AGRONOMIC EVALUATION OF BIOFARMING TECHNIQUES FOR FORAGE PRODUCTION IN COCONUT GARDENS

By

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DECLARATION

I hereby declare that this thesis entitled "*Agronomic evaluation of biofarming techniques for forage production in coconut gardens*" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled " ***Agronomic evaluation of biofarming techniques for forage production in coconut gardens*** " is a record of research work done independently by **Smt. Sansamma George** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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Abbreviations used in this thesis

%	–	per cent
@ -	–	at the rate of
^{o}C	–	degree Celsius
cc	–	cubic centimetre
cm	–	centimetre
Fig.	–	figure
g	–	gram
ha	–	hectare
hr		hour
k pa	–	kilo pascal
kg	–	kilogram
mg	–	milligram
mm	–	millimetre

INTRODUCTION

INTRODUCTION

Biofarming techniques have received world wide attention because of the growing concern about the degradation of agricultural resource base. With the hiking input costs and the low commodity prices, the farmers are looking for low cost input alternatives. These alternative management techniques minimise the use of purchased inputs and exploit biological systems such as biological nitrogen fixation, Vesicular Arbuscular Mycorrhizae (VAM), etc., to increase soil fertility, improve the efficiency of applied fertilizers and thus to enhance soil productivity. Though these are naturally occurring associations, inoculation of crop plants with the preparations of these microorganisms is generally necessary because many soils lack specific microorganisms shown to or believed to stimulate productivity. Recently the vermiculture biotechnology has also emerged as an effective biological route of soil fertility management system for sustainable agriculture.

In Kerala, inspite of the large livestock population, there is a perpetual shortage for milk and other animal products. Low productivity is mainly due to poor nourishment. The fodder produced in the state is not sufficient to meet the requirement of the present livestock population of 35 lakh heads of adult units. Forage plants are heavy feeders of nutrients but are often raised under non-fertilized or residual fertility situations, since they are considered to be of less value and least priority crops in the human food chain. Any alternative means to replace the costly fertilizers partially or fully would be a welcome preposition.

Due to the unique cropping systems followed, the scope for raising fodder as a sole crop is very limited in Kerala state. Farmers raise fodder crops mostly as border plants or as inter crops in orchards and coconut gardens. Several shade tolerant and high yielding varieties of fodder grasses have been identified during the past two decades among which Guinea grass *(Panicum maximum.* Jacq.) and Congosignal *(Brachiaria ruziziensis* Germain & Evrard*)* are the two very popular and adaptable fodder crops being palatable as well as nutritious (Nair, 1979).

Among the various biological systems known to fix atmospheric nitrogen the legume - Rhizobium association has received maximum attention all over the world. But reports on biological nitrogen fixation during the last two decades (Dobereiner et al., 1972., Dobereiner and Day, 1976) have revealed and re-emphasized the already existing association of the tropical grasses with N_2 fixing bacteria which under favourable conditions may contribute significantly to the nitrogen economy of crop plants. Nitrogen fixation in the rhizosphere of grasses has been suggested as a mechanism to explain the substantial nitrogen gain observed under plant fallows. Development of a manageable N_2 fixation association between grasses and bacteria could greatly increase forage production efficiency. Perennial forage grasses have greater opportunity for developing such an association because of their stability of ecosystem (Weaver et al., 1980).

Nitrogen fixing bacteria of many diverse genera occur in high numbers in the rhizosphere of a variety of grasses (Sreekumar and Tilak, 1988). Among them

Azospirillum and Azotobacter are documented to be of agronomic importance. Hazra (1994) observed that inoculation with non-systemic nitrogen fixers like Azospiriilum and Azotobacter is of significant consequence and benefit to almost all cereal fodder crops and pasture grasses.

There is now considerable evidence that mycorrhizal associations are of importance to plant nutrition, especially in nutrient deficient soils. Inoculating the host with VAM fungus can lead to economic use of costly fertilizer sources. Howeler et al. (1987) reported that when the mycorrhizal dependence of six tropical forage grasses and eighteen forage legumes were examined, five of the grasses were more mycorrhiza dependent than majority of the legumes. While much has been learned about the importance of mycorrhiza in increasing the productivity of many of the forage grasses, the practical utilization of the technology requires more research under specific field situations.

Importance of organic matter in sustainable agriculture is well documented. Organic wastes are produced in large quantities all over the world. These materials cause unbearable odour problems, use large quantities of land for disposal and often remain as a source of contamination to ground water. Vermiculture technology is an effective means for recycling these biowastes to soil, resulting in waste land development and sustainable agriculture.

Majority of the research on biofertilizers has been done as pot culture studies. A logical approach would be to test the value of these alternative technologies under field conditions since successful local researches may encourage more farmers to adopt these technologies.

With this background information, an investigation was carried out with the following specific objectives.

1. To investigate the potential of biofarming techniques for production of forage grasses in coconut gardens.

2. To find out the influence of different nutrient management techniques on uptake of nutrients and quality of the produce.

3. To ascertain the effect of the different nutrient management techniques on physical and chemical properties of the soil.

4. To work out the economics of these nutrient management techniques for the production of forage grasses in coconut gardens.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Within a short period of time quite an amount of work has been carried out on various aspects of biofarming techniques. The present investigation entitled "Agronomic evaluation of biofarming techniques for forage production in coconut gardens" embraces a range of bioagents, i.e., Azospirillum, Azotobacter, Vesicular Arbuscular Mycorrhiza(VAM) and earthworms and their associated effects. A perusal of the literature pertaining to the investigation revealed a dearth of specific information on the influence of these bioagents on guinea grass and congosignal. Hence relevant works on other crops are also considered and reviewed hereunder.

2.1. Azospirillum

Much interest has been generated on Azospirillum as a potential nitrogen fixing organism ever since its isolation by Dobereiner and Day (1976) and its later demonstration in active association with the roots of many monocotyledons, particularly grasses. Unlike the Rhizobium-legume symbiosis, the Azospirillum-grass association lacks visible structures to indicate successful colonisation. Although there is a general conclusion that Azospirillum occurs in large numbers in root environment of many grasses and fixes nitrogen in the rhizosphere, the precise role played by this diazotroph in harnessing atmospheric nitrogen still accommodates speculations and divergent views (Sumner, 1989).

2.1.1. Occurrence and distribution

The diazotrophic bacteria Azospirillum is widely distributed in nature. Dobereiner (1976) has suggested guinea grass to be a preferred forage grass for isolating Azospirillum bacteria. Nearly 10 per cent of the soils and roots from temperate region and more than 50 per cent of the tropical samples are positive for Azospirillum (Neyra and Dobereiner, 1977). Barak *et al.* (1983) have shown chemotaxis of Azospirillum to amino acids, carbohydrates and organic acids in the rhizosphere.

The distribution of the bacterium in India, and the response of grasses and other crops to inoculation with Indian isolates has been reported by several investigators (Lakshmikumari *et al.*, 1976., Kavimandan *et al.*, 1978., Subba Rao *et al.*, 1979).

2.1.2. Factors affecting occurrence and functioning

Azospirillum requires an optimum range of temperature lying between 32^{o} and 40^{o} C (Day *et al.*, 1975). Day and Dobereiner (1976) reported that nitrogen fixation rapidly declined below 24^{o} C and above 40^{o} C. Subba Rao *et al.* (1980) pointed out that the nitrogen fixation by the Indian isolates of Azospirillum was maximum at temperature ranging from 30^{o} to 35^{o} C.

Ron Gafny *et al.* (1986) while studying the factors essential for optimal bunching of Azospirillum to root, observed that pH has a strong effect on binding of Azospirillum to roots with a distinct optimum at pH 6.1.

However Beerkeem and Bohlool (1980) reported that although pH of the soil was having strong influence on the distribution of Azospirillum, sporadic occurrence could be noted in soil with pH as low as 4.8. The nitrogenase activity of guinea grass roots could be detected even in acid soils of pH up to 5.2, probably due to proliferation of Azospirillum within the roots (Subba Rao, 1993).

Azospirillum is microaerophilic and shows a marked preference for low oxygen potential, with very little nitrogenase activity at oxygen pressure values above 1 k pa (Patriquin *et al.*, 1983). Christiansen-Weniger and Van Veen (1991) observed that nitrogen fixation in the rhizosphere of an actively growing plant was much less sensitive to the depressing influence of free oxygen.

Studies by Thompson *et al.* (1984) showed seasonal variations in nitrogenase activity of grass associated microorganisms which was attributed to changes in soil temperature and moisture. Imposition of water stress considerably affected the rhizosphere population of Azospirillum and per cent root infection by the organism (Banwari Lal and Rao, 1990).

Scientists working with Azospirillum have divergent views on the role of applied nitrogen on nitrogen fixing potential of the bacteria. Barber *et al.* (1976) obtained maximum yield of corn at low levels of combined nitrogen, when the crop was inoculated with Azospirillum. He observed that the ability of nitrogen fixing bacteria to survive, compete and grow in the soil was not favoured by the addition of nitrogen to soil.

Millet and Feldman (1984) recorded maximum yield increase due to Azospirillum inoculation at the highest nitrogen level. However since maximum yield response occurrence was at the highest nitrogen level they concluded that contribution of Azospirillum to wheat yield was not through nitrogen fixation. O'Hara *et al.* (1987) reported that there was an interaction between growth response of maize to Azospirillum inoculation and the level of applied nitrogen. The counts of the organism associated with plant roots indicated that the number of bacteria was stimulated by combined nitrogen. Low levels of combined nitrogen in soil was suggested to be needed for bacterial growth.

2.1.2. Crop response to Azospirillum

Substantial growth and yield increases have been reported in the tropical plants especially fodder grasses inoculated with Azospirillum. Kapulnik *et al.* (1982) observed increase in vegetative growth, plant height and dry weight of foliage and increased number of ears in maize through Azospirillum inoculation. Jayaraman and Ramiah (1986) reported that the growth characters such as plant height and total number of tillers hill^{-1} were maximum in the treatments which received 75 kg nitrogen ha^{-1} and Azospirillum inoculation. Govindarajan (1987) obtained increase in fresh weight of shoot, root and also increased plant height in fodder sorghum through seed and soil inoculation under field conditions.

Root elongation was increased in a number of crops by Azospirillum inoculation under both green house and field conditions. Following inoculation, Azospirillum adsorbs to and proliferates on the roots (Okon *et al.*, 1977) and apparently invades root internal parts (Patriquin *et al.*, 1983). There it promotes root hair development and branching (Kapulnik *et al.*, 1983).

Subba Rao *et al.* (1979) reported that application of Azospirillum promoted root growth and more nitrogen fixation in graminaceous plants which helped in increasing the biomass yield. Tien *et al.* (1979) also observed that Azospirillum inoculation enhances root branching and root hair formation. Similar observations were made by Yahalom *et al.* (1984) in *Setaria italica*.. Kapulnik (1984) observed that the beneficial effect of Azospirillum inoculation in terms of root elongation and increased surface area, of several wheat cultivars varied according to the age of culture, bacterial concentration and inoculation temperature. Optimal bacterial concentration and critical level above which root growth was inhibited, varied for the different species and strains of bacteria tested (Okon and Kapulnik, 1986).

The effectiveness of Azospirillum inoculation for dry matter 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 dry matter than did uninoculated control. Up to 42 and 39 kg nitrogen ha^{-1} were replaced by inoculation of pearlmillet and guinea grass respectively. Bouton and Zuberer (1979) also obtained increased dry matter yields in field grown, low fertilized guinea grass. While working on perennial pasture grasses such as signal grass (*Brachiaria brizantha)* Pahwa (1986) reported that Azospirillum increased forage yield by 15 per cent over uninoculated control and a saving of nitrogen fertilization equivalent to 30 kg nitrogen ha^{-1}. In a pot culture experiment with different pasture grasses, Pahwa (1990) obtained an yield increase as high as 34.4 per cent with seed inoculation over uninoculated control. Summarizing the results of the studies conducted by All India Co-ordinated Research Project on Forage crops (AICRPFC) in different centers, Hazra(1994) observed that in forage grasses the increase in yield through Azospirillum inoculation varied from 4 - 12 per cent with annual forage grasses and 12 - 17 per cent in the case of perennials.

Smith *et al.* (1976) observed increased crude protein content of guinea grass through Azospirillum inoculation. Singh *et al.* (1980) reported that crude protein yield in sorghum and cowpea through Azospirillum inoculation was equal to that with 45 kg nitrogen. However Millet and Feldman (1984) observed that although Azospirillum increased wheat yield, the protein content was not influenced.

There are also instances where no positive yield response was obtained through Azospiriilum inoculation. Baltensperger *et al.* (1978) with *cynodon dactylon*, Bouton and Zuberer (1979) with *Panicum maximum* and Schank *et al.* (1981) with *Digitaria* sp. obtained no response with inoculation. O'Hara *et al.* (1987) also obtained no consistent effect of Azospirillum inoculation in the growth of wheat and pearl millet.

The inconsistency in yield responses to inoculation is probably the result of ecological and environmental factors. The success of inoculation obviously depends on many factors including the appropriate choice of carrier and inoculum, the ability of the bacterium to establish *itself* and compete with the native microflora, favourable soil chemical and physical conditions such as pH, aeration, available nutrients including nitrogen, climatic conditions and agricultural practices (Sumner, 1989).

2.1.4. Nitrogen fixation by Azospirillum

In recent years considerable evidence that several species of grasses are able to obtain significant quantities of nitrogen from associated biological nitrogen fixation has been obtained. There are several reports of high acetylene reduction activity associated with grass roots removed from soil and incubated at low oxygen partial pressure (Dobereiner *et al.,* 1972). Nitrogen fixation by grass bacterial association was confirmed in *Paspalum notatum* and *Digitaria decumbens* in amounts far beyond the analytical and experimental error (De-polli *et al.,* 1977). Weaver *et al.* (1980) reported that the most active rhizosphere samples were expected to fix nitrogen @ 33, 26, 20 and 20 kg in 100 days for *Cynodon dactylon, Paspalum* sp., *Brachiaria* sp. and *Andropogon* sp. Studies using isotope dilution techniques have revealed that approximately 10 per cent of the nitrogen in the grass

Paspalum notatum and 30 - 40 per cent of the nitrogen in the grasses *Brachiaria humidicola* and *Brachiaria decumbens* was derived from associated biological nitrogen fixation (Boddey *et al.*, 1983., Boddey and Victoria, 1986). These contributions amounted to between 20 and 45 kg N ha^{-1} $year.^{-1}$, sufficient to maintain a low although significant dry matter production. Miranda and Boddey (1987) made a detailed study using the isotope dilution technique with eleven ecotypes of *Panicum maximum* to determine whether they were able to obtain a significant contribution of nitrogen from associated biological nitrogen fixation. Contributions of the same to the Panicum ecotypes were estimated to be between 24 and 38 per cent of total nitrogen incorporated, equivalent to between 5 and 10 kg nitrogen ha^{-1} per 30 days. They also opined that the significant differences observed in ^{15}N enrichment between guinea grass genotypes suggested that further screening and selection of guinea grass ecotypes for high associated biological nitrogen fixation was a worthwhile objective.

Day *et al.* (1975) observed that nitrogenase activity varied considerably with season and was maximal during active vegetative growth of C_4 forage grasses, viz., *Pennisetum purpureum, Cynodon dactylon, Melinus minutifolia and Digitaria decumbens*. They also observed that in the field nitrogenase activity of Pennisetum and Digitaria assayed two weeks after top dressing of 20 kg nitrogen ha^{-1} was not affected even after 8 such dressings. Okon *et al.* (1988) suggested that less than 1 kg N ha^{-1} $season^{-1}$ was supplied in most cases by Azospirillum.

2.1.5. Nutrient and water uptake with Azospirillum inoculation

Several scientists have concluded that enhanced growth of inoculated plants may be due to increased uptake of nutrients (Lin *et al.*, 1983., Okon and Kapulnik, 1986).

Singh *et al.* (1980) observed increased uptake of calcium, magnesium and phosphorus in sorghum due to Azospirillum inoculation which was similar to that obtained with 45 kg nitrogen. Kapulnik (1984) reported that Azospirillum inoculation causes alteration in cell arrangement of root cortex cells and increased mineral uptake. Pacovsky *et al.* (1985) also obtained greater phosphorus uptake in sorghum plants inoculated with Azospirillum which was suggested to be because these bacteria increase nutrient availability by altering root surface characteristics involved in nutrient uptake. Microscopic examination of roots of live maize and wheat plants inoculated with Azospirillum showed distortions in the cortical cell arrangements indicating a weakening of natural adherence in cortical tissue of inoculated roots which would increase mineral absorption by a kind of sponge effect (Sumner, 1989).

Okon *et al.* (1988) reported that the moisture status of maize and sorghum was favourably affected by Azospirillum inoculation. They claimed that significantly less pressure was needed to extract water from inoculated leaves than from controls and stomatal conductance was higher and canopy temperature lower in inoculated plants under water stress than in non inoculated control. Sarig *et al.*

(1988) demonstrated that inoculation resulted in higher leaf water potentials, lower canopy temperatures and greater stomatal conductance and transpiration. Inoculated plants extracted more soil water particularly from deeper layers, indicating that yield increases resulting from inoculation are primarily from improved soil moisture utilisation.

2.1.6. Production of plant growth regulators

While there is little question that Azospirillum fixes nitrogen in the rhizosphere of plants considerable evidence have confirmed that Azospirillum produces phytohormones which can stimulate root growth and induce changes in root morphology which in turn can have a positive effect in crop growth. Gaskin (1977) observed that growth of guinea grass could be stimulated or suppressed depending on the inoculum concentration of Azospirillum. Growth regulators produced by the bacteria was suggested to account for the increase in growth. Tien *et al.* (1979) reported that Azospirillum grown in culture produced growth promoting compounds such as gibberellin like and cytokinin like substance and auxins like Indole Acetic Acid (IAA) from tryptophan. They also demonstrated that it was possible to mimic the effects of Azospirillum using a mixture of IAA, gibberellin and kinetin which increased root hairs and branching in barley. In another study Venkateswarlu and Rao (1983) showed that strains of Azospirillum that caused maximum increase in plant growth in soil showed higher quantities of auxins in culture filtrates. Govindan and Purushothaman (1984) observed excretion of IAA and gibberellin like substances by Azospirillum into culture growth. Kolb and Martin

(1985) demonstrated that spraying a solution of 10^{-9}/litre of IAA on roots of wheat growing in root boxes resulted in a significant increase in root length, which mimicked Azospirillum inoculation.

2.2. Azotobacter

Nitrogen fixation by free living microorganisms associated with plants has been of interest for many years (Lindberg and Granhall, 1984., Bashan, 1986).

Among the heterotrophic free living nitrogen fixing bacteria, Azotobacter is the most intensively investigated genera (Meshram and Shende, 1982). It has been widely used to inoculate plants to promote nitrogen fixation in agricultural crops and forage grasses (Hussain *et al.*, 1987).

2.2.1. Occurrence and distribution

Azotobacter bacteria are not usually present in the rhizoplane(root surface) but are abundant in the rhizosphere (the soil immediately surrounding roots). Studies on the occurrence of Azotobacter in some soil types of India have been done by Rangaswamy and Sadasivam (1964). The dominance of Azotobacter in the rhizosphere of plants has been consistently shown by several investigators (Kavimandan *et al.*, 1978). Root exudates and excretions which contain amino acids, vitamins and organic acids together with decaying portions of root system serve as source of energy for Azotobacter multiplication (Subba Rao, 1993). Out of the different species of Azotobacter, *Azotobacter chroococcum* and *Azotobacter beijerinckii* are the most commonly occurring species.

2.2.2. Factors affecting occurrence and functioning

Azotobacter is an aerobic organism and oxygen is required for ATP formation, but nitrogen fixation is an anaerobic process. Obviously oxygen must be excluded from the site of nitrogen fixation. Many workers believe that increased respiration by Azotobacter excludes oxygen from nitrogenase which may serve as a natural tool to scavenge oxygen from the site of nitrogen fixation (Postgate, 1974).

Nitrogenase activity of Azotobacter is very much pH dependent. Among the commonly occurring Azotobacter species *Azotobacter chroococcum* is commonly found in neutral and alkaline soils and *Azotobacter beijerinckii* in acid soils (Verma, 1993).

The lack of organic matter in the soil is a limiting factor in the proliferation of Azotobacter in soils. Kundu and Gaur (1980) opined that addition of organic manure provided better environment for proliferation of introduced bacteria. In a study by Jagtap and Shingte (1982), the grain yield increase obtained in rice due to the application of 60 kg N ha^{-1}, Azotobacter and farmyard manure @ 10 t ha^{-1} was equal to that obtained with 120 kg N ha^{-1} without the biofertilizer. Wani (1985) observed 12 per cent increase in the yield of pearl millet when Azotobacter inoculation was done along with application of farmyard manure @ 5 t ha^{-1} when compared to farmyard manure alone. Inoculation of rice with Azotobacter along with application of green manures such as sesbania, glyricidia and sunhemp and paddy straw increased grain yield by 7 - 17 per cent when compared to organic amendments alone (Prasad, 1986). The treatment of Azotobacter + 60 kg nitrogen + 7.5 ton of glyricidia gave significantly higher grain yield in rice when compared to the treatment of 90 kg N ha^{-1}

Inorganic fertilization of soil influences Azotobacter population. Fedrove (1952) reported that applied nitrogen increased the effectiveness of inoculation. Maize yields were increased by inoculation, with increase in applied nitrogen up to 150 kg ha^{-1} (Reddy *et al.*, 1977). On the other hand Hussain *et al.* (1987) observed that nitrogen application decreased the effectiveness of Azotobacter inoculation. Significant increase in the yield of wheat with the application of inoculant over control was recorded at 0, 40 and 80 kg nitrogen ha^{-1} but no such effect was recorded at application of 120 kg N ha^{-1}.

2.2.3. *Crop response to Azotobacter*

Brown *et al.* (1964) observed that inoculation can improve crop growth only when the bacteria were established and grew well in the rhizosphere. He obtained good establishment of Azotobacter in the rhizosphere of cereals and other crops by inoculation of seeds, roots or soil. The inoculation of crop plants with bacterial preparations is generally necessary because many soils lack specific microorganisms shown to or believed to stimulate productivity (Hussain *et al.*, 1987).

Increase in number of tillers through inoculation of Azotobacter was reported by Jones and Collins (1978) in wheat and oats and by Dhillon *et al.* (1980) in wheat. Studies conducted by Zambre *et al.* (1984) showed that seed bacterization of wheat with Azotobacter along with various nitrogen levels enhance the number of tillers, dry matter, grain yield and protein content in grain.

Setaria italica inoculated with Azotobacter developed eight leaves by 21 days after emergence, whereas the non-inoculated control developed only 6 leaves as reported by Yahalom *et al.* (1984). They also obtained increased shoot dry weight and panicle length through inoculation.

To evaluate the extent of influence of Azotobacter on the root biomass of plants, Dewan and Subba Rao (1979) conducted some pot culture experiments with varying doses of inorganic nitrogen. They observed that the increment in root biomass in unsterilized soil by inoculation at 0 kg nitrogen ha^{-1} was more than that obtained by the addition of 30 kg nitrogen ha^{-1} alone. This was equally true when a comparison was made between the treatment receiving 60 kg N ha^{-1} with bacterial inoculation and the one receiving 120 kg N ha^{-1} alone. In *Setaria italica* root branching, root dry weight and root/shoot ratio increased with Azotobacter inoculation (Yahalom *et al.*, 1984). Sen and Palit (1988) have also made similar observations.

Azotobacter has been widely used to inoculate crop plants to promote nitrogen fixation in agricultural crops and conclusions have been drawn that inoculation of non legumes with Azotobacter increased yield of field crops by about 10 per cent and of cereals by about 15 - 20 per cent (Mishustin *et al.*, 1963., Shende, 1965., Mishustin and Shilnikova, 1969).

