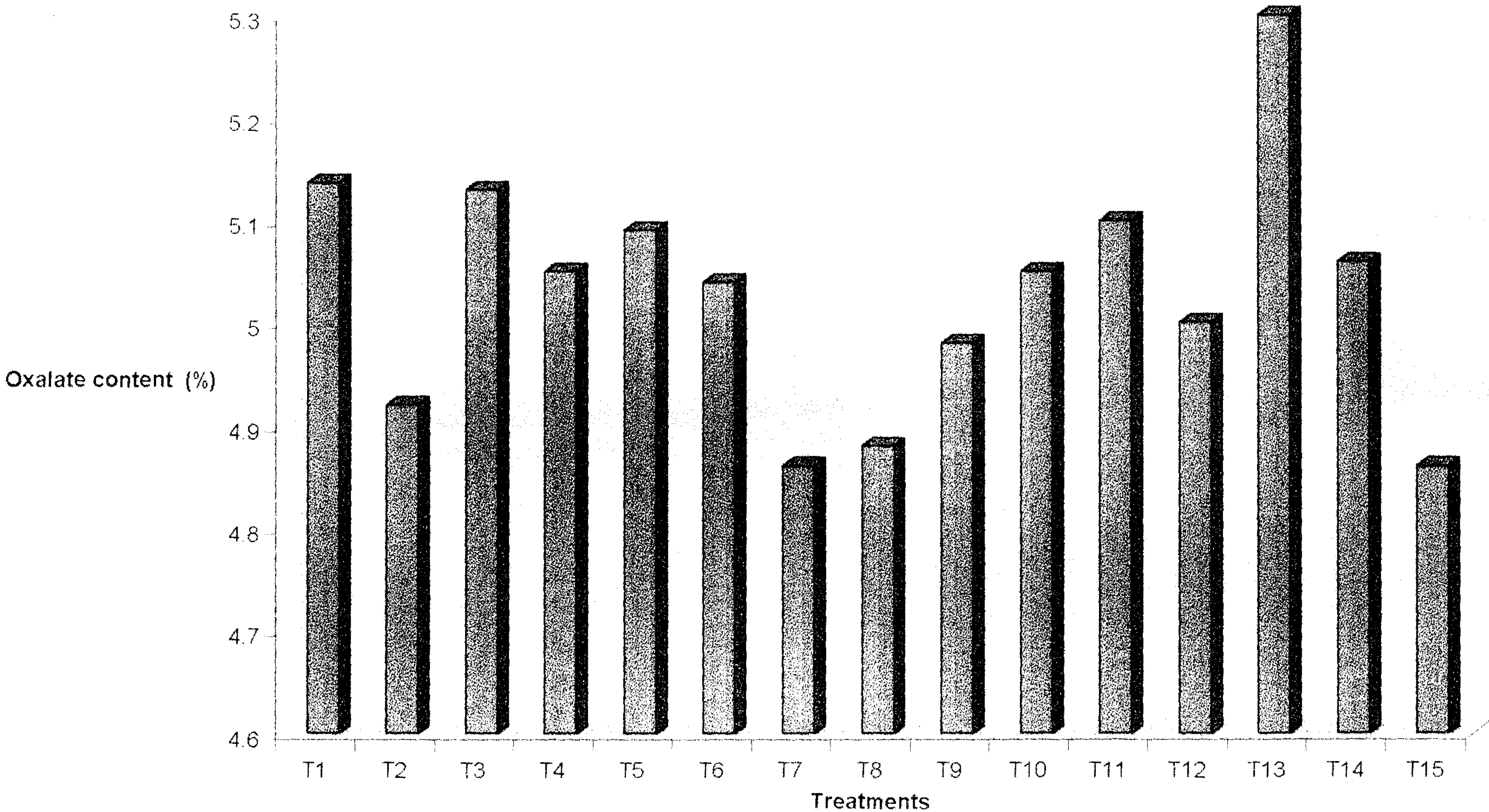


Fig. 20 Effect of bio fertilizers and chemical fertilizer levels on the oxalate content of amaranth



