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INTEGRATED NUTRIENT MANAGEMENT IN CASHEW IN RELATION TO YIELD AND QUALITY

By

K. E. USHA

THESIS

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Faculty of Agriculture
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Department of Agronomy
COLLEGE OF HORTICULTURE
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DECLARATION

I hereby declare that the thesis entitled "**Integrated nutrient management in cashew in relation to yield and quality**" is a bonafide record of the research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

College of Horticulture
Vellanikkara

USHA ,K.E.

CERTIFICATE

Certified that the thesis entitled **"Integrated nutrient management in cashew in relation to yield and quality"** is a record of research work done independently by **Ms. Usha, K.E.** 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.

Vellanikkara

Dr. R. Vikraman Nair
Chairman, Advisory Committee
Associate Director of Research
RARS, Vellayani

11-10-01

Dr. R. Vikraman Nair
Chairman, Advisory Committee
Associate Director of Research
RARS (Southern Zone)
Vellayani, Thiruvananthapuram

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Usha

USHA, K.E.

This thesis is humbly dedicated

to the lotus feet of

my GOD

without whose grace and blessings

this work would not have been possible

CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

LIST OF APPENDICES

Introduction

INTRODUCTION

Cashew (*Anacardium occidentale* L.) is one of the most important commercial crops of our country. Even though India accounts for 43% of the production in the global scenario, other countries like Brazil, Vietnam, major African countries and Indonesia have also come in the picture recently. Cashew occupies 7.20 lakh hectares with a production of 4.4 lakh tonnes and it meets only about 50% of the requirement of the country. It is absolutely essential to enhance the cashew production in the country to meet the requirements of the processing industry as the industrial demand for raw nuts by 2000 AD was estimated to be around 10 lakh tonnes (Balasubramanian, 1998). Since there is only limited scope in area expansion, an integrated approach in management strategy has to be worked upon to improve the present productivity of 835 kg nuts ha^{-1}.

Even though Kerala ranks first in cashew production (1.34 lakh tonnes) in India, the productivity is low (1140 kg ha^{-1}) when compared to Maharashtra (1570 kg ha^{-1}). It is highly essential to increase the productivity of this crop in our state to have the year round functioning of the processing units, which has a major role in our rural economy.

In Kerala, where large areas are occupied by plantation crops and tree crops, an understanding of litterfall, decomposition and nutrient release pattern is very much important because it has a significant role in maintaining the soil physical conditions and nutrient availability. Decomposition of litter provides the main source of energy and nutrients for soil microorganisms, and is a major pathway for the recycling of nutrients (Charley and Richards, 1983).

Biofertilizers occupy a very prominent role in sustainable agriculture. They are environment friendly and provide low cost agricultural input, thus playing a significant role in improving nutrient availability to the crop plants (Tilak and Singh, 1994). The significance of *Azotobacter*, the aerobic, nonsymbiotic nitrogen fixing bacteria, in crop production is quite known (Bharadwaj and Gaur, 1970). *Azospirillum*, an associative microaerophilic nitrogen fixer, commonly found in association with the roots of plants, has gained importance because the energy required for its metabolism is much less compared to that for other non-symbiotic diazotrophs. The high efficiency of nitrogen fixation combined with low energy requirements, easy establishment on plant roots and tolerance to high soil temperature exhibited by *Azospirillum* seem to make it an ideal bacterial fertiliser under tropical conditions. The beneficial effect of *Azotobacter* and *Azospirillum* are related not only to their nitrogen fixing efficiency but also with their ability to produce antibacterial and antifungal compounds and growth regulators (Pandey and Kumar, 1989) and improved soil organic matter content (Mishra *et al.*, 1991).

The role of Arbuscular Mycorrhizal Fungi (AMF) in plant growth and nutrient uptake, particularly phosphorus, in tropical P fixing soils is well documented (Tinker, 1975). Mycorrhizal infection can greatly stimulate the plant growth and development and increase the surface area for nutrient uptake, which enables the plant to extract nutrients from deficient soil system also. Phosphorus is a key nutrient for biological nitrogen fixing systems and hence, there is tremendous scope for introducing suitable strains of *Azotobacter*, *Azospirillum* and AMF especially in the perennial upland transplanted crops like cashew, where the AMF technology is highly feasible.

Since cashew is grown mainly in wastelands, the possibilities of exploiting the potentialities of biofertilizers as well as other management practices including efficient recycling of litter can be utilised best for improving the productivity. With this view in mind the present study was carried out with the following objectives:

1) estimating the quantity of litter produced in cashew plantations, its rate of decomposition and nutrient contribution
2) comparing the quantity and quality of litter in the fertilised and unfertilised cashew fields
3) evaluating the efficacy of different AMF fungi on the growth and nutrient uptake in cashew
4) knowing the extent of variation in the absorption of phosphorus by the mycorrhizal plants
5) studying the influence of *Azotobacter* and *Azospirillum* on cashew and
6) finding out the combined effect of *Azotobacter*, *Azospirillum* and AMF in cashew.

Review of Literature

REVIEW OF LITERATURE

The literature pertaining to the study has been reviewed under the following subheads:

2.1. Litterfall

2.1.1. Quantity of litter

Litterfall is an important pathway of flow of organic matter as well as nutrients from vegetation to soil. The major biogeochemical cycling processes are nutrient uptake by plants and its return by litterfall, stem flow and thorough fall (Switzer and Nelson, 1972).

Intensive studies on litter production in several agro and forest ecosystems had been carried out in many parts of the world (Bray and Gorham, 1964; Hopkins, 1966). Litterfall in a ten to forty year- old- cashew plantation ranged from 1.38 – 5.2 t ha^{-1} in Karnataka (Kumar and Hegde, 1999). Canopy biomass fallout of leaves, cashew apples and flowers and the subsequent nutrient release were estimated and nutrient balance sheets were developed by Richards (1992).

Beer (1988) studied the litter production and nutrient cycling in coffee and cocoa plantations with shade trees at Costa Rica and reported that 3700 coffee plants and 238 shade trees of erythrina contributed 17200 kg organic material ha^{-1} yr^{-1} and that 1111 cocoa plants and 278 shade trees of erythrina produced 6400 kg ha^{-1} yr^{-1}. The total annual litterfall was 5.3 t ha^{-1} yr^{-1} in the shaded field and 8.2 t ha^{-1} yr^{-1} in the open field of

cocoa in Kerala (Sreekala, 1997). Litterfall was maximum during December to March and minimum during the rainy season.

Opakunle (1989) in Nigeria investigated the distribution and cycling of nutrients in a 22-year-old cocoa agrosystem. The quantities of nutrients (kg ha^{-1}) returned annually through litterfall were estimated to be N 175.6, P 7.7, K 98.0, Ca 179.5, Mg 48.2, Fe 10.2, Cu 0.3 and Zn 0.4. Santana and Cabala (1983) reported that more than 8 t ha^{-1} of plant material fell on the soil within one year in a cocoa agrosystem. Santana *et al.* (1987) also evaluated the amount of plant residue and nutrients recycled annually in a cocoa plantation.

The annual addition of litter expressed as t ha^{-1} yr^{-1} ranged from 12-14 in moist deciduous forest ecosystems in Western Ghats of Peninsular India (Kumar and Deepu, 1992). According to Puri *et al.* (1992), leaf litterfall from a five-year-old *Leucaena leucocephala* occurred throughout the year but was highest in the dry season.

Litter production was estimated in *Albizzia lebbek* plantation under tropical to subtropical climatic conditions. The annual litter production was found to be 7.9 t ha^{-1} yr^{-1}. Two peaks were observed in the monthly production of litter, the highest one in winter during February and the second peak in summer during May (Varshney and Garg, 1996). A review of forest litterfall in India revealed that the mean leaf litterfall from trees of seven forest categories in India ranged from 3.4 - 6.9 t ha^{-1} yr^{-1} (Dadhwal *et al.*, 1997). The average annual litterfall in acacia plantations in Kerala ranged from 10.1 to 12 t ha^{-1} (Sankaran *et. al.*, 1993). It had a peak during December - January and a minimum in May.

The annual litterfall in tropical forests is estimated to range between 5.5 and 15.3 t ha^{-1} (Laudelot and Meyer, 1954; Williams and Gray, 1974). Annual litter addition by the major tree components in homesteads of Southern zone of Kerala amounted to

936.35 kg ha^{-1} (Mathew, 1993). The annual litter addition to the homestead from different trees was estimated as 384.64 kg ha^{-1} (Abraham, 1997). John and Nair (2000) estimated the leaf litter production by jack, mahagony, nutmeg, coffee, bamblimass, bread fruit and malay bush beech as 3.54,1.96,4.25,1.96,1.73,0.82 and 3.27 t ha^{-1}, respectively.

Shajikumar and Asokan (1992) estimated the quantity of litter produced by *Eucalyptus terticornis, Glyricidia sepium, Leucaena leucocephala* and *Ailanthus tryphysa* as 4059, 1751, 3323 and 1593 kg ha^{-1} yr^{-1}, respectively. Nair and Shrivastava (1985) compared the litterfall in plantations and natural stands and found that maximum litter measured was higher in the plantations than in the natural stands. Chaubey *et al.* (1988) reported that litter production was greater (1.5-2 t ha^{-1}) in teak plantation than natural forest.

In a study conducted by Nagaraja *et al.* (1996) in the Southern dry regions of Karnataka under varying systems, it was found that about 5-10 t ha^{-1} of biomass could be generated through mango, sapota and fodder trees. Viswanath *et al.* (1996) reported that jack tree contributed the maximum biomass of 4.7 t ha^{-1} yr^{-1} compared to the least (0.07 t ha^{-1} yr^{-1}) with hemmaralu (Silaras), being the shade tree in a cardamom plantation.

2.1.2. Nutrient content of litter

George (1982) emphasised the quantitative aspects of litter production as the most important due to its role in both energy and nutrient transfer in forest ecosystems. According to Das and Ramakrishnan (1985), litter on the surface acts as input - output system of nutrients.

The amounts of newly fallen plant residues and of material on the ground and their respective nutrient contents were evaluated in different agrosystems of cocoa in Brazil (Santana *et al.*, 1990). The amounts of residues and N, P, Ca, Mg, Zn and Mn contents varied among the plantations.

Khanna and Nair (1977) reported the output from leaves of a 30 year-old-coconut plantation as 33.1, 3.8, 13.4 kg ha^{-1} yr^{-1} of NPK, respectively, and 0.4, 0.1 and 0.3 kg ha^{-1} yr^{-1} NPK, respectively, from the spathe and rachis.

The inputs from litterfall of 3700 coffee plants and 238 shade trees of erythrina were 366 kg N, 30 kg P, 264 kg K, 243 kg Ca and 48 kg Mg ha^{-1} yr^{-1} (Beer, 1988). In another study, the inputs from litterfall of 1111 cocoa plants and 278 shade trees of erythrina were 116 kg N, 6 kg P, 40 kg K, 116 kg Ca and 41 kg Mg ha^{-1} yr^{-1}.

Pandey and Singh (1984) studied the nutrient release pattern of leaf litter in a Himalayan oak conifer forest. The total annual release of nutrients on the site through decomposition relative to the total input through litterfall amounted to 56% for N, 83% for Ca and 97% for water-soluble compounds.

The N contents in the leaves of six tropical species viz. Pterocarpus, Tectona, Xylia, Dillenia, Terminalia and Grewia were 1.7, 1.35, 1.61, 1.11, 0.92 and 1.6%, respectively and phosphorus content varied from 0.34 to 0.77% and K content from 0.25 to 0.62 %. The N content in the *Myrica gale* leaves was 1.85% (Schwintzer, 1984). The annual nutrient addition through litterfall from a cocoa plantation in Kerala was 109.7, 6.8, 104.2, 103.7 and 54.5 kg ha^{-1} N, P, K, Ca and Mg, respectively (Sreekala, 1997).

Singh (1969) reported that leaf litter of most species in deciduous forests at Varanasi is well supplied with mineral elements. In the order of preponderance, the

bases were Ca > Mg > K > P > Na. The N status of those species was generally low. Murthy *et al.* (1990) reported that the N contents in the leaves of siris, subabul and neem were 4.7, 3.2 and 2.6%, respectively.

The average concentration of nutrients in brown needles of *Pinus kesiya* were 1.45% N, 0.08% P, 0.86% K, 0.28% Ca and 0.15% Mg (Das and Ramakrishnan, 1985). The nutrient contents in *Eucalyptus obliqua* leaf litter were 5.2 N, 9.16 P, 0.6 K, 0.89 Na, 7.2 Ca and 3.0 Mg in terms of g kg^{-1} oven dry mass.

According to Mathew (1993), the input to the tune of 8.5, 2.0 and 6.4 kg ha^{-1} N, P and K, respectively, was contributed by the litter in a homestead of Southern zone of Kerala. Abraham (1997) worked out the annual nutrient input as 4.35, 1.17 and 3.02 kg of N, P and K, respectively, from different trees in a homestead of Kerala. The leaf litter of reed contained 1.98%N, 0.09% P, 0.46%K, 0.16%Ca and 0.12% Mg (Sujatha, 1999). The returns of nutrients by jack, nutmeg and coffee were to the tune of 42.34 N, 2.02 P, 10.97 K and 39.52 N, 4.21 P, 26.46 K and 26.3 N, 2.26 P, 15.93 K kg ha^{-1}, respectively (John and Nair, 2000).

The effect of litter on recycling plant nutrients was studied in eight species of leguminous plants and seven species of non-leguminous plants using pot and incubation experiments. Irrespective of soil type or plant type, increased uptake of all macronutrients (N, P, K, Ca and Mg) was observed in the pots treated with leaf litter (Pakrashi, 1991). Young (1986) reported that the annual nutrient contribution by the litter from coffee/cocoa and the shade trees combined was in the range of 150-300 kg N, 10-20 kg P, 75-150 kg K and 100-300 kg Ca ha^{-1}.

2.1.3. Decomposition rate of litter

Substrate quality and the micro-environmental conditions in which the litter is placed influence the rate of decomposition. According to Swift *et al.* (1979), the rates and pathways of litter decomposition are determined by the qualitative and quantitative composition of the decomposer community, their physical environment and the quality of the resources that animals and micro-organisms are utilising. Substrate quality includes not only the concentration and availability of nutrients, but also modifiers such as tannins, which affect the activity of heterotrophs.

Studies on litter decay have indicated that nitrogen and lignin content of plant materials are the most important in controlling the rates of decomposition (Millar *et al.*, 1936; Fogel and Cromack, 1977 and Meentemeyer, 1978). According to Toky and Ramakrishnan (1984), litter decomposition is related to secondary succession and species type under slash and burn agriculture (Jhum) in NE India.

According to Pakrashi (1991), the rate of decomposition for leguminous species was greater than that for non-leguminous species. Pande and Sharma (1986) and Harmon *et al.* (1990) studied the litter dynamics in temperate homogenous forests and found that the magnitude of total nutrient return was in accordance with their total litter fall. Das and Ramakrishnan (1985) reported that in the case of *Pinus kesiya* plantations in NE India, dry weight loss of decomposing litter for the first year was about 37%.

Edmonds (1980) studied the litter decomposition and the nutrient release in different ecosystems in Western Washington using litterbag technique. The nitrogen amount in the leaves of redalder ecosystem decreased continuously over the two-year

period. In the conifers, amounts of nitrogen decreased slightly in Douglas fir needles after an initial increase remained about the same in Western hemlock needles and more than doubled in pacific silver fir needles after two years. The differences were attributed to differences in C/N ratios.

Studies with buried litterbags indicated that decomposition was rapid during the high rainfall period in June to August for *Leucaena leucocephala* (Puri *et al.*, 1992). Mwiinga *et al.* (1994) studied the decomposition rates of different tree species and equations were developed for predicting the rate of decomposition from N concentration of each species.

Bahuguna *et al.* (1990) studied the decomposition of litter in bags. Dry weight loss in the case of sal litter was nearly 44% at the end of four months. Then there was gradual decrease in the rate of decomposition. Fifty per cent decomposition of the litter was observed after six months. At the end of 12 months, 65% decomposition was noticed. In the case of eucalyptus, there was a sharp decline in weight during first three months and nearly 65% of the weight loss was observed. At the end of 12 months, about 82% of the litter decomposition was noticed. The decomposition constant (K) was observed as 0.878 and 1.547 for sal and eucalyptus, respectively, for the period of one year. The rate of decomposition in both the cases was fast during the monsoon months.

Dkhar and Mishra (1987) studied the decomposition of bamboo leaf litter in NE India and found that rapid decomposition from May to September was due to high moisture content and suitable temperature. Schwintzer (1984) reported that *Myrica gale* leaf litter decayed substantially more slowly and had a much higher lignin content (40%)

than the litter of other woody nitrogen fixing species like *Alnus rubra* which had 25% lignin content.

Variations in the rate of decomposition of litter of different species under the same environmental conditions are chiefly caused by difference in chemical composition, especially in inorganic salts, water soluble substances, nature and amount of N and the amount of lignin (Westman, 1978). Monthly and progressive data of weight loss of mixed leaf litter in Diara land of Ganga basin at Bhagalpur, Bihar showed maximum decomposition of 58.3% during rainy season (Verma, 1997). According to Sujatha (1999), 50% decomposition of litter of reed in the Western Ghats occurred within three months and 95% decay was anticipated within a time span of 13 months by fitting suitable model to predict decomposition rate.

2.2. Effect of arbuscular mycorrhizal fungi (AMF)

2.2.1. Occurrence and crop response

AMF infection has been reported in cassava, apple, rubber, coffee, tea, oil palm (Hayman, 1982), coconut (Lilly, 1975), cocoa (Sivaprasad *et al.*, 1987) and tuber crops (Potty, 1978). Occurrence of AMF in rubber has been reported at College of Agriculture, Vellayani (Sivaprasad *et al.*, 1982). In Hevea, the growth responses of seedling root stocks to introduced AM fungi were observed at RRIM (Ikram, 1990). It was also found that AMF inoculation increased the seedling dry weight by 70%. The maximum colonisation of AMF occurred in plots receiving farmyard manure alone in capsicum (Nair and Peter, 1991). Role of AMF in improving the stem girth and plant biomass is well documented in tropical plantation crops like citrus and mango (Vinayak and Bagyaraj, 1990., Harinikumar and Bagyaraj, 1988).

A preliminary work conducted on the effect of different mycorrhizal isolates on cashew by Krishna *et al.* (1983) revealed the need for screening and selecting efficient

inoculant mycorrhizal fungus for cashew. The effect of different levels of AMF on the growth of cashew rootstocks was studied during 1995-'96 by Kumar *et al.*, (1998). Application of AMF @10g/bag at the time of sowing was found to be effective. According to Ramesh *et al.* (1998), there was significant increase in plant height, girth, number of leaves, leaf area, root length, number of roots and plant biomass in cashew rootstocks by the inoculation of AMF. Nine AMF were screened for their ability to enhance the growth and uptake of P in cashew rootstock under glass house condition. *Acaulospora* and *Glomus mosseae* significantly increased plant height, girth, and total biomass of cashew rootstocks as compared to uninoculated plants. Percentage root colonisation and P uptake were also significantly higher (Lakshmipathy *et al.*, 2000).

Bagyaraj *et al.* (1979) observed enhanced growth and nodulation due to dual inoculation with AMF and *Rhizobium* in many legumes. Plant height and total dry matter of root and shoot were enhanced by AMF in cowpea. Extensive mycorrhizal development to the tune of 53.78% took place in the roots of inoculated plants (Chhabra *et al.*, 1990).

Inoculation of AMF on rice in the nursery stage generally led to a higher biomass production (Dhillon and Ampornpan, 1992). *Glomus fasciculatum* proved to be the most efficient strain of AMF on maize (Rani and Mukerji, 1993). Inoculation of maize with *Glomus etunicatum* in USA increased the grain yield by 0.8 t ha^{-1} (Sylvia *et al.*, 1993). Mycorrhizal inoculation increased the growth and biomass of wheat (Suvercha and Mukerji, 1993).

Soil mycorrhization increased the seedling growth by four folds 60 days after planting in coffee seedlings (Saggin *et al.*, 1992). Screening of 60 sweet potato cultivars showed that root infection by AMF varied from 13.89 - 46.43% depending on genotypes (Kandasamy *et al.*, 1988).

In cassava, inoculation with *G. fasciculatum* gave the highest plant height, shoot and root dry weight and AMF infection when compared to *G. mosseae, G. constrictum, G. etunicatum, Acaulospora morroveae* and no inoculation (Sivaprasad *et al.*, 1990). Increased dry matter yield was also reported by Potty (1990) in cassava due to AMF inoculation.

An *et al.* (1993) studied the effects of AMF (*G. epigaeum* and *G. macrocarpum*) on the growth and mineral composition of shoots and roots of apple seedlings. The inoculated plants could achieve sufficient girth for grafting much earlier than the uninoculated. Inoculation with *Glomus sp.* in apple had a positive effect on growth during acclimatisation and subsequent development in the green house (Uosukainer, 1992). Two- year- old apple seedlings inoculated with *G. intraradices* had 3.9 times greater dry weight than nonmycorrhizal control with 1.8 and 2.7 times as many new shoots and leaves per plant, respectively (Edriss *et al.*, 1993). According to Chulan (1991) and Cuenca *et al.* (1990), AMF significantly increased plant growth and nutrient uptake in cocoa.

Significant influence of microbial inoculants on the forage yield of *Stylosanthes hamata* cv. Verano when raised as intercrop with cassava was noticed in Vellayani (Pillai *et al.*, 1994). AMF applied in combination with rhizobium recorded a high forage yield of 6.24 t ha^{-1} as against a low yield of 3.92 t ha^{-1} in control.

Banana inoculated with *G. mosseae* and *G. monosporum* recorded both enhanced growth and biomass production (Rizzardi, 1990). In green house experiments, inoculation of micropropagated pineapple plantlets with *Acaulospora*, *G. mosseae* and *G. fasciculatum* increased survival of the transplants by 100, 80 and 80%, respectively, compared with 40% in control (Vega and Azcon, 1991).

AMF increased the bulb yield in Bellary onion (*Allium cepa* L.) from 19.3 - 20.5 t ha^{-1} when applied into the sowing furrows (Gurubatham *et al.*, 1989). Mathur and Vyas (1996) recorded more than two-fold increase in shoot and root biomass along with N and P uptake, total chlorophyll, soluble protein and carotenoids in *Ziziphus mauritiana* following application of AMF.

In green house experiments, pregerminated mung bean and cashew were grown in soil inoculated with *G. intraradices* and maintained at 22, 30 or 38°C. In cashew, no infection occurred at 38°C and this was associated with low plant growth compared with the other temperatures at which infection reached 40-60% after four months (Haugen and Smith, 1993). AMF induced faster flowering and increased the number of flowers in *Tagetus zinnia* (Nasr,1996).

Results of a field experiment on sorghum and pearl millet indicated that AMF had no significant effect on the plant height, green fodder and crude protein yields of forages (Sheoran et al., 1991). Trials by Alwar et al. (1994) using *Azotobacter*, phosphorus solubiliser and AMF in coffee revealed that biofertilisers do not result in any significant increase in growth of coffee.

2.2.2. AMF and P nutrition

The role of AMF in increasing the mobilisation and uptake of P and productivity of many crops is well documented (Meenakumari, 1987 and Geethakumari *et al.*, 1990). *G. fasciculatum* was found to be more effective to enhance growth and P uptake of cashew plants (Sivaprasad *et al.*, 1992) than *G.etunicatum*.

Champawat and Pathak (1993) reported better uptake of P in pearl millet by mycorrhizal inoculation. Inoculation of *Glomus etunicatum* in maize increased the

concentration of P both in shoots and grains of maize (Sylvia *et al.*, 1993). The possibility of saving P @ 7.5 kg P_2O_5 ha^{-1} was revealed by Geethakumari *et al.*, (1994).

Soil mycorrhization increased P concentration in coffee seedlings (Saggin *et al.*, 1994). *G. mosseae* enhanced the yield and P content on oats, barley, vetch, clover, potato and onion (Muromtsev *et al.*, 1990).

The benefit derived from AMF inoculation on *Leucaena leucocephala* was inversely proportional to the soil solution P levels in black soils of Bangalore (Bagyaraj and Machado, 1996). Although it significantly enhanced P uptake even at the highest level of P tested (KH_2PO_4 was applied @ 0, 25, 50, 100, 250 and 400 mg/kg soil), it did not significantly increase plant biomass production. The level of P in soil solution that was optimum for AMF symbiosis, was estimated as 0.022 mg P/litre.

Anon *et al.* (1996) studied growth and nutrient uptake of neem seedling in response to inoculation with *G. intraradices* at two levels of P (0.65 and 1.3 mM P). Under low P conditions, this enhanced the growth and nutrient uptake. Nelsen (1987) concluded that most effects of AMF are probably on direct consequence of improved P nutrition.

The highest P uptake of shoot and root was recorded in the plants inoculated with AMF in groundnut (Champawat, 1990). Increased application of P decreased the per cent root colonization in blackgram. Superphosphate was a better source of P than rock phosphate for both mycorrhizal and nonmycorrhizal plants (Devi and Sitaramaiah, 1990).

A number of studies led to the conclusion that plants use the same available phosphate pool, whether or not they are mycorrhizal. Such a conclusion was drawn from

experiments using isotopic dilution or fertilizer labelling techniques (Sanders and Tinker, 1971; Hayman and Mosse, 1972; Mosse *et al.*, 1973 and Powell, 1975). According to Bolan *et al.* (1984), AMF plants draw most of their P from the soluble pool although they are more effective than nonmycorrhizal plants. The mycelial net work of endomycorrhizal fungi enabled plants to remove phosphate from a larger volume of soil extending beyond the immediate vicinity of the root surface.

The fact that AMF plants can respond to sparingly soluble P sources such as rock phosphate has been repeatedly shown (Tinker, 1980; Barea *et al.*, 1983 and Manjunath *et al.*, 1989). The mycorrhizal roots explored a greater volume of soil beyond the zone of P depletion near the root surface.

Mycorrhizal plants of apple were taller, produced more biomass and had a higher leaf P concentration than the uninoculated control and this was attributed to improved P nutrition (Morin *et al.*, 1994). Increased P uptake has been attributed to increase in surface area of absorption (Sanders and Tinker,1971) and further due to hyphal translocation (Huttingh *et al.*,1973).

Application of *G. fasiculatum* completely substituted for the P fertilizer requirement in sweet orange (Singh and Sharma, 1993). AMF inoculation increased seedling growth, phosphorus uptake and seedling survival after transplanting to the field and yields in coffee (Siqueria *et al.*, 1993).

2.2.3. AMF and other nutrients

Triple symbiosis of legumes with AMF and Rhizobium increased the plant N content (Muromtsev *et al.*, 1990). A number of reports show that AMF increases the N concentration and /or content in plant shoots (Barea *et al.*, 1988 ; Barton *et al.*, 1986 and

Jain and Patriquin, 1984). It is known that AMF can use both NH_4^+ and NO_3^- (Brown and Smith, 1981). AMF increased the N and K contents significantly in cowpea (Chhabra *et al.*, 1990) and banana (Rizzardi, 1990).

AMF can directly enhance the uptake of micronutrients viz., Zn, Cu and Fe (Gildon and Tinker, 1983; Tinker and Gildon, 1983; Pacovsky, 1986; Kucey and Janzen, 1987 and Rai, 1988). An *et al.* (1993) recorded improved uptake of immobile elements mainly Cu, P and Zn in apple.

Accumulation of Cu and Zn in leaves following mycorrhizal colonisation has been reported by Potty (1990) and of Cu in maize by Sylvia *et al.* (1993). The concentrations of K, Ca, Mg, S, Mn, Fe, Cu, Zn, Na, B and Al were increased by AMF in rice (Dhillon and Ampornpan, 1992). Application of *Glomus fasciculatum* increased the leaf Zn, Cu, Fe and B contents in sweet orange (Singh and Sharma, 1993).

2.3. Effect of *Azotobacter* inoculation

2.3.1. Effect on growth

Shende *et al.* (1977) has observed enhanced seed germination by *Azotobacter* inoculation.

The effect of *Azotobacter* on cashew was studied in pot culture. Inoculation caused better growth of root and shoot systems (Oblisami *et al.*, 1985). Treating seedling hypocotyles and roots of several plant species with cultures of *Azotobacter paspali* changed plant growth and development and significantly increased the weight of shoot and roots (Abbass and Okon, 1993). *Azotobacter chroococcum* provided a significant increase in seedling emergence rate, total dry weight and root and shoot length of tomato plants (Gupta *et al.*, 1995).

One- year- old mango seedlings grown in pots were treated with *Azotobacter chroococcum* alone or with various fertiliser N levels (16,32 and 48 g/plant as urea) and were compared with untreated controls and seedlings treated only with N. The greatest per cent increase in seedling height, girth, number of leaves and chlorophyll content were obtained with 48 g N, *Azotobacter* + 48 g N and *Azotobacter* alone (Kerni and Gupta, 1986).

2.3.2. Nutrient uptake, yield and quality

Hussain *et al.* (1987) reported that differences in N and P contents of grain and straw in maize due to different strains of *Azotobacter* in fertilized and unfertilized soils were highly significant.

A study was conducted in a cashew plantation at Kumari, West Bengal with cultivar M 26/1 during 1993-95. *Azotobacter chroococcum* was inoculated @ 5, 10, 15 and 20 g inoculum /plant. Application @ 15 g/plant increased cashew yield over the control by 229.1 and 94.2% in 1994 and 1995, respectively. Yield was also 106.3% higher than for the chemical fertilizers in 1994 (Singh, 1997).

Application of *Azotobacter* gave 7.7 to 15.2% more yield than *Azospirillum* in sugarcane and the biofertilizers proved to be economical in saving 25% inorganic nitrogen (Bangar *et al.*, 1995). *Azotobacter* inoculation showed effects on growth and yield of guinea grass (George, 1996). Similarly, seeds of forage sorghum inoculated with *Azotobacter* gave the maximum forage yield and higher drymatter production (Patel *et al.*, 1992). They also reported that *Azotobacter* inoculation with 75 kg N ha^{-1} increased green forage, drymatter and crude protein yields by about 17.83, 50.32 and

75.44% over 75 kg N ha^{-1} alone in fodder maize. Wani (1992) obtained eight per cent increase in yield of pearl millet through *Azotobacter* inoculation.

Seed inoculation with *Azotobacter chroococcum* recorded a drymatter yield of 7.5 t ha^{-1} as compared to 6.77 t ha^{-1} registered by uninoculated treatment in maize (Singh *et al.*, 1990). Mishustin and Shilnikova (1969) pointed out a positive benefit of 7-12% increase in yield due to inoculation of *Azotobacter* in the USSR.

Field experiments conducted in India on *Azotobacter* inoculation of seeds or seedlings of wheat, rice, onion, brinjal, tomato and cabbage showed significant increase in yield (Rao *et al.*, 1963; Mehrotra and Lehri, 1971 and Joi and Shinde, 1976). Trials conducted at Ganeshkund, India on cabbage revealed that inoculation with bacterial cultures (*Azotobacter* and /or *Azospirillum*) increased yields by 15-20% compared to uninoculated control (Wagne *et al.*, 1995). *Azotobacter chroococcum* was inoculated on tomato seedlings and planted in the field (Kumaraswamy and Adalageri, 1990). An increase in yield of 6.6 t ha^{-1} was observed in the inoculated plants with 50% of the recommended fertilizer level and this gave best quality fruits.

Quality of produce is also affected by *Azotobacter* inoculation. Zambre *et al.* (1984) reported that protein content of wheat increased to 11.9% through inoculation while it was 11.5% in control. *Azotobacter chroococcum* was applied to the roots of palmarosa at planting (Maheswari *et al.*,1991).The average oil yield was raised by 21% with *Azotobacter chroococcum* alone.