Sanario and Sundara Rao (1975) have reported significantly increased fodder yield of sorghum through Azotobacter inoculation. In *Setaria italica* inoculation with different strains of Azotobacter increased seed yield by 23.6 per cent (Yahalom *et al.*, 1984). Combined application of zinc sulphate @ 10 kg ha^{-1} and Azotobacter significantly increased forage yield of pearl millet (Hazra, 1988). Pandey and Kumar (1989) reported that the inoculation of Azotobacter to wheat, maize, sorghum, rice, millet, vegetables, potatoes, cotton and sugarcane grown under both irrigated and rain fed conditions with or without application of nitrogen, phosphorus, and potassium increased yield of these crops. They related this improvement not only to nitrogen fixation but also to the ability to produce anti-bacterial anti - fungal compounds and growth regulators. Patel *et al.* (1992) reported that Azotobacter inoculation with 75 kg N ha^{-1} increased green forage, dry matter and crude protein yields by about 17.83, 50.32 and 75.44 per cent over 75 kg N ha^{-1} alone in fodder maize. Wani (1992) obtained 8 per cent increase in yield of pearl millet through Azotobacter inoculation. She also emphasized the need for screening a large number of strains of the bacteria for different crops and varieties.

Quality of produce is also affected by Azotobacter inoculation. Zambre *et al.* (1984) reported that protein content of wheat increased to 11.9 per cent through

Azotobacter inoculation, while the content registered by uninoculated control was 11.5 per cent. They also observed that the increased nitrogen uptake and better utilisation of added manures and fertilizers due to these bacteria might be the causes for the increase in protein content in wheat grain. Hussain *et al.* (1987) reported that differences in nitrogen and phosphorus content of grain and straw in maize due to different strains of Azotobacter in fertilized and unfertilized soils were highly significant. Maximum increase in nitrogen content of grain and straw in fertilized (8.9 per cent and 32.1 per cent respectively) and unfertilized (11.5 per cent and 53 per cent respectively) soils over the corresponding controls were recorded where seeds were inoculated with strain A9 while phosphorus content was highest with strain A5.

2.2.4. Nitrogen fixation by Azotobacter

The amount of nitrogen fixation by Azotobacter in soil varied widely in different investigations. Greaves and Jones (1942) estimated it to be in the range of 0.1 - 60 kg ha^{-1} annually. Studies conducted by Sanario and Sundara Rao (1975) on the effect of seed bacteriarisation with Azotobacter on sorghum and wheat revealed that the strains K and 41 had the nitrogen fixing capacity of 17.2 and 14.2 mg nitrogen/g of sucrose consumed. Meshram and Shende (1982) while studying the nitrogen uptake by maize with Azotobacter inoculation concluded that the availability of extra nitrogen to plants in addition to levels of nitrogenous fertilizer could be attributed to nitrogen fixation by Azotobacter. They observed that there was no need to increase the nitrogen level above 80 kg ha^{-1} as it did not change total nitrogen uptake. Studies conducted by Martinez - Toledo *et al.* (1988) showed clearly that inoculation of maize with Azotobacter increased the nitrogenase activity associated with the maize roots.

2.2.5 Nutrient uptake with Azotobacter inoculation

Meshram and Shende (1982) while investigating the extent to which Azotobacter could replace the application of nitrogen fertilizers to crops observed that total nitrogen uptake by maize after inoculation with Azotobacter was significantly higher than the control treatment. Hussain *et al.* (1987) also obtained higher nutrient uptake through Azotobacter inoculation in unfertilized and fertilized soils. Nitrogen, phosphorus and potassium uptake were favourably affected by inoculation.

2.2.6 Production of plant growth regulators

The potential use of Azotobacter as a biofertilizer was reviewed by Brown (1972) who concluded that inoculation with Azotobacter occasionally promoted yields, probably by mechanisms other than biological nitrogen fixation. Azcon and Barea (1975) observed that culture supernatants of different strains of Azotobacter contain at least three gibberellin like substances, Indole Acetic Acid and three substances possessing cytokinin activity. Several other workers have also attributed the beneficial effect of Azotobacter in crops to production of growth substances and phytohormones (Chandana, 1982., Narula *et al.*, 1991).

Hussain *et al.* (1987) concluded that the increased yield of maize obtained through inoculation of Azotobacter was not necessarily due to increased nitrogen fixation alone but also due to other factors including production of plant growth hormones by the bacteria.

2.3. Vesicular Arbuscular Mycorrhiza (VAM)

The importance of Vesicular Arbuscular Mycorrhizal (VAM) associations in agricultural crops is well documented (Bagyaraj, 1990., Jeffries and Dodd, 1991). Barea (1991) observed that a key determinant of the ability of a root system to acquire nutrients from the soil was the extent to which it was symbiotically colonized by the appropriate mycorrhizal fungi.

2.3.1. Occurrence and distribution

Vesicular Arbuscular Mycorrhizae are geographically ubiquitous and occur over a broad ecological range from aquatic to desert environment (Mosse *et al.*, 1981., Bagyaraj, 1990). All but a few vascular plant species (those belonging to Cruciferae, Chenopodiaceae, Cyperaceae and Juncaceae) are able to form mycorrhizal associations (Barea, 1991).

Mycorrhizal associations have also been widely reported from the Indian sub continent (Potty, 1978., Girija and Nair, 1985). The fungi very commonly reported to form VA mycorrhizal association in field crops generally belongs to the genera *Glomus, Gigaspora* and *Acaulospora* (Mukherji and Kapoor, 1986).

2.3.2. Factors affecting occurrence and functioning

VAM fungi are ubiquitous, but several factors especially some agricultural practices affect the Mycorrhizal populations both quantitatively and qualitatively (Barea, 1991).

Saif and Khan (1975) observed that more than 50 per cent of the root segments of winter wheat seedlings examined in west Pakistan were mycorrhizal a month after they were sown. Sieverding (1981) concluded that a much higher temperature had a favourable effect on VAM infection and activity. Many reports from temperate soil reveal that infection of graminae plants by VAM does not reach appreciable levels (>30 per cent root length) until late spring or even early summer (Dodd and Jeffries, 1986).

It is well documented that particular soil pH favour particular VAM species and this factor significantly affects the effectiveness of mycorrhizal fungi (Mosse *et al.*, 1981). Their studies have shown that soil pH by changing the solubility status of plant nutrients, can indirectly influence VAM formation and activity. Out of the various species, *Glomus fasciculatum* and *Acaulospora laevis* are best suited for acid soils (Hayman, 1982).

As obligate aerobes, VAM are affected by oxygen concentration and flooding tends to reduce VAM formation. But in some cases there are adaptations and VAM can occur in water- logged conditions (Barea, 1991).

There are reports that a long dry season can reduce the VAM population under field conditions (CIAT, 1985). Drought stress significantly reduced the infected root length of maize while in sorghum plants drought stress had no influence on the total infected root length compared to unstressed plants (Osonubi, 1994).

Organic matter content, mainly because it alters the other physico chemical soil properties has a striking influence on VAM functioning (Arines *et al.*, 1990).

Mosse *et al.* (1981) observed that VAM represented a compliment of the root system being more critical when the environment was stressed, nutrient poor or competitive. Observations indicated that soluble phosphate in soil decreased both the extent of extramatricial mycelium (Abbott *et al.*, 1984) and the number of arbuscles formed(Smith and Gianinazzi - Pearson, 1988).

Mycorrhiza induced growth depression of plants in high phosphorus soil has been reported by many workers. Mosse *et al.* (1973) reported that when the added phosphorus level in the soil was more, mycorrhizal roots took up more phosphate and as a result, a supra-optimal concentration was reached in mycorrhizal plants. This would lead to the poor growth of mycorrhizae and at the end it might lead to the death of the organism. Elias and Safir (1987) found that the preference of VAM to the low phosphorus concentration was due to the quantity of root exudates. The exudates from plants experiencing phosphorus deficiency was found to stimulate hyphal elongation of VAM fungus. Marschner and Dell (1994) observed that with increasing soil phosphorus the growth enhancement effect of VAM declined and was either abolished or led to growth depression (shift from mutualism to parasitism) if the carbon cost of symbiosis was not compensated by other beneficial effects.

2.3.3. Crop response to VAM

It is well established that mycorrhizal association improve growth in a wide range of plants (Hayman, 1983., Jeffries, 1987).

Baylis (1975) observed that graminoids with profusely branched root system and long root hairs were less dependent on VAM than those with few or no root hairs.

However Hayman (1980) reported that ecologically and agriculturally important plant species of the family graminae form VAM association. Howeler *et al.* (1987) studied the mycorrhizal dependence of six tropical grasses, i.e., *Brachiaria decumbens*, *B. brizantha*, *B. dictionura*, *Andropogon gayanus* and *Panicum maximum* and eighteen forage legumes in an oxisol to which 20 kg P ha^{-1} was applied as rock phosphate. They observed that the grasses were more mycorrhiza dependent than the majority of legumes. They concluded that under conditions of low levels of available phosphorus, as was often the case in tropical soils, the grasses were as mycorrhiza dependent as the legumes or more woody species such as cassava. Significant responses to mycorrhizal infection in graminae have been reported by many other workers also (Thompson, 1990).

Geethakumari *et al.* (1990) reported that the number leaves $hill^{-1}$ of ragi was positively influenced by mycorrhizal inoculation. Lu and Koide (1994) observed that in general mycorrhizal plants had much greater leaf area, leaf weight and also more number of leaves.

Tinker (1975) observed that mycorrhizal plants showed a marked increase in chlorophyll content of leaves when compared to the uninoculated control. Mohan Raj Samuel (1984) suggested that there existed a close link between chlorophyll content of plants and colonisation of VAM in roots. Subramonian and Dwivedi (1988) also obtained similar results.

Gerdemann (1965) reported that maize inoculated with *Endogone fasciculatum* produced twice as much dry weight as uninoculated maize. Increased growth in maize by VAM inoculation was also reported by Sanni(1976).

In barley higher dry matter production, more tillers and more ears $plant^{-1}$ and greater yield were observed in mycorrhizal treatment compared to non-mycorrhizal ones (Saif and Khan, 1977). Clark and Mosse (1981) observed that in pots without added phosphorus the fresh weight of ears was doubled by inoculation in barley. Jensen (1984) also obtained 24 per cent yield increase in barley and up to 72 per cent increase in maize, through VAM inoculation.

Hazra (1994) reported the results of detailed studies in which the effect of VAM inoculation to perennial grasses such as guinea grass was tried at three distinct locations of humid region, viz., Jorhat in east, Palampur in north and Vellayani, Kerala in south. The results clearly indicated that VAM inoculation had a distinct influence on forage yields, especially in southern region. VAM fungi was also compared against non symbiotic nitrogen fixing bacteria on guinea grass in low fertility (0.3 per cent organic carbon) acid soils of Palampur at subtropical region. The data revealed that VAM fungi was much more effective in influencing forage yield than the nitrogen fixers, Azotobacter and Azospirillum. VAM fungi increased green forage by 13 per cent and dry forage yield by 24 per cent as compared to uninoculated control which indicated a possible saving of 25 kg N ha^{-1} due to VAM inoculation. He also reported that in another study conducted at Jhansi VAM inoculation in conjunction with 40 kg N ha^{-1} to forage sorghum gave similar yield level to that obtained with 80 Kg N ha^{-1} and about 17 per cent yield increase over plots fertilized with 40 kg N ha^{-1} alone.

In a trial in an alluvial soil at Ludhiana, VAM (*Glomus fasciculatum*) inoculation gave an increased yield of 32 per cent in multi - cut sorghum (3 cuts), 28 per cent in guinea grass (6 cuts), 7 per cent in pearl millet (4 cuts) and 8 per cent in single cut maize over respective controls (Hazra, 1994).

VAM increase the rate of growth of plants and also influence the partitioning of phytomass between shoot and root (Smith, 1980). Relatively less of the photosynthates are allocated to the roots and hence the root/shoot ratio is usually lower in VAM plants than in their non - mycorrhizal counter parts. Lower root/shoot ratios with VAM colonisation have been reported by Piccini *et al.* (1988) and also Berta *et al.* (1990). Kothari *et al.* (1990) found that mycorrhizal inoculation with *Glomus mossea* reduced the total root length and root dry weight of maize plants compared with non - mycorrhizal phosphorus fertilized controls.

In contrast to this, there are also reports that mycorrhizal occurrence in crop plants stimulated more of root proliferation (Bagyaraj and Manjunath, 1980). Osonubi (1994) reported that total root length and root dry weight of maize were significantly increased by mycorrhizal infection. But in sorghum, total root length was increased whereas the root dry weight was not influenced by VAM inoculation.

Kucey and Bonetti (1988) observed an increase in nitrogen content in VAM plants in comparison with controls receiving phosphorus. Azcon and Barea (1992) opined that enhancement effect of VAM on the nitrogen contents in nodulated legumes were not necessarily derived only from better nitrogen fixation but in part stem from higher uptake of soil nitrogen.

Stribley *et al.* (1980) reported that shoots of plants infected with VAM contained higher internal concentration of phosphorus than those of un-infected plants of equal size, over wide ranges of external supply and of host plants. Typically in mycorrhizal plants the phosphorus concentration per unit dry weight were higher and thus the phosphorus utilisation efficiency lower than in non mycorrhizal plants. In another study Lu and Koide (1994) observed that the foliar concentration of phosphorus in mycorrhizal plants was generally significantly higher and this difference was smaller at higher levels of phosphorus amendment.

On the other hand Smith and Daft (1977) recorded no significant difference in phosphate content of mycorrhizal and non-mycorrhizal clover plants.

The potassium content of leucern was not affected by VAM inoculation (Nielson, 1990). Marschner and Dell (1994) obtained lower concentrations of potassium in mycorrhizal plants.

Schultz *et al.* (1979) observed that VAM inoculation resulted in high concentration of calcium in the leaves of sweet gum but the magnesium concentration was unaffected. However Nielson (1990) obtained significant improvement in concentration of both the elements in leucerne.

In agreement with the importance of the external hyphae for uptake and transport of zinc and copper, the shoot concentration of zinc and copper were usually higher in mycorrhizal plants than in mycorrhizal plants (Marschner and Dell, 1994). They also observed that the depressing effect of phosphorus fertilization on concentrations of zinc and copper in plants indicated the importance of VAM in acquisition of these nutrients from the soil under the particular condition.

However Oliver *et al.*(1984) failed to get any increase in zinc content in cowpea through VAM inoculation.

Bethlenfalvay and Franson (1989) obtained reduced manganese concentration in mycorrhizal plants grown in soils high in manganese. They suggested that this mycorrhizal effect contributed to higher manganese tolerance in plants. The decrease in manganese concentration was most likely an indirect effect caused by VAM induced changes in rhizosphere microorganisms in general and decrease in population of manganese reducers in particular (Kothari *et al.*, 1991).

2.3.4 Nutrient and water uptake with VAM inoculation

A great deal of work shows that VAM enhance plant growth as a result of improved mineral nutrition of the host plant and this has been confirmed with the use of isotopic tracers (Barea, 1991). Vesicular Arbuscular Mycorrhiza are of particular importance for plant acquisition of phosphorus and other nutrients which are immobile in soil (Johansen *et al.*, 1993).

For rye grass it has been found that inoculation with *Glomus tenuis* or *Gigaspora margarita* in several soil fertilizer treatment significantly increased fertilizer recovery (Azcon-Aguilar and Barea, 1981). Krishna *et al.* (1982) reported that growth and phosphorus nutrition in finger millet on phosphorus deficient soil was improved by inoculation with VAM fungus *Glomus fasciculatum*. Jensen (1983) investigated the effect of VAM fungi on nutrient uptake and growth of barley at no phosphorus level and stated that soil with no phosphorus with VAM fungi increased concentration of phosphorus and total uptake of phosphorus. Kucey and Janzen (1987) also reported an increase in phosphorus uptake of mycorrhizal wheat.

Ames *et al.* (1984) using ^{15}N as a tracer showed that the uptake of mineral nitrogen in mycorrhizal plants was enhanced as compared to non - mycorrhizal plants. Their works also indicated that the VAM plant could derive nitrogen from sources that were less available to non-mycorrhizal plants. The field experiments by Barea *et al.* (1987) and Kucey and Bonetti (1988) confirmed by using ^{15}N labeled fertilizer that VAM hyphae took up nitrogen from soil thereby increasing nitrogen content in the VAM plant in comparison with controls receiving phosphates. Johansen *et al.* (1993) while studying the transport of nitrogen hyphae of VAM fungus observed that the recovery of ^{15}N in mycorrhizal plants was 38 or 40 per cent respectively when $^{15}NH_4^+$ or $^{15}NO_3^-$ was applied. The corresponding values for non-mycorrhizal plants were 7 and 16 per cent respectively.

Rosendahl (1943) reported enhanced uptake of potassium in mycorrhizal plants when compared to the non-mycorrhizal controls. Smith *et al.* (1981) observed that mycorrhizal infection improved the potassium nutrition of clover. They suggested that the increased potassium uptake might be an indirect result of improved phosphorus nutrition. According to Bethlenfalvay and Franson (1989) the remarkable difference in growth response of soybean to VAM inoculation seemed to be more related to improved potassium rather than phosphorus nutrition of host plant.

However according to Chapin (1980) there was no conclusive support for a role of VAM in potassium uptake. Sieverding and Toro (1988) also felt that the results on the role of mycorrhiza in potassium uptake were inconsistent and difficult to interpret.

The capacity of VAM for enhancing calcium uptake has been reported by Rhodes and Gerdemann (1978) and White and Brown (1979).

Kothari *et al.* (1990)) opined that for magnesium direct experimental evidence for uptake and transport in VAM hyphae was either lacking or inconclusive, whereas studies by Khalil *et al.* (1994) showed enhanced uptake of calcium and magnesium in mycorrhizal plants.

Uptake of minor elements such as copper and zinc also are increased by mycorrhizal infection. Kilham (1984) elucidated the incremental effect of mycorrhizal infection in the uptake of phosphorus, magnesium copper, and cobalt by livestock grasses when treated with *Glomus fasciculatum*. Le Tacon (1985) generalised that VAM increased the translocation of least soluble elements like phosphorus zinc and copper. In maize grown in calcareous soil, the VAM contribution to total uptake ranged between 16 and 25 per cent for zinc and 13 to 20 per cent for phosphorus (Kothari *et al.*, 1991). For copper the delivery through VAM hyphae ranged from 52 to 62 per cent of the total copper uptake (Li *et al.*, 1991).

Sieverding (1983) reported that VAM plants utilised water better under drought condition. According to Haung *et al.* (1985) VAM is important to decrease the resistance to water transport in the plant tissue.

2.3.5 Mechanism of nutrient and water uptake by VAM

It is well documented that VAM can absorb several times more nutrients and have greater nutrient inflow rates than roots (Barea and Azcon - Aguilar, 1983., Harley and Smith, 1983., Smith and Gianinazzi - Pearson, 1988). Marschner and Dell (1994) observed that mycorrhizal infection enhanced plant growth by increasing nutrient uptake via increases in the absorbing surface area, by mobilizing sparingly available nutrient sources or by excretion of chelating compounds or ectoenzymes.

Sanders and Tinker (1971) observed that the increased surface area due to mycelial net work was primarily responsible for the enhanced uptake of phosphorus. The fungal hyphae actually transport phosphate over distances (several cm) into the root cortical cells (Pearson and Tinker, 1975). Rhodes and Gerdemann (1980) suggested that VAM hyphae growing through soil pore spaces were able to affect phosphate absorption beyond the depletion zone that develop around the roots.

Several investigators have opined that VAM were able to take up phosphate from soil solutions with low phosphate concentrations more efficiently than simple roots (Harley and Smith, 1983., Tinker and Gildon, 1983). Bolan *et al.* (1983) documented the existence of a threshold concentration for effective phosphate uptake by non mycorrhizal clover, but not for VAM clover. ^{32}P studies by Bolan *et al.* (1984) also revealed that there are forms of phosphorus in soil that are accessible to VAM but not to non - mycorrhizal roots. They also suggested that the phosphorus that was better used by VAM was the phosphate adsorbed to iron phosphate. There are also evidence to show that VAM plants can readily respond to additions of sparingly soluble phosphorus such as rock phosphate (Manjunath *et al.*, 1989).

The qualitative and quantitative changes in the root exudation patterns (Harley and Smith, 1983) and the difference between VAM and non - mycorrhizal plants in the absorption of anions and cations (Buwalda *et al.*, 1983) which can change the pH of the rhizosphere are indirect mechanisms that Bolan *et al.* (1984) argued would explain the effect of VAM to increase phosphate availability to the plants.

Bowen and Smith (1981) reported that VAM can use both NH_4^+ and NO_3^- forms of nitrogen. Since nitrate is much more mobile in soil than ammonium (Harley and Smith, 1983) it seems unlikely that VAM exert any special effect on nitrate uptake. Nevertheless, because of the great demand for nitrogen by plants, the soil surrounding the root can be deficient in nitrate (Harley and Smith, 1983) and since the fungus can absorb nitrate ions from beyond the more deficient shells around roots it can increase nitrate uptake as well.

There are indications of a positive effect of VAM on water relations in plants that are not eqalised by addition of phosphate (Hardie and Leyton, 1981). To explain the cases where VAM seem to improve water flow through hyphae, Cooper (1984) argued that the external VAM hyphae bypass the dry zone surrounding the roots during the drought period. Thus VAM can maintain a water continuity across the soil-root interface. This argument is also supported by Hardie (1985). Azcon *et al.* (1988) suggested that VAM by maintaining the uptake of slowly diffusing nutrient under water stress situations do help plants to cope up with drought stress.

2.3.5. Influence of VAM on soil aggregation

Aggregation and aggregate stability are of fundamental importance in determining agricultural capacity of the soil (Bryan, 1969). Tisdall and Oades (1982) observed that under plants macroaggregates were stabilised mainly by root and VAM hyphae. In a further study Oades (1984) suggested that roots and microorganisms stabilized aggregates by producing polysaccharides in accessible coarse pores. Jacobson (1994) suggested that mycorrhizae improved soil structure by their stabilising effect on soil aggregates.

2.4. Vermitechnology

Vermiculture biotechnology is an aspect of biotechnology involving the use of earthworm as versatile natural bioreactors (Bhawalkar, 1989) for effective recycling of organic waste to the soil. According to Edwards (1990) a transition from chemical to sustainable agriculture takes 3 to 6 years. This time duration however could be curtailed to three months by harnessing and applying vermiculture biotechnology (Bhawalkar, 1991) This swift change over to sustainable agriculture with out loss of yield is possible by seeding the soil with vermicastings, the effective biofertilizer produced in vermitechnology.

Earthworms modify soil physical, chemical, and biological properties (Lee, 1985., Lal, 1988) and it is believed that they enhance nutrient cycling by ingestion of soil and humus and the production of casts (Basker *et al.*, 1992).

Positive earthworms effects on soil fertility have been documented in several studies, mainly in arable and grass land soils (Syers and Springett, 1984., Lee, 1985). This effect has been attributed to the ability of earthworms to influence the soil physical environment by increasing the pore volume, increasing the amount of water soluble aggregates, increasing the incorporation of organic matters and enhancing pedological processes (Shipitalo and Protz, 1988).

The influence of prevailing climatic conditions on worm activity as well as their habitual preferences in the tropical regions limit the possibilities of direct introduction of worms into the agricultural land to improve soil conditions and plant growth. Under such circumstances the use of selected species of earth worms for vermicompost is the most economic way and its application in the field is a more viable method (Kale *et al.*, 1992).

Various studies have been focused on the use of earth worms in the stabilisation of organic residues such as sewage sludge, animal wastes, crop residues and industrial refuse (Mitchell *et al.*, 1977., Tomati *et al.*, 1985). Under favourable conditions wastes are converted into a homogenous mass (castings) which may form a good soil conditioner with high nutritional value for plants (Albanell *et al.*, 1988).