Variation in mineral content was not significant with application of different biofertilizers. Nutrient levels had significant influence on total mineral content. The higher levels of fertilizer namely 25, 50 and 75 per cent POP was significantly superior to no fertilizer application. Total mineral content was about 4 per cent more for POP than FYM. This variation was registered as significant. Dual inoculation with 75 per cent POP and *Azospirillum* with 50 per cent POP gave total mineral content of 13.9 per cent, a value very close to POP (13.85 per cent). (Fig. 19). Nutrient uptake was significantly higher with 50 per cent inorganic nitrogen along with *Azospirillum* (Hemalatha, 1998) Higher nutrient uptake might have resulted in higher ash content

The content of oxalate did not vary significantly with different biofertilizers and with varying levels of fertilizers. But there was significant difference in its content among varieties. Variety Arun had more content of this undesirable principle. Vermicompost recorded lowest value of oxalate (4.86 per cent) among control. AMF with 50 per cent POP gave least oxalate content (4.86 per cent). (Fig. 20). It was on par with all treatments except application of *Azospirillum* alone and *Azospirillum* with 50 per cent POP and POP in the control treatments.

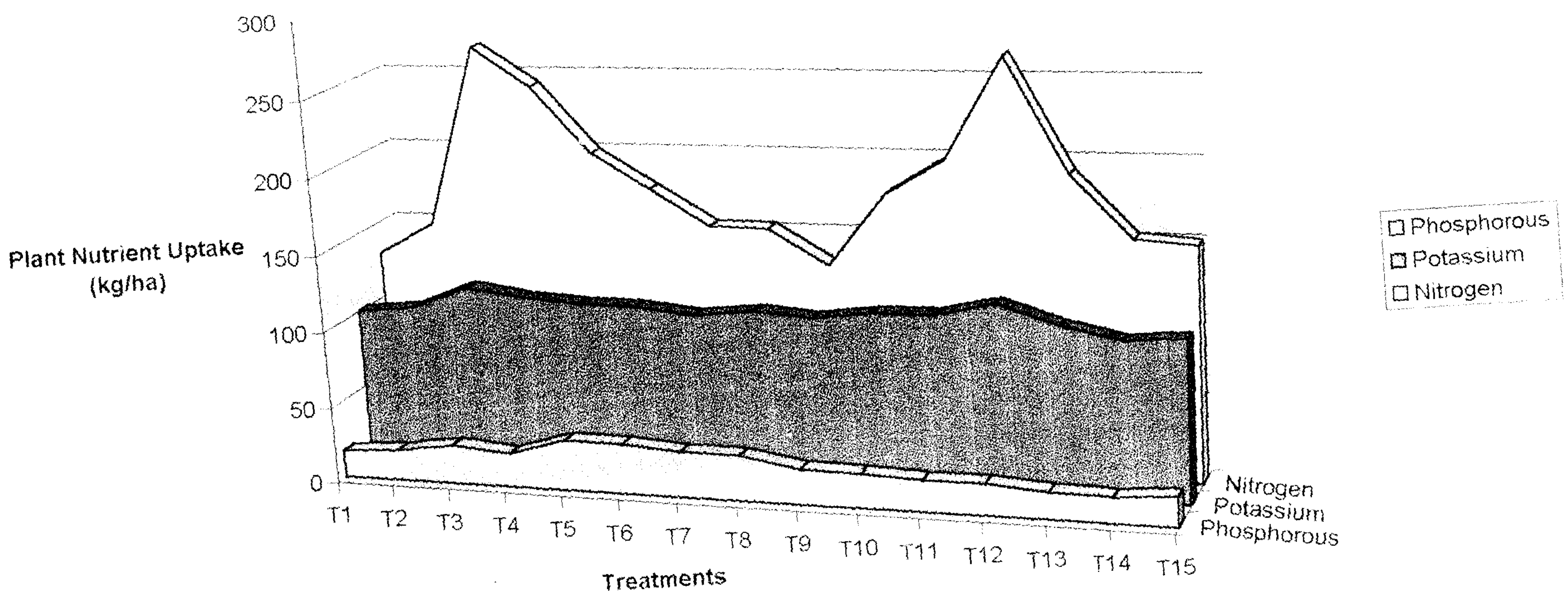
5.5 Uptake of nutrients

Examination of data on plant nutrient uptake (Table 32) revealed that uptake of nitrogen by the plants did not vary significantly with different bioagents. But *Azospirillum* gave maximum value. Application of chemical fertilizers at higher dose improved uptake of N. This is in agreement with the results of Tayel *et al.*, (1965) and Ravikrishnan (1989). There was no significant difference among varieties.