A field experiment conducted on the response of forage sorghum to *Azotobacter* revealed that there was no significant difference in green forage production between inoculated and noninoculated treatments (Patel *et al.*, 1992).

2.4. Effect of *Azospirillum* inoculation

Nearly 10% of the soils and roots from temperate region and more than 50% of the tropical samples are positive for *Azospirillum* (Neyra and Dobereiner, 1977). There is only scanty information available on the influence of *Azospirillum* in perennials especially plantation crops (Rao, 1982).

2.4.1. Influence on growth

Field experiments in India have revealed the response of crops to *Azospirillum* inoculation (Rao *et al.*, 1979). *Azospirillum* had a growth promoting effect on the roots and shoots of several nongraminaceous crops (Gamo and Ahn, 1991).

Azospirillum brasilense inoculum was applied to the seeds, soil or foliage and compared with NPK at 40:50:30 kg ha^{-1} at sowing or of a growth regulator mixture (1mM each of IAA, GA and Kinetin). The best overall results were obtained from soil application which increased the plant height, shoot girth, root length and root volume at 25 and 50 DAS (Parvatham *et al.*, 1989). Enhanced root elongation, root hair development and branching were observed by Kapulnik *et al.* (1983) in a number of crops by *Azospirillum* inoculation. Root growth and root hair density was enhanced by *Azospirillum lipoferum* in corn (Fulchieir *et al.*, 1993).

The effectiveness of *Azospirillum* inoculation for drymatter production is well documented. Smith *et al.* (1978) reported that field grown pearl millet and guinea grass, lightly fertilized and inoculated with *Azospirillum*, produced significantly higher yield of drymatter than uninoculated control. According to George (1996), *Azospirillum* inoculation alone and in combination with fertilizers had significant positive influence on guinea grass production.

A field experiment at KAU with sesamum in rice fallows revealed lesser possibility of inorganic nitrogen substitution with *Azotobacter* or *Azospirillum* (Paul, 1995).

2.4.2. Yield, drymatter production and uptake

Tilak *et al.* (1982) reported that inoculation of maize seeds with *Azospirillum brasilense* increased the drymatter production and brought about an increase of 29.8% grain yield over uninoculated control. Yadav *et al.* (1992) reported similar results with *Azospirillum lipoferum.* Field experiments conducted at ICRISAT with pearl millet showed a maximum yield increase by 26% with *Azospirillum* over control (Tilak and Singh, 1996).

Durai and Manickam (1991) recorded higher sugarcane yield and improved juice quality by the inoculation of sugarcane sets with *Azospirillum.* In field trials at Coimbatore, applying 9 kg N + 18 kg P ha^{-1} together with *Azospirillum* and phosphobacteria gave the highest fruit yields in pumpkin cv. Co-2 (Karuthamani *et al.*, 1995). *Azospirillum* increased bulb yields from 19.1 t ha^{-1} to 20.1 - 20.5 t ha^{-1} in Bellary onion (Parvatham *et al.*, 1989). Seed inoculation with *Azospirillum* increased the fruit yield of bhindi by 195% over the control (Mishra and Patjoshi, 1995).

Azospirillum brasilense inoculation not only saved 50% of the recommended rate but also improved NUE in tomato plants (Subbiah, 1990). Grain yield of rice obtained by the application 50 kg N ha^{-1} supplemented by *Azospirillum* was comparable with that recorded at 100 kg N ha^{-1} alone (Jeyaraman, 1990). According to Hegde and Dwivedi (1994), it was possible to reduce 25-50% of N from fertilizer source by inoculating *Azospirillum* without sacrificing the rice grain yield.

Patel *et al.* (1993) recorded highest grain yield in finger millet with inoculation of *Azospirillum*, which was on par with application of 20 kg N ha^{-1}. Katyal *et al.* (1994) reported increased grain and straw yield in pearl millet by *Azospirillum* and about $1/3^{rd}$ of the total nitrogen could be substituted by the inoculation. Forage yield of maize could be significantly improved with *Azospirillum* application (Anon, 1990).

Bangar *et al.* (1995) recorded increased growth and yield in sugarcane by *Azospirillum* and this contributed in economising the nitrogen use and lowering the cost of cultivation.

Summarising the results of the studies conducted by AICRP on forage crops at different centres, Hazra (1994) observed that in forage grasses, the increase in yield through *Azospirillum* inoculation varied from 4-12% with annual forage grasses and 12-17% in the case of perennials. High crude protein content was also registered by the inoculated plants (Patel *et al.*, 1993). Plants inoculated with a mixture of *Azospirillum* species had increased grain protein and leaf N in maize (Purcino *et al.*, 1996).

According to Singh *et al.* (1980), uptake of Ca, Mg and P was increased in sorghum due to *Azospirillum* inoculation, which was similar to that obtained with 45 kg N.

2.5. Interaction of AMF with nitrogen fixers

Significant increase in the fodder yield due to combined application of mineral N and biofertilizers was reported by many workers (Anon, 1991; Patel *et al.*, 1992 and Singh *et al.*, 1990).

Dual application of *Azotobacter* and *Azospirillum* recorded 41% increase in yield of fodder maize at Bhubaneswar (Anon, 1990) and 24-38% at Jabalpur and Rahuri (Anon, 1991). Forage yield of maize could be significantly improved with dual application and a saving of 30 kg N ha^{-1} could be obtained (Anon, 1990).

Combined inoculation of *Azotobacter chroococcum* and *Glomus fasciculatum* stimulated plant growth and resulted in increased shoot N, Ca, Mg and K in tomato (Elshanshoury *et al.*, 1989).

Dual inoculation of AMF and *Azospirillum* was found to be more advantageous in pearl millet than single inoculation with either organism (Katyal *et al.*, 1994). Increase in grain yield was higher when *Glomus fasciculatum* and *Azospirillum brasilense* were coinoculated. Nitrogen and phosphorus contents in plants were also higher after soil inoculation with *Glomus fasciculatum* (Singh *et al.*, 1990). Wheat grown in pots was seed inoculated with *Azospirillum brasilense* and soil inoculated with *Glomus fasciculatum* (Panwar, 1991). Chlorophyll concentration, photosynthetic rate, nitrate reductase and glutamine synthase activities and grain yield were highest in the dual inoculated plants. *Azospirillum brasilense* mainly increased root growth while AMF increased both root and shoot weights.

Inoculation of sweet potato cuttings with AMF fungi (*G. fasciculatum* or *G. mosseae*) and *Azospirillum brasilense* significantly increased growth, plant N and P contents, tuber weight and starch content (Kandasamy *et al.*, 1988). Effect of combined inoculation of *Azospirillum brasilense* and *G. fasciculatum* on mulberry was studied by Nagarajan *et al.* (1989). This enhanced the shoot biomass and leaf weight compared to the control. The effect of combined inoculation of AM fungi (*G. fasciculatum* and *Gigaspora margarita*) and *Acaulospora laevis* with *Azospirillum brasilense* on growth and nutrient uptake by coffee seedlings was evaluated in a nursery experiment (Kumari

and Balasubramanian, 1993). *Gigaspora* and *Azospirillum* significantly increased root and shoot length and total dry weight of the plants. There was also significant increase in uptake of micronutrients, Fe, Cu, Zn and Mn. Uptake of nitrogen and phosphorus also was found to increase.

Combined inoculation of *Azotobacter*, *Azospirillum* and AMF increased the plant height and shoot and root weight of pepper (Bopaiah and Khader, 1989).

From the above review, the following general trends are noted:

(i) Litter production, decomposition and nutrient recycling play a vital role in soil fertility of plantations and forest ecosystem.

(ii) Plant growth and uptake (phosphorus, zinc, copper etc.) are found to be enhanced by AMF inoculation, especially in the early stages of growth.

(iii) Uptake of both soluble and insoluble phosphates is enhanced by the inoculation of AMF.

(iv) *Azotobacter* and *Azospirillum* inoculation is beneficial in nitrogen fixation and provides a favourable environment in the rhizosphere by secreting hormones like IAA, giberellins and vitamins.

(v) Combined inoculation is of advantage in as much as it imparts synergistic effect.

Materials and Methods

MATERIALS AND METHODS

A study was conducted during 1995-99 at the College of Horticulture, Vellanikkara to quantify the litterfall in cashew plantation and also to evaluate the effect of biofertilizers on cashew.

3.1. Materials

3.1.1. Site, weather and soil

The fields of Cashew Research Station, Madakkathara, Campus Development, Vellanikkara and Cashew Research Station, Anakkayam were utilised for the study. The locations enjoy a typical humid tropical climate.

The weather conditions prevailing during the period of study at Vellanikkara and Anakkayam are furnished in Appendices I and II and Fig. 1, 1(a), 2 and 2(a).

The information regarding the locations and the soil are presented in Appendix III.

3.1.2. Season

The study on litterfall was conducted for two years from March 1997 to February 1999. Experiments on biofertilizers were started in November 1996 and were continued up to December 1999.

Fig. 1. Weather data at Vellanikkara from 3/96 to 6/99

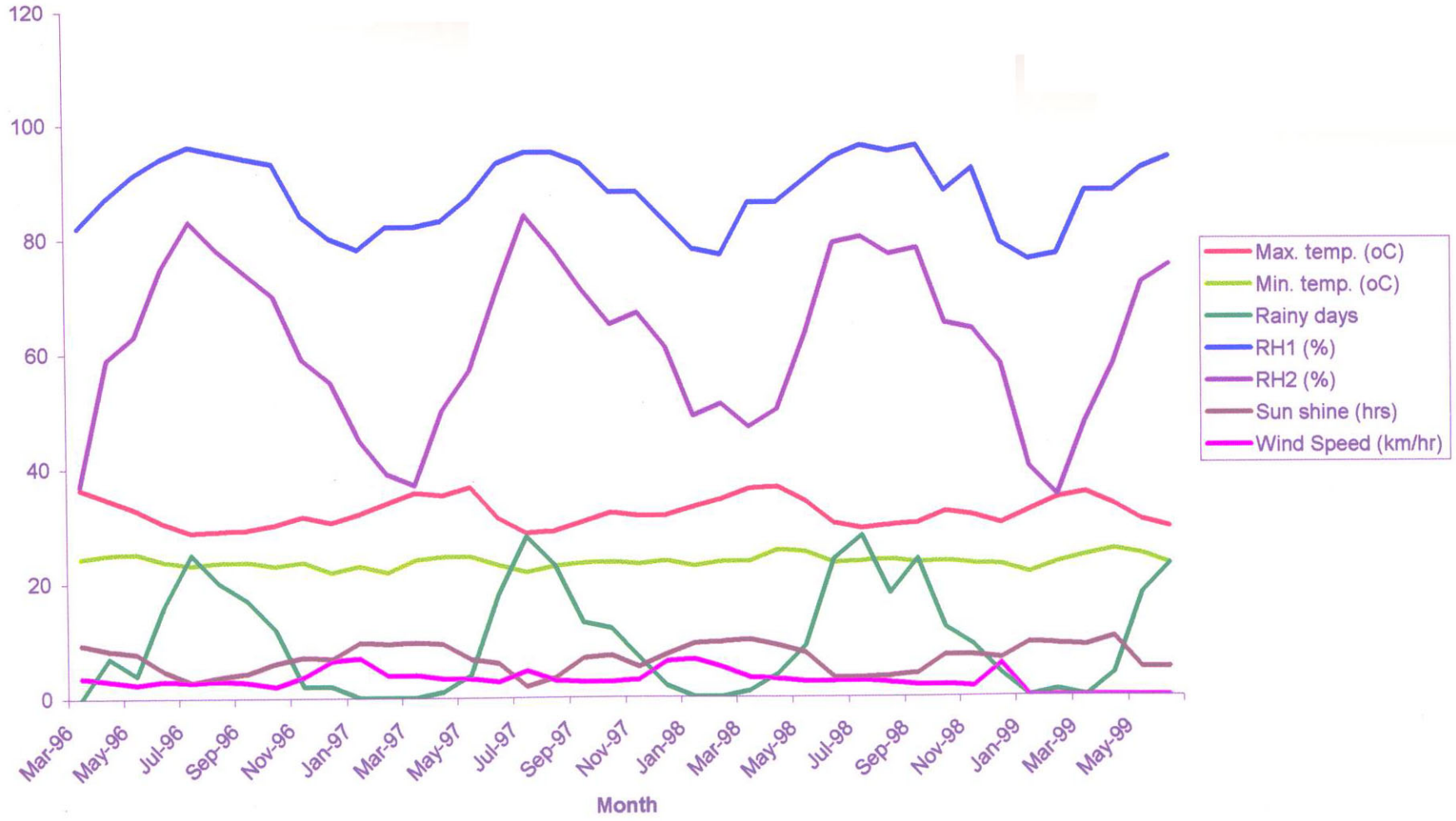


Fig. 1(a). Rainfall data at Vellanikkara from 3/96 to 6/99

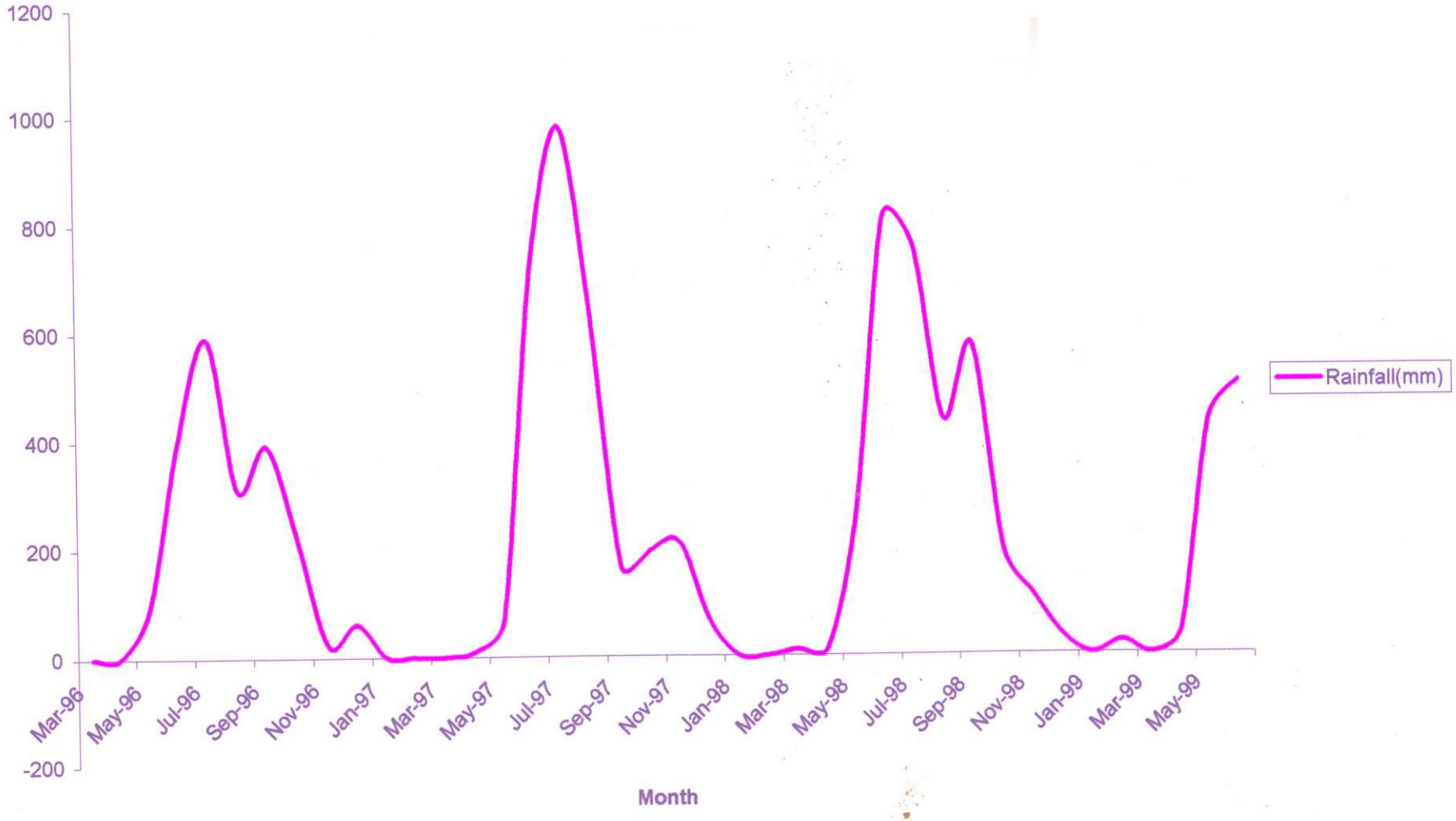


Fig. 2. Weather data at CRS, Anakkayam from 11/93 to 5/99

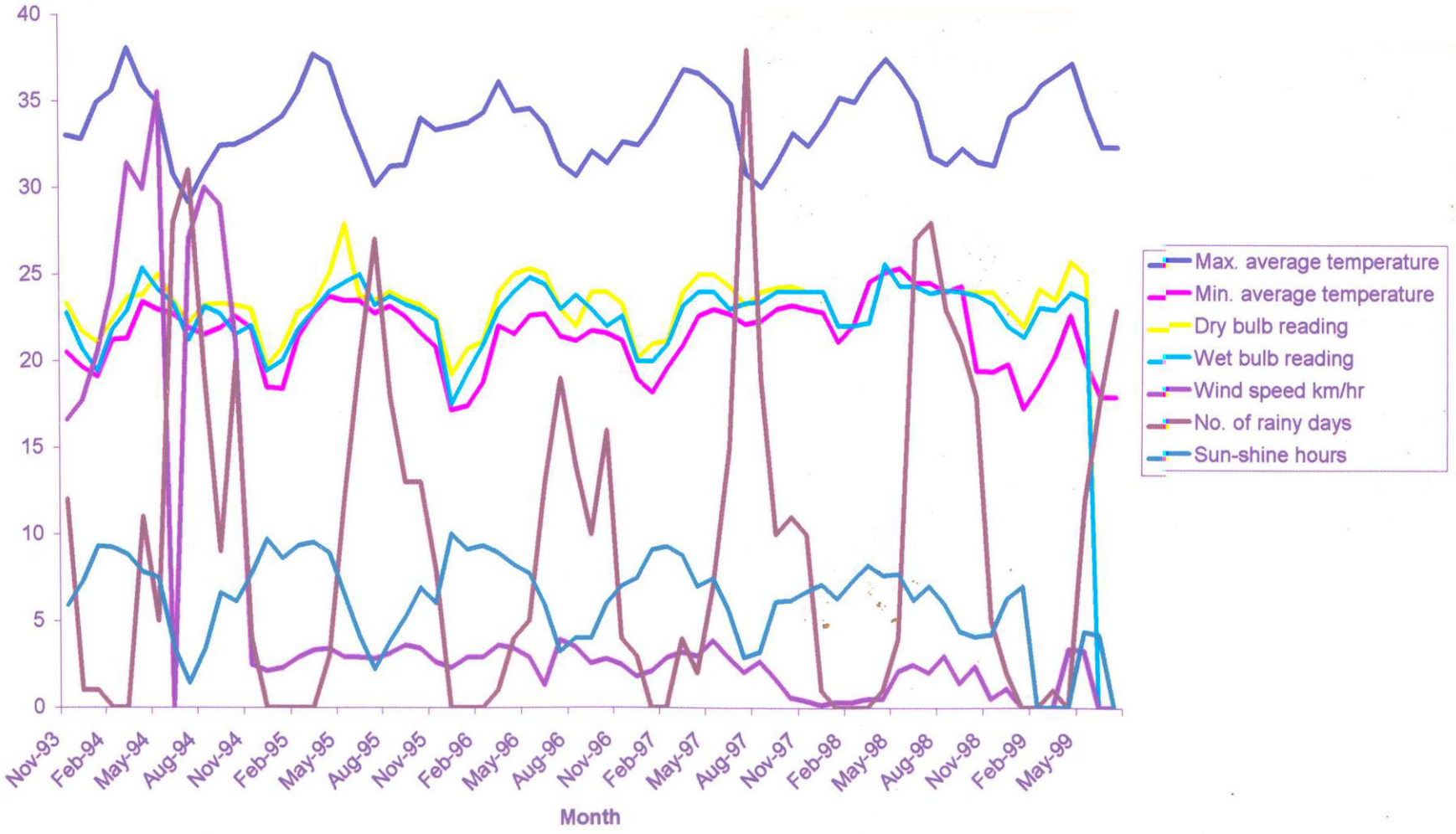
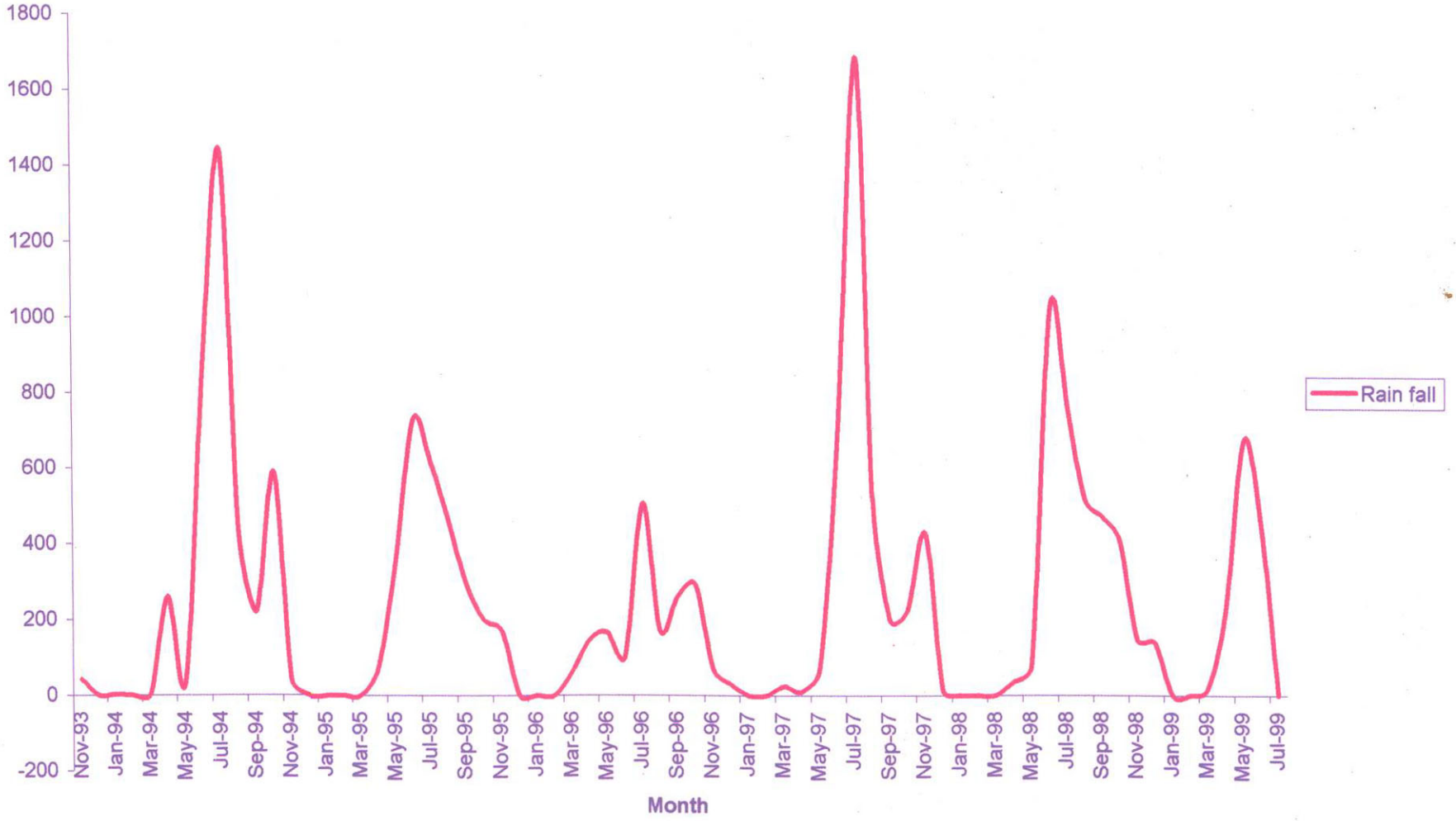


Fig. 2(a). Rain fall at CRS, Anakkayam from 11/93 to 5/99



3.1.3. Variety

The high yielding hybrid variety Dhana (H-1608) developed at CRS, Anakkayam was utilised for the study. This variety was evolved by hybridisation using ALGD 1-1 as the female parent and K-30-1 as the male parent. The salient characters of the variety are presented below.

Canopy	:	Compact
Branching	:	Intensive
Flowering	:	December - January
Fruiting	:	February - March
Mean yield	:	10.66 kg/tree
Shelling percentage	:	27.08
Nut weight	:	9.6 g
Kernel weight	:	2.22 g
Apple colour	:	Yellow
Export grade	:	W 210

3.1.4. Biofertilizers

The inoculum of biofertilizers viz. *Azotobacter, Azospirillum* and AMF collected from different Research Stations were utilised for the study. *Azotobacter chroococcum* and *Azospirillum lipoferum* were received from TNAU, Coimbatore and College of Agriculture, Vellayani. Different species of AMF were supplied from the College of Agriculture, Vellayani except *Glomus intraradices,* which was received from the TNAU, Coimbatore.

3.1.5. ^{32}p Labelled fertilizers of phosphorus

^{32}p labelled monocalcium and tricalcium phosphates supplied by the Board of Radiation and Isotope Technology (BRIT), Mumbai were used for evaluating the efficiency of AMF in P uptake.

3.2. Methods

3.2.1. Layout

The experiments on litterfall were laid out in CRD.The experiments on biofertilizers were laid out in CRD for nursery screening and RBD for field screening.

3.2.2. Technical programme

Six experiments were conducted during the year 1996-1999.

EXPERIMENT I

Effect of cashew litter in the nutrition of cashew

The experiment was started during March 1997 in the existing ten- year old Multi Location Trial plot of AICRP on cashew at CRS, Madakkathara. The spacing between the trees was 7.5m X 7.5m. Wooden trays of 1m x 1m x 45 cm with wire mesh bottom were placed at 50 different points below the canopy for litter collection (Plate I). Five trays were placed in the middle of two rows of the same variety so as to compare the litter contribution by 10 different varieties.

Plate I

Fig.1. A view of ten year old cashew graft plantation

Fig.2. Wooden tray of 1m × 1m × 45 cm placed for litter collection

The varieties were

1) Anakkayam-1 (BLA 139-1)
2) Madakkathara-1 (BLA39/4)
3) Madakkathara-2 (NDR 2-1)
4) Kanaka (H-1598)
5) Dhana (H-1608)
6) Priyanka (H-1591)
7) H-856
8) H-1600
9) H-1602
10) Vridhachalam-3 (M 26/2)

Litter accumulated in the trays was collected at monthly intervals. It was oven dried at 80°C for 48 hours and the dry weight was recorded. This was continued for two years.

Decomposition rate was estimated by recording the weight loss at monthly intervals. Proportionate quantities of air dried litter were packed in mesh litter bags (50 cm x 40 cm) and 120 such litter bags were placed over the soil surface and a sprinkle of surface soil applied over it. For sampling, 10 bags were removed randomly and the loss in weight was recorded at monthly intervals. This was started in April, 1997 and carried out for one year.

Nutrient content in the litter was estimated by collecting homogenised samples and contribution of nutrient ha^{-1} was then worked out.

EXPERIMENT II

Effect of fertilizer application on organic recycling in cashew plantation

This experiment was done to compare the litter production from the fertilized and unfertilized fields of cashew. Ten litter trays were installed randomly in the unfertilized field of eleven- year-old cashew trees in the old KADP area of College of Horticulture,

Vellanikkara. Litterfall was quantified at monthly intervals for 12 months from May 1998 to April 1999. The dry weight was recorded as in Experiment I.

Nutrient contained in the litter and the organic carbon content of the soil were analysed and compared with that of Experiment I which was reckoned as representing the fertilised situation. (The fertilizers were applied as per the POP recommendations i.e.,750:325:750 g N, P and K tree^{-1} year $^{-1}$) .

EXPERIMENT III

PART I Effect of inoculation with AMF on growth and establishment of cashew seedlings (Nursery stage)

The experiment was started in October 1996. Potting mixture (sand + soil + cowdung) was filled in 3/4th of the polybags (17.78 cm X 12.70 cm) and ten grams each of the inoculum of different AMF were then added. Again, the polybags were completely filled with the potting mixture. Pre-soaked cashew seeds were sown in the bags so that after germination the roots of the seedlings will come in direct contact with the inoculum. The treatments were:

T_1 - *Glomus fasciculatum*

T_2 - *Glomus monosporum*

T_3 - *Glomus constrictum*

T_4 - *Glomus etunicatum*

T_5 - Native isolates from Vellayani

T_6 - *Glomus intraradices*

T_7 - Control

The management practices were adopted according to the POP recommendations. (N, P and K @ 750:325:750 g tree^{-1} year $^{-1}$)

Part II Effect of AMF inoculation on the growth and development of cashew (main field)

Based on the growth characters, the performance of seedlings under different treatments was compared. A set of seedlings was used as rootstocks for softwood grafting. The same variety Dhana was used as scion. Both the seedlings as well grafts were planted in the main field. Observations on growth characters and nutrient uptake were recorded.

Part III Comparative efficacy of different strains of AMF with different sources of ^{32}P labelled fertilizers

The experiment was done during July 1998 to evaluate the efficiency of AMF in enhancing the uptake of different P fertilizers. It was conducted in the RadioTracer Laboratory of College of Horticulture, Vellanikkara. The treatments consisted of two species of AMF and two sources of P (mono and tricalcium phosphate) at three doses, viz: 50% of the recommended dose, recommended dose and 200% of the recommended dose as described below.

1. AMF species
   - V_1 - *Glomus fasciculatum*
   - V_2 - *Glomus etunicatum*
   - V_3 - Control
2. Sources of P
   - P_1 - Monocalcium phosphate

P_2 - Tricalcium phosphate

3. Doses of P

D_1 - 50% of the recommended dose

D_2 - Recommended dose

D_3 - 200% of the recommended dose

The experiment was laid out in RBD with three replications with three plants in each treatment. Seeds were sown in plastic buckets containing 5 kg soil and inoculation with 20 g each of AMF was done based on the treatments. After three months, ^{32}p labelled fertilizers were applied as per the technical programme. After 35 days of application, the plants were pulled out, oven dried and dry weight was recorded. Observations of leaf and stem were taken separately. Samples were digested and transferred into the counting vials for Liquid Scintillation Counting. After counting, total P in the plants was also estimated. Specific activity was worked out for comparing the efficiency of AMF.

EXPERIMENT IV

Part I Screening of effective *Azotobacter* and *Azospirillum* strains of cashew (nursery stage)

This experiment was started in October 1996. Cashew seeds were sown in polybags inoculated with 10 grams each of the *Azotobacter* and *Azospirillum* strains as in Experiment III. There were seven treatments as listed below:

T_1 - *Azotobacter chroococcum* (TNAU, Coimbatore)
T_2 - *Azotobacter chroococcum* (COA, Vellayani)
T_3 - *Azospirillum lipoferum* (TNAU, Coimbatore)
T_4 - *Azospirillum lipoferum* (COA, Vellayani)
T_5 - Control
T_6 - Dressing the seeds with the inoculum of T_1
T_7 - Dressing the seeds with the inoculum of T_3

Part II Influence of *Azotobacter* and *Azospirillum* on growth and development of cashew (main field)

The growth characters of seedlings were observed periodically and a set of seedlings was used for producing grafts. Both the seedlings and grafts were planted in the field and observations were continued for two years.