2.4.1. Crop response to vermicompost

Khan (1960) reported that growth of maize in a loamy soil was enhanced by the addition of vermicompost and their effects were greater than that was obtained with the addition of FYM. The yield enhancing property of vermicompost for rice was reported by Kale and Bano (1988). Zao Shi - Wei and Huong Fu - Zhan (1988) demonstrated that chemical fertilizer application along with vermicompost increased the nutrient uptake and net production of wheat and sugar cane. Perreira and Cruz (1992) observed that while vermicompost was not a substitute for fertilizer or lime it was advantageous to use it in combination with one or both. Bhawalkar and Bhawalkar (1993) concluded that vermicastings if applied at a basal dose of 2.5 t ha^{-1} would trigger the soil biology and the transition from chemical nutrition to bionutrition iwas quick and with out a significant loss of yield.

Considerable scientific data are being generated to testify that the produce obtained with the use of vermicompost is nutritionally superior, tastes good, has good texture and have better keeping qualities (Lampkin, 1990). Tomati *et al.* (1990)

reported that earthworm castings increased protein yield by 24 per cent in lettuce and 32 per cent for radish. In sugarcane the quality of produce was increased when vermiculture was adopted (Phule, 1993). Stephens *et al.* (1994) obtained significant increase in foliar concentration of N, P, K, Ca ,Cu, and Na and they attributed the enhancement to increased availability and uptake of nutrients from the soil.

Shuxin *et al.* (1991) observed 30 to 50 per cent increase in nitrogen uptake in vermicompost applied sugarcane. Kale *et al.* (1992) also found increased nitrogen and phosphorus uptake in rice treated with vermicompost.

Increased phosphorus availability by increase in phosphatase activity by vermicompost application was noticed by Syres and Springett (1984).

Anina (1995) observed that the increase in K uptake in vermicompost applied plants might be due to the increase in K availability by shifting the equilibrium among the forms of potassium, relatively unavailable forms to more available forms in the soil.

The increased availability of calcium and magnesium in vermicompost was attributed to be the reason for increased calcium and magnesium uptake in plants treated with vermicompost (Shuxin *et al.*, 1991).

Vijayalekshmi (1993) reported that soil physical properties such as porosity, soil aggregation, soil transmission, and conductivity of wormcast applied soil was higher when compared to no wormcast amended soil in paddy.

Vermiculture is nature's own way of balanced nutrition to plants. The excellence of vermitechnology is that it can be used even at homes in a simple domestic recycling unit (Ismail, 1993).

MATERIALS AND METHODS

MATERIALS AND METHODS

This investigation envisages the agronomic evaluation of biofarming techniques for forage production under coconut garden conditions. Two field experiments were conducted to assess the potential for utilising microbial biofertilizers and vermicompost for production of forage grasses. The materials used and the methods adopted in the experiments are detailed hereunder.

3.1. Site description

The experiment was carried out in the uplands of the Instructional farm attached to the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The farm is situated at 8.5^{O} N latitude and 76.9^{O} E longitude at an altitude of 29 m above Mean sea level.

3.1.1. Climate and season

A humid tropical climate prevails in the area of the experimental site. The experiment was extended for a period of two years from September 1993 to August 1995. The data on various weather parameters during the cropping period and the previous five years' average are given in appendix - I and graphically presented in Fig. 1 and 2. The mean values of the weather parameters during the cropping period are presented in Table 1.

3. 1.2. Soil

Prior to the experiments, composite samples of the soil were drawn from a depth of 0-15 cm and analysed for physico-chemical properties and the data are presented in Table 2. The soil of the experimental site was sandy clay loam belonging to the taxonomic class, loamy kaolinitic isohyperthermic rhodic hapulstox. It was acidic in reaction, low in available nitrogen, potassium and organic carbon

Table 1. Mean values of the weather parameters during the cropping period

Parameters	The average values	
	September 1993 to August 1994	September 1994 to August 1995
Mean max. Temp. (^{O}C)	30.41	30.76
Mean min. Temp. (^{O}C)	23.55	23.72
Mean relative humidity(%)	83.15	79.79
Mean daily evaporation(mm)	3.20	3.26
Mean monthly rainfall(mm)	179.75	150.14
Total rainfall(mm)	2157.70	1802.30

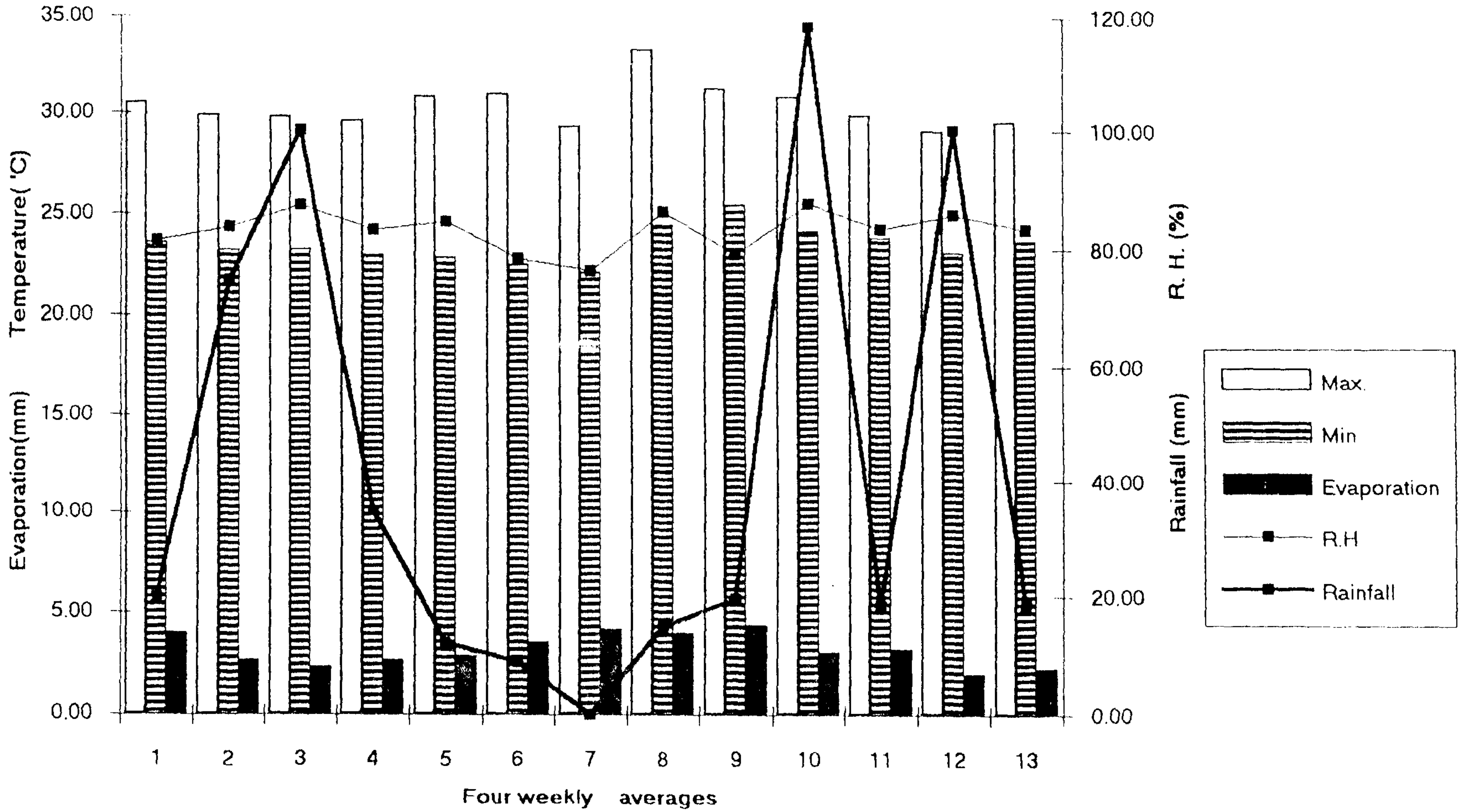

Fig 1. Weather parameters of the cropping period September 1993 to August 1994

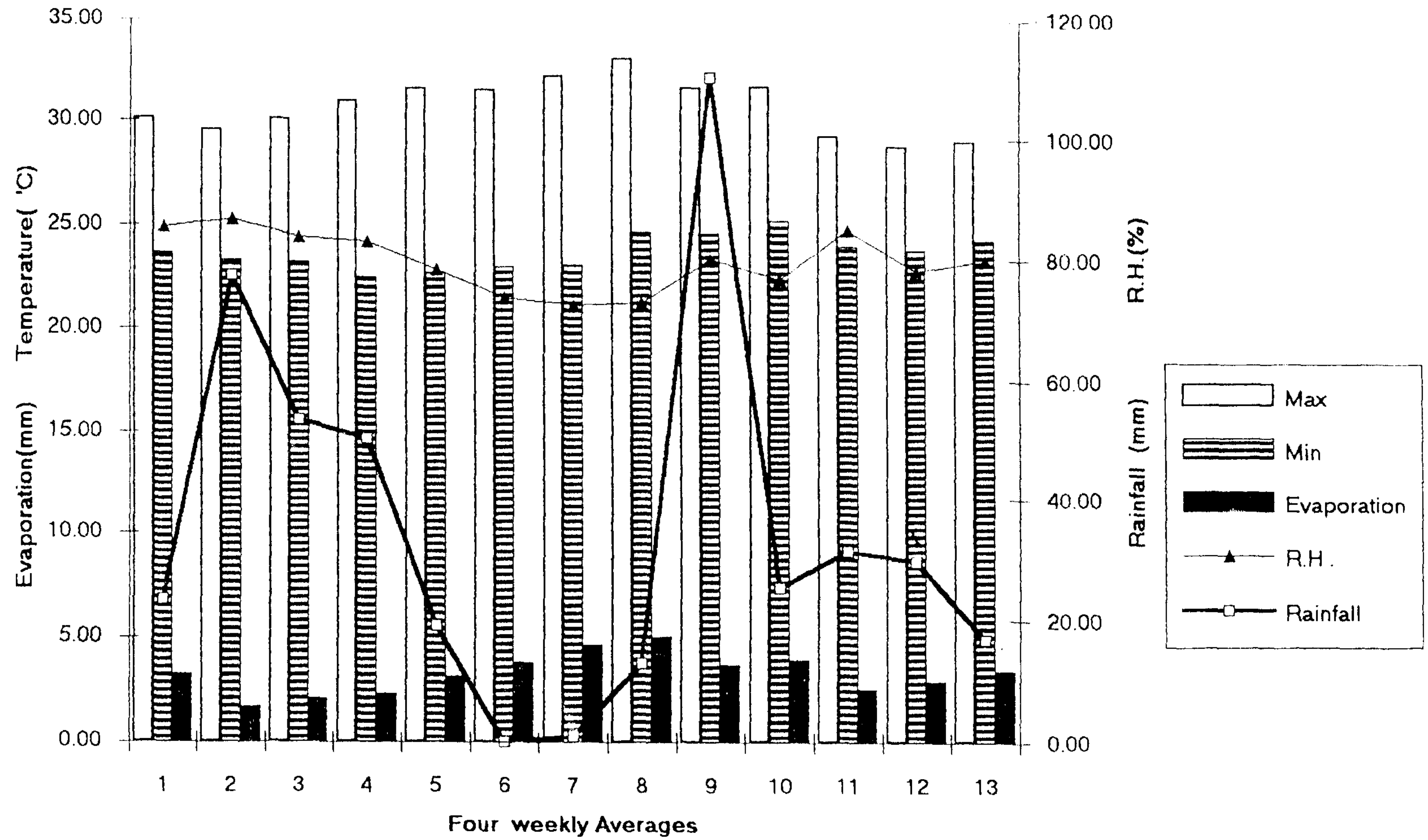

Fig 2. Weather parameters of the cropping period from September 1994 to August 1995

Table 2. Soil properties of the experimental site

Sl.no.	Particulars	Mean values	Methods used
A	**Physical properties**		Bouyoucos Hydrometer (Bouyoucos, 1962)
1	Mechanical composition constituents		
	Coarse sand	16.70	
	Fine sand	31.30	
	Silt	25.50	
	clay	26.50	
	Textural class	Sandy clay loam	
2	Bulk density (g cc^{-1})	1.38	Gupta and Dakshinamoorthy (1980)
3.	Water holding capacity (per cent)	20.03	"
4	Porosity (per cent)	30.65	"
5	Mean weight diameter(mm)	0.462	Yoder's wet sieving method (Yoder, 1937)

Table 2. (continued.........)

B	**Chemical properties**		
1	Soil reaction (pH)	5.00	pH meter with glass electrode (Jackson, 1973)
2	Organic carbon (per cent)	0.448	Walkely and Black's Method (Jackson, 1973)
3	Available nitrogen (Kg ha^{-1})	196.00	Alkaline Potassium Permanganate method (Subbiah and Asija, 1956)
4	Available P_2O_5 (kg ha^{-1})	22.80	Bray's colorimetric method(Jackson, 1973)
5	Available K_2O (kg ha^{-1})	98.80	Ammonium acetate method (Jackson, 1973)
6	Available Calcium (kg ha^{-1})	264.00	Ammonium acetate method(Jackson, 1973)
7	Available Magnesium (kg ha^{-1})	48.29	Ammonium acetate mehod(Jackson,1973)

status and medium in available phosphorus.

3.1.3. Cropping history of the experimental site

The experimental site was a partially shaded coconut garden having palms of 65 - 72 years age permitting 70 per cent of the solar radiation to filter through the canopy. The land area in the interspaces of coconuts was lying fallow for one year prior to the commencement of the experiment.

3.2. Materials

3.2.1 Test crops used

Guinea grass *(Panicum maximum.* Jacq.) var. Hamil and congosignal (*Brachiaria ruziziensis.*Germain & Evrard*)* were the test crops used for experiment no. 1 and guinea grass was used for experiment no. 2.

3.2.2. Manures and fertilizers

Urea (45.8 per cent N), Mussoriephos (20.1 per cent P_2O_5) and Muriate of potash(60 per cent K_2O) were used for the experiment.

The Farm yard manure and vermicompost used for the study were of the following composition.

	N	P_2O_5 (Percent)	K_2O
Farm yard manure	0.63	0.38	0.67
Vermicompost	1.16	0.67	2.02

Lime ($CaCO_3$) @ 500 kg ha^{-1} was applied uniformly to the main field two weeks before transplanting of experiment no. 1.

3.2.3. Biofertilizers

Azospirillum and Azotobacter cultures obtained from GKVK campus, UAS, Bangalore were used for the study. A starter culture of Vesicular Arbuscular Mycorrhiza(VAM) of the species *Glomus fasciculatum* was obtained from the Department of Plant Pathology, College of Agriculture, Vellayani. The culture was further multiplied in pots by growing sorghum plant as the symbiont for three months. The plants were then detopped and the soil - sand mixture along with the finely chopped, infected roots was used as the inoculum for raising the mycorrhizal seedlings of test crops in the nursery. The vermicompost for experiment no. 2 was obtained from the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. *Eudrillus eugeniae* was the earthworm species used for compost making.

3.3. Methods

3.3.1. Nursery.

The seedlings of both guinea grass and congosignal were raised in the nursery and then transplanted to the main field. The mycorrhizal seedlings were raised in a separate nursery bed. The nursery area was dug twice, stubbles removed, clods broken and leveled. The VAM culture was then placed 2.0 cm below the surface soil and the seeds were sown on the same day. The sowing was done on 23-9-93 and the seedlings were tested for VAM infection 40 days after sowing.

3.3.2. Main field

3.3.2.1. Land preparation

The main field selected as the experimental site was a coconut garden with coconut palms of uniform crown shape and height. Around the bole of each palm an area of 1.8 m radius was left out being the effective root zone of the coconut palm and the rest of the area in the coconut garden was dug twice, stubbles removed, clods broken and laid out in to blocks and plots.

3.3.2.2. Transplanting

A light irrigation was given to the nursery beds and the seedlings were pulled out carefully to assure minimum damage to the roots. Shallow furrows were taken in the main field at the required spacing and the uprooted seedlings were transplanted as per the treatments. 40 days old grass seedlings were transplanted on 4-11-93. A life irrigation was given immediately after transplanting to enable the seedlings to withstand transplanting shock. Gap filling was done wherever required.

3.3.2.3. Application of manures and fertilizers

Fertilizers, viz., urea, Mussoriephos and Muriate of potash were applied as per treatment. The fertilizer recommendations for guinea grass and congosignal were 200:50:50 kg and 150:50:50 kg N, P_2O_5 and K_2O ha^{-1} respectively (Kerala Agricultural University, 1989). Full dose of phosphorus and potassium were applied as basal, while nitrogen was applied in two equal splits, the first dose immediately after the first cutting and the second dose during the south west monsoon period. In experiment no. 1 farm yard manure was applied @ 10 t ha^{-1} for guinea grass and @ 5 t ha^{-1} for congosignal and incorporated. In experiment no. 2 farm yard manure and vermicompost were applied as per treatments before transplanting. The application of manures and fertilizers was repeated during the second year of

Plate -1 General view of the experimental site


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cultivation as well.

3.3.2.4. Application of biofertilizers

Azospirillum and Azotobacter were applied four times during the cropping period @ 2 kg ha^{-1}, i.e., at the time of transplanting as seedling root dip and re-inoculation at 6 monthly intervals. For seedling root dip the seedlings were carefully pulled out and the roots were dipped in a solution containing 2 kg inoculation culture in 40 liters of water. For re-inoculation 2 kg inoculum was mixed with 15 kg powdered FYM and broadcasted in to the main field. VAM inoculation was done only in the nursery stage.

3.3.2.5. Irrigation.

During the summer season protective irrigation was given as and when necessary.

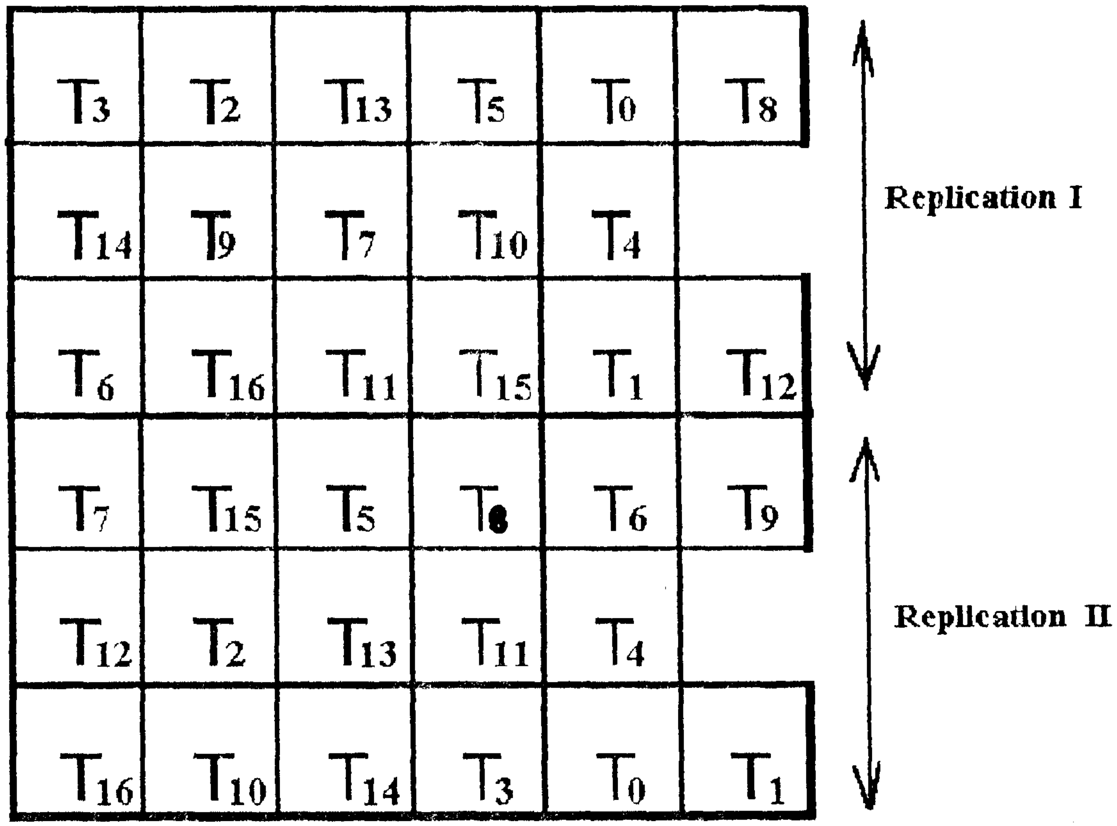
3.3.2.6. Harvest

Cuttings were taken at intervals of 45 days in rainy seasons and at 90 days interval during summer. Two border rows all around the plots were discarded and the crop was harvested from the net plot at a height of 15 cm from the ground level. All together five harvests were taken during the first year (from September 1993 to August 1994 including the nursery period) and six harvests during the second year (from September 1994 to August 1995).

3.3.3. Technical Programme

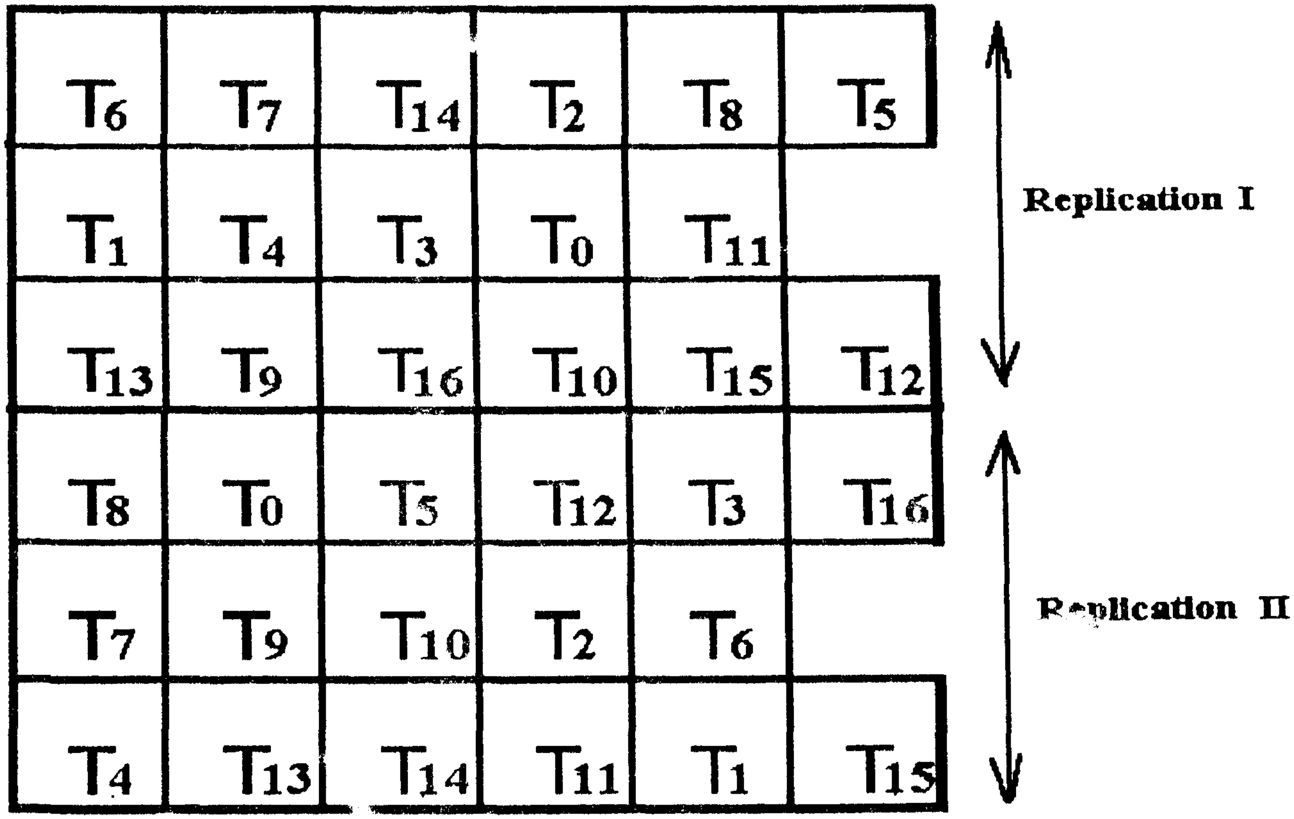
3.3.3.1. Design and lay out

Both the experiments were laid out in Randomised Block Design (RBD). The layout plans are given in Fig 3, 4 and 5.