Azospirillum along with 50 per cent POP gave highest value of N uptake. (Fig. 21). Increase in plant nitrogen content with *Azospirillum* indicated the effects of inoculation on nitrogen fixation and more nitrogen assimilation by plants (Kapulnik *et al.* 1981; Baldani *et al.*, 1983; Pacovsky *et al.*, 1985; Pereira *et al.*, 1988). *Azospirillum* increased plant nitrogen uptake in mulberry without affecting leaf and nitrogen yield in leaves (Yadav and Kumar, 1991). Microscopic examination of roots of live maize and wheat inoculated with *Azospirillum* showed distortion in cortical cell arrangements indicating a weakening of natural adherence in cortical tissue of the inoculated plants thereby increasing mineral uptake by sponging effect (Sumner, 1989).

AMF significantly influenced the uptake of P (Table 32, Fig. 21). Gray and Gerdemann, (1969); Haymann and Mosse, (1971) and Sanni (1976) also reported similar findings in onion and tomato. Sanders and Tinkers (1971) observed that increased surface area due to mycelia network was primarily responsible for the enhanced uptake of phosphorus. Several investigators have opined that AMF were able to take up phosphate from soil solution with low phosphate concentration more efficiently than simple roots (Harley and Smith, 1983; Tinker and Gildon, 1983). 75 per cent level of POP was significantly inferior to no fertilizer application. Reduction in AMF effect with higher levels of soluble phosphate has been reported by Smith and Gianinazzi Pearson (1988). Mosse *et al.*, (1981) observed that AMF formation was favoured by low to medium fertility level. There was no significant difference among varieties in this parameter.

Fig. 21. Effect of biofertilizers and chemical fertilizer levels on the plant nutrient uptake (NPK) in amaranth



Significant difference was absent for plant K uptake by application of different fertilizers and due to varying levels of chemical fertilizer. Performance of varieties were also on par. Higher plant K was noted for dual inoculation with 75 per cent POP. Kumutha *el al.,* (1993) found increased root growth in plants having dual inoculation. Sharma and Mukherjee (1995) have noted root length of dual inoculated plants to be double that of single inoculation or in absence of inoculation. As uptake of K is mostly through root interception better the root system, the more is the uptake.

5.6 Soil nutrient status

The results of the soil analysis indicated that nitrogen content of soil after the experiment was significantly higher for dual inoculation of *Azospirillum* and AMF over AMF alone. Higher levels of chemical fertilizer increased significantly the soil nitrogen content after the experiment. Varieties Arun and Kannara local were on par. Dual inoculation with 75 per cent POP gave maximum value of soil N. Dual inoculated plants have excellent root system giving better residual nitrogen in soil. Application of *Azospirillum* might have promoted root growth and nitrogen fixation in plants (Subba Rao, *et al.,* 1979). Work of Ames *et al.*, (1984) indicated that AMF plant could derive nitrogen from sources less available to non-mycorrhizal plants. There is confirmed evidence that AMF tap soil nitrogen (Barea *et.al.* 1989 and Kucey and Bonetti, 1988).

There was significant difference in soil phosphorus after the experiment when different biofertilizers were used. Application of *Azospirillum* gave significantly more residual P over application of AMF and dual inoculation. Soil P increased with increasing level of fertilizer. Gray and Gerdemann (1969) have reported higher uptake of P by *AMF* inoculated plants. Jalali (1983) also obtained similar results. AMF fungal hyphae mops up more thoroughly phosphate ions dissociating chemically at particle surface (Hayman, 1983). AMF has also been reported to utilise phosphate fertilizer in a better way. This may be one of the reasons of low residual P in AMF inoculated plots.

Performance of *Azospirillum* was on par with that of AMF and it was significantly superior to dual inoculation of *Azospirillum* and AMF. Higher fertilizer level recorded higher soil K. Varietal performance was on par. Better growth due to dual inoculation increased potassium mobilisation by increased root biomass and percentage root colonization. Potassium is absorbed into plant system by contact (Tisdale, *et al.* 1985). Better root system in dual inoculation helped better contact of root with potassium promoting uptake resulting in low residual potassium.