Part III Interaction effect of Azotobacter, Azospirillum and AMF on cashew

Based on the performance for one year in the nursery and main field, the best AMF (*G.intraradices*) was selected and those plants were inoculated with the promising strains of *Azotobacter* and *Azospirillum* {*Azotobacter chroococcum* (V) and *Azospirillum lipoferum* (V)} in order to assess the combined effect.

Treatments

T_1 - AMF alone

T_2 - AMF + *Azotobacter*

T_3 - AMF + *Azospirillum*

T_4 - AMF + *Azotobacter* + *Azospirillum*

T_5 - Control

EXPERIMENT V

Impact of inoculation of *Azotobacter* and *Azospirillum* in established cashew plantations

The promising strains of *Azotobacter* and *Azospirillum* {*Azotobacter chroococcum* (v) and *Azospirillum lipoferum* (v)} were inoculated in the rhizosphere of

cashew trees. The experiment was conducted at CRS, Anakkayam. Ten cashew varieties/cultivars were selected and the treatments were imposed. The varieties/cultivars were:

1) Anakkayam-1	6) K-16-1
2) H-3-13	7) UL-28-1
3) K-28-2	8) H-4-7
4) K-10-2	9) K-22-1
5) K-25-2	10) K-19-1

Hundred and fifty grams each of the inoculum were applied to the basins of the trees. The treatments were:

T_1 - *Aztobacter* alone

T_2 - *Azospirillum* alone

T_3 - *Azotobacter* + *Azospirillum*

T_5 - Control

Total number of trees selected - 40

All the cultural operations according to the POP recommendations were adopted.

3.2.3. Observations

3.2.3.1. Biometric observations

EXPERIMENT I

1) Quantity of litter

Litter collected in the trays was oven dried and the weight recorded at monthly intervals.

2) Rate of decomposition of litter at monthly intervals

Ten samples were drawn at monthly intervals from the 120 litterbags kept for decomposition and the loss in weight was recorded after removing the soil particles adhering on the litter.

3) Nutrient content of the litter

Litter samples were dried and the nutrient content, viz.: N, P, K, Ca, Mg, Fe, Cu, Zn and Mn were estimated.

4) Quantity of nutrients incorporated

Quantity of nutrients incorporated per ha was worked out from the nutrient content and dry weight.

5) Decay coefficient per hectare

Decay coefficient was worked out for the constant potential weight loss by using the formula suggested by Olson (1963), viz.: $X/X_o = e^{-kt}$ where X = Weight remaining at time t (g), X_o = Original weight (g), e = Base of natural logarithm, k = Decay rate coefficient and t = Time.

EXPERIMENT II

1) Quantity of litter in the unfertilized plot

Quantity of litter in the unfertised plot was recorded at monthly intervals for one year and the dry weight was taken.

2) Nutrient content of the litter in the unfertilized plot

Content of N, P, K, Ca, Mg, Fe, Zn, Cu, Mn in the litter of unfertilised plot was estimated.

3) Organic carbon content of the soil

Organic carbon content in the fertilised and unfertilised plots was estimated.

EXPERIMENTS III AND IV

Nursery

1) *Height of plants*

Height of plants from ground level to the terminal bud was recorded at monthly intervals.

2) *Girth of plants*

Girth of plants at collar region was observed at monthly intervals.

3) *Internodal length*

Internodal length was taken at intervals. The distance between the four consecutive leaves from the base of the plant was measured and the average was worked out.

4) *Root spread*

Lateral and vertical spread of roots was measured after washing out the soil mass in the container. The length from collar region to the longest root in horizontal and vertical directions was recorded.

5) *Dry weight*

Dry weight of roots and shoots was recorded. For estimating the weight of roots, the soil mass of the container was washed out in running water and the weight of the soil - free material was taken.

6) *Root-shoot ratio*

Root-shoot ratio was worked out based on dry weight values.

7) *Nutrient content*

N, P, Fe, Zn and Cu contents of the leaf and stem were estimated.

8) *Nutrient uptake*

Uptake of nutrients, viz: N, P, Fe, Zn and Cu was calculated from the dry weight of leaf and stem and the nutrient content.

Main field

1) Height of plants

Height of plants from ground level to the terminal bud was recorded at an interval of three months.

2) Girth of plants

Girth of plants at collar region was recorded at an interval of three months.

3) Number of branches

Number of branches was observed at an interval of three months.

4) Leaf nutrient content

Content of N, P, K, Ca, Mg, Fe, Cu, Zn and Mn was estimated. Fourth leaf from the tip of mature branches was taken as the index leaf. Fifteen such leaves were collected from each treatment plant at the beginning of flowering. The leaves were oven dried, powdered and the content of nutrients was estimated.

Part III of Expt. III

Three month old seedlings

1) Plant dry weight

The plants were harvested, oven dried and the dry weight of leaf and stem was recorded separately.

2) Counts (cpm)

One gram each of dried leaf and stem samples were digested with the diacid mixture and transferred to sample bottles. The bottles were kept in the Liquid Scintillation Counter and the counts were recorded.

3) Total P in leaf and stem

Total P content in the leaf and stem was estimated as per the standard procedure.

4) Specific activity (leaf and stem)

Total cpm in the leaf and stem was worked out and specific activity was calculated using the formula Specific activity = Total cpm / Total P

EXPERIMENT V

1) Height

Height of trees from ground level to terminal bud was recorded at an interval of three months.

2) Girth

Girth of trees at collar region was observed at an interval of three months.

3) Length of panicle

Length of panicle in three quadrants was measured and the average was worked out.

4) Number of nuts/panicle

The number of nuts/panicle in three quadrants was counted and the average was worked out.

5) Yield/tree

Nut yield of trees before and after the treatment application was recorded. Nuts collected from each tree were dried and the total weight was recorded.

3.2.3.2. Estimation of infection by microbial inoculants

3.2.3.2.1. AMF

The thin feeder roots of the plants taken from different treatments were washed and cut into bits of about 1 cm. They were transferred into test tubes and fixed in FAA (Formalin, acetic acid and ethanol @ 5:5:90 ml) for three hours. The root bits were hydrolysed in 10% KOH solution at 100°C for 15 minutes. After washing with water it was neutralised with one per cent HCl and then stained with 0.05% trypan blue in lactophenol by boiling for three minutes. The roots were observed under the microscope for AMF colonisation (Philips and Hayman, 1970).

The per cent infection was worked out as given below:

$$\text{Per cent infection} = \frac{\text{No. of positive root segments}}{\text{No. of root segments observed}} \times 100$$

3.2.3.2.2. *Azotobacter*

Azotobacter population was estimated by the soil dilution and plating method. Soil samples from the rhizosphere of different treatments were taken and sieved in 2mm mesh. One gram of the soil was suspended in 99 ml of sterilised water and serial dilutions of the suspension were prepared by further dilutions (10^{-4} and 10^{-5} dilutions were made). One ml aliquots of 10^{-4} and 10^{-5} dilutions were transferred to sterile petri dishes and then 20 ml of Ashby's N free medium was poured into each dish. Composition of Ashby's medium is as follows:

Mannitol	-	20 g
K_2HPO_4	-	0.2 g
$MgSO_4.7H_2O$	-	0.2 g
NaCl	-	0.2 g
K_2SO_4	-	0.1 g
$CaCO_3$	-	5.0 g
Agar	-	18 g
Distilled water	-	1000 ml
pH	-	6.5-7

The dilution and plating were done aseptically in a laminar air flow chamber. The plates were incubated in a BOD incubator for three to four days at 31°C and the colony count was recorded.

3.2.3.2.3. *Azospirillum* colonization

Azospirillum colonization intensity in roots of cashew was estimated using the semisolid medium of following composition.

Malic acid	-	5 g
KOH	-	4 g
K_2HPO_4	-	0.5 g
$FeSO_4$	-	0.05 g
$MnSO_4$	-	0.1 g
$MgSO_4$	-	0.1 g
NaCl	-	0.02 g
$CaCl_2$	-	0.01 g
Na_2MoO_4	-	0.002 g
Bromothymol blue in ethyl alcohol (0.5%)	-	2.5 ml
Agar	-	1.75 g
pH	-	6.5 -7

The medium was taken in test tubes. Ten root bits each of different treatments were washed in sterilised water and inserted to the media inside the laminar flow chamber. After that, the test tubes were kept in BOD incubator for three to four days at 31°C. Blue colour developed around the roots indicated the presence of *Azospirillum*.

3.2.4. Chemical analysis

The samples of litter, leaf and stem of plants were oven dried, ground and subjected to nutrient analysis following the standard procedures as given below:

Nitrogen	-	Micro Kjeldhal's method (Jackson, 1958)
Phosphorus	-	Vanadomolybdate phosphoric yellow colour method (Jackson, 1958)
Potassium	-	Flame photometry(Jackson, 1958)
Calcium Magnesium Iron Copper Zinc Manganese	-	Atomic Absorption Spectrophotometry (Sims and Jhonson,1991)

3.2.5. Statistical analysis

The data were subjected to appropriate statistical analysis using the MSTAT and STATISTICA packages.

Results

RESULTS

The results of the experiments conducted on **"Integrated nutrient management in cashew in relation to yield and quality"** are furnished below:

4.1. EXPERIMENT I

Effect of cashew litter in the nutrition of cashew

Data presented here refer to the fertilised plot at Cashew Research Station, Madakkathara.

4.1. 1. Quantity of litter

The average oven dry weight of the litter collected every month is presented in Table 1. The study revealed that the average annual litterfall in ten - year - old cashew graft plantation is 5014 kg ha^{-1}. Monthly litter contribution ranged from 138 kg during May to 738 kg in March.

From the Table, it can also be seen that there is variation in the quantity of litter between months of the year and between varieties. The maximum litterfall was in March (738 kg ha^{-1}) followed by October (577 kg ha^{-1}) and the minimum in May (138 kg ha^{-1}). Among the 10 varieties, H-856 had contributed maximum litter (6384 kg ha^{-1} yr^{-1}) followed by NDR 2-1(5448 kg ha^{-1} yr^{-1}). BLA 139-1 recorded the minimum quantity of litter of 3840 kg ha^{-1} yr^{-1}.

Table 1 Average monthly and annual litter fall in 10 cashew varieties (1997-1999)

Variety	Litter fall (kg ha^{-1})												
	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Total
BLA 139-1	550	432	186	250	270	220	160	390	460	430	250	238	3840
H-1600	910	410	168	160	260	260	170	640	440	630	320	170	4536
M 26/2	180	448	268	340	670	360	160	660	440	650	610	410	5196
H-1598	854	448	126	172	400	210	140	640	350	620	580	450	4992
BLA 39/4	312	382	168	614	460	220	190	620	428	310	490	470	4668
H-856	960	574	134	700	670	350	150	690	410	600	630	520	6384
H-1608	820	350	130	450	790	300	150	440	300	540	450	420	5256
H-1602	940	522	196	460	500	196	150	600	360	490	440	470	5328
H-1591	870	602	174	300	270	200	190	620	440	430	510	470	5076
NDR 2-1	980	788	200	358	390	160	150	470	470	520	538	324	5448
Mean	738	496	138	380	468	248	161	577	410	522	482	394	5014
SEm ±	6.79	6.12	2.36	6.22	7.4	3.35	NS	5.46	3.75	7.23	6.63	4.33	--
CD (0.05)	19.4	17.5	6.7	17.8	21.1	9.6	--	15.6	10.7	20.7	18.9	12.4	--

4.1.2. Rate of decomposition of litter

Data on the weight loss of litter during the decomposition are given in Table 2. The data showed that the weight loss of cashew leaf litter which was only to the tune of 0.9 per cent one month after laying increased steadily to 65 per cent by April, twelve months after litterfall. The rate of decomposition was slow in the early stages and then became faster especially during rainy season and then declined in the subsequent dry season.

Correlation analysis worked out between monthly weight loss of litter and the atmospheric parameters (Table 3) showed that the litter decomposition was positively correlated with rainfall, number of rainy days and relative humidity but negatively correlated with maximum temperature, minimum temperature, sunshine hours and wind speed.

4.1.3. Decay model

Data on mean weight of residue are given in Fig.3. Attempts were made to arrive at a suitable model to predict decomposition rate and one linear and one curvilinear equation were tested. The linear model of the type $y = 1.0041 + 16.549$ gave a correlation coefficient value of 0.9758, which was statistically significant. However, the curvilinear model gave higher correlation values and it was found to fit better. The equation that was the best fit took the form $W = A (B^m)(M^c)$. Estimated values based on this equation are also given in Fig.4. Extrapolations from this curve show that there will be over 90 per cent weight loss in 21 months after litterfall.

4.1.4. Nutrient content in the litter

Contents of macro and micronutrient elements in the litter are presented in Tables 4 and 5. The results revealed that the N content of the litter significantly varied with the

Table 2 Loss of weight of cashew litter during decomposition

	Months (1997-98)											
	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Residual mass (g)	14.87	14.69	13.99	12.88	12.0	11.01	9.4	7.6	6.73	6.09	5.67	5.31
Cumulative percent of decomposition	0.87	2.2	6.73	14.13	20.0	26.6	37.33	49.33	55.13	59.4	62.2	64.6

Weight of cashew litter kept for decomposition in April 1997- 15 g

Table 3 Correlation coefficient between the litter decomposition and the weather parameters

Correlation	Max. temp.	Min. temp.	Rain-fall	Rainy days	RH 1	RH 2	Sunshine hours	Wind speed
Litter decomposition	-0.664*	-0.403	0.707*	0.746**	0.650*	0.775**	-0.775**	-0.442

Fig.3. Rate of decomposition of cashew litter

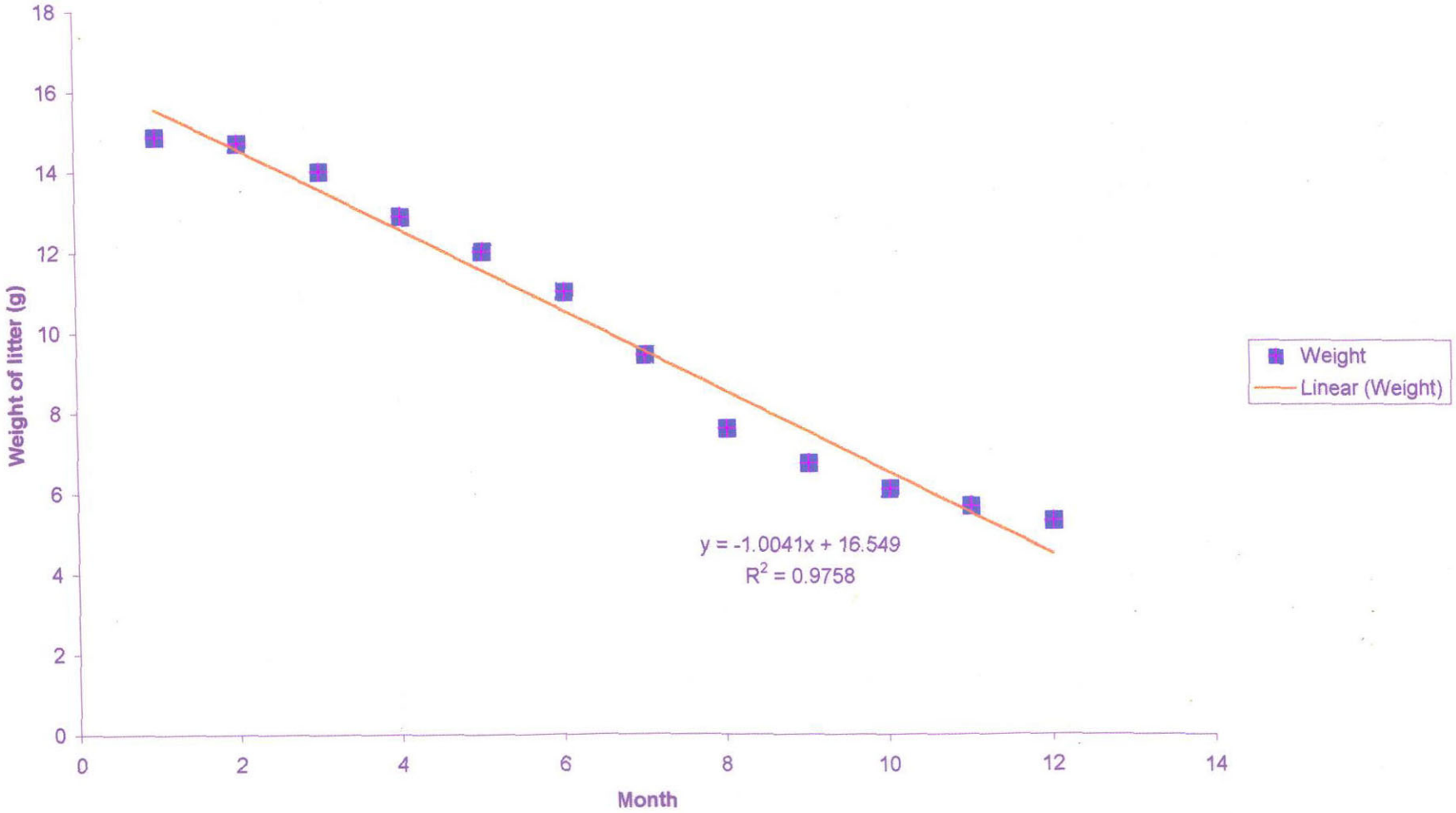


Fig. 4. Rate of decomposition of cashew litter

Weight = A*(B**Month)*(Month**C)
y= (17.24)*((0.86)**X)*(X**(0.244))

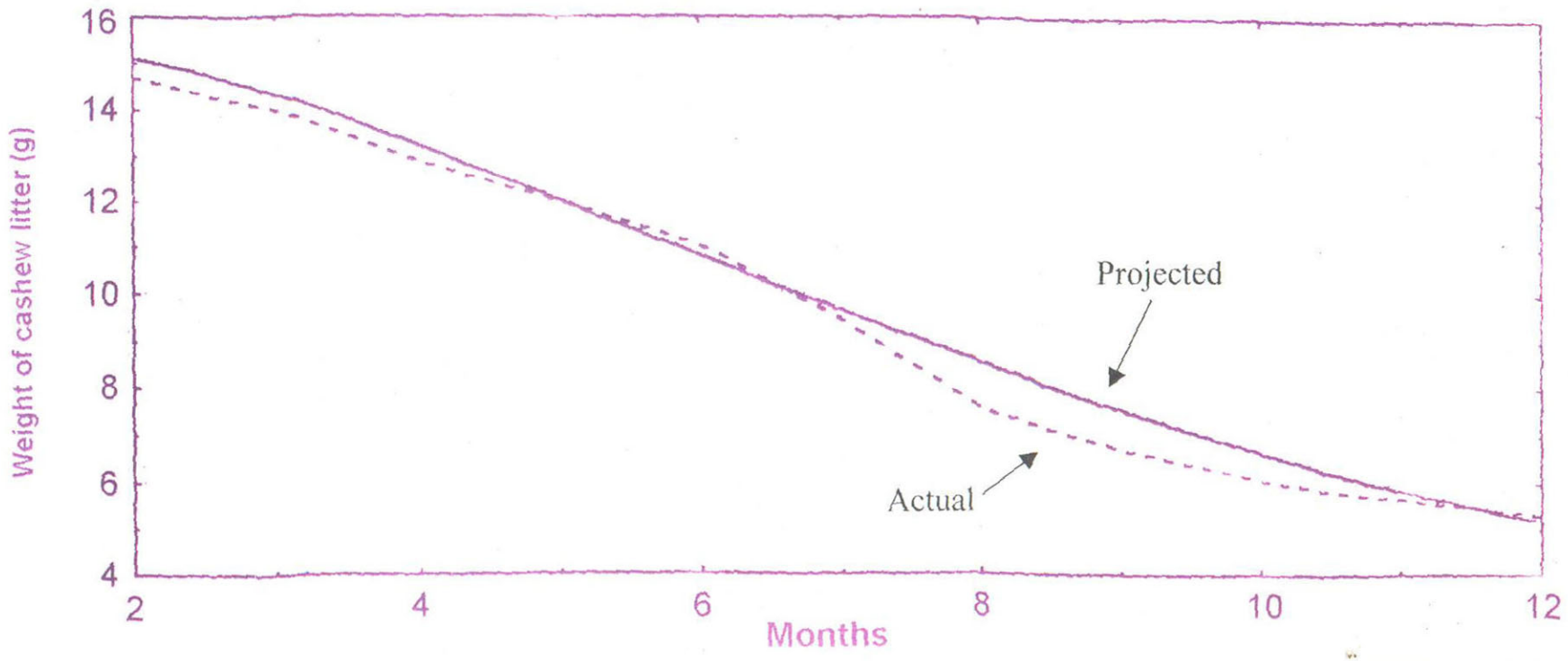


Table 4 Macro nutrient content in cashew litter

Varieties	Nutrient content (%)				
	N	P	K	Ca	Mg
BLA 139-1	0.631	0.016	0.772	0.228	0.165
H-1600	0.638	0.027	0.746	0.168	0.164
M 26/2	0.694	0.026	0.638	0.257	0.175
H-1598	0.528	0.019	0.906	0.185	0.137
BLA 39/4	0.594	0.015	0.596	0.199	0.184
H-856	0.638	0.020	0.842	0.212	0.211
H-1608	0.694	0.025	0.592	0.281	0.276
H-1602	0.572	0.024	0.658	0.222	0.171
H-1591	0.662	0.018	0.660	0.225	0.209
NDR 2-1	0.784	0.030	0.770	0.215	0.189
Mean	0.645	0.022	0.718	0.220	0.188
SEm±	0.040	0.010	0.110	0.020	0.019
CD (0.05)	0.11	NS	NS	NS	0.06

Table 5 Micro nutrient content in cashew litter

Varieties	Micro nutrient content (ppm)			
	Fe	Cu	Zn	Mn
BLA 139-1	252	16.4	15.4	196
H-1600	550	14.4	11.8	402
M 26/2	258	10.6	9.0	243
H-1598	277	10.4	8.0	84
BLA 39/4	297	11.4	25.2	271
H-856	478	9.2	10.2	434
H-1608	351	9.4	23.2	272
H-1602	404	11.8	18.6	185
H-1591	510	26.2	13.4	495
NDR 2-1	308	26.6	30.6	247
Mean	369	14.6	16.5	283
SEm±	67	5	5	84
CD (0.05)	191	NS	14.3	240

varieties. Litter of NDR 2-1 had the maximum content of 0.78 per cent and that of H-1598 had the minimum, being 0.53 per cent. P content also varied with varieties though not significantly. Litter of NDR 2-1 recorded the maximum of 0.03 per cent. There was no significant difference among varieties on the potassium and calcium contents. Potassium content ranged from 0.59 per cent to 0.91 per cent, the maximum in H-1598 and that of calcium was from 0.17 to 0.28 percent, the highest value in H-1608. Magnesium content differed significantly with varieties, which was in the range of 0.14 to 0.28 percent.

The micronutrients, except copper, showed significant difference among varieties. Iron content was maximum in H-1600 (550 ppm) and the minimum in BLA 139-1(252 ppm). Copper content varied from 9.2 ppm (H-856) to 26.6 ppm (NDR 2-1). NDR 2-1 contained the maximum zinc of 30.6 ppm and H-1591 had the highest value of 495 ppm for manganese.

4.1.5. Nutrient return

The quantities of nutrients incorporated per hectare per year were calculated and are presented in Tables 6 and 7. NDR 2-1 contributed the maximum nitrogen of 42.7 kg ha^{-1} followed by H-856 (40.5 kg ha^{-1}) and H-1598 contributed the minimum of 21.0 kg ha^{-1}. Annual return of phosphorus by NDR 2-1 was found to be the highest (1.7 kg ha^{-1}) and that by BLA 139-1(0.6 kg ha^{-1}), the lowest. The litter contributed 27.8 to 53.5 kg ha^{-1} potassium annually, the lowest by BLA 39/4 and the highest by H-856.Calcium return was maximum in H-1608 (15.1 kg ha^{-1}) whereas it was the minimum in H-1600 (6.1 kg ha^{-1}). Magnesium contribution ranged from 6.3 - 14.5 kg ha^{-1}, the maximum by H-1608 and the minimum by BLA 139-1.

Table 6 Annual Macro nutrient return through litter

Varieties	Nutrient return (kg ha^{-1})				
	N	P	K	Ca	Mg
BLA 139-1	23.65	0.62	29.64	8.8	6.3
H-1600	28.94	1.22	33.84	6.1	7.4
M 26/2	36.06	1.34	33.15	12.2	10.3
H-1598	20.96	0.94	45.23	10.0	6.9
BLA 39/4	27.73	0.69	27.82	9.3	8.6
H-856	40.50	1.26	53.45	13.5	13.4
H-1608	36.48	1.31	31.12	15.1	14.5
H-1602	30.48	1.26	35.06	11.8	6.9
H-1591	33.60	0.92	33.5	11.4	10.6
NDR 2-1	42.71	1.65	41.95	11.8	10.3
Mean	32.11	1.12	36.48	10.9	9.5
SEm±	2.35	0.16	1.88	0.10	0.10
CD (0.05)	6.71	0.46	5.37	0.29	0.29

Table 7 Quantity of micronutrients incorporated

Varieties	Micronutrient incorporated (kg ha^{-1})			
	Fe	Cu	Zn	Mn
BLA 139-1	1.0	0.10	0.10	0.7
H-1600	2.5	0.10	0.10	1.1
M 26/2	1.3	0.10	0.10	1.2
H-1598	3.2	0.10	0.10	0.5
BLA 39/4	1.4	0.10	0.10	0.8
H-856	3.0	0.10	0.10	2.5
H-1608	1.8	0.10	0.20	1.2
H-1602	2.2	0.10	0.10	1.0
H-1591	1.0	0.20	0.10	2.1
NDR 2-1	1.7	0.20	0.10	1.1
Mean	2.1	0.10	0.10	1.2
SEm±	0.01	0.01	0.01	0.03
CD (0.05)	NS	NS	NS	NS

Iron incorporation was maximum by H-1598 (3.2 kg ha^{-1}) and the minimum by BLA 139-1 and H-1591 (1.0 kg ha^{-1}) even though the differences were not significant. There was no significant difference among varieties with regard to contribution of copper, zinc and manganese also. H-1591 and NDR 2-1 recorded the maximum return of copper being 0.2 kg ha^{-1}. Contribution of zinc was maximum by H-1608 (0.2 kg ha^{-1}) and the minimum of 0.1 kg ha^{-1} was recorded by all other varieties. H-856 contributed more manganese (2.5 kg ha^{-1}) and H-1598 recorded the least value of 0.5 kg ha^{-1}.

4.2. EXPERIMENT II

Effect of fertilizer application on organic recycling in cashew plantation

This study was made by comparing the data from the fertilised plots of Expt.1 and those from an unfertilised plot of the KADP area of Vellanikkara. Data of the fertilised plot were presented earlier (Table 1 to 7).

4.2.1. *Quantity of litterfall*

Litterfall in the unfertilized plot recorded at monthly intervals for one year is presented in Table 8. It can be seen that the annual average litter production was 3215 kg ha^{-1}. The litterfall varied with the months. The maximum litterfall was in November (462 kg ha^{-1}) followed by October (455 kg ha^{-1}) and the minimum in June (79 kg ha^{-1}) whereas the fertilised plot contributed 738 Kg ha^{-1} in March and 138 Kg ha^{-1} in May.

Results of paired `t' test revealed that there was significant variation in the litterfall in the fertilized and unfertilized plots. Litter was 1799 kg more in the fertilized plot.

Table 8 Monthly litter fall in the unfertilised plot

Months	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
Litter fall ($kg\ ha^{-1}$)	86	79	156	209	254	455	462	219	195	431	316	295	3215

Table 9 Nutrient content in the litter of un fertilized plot

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)
Nutrient content	0.71	0.027	0.63	0.192	0.143	230	17	12	469
Nutrient return ($kg\ ha^{-1}$)	22.83	0.87	20.25	6.17	4.60	0.74	0.06	0.04	1.50

Table 10 Nutrient content in the litter of fertilized and unfertilized plots

Nutrients	Nutrient content		Nutrient return	
	Fertilized plot	Unfertilized plot	Fertilized plot	Unfertilized plot
N(%)	0.645	0.710	32.11	22.83
P(%)	0.022	0.027	1.12	0.87
K(%)	0.718	0.630	36.48	20.25
Ca(%)	0.220	0.192	10.9	6.17
Mg(%)	0.188	0.143	9.5	4.60
Fe(ppm)	369	230	2.1	0.74
Cu(ppm)	15	17	0.10	0.06
Zn(ppm)	17	12	0.10	0.04
Mn(ppm)	283	469	1.2	1.50

4.2.2. Nutrient content in the litter

Nutrient content in the litter of unfertilized plot is summarised in Table 9. On an average, it contained 0.71 per cent N, 0.03 per cent P, 0.63 per cent K, 0.19 per cent Ca, 0.14 per cent Mg, 230 ppm Fe, 17 ppm Cu, 12 ppm Zn and 469 ppm Mn.

A comparison of the nutrient contents done by paired `t' test showed that there was no significant variation in the contents of N, P, K, Ca, Mg and Cu among the fertilized and unfertilised plots. But significant differences could be noted in the content of Fe, Zn and Mn. It was found that Fe and Zn contents of litter were higher in fertilized plot whereas Mn was higher in litter from the unfertilised plot (Table 10).

4.2.3. Nutrient return

Nutrient return is also presented in Table 9. On an average, the litter of unfertilised plot contributed 22.8, 0.9, 20.3, 6.2, 4.6, 0.7, 0.1, 0.04 and 1.5 Kg N, P, K, Ca, Mg, Fe, Cu, Zn and Mn, respectively, per hectare.

4.2.4. Organic carbon content of the soil

The organic carbon content of soil in the fertilized plot was 1.67 per cent whereas that of unfertilized plot was 0.70 per cent.

4.3. EXPERIMENT III

4.3.1. Part I Effect of AMF inoculation on growth and establishment of cashew seedlings (Nursery stage)

Plate II

Fig.1. Seed germination enhanced by AMF inoculation

Fig. 2. A plant inoculated with *Glomus intraradices* (T_6) and Control (T_7)

4.3.1.1. Height

Height of plants was observed initially two weeks after germination and then at monthly intervals. The mean values are presented in Table 12. Plants inoculated with *G. constrictum* (T_3), G. *fasciculatum* (T_1),*G.etunicatum* (T_4) and *G. intraradices* (T_6) were superior and on par with regard to height at two weeks after germination. The same trend was observed one and two months after sowing (2MAS). At three months after sowing, *G. intraradices* gave the maximum height (55 cm) followed by *G. constrictum* (54.6 cm). The same trend was observed at 4 MAS. At 5 and 6 MAS, *G. fasciculatum* (T_1) followed by *G. intraradices* (T_6) recorded better growth.

The plants inoculated with *G. intraradices* showed consistently higher values from the 3rd month onwards.

4.3.1.2. Girth

Data on the girth of plants recorded at intervals are furnished in Table 13. At two weeks after sowing, T_1 (*G. fasciculatum*) showed significantly higher girth of 2.2 cm followed by T_5 (Native isolates from Vellayani) with 2.1 cm. By one MAS, T_1 (*G. fasciculatum*) and T_6 (*G.intraradices*) produced the highest girth of 2.3 cm even though the differences between treatments were not significant. T_4 (*G. etunicatum*) recorded the maximum girth of 3.6 cm 2 MAS.T_6 (*G. intraradices*) produced the maximum girth of 5.4 cm at 3 MAS and the same trend followed afterwards.

Highest values of girth could be observed in plants inoculated with *G. intraradices* from 3 MAS onwards.