Plot Size : 4m x 4m **Design : Randomised Block Design**

Fig.3. Layout Plan : Experiment No. I (Guinea Grass)



Plot Size : 4 x 4 m Design : Randomised Block Design

Fig 4. Layout Plan : Experiment No. I (Congosignal)

T_2	T_9	T_7	T_3	T_5	Replication I
T_{10}	T_6	T_4	T_8	T_1	
T_1	T_5	T_4	T_3	T_9	Replication II
T_8	T_2	T_7	T_6	T_{10}	
T_1	T_5	T_2	T_9	T_8	Replication III
T_{10}	T_7	T_3	T_4	T_6	

N

Plot size I x I m

Design Randomised Block Design

Fig 5. LAYOUT PLAN OF EXPERIMENT no. 2

Experiment no. 1 Microbial biofertilizers for forage production

Gross plot size	4.0 m x 4.0 m
Net plot size	2.4 m x 3.2 m
Spacing	40 cm x 20 cm
No. of treatments	17
No. of replications	2
Total no. of plots	34

Experiment no. 2 Vermitechnology for forage production

Gross plot size	1.0 m x 1.0 m
Net plot size	Three hills after leaving one border row all around
Spacing	40 cm x 20 cm
No.of treatments	10
No. of replications	3
Total No. of plots	30

3.3.3.2. Treatments

The treatment details of the two experiments are furnished in Table 3.

3.3.4. Observations

In experiment no. 1 observations on growth characters were recorded from 10 sample plants selected randomly from the net plot area of each plot and the average worked out. In experiment no. 2 the observations were taken from the plants in the net plot area. Observations on growth characters were taken on the day before each harvest and the mean values for the first and second year of cropping were worked out separately.

Table. 3. Treatment details

Experiment No. 1. **Microbial biofertilizers for forage production**

Treatments	Notations
Absolute control	T0
Azospirillum inoculation alone	T1
Azotobacter inoculation alone	T2
V A M inoculation alone	T3
Azospirillum + 0 N + full P + full K	T4
Azospirillum + 1/4 N + full P + full K	T5
Azospirillum + 1/2 N + full P + full K	T6
Azospirillum + 3/4 N + full P + full K	T7
Azotobacter + 0 N + full P + full K	T8
Azotobacter + 1/4 N + full P + full K	T9
Azotobacter + 1/2 N + full P + full K	T10
Azotobacter + 3/4 N + full P + full K	T11
V A M + full N + 0P + full K	T12
V A M + full N + 1/4 P + full K	T13
V A M + full N + 1/2 P + full K	T14
V A M + full N + 3/4 P + full K	T15
Full N + full P + full K as per package of practices recommendations, Kerala Agricultural University(1989)	T16

Total treatments 17 Replications 2

Table 3. (Continued......)

Experiment No. 2. **Vermitechnology for forage production**

Treatments	Notations
Absolute control	T0
Vermicompost @ 5 t ha^{-1} alone	T1
Vermicompost + 1/4 N + 1/4 P + 1/4 K	T2
Vermicompost + 1/2 N + 1/2 P + 1/2 K	T3
Vermicompost + 3/4 N + 3/4 P + 3/4 K	T4
Farm yard manure @ 10 t ha^{-1} alone	T5
Farm yard manure + 1/4 N + 1/4 P + 1/4 K	T6
Farm yard manure + 1/2 N + 1/2 P + 1/2 K	T7
Farm yard manure + 3/4 N + 3/4 P + 3/4 K	T8
N P K as per package of practices recommendations Kerala Agricultural University (1989)	T9

Total treatments 10 Replications 3

3.3.4.1. Observations on growth and yield characters

3.3.4.1.1. Plant height

Plant height was measured from the base to the tip of the tallest leaf in each sample plant , the averages worked out and was expressed in cm.

3.3.4.1.2. Tiller number hill^{-1}

Number of tillers of the sample plants in each plot were counted and the averages worked out.

3.3.4.1.3. Leaf : stem ratio

The sample plants taken for computation of dry matter were separated into leaf and stem, dried , weighed and the ratio was worked out. The mean of the leaf : stem ratio was then found out.

3.3.4.1.4. Green fodder yield

The green matter yield from the net plot area was recorded immediately after each harvest, and total green matter produced ha^{-1} during first and second year of cropping was worked out.

3.3.4.1.5. Dry fodder yield

The ten sample plants collected from each net plot on the day prior to each harvest was sun dried and then oven dried to a constant weight at 70^{o}C. The dry matter yield ha^{-1} was computed using the ratio between the fresh weight and oven dry weight of the sample plants at each harvest. From this the total dry fodder yield obtained during the first and second year of cropping was worked out.

3.3.4.1.6. Yield of coconut

The yield of coconuts (no. of nuts $tree^{-1}$) from the palms in the experimental area and the border lines during the November, January, March and May harvests were recorded two years prior to the experiment, during the experimental period and also during the year after the experiment.

3.3.4.2. Physiological parameters

3.3.4.2.1. Leaf Area Index(LAI)

LAI was worked out before each harvest using the length width method suggested b Gomez(1972) and averages worked out.

3.3.4.2.2 Absolute Growth Rate (AGR)

The absolute growth rate was worked out as follows as suggested by Kvet *et al.* (1971)

AGR = W2 - W1 / T2 - T1

W2 = total dry weight of plant at time T2

W1 = total dry weight of plant at time T1

The mean value was worked out and expressed as g $plant^{-1} day^{-1}$

3.3.4.2.3. Chlorophyll content

Chlorophyll content was estimated from the fully opened second leaf from the tip by the method suggested by Arnon (1949). Total chlorophyll, chlorophyll 'a' and chlorophyll 'b' were estimated using following equations and expressed in mg g^{-1} fresh weight of leaf.

Total chlorophyll = 8.05 A 663 + 20.29 A 645

Chlorophyll 'a' = 12.72 A 663 - 2.58 A 645

Chlorophyll 'b' = 22.87 A 645 - 4.67 A 663

From the values of chlorophyll 'a' and chlorophyll 'b', the a : b ratio was also worked out.

3.3.4.3. Root studies

During July 1995 (40 days after the previous harvest), ten plants from the net plot area at random were uprooted carefully, the roots were washed free of soil particles and the following root studies were made in experiment no. 1.

3.3.4.3.1. Root length

Maximum length of roots of each of the sample plant was measured and the mean length expressed in cm.

3.3.4.3.2. Root volume

Root volume was estimated by displacement method and expressed in cm^3 $plant^{-1}$.

3.3.4.3.3. Root weight

Roots removed from each of the sample plant were dried, weighed, average worked out and expressed in g $plant^{-1}$.

3.3.4.3.4. Root : shoot ratio

Root and shoot weights were recorded separately for each plant and the root to shoot ratio was worked out.

3.3.4.4. Mycorrhizal colonisation in the root

Few fine roots from ten plants at random, carefully removed from each net plot area towards the end of cropping period (August, 1995) were examined for VAM colonisation by viewing the properly stained root bits under microscope(Phillips and Hayman, 1970) and the colonisation per cent was recorded.

3.3.4.5. Plant analysis

3.3.4.5.1. Plant nutrient content

Sample plants collected from each plot at each harvest were sun dried, oven dried to a constant weight and finely ground in a Willey mill. A composite sample from samples of each harvest thus prepared was drawn and used for various analysis works. The nitrogen content (Modified Microkjeldhal method), phosphorus content (Vanado-molybdo-phosphoric yellow colour method), potassium and calcium content (Flame photometric method), magnesium, zinc, copper and manganese content (Atomic Absorption Spectrophotometer) were estimated.

3.3.4.5.2. Crude protein content

Crude protein content was calculated by multiplying the nitrogen content of the plant with the factor 6.25 (Simpson *et al.*, 1965).

3.3.4.5.3. Crude fibre

Crude fibre content was determined by the A.O.A.C method (1975).

3.3.4.5.4. Ash content

Ash content was determined by A.O.A.C. method(1975).

3.3.4.5.5. K : (Ca+Mg) Ratio

The ratio was worked out from the values of K, Ca and Mg content obtained through the analysis of whole plant samples.

3.3.4.5.6. Uptake studies

Uptake of nitrogen, phosphorus, potassium, calcium, magnesium, zinc, copper and manganese were calculated by multiplying the nutrient contents of the plant with the total dry matter production and expressed in kg ha^{-1}.

3.3.4.6. Soil analysis

3.3.4.6.1.Physical constants

At the end of the cropping period core samples were collected from the top 0-15 cm and analysed for bulk density, porosity and water holding capacity as described by Gupta and Dakshinamoorthy(1980).

3.3.4.6.2 Hydraulic conductivity

Hydraulic conductivity of undisturbed core samples, collected from 0-15 cm depth was determined using Jodpur Constant Head Permeameter(Gupta and Dakshinamoorthy, 1980).

3.3.4.6.3. Aggregate analysis

Aggregate analysis was carried out by Yoder's wet sieving method(Yoder, 1937). Mean weight diameter was taken as the structural index (Van Bavel, 1949).

3.3.4.6.4. Soil chemical analysis

The composite soil samples collected prior to the field experiments and the soil samples collected from individual plots after the experiment were analysed for organic carbon, available nitrogen, available P_2O_5, available K_2O, available calcium and available magnesium.

Organic carbon was estimated by Walkley and Black's method (Jackson ,1973). Available nitrogen was estimated by alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus by Bray method (Jackson, 1973) and available potassium by neutral normal ammonium acetate method (Jackson, 1973) Available calcium and magnesium were estimated by Atomic Absorption Spectrophotometer using neutral normal ammonium acetate method (Jackson, 1973).

3.3.4.7. Economic analysis

Economics of cultivation was worked out for both the field experiments after taking into account the cost of cultivation and prevailing market price of the forage grass.

The net income and benefit : cost ratio were calculated as follows

Net income (Rs ha^{-1}) = gross income - total expenditure
Benefit : cost ratio = gross income / total expenditure

3.3.4.8. Statistical analysis

Data relating to different characters were analysed statistically by applying the technique of Analysis of Variance for Randomised Block Design(Panse and Sukhatme, 1978). Wherever F was found significant it was marked by * and ** according to 0.05 and 0.01 level of significance respectively. Important correlations were also worked out.

Direct and indirect effects of root parameters and soil properties after the experiment on dry fodder yield were studied through path analysis techniques (Wright, 1934).

RESULTS

RESULTS

Field experiments were conducted at the Instructional farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala State, during the period from September 1993 to August 1995 to investigate the potential of biofarming techniques for forage production in coconut gardens. The results obtained during the cropping periods 1993 - 94 (September 1993 to August 1994) and 1994 - 95 (September 1994 to August 1995) are presented separately. The quality characteristics are presented as mean values for the entire cropping period.

4.1. Experiment no. 1 Microbial biofertilizers for forage production

The influence of two nitrogen fixing organisms, viz. Azospirillum and Azotobacter, and the role of Vesicular Arbuscular Mycorrhiza(VAM) in improving the growth and production of guinea grass and congosignal was studied. The diazotrophs were tested under varying levels of nitrogen and for VAM the level of applied phosphorus differed between treatments. The results on the inoculation response are furnished separately for the individual crops.

A major objective of the present experiment was to assess the extent to which chemical fertilizers could be saved by supplementing with biofertilizers. Thus the results obtained from the biofertilizer treatments are compared with the POP treatment T16 (Package of Practices Recommendation for fertilizer dose) to highlight the achievements.

4.1.1. Guinea grass (*Panicum maximum* Jacq.)

4.1.1.1. Growth and yield characters

4. 1. 1. 1. 1. Plant height(Table 4)

A perusal of the data collected during 93 - 94 revealed that plant height of guinea grass was favourably influenced by the biofertilizer treatments. All treatments except T1, T2, T3 and T4 recorded significant improvement in plant height over T0. The response of Azospirillum treatment T7 was comparable with T16 while T1, T4, T5 and T6 seemed less effective. The Azotobacter treatments also (T2, T8, T9, T10 and T11) revealed an increasing trend in plant height with incremental doses of applied nitrogen but were inferior to T16. The combination doses of VAM and chemical fertilizers (T12, T13, T14 and T15) responded more or less similar to that of POP treatment

During 94 - 95 the positive response of biofertilizer treatments over T0 was significant in all treatments except T2 and T3. The Azospirillum treatments recorded plant height on par among themselves and also with T16. Combined doses of Azotobacter with chemical fertilizers also responded similarly. Among VAM treatments, T14 recorded significantly higher plant height than T16 while in T12, T13 and T15 the improvement did not reach the level of significance.

Pooled analysis revealed that all treatments except T2 and T3 improved the plant height of guinea grass over T0. Among Azospirillum treatments T7 was comparable with the POP treatment and T1, T4, T5 and T6 were inferior. Azotobacter treatment T11 also responded similar to T16. The combination doses of VAM and chemical fertilizers T12, T13 and T15 recorded plant height on par with T16 while T14 was significantly superior.

4.1.1.1.2. Number of tillers hill^{-1} (Table 4)

The data during 93 - 94 indicated that the biofertilizer inoculation enhanced tiller production in guinea grass. All treatments except T1, T2 and T3 were significantly superior to T0. Azospirillum treatment T7 recorded tiller number on par with T6 and was significantly superior to T1, T4 and T5. Both T6 and T7 were comparable with T16. The Azotobacter treatments were less effective than T16 in terms of tiller production. Among VAM treatments, T12 and T15 were on par with T16 while T13 and T14 responded distinctly superior.

Table 4. Effect of microbial biofertilizers on plant height, number of tillers $hill^{-1}$ and leaf:stem ratio of guinea grass

Treatments	plant height(cm)			number of tillers			leaf:stem	
	93-94	94-95	pooled	93-94	94-95	pooled	93-94	94-95
T0	87.50	80.50	84.00	7.95	7.38	7.66	2.05	1.97
T1	89.70	93.50	90.93	10.20	10.90	10.55	2.18	2.15
T2	84.40	85.15	84.78	8.18	9.30	8.74	2.17	2.05
T3	88.10	87.60	87.85	9.83	11.00	10.41	2.21	2.10
T4	95.20	93.50	94.35	11.95	12.70	12.33	2.30	2.13
T5	98.90	96.40	97.65	13.18	14.00	13.59	2.23	2.09
T6	104.10	98.50	101.30	14.76	15.75	15.26	2.15	2.08
T7	110.60	102.00	106.30	16.55	18.10	17.32	2.15	2.05
T8	92.60	94.50	93.55	10.50	11.10	10.80	2.25	2.02
T9	98.50	96.50	97.50	12.42	14.55	13.49	2.25	2.05
T10	103.20	100.00	101.60	13.52	15.30	14.41	2.20	2.00
T11	103.10	102.50	102.80	14.48	16.15	15.32	2.25	2.10
T12	113.90	112.50	113.20	19.38	19.55	19.47	2.25	2.14
T13	114.50	110.50	112.50	19.63	20.55	20.09	2.34	2.17
T14	116.90	113.00	114.95	21.51	19.95	20.73	2.35	2.10
T15	107.80	105.00	106.40	16.29	16.65	16.47	2.10	2.08
T16	112.90	103.00	107.95	17.04	15.05	16.04	2.25	2.11
F	19.51**	8.03**	25.49**	26.04**	16.14**	40.42**	0.47	1.01
SE	2.40	3.19	1.92	0.79	0.91	0.60	0.12	0.05
CD	7.18	9.70	5.76	2.37	2.72	1.70	--	--

During 94 - 95 all treatments except T2 produced significantly higher number of tillers hill^{-1} than T0. T7 was significantly superior and T4, T5 and T6 were on par with the POP treatment. Azotobacter treatments T9, T10 and T11 were on par among themselves and were comparable with T16. VAM treatments T12, T13 and T14 recorded significantly higher number of tillers hill^{-1} than T16 while T15 remained on par.

Pooled analysis data showed that all treatments except T2 had significantly higher number of tillers than T0. Azospirillum treatments T6 and T7 had tiller number on par with that of T16 and T1, T4 and T5 were inferior. Response of Azotobacter treatments T10 and T11 also was similar to that of T16. Among the VAM treatments T3 was inferior, T15 was on par and T12, T13 and T14 were superior to The POP treatment.

4. 1. 1. 1. 3. Leaf : stem ratio (Table 4)

The influence of the microbial biofertilizers on the leaf : stem ratio of guinea grass was insignificant.

4.1.1.1.4. Green fodder yield (Table 5)

The data during 93 - 94 revealed that all treatments except T2 were effective in improving the fodder yield of guinea grass. T7 yielded higher than the other Azospirillum treatments and was comparable with T16. In spite of the increasing trend in fodder yield with increasing levels of applied nitrogen all Azotobacter treatments were distinctly inferior to T16. Among VAM treatments T12, T13 and T14 were more responsive than T16 while T15 faired on par.

During 94 - 95 also T2 remained on par with T0 and all other treatments were significantly superior. Azospirillum treatments T6 and T7 were more effective than T1, T4 and T5 and both these responded similar to T16. T10 and T11 recorded green fodder yield on par with T16 and the other Azotobacter treatments were inferior. The VAM treatments in comparison with the controls showed the

Table 5. Effect of microbial biofertilizers on green fodder and dry fodder yield of guinea grass (t ha^{-1})

Treat-ments	Green fodder yield 93-94	94-95	pooled	Dry fodder yield 93-94	94-95	pooled
T0	14.00	18.38	16.19	3.50	4.60	4.05
T1	21.18	26.47	23.83	5.30	6.62	5.96
T2	15.49	23.31	19.40	3.88	5.83	4.85
T3	18.79	26.39	22.59	4.70	6.60	5.65
T4	25.53	33.08	29.31	6.13	7.94	7.03
T5	28.43	36.64	32.53	6.82	8.79	7.81
T6	33.20	43.27	38.23	8.01	10.39	9.42
T7	39.50	50.07	44.79	9.08	12.08	10.63
T8	22.44	29.99	26.21	5.38	7.20	6.29
T9	28.82	38.05	33.43	6.92	9.13	8.03
T10	31.86	42.80	37.33	7.65	10.27	8.96
T11	35.06	44.46	39.76	8.42	10.67	9.54
T12	48.48	60.03	54.25	11.64	14.41	13.02
T13	49.14	60.44	54.79	11.84	14.53	13.19
T14	53.47	62.49	57.98	12.84	15.00	13.92
T15	40.50	50.29	45.39	9.72	12.07	10.89
T16	40.25	45.26	42.76	9.66	10.86	10.26
F	66.82**	53.51**	123.64**	63.92**	50.32**	113.81**
SE	1.46	1.81	1.13	0.35	0.44	0.28
CD	4.38	5.43	3.22	1.05	1.31	0.79

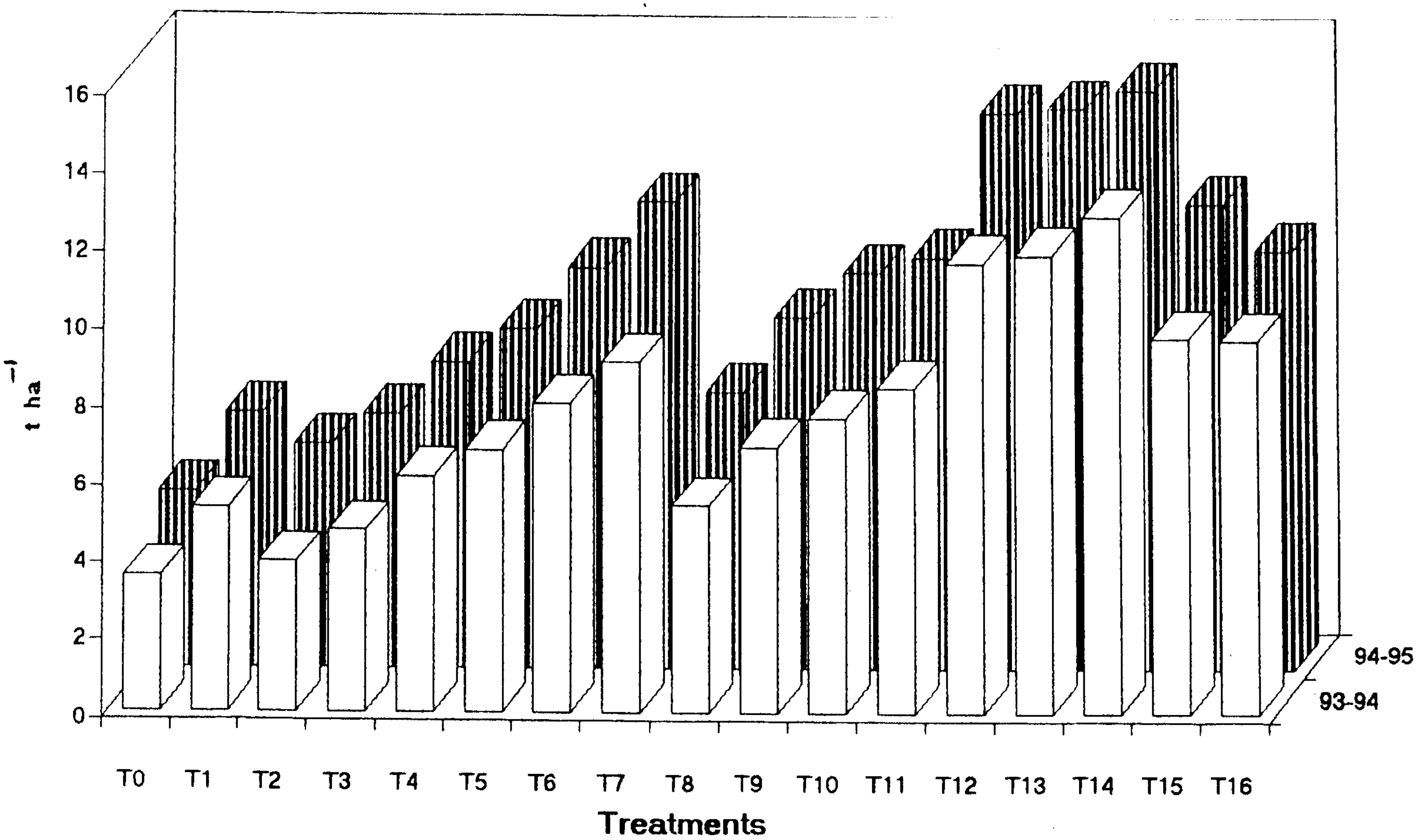


Fig. 6. Effect of microbial biofertilizers on dry fodder yield of Guinea grass

same trend as that of the previous year.

The pooled analysis studies showed that year had a distinct effect on the yield pattern of the treatments. The year - treatment interaction was found insignificant. All treatments except T2 resulted in significant yield increase over T0. Azospirillum treatment T7 was as effective as T16 and the others were inferior. Among Azotobacter treatments, T11 alone was comparable with T16. Pooled analysis studies confirmed that the VAM treatments T12, T13 and T14 were more responsive than T16 while T15 yielded on par.

4.1.1.1.5. Dry fodder yield (Table 5, Fig. 6)

Perusal of the data revealed that the effect of the microbial biofertilizers on dry fodder yield of guinea grass followed the same trend as that of green fodder yield.