5.7 Economics

The results of the economic analysis (Table 34) indicated that *Azospirillum* with 50 per cent POP gave maximum net returns, B:C ratio and return per rupee invested. It was 2.87, 2.28 and 2.7 times more than the corresponding figures recorded by the best control namely FYM. 50 percent savings of fertilizer may be there because of the nitrogen fixing potential of *Azospirillum.* Nitrogen fixing by grass bacterial association was confirmed in *Paspalum notatum* and *Digiteria decumbers* (De-Polli *et al.*, 1977). There are also estimates ranging from modest contribution of 8-13 per cent of plant nitrogen for *Papsalum notatum* (Boddey *et al.*, 1983; Boddey and Victoria, 1986) to a substantial input of 40 per cent in the case of *Brachiaria decumbens* (Boddey and Victoria, 1986).

Fig 22. Effect of bio fertilizers and chemical fertilizer levels on the gross and net income in amaranth

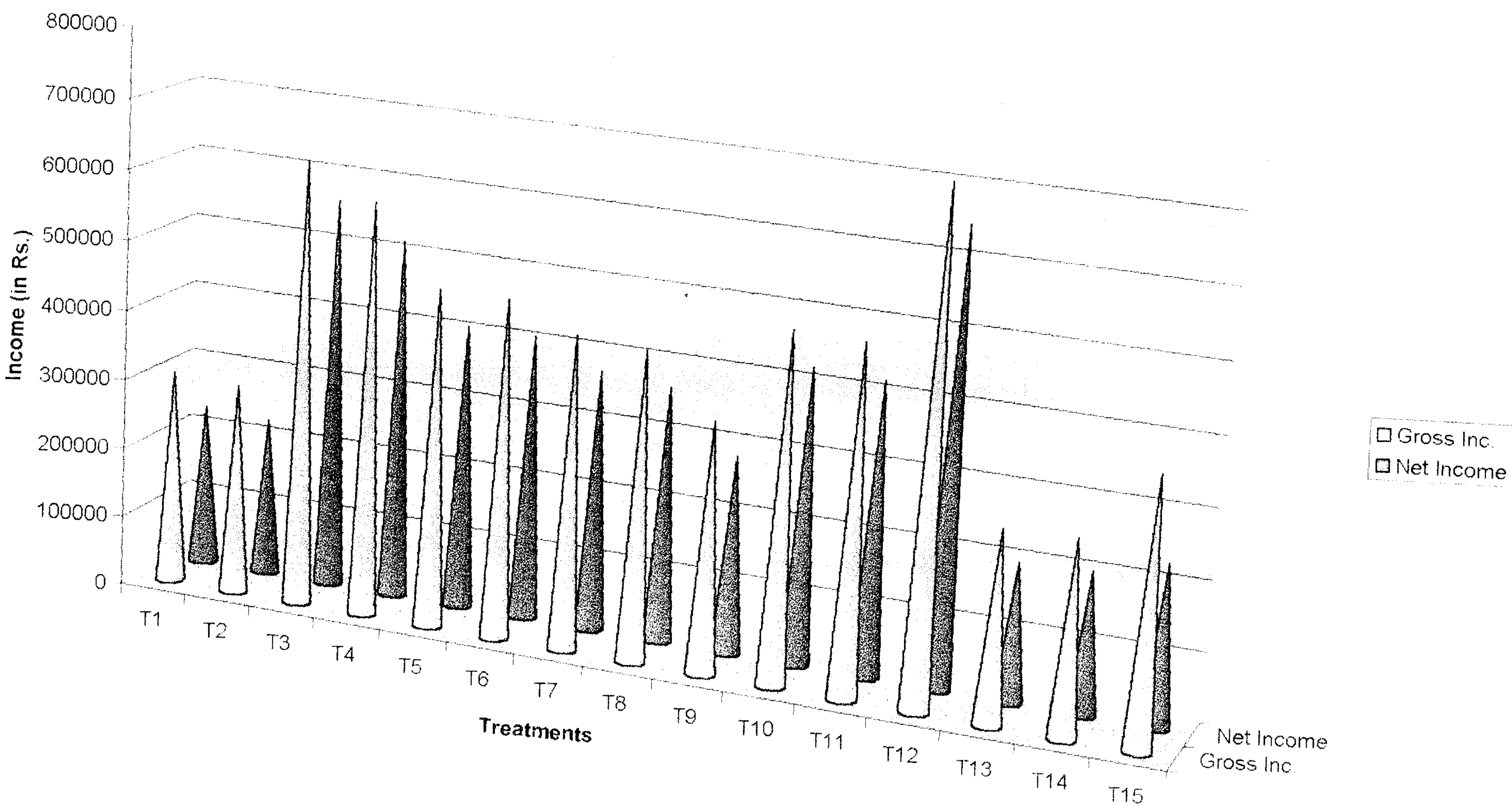
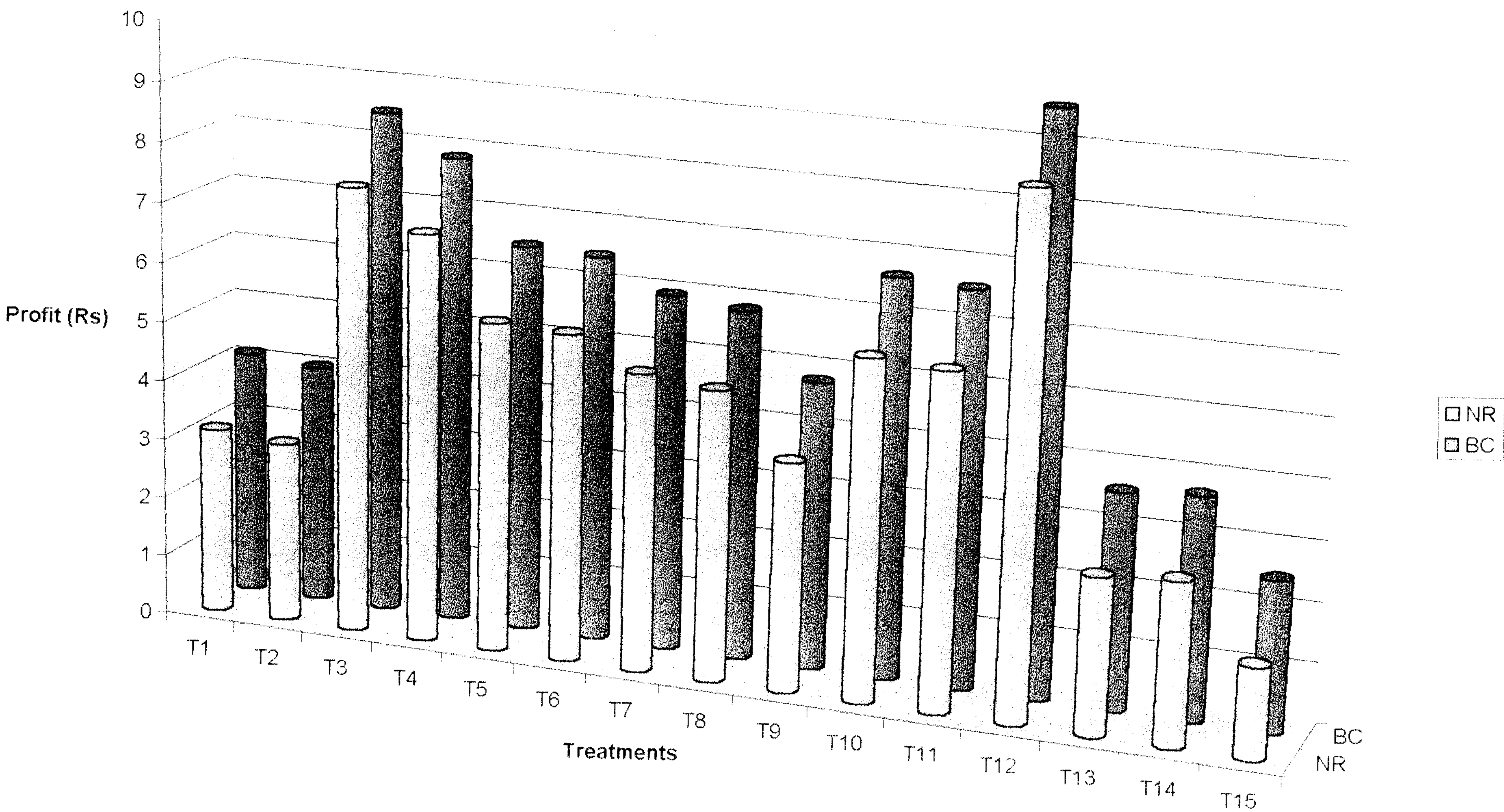