Table 11 Percentage of germination as influenced by different types of AMF

Treatment	No. of seeds sown	No. of seeds germinated	Germination percentage
T_1 *Glomus fasciculatum*	108	88	81.5
T_2 *Glomus monosporum*	126	110	87.3
T_3 *Glomus constrictum*	126	116	92.1
T_4 *Glomus etunicatum*	128	116	90.6
T_5 Native isolates from Vellayani	126	118	93.7
T_6 *Glomus intraradices*	116	100	86.2
T_7 Control	110	94	85.5

Table 12 Height of plants at intervals as influenced by different AMF

Treatment	Height (cm)						
	Two weeks after germination	1 MAS	2 MAS	3 MAS	4 MAS	5 MAS	6 MAS
T_1 *Glomus fasciculatum*	26.7	39.2	45.0	50.0	66.2	71.6	81.8
T_2 *Glomus monosporum*	23.4	34.4	42.2	51.6	64.4	66.8	71.8
T_3 *Glomus constrictum*	28.2	40.1	46.4	54.6	69.0	70.4	73.8
T_4 *Glomus etunicatum*	26.2	33.4	40.8	52.6	64.8	67.3	75.4
T_5 Native isolates from Vellayani	23.4	35.0	37.9	49.8	64.8	68.4	77.4
T_6 *Glomus intraradices*	25.3	36.6	44.9	55.0	72.8	76.6	89.2
T_7 Control	24.4	29.8	42.2	49.0	68.2	70.4	79.2
SEm±	0.98	1.43	2.13	2.00	1.93	2.76	2.46
CD (0.05)	2.86	4.17	NS	5.83	5.63	NS	7.18

Table 13 Girth of plants at intervals as influenced by different AMF

Treatment	Girth (cm)						
	2 weeks after germination	1 MAS	2 MAS	3 MAS	4 MAS	5 MAS	6 MAS
T_1 *Glomus fasciculatum*	2.2	2.3	3.3	4.8	5.2	5.5	6.1
T_2 *Glomus monosporum*	2.1	2.2	2.9	5.2	5.3	5.5	6.5
T_3 *Glomus constrictum*	2.0	2.1	3.1	4.9	5.0	5.2	6.0
T_4 *Glomus etunicatum*	1.9	2.1	3.6	5.2	5.2	5.2	5.7
T_5 Native isolates from Vellayani	2.1	2.2	2.9	5.2	5.2	5.5	6.0
T_6 *Glomus intraradices*	2.0	2.3	3.3	5.4	5.6	5.8	6.6
T_7 Control	1.8	2.1	3.0	4.9	5.1	5.2	5.3
SEm±	0.07	0.15	0.17	0.24	0.17	0.21	0.16
CD (0.05)	0.20	NS	NS	NS	NS	0.61	0.47

Table 14 Inter nodal length at intervals as influenced by different AMF

Treatment	Inter nodal length (cm)				
	2 MAS	3 MAS	4 MAS	5 MAS	6 MAS
T_1 *Glomus fasciculatum*	2.7	2.8	3.4	4.0	4.4
T_2 *Glomus monosporum*	2.7	2.6	3.1	3.4	3.0
T_3 *Glomus constrictum*	3.6	3.9	3.2	3.9	4.7
T_4 *Glomus etunicatum*	3.2	3.3	2.9	4.2	4.5
T_5 Native isolates from Vellayani	2.8	2.9	3.1	3.5	4.0
T_6 *Glomus intraradices*	2.7	3.0	3.2	3.5	4.1
T_7 Control	3.4	4.0	3.1	4.0	4.8
SEm±	0.19	0.21	0.27	0.24	0.30
CD (0.05)	0.55	0.61	0.79	0.70	NS

4.3.1.3. Inter nodal length

Data on the inter nodal length of plants are presented in Table 14. T_3 (*G. constrictum*) recorded the higher value of internodal length at 2 MAS. T_7(Control) has recorded significantly higher inter nodal length followed by T_3 at 6 MAS.

4.3.1.4. Number of leaves

Table 15 shows the variation in the number of leaves. At 2 MAS, there was significant difference in the number of leaves. T_6 (*G. intraradices*) and T_1 (*G. fasciculatum*) recorded the maximum of 16.8 and 16.2, respectively. At 3 MAS, T_2 (G. *monosporum*) had the maximum number followed by T_6 (*G. intraradices*) though the difference was not significant. During 4^{th} and 5^{th} months again, T_6 (*G. intraradices*) has recorded the highest values of 22.8 and 22.0, respectively. The leaves began to fall off from fifth month onwards and hence there was reduction in the number of leaves. At 6 MAS, T_2 (*G. monosporum*) had the maximum (23.6) and T_3 (*G. constrictum*), the minimum (15.6) mean leaf number values.

Plants inoculated with *G. monosporum* (T_2) had the maximum number of leaves at 6 MAS.

4.3.1.5. Root spread

Data on the horizontal and vertical spread of roots 6 MAS are given in Table 16. T_6 (*G. intraradices*) had the maximum spread of roots both vertically and horizontally. It had 44.3 cm length horizontally and 23.2 cm vertically. T_1 (*G. fasciculatum*) recorded the second highest values of 37.9 and 18 cm, respectively.

Table 15 Number of leaves at intervals as influenced by AMF

Treatment	Number of leaves				
	2 MAS	3 MAS	4 MAS	5 MAS	6 MAS
T_1 *Glomus fasciculatum*	16.2	17.6	19.4	17.8	18.6
T_2 *Glomus monosporum*	15.6	19.6	21.0	19.8	23.6
T_3 *Glomus constrictum*	13.0	14.0	21.6	18.0	15.6
T_4 *Glomus etunicatum*	12.6	16.0	22.6	16.0	16.8
T_5 Native isolates from Vellayani	13.4	17.0	20.8	19.8	19.2
T_6 *Glomus intraradices*	16.8	18.2	22.8	22.0	22.0
T_7 Control	12.4	15.2	22.2	17.6	16.4
SEm±	0.95	1.64	1.57	1.82	1.70
CD (0.05)	2.77	NS	NS	NS	4.96

Table 16 Root spread six months after sowing as influenced by AMF

Treatment	Root spread (cm)	
	Horizontal	Vertical
T_1 *Glomus fasciculatum*	37.9	18.0
T_2 *Glomus monosporum*	22.8	13.0
T_3 *Glomus constrictum*	26.6	15.5
T_4 *Glomus etunicatum*	31.1	16.5
T_5 Native isolates from Vellayani	33.9	17.1
T_6 *Glomus intraradices*	44.3	23.2
T_7 Control	21.3	14.9
SEm±	1.49	0.73
CD (0.05)	4.35	2.13

4.3.1.6. Dry weight

Table 17 gives the dry weight of leaf, stem and root and the root-shoot ratio recorded six months after sowing (Plate II Fig. 2).

The leaf dry weight of 66.9 g recorded in T_6 (*G. intraradices*) was the highest followed by T_1 (*G. fasciculatum*) being 58.0 g. Stem dry weight was the highest in *G. fasciculatum* (158.9 g) while T_5 (Native isolates from Vellayani) recorded the second highest value of 155 g. Root weight was higher in T_6 (*G. intraradices*) and T_1 (*G. fasciculatum*) being 25.3 and 21.0 g, respectively. Root-shoot ratio was the highest in T_6 (0.17) followed by T_1 (0.13).

4.3.1.7. Nutrient content

Table 18 shows the nutrient content in the leaf. The highest nitrogen content was noticed in T_6 (*G. intraradices*), being 2.0 per cent, though the differences were not significant. Phosphorus content was the highest (0.09%) in T_6, T_1 and T_4. Content of zinc was significantly higher in T_6 (*G. intraradices*) followed by T_5 (Native isolates from Vellayani). Copper content was maximum in T_2 followed by T_1 (37 and 18 ppm, respectively) while iron content was the highest in T_6 followed by T_1 (290 and 202 ppm, respectively).

Data on the nutrient content in the stem are presented in Table 19. T_6 (*G. intraradices*) and T_1 (*G. fasciculatum*) recorded two per cent nitrogen, which was the highest. T_1 (*G. fasciculatum*) had the highest phosphorus content (0.87%) followed by T_6 (*G. intraradices*) being 0.84%. Zinc content was the highest (21 ppm) in T_6 (*G. intraradices*). Regarding copper and iron contents, T_6 (*G. intraradices*) showed the

Table 17 Dry weight of leaf, stem, root and root/shoot ratio as influenced by different AMF

Treatment	Dry weight plant^{-1} (g)			
	Leaf	Stem	Root	Root/Shoot ratio
T_1 *Glomus fasciculatum*	58.0	158.9	21.0	0.13
T_2 *Glomus monosporum*	38.2	140.3	14.6	0.10
T_3 *Glomus constrictum*	43.1	143.4	15.2	0.11
T_4 *Glomus etunicatum*	48.2	148.1	17.4	0.12
T_5 Native isolates from Vellayani	54.6	155.0	17.7	0.11
T_6 *Glomus intraradices*	66.9	150.8	25.3	0.17
T_7 Control	37.7	138.7	14.9	0.11
SEm±	1.61	3.53	1.06	0.01
CD (0.05)	4.70	10.30	3.09	0.03

Table 18 Nutrient content in the leaf as influenced by different AMF

Treatment	Nutrient content				
	N (%)	P (%)	Zn(ppm)	Cu (ppm)	Fe (ppm)
T_1 *Glomus fasciculatum*	1.8	0.09	7	18	202
T_2 *Glomus monosporum*	1.3	0.07	8	37	140
T_3 *Glomus constrictum*	1.7	0.08	8	16	140
T_4 *Glomus etunicatum*	1.5	0.09	7	12	130
T_5 Native isolates from Vellayani	1.2	0.08	12	13	160
T_6 *Glomus intraradices*	2.0	0.09	15	15	290
T_7 Control	1.1	0.07	6	13	150
$SEm_{\pm}$	0.27	0.01	1	0.04	32
CD (0.05)	NS	NS	3	NS	93.4

Table 19 Nutrient content in the stem as influenced by different treatments

Treatment	Nutrient content				
	N (%)	P (%)	Zn (ppm)	Cu (ppm)	Fe (ppm)
T_1 *Glomus fasciculatum*	2.0	0.87	20	27	180
T_2 *Glomus monosporum*	1.6	0.71	19	19	151
T_3 *Glomus constrictum*	1.4	0.59	19	18	154
T_4 *Glomus etunicatum*	1.7	0.62	19	18	163
T_5 Native isolates from Vellayani	1.8	0.59	19	19	170
T_6 *Glomus intraradices*	2.0	0.84	21	41	189
T_7 Control	1.7	0.57	18	19	162
SEm±	0.09	0.03	1.0	1.0	61
CD (0.05)	0.26	0.07	NS	NS	NS

Table 20 Nutrient uptake as influenced by different treatments

Treatment	Nutrient uptake (g plant^{-1})				
	N	P	Zn	Cu	Fe
T_1 *Glomus fasciculatum*	4.1	1.4	0.004	0.005	0.030
T_2 *Glomus monosporum*	2.7	1.0	0.003	0.005	0.022
T_3 *Glomus constrictum*	2.7	0.9	0.003	0.003	0.023
T_4 *Glomus etunicatum*	3.2	1.0	0.003	0.004	0.025
T_5 Native isolates from Vellayani	3.2	1.0	0.004	0.005	0.027
T_6 *Glomus intraradices*	4.3	1.3	0.004	0.007	0.031
T_7 Control	2.6	0.8	0.003	0.003	0.023
SEm±	0.19	0.5	0.001	0.001	0.001
CD (0.05)	0.55	NS	NS	0.002	0.003

highest values of 41 and 189 ppm, respectively. It is to be noted that these differences in the stem micronutrient content were not significant except that of Fe.

4.3.1.8. Nutrient uptake

Nutrient uptake worked out from the nutrient content and the plant dry weight is presented in Table 20. Uptake of nitrogen was the highest in T_6 (*G. intraradices*) with 4.3 g. In the case of phosphorus, uptake was 1.4 g in T_1 (*G. fasciculatum*) followed by T_6 (*G. intraradices*) with 1.3g. Maximum uptake was observed in T_6 (*G. intraradices*), T_5 (Native isolates from Vellayani) and T_1 (*G. fasciculatum*) for zinc (0.004g). The values of 0.007 and 0.005 were recorded as the uptake of copper in T_6 (*G. intraradices*) and T_1 (*G. fasciculatum*), T_2 and T_5. The same trend was observed in the case of iron uptake where T_6 (*G. intraradices*) had the value of 0.031 g and T_1 (*G. fasciculatum*) had 0.030 g.

4.3.1.9. AMF infection

The percentage infection of AMF in different treatments, which ranged from 57.2 to 89.5%, is furnished in Table 21. Among the different species, the percentage infection was maximum in T_6 (*G. intraradices*), followed by T_1 (*G.fasciculatum*) being 89.5 and 82.3%, respectively. T_2 (*G. monosporum*) had the minimum of 57.2% (Plate II Fig.3 & 4). Uninoculated control had 59.3% infection.

4.3.2. Part II Effect of AMF inoculation on growth and development of cashew (main field)

A set of seedlings treated with different AMF species from the nursery study were used as rootstock and scion of variety "Dhana" was grafted on them in May 1997.

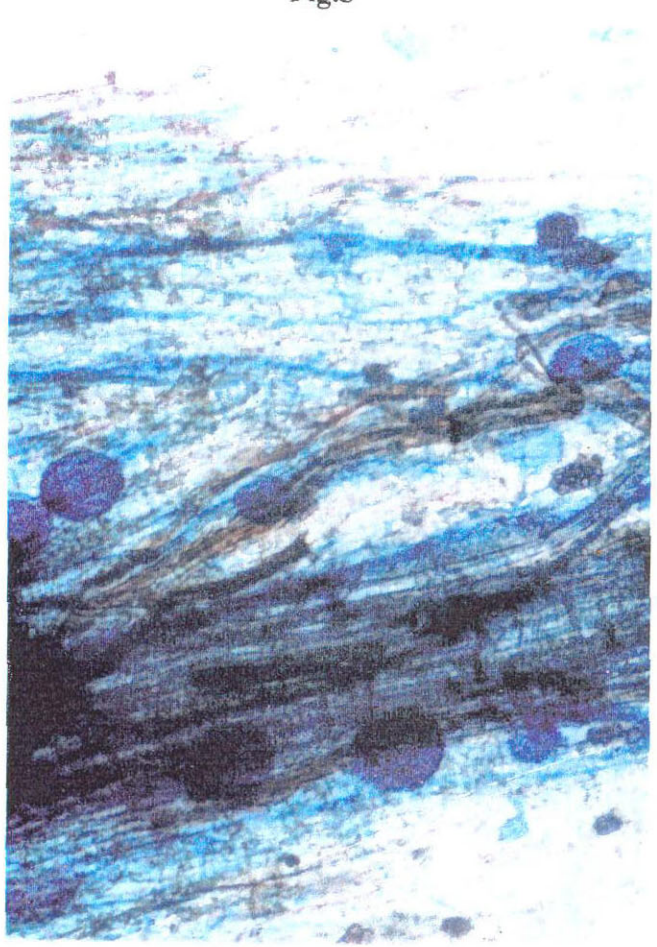
Table 21 Percentage infection of AMF in different treatments

Treatment	Infection (%)
T_1 *Glomus fasciculatum*	82.3
T_2 *Glomus monosporum*	57.2
T_3 *Glomus contrictum*	75.6
T_4 *Glomus etunicatum*	70.4
T_5 Native isolates from Vellayani	78.1
T_6 *Glomus intraradices*	89.5
T_7 Control	59.3

Table 22 Height of seedlings in the field as influenced by AMF

Treatment	Height (cm)					
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP
T_1 *Glomus fasciculatum*	124.3	158.7	191.5	272.0	329.3	386.7
T_2 *Glomus monosporum*	138.0	169.3	197.2	272.5	296.7	330.0
T_3 *Glomus constrictum*	126.5	188.2	204.8	261.8	299.0	366.7
T_4 *Glomus etunicatum*	116.7	167.2	186.2	240.8	280.0	361.7
T_5 Native isolates from Vellayani	127.2	176.0	195.7	256.2	299.3	336.7
T_6 *Glomus intraradices*	138.7	191.3	214.3	301.7	321.8	401.7
T_7 Control	124.2	166.8	191.3	239.0	294.0	356.7
SEm±	6.79	10.38	9.34	19.93	16.23	19.85
CD (0.05)	NS	NS	NS	NS	NS	57.70

Plate II



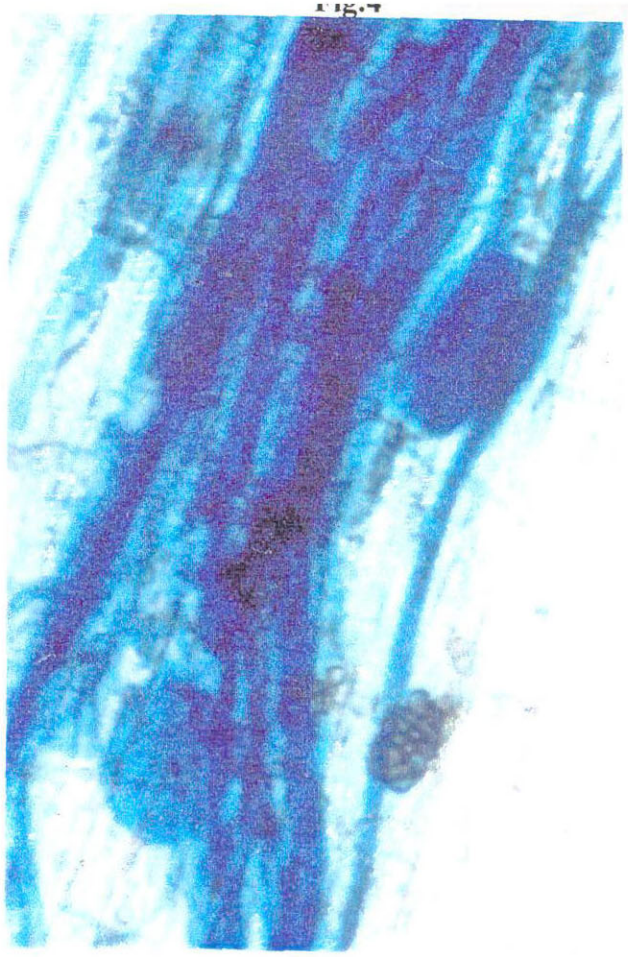


Fig. 3 & 4. Arbuscules formed by the infection of AMF in the root

Both the seedlings and grafts were planted in the main field during August 1997 and the performance was evaluated for two years. Growth characters as well as yield of the first year were recorded.

4.3.2.1. Height

Height of plants was observed at an interval of three months. In the case of seedlings, T_6 (*G. intraradices*) has recorded consistently higher values till 12 MAP. T_6 (*G. intraradices*) had the maximum height during 18 MAP. Data are presented in Table 22. In the case of grafts also the same trend was observed (Table 23) upto 12 MAP. But, at 15 MAP, *G.etunicatum* inoculated plants were superior, while T_6 recorded the maximum height of 336.3 cm at 18 MAP.

4.3.2.2. Girth

Regarding girth of seedlings in the field during 6 and 9 MAP, T_6 (*G. intraradices*) recorded the highest values but 3 MAP, T_3 and T_5 had higher values though not significant. In the grafts, T_6 (*G. intraradices*) showed the maximum girth of 5.2 cm (3 MAP) and 38.2 cm (18 MAP) during the period (Tables 24 and 25).

4.3.2.3. Branches

Figures on the number of branches are given in Table 26 and 27. During 9 MAP, T_6 (*G. intraradices*) has recorded the maximum number of branches (5) and the same trend was observed during subsequent periods. In the grafts also, T_6 was better though not significant, followed by T_4 (G. *etunicatum*).

Table 23 Height of grafts in the field as influenced by AMF

Treatment	Height (cm)					
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP
T_1 *Glomus fasciculatum*	101.5	144.2	171.2	231.2	271.0	299.4
T_2 *Glomus monosporum*	96.3	133.7	145.3	212.2	228.7	300.5
T_3 *Glomus constrictum*	88.8	130.8	162.8	216.7	267.5	305.6
T_4 *Glomus etunicatum*	93.5	148.7	152.8	244.2	306.0	321.5
T_5 Native isolates from Vellayani	88.7	132.0	147.3	226.2	251.2	284.7
T_6 *Glomus intraradices*	109.3	157.5	176.2	251.8	273.5	336.3
T_7 Control	96.0	137.5	170.0	217.2	232.3	280.1
SEm±	5.28	9.24	8.88	11.78	16.97	27.99
CD (0.05)	NS	NS	NS	NS	49.3	81.4

Table 24 Girth of seedlings in the field as influenced by different AMF

Treatment	Girth (cm)					
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP
T_1 *Glomus fasciculatum*	8.0	11.8	14.5	20.8	28.0	33.7
T_2 *Glomus monosporum*	8.2	12.9	16.5	23.7	30.8	35.0
T_3 *Glomus constrictum*	8.4	12.7	16.7	22.7	28.5	35.7
T_4 *Glomus etunicatum*	8.1	13.0	15.8	21.7	28.0	33.8
T_5 Native isolates from Vellayani	8.3	13.8	16.0	22.7	30.0	32.3
T_6 *Glomus intraradices*	8.0	14.5	17.0	23.2	31.0	35.3
T_7 Control	7.5	12.3	15.7	21.8	29.3	30.5
SEm±	0.39	0.60	0.69	0.87	1.31	1.26
CD (0.05)	NS	NS	NS	NS	NS	3.70

Table 25 Girth of grafts in the field as influenced by different AMF

Treatment	Girth (cm)					
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP
T_1 *Glomus fasciculatum*	4.7	10.6	14.8	20.3	28.2	31.5
T_2 *Glomus monosporum*	4.0	9.7	13.3	20.2	27.5	30.4
T_3 *Glomus constrictum*	4.3	9.8	13.5	20.0	29.2	33.6
T_4 *Glomus etunicatum*	4.3	11.1	14.3	22.0	30.2	36.1
T_5 Native isolates from Vellayani	4.3	10.6	14.2	19.5	29.0	33.7
T_6 *Glomus intraradices*	5.2	11.8	15.7	22.5	30.2	38.2
T_7 Control	4.6	10.3	14.2	20.0	26.7	30.1
SEm±	0.24	0.57	0.70	0.77	1.21	1.20
CD (0.05)	0.70	NS	NS	NS	NS	3.50

Table 26 Number of branches of seedlings in the field as influenced by AMF

Treatment	Number of branches		
	9 MAP	12 MAP	15 MAP
T_1 *Glomus fasciculatum*	3.70	4.50	11.0
T_2 *Glomus monosporum*	4.50	4.70	9.70
T_3 *Glomus constrictum*	4.00	4.30	9.00
T_4 *Glomus etunicatum*	4.30	4.30	11.00
T_5 Native isolates from Vellayani	4.70	4.70	10.50
T_6 *Glomus intraradices*	5.00	5.00	12.70
T_7 Control	4.20	4.50	10.00
SEm±	0.51	0.41	1.09
CD (0.05)	NS	NS	NS

4.3.2.4. Nutrient content

Tables 28, 29, 30 and 31 give the macro and micro nutrient contents in the leaf of both seedlings and grafts.

Nitrogen content was relatively higher (2.3% and 1.97%, respectively) in T_6 (*G. intraradices*) and T_1 (*G. fasciculatum*) in the seedlings, though the differences were not significant. Phosphorus content was higher in T_1 (*G. fasciculatum*) being 0.11% followed by T_6 (*G. intraradices*). Potassium content ranged from 0.74-1.49%, the highest value being 1.49 % recorded by T_6 (*G. intraradices*). Ca content varied from 0.11 to 0.26 %. T_6 (*G. intraradices*) had the highest content of magnesium (0.26%).

Regarding micronutrients, T_6 (*G. intraradices*) and T_1 (*G. fasciculatum*) showed higher values of Fe being 293 and 269 ppm, respectively whereas, T_2 (*G. monosporum*) contained more of copper (34.7ppm). T_1 (*G. fasciculatum*) had the highest value of manganese (230ppm). Zinc content was maximum in T_5 (12.6 ppm). None of these differences in the content of micronutrients was statistically significant.

In the case of grafts (Table 29), nitrogen content was higher in T_6 (*G. intraradices*) being 2.3%. Phosphorus content was higher in T_5 (Native isolates from Vellayani) and T_4 (*G. etunicatum*) being 0.11%. Potassium content was in the range of 0.94-2.25%, the maximum being in T_1 (*G. fasciculatum*). Ca content ranged from 0.11 to 0.18%, the maximum in T_6 (*G. intraradices*) andT_2 (*G. monosoporum*). T_6 (*G. intraradices*) contained 0.21% magnesium. Fe content was the highest in T_1 (*G. fasciculatum*) being 294 ppm. Mn content was highest in T_6 (*G. intraradices*) with 302 ppm followed by T_2 (272 ppm). Cu content was maximum in T_1 (*G. fasciculatum)* with 20.7 ppm followed by T_5 (Native isolates from Vellayani) being 20.3 ppm. T_3 contained

Table 27 Number of branches of grafts in the field as influenced by AMF

Treatment	Number of branches		
	9MAP	12 MAP	15 MAP
T_1 *Glomus fasciculatum*	2.8	3.3	7.2
T_2 *Glomus monosporum*	1.8	3.2	6.2
T_3 *Glomus constrictum*	2.6	3.7	6.7
T_4 *Glomus etunicatum*	3.3	3.8	8.0
T_5 Native isolates from Vellayani	3.2	3.5	7.2
T_6 *Glomus intraradices*	3.5	4.2	8.3
T_7 Control	2.6	2.9	6.4
SEm±	0.45	0.44	0.78
CD (0.05)	NS	NS	NS

Table 28 Macronutrient content in the leaf of seedlings in the field as influenced by AMF

Treatment	Nutrient content (%)				
	N	P	K	Ca	Mg
T_1 *Glomus fasciculatum*	1.97	0.11	1.14	0.15	0.20
T_2 *Glomus monosporum*	1.19	0.08	0.74	0.11	0.17
T_3 *Glomus constrictum*	1.77	0.09	1.16	0.11	0.18
T_4 *Glomus etunicatum*	1.74	0.09	1.12	0.13	0.15
T_5 Native isolates from Vellayani	0.97	0.08	0.88	0.12	0.16
T_6 *Glomus intraradices*	2.30	0.10	1.49	0.26	0.26
T_7 Control	1.25	0.09	0.81	0.13	0.14
SEm±	0.39	0.01	0.13	0.12	0.02
CD (0.05)	NS	NS	NS	NS	NS

Table 29 Macronutrient content in the leaf of grafts in the field as influenced by AMF

Treatment	Nutrient content (%)				
	N	P	K	Ca	Mg
T_1 *Glomus fasciculatum*	1.62	0.76	2.25	0.14	0.16
T_2 *Glomus monosporum*	1.57	0.09	1.78	0.18	0.18
T_3 *Glomus constrictum*	0.87	0.07	0.94	0.14	0.19
T_4 *Glomus etunicatum*	1.57	0.11	1.62	0.11	0.16
T_5 Native isolates from Vellayani	1.37	0.11	1.20	0.13	0.20
T_6 *Glomus intraradices*	2.30	0.10	1.76	0.18	0.21
T_7 Control	1.70	0.09	1.93	0.17	0.16
Sem±	0.22	0.01	0.33	0.03	0.02
CD (0.05)	0.68	NS	NS	0.09	NS

Table 30 Micronutrient content in the leaf of seedlings in the field as influenced by AMF

Treatment	Micronutrient content (ppm)			
	Fe	Cu	Zn	Mn
T_1 *Glomus fasciculatum*	269	16.3	7.2	230
T_2 *Glomus monosporum*	139	34.7	9.4	141
T_3 *Glomus constrictum*	144	14.3	5.2	183
T_4 *Glomus etunicatum*	201	11.7	4.0	170
T5 Native isolates from Vellayani	204	12.0	12.6	123
T_6 *Glomus intraradices*	293	14.0	10.8	178
T_7 Control	136	11.7	4.8	113
SEm±	60.0	5.7	5.3	103
CD (0.05)	NS	NS	16.3	NS

Table 31 Micronutrient content in the leaf of grafts in the field as influenced by AMF

Treatment	Micronutrient content (ppm)			
	Fe	Cu	Zn	Mn
T_1 *Glomus fasciculatum*	294	20.7	6.8	196
T_2 *Glomus monosporum*	209	18.0	10.2	272
T_3 *Glomus constrictum*	216	13.7	20.0	137
T_4 *Glomus etunicatum*	261	10.0	10.2	111
T_5 Native isolates from Vellayani	190	20.3	14.0	182
T_6 *Glomus intraradices*	151	16.0	14.8	302
T_7 Control	175	13.7	10.4	186
SEm±	44.3	4.1	3.2	53
CD (0.05)	NS	NS	9.9	163

Table 32 Nut yield as influenced by AMF

Treatment	Nut yield (g)	
	Seedlings	Grafts
T_1 *Glomus fasciculatum*	110.4	842.9
T_2 *Glomus monosporum*	16.3	184.3
T_3 *Glomus constrictum*	86.4	697.9
T_4 *Glomus etunicatum*	60.5	388.8
T_5 Native isolates from Vellayani	45.1	433.9
T_6 *Glomus intraradices*	547.2	1001.3
T_7 Control	12.5	223.7

Plate III

Fig.1. A view of AMF inoculated plants in the fiel

Fig.2. AMF inoculated seedling in bearing stage

Fig. 3. AMF inoculated graft in bearing stage

maximum Zinc being 20 ppm. Manganese content was the highest in T_6 (*G. intraradices*) with 302 ppm.

4.3.2.5. Yield

Both the seedlings and grafts flowered during the second year of planting but no fruit set was observed. The inoculated plants as well as those of the uninoculated control showed flowering (Plate III) but the inoculated plants were apparently superior in flowering. During the third year, the seedlings gave 45 to 547 g of nuts whereas the grafts recorded 184 to 1001 g. In the case of nut yield also, T_6 (*G. intraradices*) was superior compared to other treatments. T_1 (*G. fasciculatum*) was the second highest yielder followed by T_3 (Table 32).

4.3.3. Part III Comparative efficacy of different strains of AMF with different sources of ^{32}P labelled fertilizers.

Table 33 shows the total counts (cpm) in LSC indicating the absorption of ^{32}P from labelled mono calcium phosphate and tri calcium phosphate, total P content and the specific activity as influenced by AMF in three-month-old seedlings. The study revealed that mycorrhizae had significant influence on ^{32}P uptake.

4.3.3.1. Total count

Among the two AMF species tried, *G. fasciculatum* showed the maximum uptake of ^{32}P being 12318.2 cpm. The value was minimum in the control (4985.0 cpm). Regarding the sources of ^{32}P, the uptake from MCP was the maximum (14472.1 cpm) while that from TCP was only 552.7 cpm. The highest count of 12929.3 cpm was observed with 200% of the recommended dose whereas the value was the least with

Table 33 ^{32}P count, total P and specific activity as influenced by different AMF and sources and doses in three-month-old seedlings

Treatment	Total count (cpm)	Total P (µg)	Specific activity (cpm/µg)
AMF			
V_1 *G. fasciculatum*	12318.2	31725.8	1.00
V_2 *G. etunicatum*	5525.2	28826.7	0.32
V_3 Control	4985.0	16858.8	0.35
SEm±	1750	3055.2	0.17
CD (0.05)	5073.5	8848.8	0.49
Sources of P			
P_1 Monocalcium phosphate	14472.1	19521.0	1.10
P_2 Tricalcium phosphate	552.7	12087.0	0.02
SEm±	583.4	2494.5	0.15
CD (0.05)	1691.4	7231.9	0.43
Doses of P			
D_1 50% of the recommended dose	6505.5	31211.2	0.43
D_2 Recommended dose	3102.3	17886.0	0.17
D_3 200% of the recommended dose	12929.3	21313.7	1.08
SEm±	714.5	3055.1	0.18
CD (0.05)	NS	8857.2	0.52

Table 34 Interaction effect of AMF and sources of P on total count in three-month-old seedlings

AMF	Count (cpm)	
	MCP(P_1)	TCP(P_2)
V_1 *G. fasciculatum*	24373	263
V_2 *G. etunicatum*	9304	667
V_3 Control	9739	728
SEm±	1011	
CD (0.05)	2931	

recommended dose being 3102.3 cpm. A count of 6505.5 cpm was noted with 50% of the recommended dose (Table 33).