4.1.1.2. Physiological parameters

4. 1. 1. 2. 1. Leaf area index (Table 6)

The leaf area index (LAI) showed considerable variation between treatments. During 93 - 94 all treatments except T2 recorded significantly higher LAI than T0. Among Azospirillum treatments, T7 recorded the highest LAI and was on par with T16 while T1, T4, T5 and T6 were inferior. The Azotobacter treatments had lower LAI values than T16. VAM treatments T12, T13 and T14 were significantly superior to T15 and also the POP treatment.

All treatments except T2 responded positively to leaf area index during 94 - 95 also. Azospirillum treatments T6 and T7 were on par among themselves and also T16 while T1, T4 and T5 were inferior. The Azotobacter treatments T10 and T11 responded similar to T16. Combination doses of VAM and chemical fertilizers showed enhancement in LAI during the second year also. T12, T13 and T14 were superior to T16 while T15 faired on par.

Table 6. Effect of microbial biofertilizers on leaf area index (LAI) and absolute growth rate (AGR) of guinea grass

Treat-ments	LAI		AGR ($g\ plant^{-1}\ day^{-1}$)	
	93-94	94-95	93-94	94-95
T0	2.670	2.965	0.467	0.504
T1	3.645	3.550	0.773	0.726
T2	3.030	3.155	0.517	0.639
T3	3.420	3.565	0.627	0.724
T4	4.360	4.700	0.817	0.870
T5	5.180	5.020	0.909	0.964
T6	5.680	5.500	1.068	1.139
T7	6.030	5.825	1.211	1.335
T8	4.400	4.165	0.719	0.789
T9	5.145	4.975	0.923	1.001
T10	5.405	5.350	1.019	1.126
T11	5.615	5.800	1.122	1.169
T12	6.765	6.240	1.551	1.579
T13	6.890	6.340	1.578	1.587
T14	7.200	6.440	1.711	1.644
T15	6.290	5.830	1.295	1.323
T16	6.215	5.495	1.288	1.190
F	65.728**	89.881**	62.618**	50.418**
SE	0.171	0.119	0.047	0.048
CD	0.512	0.358	0.140	0.144

4.1.1.2.2. Absolute Growth Rate (Table 6)

During 93 - 94 all treatments except T2 recorded significantly higher absolute growth rate (AGR) than T0. There was an increasing trend in AGR with increasing levels of applied nitrogen in both Azospirillum and Azotobacter treatments. T7 recorded higher AGR than the other Azospirillum treatments and was on par with T16. All Azotobacter treatments were inferior to the POP treatment. Among VAM treatments T12, T13 and T14 were significantly superior to T16 while T15 faired on par.

The positive influence of all treatments except T2 on AGR of guinea grass was evident during the second year also. The Azospirillum treatments T6 and T7 recorded AGR values on par with each other and both were comparable with T16. Azotobacter treatments T10 and T11 also responded similar to T16. The response of VAM treatments to AGR followed the same trend as recorded during the previous year.

4.1.1.3. Chlorophyll content (Table 7)

A perusal of the data on chlorophyll content indicated that the influence of the treatments on total chlorophyll and its components ' a ' and ' b ' followed more or less a similar trend and hence are dealt together hereunder.

The inoculation treatments showed positive effect on chlorophyll content of guinea grass. Among Azospirillum treatments, T6 and T7 were on par among themselves and also with T16 while T1, T4 and T5 recorded lower chlorophyll content. Azotobacter treatments T10 and T11 also responded similar to T16. Combination doses of VAM and chemical fertilizers were comparable to T16 irrespective of the level of applied phosphorus.

The microbial inoculants did not show significant influence on the chlorophyll a : b ratio of guinea grass.

Table 7. Effect of microbial biofertilizers on chlorophyll content of guinea grass(mg g^{-1} fresh weight)

Treatments	chlorophyll			
	a	b	a : b	a + b
T0	1.01	0.86	1.18	1.87
T1	1.04	0.86	1.17	1.86
T2	1.04	0.87	1.19	1.91
T3	1.01	0.89	1.18	1.93
T4	1.22	1.04	1.18	2.27
T5	1.25	1.06	1.18	2.31
T6	1.35	1.16	1.16	2.51
T7	1.44	1.19	1.22	2.62
T8	1.10	0.94	1.16	2.02
T9	1.28	1.09	1.18	2.37
T10	1.38	1.15	1.21	2.53
T11	1.44	1.23	1.17	2.67
T12	1.50	1.26	1.19	2.75
T13	1.50	1.31	1.15	2.81
T14	1.53	1.29	1.19	2.82
T15	1.49	1.24	1.20	2.73
T16	1.45	1.24	1.17	2.68
F	14.93**	19.19**	1.26	18.42**
SE	0.05	0.04	0.02	0.08
CD	0.15	0.11	--	0.25

4.1.1.3. Root studies

4.1.1.3.1. Root length (Table 8)

The influence of the biofertilizers on root length of guinea grass did not reach the level of significance.

4.1.1.3.2. Root weight (Table 8, Fig.7)

Perusal of the data revealed that biofertilizer treatments positively influenced the root weight of guinea grass. Azospirillum treatments T7 recorded root weight significantly higher than that of T1 and T5 and on par with that of T4 and T6. All Azospirillum treatments except T1 had root weight on par with that of T16. Combined doses of Azotobacter and chemical fertilizers also responded similar to T16. VAM treatments T12, T13 and T14 recorded significantly higher root weight than T16 while T15 showed only marginal improvement.

4.1.1.3.3. Root volume (Table 8)

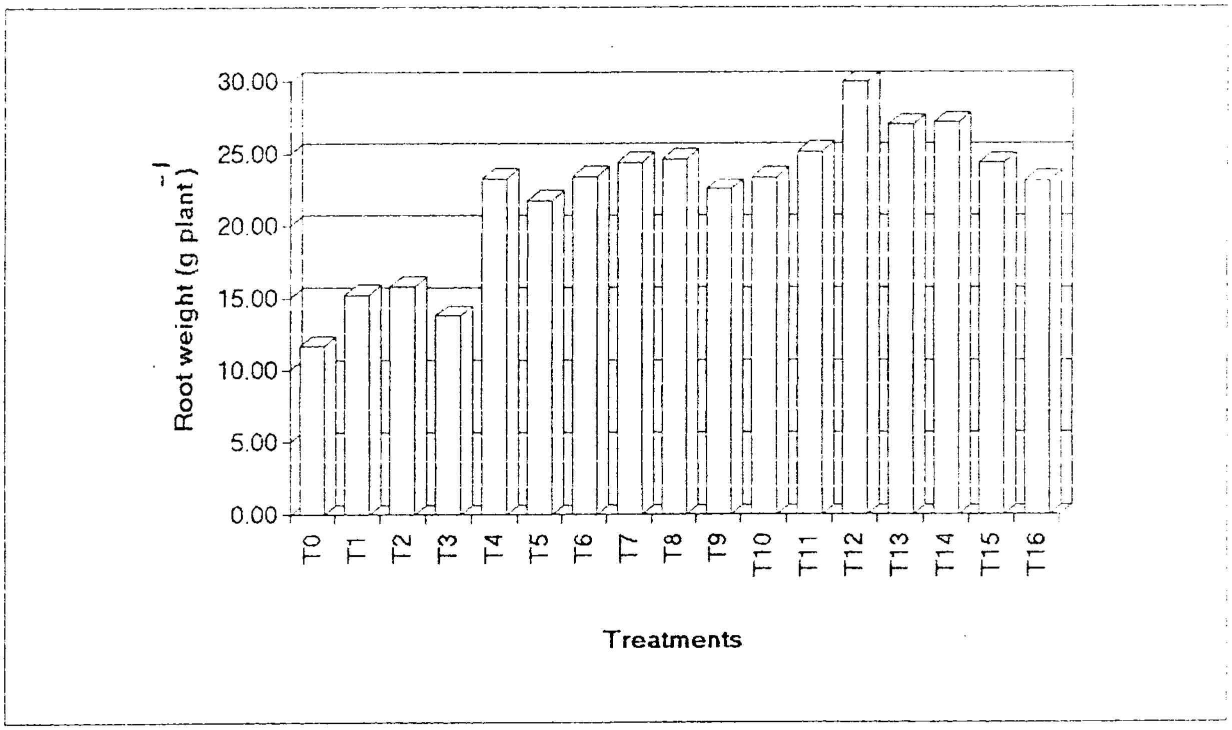
Root volume recorded by all treatments was significantly higher than that of T0. All Azospirillum treatments except T1 was on par among themselves and also with T16. Azotobacter treatments supplemented with chemical fertilizers also responded similarly. T12, T13 and T14 were significantly superior to T16 while T15 was on par.

4.1.1.3.4. Root : shoot ratio (Table 8, Fig. 7)

The data revealed that the root : shoot ratio was the highest in T2. Among the other treatments T1, T2 and T3, T4 and T8 showed only marginal difference over T0 but treatments receiving combined nitrogen recorded distinctly lower ratios over T0. Among Azospirillum treatments the ratio recorded by T1 was significantly higher than that of the treatments receiving chemical fertilizers. When compared to the POP treatment T1, T4, T5 and T6 were superior and T7 was on par. All

Table 8. Effect of microbial biofertilizers on the root parameters of guinea grass

Treat - ments	root length (cm)	root weight (g $plant^{-1}$)	root volume (cm^3 $plant^{-1}$)	root:shoot ratio
T0	34.65	11.65	24.15	0.420
T1	33.30	15.20	30.15	0.405
T2	34.25	15.80	31.00	0.435
T3	34.85	13.78	28.80	0.405
T4	35.60	23.35	46.40	0.405
T5	32.60	21.80	44.00	0.355
T6	31.60	23.50	44.75	0.335
T7	33.20	24.45	47.75	0.320
T8	35.75	24.65	46.25	0.415
T9	34.05	22.55	45.65	0.370
T10	35.05	23.40	47.15	0.365
T11	35.60	25.05	50.05	0.345
T12	37.40	30.00	59.15	0.330
T13	36.30	27.05	52.55	0.320
T14	35.10	27.20	54.22	0.315
T15	34.00	24.40	51.15	0.320
T16	32.35	23.20	46.95	0.315
F	1.02	63.86**	37.24**	50.559**
SE	1.50	0.64	1.60	0.006
CD	--	1.90	4.80	0.018



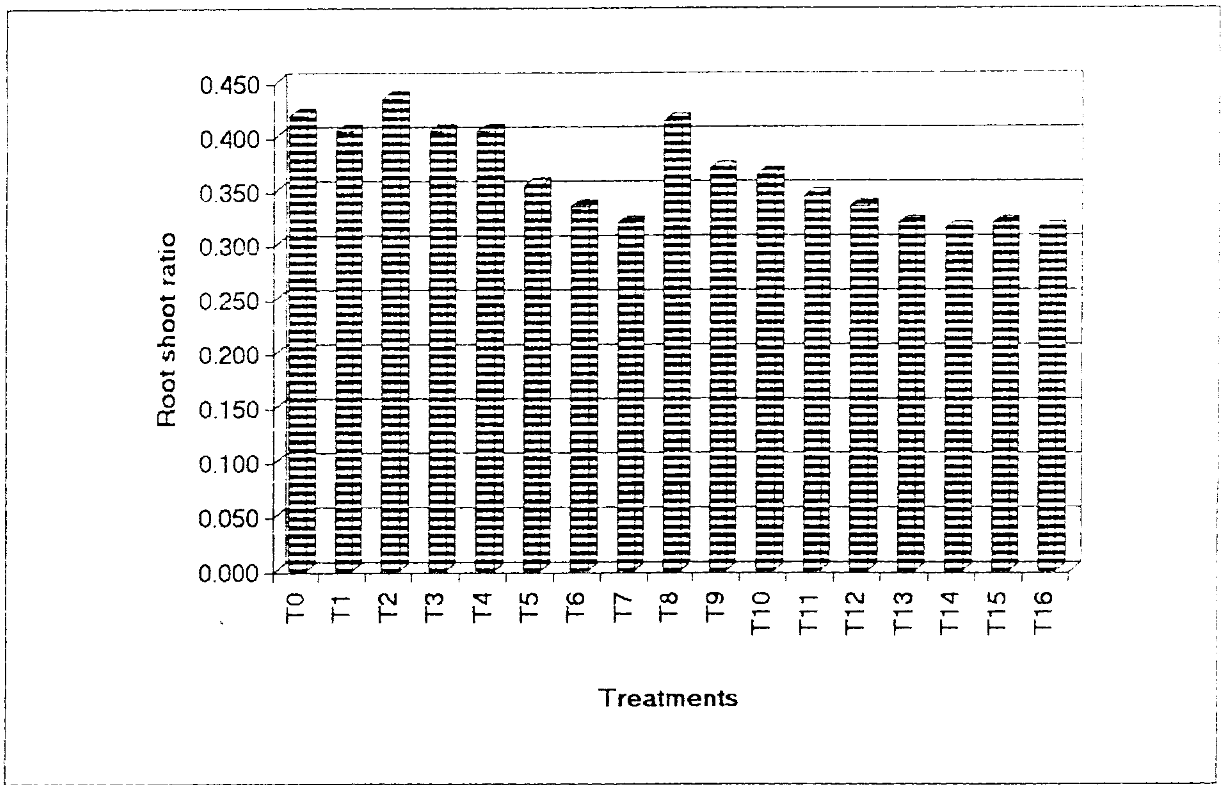


Fig 7. Effect of microbial biofertilizers on root weight and root shoot ratio of guinea grass

Azotobacter treatments showed distinct increase in the ratio over T16. VAM treatments T3 was significantly superior to T16 while T12, T13, T14 and T15 responded on par.

4.1.1.4. Mycorrhizal colonisation in the root (Table 9)

Mycorrhizal colonisation in guinea grass was evident in all treatments. In Azospirillum and Azotobacter treatments colonisation percentage decreased when combined with fertilizers but between treatments the combination doses of Azospirillum and Azotobacter showed only marginal variation and were on par with T16. The infection percentage increased sharply with inoculation with VAM culture. T12, T13 and T14 were on par among themselves and were significantly superior to T3 and T15 in terms of colonisation percentage.

4.1.1.5. Quality

4.1.1.5.1. Crude protein (Table 10)

A perusal of the data revealed that all treatments except T2 and T3 improved the crude protein content of guinea grass. All Azospirillum treatments except T1 and T4 recorded crude protein content more or less similar to that of T16. Among Azotobacter treatments T11 was comparable with T16 while the others were inferior. Combination doses of VAM and chemical fertilizers responded similar to T16 in terms of crude protein content.

4.1.1.5.2. Crude fibre (Table 10)

The data indicated that biofertilizer treatments lowered the crude fibre content of guinea grass over that of T0. The effect was distinct in combination doses of biofertilizers and chemical fertilizers. Between treatments the Azospirillum inoculated plants recorded more or less similar crude fibre content and were comparable with T16. Azotobacter treatments receiving chemical fertilizers also showed a similar response. The crude fibre content of VAM treatments showed only

Table 9. Mycorrhizal colonisation in the root of guinea grass

Treatments	% colonisation
T0	24.00
T1	26.00
T2	21.00
T3	37.00
T4	15.00
T5	13.50
T6	15.00
T7	16.50
T8	15.00
T9	13.00
T10	14.00
T11	16.50
T12	44.00
T13	48.50
T14	46.50
T15	31.50
T16	15.00
F	38.80**
SE	2.01
CD	6.03

marginal variation with T16.

4.1.1.5.3. Phosphorus content (Table 10)

The treatments improved the phosphorus content of guinea grass over T0. However in Azospirillum treated plants the increase over the control treatments was marginal. T1, T4, T5, T6 and T7 recorded phosphorus more or less similar to that of T16. Among Azotobacter treatments T8, T9 and T10 had significantly higher phosphorus content than T0 and when compared to T16 these treatments were on par. T11 responded similar to both control treatments. Between VAM treatments the variation in phosphorus content was insignificant but when compared to T0 they were all superior. T3 recorded significant improvement in phosphorus content over T16 while T12, T13, T14 and T15 were on par.

4.1.1.5.4. Potassium content (Table 10)

Inoculation treatments showed an increase in potassium content over the controls but the difference did not reach the level of significance.

4.1.1.5.5. Content of secondary nutrients (Table 10)

The data indicated that the influence of the treatments on the content of secondary nutrients was not significant.

4.1.1.5.6. Content of micronutrients (Table 11)

The influence of microbial inoculants on copper and manganese content of guinea grass was found insignificant. The zinc content showed significant variation between treatments.

The Azospirillum treatments had zinc content more or less similar to that of the controls. The response of Azotobacter treatments was in similar lines. However VAM inoculation resulted in enhancement in zinc content over T16 and the

Table 10. Effect of microbial biofertilizers on crude protein(CP), crude fibre(CF), phosphorus, potassium calcium AND magnesium content in guinea grass(%)

Treat-ments	CP	CF	P	K	Ca	Mg
T0	8.400	33.000	0.243	1.310	0.570	0.645
T1	8.750	32.250	0.247	1.325	0.565	0.640
T2	8.575	32.375	0.247	1.340	0.565	0.665
T3	8.400	32.375	0.255	1.325	0.570	0.665
T4	8.750	32.250	0.248	1.360	0.580	0.650
T5	8.925	32.000	0.247	1.350	0.585	0.640
T6	8.925	32.000	0.246	1.345	0.570	0.665
T7	9.100	31.750	0.247	1.340	0.570	0.660
T8	8.750	32.250	0.249	1.355	0.570	0.670
T9	8.750	32.250	0.249	1.340	0.575	0.650
T10	8.750	32.250	0.249	1.345	0.575	0.650
T11	8.925	32.000	0.248	1.350	0.565	0.680
T12	9.100	31.750	0.250	1.325	0.570	0.660
T13	8.925	31.500	0.252	1.335	0.570	0.665
T14	8.925	31.750	0.252	1.340	0.560	0.665
T15	9.100	31.625	0.248	1.340	0.585	0.655
T16	9.100	31.750	0.247	1.325	0.565	0.655
F	4.373**	3.150*	3.296*	1.860	0.325	1.117
SE	0.107	0.207	0.002	0.009	0.012	0.010
CD	0.321	0.621	0.005	--	--	--

variation was significant in T3, T13 and T14.

4.1.1.5.7. Ash content (Table 11)

The data indicated that biofertilizer treatments favourably influenced the ash content of guinea grass. Combination doses of biofertilizers and chemical fertilizers had ash content significantly higher than that of T0 and were on par with T16.

4.1.1.5.8. K : (Ca + Mg) ratio (Table 11)

The influence of the treatments on the K : (Ca + Mg) ratio was not significant.

4.1.1.6. Crude protein yield (Table 12)

During 93 - 94 all treatments except T2 recorded significantly higher crude protein yield than T0. In both Azospirillum and Azotobacter treatments the crude protein yield increased progressively with increasing levels of chemical fertilizers applied. T7 yielded superior to the other Azospirillum treatments and was comparable with T16. Azotobacter treatments were found inferior to T16 at all levels of nitrogen applied. VAM treated plants responded well to chemical fertilizers. T12, T13 and T14 registered significant improvement in protein yield over T16 while T15 responded on par.

The positive effect of biofertilizer treatments on protein yield of guinea grass was evident during 94 - 95 period also. Azospirillum treatments T6 and T7 responded similar to T16 while T1, T4 and T5 were found inferior. Among Azotobacter treatments also treated plants receiving 50 and 75 per cent of the recommended fertilizer nitrogen(T10 and T11 respectively) were comparable with T16 and the others were less effective. The influence of VAM treatments on crude protein yield of guinea grass in comparison with the controls followed the same trend as that of the previous year.

Table 11. Effect of microbial biofertilizers on zinc,copper,manganese,ash content and K:(Ca+Mg) ratio of guinea grass

Treat-ments	zinc (ppm)	copper (ppm)	manganese (ppm)	ash (%)	K:(Ca+Mg) ratio
T0	31.10	18.40	199.85	9.57	1.08
T1	29.65	20.40	220.35	9.65	1.10
T2	33.30	20.60	214.65	9.63	1.09
T3	44.85	22.40	202.85	9.66	1.08
T4	25.85	19.55	206.30	9.77	1.11
T5	26.90	20.55	196.95	9.74	1.10
T6	30.70	21.50	207.70	9.80	1.09
T7	32.80	21.65	206.70	9.80	1.09
T8	30.50	20.30	207.90	9.80	1.10
T9	31.55	20.30	196.20	9.78	1.10
T10	28.70	20.55	204.60	9.78	1.10
T11	32.15	20.55	210.10	9.78	1.09
T12	35.55	29.30	166.40	9.80	1.08
T13	35.95	25.40	170.55	9.78	1.08
T14	36.35	22.90	180.45	9.81	1.10
T15	33.80	25.15	193.40	9.77	1.08
T16	29.40	25.75	222.20	9.73	1.09
F	4.05**	1.83	1.45	4.15**	0.28
SE	2.18	2.07	12.98	0.04	0.02
CD	6.54	--	--	0.11	--

Table 12. Effect of microbial biofertilizers on crude protein yield of guinea grass (kg ha^{-1})

Treatments	93-94	94-95
T0	294.66	385.95
T1	507.10	579.25
T2	331.95	499.05
T3	394.80	554.40
T4	535.95	694.75
T5	608.80	783.65
T6	712.39	927.95
T7	826.30	1107.90
T8	471.65	630.00
T9	605.50	798.90
T10	668.95	898.60
T11	750.95	951.20
T12	1058.80	1311.30
T13	1056.42	1290.35
T14	1143.85	1338.65
T15	884.10	1098.35
T16	879.05	988.25
F	86.92**	52.82**
SE	27.65	39.98
CD	82.89	119.87

4.1.1.7. Nutrient uptake

4.1.1.77.1. Uptake of major nutrients (Table 13 , Fig. 8)

A perusal of the data on uptake of nitrogen, phosphorus and potassium showed that the influence of the treatments on the uptake followed more or less a similar pattern and hence are dealt together hereunder.

During 93 - 94 uptake of nitrogen, phosphorus and potassium recorded by all treatments except T2 was found significantly higher than that of T0. Among Azospirillum treatments T7 registered higher uptake values than T1, T4, T5 and T6 and was on par with the POP treatment T16. Azotobacter treatments also showed an increase in uptake of all three major nutrients with increasing levels of applied chemical fertilizers but they were inferior to T16. VAM treatments T12, T13 and T14 showed definite improvement in nutrient uptake over T15 and also the POP treatment T16 and the latter two in turn were on par.

The results during 94 -95 also indicated the effectiveness of biofertilizer treatments in enhancing the uptake of nitrogen, phosphorus and potassium. All treatments except T2 showed distinct improvement in nutrient uptake over T0. Azospirillum treatment T6 and T7 recorded uptake of nitrogen and phosphorus on par with that of T16 while the potassium uptake by T7 was significantly superior. Among Azotobacter treatments T10 and T11 responded on par with T16 and T2, T8 and T9 were inferior. Uptake of major nutrients by T12, T13 and T14 showed definite improvement over T16 while T15 remained on par.