Fig 23. Effect of biofertilizers and chemical fertilizer levels on the net return per rupee invested and benefit cost ratio in amaranth cultivation



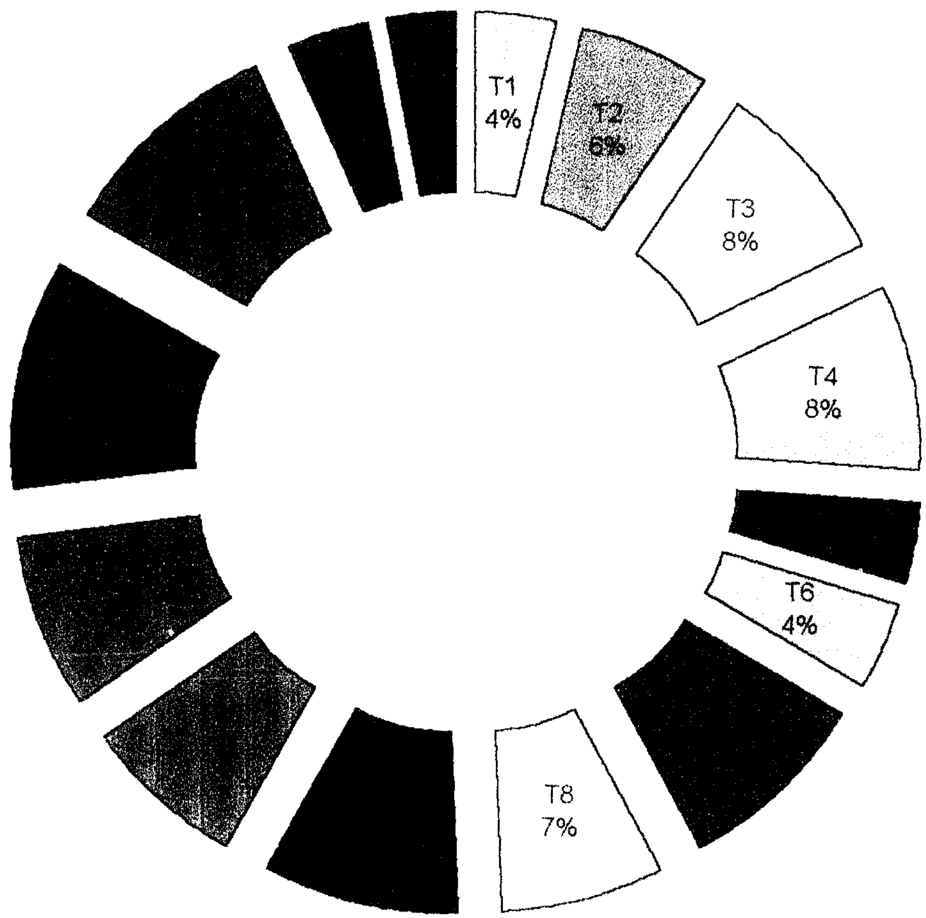
AMF inoculation performed the best. Its B:C ratio steadily declined with the addition of inorganic fertilizer. AMF recorded B:C ratio 1.75 times more than FYM alone. (Fig. 22 and Fig. 23). Mosse *et al.*,(1981) observed that AMF performed better under stress conditions and poor nutrient status of soil. AMF was favoured by low to moderate soil fertility levels. This is very evident from Plates 5 and 6.

Dual inoculation with 75 per cent POP gave highest net return, B:C ratio and net return per rupee invested. B:C ratio of dual inoculation and 75 percent POP was almost three times that recorded by FYM. High yield recorded by the treatment (Table 34) and savings of 25 per cent chemical fertilizer might have made it the most economic treatment. Of the three control treatments, net return was maximum for plots applied with vermicompost. But this treatment recorded net return of about three times that of best control in this regard. This may be due to the high yield obtained in vermicompost applied plots (Plate 3)

5.8 Disease score

Treatments having inoculation of VAM recorded low disease incidence (Fig. 24). Disease score was found to increase with increasing dose of chemical fertilizer (Plates 11– 18). There was no significant difference in this aspect between varieties. The low disease score of vermicompost was note worthy. It was lowest among all treatments studied.