The interactions among AMF and sources of P, AMF and doses of P, sources of P and doses of P were significant (Table 34,35 and 36). *Glomus fasciculatum* with MCP recorded the highest count of 24373 cpm and with 200% of the recommended dose, which was 20485 cpm. MCP with 200% of the recommended dose gave the maximum count of 25243 cpm. The interaction among AMF, sources of P and doses of P was also significant. *G. fasciculatum* recorded the highest count of 40521 cpm with MCP at 200% of the recommended dose.

4.3.3.2. Total phosphorus

Total P content was the highest in *G. fasciculatum* inoculated plants (31725.8 ppm) whereas it was 28826.7 ppm in *G. etunicatum* inoculated ones. Control plants had the lowest value of 16858.8 ppm. MCP treated plants recorded the higher content of 19521 ppm while it was 12087 ppm with TCP treated plants. P content had the maximum value of 31211.2 ppm at 50% of the recommended dose and the minimum of 21313.7 ppm at 200% of the recommended dose.

None of the interaction effects was significant.

4.3.3.3. Specific activity

The specific activity was higher in *G. fasciculatum* inoculated plants (1.00) followed by the control (0.35) as given in table 33. It was the least in *G. etunicatum* treated plants (0.32). Among the sources of P, MCP had the specific activity of 1.10 and that of TCP was 0.02. Specific activity was the highest with 200% of the recommended

Table 35 Interaction effect of AMF and doses of P on total count in three-month-old seedlings

AMF	Count (cpm)		
	D_1 50% of the recommended dose	D_2 recommended dose	D_3 200% the recommended dose
V_1 *G. fasciculatum*	14711	1759	20485
V_2 *G. etunicatum*	1661	5431	7865
V_3 Control	3145	2117	10438
SEm±	1238		
CD (0.05)	3589		

Table 36 Interaction effect of sources of P and doses of P on total count in three-month-old seedlings

Sources of P	Count (cpm)		
	D_1 50% of the recommended dose	D_2 Recommended dose	D_3 200% of the recommended dose
P_1 (MCP)	12489	5685	25243
P_2 (TCP)	524	519	615
SEm±	1010		
CD (0.05)	2928		

Table 37 Interaction effect of AMF, sources of P and doses of P on total count in three-month-old seedlings

AMF	Count (cpm)					
	P_1 (MCP)			P_2 (TCP)		
	D_1 50% of recomm-ended dose	D_2 Recomm -ended dose	D_3 200% of recomm-ended dose	D_1 50% of recomm-ended dose	D_2 Recomm -ended dose	D_3 200% of recomm-ended dose
V_1 *G.fasciculatum*	29230	3368	40521	192	149	449
V_2 *G. etunicatum*	2495	10081	15337	826	781	392
V_3 Control	5738	3607	19872	552	628	1005
SEm±	1750					
CD (0.05)	5074					

Table 38 Interaction effect of AMF and sources of P on specific activity in three-month-old seedlings

AMF	Specific activity (cpm/ µg)	
	P_1 (MCP)	P_2 (TCP)
V_1 *G. fasciculatum*	1.99	0.02
V_2 *G. etunicatum*	0.62	0.02
V_3 Control	0.68	0.02
SEm±	0.25	
CD (0.05)	0.72	

dose (1.08) whereas the values for the recommended doses and 50% of the recommended dose were 0.17 and 0.43, respectively.

The interactions among AMF and sources of P, sources and doses of P were also significant. It was 1.99 with *G. fasciculatum* and MCP (Tables 38).

4.4. EXPERIMENT IV

4.4.1. Part I Screening of effective *Azotobacter* and *Azospirillum* strains for cashew (nursery stage)

The experiment was started in October, 1996. The details regarding germination are presented in Table 39. It is seen that the highest mean germination percentage was achieved in *Azospirillum* inoculated seeds {*Azospirillum lipoferum* (V) and *Azospirillum lipoferum*(C) dressing with seeds}. The germination percentage ranged from 81.0 to 93.3% (Plate IV Fig.1).

4.4.1.1. Height

Height of plants recorded at intervals is furnished in Table 40. Two weeks after germination *Azospirillum* treated plants showed the maximum height though the differences were not significant. However, subsequent observations showed significant differences between the treatments. *Azospirillum lipoferum* (V) recorded 28.5 cm followed by T_3 [*Azospirillum lipoferum* (C)] with 27.9 cm. At 1 MAS, *Azospirillum lipoferum* dressing with seeds (T_7) resulted in the maximum height of 42.9 cm followed by *Azospirillum lipoferum* (V) with (40.3 cm). Two months after sowing, again, *Azospirillum lipoferum* dressing with seeds (T_7) had the highest value of 45.9 cm. Treatments involving *Azospirillum lipoferum* dressing with seeds and *Azospirillum*

Plate IV

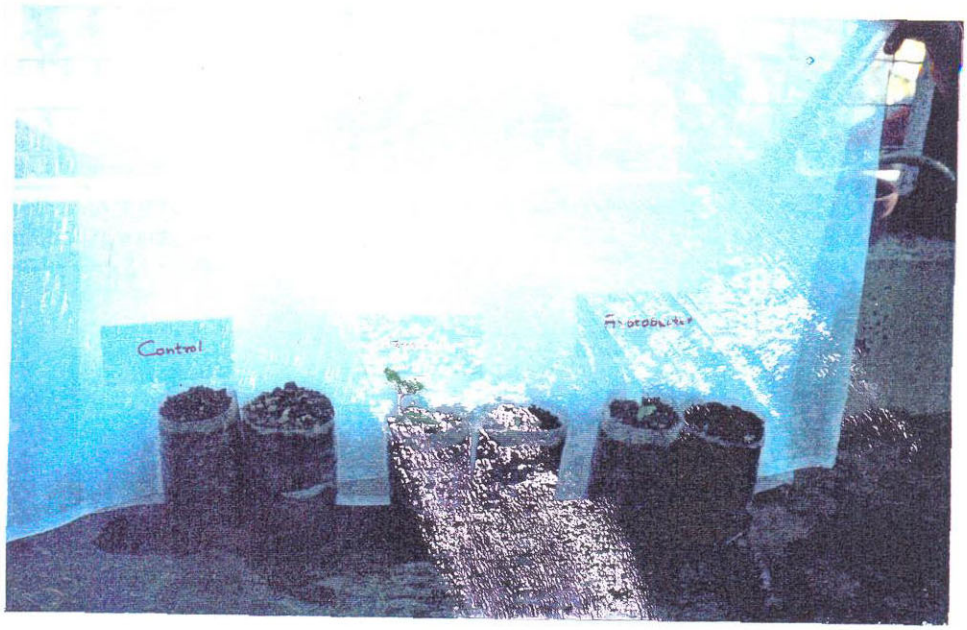


Fig. 1. Seed germination enhanced by the inoculation of *Azotobacter* and *Azospirillum*

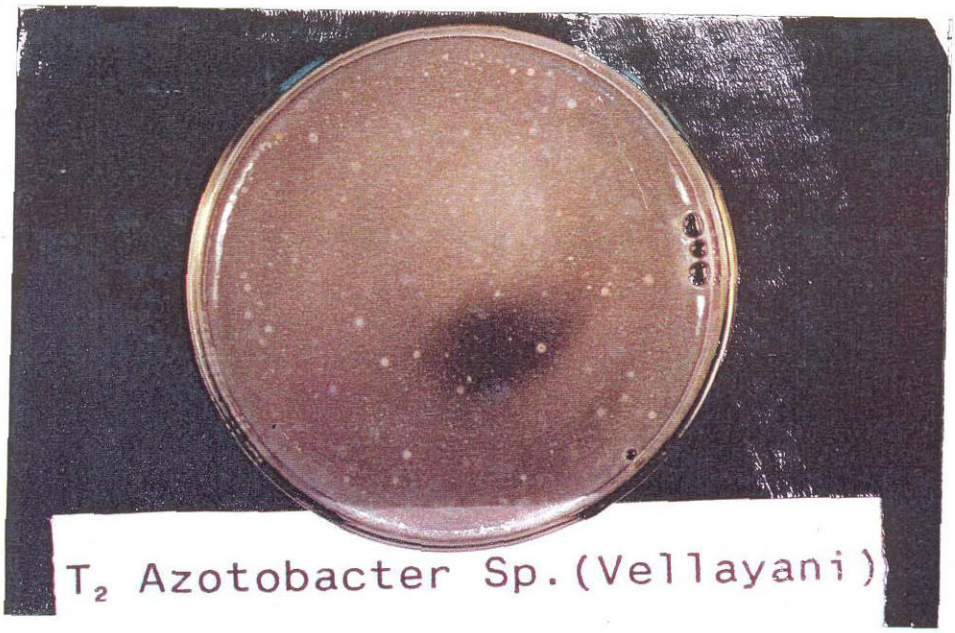


Fig. 2. Colonisation of *Azotobacter chroococcum* (V)

Table 39 Germination percentage as influenced by *Azotobacter* and *Azospirillum*

Treatment	Number Sown	Number Germinated	Germination (%)
T_1 *Azotobacter chroococcum* (C)	86	70	81.4
T_2 *Azotobacter chroococcum* (V)	80	68	85.0
T_3 *Azospirillum lipoferum* (C)	92	76	82.6
T_4 *Azospirillum lipoferum* (V)	90	84	93.3
T_5 Control	84	68	81.0
T_6 Dressing seeds with T_1	95	86	90.5
T_7 Dressing seeds with T_3	96	89	92.7

Table 40 Height of plants at intervals as influenced by *Azotobacter* and *Azospirillum*

Treatment	2 weeks after germination	Height (cm)					
		1 MAS	2 MAS	3 MAS	4 MAS	5 MAS	6 MAS
T_1 *Azotobacter chroococcum* (C)	22.8	33.9	39.1	46.0	56.0	63.6	74.0
T_2 *Azotobacter chroococcum* (V)	25.9	36.3	42.3	50.4	62.2	80.2	87.0
T_3 *Azospirillum lipoferum* (C)	27.9	35.9	41.5	49.8	64.4	64.0	71.6
T_4 *Azospirillum lipoferum* (V)	28.5	40.3	44.6	50.6	72.0	74.2	80.0
T_5 Control	26.1	36.9	40.3	47.2	59.0	61.8	65.2
T_6 Dressing the seeds with T_1	25.6	40.1	41.1	52.6	73.6	74.6	84.6
T_7 Dressing the seeds with T_3	27.2	42.9	45.9	67.0	68.6	75.2	86.8
SEm±	1.29	1.53	1.25	1.25	1.88	2.44	2.63
CD(0.05)	NS	4.43	3.62	3.62	5.45	7.07	7.62

lipoferum (V) were superior at 3 MAS also. The same trend was followed during fourth month where *Azospirillum lipoferum* (V) dressing with seeds recorded the maximum height of 67.0 cm. *Azospirillum* treated plants were superior in height upto 4 MAS. The same trend followed at 5 and 6 MAS. Uninoculated plants were inferior at all stages of growth.

4.4.1.2. Girth

Data on girth of plants are presented in Table 41. Girth was significantly higher in *Azotobacter chroococcum* (V) being 2.5 cm at two weeks after germination. One month after sowing, maximum girth was observed in *Azospirillum lipoferum* (C) dressing with seeds (2.6 cm) followed by *Azospirillum lipoferum* (V) being 2.5 cm. *Azospirillum lipoferum* (C) dressing with seeds had the highest girth of 3.4 cm whereas *Azospirillum lipoferum* (C) had 3 cm at 2 MAS. *Azospirillum lipoferum* (V) and *Azotobacter chroococcum* (V) scored the maximum values at 3 MAS. The same trend was seen at 4 and 5 MAS. At 6 MAS, *Azospirillum lipoferum* (V) had the maximum (5.9 cm) followed by *Azotobacter chroococcum* (V) and *Azospirillum lipoferum* dressing with seeds (5.5 cm).

Azospirillum inoculated plants showed higher girth during all stages of growth followed by *Azotobacter* inoculated ones. Uninoculated plants were inferior throughout all the growth stages.

4.4.1.3. Internodal length

Table 42 provides data on internodal length. It was higher in *Azospirillum lipoferum* (V) and *Azotobacter chroococcum*(C) dressing with seeds being 3.4 and 3.3, respectively, two months after sowing but at 3 and 4 MAS, *Azospirillum lipoferum* (V)

Table 41 Girth of plants at intervals as influenced by *Azotobacter* and *Azospirillum*

Treatment	2 weeks after germi-nation	Girth (cm)					
		1 MAS	2 MAS	3 MAS	4 MAS	5 MAS	6 MAS
T_1 *Azotobacter chroococcum* (C)	2.2	2.3	2.6	4.8	5.1	5.3	5.4
T_2 *Azotobacter chroococcum* (V)	2.5	2.6	2.9	5.0	5.1	5.3	5.5
T_3 *Azospirillum lipoferum* (C)	2.2	2.4	2.6	4.8	4.9	5.2	5.4
T_4 *Azospirillum lipoferum* (V)	2.3	2.5	3.0	5.0	5.2	5.6	5.9
T_5 Control	2.0	2.1	2.6	4.6	4.9	5.0	5.2
T_6 Dressing the seeds with T_1	2.1	2.3	2.9	4.4	4.8	5.1	5.3
T_7 Dressing the seeds with T_3	1.8	2.6	3.4	4.6	4.9	5.2	5.5
SEm±	0.08	0.09	0.16	0.28	0.26	0.21	0.22
CD (0.05)	0.23	0.26	0.46	0.81	NS	0.61	0.64

Table 42 Inter nodal length at intervals as influenced by *Azotobacter* and *Azospirillum*

Treatment	Inter nodal length (cm)				
	2 MAS	3 MAS	4 MAS	5 MAS	6 MAS
T_1 *Azotobacter chroococcum* (C)	2.8	3.0	2.8	3.3	4.1
T_2 *Azotobacter chroococcum* (V)	3.0	3.7	3.3	3.5	4.2
T_3 *Azospirillum lipoferum* (C)	2.9	3.6	2.9	3.1	3.5
T_4 *Azospirillum lipoferum* (V)	3.4	3.8	3.5	3.2	4.2
T_5 Control	3.0	3.0	3.2	3.6	3.8
T_6 Dressing the seeds with T_1	3.3	3.2	3.3	4.5	3.8
T_7 Dressing the seeds with T_3	3.2	3.5	3.0	4.5	4.8
SEm±	0.26	0.24	0.32	0.24	0.43
CD (0.05)	0.75	0.70	0.93	0.70	1.25

had the highest values. At 5 MAS, *Azotobacter chroococcum* (C) and *Azospirillum lipoferum* both dressed with seeds had higher values. Six months after sowing, *Azospirillum lipoferum* (C) dressing with seeds gave the maximum girth (4.8 cm).

Azospirillum inoculated plants showed the maximum inter nodal length throughout the period followed by *Azotobacter* inoculated plants.

4.4.1.4. Number of leaves

Table 43 gives the number of leaves at intervals. It was relatively more in *Azospirillum lipoferum* (C) at 2 MAS. *Azotobacter chroococcum*(C) dressing with seeds (T_6) and *Azospirillum lipoferum* (C) dressing with seeds (T_7) were better for the next two consecutive months with mean values of 19, 16.6 and 23.2, 22.6, respectively. From fourth month onwards leaves began to fall. *Azotobacter chroococcum*(C) and *Azospirillum lipoferum* (C) retained more number of leaves compared to other treatments at 5 MAS. Six months after sowing, *Azospirillum lipoferum* (C) dressing with seeds (T_7) and *Azotobacter chroococcum* (C) had the highest number of leaves.

The data in general, did not show any consistent trend in the number of leaves.

4.4.1.5. Root spread

Data on the horizontal and vertical spread of roots are furnished in Table 44.There was significant increase in the length of roots both horizontally and vertically in *Azospirillum lipoferum* (V) being 57.2 cm and 35.2 cm, respectively, followed by inoculation of both *Azotobacter* and *Azospirillum.*

Table 43 Number of leaves at intervals as influenced by *Azotobacter* and *Azospirillum*

Treatment	Number of leaves				
	2 MAS	3 MAS	4 MAS	5 MAS	6 MAS
T_1 *Azotobacter chroococcum* (C)	13.8	16.2	21.8	24.2	21.4
T_2 *Azotobacter chroococcum* (V)	13.2	12.6	16.0	18.2	17.6
T_3 *Azospirillum lipoferum* (C)	15.4	13.0	22.2	23.6	19.0
T_4 *Azospirillum lipoferum* (V)	12.4	14.2	22.0	20.0	20.6
T_5 Control	13.4	15.6	17.4	17.0	17.2
T_6 Dressing the seeds with T_1	12.4	16.6	22.6	16.6	19.6
T_7 Dressing the seeds with T_3	14.4	19.0	23.2	16.8	22.6
SEm±	0.75	1.25	1.86	1.41	1.47
CD (0.05)	NS	3.62	5.39	4.08	NS

Table 44 Root spread as influenced by *Azotobacter* and *Azospirillum*

Treatment	Root spread (cm)	
	Horizontal	Vertical
T_1 *Azotobacter chroococcum* (C)	45.6	20.4
T_2 *Azotobacter chroococcum* (V)	50.4	34.4
T_3 *Azospirillum lipoferum* (C)	34.6	25.8
T_4 *Azospirillum lipoferum* (V)	57.2	35.2
T_5 Control	23.0	15.6
T_6 Dressing the seeds with T_1	25.4	18.6
T_7 Dressing the seeds with T_3	55.4	23.6
SEm±	4.06	3.21
CD (0.05)	NS	12.54

4.4.1.6. Dry matter production

Data on dry weight of leaf, stem, root and root/shoot ratio are shown in Table 45. Dry matter production was maximum in *Azospirillum lipoferum* (V) and all other treatments registered much lower values. Root/shoot ratio was also the highest in *Azospirillum lipoferum* (V) closely followed by *Azotobacter chroococcum* (V) with 0.18 and 0.16, respectively. Control of no culture inoculation gave the lowest values of all the components.

4.4.1.7. Nutrient content

Nutrient content in the plants is furnished in Table 46. Content of nutrients except iron differed significantly with treatments. Nitrogen content was significantly superior in *Azospirillum lipoferum* (V) being 2.3% followed by 2.1% in *Azotobacter chroococcum* (V). Phosphorus content varied from 0.11% in *Azotobacter chroococcum* (C) dressing with seeds to 0.09% in *Azospirillum lipoferum* (C) dressing with seeds. Among the micronutrients, Fe content was maximum in T_5 (221 ppm) followed by T_6 (211 ppm). Copper content was higher in T_7 (26 ppm) and T_6 (21 ppm). Maximum Zn content was observed in T_1 [*Azotobacter chroococcum* (C)] and T_6 [*Azotobacter chroococcum* (C) dressing with seeds] with 27 ppm.

4.4.1.8. Nutrient uptake

Table 47 represents the nutrient uptake values on per plant basis. Uptake of nitrogen was the highest in *Azospirillum lipoferum* (V) followed by *Azotobacter chroococcum* (V) being 2.94 and 2.53 g, respectively). Phosphorus uptake was more (0.16 g) in *Azospirillum lipoferum* (V) followed by 0.14g in *Azotobacter chroococcum* (V). Regarding the micronutrients, iron uptake was maximum T_7 (0.032g) followed by

Table 45 Dry matter production as influenced by *Azotobacter* and *Azospirillum*

Treatment	Dry matter production (g)			
	Leaf	Stem	Root	Root/shoot
T_1 *Azotobacter chroococcum* (C)	24.5	74.0	9.4	0.15
T_2 *Azotobacter chroococcum* (V)	18.4	55.2	8.0	0.16
T_3 *Azospirillum lipoferum* (C)	19.7	59.0	9.4	0.12
T_4 *Azospirillum lipoferum* (V)	35.7	107.0	15.0	0.18
T_5 Control	14.9	44.8	7.2	0.11
T_6 Dressing the seeds with T_1	20.5	67.6	10.0	0.15
T_7 Dressing the seeds with T_3	22.7	68.2	9.0	0.14
Sem±	5.54	14.24	1.53	0.05
CD (0.05)	NS	NS	4.4	NS

Table 46 Nutrient content as influenced by *Azotobacter* and *Azospirillum*

Treatment	Nutrient content				
	N (%)	P (%)	Zn (ppm)	Cu (ppm)	Fe (ppm)
T_1 *Azotobacter chroococcum* (C)	2.1	0.11	27	19	210
T_2 *Azotobacter chroococcum* (V)	1.7	0.11	5	15	180
T_3 *Azospirillum lipoferum* (C)	1.8	0.10	14	12	210
T_4 *Azospirillum lipoferum* (V)	2.3	0.10	20	14	170
T_5 Control	1.6	0.09	7	13	221
T_6 Dressing the seeds with T_1	1.3	0.10	27	21	211
T_7 Dressing the seeds with T_3	0.7	0.09	19	26	150
SEm±	0.21	0.01	2.0	3.0	35
CD (0.05)	0.61	NS	5.8	8.7	NS

Table 47 Nutrient uptake as influenced by *Azotobacter* and *Azospirillum*

Treatment	Nutrient uptake (g plant^{-1})				
	N	P	Zn	Cu	Fe
T_1 *Azotobacter chroococcum* (C)	1.39	0.09	0.003	0.002	0.021
T_2 *Azotobacter chroococcum* (V)	2.53	0.14	0.004	0.002	0.013
T_3 *Azospirillum lipoferum* (C)	1.55	0.06	0.001	0.001	0.009
T_4 *Azospirillum lipoferum* (V)	2.94	0.16	0.003	0.003	0.023
T_5 Control	1.26	0.07	0.005	0.002	0.100
T_6 Dressing the seeds with T_1	1.67	0.12	0.009	0.003	0.026
T_7 Dressing the seeds with T_3	0.85	0.10	0.002	0.002	0.032
SEm±	0.40	1.86	0.006	0.001	0.043
CD (0.05)	1.16	5.39	NS	0.002	NS

Table 48 Colonization of *Azotobacter* in different treatments

Treatment	Number of colonies	
	10^{-4} dilution	10^{-5} dilution
T_1 *Azotobacter chroococcum*(C)	46	32
T_2 *Azotobacter chroococcum(V)*	78	60
T_5 Control	32	18
T_6 T_1 dressing with seeds	67	48

Table 49 Intensity of *Azospirillum* colonization in the roots of different treatments

Treatment	Intensity (%)
T_3 *Azospirillum lipoferum*(C)	75
T_4 *Azospirillum lipoferum*(V)	88
T_5 Control	38
T_7 T_3 dressing with seeds	88

Plate IV

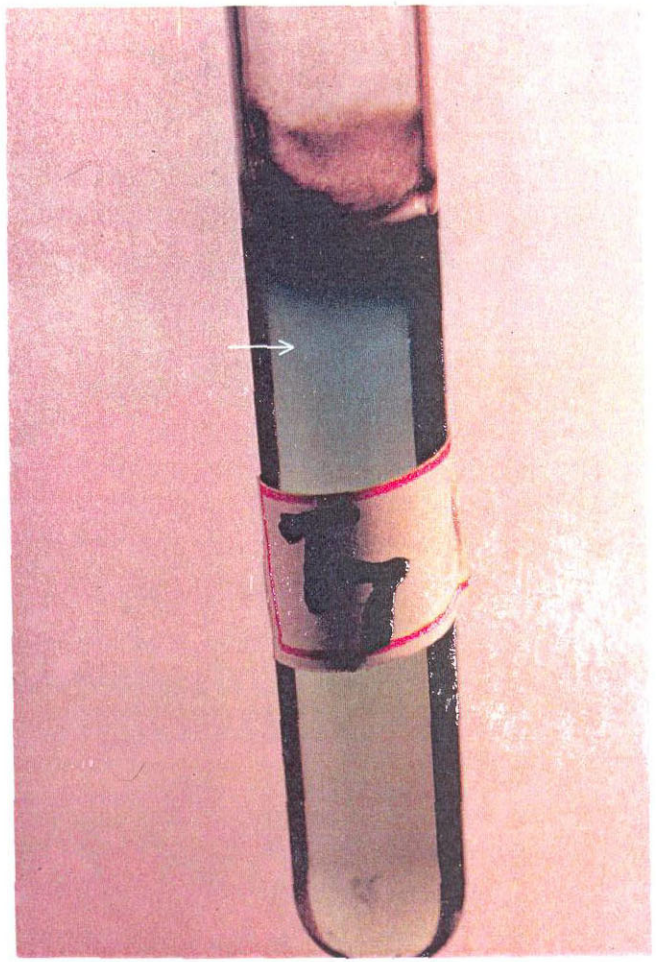


Fig. 3. Presence of *Azospirillum* indicated by the bluish colour (T_7)

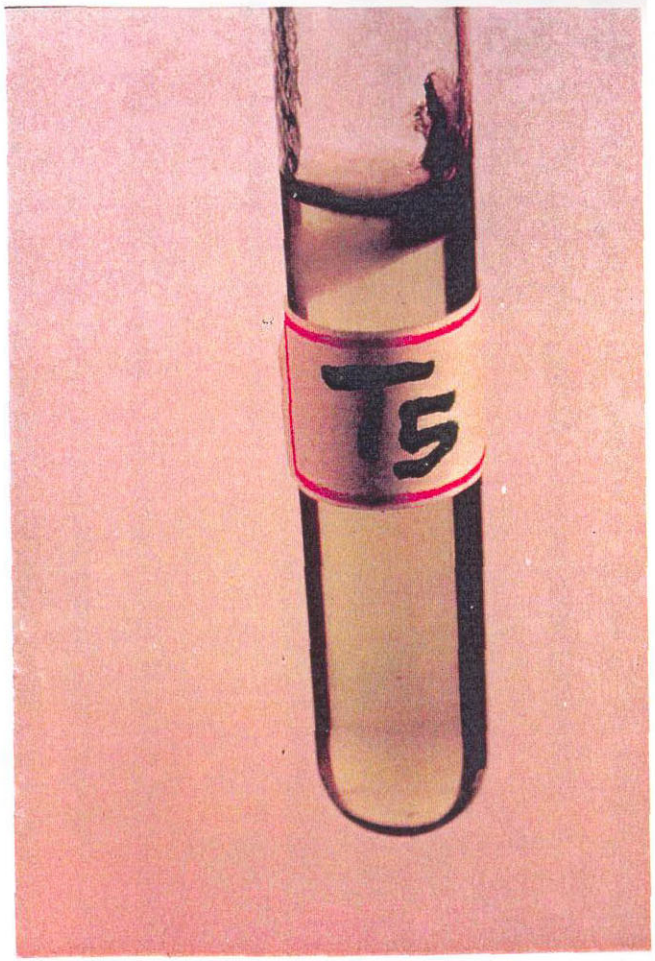


Fig.4. Control (T_5)

Azotobacter chroococcum (C) dressing with seeds (0.026g) . T_6 and T_4 recorded the highest uptake of Cu(0.003g). Maximum uptake of Zn (0.009 g) was observed in *Azospirillum lipoferum* (V) and *Azotobacter chroococcum* (C).

Azospirillum lipoferum (V) is found to be superior with regard to the nutrient uptake.

4.4.1.9. *Azotobacter* colonization

The number of colonies of *Azotobacter* developed in different treatments varied from 32 to 78 (Table 48). The count was more in 10^{-4} dilution when compared to that in 10^{-5} dilution. *Azotobacter chroococcum* (V) recorded the maximum number of colonies, being 78, whereas, the control had only 32 at 10^{-4} dilution. The same trend was observed in 10^{-5} dilution (Plate IV Fig.2).

4.4.1.10. Intensity of *Azospirillum* colonization

The intensity of *Azospirillum* colonization expressed in percentage is furnished in Table 49.It was highest in *Azospirillum lipoferum* (V) and T_7 (T_3 dressing with seeds), being 88%. Uninoculated control had the minimum of 38%(Plate IV Fig.3 & 4).

4.4.2. Part II Influence of *Azotobacter* and *Azospirillum* on growth and development of cashew (main field)

The inoculated seedlings were planted in the field during August 1997. A set of seedlings were used as root stocks for grafting the variety "Dhana" and the grafts were planted in the field and the evaluation continued for two years (Plate V Fig.1 & 2).

4.4.2.1. Height

Height of seedlings was relatively higher (104.2 cm) in *Azotobacter chroococcum* (C) and *Azotobacter chroococcum* (C) dressing with seeds (102.3 cm) three months after planting (Table 50). During later stages *Azospirillum lipoferum* (V) recorded the maximum height of 167.3,197.5,281.0,337.2 and 491.7cm,respectively at 6,9,12,15 and 18 months after sowing, though the differences between the treatments were not significant.

In the case of grafts also, the same trend was followed (Table 51). Initially T_6 *Azotobacter chroococcum* (C) dressing with seeds had the maximum height (104.4 cm), while in later periods, *Azospirillum lipoferum* (V) showed the maximum values of 175.0, 233.0, 268.7 and 329.3 cm respectively at 9,12,15 18 months after sowing.

In general, height of seedlings increased following inoculation. Though the same trend was observed in grafts also, the trend was inconsistent.

4.4.2.2. Girth

Table 52 and 53 provide the data on girth of both seedlings and grafts. In the case of both seedlings and grafts, the differences were not statistically significant except at one stage in seedlings (9 MAP). At 9 MAP, *Azotobacter chroococcum* (V) had the maximum girth of 17 cm.

4.4.2.3. Branches

Data on the number of branches of seedlings and grafts appear in Tables 54 and 55. The differences between treatments were not significant at any of the stages in both seedlings and grafts.