4.1.1.7.2. Uptake of calcium (Table 14)

Uptake of calcium was significantly influenced by the biofertilizer treatments. During 93 - 94 there was significant improvement over T0 in all treatments except T2 and T3. Azospirillum treatment T7 recorded calcium uptake on par with T6 and significantly superior to T1, T4 and T5. Response of T7 was more or less similar to that of T16. Among Azotobacter treatments T11 was on par

Table 13. Effect of microbial biofertilizers on uptake of nitrogen, phosphorus and potassium by guinea grass (kg ha^{-1})

Treat-ments	nitrogen		phosphorus		potassium	
	93-94	94-95	93-94	94-95	93-94	94-95
T0	47.04	61.76	8.48	11.15	45.90	60.15
T1	74.13	92.68	13.05	16.32	70.16	87.72
T2	53.12	79.85	9.58	14.41	51.93	78.13
T3	63.17	88.71	11.97	16.79	62.28	87.47
T4	85.75	111.16	15.16	19.66	83.24	108.09
T5	97.41	125.38	16.81	21.68	92.07	118.72
T6	114.35	148.48	19.70	25.57	109.32	139.65
T7	132.21	177.27	22.43	30.07	121.69	163.22
T8	75.46	100.80	13.42	17.93	73.02	97.56
T9	96.88	127.82	17.20	22.69	92.69	122.33
T10	107.03	143.78	19.04	25.58	102.78	138.21
T11	120.15	152.19	20.87	26.46	113.62	144.06
T12	169.41	209.81	29.09	36.03	154.15	190.94
T13	162.00	207.48	29.83	36.61	155.63	193.98
T14	183.02	214.19	32.27	37.73	171.99	201.00
T15	141.45	175.74	24.09	29.95	130.20	161.69
T16	140.65	158.12	23.81	26.78	128.03	143.86
F	60.01**	52.83**	70.99**	45.73**	61.01**	45.02**
SE	5.29	6.40	0.84	1.16	4.76	6.19
CD	15.87	19.18	2.51	3.47	14.28	18.54

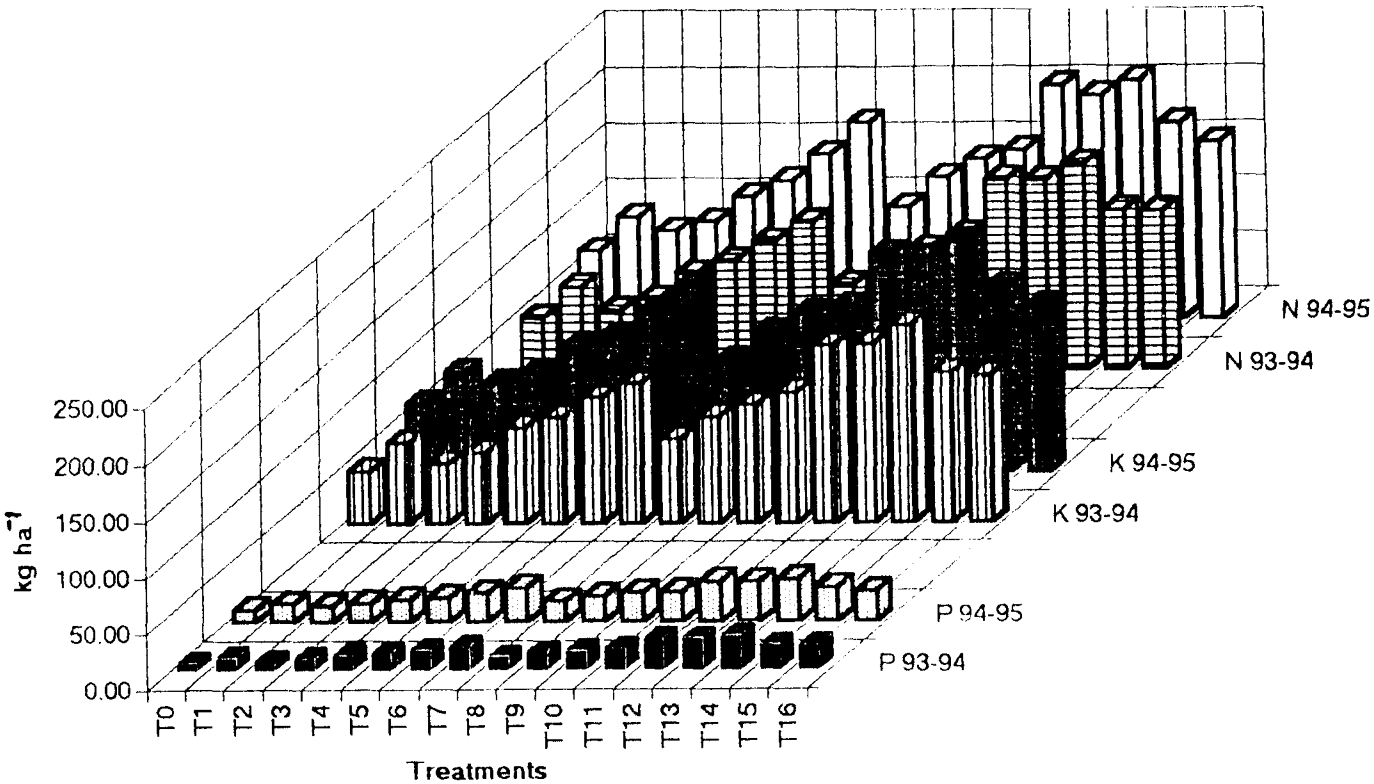


Fig.8 Effect of microbial biofertilizers on uptake of major nutrients by guinea grass

with T16 and the others were inferior. Significant improvement in uptake of calcium over T16 was observed in VAM treatments T12, T13 and T14 while T15 was on par.

During 93 - 94 uptake of calcium by T2 remained on par with T0 and the other treatments were superior. Azospirillum and Azotobacter treatments at 50 and 75 per cent N levels (T6, T7 and T10, T11 respectively) were on par with T16 and the others were significantly inferior. All the combination doses of VAM recorded significant increase in calcium uptake over T16.

4.1.1.7.3. Uptake of magnesium (Table 14)

During 93 - 94 the magnesium uptake recorded by all treatments except T2 was significantly superior to that of T0. Azospirillum treatment T7 recorded magnesium uptake on par with that of the POP treatment. Azotobacter treatment T11 also responded similar to T16 . Among VAM treatments T3 recorded significantly lower magnesium uptake, T15 was on par and T12, T13 and T14 were distinctly superior.

During 94 - 95 period T2 remained on par with T0 and the other treatments recorded significant improvement in magnesium uptake. T6 and T7 were on par with T16 and among the Azotobacter treatments T10 and T11 recorded comparable magnesium uptake. The influence of VAM treatments on magnesium uptake followed the same trend as noticed during the previous year.

4.1.1.7.4. Uptake of zinc (Table 15)

During 93 - 94 T1, T2, T4 and T8 were on par with T0 and the other treatments were significantly superior in terms of zinc uptake. Azospirillum treatments T6 and T7 recorded zinc uptake on par with each other and also with T16 while T1, T4 and T5 were inferior. Azotobacter treatments also followed a similar trend. Combined doses of VAM and chemical fertilizers showed distinct improvement in zinc uptake over T16.

Table 14. Effect of microbial biofertilizers on uptake of calcium and magnesium by guinea grass (kg ha^{-1})

Treat-ments	calcium		magnesium	
	93-94	94-95	93-94	94-95
T0	19.90	26.25	22.56	29.67
T1	29.92	37.40	33.89	42.37
T2	21.89	32.91	25.74	38.69
T3	26.80	37.59	31.27	43.84
T4	35.47	46.16	39.82	51.61
T5	39.91	51.35	43.66	56.21
T6	45.64	59.26	53.26	69.09
T7	51.74	69.34	59.97	80.49
T8	30.69	41.04	36.08	48.24
T9	39.77	52.49	44.98	59.35
T10	43.92	59.13	49.66	66.81
T11	47.56	60.32	57.22	72.52
T12	66.28	82.14	76.75	95.11
T13	67.46	82.82	78.70	96.62
T14	72.07	84.02	85.50	99.76
T15	56.84	70.59	63.64	79.04
T16	54.61	61.33	63.25	71.17
F	40.03**	35.61**	51.80**	36.68**
SE	2.51	2.95	2.60	3.44
CD	7.53	8.85	7.81	10.31

Zinc uptake values recorded by T1, T2, T4, T5 and T8 were comparable with that of T0 during 94 - 95 period. Azospirillum treatments T5, T6, and T7 were on par with T16. Azotobacter treatments T9, T10 and T11 also responded more or less similar to T16. VAM treatment T3 registered zinc uptake on par with that of T16 while T12, T13, T14 and T15 registered significantly higher values during the second year.

4.1.1.7.5. Uptake of copper (Table 15)

The results during 93 - 94 indicated that copper uptake by T2 and T3 were on par with that of T0 and all other treatments were significantly superior. Copper uptake by Azospirillum and Azotobacter treatments increased progressively with increasing levels of chemical fertilizers applied but all these treatments were inferior to T16. VAM treatments T12, T13 and T14 showed appreciable improvement in copper uptake over T16 while T15 was on par.

During 94 - 95 period copper uptake by T1, T2, T3, T4 and T8 showed only marginal variation with T0. Azospirillum and Azotobacter treatments at 50 and 75 per cent N levels (T6, T7 and T10, T11 respectively) responded similar to T16 and the lower N levels were inferior. Among VAM treatments T12 and T13 showed definite improvement in copper uptake over T16 while in T14 and T15 the enhancement was marginal.

4.1.1.7.6. Uptake of manganese (Table 15)

The results on manganese uptake during 93 -94 showed significant increase over T0 in all treatments except T2 and T3. Azospirillum treatment T7 was on par with T16 while T1, T4, T5 and T6 were inferior. All Azotobacter treatments took up manganese decidedly lower than T16. Manganese uptake by VAM treatments T12, T13, T14 and T15 was comparable with that of the POP treatment.

Manganese uptake by T2 remained on par with T0 during 94 - 95 period also and all other treatments were superior. Among Azospirillum treatments T6 and

Table 15. Effect of microbial biofertilizers on the uptake of zinc,copper and manganese by guinea grass(kg ha^{-1})

Treat-ments	zinc		copper		manganese	
	93-94	94-95	93-94	94-95	93-94	94-95
T0	0.110	0.143	0.064	0.085	0.701	0.917
T1	0.157	0.197	0.109	0.136	1.171	1.459
T2	0.129	0.194	0.080	0.121	0.828	1.239
T3	0.211	0.293	0.106	0.146	0.954	1.337
T4	0.152	0.198	0.121	0.154	1.265	1.635
T5	0.184	0.236	0.140	0.182	1.343	1.736
T6	0.252	0.318	0.177	0.224	1.660	2.144
T7	0.298	0.400	0.197	0.263	1.877	2.517
T8	0.164	0.220	0.110	0.147	1.124	1.497
T9	0.220	0.289	0.141	0.186	1.355	1.790
T10	0.220	0.293	0.157	0.211	1.565	2.100
T11	0.271	0.345	0.173	0.220	1.766	2.231
T12	0.414	0.513	0.340	0.423	1.933	2.398
T13	0.426	0.522	0.301	0.369	2.019	2.420
T14	0.466	0.546	0.293	0.344	2.303	2.706
T15	0.376	0.472	0.244	0.304	1.877	2.342
T16	0.284	0.320	0.247	0.283	2.148	2.412
F	23.787**	15.019**	32.548**	15.065**	21.965**	14.072**
SE	0.022	0.032	0.014	0.024	0.102	0.139
CD	0.067	0.096	0.043	0.073	0.305	0.417

T7 were on par with T16. A similar response was observed with T10 and T11. Combination doses of VAM and chemical fertilizers registered manganese uptake values on par with T16.

4.1.1.8. Soil properties after the experiment

4.1.1.8.1. Soil physical properties

4.1.1.8.1.1. Bulk density (Table 16)

Under all treatments the bulk density of soil was lower than that under T0 but in T1, T2 and T3 the difference was marginal. Combined doses of biofertilizers and chemical fertilizers effectively lowered the soil bulk density. Azospirillum treatment T4 recorded bulk density significantly lower than T1, T5, T6, T7 and also the POP treatment T16. Bulk density of soil under Azotobacter treatments were on par among themselves and were comparable with T16. Among VAM treatments T12, T13 and T14 recorded distinctly lower bulk density than T16 while T15 faired on par.

4.1.1.8.1.2. Water holding capacity (Table 16)

The data indicated an improvement in water holding capacity of soil when guinea grass was treated with biofertilizers and the increase was significant in all treatments except T1, T2 and T6. T4 recorded higher water holding capacity than the other Azospirillum treatments. T4, T5, T6 and T7 responded similar to T16. The effect of all Azotobacter treatments on water holding capacity of soil also compared well with T16. VAM association effectively enhanced the water holding capacity of soil over T16 in treatments T12, T13 and T14. The difference was marginal in T15.

4.1.1.8.1.3. Porosity (Table 16)

Under all treatments the porosity of soil was higher than that of T0. Among Azospirillum treatments T4 and T7 recorded porosity significantly higher than that of T0 while in T1, T5 and T6 the variation was marginal. All Azospirillum and

Azotobacter treatments recorded soil porosity on par with that of T16. VAM treatments T12, T13 and T15 responded similar to T16 while T14 recorded distinct superiority over the POP treatment.

4.1.1.8.1.4. Hydraulic conductivity (Table 16)

Hydraulic conductivity of soil showed wide variation between treatments. All Azospiriilum treatments except T1 recorded hydraulic conductivity significantly higher than T0 and were comparable with T16. Azotobacter inoculation of guinea grass also had a similar influence on hydraulic conductivity of soil. VAM treatments recorded hydraulic conductivity significantly higher than that of T0. When compared to T16, significant increase was registered by T12 and T13 while in T3, T14 and T15 the difference did not reach the level of statistical significance..

4.1.1.8.1.5. Mean weight diameter (Table 16)

The mean weight diameter differed significantly between treatments but with Azospirillum and Azotobacter inoculation the variation from control treatments was only marginal. The mean weight diameter showed a general increase in VAM treatments. T3, T12, T13 and T14 recorded significantly higher mean weight diameter than T0 and T16 while in T15 the difference was marginal.

4.1.1.8.2. Nutrient status of soil after the experiment

4.1.1.8.2.1. Available nitrogen (Table 17)

The available nitrogen status of soil under various treatments improved over T0 but the variation was not significant.

4.1.1.8.2.2. Available phosphorus (Table 17)

The phosphorus status of soil showed a general improvement over T0 and the change was of statistically significant in all treatments except T1, T2, T3,

Table 16. Effect of microbial biofertilizers on the bulk density (BD), water holding capacity (WHC) porosity, hydraulic conductivity (HC) and mean weight diameter (MWD) of soil

Treat-ments	BD ($g\ cc^{-1}$)	WHC (%)	porosity (%)	HC ($cm\ hr^{-1}$)	MWD (mm)
T0	1.352	23.850	35.125	7.965	0.537
T1	1.339	24.100	35.915	9.150	0.531
T2	1.337	25.450	36.165	10.095	0.519
T3	1.343	26.750	36.850	11.185	0.575
T4	1.315	27.700	39.410	15.300	0.548
T5	1.333	25.800	37.795	12.475	0.549
T6	1.334	25.380	37.895	11.610	0.533
T7	1.331	27.690	39.175	14.160	0.530
T8	1.322	28.605	39.285	13.600	0.540
T9	1.327	27.915	38.495	12.155	0.537
T10	1.333	27.710	38.735	12.125	0.533
T11	1.327	27.170	38.780	13.220	0.518
T12	1.311	29.040	40.630	16.680	0.583
T13	1.316	29.415	40.340	14.890	0.574
T14	1.311	30.280	41.525	13.365	0.588
T15	1.326	28.075	40.000	11.885	0.546
T16	1.334	26.490	37.965	12.045	0.536
F	5.042**	8.038**	3.423**	5.483**	8.088**
SE	0.005	0.633	0.943	0.938	0.008
CD	0.015	1.899	2.829	2.812	0.023

and T12. Among Azospirillum treatments the phosphorus status was highest in T4 closely followed by T5 and significantly superior to T2, T6, T7 and also the POP treatment T16. T8 recorded the highest phosphorus status among Azotobacter treatments, on par with T9 and superior to T10, T11 and also T16. VAM treatments registered phosphorus status of soil comparable among themselves and showed no improvement over T16.

4.1.1.8.2.3. Available potassium (Table 17)

The potassium status of soil showed wide variation between treatments. Among Azospirillum treatments T4 recorded potassium status significantly higher than that of T0 and T16 while T1, T5, T6 and T7 were on par with both the controls. Azotobacter treatments T8 and T9 showed significant improvement in available potassium over the controls but T2, T10 and T11 were on par. VAM treatments showed no distinct improvement in available potassium content of soil over the controls.

4.1.1.8.2.4. Available calcium (Table 17)

The available calcium status of soil did not differ significantly between treatments.

4.1.1.8.2.5. Available magnesium (Table 17)

The data indicated that the microbial inoculants did not influence the available magnesium status of soil under guinea grass.

4.1.1.8.2.6. Organic carbon (Table 17)

The organic carbon status of soil under all treatments showed an improvement over T0. Azospirillum treatment T4 was significantly superior to T1, T5 and T6 and was on par with T7 and both T4 and T7 were comparable with T16. Combination doses of Azotobacter and chemical fertilizers responded similar to T16

Table 17. Available nitrogen, phosphorus, potassium, calcium, magnesium (kg ha^{-1}) and organic carbon (%) status of the soil

Treat-ments	N	P	K	Ca	Mg	organic carbon
T0	212.36	23.26	65.55	308.00	80.92	0.608
T1	235.13	24.02	67.10	300.00	76.67	0.630
T2	227.36	26.60	71.95	282.00	75.99	0.638
T3	231.30	27.27	69.85	307.00	74.86	0.656
T4	252.51	32.29	94.00	288.00	80.32	0.707
T5	231.28	31.09	81.95	319.00	70.49	0.638
T6	223.44	28.51	65.65	286.00	70.95	0.630
T7	233.44	27.51	60.80	310.00	76.54	0.664
T8	254.12	32.63	96.50	312.00	79.76	0.681
T9	227.36	32.55	98.10	308.00	78.05	0.664
T10	239.12	28.07	74.60	312.00	72.49	0.681
T11	239.12	27.01	61.35	313.00	70.62	0.655
T12	241.28	26.51	64.65	316.00	66.44	0.733
T13	235.20	29.13	68.75	314.00	66.19	0.724
T14	243.04	28.02	69.30	303.00	68.53	0.733
T15	246.96	29.01	61.40	314.00	72.16	0.707
T16	233.44	28.02	67.65	306.00	71.42	0.706
F	1.37	4.86**	2.44*	0.19	1.00	7.206**
SE	8.91	1.22	7.86	24.60	4.65	0.015
CD	--	3.65	23.58	--	--	0.044

and were superior to T0. VAM treatments T12, T13, T14 and T15 recorded organic carbon status significantly superior to T0 but showed only marginal improvement over T16.

4.1.1.9. Economics

4.1.1.9.1. Net income (Table 18, Fig. 9)

The data on economics during 93 - 94 revealed a net loss in income under T0 and T2. All other treatments recorded higher net income than T0 but the difference was marginal in T3. Azospirillum treatment T7 recorded net income as high as that from T16. However the income from Azotobacter treatments was inferior to T16. Combination doses of VAM and chemical fertilizers recorded substantially higher net income. T14 recorded the highest net income of Rs.. 20353/ and T12, T13 and T14 were significantly superior to T16 (Rs. 12540/). Net income from T15 was on par with that from the POP treatment.

During 94 - 95 net income from all treatments was found positive. When compared to T0 there was distinct superiority in net income from all the treatments except T2. Azospirillum treatment T6 recorded net income of Rs. 16959/ on par with T16 (Rs. 17745/) while with T7 it was Rs. 21142/. T1, T4 and T5 were inferior to the POP treatment. Among Azotobacter treatments T10 and T11 were comparable with T16. T12, T13 and T14 registered Rs. 26965/, Rs. 25913/ and Rs. 288254/ respectively and were significantly superior to T16 while T15 remained on par.

Pooled analysis studies revealed that the year was a significant factor deciding the net income from guinea grass cultivation. Treatment- season interaction was found insignificant. All treatments except T2 gave distinctly higher net income that T0. Azospirillum treatment T7 was comparable with T16 and the other Azospirillum treatments were inferior. Azotobactor treatment T11 also responded on par with the POP treatment. Among VAM treatments T12, T13 and T14 were significantly superior to T16 while T15 was on par.

Table 18. Effect of microbial biofertilizers on the net income from guinea grass cultivation (Rs.)

Treatments	93-94 cost of cultivation	93-94 Net income	94-95 Cost of cultivation	94-95 Net income	Pooled
T0	9675	-1280	7505	3520	1120
T1	9835	2870	7665	8214	5542
T2	9835	-540	7665	6323	2891
T3	10000	1272	7505	8326	4799
T4	10575	4743	8405	11443	8093
T5	10874	6182	8704	13280	9731
T6	11173	8752	9003	16959	12855
T7	11472	11914	9302	21142	16528
T8	10575	2894	8405	9586	6240
T9	10874	6420	8704	14120	10270
T10	11173	7940	9003	16677	12309
T11	11472	9564	9302	17372	13468
T12	11546	17543	9051	26965	22254
T13	11644	17843	9149	27115	22479
T14	11736	20353	9241	28254	24303
T15	11839	12460	9344	20833	16646
T16	11611	12540	9441	17745	15142
F		53.75**		45.50**	99.08**
SE		883.00		1090.00	692.00
CD		2647		3270	1969

Cost (Rs): 1 Kg Nitrogen - 5.98 1 Kg Phosphorus - 7.80
1 Kg Potassium - 7.00 Labour cost @ Rs 65/-

Price of green fodder - Rs 600 ton^{-1}

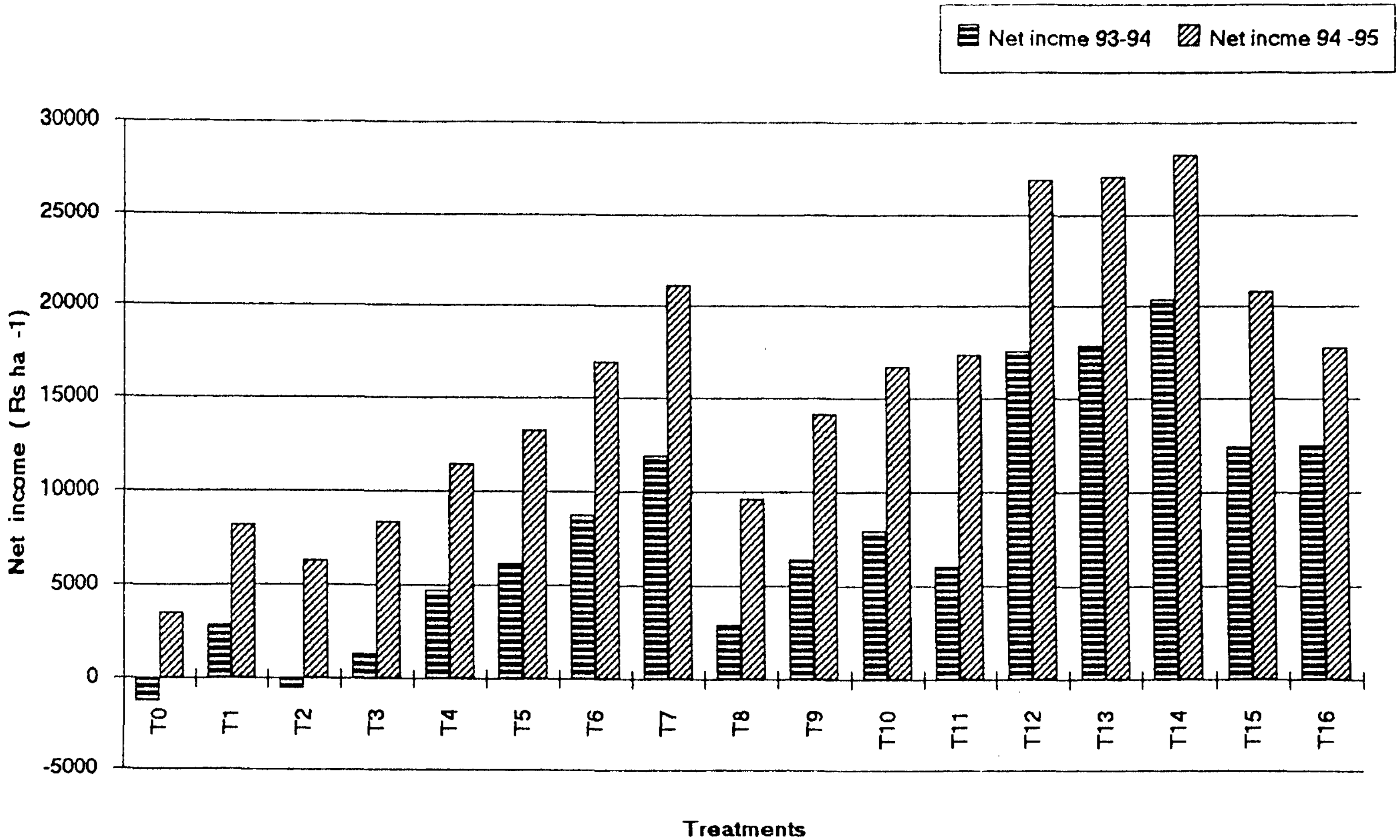


Fig .9 . Effect of microbial biofertilizers on net income from Guinea grass cultivation

4.1.1.9.2. Benefit : cost ratio (Table 19, Fig. 10)

Benefit : cost ratio of all treatments was found higher than that of T0 during 93 - 94. In Azospirillum treatments the ratio improved progressively with increasing levels of chemical fertilizers added and was highest at T7 which was significantly superior to the other Azospirillum treatments and was on par with T16. In Azotobacter treatments also chemical fertilizer application improved the ratio but these treatments were less effective than T16. The VAM treatments T12, T13 and T14 registered distinct superiority over T15 and T16 and the latter two in turn were on par.