Fig 24. Effect of biofertilizers and chemical fertilizer levels on the disease score (Laf Blight) in amaranth



LEAF BLIGHT DISEASE INCIDENCE IN
AMARANTHI VARIETIES TREATED WITH VERMICOMPOST

PLATE 11

VARIETY ARUN

PLATE 12

VARIETY KANNARA LOCAL

LEAF BLIGHT DISEASE INCIDENCE IN
AMARANTH VARIETIES TREATED WITH *AZOSPIRILLUM*

PLATE 13

VARIETY ARUN

PLATE 14

VARIETY KANNARA LOCAL

LEAF BLIGHT DISEASE INCIDENCE IN AMARANTH VARIETIES TREATED WITH AMF

PLATE 15

VARIETY ARUN

PLATE 16

VARIETY KANNARA LOCAL

LEAF BLIGHT DISEASE INCIDENCE IN AMARANTH VARIETIES TREATED WITH POP

PLATE 17

VARIETY ARUN

PLATE 18

VARIETY KANNARA LOCAL

SUMMARY

6. SUMMARY

The study entitled 'Effect of biofertilizers in amaranth (*Amaranthus tricolor* L.) was carried out at the Instructional Farm attached to the College of Agriculture, Vellayani during April-Sept 96. The main objectives of the study were to investigate the effect of bioinoculants like *Azospirillum* and Arbuscular mycorrhizal fungi on the productivity and quality of amaranth and to assess the possibility of economizing fertilizer nutrients by using these bioinoculants.

The trial was conducted as in split plot design with thirty treatments (Main plot treatments were combinations of biofertilizers (*Azospirillum*, AMF and dual inoculation of *Azospirillum* and AMF and four levels of chemical fertilizer (0, 25, 50 and 75 per cent POP) three control (POP, FYM and vermicompost), while sub plot treatment included two varieties (Arun and Kannara local). The main plot treatments were *Azospirillum* inoculation alone (T_1), *Azospirillum* + 25 per cent POP (T_2), *Azospirillum* + 50 per cent POP (T_3) *Azospirillum* +75 per cent POP (T_4), AMF alone (T_5) , AMF+25 per cent POP (T_6), AMF + 50 per cent POP (T_7), AMF + 75 per cent POP (T_8), *Azospirillum* +AMF (T_9), *Azospirillum* + AMF + 25 per cent POP (T_{10}), *Azospirillum* +AMF + 50 per cent POP (T_{11}), *Azospirillum* + 75 per cent POP (T_{12}), POP (T_{13}), FYM (T_{14}), Vermicompost (T_{15}). The 15 main plot treatments were tried for both varieties, in two replications.

The data generated were analyzed, presented in tables and discussed in the previous chapters. The findings of the study are summarised below.

1. Yield attributing characters viz number of harvests, yield harvest^{-1}, total yield, marketable yield were highest in dual inoculation with 75 per cent POP and

Azospirillum with 50 per cent POP applied plots. Dry weight was maximum in the plots with the latter treatment.

2. Biofertilizer along with 75 and 50 per cent POP gave saving of 25 to 50 per cent chemical fertilizer. The treatment had appreciable influence on the yield of the crop and it was comparable with POP.

3. Growth characters viz seedling growth rate, plant height, number of leaves, number of branches were maximum in plots inoculated with *Azospirillum* and 50 per cent of POP in the early stages while plots having AMF with varied fertilizer level performed best at later stages. LAI was most responsive to dual inoculation.

4. Physiological parameters were influenced by dual inoculation with higher dose of chemical fertilizer. Biomass, root dry weight, leaf dry weight and NAR recorded maximum value with the said treatment. Stem dry weight, was most responsive with AMF but dual inoculation also gave very good performance. *Azospirillum* performed well in the initial phase of the study while AMF catched on later. Control vermicompost was notable in recording fresh weight of the plant. Kannara Local gave good performance at early stages for leaf and stem dry weight.

5. Various biofertilizer along with 75 per cent POP showed definite advantage in all qualities discussed, except vitamin C. Dual inoculation with 75 per cent POP was best for getting maximum mineral and moisture content. Dual inoculation alone and with 25 per cent POP was best for highest content vitamin C. *Azospirillum* with 75 per cent POP gave least fibre content AMF with 75 per cent and 50 per cent was best for highest protein content and lowest oxalate content respectively.