Table 50 Height of seedlings in the field as influenced by *Azotobacter* and *Azospirillum*

Treatment	Height (cm)					
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP
T_1 *Azotobacter chroococcum* (C)	104.2	147.2	195.3	248.2	296.5	403.3
T_2 *Azotobacter chroococcum* (V)	85.5	143.0	188.7	256.8	295.2	410.0
T_3 *Azospirillum lipoferum* (C)	92.2	155.5	191.7	199.0	273.2	425.0
T_4 *Azospirillum lipoferum* (V)	95.8	167.3	197.5	281.0	337.2	491.7
T_5 Control	86.7	135.5	153.0	210.0	307.2	388.3
T_6 Dressing the seeds with T_1	102.3	150.7	189.7	246.5	303.3	465.0
T_7 Dressing the seeds with T_3	100.3	148.0	171.5	243.2	281.0	461.7
SEm±	5.17	8.32	13.22	19.99	17.26	35.36
CD (0.05)	15.0	NS	NS	NS	NS	NS

Table 51 Height of grafts in the field as influenced by *Azotobacter* and *Azospirillum*

Treatment	Height (cm)					
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP
T_1 *Azotobacter chroococcum* (C)	72.8	127.8	147.0	200.4	245.2	280.0
T_2 *Azotobacter chroococcum* (V)	82.0	130.0	149.7	180.6	244.0	296.7
T_3 *Azospirillum lipoferum* (C)	72.0	120.5	138.3	203.8	255.5	299.0
T_4 *Azospirillum lipoferum* (V)	84.0	150.2	175.0	233.0	268.7	329.3
T_5 Control	80.8	130.8	157.5	195.5	238.8	267.3
T_6 Dressing the seeds with T_1	104.4	161.3	166.3	217.5	262.3	321.8
T_7 Dressing the seeds with T_3	95.2	139.8	159.0	198.5	264.7	291.4
SEm±	7.13	10.33	8.77	13.08	15.06	26.9
CD (0.05)	20.7	30.0	25.5	38.0	43.8	78.2

Plate V

Fig.1. A plant inoculated with *Azospirillum lipoferum* (T_4) and the control (T_5)

Fig.2. A view of *Azotobacter* and *Azospirillum* inoculated plants in the field

Table 52 Girth of seedlings in the field as influenced by Azotobacter and *Azospirillum*

Treatment	Girth (cm)					
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP
T_1 *Azotobacter chroococcum* (C)	6.0	13.3	14.2	20.8	28.8	38.83
T_2 *Azotobacter chroococcum* (V)	6.3	13.2	17.0	22.3	30.2	39.00
T_3 *Azospirillum lipoferum* (C)	5.8	11.9	16.3	21.2	28.5	37.83
T_4 *Azospirillum lipoferum* (V)	6.1	12.5	16.5	23.7	29.7	40.33
T_5 Control	5.5	10.3	15.3	19.2	25.5	34.00
T_6 Dressing the seeds with T_1	6.5	11.6	15.2	20.2	27.5	38.00
T_7 Dressing the seeds with T_3	6.3	11.9	16.5	21.4	29.0	39.30
SEm±	0.23	0.82	1.31	1.14	1.14	1.82
CD (0.05)	NS	NS	3.81	NS	NS	NS

Table 53 Girth of grafts in the field as influenced by *Azotobacter* and *Azospirillum*

Treatment	Girth (cm)					
	3 MAP	6 MAP	9 MAP	12 MAP	15 MAP	18 MAP
T_1 *Azotobacter chroococcum* (C)	3.8	9.8	14.7	19.9	27.0	28.0
T_2 *Azotobacter chroococcum* (V)	4.3	10.3	15.0	19.8	26.2	30.8
T_3 *Azospirillum lipoferum* (C)	4.0	10.5	15.2	22.3	28.2	28.5
T_4 *Azospirillum lipoferum* (V)	4.3	10.2	15.7	22.8	28.0	28.0
T_5 Control	3.7	10.3	15.0	20.1	25.8	30.0
T_6 Dressing the seeds with T_1	4.3	11.0	17.3	22.7	30.7	31.0
T_7 Dressing the seeds with T_3	4.2	10.5	14.3	19.9	28.5	29.3
SEm±	0.39	0.72	0.67	1.13	1.42	1.40
CD (0.05)	NS	NS	NS	NS	NS	NS

Plate V

Fig.3. *Azospirillum* inoculated seedling in bearing stage

Fig. 4. *Azospirillum* inoculated graft in bearing stage

Table 54 Number of branches of seedlings in the field as influenced by *Azotobacter* and *Azospirillum*

Treatment	Number of branches			
	9 MAP	12 MAP	15 MAP	18 MAP
T_1 *Azotobacter chroococcum* (C)	4.2	5.0	6.2	12.7
T_2 *Azotobacter chroococcum* (V)	3.5	5.8	6.0	10.5
T_3 *Azospirillum lipoferum* (C)	3.3	5.2	6.5	9.2
T_4 *Azospirillum lipoferum* (V)	3.0	4.7	6.3	13.8
T_5 Control	2.9	3.2	4.3	7.8
T_6 Dressing the seeds with T_1	3.0	3.2	4.3	8.8
T_7 Dressing the seeds with T_3	3.8	3.5	4.8	8.7
SEm±	1.94	0.74	0,73	1.30
CD (0.05)	NS	NS	NS	NS

Table 55 Number of branches of grafts in the field as influenced by *Azotobacter* and *Azospirillum*

Treatment	Number of branches			
	9MAP	12MAP	15MAP	18MAP
T_1 *Azotobacter chroococcum* (C)	3.3	4.0	9.2	11.0
T_2 *Azotobacter chroococcum* (V)	3.8	4.3	7.5	9.7
T_3 *Azospirillum lipoferum* (C)	3.5	3.7	8.5	10.5
T_4 *Azospirillum lipoferum* (V)	4.2	4.7	8.8	12.7
T_5 Control	4.0	4.3	7.5	9.0
T_6 Dressing the seeds with T_1	4.2	4.7	8.3	11.0
T_7 Dressing the seeds with T_3	4.0	5.2	8.3	10.0
SEm±	0.42	0.63	0.92	0.88
CD (0.05)	NS	NS	NS	NS

4.4.2.4. Nutrient content

Nutrient content in plants is given in Table 56,57,58 & 59. Highest nitrogen content in seedlings (2.3%) was observed in *Azospirillum lipoferum* (V) and 2.1% in *Azospirillum lipoferum* (C), whereas T_5 (Control) recorded the maximum phosphorus content of 0.11%, even though not significant. Potassium content varied from 0.84 to 2.04 %. Calcium and magnesium content did not differ significantly. Calcium content was higher in *Azospirillum lipoferum* (C) and *Azospirillum lipoferum* (V) being 0.18 % and 0.17%, respectively. *Azospirillum lipoferum* (V) had the highest content of Mg (0.21%).

In grafts, maximum nitrogen content (2.26%) was observed in *Azospirillum lipoferum* (V) followed by *Azospirillum lipoferum* (C) with 1.99%. Phosphorus content was relatively more in *Azotobacter chroococcum* (V) and *Azospirillum lipoferum* (C) dressing with seeds (0.11 and 0.10 %, respectively). *Azospirillum lipoferum* (V) had the highest potassium content of 1.89%. The calcium content was the highest (0.20%) in the uninoculated plants and in *Azospirillum lipoferum* (V). Magnesium content ranged from 0.15-0.19%.

Regarding the micronutrients in seedlings, Fe content was the highest in control (330 ppm) followed by *Azotobacter chroococcum* (C) dressing with seeds (280 ppm). Copper content was maximum in *Azospirillum lipoferum* (C) dressing with seeds (31 ppm) followed by *Azotobacter chroococcum* (C) dressing with seeds (23 ppm). *Azotobacter chroococcum* (V) had the maximum content of Zn (26 ppm) followed by

Table 56 Macronutrient content in seedlings in the field as influenced by *Azotobacter* and *Azospirillum*

Treatment	Nutrient content (%)				
	N	P	K	Ca	Mg
T_1 *Azotobacter chroococcum* (C)	1.7	0.10	0.84	0.14	0.17
T_2 *Azotobacter chroococcum* (V)	1.8	0.10	1.09	0.14	0.14
T_3 *Azospirillum lipoferum* (C)	2.1	0.10	1.42	0.18	0.16
T_4 *Azospirillum lipoferum* (V)	2.3	0.10	1.43	0.17	0.21
T_5 Control	1.8	0.11	1.14	0.16	0.20
T_6 Dressing the seeds with T_1	1.3	0.09	2.04	0.12	0.16
T_7 Dressing the seeds with T_3	0.4	0.08	1.50	0.01	0.15
SEm±	0.43	0.009	0.31	0.04	0.02
CD (0.05)	1.27	NS	0.91	NS	NS

Table 57 Macronutrient content in grafts in the field as influenced by *Azotobacter* and *Azospirillum*

Treatment	Nutrient content (%)				
	N	P	K	Ca	Mg
T_1 *Azotobacter chroococcum* (C)	1.42	0.08	1.11	0.13	0.15
T_2 *Azotobacter chroococcum* (V)	1.99	0.11	1.11	0.13	0.18
T_3 *Azospirillum lipoferum* (C)	0.94	0.09	1.08	0.14	0.16
T_4 *Azospirillum lipoferum* (V)	2.26	0.09	1.89	0.16	0.18
T_5 Control	0.94	0.09	1.54	0.16	0.19
T_6 Dressing the seeds with T_1	0.99	0.09	0.82	0.14	0.16
T_7 Dressing the seeds with T_3	1.27	0.10	1.13	0.15	0.18
SEm±	0.43	0.01	0.29	0.02	0.09
CD (0.05)	NS	NS	0.86	0.06	0.27

Table 58 Micronutrient content in seedlings in the field as influenced by *Azotobacter* and *Azospirillum*

Treatment	Micronutrient content (ppm)			
	Fe	Cu	Zn	Mn
T_1 *Azotobacter chroococcum* (C)	243	20	15	610
T_2 *Azotobacter chroococcum* (V)	239	13	26	482
T_3 *Azospirillum lipoferum* (C)	225	14	11	348
T_4 *Azospirillum lipoferum* (V)	187	13	20	320
T_5 Control	330	14	07	507
T_6 Dressing the seeds with T_1	280	23	05	230
T_7 Dressing the seeds with T_3	154	31	18	550
SEm±	72.9	6	4.3	99.5
CD (0.05)	NS	NS	12.7	NS

Table 59 Micronutrient content in grafts in the field as influenced by *Azotobacter* and *Azospirillum*

Treatment	Micronutrient content (%)			
	Fe	Cu	Zn	Mn
T_1 *Azotobacter chroococcum* (C)	235	13	08	160
T_2 *Azotobacter chroococcum* (V)	205	17	10	234
T_3 *Azospirillum lipoferum* (C)	124	12	22	126
T_4 *Azospirillum lipoferum* (V)	230	22	25	276
T_5 Control	143	17	15	167
T_6 Dressing the seeds with T_1	209	20	07	205
T_7 Dressing the seeds with T_3	282	26	07	154
SEm±	34.3	4.2	8.3	90.3
CD (0.05)	101.2	12.4	24.5	266.4

Azospirillum lipoferum (V) with 20 ppm, whereas, Mn content was the highest in *Azotobacter chroococcum* (C) with 610 ppm.

In grafts, *Azospirillum lipoferum* (C) dressing with seeds contained more Fe (282 ppm) followed by 235 ppm in *Azotobacter chroococcum* (C). Copper content was the highest in *Azospirillum lipoferum* (C) dressing with seeds (26 ppm) and 22 ppm in *Azospirillum lipoferum* (V). Maximum Zn content of 25 ppm was noticed in *Azospirillum lipoferum* (V) followed by 22 ppm in *Azospirillum lipoferum* (C) while *Azospirillum lipoferum* (V) and *Azotobacter chroococcum* (V) had higher Mn content of 276 ppm and 234 ppm, respectively.

4.4.2.5. Yield

Table 60 shows the nut yield from each treatment in seedlings and grafts. In both the cases, *Azospirillum lipoferum* (V) had produced the maximum nut yield of 355.2 and 251.2 g, respectively (Plate V Fig. 3 & 4). *Azotobacter chroococcum* (V) was the second (PlateVI Fig.1) in seedlings (223.7 g) and *Azospirillum lipoferum* (C) in grafts (182.4 g).

4.4.3. Part III Interaction effect of *Azotobacter, Azospirillum* and AMF on cashew

Treatments for this experiment, which were selected based on the screening trial in nursery, are given below.

T_1 AMF alone (*Glomus intraradices*)

T_2 AMF + *Azotobacter chroococcum* (V)

T_3 AMF+ *Azospirillum lipoferum* (V)

T_4 AMF+ *Azotobacter* + *Azospirillum*

Table 60 Nut yield /plant as influenced by *Azotobacter* and *Azospirillum*

Treatment	Nut yield (g)	
	Seedling	Grafts
T_1 *Azotobacter chroococcum* (C)	81.6	129.6
T_2 *Azotobacter chroococcum* (V)	223.7	94.4
T_3 *Azospirillum lipoferum* (C)	97.2	182.4
T_4 *Azospirillum lipoferum* (V)	355.2	251.2
T_5 Control	41.5	154.8
T_6 Dressing the seeds with T_1	48.0	148.8
T_7 Dressing the seeds with T_3	137.3	124.8

Table 61 Height and girth of plants as influenced by combined inoculation

Treatment	3 months after inoculation		6 months after inoculation	
	Height (cm)	Girth (cm)	Height (cm)	Girth (cm)
T_1 AMF alone	82.1	7.1	107.5	11.4
T_2 AMF + *Azotobacter*	91.3	7.2	105.4	9.4
T_3 AMF + *Azospirillum*	109.0	8.2	116.9	8.2
T_4 AMF + *Azotobacter* + *Azospirillum*	95.5	7.2	112.0	9.1
T_5 Control	66.7	6.5	75.5	8.2
SEm±	0.54	0.06	0.59	0.22
CD (0.05)	2.18	0.24	2.39	0.89

Plate VI

Fig. 1. *Azotobacter* inoculated seedling in bearing stage

Fig. 2. Root spread as influenced by different biofertilizers

T_5 Control

4.4.3.1. Height and girth

Table 61 shows that among the different treatments of combined inoculation, AMF + *Azospirillum* (T_3) is significantly superior in the height of plants (109 cm) followed by AMF + *Azospirillum* + *Azotobacter* (95.5 cm) three months after inoculation. Regarding the girth, AMF+ *Azospirillum lipoferum* (T_3) recorded the maximum of 8.2 cm (Table 61).

The same trend was observed in height six months after inoculation. T_3 which has AMF+ *Azospirillum* recorded the maximum height of 116.9 cm whereas the treatment receiving AMF alone had the maximum girth of 11.4 cm followed by AMF + *Azotobacter* (9.4 cm). Control gave the lowest mean of 75.5cm (height) and 8.2 cm (girth), respectively (Plate VI Fig. 4).

4.4.3.2. Root spread

Root spread (both lateral and vertical) of plants is furnished in Table 62. Vertical spread was the highest in AMF + *Azospirillum* (75.2 cm). The lateral spread was more in AMF + *Azotobacter* (T_2) and AMF alone (T_1) being 26.7 and 26.0 cm, respectively (Plate VI Fig.2 & 3).

4.4.3.3. Dry matter production

Dry weight data of leaf, stem and root are presented in Table 63. AMF + *Azospirillum* (T_3) had the highest value for leaf dry weight of 69 g followed by AMF+ *Azotobacter* + *Azospirillum* (44 g). Stem dry weight was the highest in AMF +

Plate VI

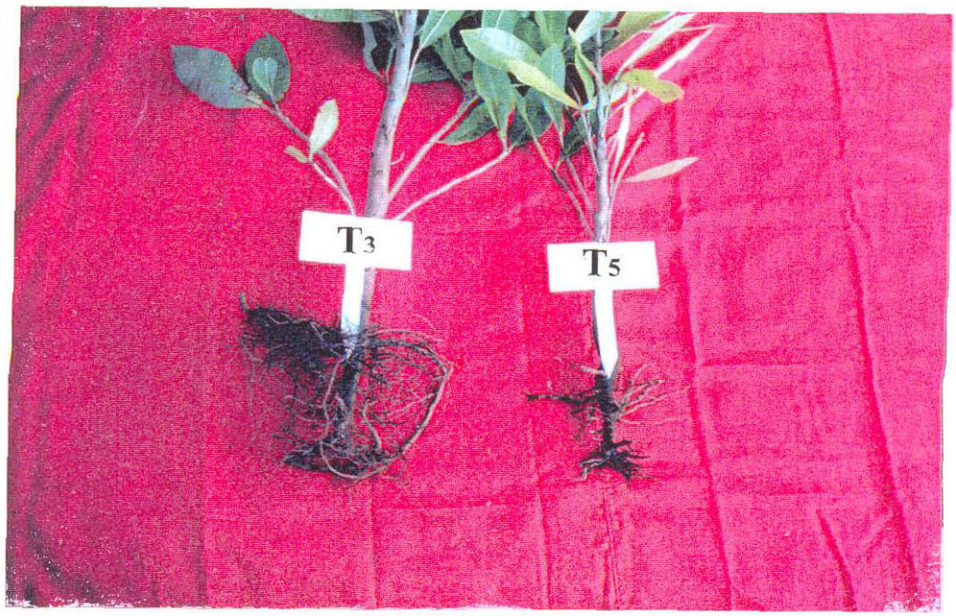


Fig. 3. Root spread as influenced by combined inoculation
T_3 – AMF + *Azospirillum* T_5 – Control

Fig. 4. Effect of combined inoculation

T_1 – AMF alone
T_2 – AMF + *Azotobacter*
T_3 – AMF + *Azospirillum*
T_4 – AMF + *Azotobacter* + *Azospirillum*
T_5 – Control

Table 62 Root spread of plants as influenced by combined inoculation

Treatment	Root spread (cm)	
	Vertical	Lateral
T_1 AMF alone	42.4	17.7
T_2 AMF + *Azotobacter*	54.5	26.0
T_3 AMF + *Azospirillum*	75.2	26.7
T_4 AMF + *Azotobacter* + *Azospirillum*	62.1	21.0
T_5 Control	34.0	16.3
SEm±	0.62	0.51
CD (0.05)	1.87	1.54

Table 63 Dry weight of leaf, stem and roots as influenced by combined inoculation

Treatment	Dry weight (g)		
	Leaf	Stem	Root
T_1 AMF alone	44.0	85.8	24.0
T_2 AMF + *Azotobacter*	38.0	93.8	11.5
T_3 AMF + *Azospirillum*	69.0	107.0	27.0
T_4 AMF + *Azotobacter* + *Azospirillum*	33.0	75.5	22.5
T_5 Control	26.5	54.8	11.3
SEm±	4.39	11.71	2.11
CD (0.05)	17.8	47.37	8.53

Azospirillum (207 g). Root dry weight was also highest in AMF+ *Azospirillum lipoferum* (27 g). Control receiving none of the inoculants gave the lowest mean growth indices.

4.4.3.4. Nutrient content

Nutrient content of macro elements in the leaf is furnished in Table 64. Nitrogen content was higher in AMF+ *Azotobacter* + *Azospirillum* (1.80%) and AMF+ *Azospirillum lipoferum* (1.78%), whereas phosphorus content was the highest in AMF + *Azospirillum* (0.97%). Potassium content ranged from 0.82 to 1.10%, the maximum in AMF + *Azospirillum.* AMF+ *Azotobacter* had the highest Ca content of 0.20 % followed by AMF alone 0.16%. Magnesium content was also the highest in AMF + *Azospirillum* (0.29%).

Table 65 represents the micronutrient content in the leaf. AMF alone recorded the maximum Fe content of 270 ppm followed by the uninoculated control (257 ppm). Zn content was highest in AMF+*Azospirillum lipoferum* (11 ppm) whereas AMF alone had the highest Cu content of 27ppm. Mn content was more in AMF+*Azotobacter* (315 ppm).

Content of macronutrients in the stem is given in Table 66. AMF +*Azospirillum* (2.15%) contained the highest nitrogen. The phosphorus content was the highest in T_1 (AMF alone) being 0.88%. Potassium content varied from 0.67 to 0.80%, having the maximum in AMF+ *Azospirillum*. Ca content was the highest in AMF alone, AMF+ *Azotobacter* and the control (0.26%). Magnesium content ranged from 0.21 to 0.29%. AMF+ *Azospirillum* (304 ppm) had the highest content of Fe (Table 67). Zn content was higher in AMF+ *Azotobacter* (19 ppm). AMF alone contained the maximum copper of 40 ppm. AMF+ *Azospirillum* recorded the highest Mn content of 412 ppm.

4.5. EXPERIMENT V

Impact of inoculation of *Azotobacter* and *Azospirillum* in established cashew plantations

Based on the results of the nursery studies, the best strains of *Azotobacter* and *Azospirillum* viz. *Azotobacter chroococcum* (V) and *Azospirillum lipoferum* (V) were selected and inoculated in the basins of 12- year- old cashew trees. The treatments were *Azotobacter* alone, *Azospirillum* alone, *Azotobacter* + *Azospirillum* and control. Observations of individual trees were recorded before inoculation and six months after inoculation when the next harvesting was done. Data were collected on growth, yield and yield parameters and these are given in Table 68 and 69.

4.5.1. Height

Increase in height of trees under different treatments is furnished in Table 69. It was seen that the variation among the varieties is more prominent than the treatments i.e. inoculation with biofertilizers. The increase in height due to combined inoculation was 53 cm whereas an increase of 50 cm and 40 cm was recorded in trees inoculated either with *Azotobacter* and *Azospirillum*. Uninoculated plants showed only 34cm increase in height.

4.5.2. Girth

Significant increase could not be noted in girth due to inoculation (Table 69). There was only an increase of 0.04 m in the girth of *Azotobacter* inoculated trees and it was 0.03 m in other treatments.

Table 64 Macronutrient content in the leaf as influenced by combined inoculation

Treatment	Nutrient content (%)				
	N	P	K	Ca	Mg
T_1 AMF alone	1.23	0.70	0.92	0.16	0.22
T_2 AMF + *Azotobacter*	1.28	0.86	0.99	0.20	0.16
T_3 AMF + *Azospirillum*	1.78	0.97	1.10	0.13	0.29
T_4 AMF + *Azotobacter* + *Azospirillum*	1.80	0.52	0.86	0.08	0.25
T_5 Control	1.13	0.68	0.82	0.09	0.12
SEm±	0.05	0.04	0.13	0.02	0.02
CD (0.05)	0.20	0.16	NS	0.06	0.06

Table 65 Micronutrient content in the leaf as influenced by combined inoculation

Treatment	Micronutrient content (ppm)			
	Fe	Zn	Cu	Mn
T_1 AMF alone	270	09	27	264
T_2 AMF + *Azotobacter*	232	12	16	315
T_3 AMF + *Azospirillum*	212	11	18	165
T_4 AMF + *Azotobacter* + *Azospirillum*	225	04	24	205
T_5 Control	257	08	20	106
SEm±	62	3	10	21
CD (0.05)	187	9	30	70

Table 66 Macronutrient content in the stem as influenced by combined inoculation

Treatment	Nutrient content (%)				
	N	P	K	Ca	Mg
T_1 AMF alone	1.78	0.88	0.67	0.26	0.21
T_2 AMF + *Azotobacter*	1.83	0.86	0.74	0.26	0.24
T_3 AMF + *Azospirillum*	2.15	0.73	0.80	0.18	0.29
T_4 AMF + *Azotobacter* + *Azospirillum*	1.75	0.62	0.69	0.19	0.29
T_5 Control	1.75	0.57	0.76	0.26	0.22
SEm±	0.05	0.02	0.07	0.09	0.02
CD (0.05)	0.20	0.08	0.21	3.68	0.06

Table 67 Micronutrient content in the stem as influenced by combined inoculation

Treatment	Micronutrient content (ppm)			
	Fe	Zn	Cu	Mn
T_1 AMF alone	195	17	40	275
T_2 AMF + *Azotobacter*	203	18	26	345
T_3 AMF + *Azospirillum*	304	19	21	412
T_4 AMF + *Azotobacter* + *Azospirillum*	259	17	16	271
T_5 Control	195	17	16	271
SEm±	26	1	1	10
CD (0.05)	78	NS	3.0	30.1

Table 68 Growth and yield characters as influenced by *Azotobacter* and *Azospirillum*

	Height (m)		Girth (m)		Branches		Length of panicle		Number of nuts/panicle	
	Before inocula-tion	After inocula-tion	Before inocula-tion	After inocula-tion	Before inocula-tion	After inocula-tion	Before inocula-tion	After inocula-ition	Before inocul-ation	After inocula-tion
T_1 *Aztotobacter* alone	7.27	7.71	1.12	1.15	2.6	2.6	19.6	19.6	4.1	4.1
T_2 *Azospirillum* alone	7.27	7.77	1.15	1.18	3.1	3.1	20.1	20.1	4.5	4.6
T_3 *Azotobacter* + *Azospirillum*	7.32	7.87	1.05	1.08	2.2	2.2	19.5	19.6	3.7	4.0
T_4 Control	7.30	7.66	1.17	1.20	2.6	2.6	20.2	20.2	4.1	4.0

Table 69 Increase in the morphological and yield characters due to inoculation of *Azotobacter* and *Azospirillum*

Treatment	Height (m)	Girth (m)	Length of panicle (cm)
T_1 *Azotobacter* alone	0.40	0.04	0.40
T_2 *Azospirillum* alone	0.50	0.03	0.70
T_3 *Azotobacter+Azospirillum*	0.53	0.03	0.60
T_4 Control	0.34	0.03	0.50

Table 70 Yield of cashew as influenced by inoculation of Azo*tobacter* and *Azospirillum*

Treatment	Yield (kg/tree)	Percentage increase over control
T_1 *Azotobacter* alone	2.91	2.83
T_2 *Azospirillum* alone	3.25	14.84
T_3 *Azotobacter* + *Azospirillum*	3.51	24.03
T_4 Control	2.83	-

SEm± (To compare treatments)	0.0589
CD (0.05)	0.2300

4.5.3. Number of branches

There was no change in the number of branches during the period under observation as is evident from Table 69.

4.5.4. Length of panicle

Table 68 revealed that there is no considerable difference in the length of panicle among the different treatments.

4.5.5. Number of nuts/panicle

It was revealed that there is no considerable variation in the number of nuts/panicle (Table 68). It differed among the varieties but not among the treatments receiving inoculation.

4.5.6. Yield

Co-variance analysis of the yield of 97-98 and 98-99 was done to eliminate the seasonal effect on yield. The data are given in Table 70. It was found that there is significant difference among the varieties with regard to yield. It was also seen that the combined inoculation of *Azotobacter* and *Azospirillum* has given an increase in yield over the control. The extent of increase was 24.03% over uninoculated treatment.

Discussion

DISCUSSION

5.1. EXPERIMENT I

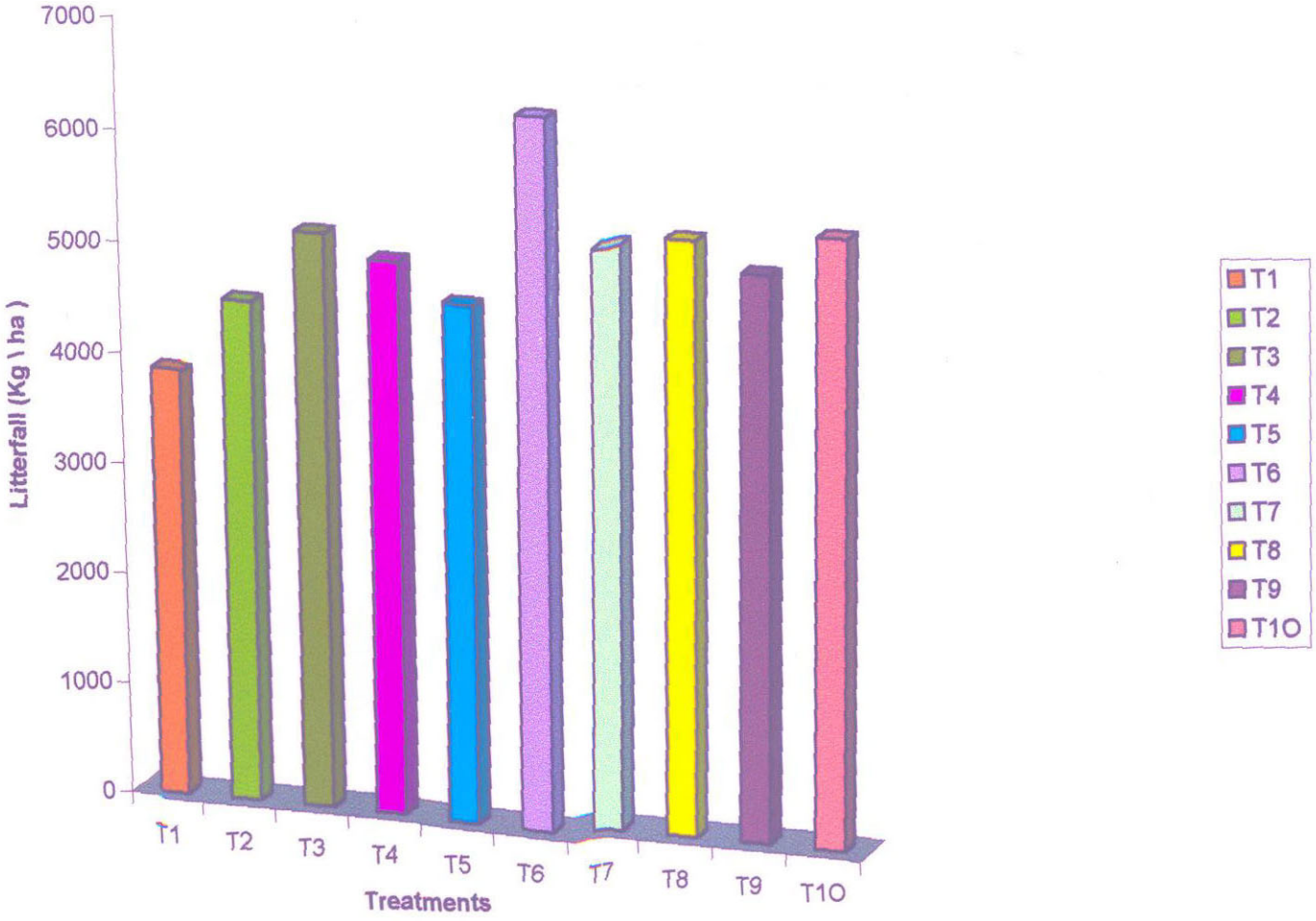
Effect of cashew litter in the nutrition of cashew

The results reveal that the annual average litterfall in a ten to twelve year old cashew graft plantation ranged from 1656 to 8856 kg/ha with an average of 5014 kg/ha (Fig5). It is also seen that the quantity of litter varies between months of the year, though litterfall occurred throughout the year. The age of the stands, site quality and climatic conditions apparently influenced litter production. Litter production and its accumulation are known to be dependent on density, basal area and age structure of the stand (Stohlgren, 1988), altitude (Reiners and Lang, 1987) and latitude of the area (Bray and Gorham, 1964) and also the season (Luizao and Schubart, 1987).

Data on monthly litterfall indicated that dry months account of for higher fraction of annual litter production than the wet months. The observed maximum litterfall during dry months can be attributed to moisture stress for trees. Water stress triggers synthesis of abscissic acid in the foliage of plants which inturn can stimulate senescence of leaves and other parts. The highest litterfall during summer months has been reported for cocoa (Sreekala, 1997), acacia (Sankaran *et. al.*, 1993) and for other species and forest types in India and elsewhere (Das and Ramakrishnan, 1985). The observed maximum litterfall in cashew during March and October can also be attributed to the leaf fall prior to pre and post harvest flushing.

Monthly litterfall was found to be positively correlated with temperature, sunshine and wind speed and negatively with rainfall, rainy days and relative humidity,

Fig. 5. Quantity of litterfall in 10 cashew varieties



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though the correlation coefficient values were not significant. There were also significant differences in litter yield between cashew varieties. This can be attributed to the difference in vegetative growth characteristics of the different varieties (Penfold and Willis, 1961) and or to the differences in susceptibility to moisture stress as reported by Latha (1998).

Decomposition rate of litter was estimated as 65% per year. The exponential decay model (Olson, 1963) was used to calculate the decay coefficient and the time required for the complete weight loss of litter. It is found that the complete loss of litter will take place within 16.5 months and the decay coefficient is 1.04. The curvilinear model revealed that it would take 21 months for the complete decomposition of the litter. Physical and chemical properties of litter might exert a strong influence on decomposition (Swift *et al.*, 1979). Hence, the low rate of decomposition can be attributed to low N content and high lignin and tannin content of the litter (Singh and Gupta, 1977; Meentemeyer, 1978 and Kumar and Deepu, 1992) which are known to affect the microbial activity.