During 94 - 95 also T2 was on par with T0 and the other treatments were superior. Azospirillum treatments T5 and T6 were comparable with T16 while T7 recorded distinctly higher ratio. Azotobacter treatments T9, T10 and T11 responded similar to T16. VAM treatments T12, T13 and T14 registered significantly higher benefit : cost ratio than T16 and T15 was on par.

Pooled analysis studies showed that the benefit : cost ratio from all treatments except T2 was significantly higher than that of T0. Azospirillum treatment T6 and T7 were comparable with T16 and among Azotobacter treatments T10 and T11 responded in similar lines. The superiority of T12, T13 and T14 over T16 was confirmed while T15 faired on par.

4.1.1.10. Correlation studies (Table 20)

The correlation studies revealed that plant height, number of tillers, leaf area index, absolute growth rate, and uptake of major nutrients had significant positive correlation with dry fodder yield of guinea grass. Among root parameters root weight and root volume were positively correlated with dry fodder yield while root : shoot ratio recorded significant negative correlation. Soil bulk density recorded high negative coefficient. Water holding capacity, porosity, hydraulic conductivity, mean weight diameter and organic carbon content was significantly and positively correlated with the dry fodder yield of 94 - 95.

Table 19. Effect of microbial biofertilizers on benefit: cost ratio of guinea grass

Treatments	93 - 94	94 - 95	pooled
T0	0.87	1.47	1.17
T1	1.30	2.07	1.68
T2	0.95	1.82	1.38
T3	1.13	2.11	1.62
T4	1.45	2.36	1.91
T5	1.57	2.53	2.05
T6	1.79	2.89	2.34
T7	2.04	3.28	2.66
T8	1.27	2.14	1.71
T9	1.59	2.63	2.11
T10	1.71	2.86	2.28
T11	1.84	2.87	2.35
T12	2.52	3.98	3.25
T13	2.53	3.96	3.25
T14	2.74	4.06	3.40
T15	2.05	3.23	2.64
T16	2.08	2.88	2.48
F	49.73**	36.16**	33.92**
SE	0.08	0.12	0.11
CD	0.23	0.37	0.32

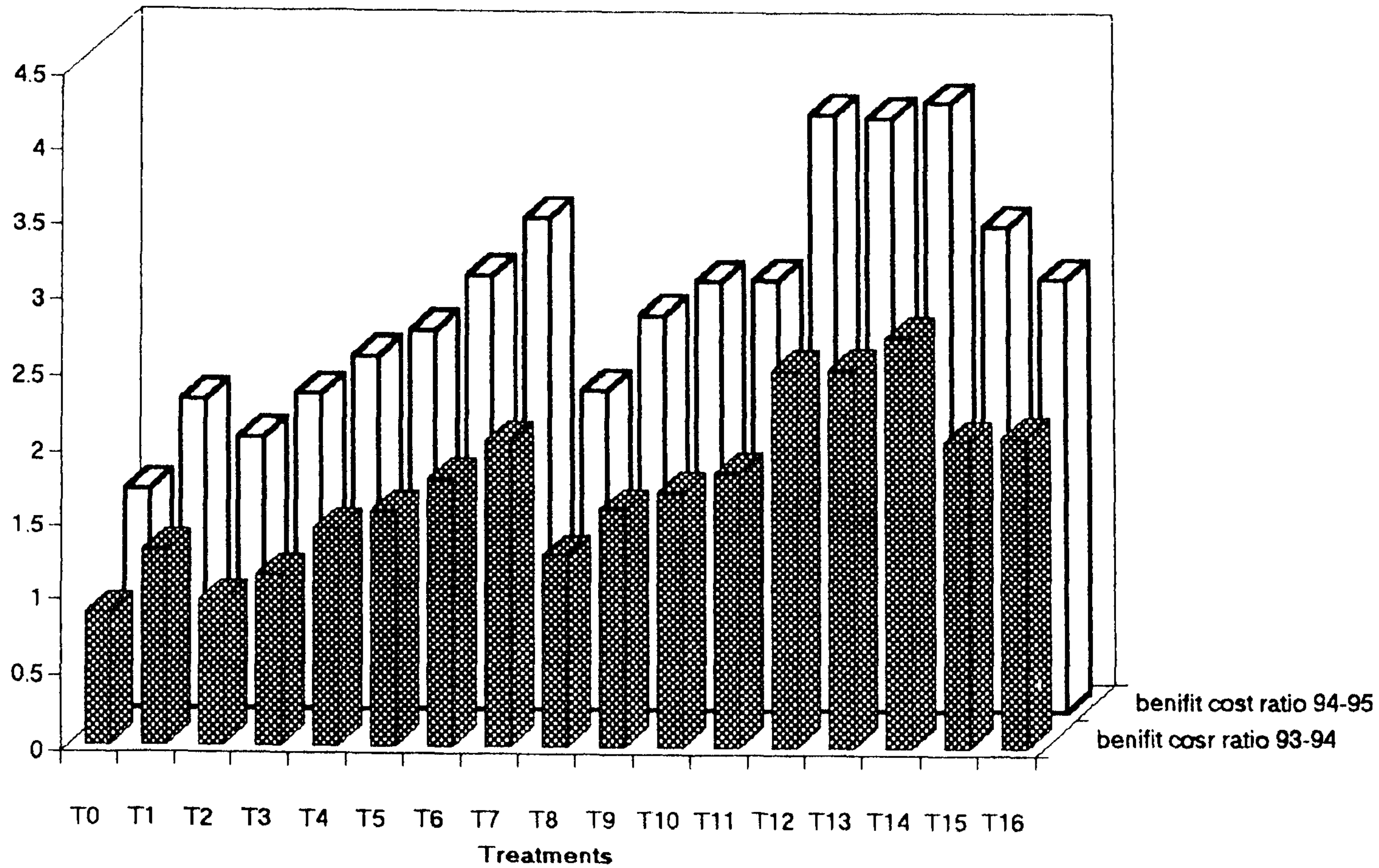


Fig .10. Effect of microbial biofertilizers on Benefit cost ratio of Guinea grass

Table 20. Simple correlation coefficients of important parameters with dry fodder yield of guinea grass

Parameters	Correlation coefficients	
	93-94	94-95
plant height	.9352**	.9372**
Tiller count	.9736**	.9521**
LAI	.9628**	.9522**
AGR	.9891**	.9500**
Root length	-	.1547
Root weight	-	.8252**
Root volume	-	.8525**
Root : Shoot ratio	-	-.8988**
Uptake of N	.9986**	.9983**
Uptake of P	.9995**	.9985**
Uptake of K	.9993**	.9983**
Soil bulk density	-	-.6493**
Water holding capacity	-	.6880**
Porosity	-	.7412**
Hydraulic conductivity	-	.6078**
Mean weight diameter	-	.4535**
organic carbon	-	.7178**

Table 21(a). Direct and indirect effects of root parameters on dry fodder yield of guinea grass during 94- 95

Root length	Root weight	Root volume	Root :shoot	Total correlation
<u>0.1610</u>	0.0936	-0.0309	-0.0690	0.1547
0.0366	<u>0.4111</u>	-0.1253	0.5028	0.8252
0.0385	0.3988	<u>-0.1291</u>	0.5443	0.8525
0.0153	-0.2845	0.0967	<u>-0.7263</u>	-0.8988

residue 0.3052

Table 21(b). Direct and indirect effects of soil properties after the experiment on the dry fodder yield of guinea grass during 94-95

Bulk Density	Water holding capacity	Porosity	Hydraulic conductivity	Mean weight diameter	Organic carbon	Total correlation
<u>-0.0731</u>	0.0221	-0.2693	-0.0945	-0.0439	-0.1906	-0.6493
0.0531	<u>-0.0305</u>	0.3150	0.0807	0.0481	0.2216	0.6880
0.0501	-0.0244	<u>0.3932</u>	0.0773	0.0360	0.2089	0.7412
0.0543	-0.0193	0.2389	<u>0.1273</u>	0.0385	0.1682	0.6078
0.0325	-0.0149	0.1436	0.0497	<u>0.0986</u>	0.1439	0.4535
0.0470	-0.0228	0.2769	0.0722	0.0478	<u>0.2967</u>	0.7178

residue 0.5890

(The underlined figures are the direct effects)

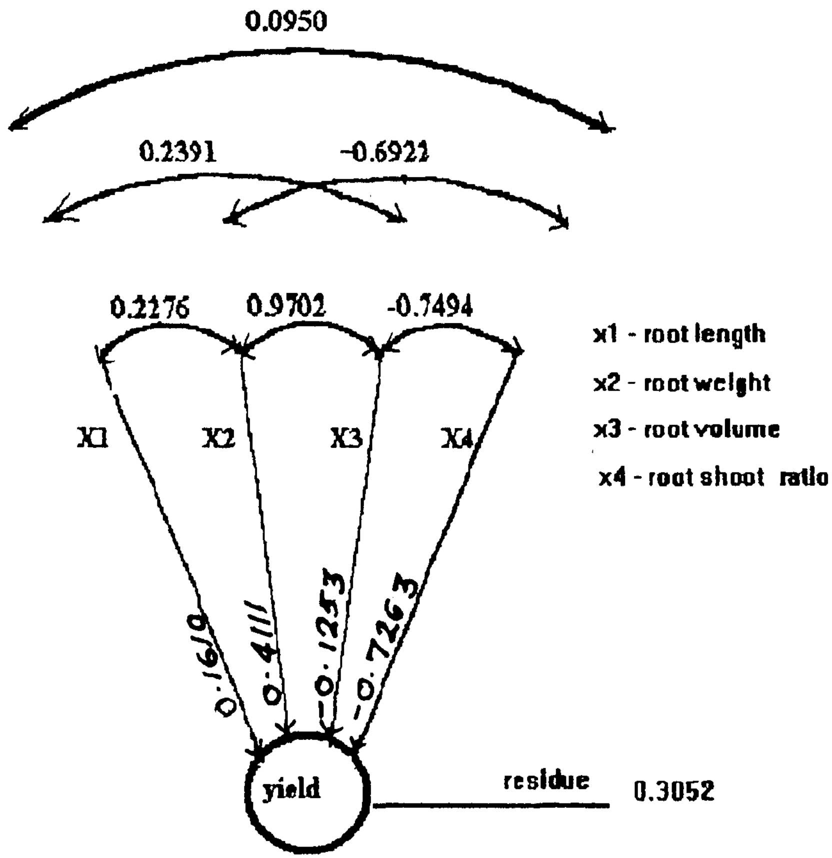


Fig . 11 Path diagram showing direct effects and interrelationship of root parameters with dry fodder yield of guinea grass (94-95). Direct effects shown in single arrows and correlation coefficients shown in double arrows

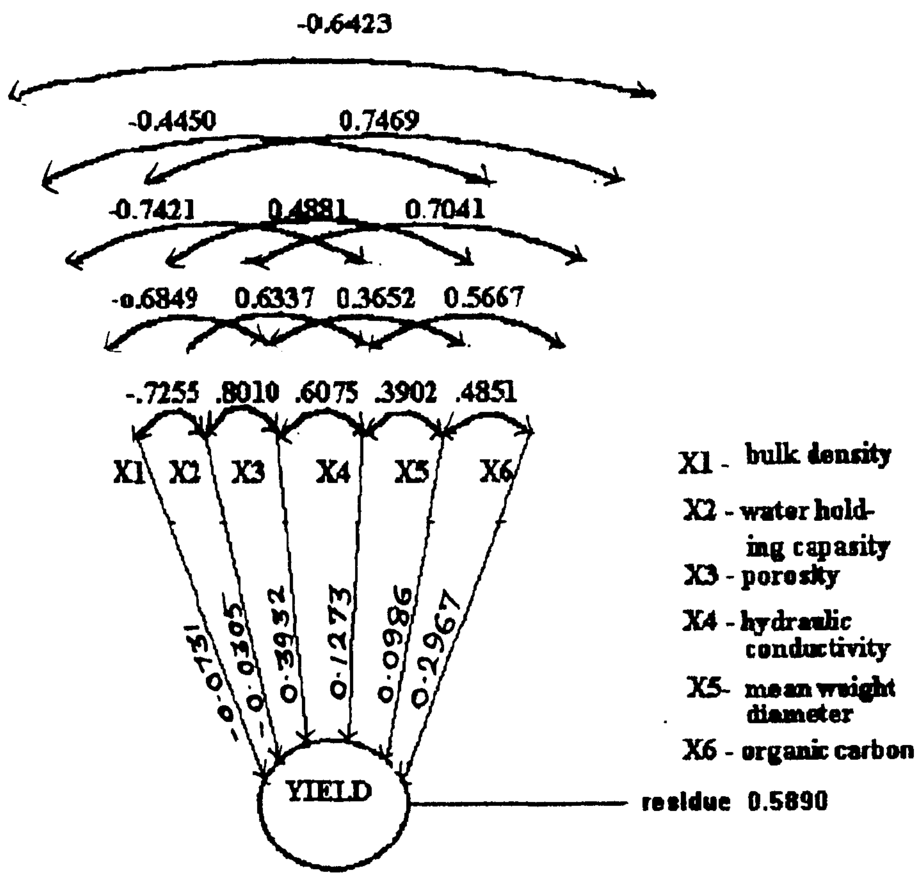


Fig. 12. Path diagram showing direct effects and interrelationships of soil properties with dry fodder yield of guinea grass (94-95). Direct effects shown in single arrows and correlation coefficients shown in double arrows

4.1.1.11. Path analysis studies (Table 21(a), 21(b), Fig. 11, Fig.12)

Direct and indirect effects of root parameters on dry fodder yield of guinea grass during the 94 - 95 period was investigated through path analysis studies. Similar studies were made also with the soil properties after the experiment. The results are shown in Table 21(a), 21(b) and Fig.11 and Fig.12.

Among the root parameters studied, root weight recorded the maximum positive direct effect on fodder yield and root : shoot ratio showed high negative direct effect. Root volume exerted high indirect effect on fodder yield through its influence on root : shoot ratio.

Path analysis studies on the cause and effect relationship of properties of soil on dry fodder yield revealed that these factors could influence the fodder yield of guinea grass during 94 - 95 period to an extent of 41 per cent. Maximum positive direct effect was shown by soil porosity. Water holding capacity of the soil exerted maximum indirect effect on fodder yield of guinea grass.

4.1.2. Congosignal (*Brachiaria ruziziensis* Germain & Evrard))

4.1.2.1. Growth and yield characters

4.1.2.1.1. Plant height (Table 22)

The data on effect of microbial inoculants on plant height of congosignal during 93 - 94 revealed that T1, T2, T3 and T8 were on par with T0 and the others were distinctly superior. The Azospirillum treatments T5, T6 and T7 showed marginal difference in plant height among themselves and were on par with the POP treatment T16. All Azotobacter treatments recorded plant height significantly lower than that of T16. Combination doses of VAM and chemical fertilizers responded on par among themselves and also T16.

During 94 - 95 period T1, T2 and T4 remained on par with T0 while the other treatments recorded significantly higher plant height. As during the previous year, the Azospirillum treatments T5, T6 and T7 were comparable among themselves and also with T16. The response of combination doses of Azotobacter and chemical fertilizers to plant height was more or less similar to T16. Effect of VAM treatments on plant height also followed a similar trend.

Pooled analysis indicated that all treatments except T1 and T2 were superior to T0 in terms of plant height. Azospirillum treatments T5, T6 and T7 were comparable with T16. Azotobacter treatment T11 responded similar to T16 and the others were inferior. The combination doses of VAM with chemical fertilizers were on par among themselves and also T16.

4.1.2.1.2. Number of tillers hill^{-1} (Table 22)

The data on tiller number hill^{-1} during 93 - 94 revealed significant positive influence of biofertilizer treatments over T0 in all except T1 and T2. In Azospirillum and Azotobacter treatments tiller number increased progressively with each incremental dose of fertilizer applied but at all levels of nitrogen studied they were less responsive than T16. VAM treatments T12, T13 and T14 responded on par with T16 but T3 and T15 were inferior.

During 94 - 95 also T1 and T2 recorded tiller number on par with T0 and all other treatments were significantly superior. Among themselves the Azospirillum treatments T4, T5, T6 and T7 showed only marginal variation in tiller production and the latter two were comparable with T16. The tiller production in Azotobacter treatments T9, T10 and T11 compared well with the POP treatment. VAM treatments T12, T13 and T14 showed distinct improvement in tiller production over T16 while T15 was on par.

Pooled analysis showed that T1 and T2 were comparable with T0 and all other treatments were significantly superior in terms of tiller production. When compared to T16 the Azospiriilum treatment T7 was on par and the other

Table 22. Effect of microbial biofertilizers on plant height, number of tillers $hill^{-1}$ and leaf:stem ratio of congosignal

Treat-ments	plant height(cm)			tiller number $hill^{-1}$			leaf:stem	
	93-94	94-95	pooled	93-94	94-95	pooled	93-94	94-95
T0	70.00	66.38	68.19	16.00	15.80	15.90	1.85	1.75
T1	76.00	68.18	72.09	19.15	17.15	18.15	1.88	1.84
T2	64.55	68.71	66.63	16.75	16.20	16.48	1.83	1.84
T3	77.75	72.38	75.06	23.75	22.15	22.95	1.99	1.75
T4	80.00	72.00	76.00	25.25	22.00	23.63	2.03	1.82
T5	86.00	76.75	81.38	28.75	24.55	26.65	2.05	1.85
T6	89.50	78.88	84.19	31.25	26.05	28.65	2.05	1.89
T7	88.50	80.88	84.69	34.25	27.45	30.85	2.02	1.95
T8	77.50	78.00	77.75	23.00	22.75	22.88	2.00	1.99
T9	80.50	77.50	79.00	26.00	26.70	26.35	1.96	1.89
T10	81.00	80.75	80.88	28.13	31.05	29.59	1.97	1.90
T11	82.50	84.25	83.38	32.25	33.00	32.63	2.04	1.97
T12	93.50	87.60	90.55	41.63	37.20	39.41	2.10	2.00
T13	92.50	84.38	88.44	41.38	36.80	39.09	2.14	1.99
T14	90.50	82.75	86.38	40.00	36.50	38.25	2.11	2.04
T15	90.00	80.63	85.31	33.50	31.65	32.58	2.10	2.08
T16	91.50	81.75	86.62	38.88	30.67	34.77	2.11	1.98
F	9.40**	10.83**	14.48	50.31**	14.46**	38.18**	1.22	0.89
SE	2.79	1.99	1.91	1.17	1.88	1.23	0.08	0.10
CD	8.37	5.97	5.43	3.50	5.62	3.49	--	--

Azospirillum treatments were less responsive. Among Azotobacter treatments T10 and T11 responded similar to T16. Superiority of VAM treatments in tiller production was evident in T12 and T13 while in T14 and T15 the enhancement did not reach the level of significance.

4.1.2.1.3. Leaf : stem ratio (Table 22)

The influence of microbial inoculants on leaf : stem ratio of congosignal was insignificant.

4.1.2.1.4. Green fodder yield (Table 23)

The data during 93 - 94 indicated that all treatments except T1 and T2 positively influenced the green fodder yield over T0. Azospirillum and Azotobacter treatments showed progressive yield increase with increasing levels of applied fertilizers. T7 receiving 75 per cent of the recommended fertilizer nitrogen recorded fodder yield superior to other Azospirillum treatments but was less effective than the POP treatment T16. Azotobacter treatments also performed inferior to T16. Among VAM treatments T12 yielded highest and was on par with T13 and T14 and all three were comparable with T16. T15 performed inferior to T12, T13 and T14 and also T16.

During 94 - 95 also T1 and T2 yielded on par with T0 and the other treatments were significantly superior. Azospirillum treatment T7 responded similar to T16 while T1, T4, T5 and T6 remained distinctly inferior. Among Azotobacter treatments T2, T8 and T9 were inferior, T10 was on par and T11 was significantly superior to T16. VAM treatments T12, T13 and T14 were also found more responsive than T16. The fodder yield recorded by T15 showed no improvement over T16.

Pooled analysis revealed that year had a significant effect on fodder yield of congosignal. The treatment - season interaction was found significant. T1 and T2 yielded on par with T0 and the other treatments were significantly superior.