6. Plant uptake of N improved with inoculation of *Azospirillum* and higher dose of fertilizer. But uptake of P enhanced with application of AMF alone or with lower dose of fertilizer. Biofertilizer and chemical fertilizer failed to show any influence on K uptake .

7. Residual soil nutrients were always higher at higher dose of chemical fertilizer. Soil N, P and K was maximum in plots which had dual inoculation, *Azospirillum* and AMF respectively.

8. B:C ratio and net returns were maximum for dual inoculation with 75 per cent POP and *Azospirillum* with 50 per cent POP. All the treatments fetched good profit.

9. Disease score increased with increase in dose of chemical fertilizer. Vermicompost notably gave low disease incidence.

From the results, it can be noticed that dual inoculation along with 75 per cent POP and *Azospirillum* inoculation along with 50 per cent POP gave marked increase in yield and quality. This offers considerable economy of fertilizer to the tune of 25 to 50 per cent of recommendation and a balanced low cost approach for vegetable cultivation.

APPENDIX

APPENDIX-1

WEATHER CONDITIONS DURING THE CROPPING PERIOD

(APRIL1996-SEPTEMBER1996)

Cropping period	Temperature(*C)		Mean R.H.(per cent)	Total rainfall (cms.)
	Max.	Min.		
April 1996	32.8	23.2	79.7	5.1
May 1996	33.2	23.9	74.9	5.1
June 1996	29.8	22.0	81.2	25.8
July 1996	28.6	21.5	83.2	17.3
August 1996	29.3	21.8	83.1	10.7
September 1996	30.1	23.2	82.5	16.2

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BIO FARMING IN VEGETABLES

i) EFFECT OF BIOFERTILIZERS IN AMARANTH (*Amaranthus tricolor* L.)

By

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ABSTRACT OF THESIS
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ABSTRACT

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An experiment was conducted at the Instruction farm attached to the College of Agriculture, Vellayani, during April – Sept 1996 with objectives of finding out the impact of biofertilizers *Azospirillum* , AMF and dual inoculation under varying and varied levels of fertilizer on amaranthus. Study also aimed to note the economics of the integrated approach and to identify the best economic combinations which improve yield and quality of amaranth varieties Arun and Kannara local. The study had three controls and two number of replications.

The results of the study revealed that yield attributing characters like no: of harvests, yield harvest^{-1}, marketable yield and dry weight were highest in plots applied with dual inoculation of *Azospirillum* and AMF with 75 per cent dose of POP. *Azospirillum* with 50 per cent POP also gave good results. Both these treatments were on par and was better than our state recommendation.

Growth characters viz. Seedling growth rate, plant height, number of leaves per plant, number of branches per plant, LAI were highest for *Azospirillum* inoculation at early stages. While AMF inoculation gave notable results at later stages.

Physiological parameters namely Biomass, NAR, Root dry weight were significantly improved with dual inoculation and higher dose of chemical fertilizer. Leaf dry weight, RGR and CGR responded most to inoculation with *Azospirillum* at early stages, while at later stage AMF performed well. Kannara local was superior to

Arun at early stages. But Arun performed superior to Kannara local with the progress of time. Stem dry weight was significantly influenced by application of AMF. Vermicompost gave high biomass till 45 DAT.

Quality of amaranth improved when biofertilizer was given with higher dose of chemical fertilizer in almost all parameters discussed. Dual inoculation with 75 per cent POP gave maximum content of total mineral and moisture. Ascorbic acid content was highest for the treatment dual inoculation with 25 per cent POP. AMF with 75 per cent POP recorded high protein content, the same bioagent with 50 per cent POP gave lowest content of oxalates. Less fiber flush of amaranth was got from plots given *Azospirillum* + 75 per cent POP.

Uptake of major nutrients namely N and P was influenced by inoculation of *Azospirillum* along with higher dose of chemical and AMF with lower inorganics respectively.

Major nutrient status in the soil after the experiment was more in case N,P,K for dual inoculation, *Azospirillum* and AMF respectively. Irrespective of biofertilizer higher dose of inorganic gave greater residual amount of nutrients.

Dual inoculation with 75 per cent dose and *Azospirillum* along with 50 per cent dose gave maximum B:C ratio and net returns.

Vermicompost recorded minimum disease score. Lower levels of chemical fertilizers recorded less infection.