The rate of decomposition of litter was found to be controlled by the weather parameters also. The loss in weight of leaf litter was high during the monsoon. It is seen that decomposition rate increases with increase in rainfall and RH, but decreases with increase in temperature, sunshine and wind speed. Effect of these factors on microbial activity is already established. The early stage of decay process of plant materials in soil is characterised by the relatively high cellulase activity and rapid disappearance of cellulose from the litter. Eventually cellulase activity declines and finally the decomposition process is characterised by very low rates of mass loss. The initial rapid phase of decomposition of litter can be related to the availability of easily soluble carbon on the surface of the litter which favours the fast multiplication of micro organisms and

Fig. 6. Macronutrient content in cashew litter

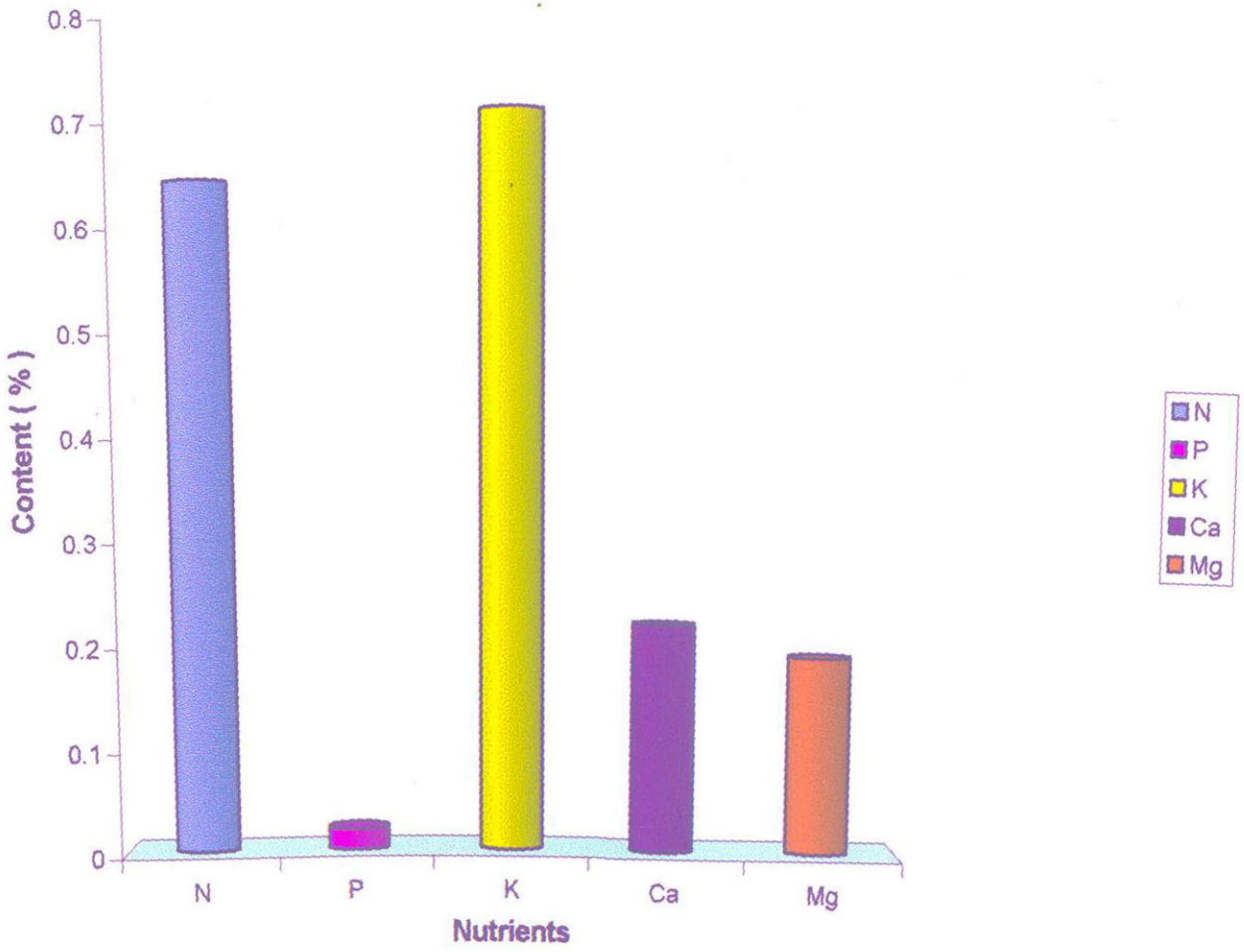
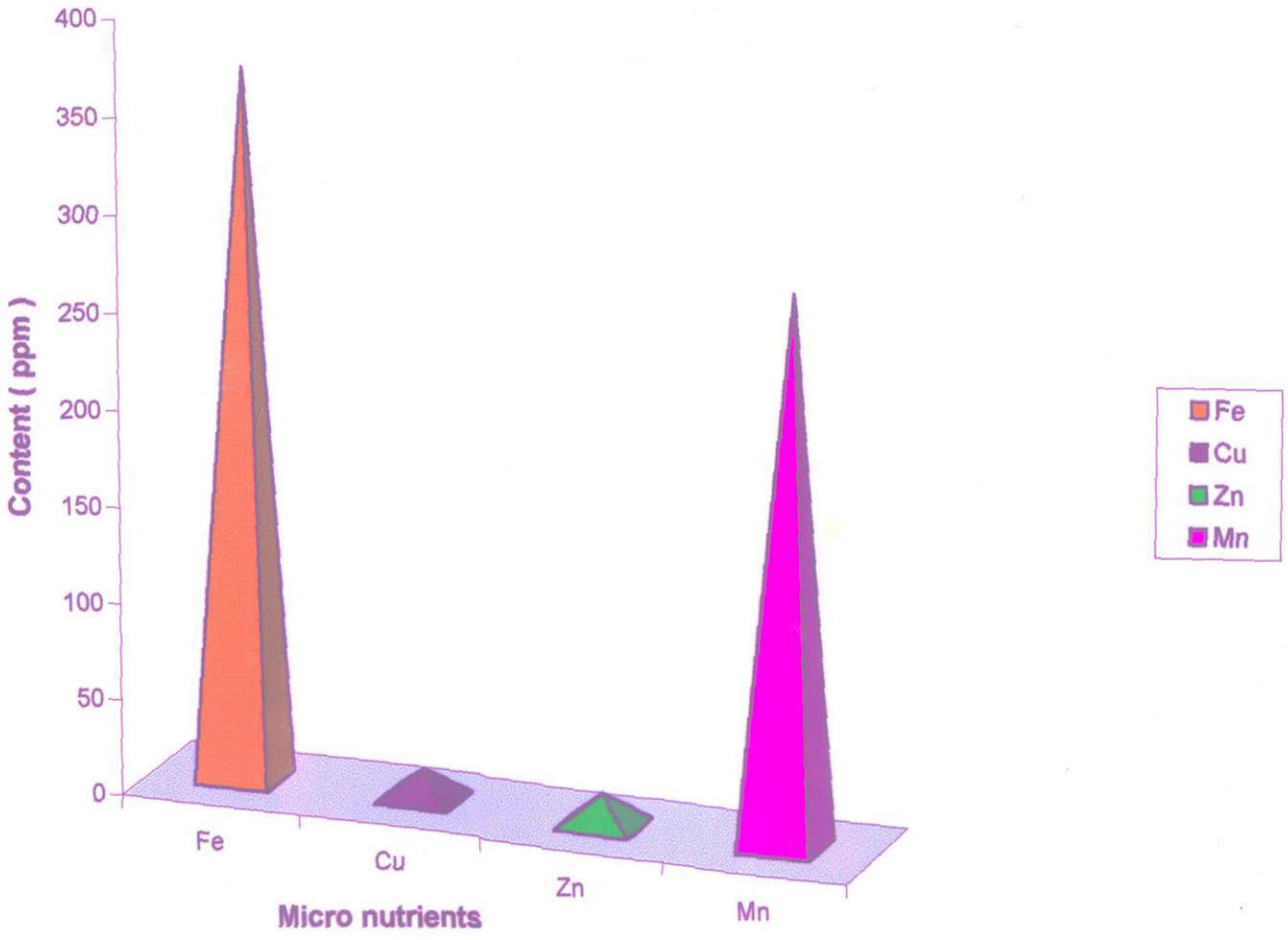


Fig. 7. Micro nutrient content in cashew litter



also due to the most favourable environmental conditions for decomposition (Singh, 1969 and Anderson, 1973).

Data on macro and micronutrient content in the litter revealed that the nutrient content, though varied with varieties had average values of 0. 65% N, .022% P, 0.72% K, 0.22% Ca, 0.19% Mg, 369 ppm Fe, 17 ppm Zn, 15 ppm Cu and 283 ppm Mn (Fig. 6 & 7). The variety NDR 2-1 contained more N, P, Zn and Cu. The content of Ca was highest in H-1608, Fe in H-1600 and Mn in H-1591.

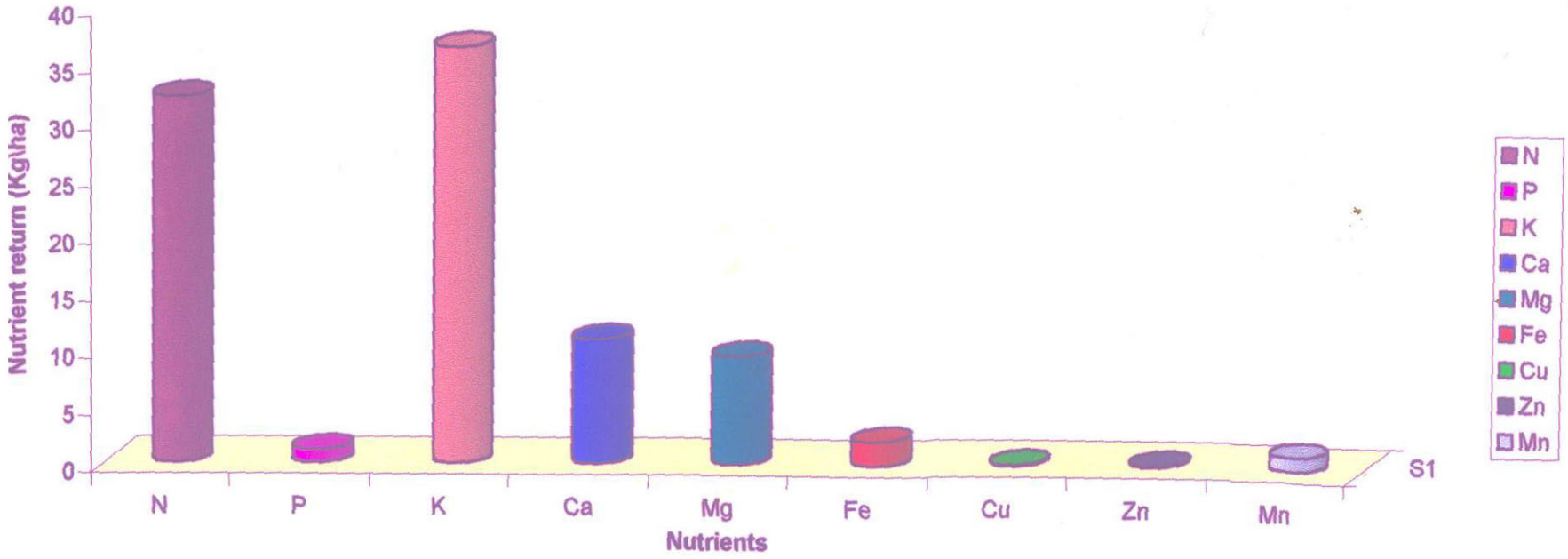
The quantity of nutrients incorporated per hectare also varied with the varieties. The overall mean figures were 32.1 kg N, 1.1 kg P, 36.5 kg K, 10.9 kg Ca, 9.5 kg Mg, 2.1 kg Fe, 0.1 kg Cu and Zn and 1.2 kg Mn per hectare (Fig.8). Annual return of nutrients through litterfall is a dynamic phenomenon, which is influenced by annual and seasonal climatic differences in litterfall and nutrient concentrations (Lousier and Parkinson, 1976). The magnitude of total nutrient return was in accordance with their total litterfall (Pande and Sharma, 1986). In general, the quantities of nutrients returned were in the order K> N> Ca> Mg> Fe> Mn> P> Zn = Cu.

5.2. EXPERIMENT II

Effect of fertilizer on organic recycling in cashew plantation

The results showed that the annual average litter production in the unfertilized plot was 3235 kg ha^{-1} whereas it was 5014 kg ha^{-1} in the fertilized plot. This difference can be attributed to the better vegetative growth in the fertilized plot. The litterfall was maximum during March and October and the minimum in June and May. As reported in other plant species (Sreekala, 1997), the cashew plant also showed maximum litterfall during summer months, probably due to the moisture stress and deciduous nature of the cashew trees.

Fig. 8. Nutrient return by the cashew litte



The average composition of litter from the unfertilised experimental plots was 0.71% N, .03% P,0.63% K, 0.19% Ca, 0.14% Mg, 230 ppm Fe, 17 ppm Cu, 12 ppm Zn and 469 ppm Mn. Comparison of nutrient contents in the fertilized and unfertilized plots revealed that there was no significant difference among them. The significant impact of fertilisers on litter production was very much evident in the present study, which inturn increased the nutrient return to the soil. Hence, it could be concluded that fertilisers had their impact on nutrient return through the quantity of litter rather than the quality.

As indicated earlier, fertiliser application led to larger return of organic residues which contributed not only to larger availability of nutrients in the organic form but also to the build up of soil organic fraction. Estimated organic carbon content of soil in the fertilised plot was 1.67% as against 0.69% in the unfertilised control, which account to an increment of 142 %. The organic carbon content of Vellanikkara soil varied from 0.51 to1.26% (Sajnanath, 2000). The organic carbon content in the fields of cocoa (Sreekala, 1997), rubber and the crop museum at Vellanikkara was estimated to be 1.4,1-1.5,0.84-1.15, respectively.

Cashew litter, which remained on the soil surface for a longer period, had given a mulching effect. In the long run this helped to the build up of soil organic matter which is indicated by the higher organic carbon content of the soil.

5.3. EXPERIMENT III

5.3.1. Part I Effect of AMF inoculation on growth and establishment of cashew seedlings (Nursery stage)

Inoculation with AMF significantly improved the growth characters of cashew seedlings in the nursery. Observations on growth characters due to the inoculation of six

species of AMF revealed the superiority of *G. intraradices* and *G. fasciculatum* over other species and control. Inoculation with *G. intraradices* contributed to more plant height, girth, root spread, leaf and root dry weight and root shoot ratio. Such interspecific differences in the effect of AMF have been reported in *Paspalum notatum* (Mosse, 1973), onion and cloves (Powell, 1975), and soybean (Carling and Brown, 1980). This variation could be attributed to plant fungal compatibility and the interaction between endophytes and their environment (Fig.9). It may also be due to the differences in inducing changes in physiological traits of the plant, as these characters are also known to improve with AMF colonisation (Sivaprasad and Rai, 1987). Nitrogen, phosphorus and iron contents in the leaf were also maximum in *G. intraradices* inoculated plants. Regarding the stem, N, Cu and Fe contents were the highest in *G. intraradices*. Considering the total uptake, *G. intraradices* recorded the maximum uptake of Cu and Fe whereas G. *fasciculatum* had the maximum P uptake. In all cases involving AMF species, uptake values were generally and appreciably higher than uninoculated control. It is reported that in mycorrhizal association, the fungal hyphae function synonymous to root hair. This increases the surface area and available nutrient absorption and transportation, which ultimately result in the higher absorption and accumulation of nutrients by the plant. Production of plant growth hormones leading to better root development also favours nutrient uptake (Sivaprasad *et al.*, 1992; An *et al.*, 1993 and Rizzardi, 1990). Mycorrhizal plants increased the rates of respiration and photosynthesis, increased amplitude of sugars, amino acids, RNA etc. and more chloroplasts, mitochondria, xylem vessels (Krishna and Bagyaraj,1982 and Hayman, 1982). These improved physiological and biochemical traits along with better nutrition of the plant ultimately resulted in better growth and development of the plant.

Fig. 9. Percentage of infection of AMF in different treatments

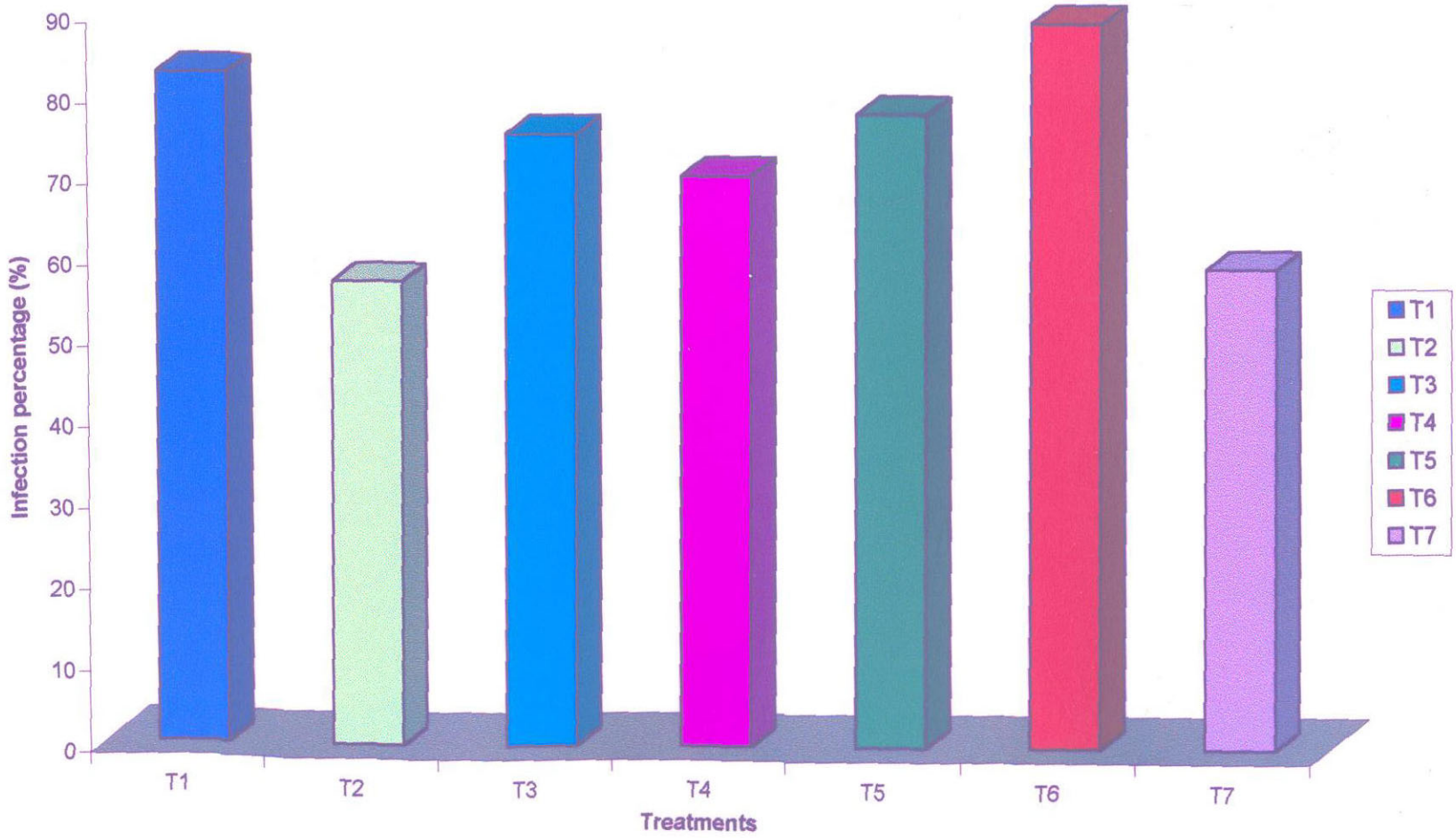


Fig. 10. Nut weight as influenced by different AMF

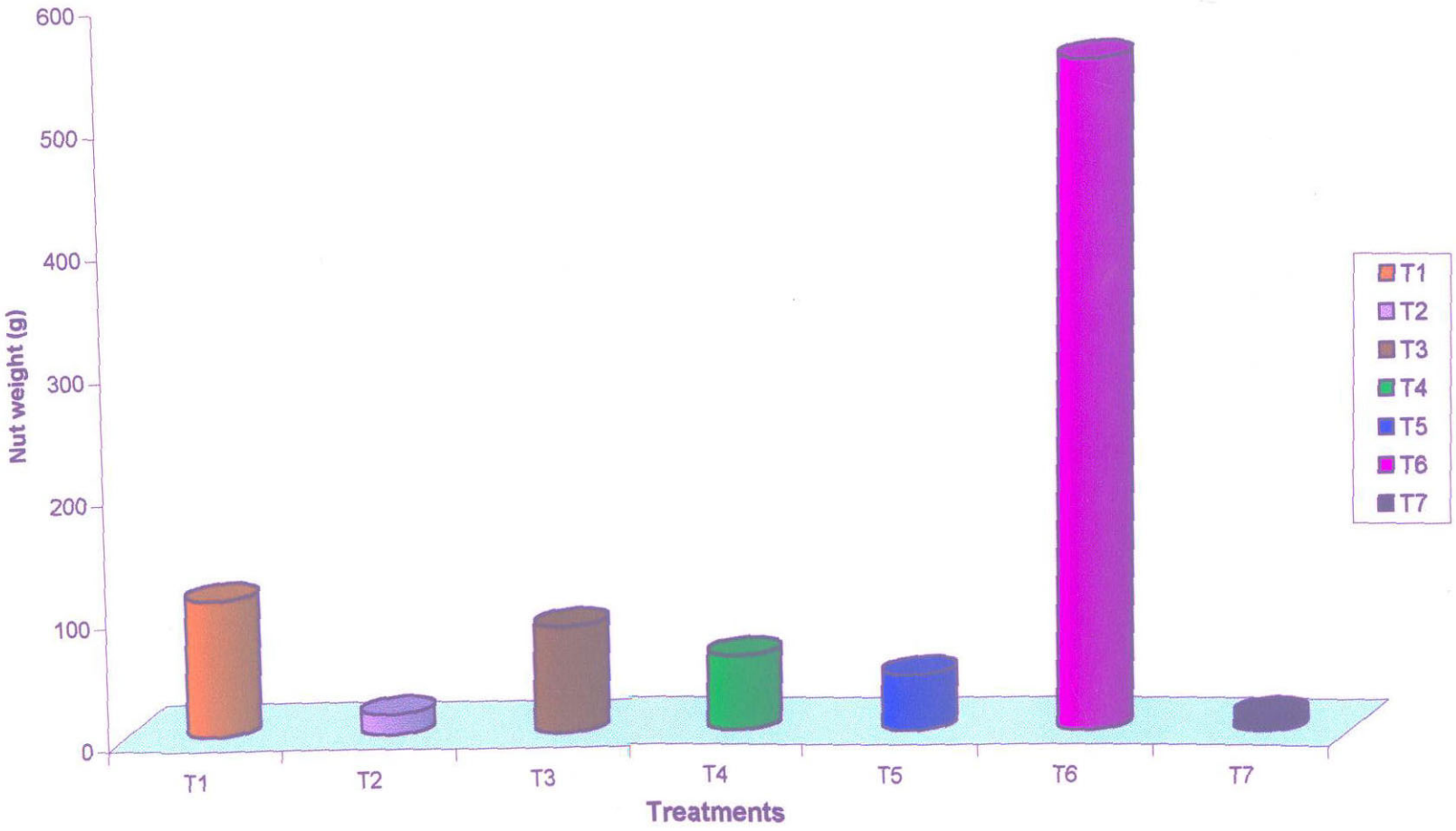
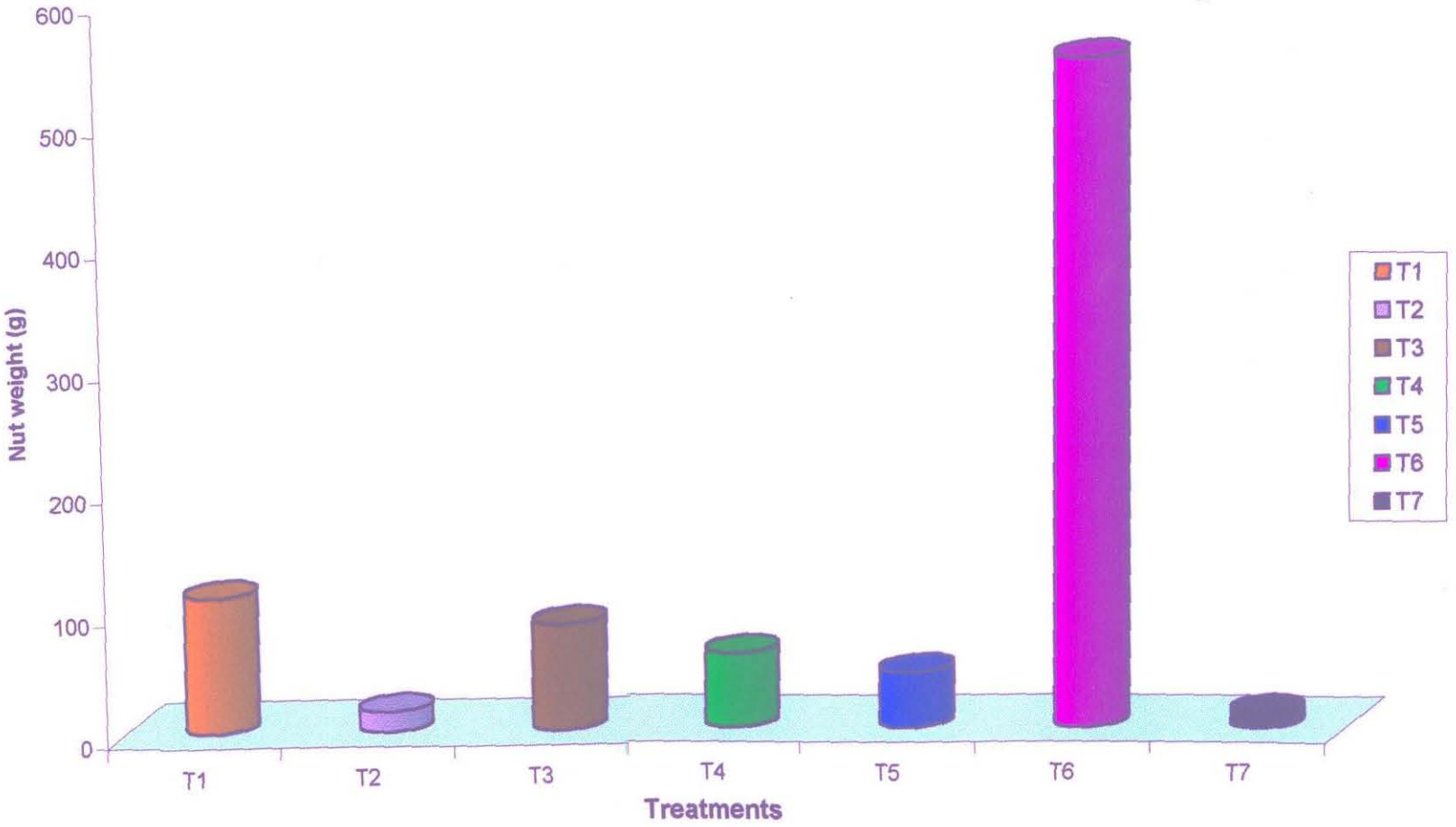


Fig. 10. Nut weight as influenced by different AMF



5.3.2. Part II Effect of AMF inoculation on growth and development of cashew (main field)

Data on plant growth characters of seedlings and grafts in the field also established the superiority of *G. intraradices* among the different AMF tested. Height, girth and number of branches were maximum in *G. intraradices* inoculated plants. The nutrient contents were also higher in inoculated plants. As in the nursery, all AMF treatments were generally superior to control in terms of growth. Though estimates of uptake could not be made in this part of trials, it is only reasonable to assume that nutrient uptake also must have increased because of AMF inoculation. As in the case of seedlings grown in containers, there was no consistent and appreciable increase in the content of nutrients because of AMF inoculation.

The inoculated plants performed better than control in flowering and fruit setting. Even though the yield had not stabilized, the trend of higher nut yield of grafts as compared to seedlings was evident. Nut yield was also higher in plants inoculated with *G. intraradices* and *G. fasciculatum* (Fig.10). This vividly indicates the effectiveness of these cultures as a biofertiliser for improving the growth and yield of cashew. Instances of enhanced growth and yield following AMF application were also reported earlier by Geethakumari *et al.* (1990) in cowpea, Pillai *et al.* (1994) in *Stylosanthes hamata* and Sivaprasad *et al.* (1992) in cashew in Kerala soils.

5.3.3. Part III Comparative efficacy of different strains of AMF with different sources of ^{32}P labelled fertilizers.

The results revealed that absorption of ^{32}P labelled fertilizers was more in AMF inoculated three-month-old cashew plants. *G. fasciculatum* proved to be more efficient

than *G. etunicatum*. Absorption of MCP was higher than that of TCP and the rate of absorption increased with increase in dose of application. Total P content was maximum in *G. fasciculatum* inoculated plants with MCP at 50% of the recommended dose. The specific activity recorded the maximum with *G. fasciculatum* and MCP at 200% of the recommended dose.

The mycorrhizal plants have drawn more phosphorus from the soluble pool because of the mycelial net work of the AMF which enabled the plants to remove phosphate from a larger volume of soil extending beyond the immediate vicinity of the root surface. This leads to a conclusion that plants use the same available phosphate pool whether or not they are mycorrhizal as explained by Sanders and Tinker (1971) and Powell (1975). But AMF inoculated plants are more efficient in P uptake. It is also seen that the mycorohizal hyphae of inoculated plants obtained their extra phosphate from the labile pool rather than by dissolving insoluble phosphate (Barea *et al.*, 1983).

The higher specific activity at lower doses of ^{32}P application reveals the possibility of reducing the application of phosphorus up to 50% of the recommended doses.

5.4. EXPERIMENT IV

5.4.1. Part I Screening of effective *Azotobacter* and *Azospirillum* strains for cashew (nursery stage)

Azotobacter and *Azospirillum* gave consistent positive influence on germination, growth and development of cashew seedlings. The beneficial effects of these bacteria on

the germination of seeds can be attributed to the synthesis and secretion of thiamine, riboflavin, pyridoxine, cyanocobalamine, nicotinic acid and pantothenic acid, IAA, giberellins or giberellin like substances as documented by Russian workers (Rao, 1982). Germination percentage was more in *Azospirillum* treated seeds. *Azospirillum* inoculated seedlings, on the contrary, recorded maximum height, girth, number of leaves and root spread. Dry matter production and root-shoot ratio were also highest in these treatments. The increase in growth characters is often attributed to the production of biologically active metabolites like IAA, giberellins, cytokinins and Vitamin B by the micro-organisms (Tien *et al.*, 1979) in addition to the fixation of nitrogen and production of antibiotics and quinones which are harmful to the plant pathogens in the rhizosphere (Mishutin, 1969).

Nutrient contents were generally higher in *Azospirillum* and *Azotobacter* inoculated plants. This is in marked contrast to the effect of AMF, which only increased the total uptake of nutrients but not their concentration. This, combined with better growth of plants resulted in higher uptake of all the nutrients.

In general, *Azospirillum* was found to be more efficient than *Azotobacter* for cashew based on growth and uptake of nutrients. Ramesh *et al.* (1998) based on trials in Karnataka had also noted similar effects. Inoculated plants also showed increase in number of lateral roots, root volume and root dry weight.

5.4.2. Part II Influence of *Azotobacter* and *Azospirillum* on growth and development of cashew (main field)

The performance of *Azospirillum* inoculated plants (both seedlings and grafts) in the field was better when compared to *Azotobacter* inoculated ones. Height, girth and number of branches were more in inoculated plants compared to control. This can be

due to the combined effect of initial vigour in the nursery stage (Kumar *et al.*, 1998) and continued effect of the organisms in the field. The benefit of these nonsymbiotic bacteria in nitrogen fixation is well documented and the quantity of nitrogen fixed ranges from 5-20 Kg / ha. In our soils of average fertility, it is difficult to quantify the relative significance of these biofertilisers and also to make out the benefit due to the nitrogen uptake vs hormonal effects.

Except Fe and Mn, the content of nutrients was higher in inoculated plants. Increase in nitrogen content may be due to enhanced uptake of NO_3, NH_4 and nitrogen fixation by the inoculated plants (Barton *et al.*, 1986 and Jain and Patriquin,1984). Enhanced uptake of other nutrients is attributable to improved growth under microbial inoculation (Yadav *et al.*, 1992 and George, 1996).

The same trend was observed in flowering and nut production also (Fig.11). It is seen that *Azospirillum* inoculated plants produced maximum nuts in seedlings and grafts. Bangar et *al.* (1995), Hazra (1994) and Singh (1997) have reported increase in yield due to inoculation of *Azospirillum* in different crops. Increase in yield is the sum total of the beneficial effects of the inoculation including early vigour of inoculated plants and continued benefits from these organisms in the field.

The advantage of *Azospirillum* over *Azotobacter* can be attributed to the colonisation of *Azospirillum* on root surface and in the cortex whereas the *Azotobacter* is confined to the rhizosphere. *Azospirillum*, hence, will be able to resist the adverse soil conditions. Also, there is possibility of getting more nitrogen to plants due to the nitrate reductase activity of *Azospirillum* and also due to high relative adsorption. Moreover, *Azotobacter* requires more organic matter and controlled pH for its better growth.

Plate VII Effect of combined inoculation on rooting

Fig.1. AMF alone

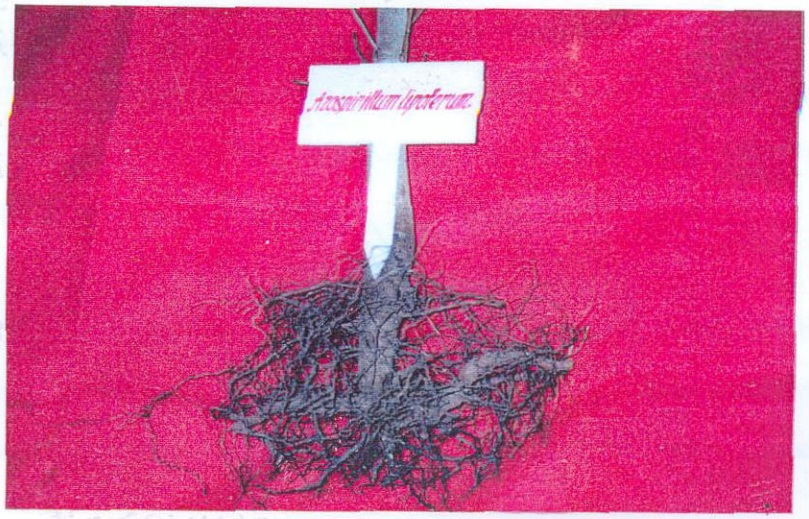


Fig.2. *Azozpirillum* alone

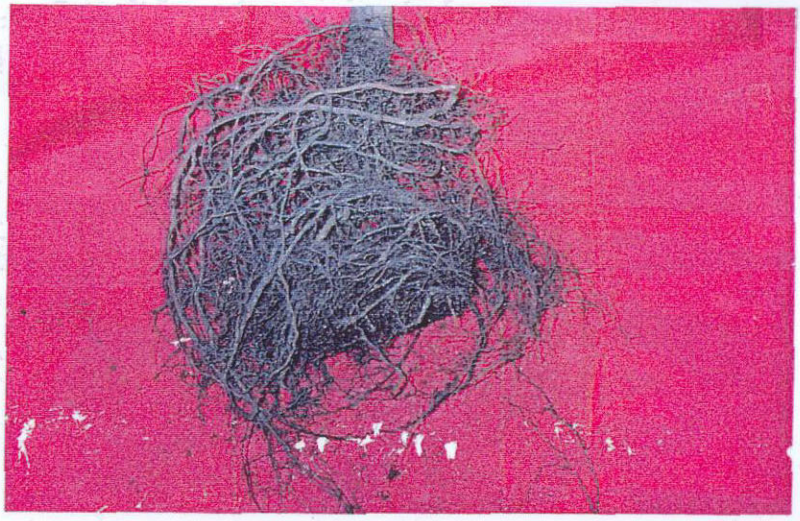


Fig. 3. AMF + *Azospirillum*

5.4.3. Part III Interaction effect of *Azotobacter* , *Azospirillum* and AMF on cashew

The results indicate that the combined inoculation of AMF and *Azospirillum* is generally the best among the different combinations tried. The growth characters as well as the nutrient content was expressed maximum in this treatment. Both AMF and *Azospirillum* apparently acted synergistically when added simultaneously and resulted in better growth. *Azospirillum* must have increased nitrogen availability through fixation and must have provided hormones to enhance growth. AMF probably would have helped in utilisation of nutrients from soil including fixed nitrogen. It has also been reported that synergism between bacteria and fungi can arise from organic acids like citric acid and malic acid released by the bacteria which stimulate the growth of fungi thus resulting ultimately in increased absorptive surface area of roots and also feeder root longevity (Plate VII). The effect of combined inoculation of AMF and *Azospirillum* has also been reported earlier by Kumari and Balasubramanian (1993), Nagarajan *et al.* (1989) and Tilak and Singh (1994).

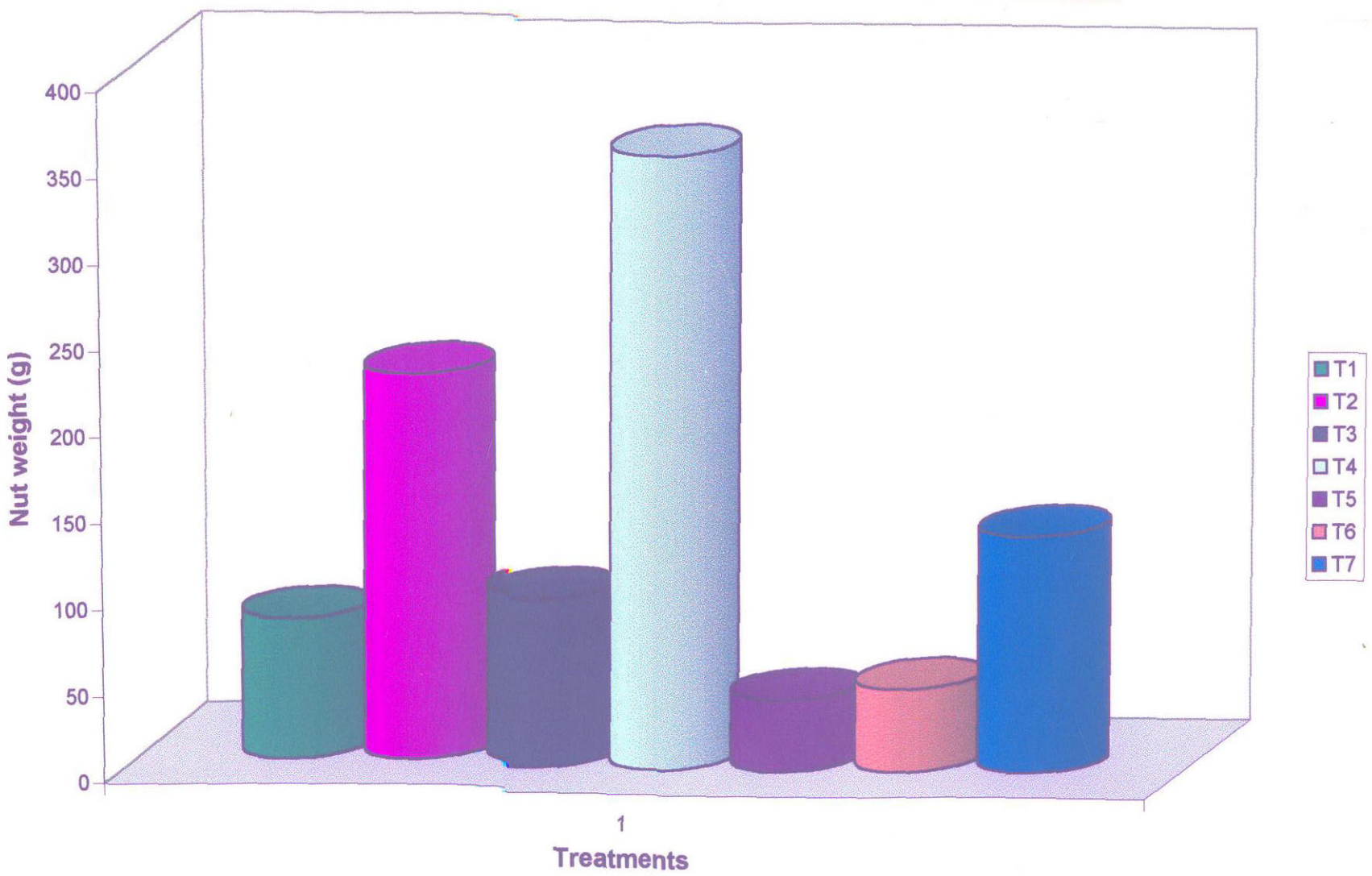
This part of study was done only on seedling in containers and these were not carried forward to the field. To draw conclusions on the ultimate benefit in the field is difficult other than to infer that at least advantage from early vigour is likely to continue.

5.5. Experiment V

Impact of inoculation of *Azotobacter* and *Azospirillum* in established cashew plantations

The effective strains of *Azotobacter* and *Azospirillum* identified from the nursery screening viz. *Azotobacter chroococcum* (V) and *Azospirillum lipoferum* (V) were

Fig.11. Nut yield as influenced by *Azotobacter* and *Azospirillum*



inoculated in the basins of twelve-year-old cashew trees. The experiment consisted of four treatments viz. *Azotobacter* alone, *Azospirillum* alone, *Azotobacter* + *Azospirillum* and control. The results revealed that inoculation of both *Azotobacter* and *Azospirillum* was beneficial in terms of yield in established cashew plantations. However, no marked increase in growth characters was evident. Both *Azotobacter* and *Azospirillum* alone and in combination were found to be better than control in the case of yield. There was 24% increase in yield due to combined inoculation of *Azotobacter* and *Azospirillum* than the uninoculated plants. The respective values for *Azospirillum* and *Azotobacter* alone were 14.8 % and 2.8%. The most important aspect is the fact that both the nonsymbiotic nitrogen fixers were beneficial with some indications of superiority of *Azospirillum*. There are also indications of synergism between these two groups of organisms either because they have different types of beneficial functions or because their routes of nitrogen fixation are independent. There had been reports of synergistic effects of these two organisms (Anon, 1990).

The salient features of the discussion may be summarized as follows.

1. The litterfall in a ten to twelve-year-old cashew plantation varied between months and varieties. The age of plants, site quality and climatic conditions influenced the litter production. The slow rate of decomposition of cashew litter can be attributed to the high lignin and tannin content, which contributed to the build up of soil organic matter. Litter contained more N and K among the essential nutrients. Fertiliser application led to larger return of organic residues to the soil.
2. Among the different AMF species tried, *Glomus intraradices* inoculated cashew plants performed well with regard to growth and nutrient uptake followed by *Glomus fasciculatum*. It can be due to the host specificity. Mycorrhizal plants had enhanced the growth and nutrient uptake. The influence was more prominent in early stages of growth.

3. *Azospirillum lipoferum* strain from Vellayani was the best among the different strains of Azotobacter and Azospirillum tested in cashew. Enhanced growth and uptake can be attributed to the production of hormones besides the benefit from nitrogen fixation.
4. Seedlings inoculated with AMF, *Azotobacter* and *Azospirillum* could be made ready for grafting within a short time.
5. Combined inoculation was found to be *beneficial* than single inoculation since there is synergistic effect.

FUTURE LINE OF WORK

1. Rate of mineralisation of cashew litter need to be estimated to know the extent of release of nutrients during litter decomposition.
2. The extent of substitution of nitrogenous fertilizers by *Azotobacter* and *Azospirillum* and phosphatic fertilizers by AMF may be estimated by trying different combinations of biofertilizers and chemical fertilizers.
3. The combined inoculation of AMF and *Azospirillum* can be done at the time of sowing itself.
4. Different genera of AMF along with local strains may also be screened.
5. Since the pH of Kerala soils is acidic in general, lime (different doses) can be included as a treatment.

Summary

SUMMARY

The project entitled " **Integrated nutrient management in cashew in relation to yield and quality** " was taken up in the College of Horticulture, Vellanikkara during 1995-1999. It consisted of five experiments to estimate the litter contribution in cashew plantations, compare the quantity and quality of litter in fertilised and unfertilised cashew fields, study the effect of biofertilisers viz: AMF, *Azotobacter* and *Azospirillum* in cashew and the interaction effect of combined inoculation of these biofertilisers.

The salient findings are as follows:

EXPERIMENT I Effect of cashew litter in the nutrition of cashew

1. The annual average litterfall in a ten year old cashew graft plantation ranged from 1656-8856 kg ha^{-1} with an average of 5014 kg ha^{-1}.
2. The quantity of litter varied between months of the year and between varieties. Monthly litter contribution varied from 138 kg during May to 738 kg in March. Among the ten varieties, H-856 had contributed maximum litter (6348 kg $ha^{-1}yr^{-1}$) and BLA 139-1 (3840 kg $ha^{-1}yr^{-1}$), the minimum.
3. Decomposition studies of leaf litter revealed that there would be over 90% weight loss within 21 months after litterfall.
4. The rate of decomposition of cashew leaf litter was slow in early stages and then became faster especially during rainy season and then declined in the subsequent dry season. The low rate of decomposition can be attributed to low N content and high lignin and tannin contents of the litter.

5. Litter decomposition was positively correlated with rainfall, number of rainy days and RH and negatively with maximum temperature, minimum temperature, sunshine hours and wind speed.
6. Cashew leaf litter contained 0.65% N, 0.22% P, 0.72% K, 0.22% Ca, 0.19% Mg, 369 ppm Fe, 17 ppm Zn, 15 ppm Cu and 283 ppm Mn.
7. On an average, the litter incorporated 32.1 kg N, 1.1 kg P, 36.5 kg K, 10.9 kg Ca, 9.5 kg Mg, 2.1 kg Fe, 0.1 kg Cu and Zn and 1.2 kg Mn per hectare.

EXPERIMENT II Effect of fertilizer application on organic recycling in cashew plantation

1. The average annual litter production in the unfertilized plot was 3235 kg ha^{-1} as compared to 5014 kg ha^{-1} in the fertilized plot.
2. The average composition of litter from unfertilized plots was 0.71% N, 0.03% P, 0.63% K, 0.19% Ca, 0.14% Mg, 230 ppm Fe, 17 ppm Cu, 12 ppm Zn and 469 ppm Mn while the fertilised plot of Expt.I recorded the values of 0.65% N, 0.22% P, 0.72% K, 0.22% Ca, 0.19% Mg, 369 ppm Fe, 17 ppm Zn, 15 ppm Cu and 283 ppm Mn.
3. Comparison of nutrients in the fertilized and unfertilized plots revealed that there was no significant difference among them.
4. The average annual nutrient return in the unfertilized plot was 23 kg N, 0.9 kg P, 20.4 kg K, 6.2 kg Ca, 4.5 kg Mg, 0.7 kg Fe, 0.05 kg Cu, 0.04 kg Zn and 1.5 kg Mn per hectare as against 32.1 kg N, 1.1 kg P, 36.5 kg K, 10.9 kg Ca, 9.5 kg Mg, 2.1 kg Fe, 0.1 kg Cu and Zn and 1.2 kg Mn per hectare in the fertilised plot.
5. Lesser contribution of nutrients in the unfertilized plots was due to the lesser quantity of litterfall. Hence, it is revealed that the fertilizers had their impact on nutrient return through the quantity of litter and not through the quality.

6. Organic carbon content of soil in the fertilized plot was 1.67% and that of unfertilized plot was 0.70%. Fertilizer application led to larger return of organic residues and there was an increment in organic carbon content to the tune of 142% than the unfertilized plot.

EXPERIMENT III

Part I Effect of AMF inoculation on growth and establishment of cashew seedlings (nursery stage)

1. AMF inoculation improved the growth and nutrient uptake of cashew seedlings in the nursery.
2. Among the six species of AMF, *G. intraradices* inoculated plants had the maximum advantage in enhancing plant height, girth, root spread, leaf and root dry weight, root-shoot ratio etc.
3. N, P and Fe contents in the leaf and N, Cu and Fe contents in the stem were maximum in *G. intraradices* inoculated plants.

Part II Effect of AMF inoculation on growth and development of cashew (main field)

1. AMF inoculated seedlings and grafts continued to be superior in growth and nutrient content when planted in the field also.
2. Even though yield had not stabilized, the trend of higher nut yield of grafts as compared to seedlings was also evident.

Part III Comparative efficacy of different strains of AMF with different sources of ^{32}P labelled fertilizers

1. AMF inoculation enhanced absorption of ^{32}P labelled fertilizers in three-month-old cashew seedlings.

EXPERIMENT IV

Part I Screening of effective *Azotobacter* and *Azospirillum* strains for cashew (nursery stage)

1. *Azotobacter* and *Azospirillum* inoculation enhanced the germination, growth and development of cashew seedlings in the nursery.
2. *Azospirillum* inoculated seedlings recorded the maximum height, girth, number of leaves, root spread and dry matter production.
3. Content and uptake of nutrients were also higher in *Azotobacter* and *Azospirillum* inoculated plants.
4. In general, *Azospirillum* was found to be more efficient than *Azotobacter* for cashew based on growth and uptake of nutrients.

Part II Influence of *Azotobacter* and *Azospirillum* on growth and development of cashew (main field)

1. Growth characters were improved by *Azotobacter* and *Azospirillum* inoculation in seedlings and grafts when planted in the field also.
2. The performance of *Azospirillum* inoculated plants was better than *Azotobacter* inoculated ones.
3. Except Fe and Mn, the content of nutrients was also higher in inoculated plants.
4. *Azospirillum* inoculation contributed to production of more nuts both in seedlings and grafts.

Part III Interaction effect of *Azotobacter* , *Azospirillum* and AMF on cashew

1. Combined inoculation of AMF and *Azospirillum* was found to be the best among the different combinations tried in the nursery.

2. The growth characters as well as the nutrient content were expressed maximum in this combination. Both AMF and *Azospirillum* acted synergistically which resulted in better growth.

Experiment V Impact of inoculation of *Azotobacter* and *Azospirillum* in established cashew plantations

1. Inoculation of *Azotobacter* and *Azospirillum* in twelve-year-old cashew trees resulted in no marked increase in growth characters.
2. An increase of 24.03 % in yield due to combined inoculation of *Azotobacter* and *Azospirillum* could be observed when compared to the uninoculated plants.

171934

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*Original not found

Appendices

Appendix I

Weather data at Vellanikkara from 3/96 to 6/99

	Max. temp. (°C)	Min. temp. (°C)	Rain-fall (mm)	Rainy days	RH1 (%)	RH2 (%)	Sun shine (hrs)	Wind Speed (km/hr)
1996								
March	36.4	24.3	-	-	82	37	9.3	3.6
April	34.6	25.0	1.52	7	87	59	8.3	3.0
May	32.8	25.2	95.4	4	91	63	7.7	2.4
June	30.5	23.8	400.3	16	94	75	4.7	3.0
July	28.8	23.1	588.7	25	96	83	2.7	2.7
August	29.1	23.6	310	20	95	78	3.7	3.0
September	29.2	23.7	391.6	17	94	74	4.3	2.7
October	30.1	22.9	219.3	12	93	70	6.0	2.0
November	31.5	23.6	22.1	2	84	59	7.1	3.7
December	30.5	21.8	60.4	2	80	55	6.8	6.4
1997								
January	32.0	22.9	-	-	78	45	9.6	6.9
February	33.9	21.8	-	-	82	39	9.3	3.9
March	35.7	24.0	-	-	82	37	9.6	4.0
April	35.2	24.5	8.2	1	83	50	9.3	3.3
May	36.6	24.5	63	4	87	57	6.7	3.3
June	31.2	23.0	720.5	18	93	71	5.9	2.7
July	28.6	21.8	979.2	28	95	84	1.9	4.6
August	29.0	22.8	636.8	23	95	78	3.4	2.9
September	30.6	23.4	164	13	93	71	6.8	2.6
October	32.2	23.6	194.7	12	88	65	7.3	2.6
November	31.6	23.2	209.7	7	88	67	5.3	3.0
December	31.7	23.8	66.7	2	83	61	7.5	6.2

	Max. temp. (°C)	Min. temp. (°C)	Rain-fall (mm)	Rainy days	RH1 (%)	RH2 (%)	Sun shine (hrs)	Wind Speed (km/hr)
1998								
January	33.1	22.8	-	-	78	49	9.3	6.6
February	34.4	23.6	-	-	77	51	9.6	5.2
March	36.2	23.6	11	1	86	47	10	3.4
April	36.5	25.6	11.4	4	86	50	9	3.1
May	34.1	25.2	263	9	90	63	7.6	2.6
June	30.2	23.3	809.3	24	94	79	3.4	2.7
July	29.2	23.6	752.9	28	96	80	3.3	2.8
August	29.8	23.9	433.6	18	95	77	3.6	2.5
September	30.2	23.3	571.3	24	96	78	4.1	2.0
October	32.2	23.6	194.7	12	88	65	7.3	2.1
November	31.5	23.1	109.4	9	92	64	7.2	1.7
December	30.1	22.9	33	4	79	58	6.6	5.7
1999								
January	32.4	21.5	-	-	76	40	9.3	-
February	34.5	23.3	22.8	1	77	35	9.1	-
March	35.5	24.5	-	-	88	48	8.8	-
April	33.4	25.6	39	4	88	58	10.3	-
May	30.7	24.7	430.5	18	92	72	4.9	-
June	29.4	23.0	500.2	23	94	75	5.0	-

Appendix II

Weather data at CRS, Anakkayam

	Max. temp.	Min. temp.	Dry bulb reading	Wet bulb reading	Wind speed km/hr	No. of rainy days	Sun-shine hours	Rain fall
1993								
November	33.02	20.49	23.32	22.76	16.6	12	5.9	42.1
December	32.80	19.65	21.72	20.72	17.7	1	7.3	-
1994								
January	34.90	19.10	21.06	19.4	20.5	1	9.3	3.2
February	35.60	21.20	22.30	21.8	24.3	-	9.2	-
March	38.05	21.30	23.67	22.90	31.4	-	8.8	2.4
April	35.90	23.40	23.8	25.35	29.9	11	7.8	259.7
May	34.90	22.95	25.0	24.13	35.5	5	7.5	36.6
June	30.80	22.70	23.5	23.3	27,0	28	3.5	870.9
July	29.15	21.90	22.2	21.2	27	31	1.4	1435
August	30.95	21.50	23.2	23.1	30	19	3.4	437.5
September	32.40	21.90	23.3	22.7	29.0	9	6.6	220.1
October	32.50	22.55	23.2	21.5	21.0	20	6.1	588.0
November	32.90	21.90	23.0	22.0	2.5	4	7.7	42.1
December	33.45	18.45	19.7	19.4	2.1	-	9.7	-
1995								
January	34.10	18.35	20.8	20.0	2.3	-	8.6	-
February	35.50	21.35	22.8	21.8	2.9	-	9.3	-
March	37.70	22.75	23.3	22.9	3.3	-	9.5	-
April	37.15	23.70	25.03	24.0	3.4	3	8.9	73.8
May	34.45	23.45	27.9	24.5	2.9	12	6.5	357.2
June	32.25	23.45	23.74	24.98	2.9	20	4.1	729.4
July	30.10	22.75	23.5	23.2	2.8	27	2.2	612.5
August	31.20	23.15	24.0	23.7	3.1	18	3.8	456.6
September	31.30	22.55	23.5	23.24	3.6	13	5.2	294.7

	Max. temp.	Min. temp.	Dry bulb reading	Wet bulb reading	Wind speed km/hr	No. of rainy days	Sun-shine hours	Rain fall
October	34.00	21.60	23.22	22.9	3.4	13	6.9	198.6
November	33.30	20.80	22.5	22.3	2.6	8	6.0	170.6
December	33.50	17.15	19.2	17.5	2.3	-	10.0	-
1996								
January	33.70	17.40	20.7	19.3	2.9	-	9.1	-
February	34.30	18.75	21.1	20.9	2.9	-	9.3	-
March	36.10	22.00	24.0	23.0	3.6	1	8.9	63.2
April	34.40	21.55	25.0	24.0	3.4	4	8.2	146.6
May	34.55	22.60	25.3	24.8	2.9	5	7.7	166.0
June	33.55	22.70	25.0	24.4	1.3	13	5.9	101.3
July	31.35	21.40	23.0	23.0	3.9	19	3.2	508.9
August	30.65	21.15	22.0	23.8	3.5	14	4.0	171.4
September	32.10	21.75	24.0	23.0	2.54	10	4.0	263.2
October	31.40	21.60	24.0	22.0	2.79	16	6.0	291.9
November	32.65	21.20	23.3	22.60	2.5	4	7.02	72.2
December	32.45	18.95	20.2	20.0	1.8	3	7.5	30.2
1997								
January	33.65	18.20	21.0	20.0	2.1	-	9.11	-
February	35.25	19.65	21.2	21.0	2.9	-	9.3	-
March	36.85	20.90	24.0	23.2	3.2	4	8.8	24.1
April	36.60	22.60	25.0	24.0	3.0	2	7.0	9.4
May	35.85	23.00	25.0	24.0	3.9	7	7.5	69.2
June	34.85	22.70	24.3	23.0	2.93	15	5.6	684.1
July	30.80	22.10	23.2	23.3	2.05	38	2.9	1685.2
August	30.00	22.30	24.0	23.4	2.68	19	3.2	523.3
September	31.45	23.00	24.2	24.0	1.7	10	6.1	199.2
October	33.15	23.20	24.3	24.0	0.6	11	6.2	223.6
November	32.40	23.00	24.0	24.0	0.42	10	6.7	426.8
December	33.65	22.80	24.0	24.0	0.15	1	7.1	15.0

	Max. temp.	Min. temp.	Dry bulb reading	Wet bulb reading	Wind speed km/hr	No. of rainy days	Sun-shine hours	Rain fall
1998								
January	35.20	21.10	22.0	22.0	0.35	-	6.3	-
February	34.95	22.05	22.0	22.0	0.3	-	7.3	-
March	36.40	24.55	22.2	22.2	0.5	-	8.2	-
April	37.50	25.10	25.6	25.6	0.5	1	7.6	36.0
May	36.40	25.35	24.3	24.3	2.1	4	7.7	75.0
June	35.00	24.50	24.3	24.3	2.5	27	6.2	1027.0
July	31.80	24.50	23.9	23.9	2.0	28	7.0	756.8
August	31.35	24.00	24.1	24.1	3.0	23	6.0	520.3
September	32.25	24.35	24.0	24.0	1.4	21	4.4	472.2
October	31.50	19.45	24.0	23.8	2.4	18	4.1	405.7
November	31.30	19.40	24.0	23.3	0.5	5	4.2	149.8
December	34.15	19.85	23.0	22.0	1.1	2	6.3	141.1
1999								
January	34.75	17.30	22.0	21.4	-	-	7.0	-
February	36.00	18.65	24.2	23.1	-	-	-	-
March	36.65	20.30	23.6	23.0	-	1	-	17.0
April	37.30	22.70	25.8	24.0	3.4	-	-	225.4
May	34.55	20.00	25.0	23.6	3.3	12	4.4	675.3
June	32.40	18.00	-	-	-	18	4.2	447.5
July	32.40	18.00	-	-	-	23		

Appendix III

Soil characteristics of Vellanikkara and Madakkathara

Characters	Vellanikkara	Madakkathara
Organic carbon (%)	1.59	1.67
pH	4.29	5.6
Available Nitrogen (Kg ha^{-1})	425 – 452	332
Available Phosphorus (Kg ha^{-1})	11.2 – 14.5	4.8
Available Potassium (Kg ha^{-1})	430 – 443	216

Appendix IV

Salient characters of ten varieties in the Multi-location trial plot of cashew at CRS, Madakkathara

Varieties	Canopy	Branching	Flowering	Mean yield (kg/tree)	Nut weight (g)	Shelling percentage (%)	Export grade (%)
Anakkayam – 1 (BLA 139-1)	Compact	Intensive	Oct-Nov	12	6.0	28.0	W280
Madakkathara-1 (BLA 39/4)	Compact	Intensive	Nov.	14.7	6.2	26.8	W280
Madakkathara-2 (NDR 2-1)	Open	Intensive	Jan-Mar	17.1	7.3	26.2	W210
Kanaka (H-1598)	Open	Intensive	Nov-Dec	15.4	6.8	40.3	W280
Dhana (H-1608)	Compact	Intensive	Dec-Jan	10.7	9.6	27.1	W210
Priyanka (H-1591)	Open	Intensive	Dec-Jan	12.7	10.9	28.5	W180
H-856	Semi erect	Intensive	Jan-Mar	10.0	9.1	30.4	W210
H-1600	Semi erect	Intensive	Nov-Dec	11.9	8.2	27.3	W210
H-1602	Semi erect	Intensive	Nov-Dec	14.1	10.2	23.1	W180
Vridhachalam-3 (M 26/2)	Compact	Intensive	Jan-Feb	11.7	7.2	29.1	W210

INTEGRATED NUTRIENT MANAGEMENT IN CASHEW IN RELATION TO YIELD AND QUALITY

By

K. E. USHA

ABSTRACT OF THE THESIS

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Faculty of Agriculture

Kerala Agricultural University

Department of Agronomy

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR - 680656

KERALA, INDIA

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ABSTRACT

A study on **"Integrated nutrient management in cashew in relation to yield and quality"** was taken up during 1995-1999 at College of Horticulture, Vellanikkara. It consisted of five experiments to find out the litter contribution and the nutrient return through cashew litter, to compare the litter production in the fertilized and unfertilized plots, to evaluate the effect of AMF, *Azotobacter* and *Azospirillum* on growth and establishment of cashew in the nursery and main field and also to know the interaction effect of these biofertilizers on cashew.

The average annual litterfall in ten year old cashew plantation was 5014 kg ha^{-1}. Litter contribution varied with the season and variety. Dry months contributed to the major share of annual litter production. Decomposition studies of leaf litter revealed that there would be over 90% weight loss within 21 months after litterfall. Correlation between leaf litterfall, decomposition and weather parameters was worked out. The nutrient content of the litter from a normally fertilised garden was estimated to be 0.65% N, 0.22% P, 0.72% K, 0.22% Ca, 0.19% Mg, 369 ppm Fe, 17 ppm Zn, 15 ppm Cu and 283 ppm Mn and the nutrient return was calculated as 32.1 kg N, 1.1 kg P, 36.5 kg K, 10.9 kg Ca, 9.5 kg Mg, 2.1 kg Fe, 0.1 kg Cu and Zn and 1.2 kg Mn per hectare.

The average annual litter production in the unfertilized plot was 3235 kg ha^{-1}. The average composition of litter from unfertilized plot was 0.71% N, 0.03% P, 0.63% K, 0.19% Ca, 0.14% Mg, 230 ppm Fe, 17 ppm Cu, 12 ppm Zn and 469 ppm Mn. There was no significant difference in the nutrient content of the fertilized and unfertilized plots. Fertilizer application led to an increase in the organic carbon content of the soil.

AMF inoculation enhanced the growth and uptake of cashew seedlings in the nursery. *G. intraradices* inoculated plants were superior among the six species of AMF tested. The same trend was observed in seedlings and grafts when planted in the field. AMF inoculation enhanced the absorption of ^{32}P labeled fertilizers.

Azotobacter and *Azospirillum* inoculation enhanced the germination, growth and development of cashew seedlings in the nursery. In general, *Azospirillum* inoculated plants were more efficient than *Azotobacter* inoculated cashew plants. The same trend was observed in the seedlings and grafts planted in the field.

Combined inoculation of AMF and *Azospirillum* was found to be the best among the different combinations tried in the nursery.

An increase of 24.03% in yield due to combined inoculation of *Azotobacter* and *Azospirillum* could be observed in twelve years old cashew trees.