Table 23. Effect of microbial biofertilizers on green and dry fodder yield of congosignal ($t\ ha^{-1}$)

Treat-ments	green fodder yield			dry fodder yield		
	93-94	94-95	pooled	93-94	94-95	pooled
T0	30.93	27.89	29.41	8.33	7.66	7.99
T1	34.94	29.91	32.42	9.27	8.08	8.67
T2	26.85	28.09	27.47	7.38	7.72	7.55
T3	41.48	35.49	38.48	11.22	9.57	10.39
T4	47.35	35.14	41.24	12.78	9.30	11.04
T5	50.24	43.70	46.97	13.28	11.58	12.43
T6	55.56	44.82	50.19	14.72	12.09	13.40
T7	61.88	49.98	55.93	16.38	12.99	14.69
T8	39.25	38.89	39.07	10.78	10.69	10.74
T9	45.90	45.17	45.53	12.63	12.04	12.33
T10	52.54	53.55	53.04	13.92	13.93	13.92
T11	58.59	56.09	57.34	15.24	15.14	15.19
T12	72.93	59.18	66.05	18.94	15.39	17.16
T13	69.88	56.51	63.19	18.53	15.06	16.79
T14	68.67	56.54	62.60	17.85	14.98	16.42
T15	60.03	50.63	59.32	16.21	13.54	14.88
T16	67.79	50.06	58.92	17.97	13.51	15.74
F	51.85**	50.53**	16.26**	47.41**	49.68**	15.14**
SE	1.97	1.48	3.00	0.52	0.38	0.79
CD	5.89	4.43	8.99	1.57	1.15	2.37

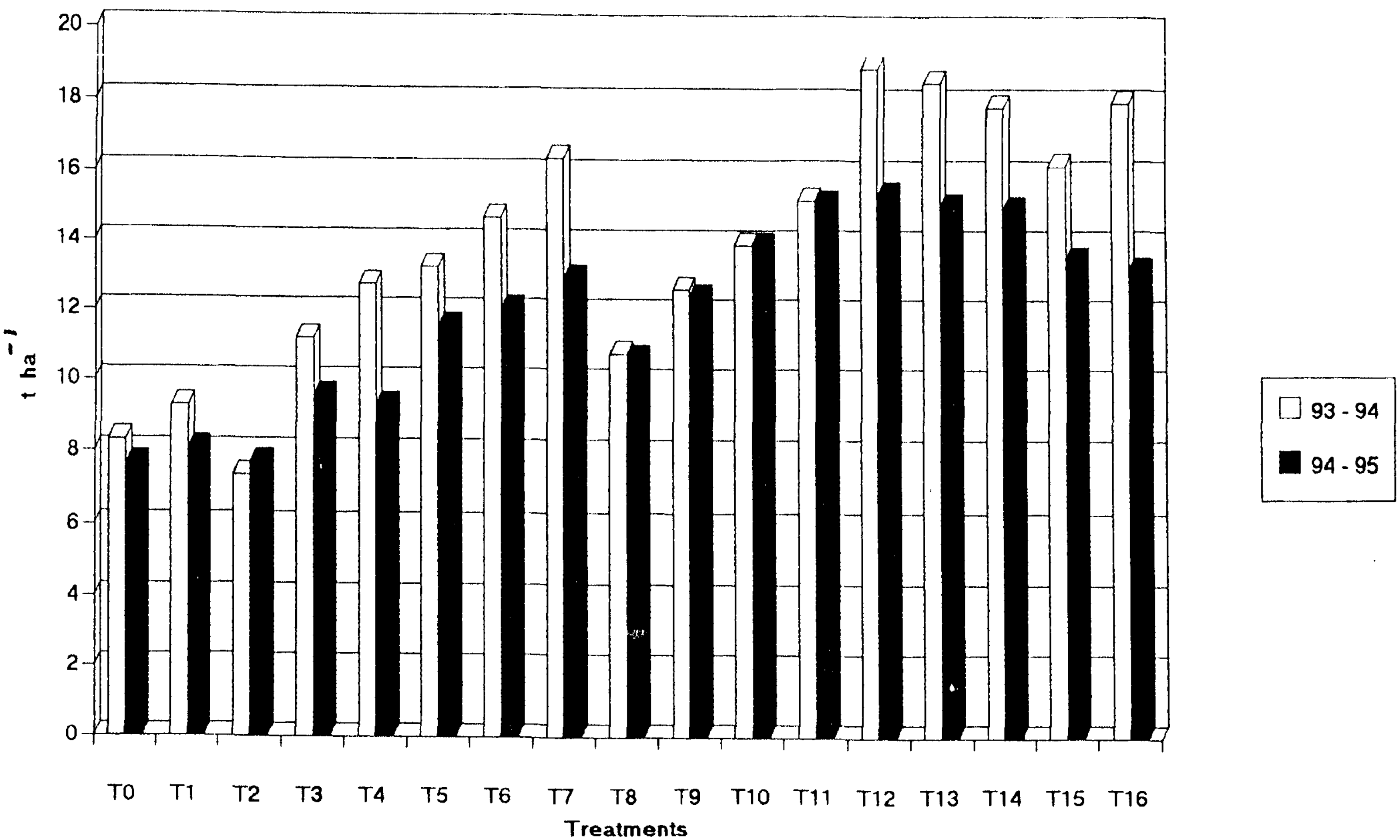


Fig 13. Effect of microbial biofertilizers on dry fodder yield of Congosignal

Azospirillum treatments T6 and T7 and Azotobacter treatments T10 and T11 were found as effective as the POP treatment T16 and the other diazotroph treatments were inferior. VAM treatments T12, T13, T14 and T15 yielded on par among themselves and also with T16.

4.1.2.1.5. Dry fodder yield (Table 23, Fig. 13)

A perusal of the data on the effect of microbial inoculants on dry fodder yield indicated that the response pattern followed a trend similar to that of green fodder yield.

4.1.2.2. Physiological parameters

4.1.2.2.1. Leaf area index (Table 24)

During 93 - 94 all treatments except T1 and T2 recorded significantly higher LAI than T0. Azospirillum treated plants at 75 per cent N dose had significantly higher LAI than that of the lower N doses but was inferior to the POP treatment T16. Azotobacter treatments also recorded a similar response. Among VAM treatments maximum LAI was recorded by T12, and was on par with T13 and T14 and superior to T15. All four treatments were found comparable with T16.

During 94 - 95 also LAI of T1 and T2 were found on par with T0 and the other treatments were significantly superior. Azospirillum treatments T6 and T7 responded more or less similar to T16 while T1, T4 and T5 recorded lower LAI. Among Azotobacter treatments T10 and T11 were on par and T2, T8 and T9 were inferior to T16. Significant improvement in LAI over T16 was observed in VAM treatments T12 and T13 while T14 and T15 were on par.

4.1.2.2.2. Absolute growth rate (Table 24)

The favourable effect of biofertilizer treatments on absolute growth rate (AGR) was evident from the data during 93 - 94 period. When compared to the other

Table 24. Effect of microbial biofertilizers on leaf area index (LAI) and absolute growth rate (AGR) of congosignal

Treatments	LAI		AGR($g\ plant^{-1}\ day^{-1}$)	
	93-94	94-95	93-94	94-95
T0	3.350	3.190	1.150	0.840
T1	3.970	3.500	1.259	0.885
T2	3.500	3.185	1.017	0.850
T3	4.395	3.925	1.548	1.045
T4	4.855	4.360	1.762	1.020
T5	5.860	5.445	1.832	1.265
T6	6.465	6.045	2.030	1.325
T7	7.490	6.315	2.249	1.425
T8	4.620	4.425	1.487	1.170
T9	5.235	5.095	1.742	1.320
T10	6.315	5.880	1.920	1.525
T11	6.985	6.430	2.101	1.660
T12	8.630	6.895	2.612	1.685
T13	8.490	6.735	2.555	1.654
T14	8.320	6.610	2.460	1.640
T15	7.635	5.925	2.235	1.484
T16	8.170	6.115	2.475	1.467
F	71.814**	53.022**	44.712**	48.648**
SE	0.215	0.176	0.075	0.042
CD	0.643	0.528	0.223	0.127

Azospirillum treatments, T7 had a higher growth rate but the effect was inferior to T16. The Azotobacter treatments also recorded AGR values distinctly inferior to T16. Between T12, T13 and T14 the difference in AGR was marginal and their response was similar to that of T16. However T15 recorded distinctly lower AGR.

During 94 - 95 also the effect of T1 and T2 were comparable with T0 and the other treatments were superior. T7 responded on par with T16 while T1, T4, T5 and T6 were inferior. Among Azotobacter treatments T10 faired on par with T16. The response of T11 was distinctly superior while T2, T8 and T9 remained inferior. VAM treatments T12, T13 and T14 were found more effective than T16 in terms of AGR while T15 showed no distinct improvement.

4.1.2.2.3. Chlorophyll content (Table 25)

Combination doses of biofertilizers and chemical fertilizers significantly improved the content of total chlorophyll and its components over T0. Azospirillum treatments T5, T6 and T7 recorded total chlorophyll and its components on par among themselves. The response of T7 to chlorophyll ' a ' and total chlorophyll content was comparable with T16 while the chlorophyll ' b ' content was inferior. Azotobacter treatments T10 and T11 recorded chlorophyll ' a ' and total chlorophyll content on par with that of T16 but the chlorophyll ' b ' content in T10 was inferior. Combination doses of VAM and chemical fertilizers responded similar to T16 at all levels of applied phosphorus.

The microbial inoculants showed no distinct influence on chlorophyll a : b ratio.

4.1.2.3. Root studies

4.1.2.3.1. Root length (Table 26)

The effect of Azospirillum treatments on root length was found insignificant. Azotobacter treatments T9, T10 and T11 recorded root length

Table 25. Effect of microbial biofertilizers on chlorophyll content of congosignal ($mg\ g^{-1}$ fresh weight)

Treat-ments	chlorophyll a	b	a:b	a+b
T0	0.88	0.77	1.14	1.65
T1	1.01	0.87	1.16	1.88
T2	0.99	0.86	1.15	1.84
T3	1.02	0.90	1.13	1.92
T4	1.17	1.03	1.13	2.20
T5	1.31	1.09	1.20	2.40
T6	1.33	1.15	1.16	2.48
T7	1.44	1.20	1.19	2.64
T8	1.23	1.04	1.18	2.28
T9	1.35	1.17	1.16	2.51
T10	1.44	1.20	1.19	2.64
T11	1.46	1.24	1.19	2.75
T12	1.62	1.38	1.17	3.00
T13	1.56	1.36	1.18	2.92
T14	1.58	1.32	1.18	2.90
T15	1.53	1.31	1.17	2.84
T16	1.57	1.33	1.18	2.90
F	20.69**	25.31**	1.07	24.91**
SE	0.05	0.04	0.02	0.09
CD	0.16	0.11	--	0.26

significantly higher than that of T0 and T16. Root length recorded by VAM treatments T13 and T14 showed significant improvement over T16 while T3, T12 and T15 were on par.

4.1.2.3.2. Root weight (Table 26, Fig. 14)

All treatments except T2 showed an improvement in root weight over T0 and the difference reached the level of significance in combination doses of biofertilizers and chemical fertilizers. Among Azospirillum treatments, T7 recorded the maximum root weight on par with T6 and both these were on par with T16. Azotobacter treatments T8, T9, T10 and T11 recorded root weight on par among themselves and also with the POP treatment. Significant improvement in root weight over T16 was recorded by VAM treatments T12, T13 and T14 while in T15 the improvement was marginal.

4.1.2.3.3. Root volume (Table 26)

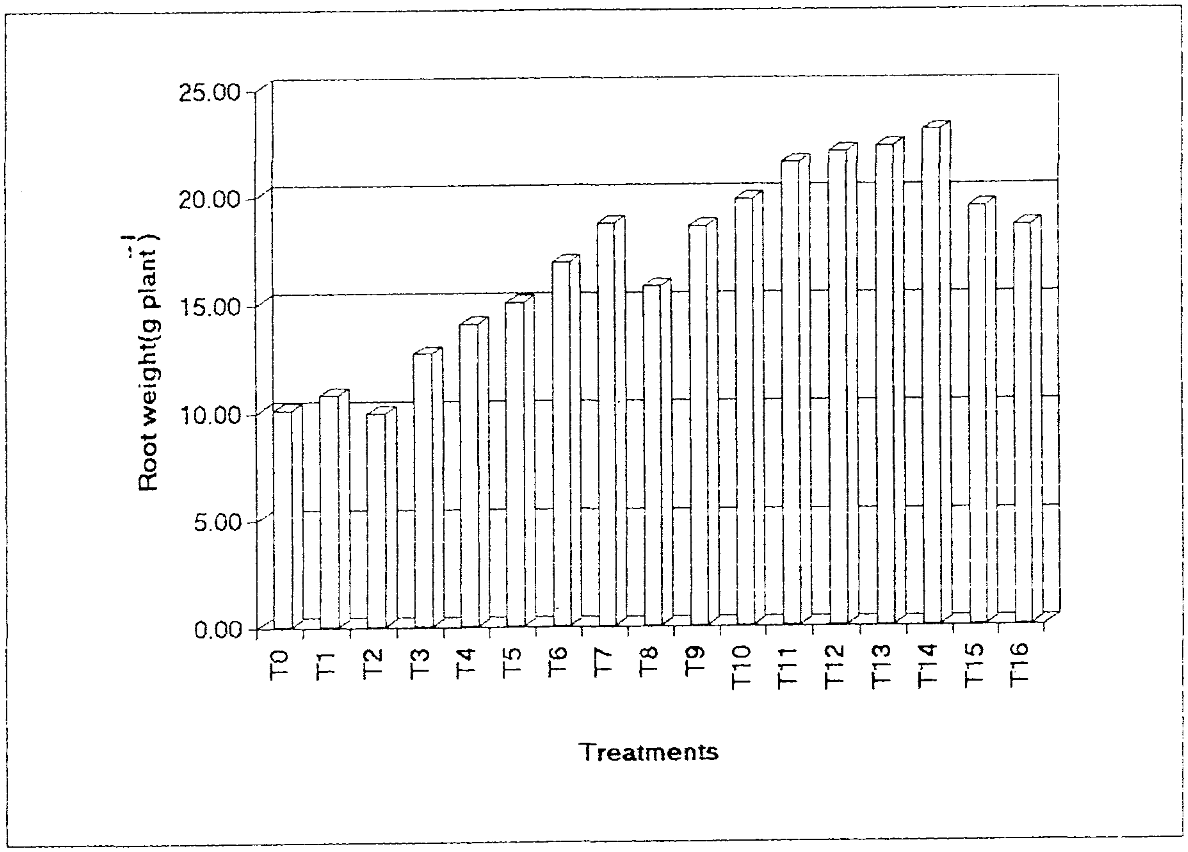
Significant improvement in root volume over T0 was observed in all treatments except T1 and T2. In Azospirillum treatments the root volume increased with incremental doses of fertilizer added and it was comparable with T16 in T6 and T7. Azotobacter treatments T9, T10 and T11 also responded on par with T16 and the others were inferior. Among VAM treatments T12, T13 and T14 were superior and T15 faired on par with the POP treatment.

4.1.2.3.4. Root : shoot ratio (Table 26, Fig. 14)

Azospirillum treatment T7 had the ratio significantly lower than that in T0 while T1 T4, T5 and T6 showed only marginal difference. T6 and T7 were on par with T16 and T1, T4 and T5 were superior. The Azotobacter treatments recorded root : shoot ratio on par with T0 and were superior to T16. Combination doses of VAM and chemical fertilizers responded similar to T16 and were inferior to T0.

Table 26. Effect of microbial biofertilizers on root parameters of congosignal

Treat-ments	root length (cm)	root weight (g $plant^{-1}$)	root volume (cm^3 $plant^{-1}$)	root:shoot ratio
T0	22.90	10.05	17.25	0.335
T1	23.90	10.75	18.38	0.325
T2	22.45	9.90	16.00	0.335
T3	23.15	12.65	21.85	0.320
T4	23.95	14.00	24.50	0.315
T5	24.50	15.00	25.58	0.320
T6	23.80	16.90	30.65	0.305
T7	24.70	18.65	33.48	0.300
T8	25.00	15.75	26.88	0.330
T9	26.65	18.50	32.75	0.330
T10	25.85	19.75	33.13	0.320
T11	26.80	21.50	36.00	0.315
T12	25.60	22.00	38.50	0.280
T13	26.10	22.25	39.65	0.280
T14	26.60	23.00	40.00	0.290
T15	25.20	19.40	34.75	0.290
T16	23.70	18.50	32.63	0.275
F	3.93**	17.39**	40.24**	4.116**
SE	0.69	1.03	1.23	0.010
CD	2.07	3.10	3.67	0.030



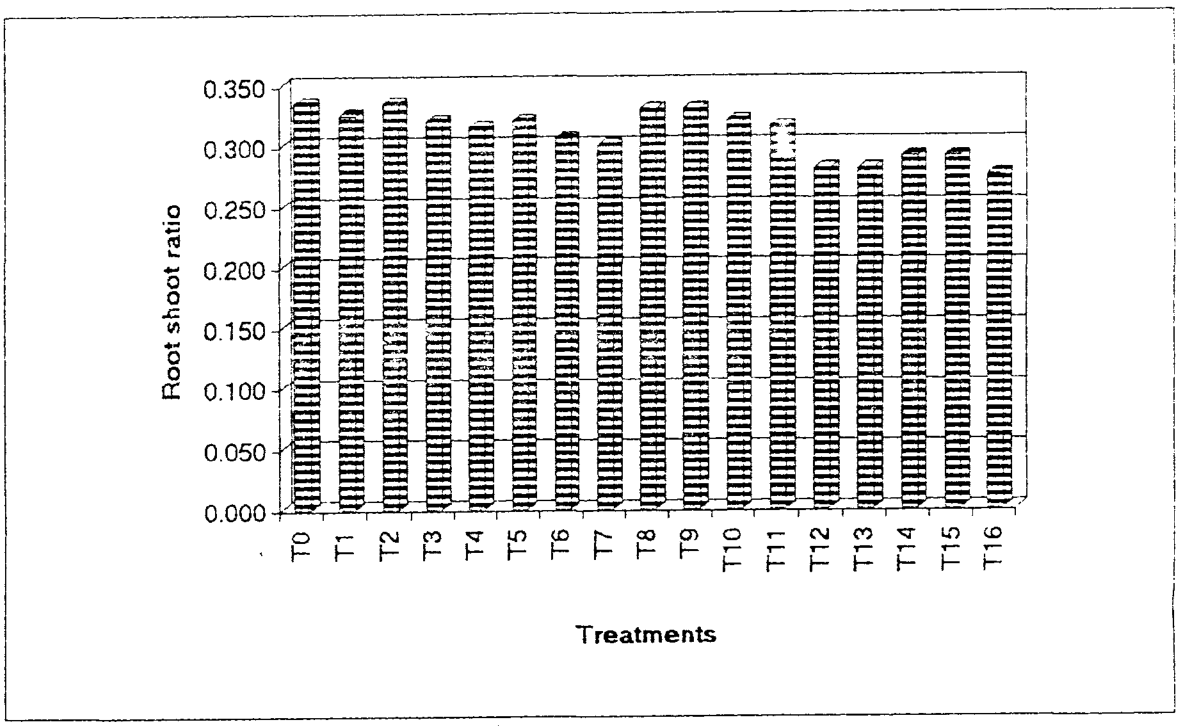


Fig.14. Effect of microbial biofertilizers on root weight and root shoot ratio of Congosignal

4.1.2.4. Mycorrhizal colonisation of the roots (Table 27)

Mycorrhizal colonisation of congosignal was evident in all treatments in the study. In Azospirillum and Azotobacter treatments the colonisation rate was higher in treatments receiving no fertilizers. However the combination treatments showed no significant variation between them and were on par with T16. Among VAM inoculation treatments T3 recorded the maximum colonisation rate which was on par with T12 and significantly superior to T13, T14 and T15. The colonisation percentage in all VAM treatments was significantly superior to all other treatments.

4.1.2.5. Quality

4.1.2.5.1. Crude protein (Table 28)

The data indicated that combination doses of biofertilizers and chemical fertilizers improved the crude protein content of congosignal. Azospirillum treatments T4, T6 and T7 recorded crude protein content significantly superior to that of T0 and on par with 16. Among Azotobacter treatments T9 and T11 showed an improvement in crude protein content and responded similar to T16. The combination doses of VAM and chemical fertilizers at all levels of applied phosphorus were on par among themselves and also T16.

4.1.2.5.2. Crude fibre (Table 28)

The crude fibre content recorded was maximum in T0 and it lowered under various treatments in the study. T7 recorded significant decrease in crude fibre content over T0 while the other Azospirillum treatments showed only marginal difference. In Azotobacter treatment T11 also the decrease in crude fibre content was distinct. Both T7 and T11 were on par with T16. Among VAM treatments T3 recorded crude fibre content on par with T0 and the fertilizer supplemented treatments were significantly superior. When compared to T16 VAM treatments T12 , T13, T14 and T15 showed only marginal difference in crude fibre content.

Table 27. Mycorrhizal colonisation in the root of congosignal

Treatments	% colonisation
T0	19.00
T1	20.00
T2	18.00
T3	46.00
T4	14.00
T5	15.00
T6	13.50
T7	12.00
T8	12.50
T9	14.00
T10	13.00
T11	11.50
T12	45.50
T13	38.00
T14	33.00
T15	29.00
T16	12.00
F	29.44**
SE	2.21
CD	6.64

4.1.2.5.3. Phosphorus content (Table 28)

Biofertilizer treatments showed an improvement in phosphorus content but the difference did not reach the level of significance.

4.1.2.5.4. Potassium content (Table 28)

The microbial inoculants showed no significant influence on the potassium content of congosignal.

4.1.2.5.5. Content of secondary nutrients.(Table 28)

The calcium and magnesium content of congosignal was not significantly influenced by the biofertilizer treatments.

4.1.2.5.6. Content of micronutrients (Table 29)

The content of zinc, copper and manganese showed variation between treatments but the difference reached the level of significance only in the case of copper.

Among Azospirillum treatments T7 recorded copper content significantly superior to T0 and T16 while T1, T4, T5 and T6 were on par with both the controls. The Azotobacter treatments were on par among themselves and also with the control treatments T0 and T16. Copper content of VAM treatments also followed a similar trend.

4.1.2.5.7. Ash content (Table 29)

All treatments except T1 and T2 recorded ash content significantly higher than that of T0. Azospirillum treatments recorded ash content on par among themselves and also T16. Ash content in Azotobacter treatments T9, T10 and T11 and all the VAM treatments also were comparable with T16.

Table 28. Effect of microbial biofertilizers on crude protein(CP), crude fibre(CF), phosphorus, potassium, calcium and magnesium content of congosignal (%)

Treat-ments	CP	CF	P	K	Ca	Mg
T0	7.700	31.650	0.216	1.215	0.475	0.615
T1	7.700	31.625	0.218	1.210	0.445	0.605
T2	7.875	31.625	0.215	1.220	0.435	0.610
T3	7.700	31.500	0.235	1.220	0.440	0.600
T4	8.050	31.375	0.228	1.215	0.450	0.625
T5	7.875	31.375	0.222	1.215	0.440	0.620
T6	8.050	31.250	0.223	1.220	0.440	0.620
T7	8.050	30.750	0.223	1.225	0.470	0.610
T8	7.700	31.250	0.220	1.220	0.485	0.610
T9	8.050	31.250	0.228	1.230	0.465	0.615
T10	7.875	31.250	0.223	1.220	0.465	0.600
T11	8.050	30.750	0.228	1.220	0.430	0.615
T12	8.050	30.875	0.230	1.220	0.450	0.595
T13	8.050	30.750	0.233	1.225	0.460	0.605
T14	8.050	30.750	0.236	1.225	0.470	0.605
T15	8.225	30.750	0.233	1.230	0.460	0.610
T16	8.225	30.375	0.228	1.225	0.450	0.620
F	3.632**	2.600*	1.816	0.384	1.054	1.005
SE	0.093	0.242	0.005	0.009	0.015	0.008
CD	0.277	0.724	--	--	--	--

Table 29. Effect of microbial biofertilizers on the zinc, copper, manganese, ash content and K:(Ca+Mg) ratio of congosignal

Treat-ments	zinc (ppm)	copper (ppm)	manganese (ppm)	ash (%)	K:(Ca+Mg) ratio
T0	34.350	18.750	178.550	8.355	1.115
T1	33.000	19.550	185.500	8.420	1.150
T2	35.200	18.650	182.100	8.440	1.165
T3	37.300	18.550	175.000	8.535	1.175
T4	33.800	17.400	196.500	8.485	1.125
T5	33.650	17.400	201.900	8.480	1.135
T6	31.500	17.750	188.500	8.490	1.150
T7	34.500	22.550	189.800	8.510	1.135
T8	35.150	21.400	177.950	8.455	1.115
T9	33.300	19.450	186.300	8.500	1.140
T10	32.950	19.600	187.150	8.515	1.165
T11	34.150	18.950	189.250	8.590	1.165
T12	39.100	17.300	181.000	8.585	1.165
T13	38.050	16.750	178.000	8.600	1.150
T14	38.550	19.100	181.000	8.580	1.140
T15	35.900	18.000	182.500	8.605	1.150
T16	34.700	18.700	205.800	8.555	1.145
F	2.306	2.526*	2.160	4.564**	0.811
SE	1.406	0.928	5.817	0.033	0.020
CD	--	2.781	--	0.098	--

4.1.2.5.8. K : (Ca + Mg) ratio (Table 29)

The microbial inoculants had no significant influence on the K :(Ca + Mg) ratio of congosignal.

4.1.2.6. Crude Protein yield (Table 30)

The data on crude protein yield during 93 - 94 indicated the favourable effect of biofertilizer treatments. All treatments except T1 and T2 recorded crude protein significantly higher than that of T0. T7 yielded higher crude protein than the other Azospirillum treatments but was less effective than T16. The Azotobacter treatments also recorded distinctly lower crude protein yield. Among VAM treatments T12, T13 and T14 were on par with the POP treatment and T15 was found inferior.

During 94 - 95 period also the crude protein yield of T1 and T2 showed no significant improvement over T0 and all other treatments were superior. Azospirillum treatment T7 yielded crude protein on par with T16. Among Azotobacter treatments T10 was on par, T11 showed significant improvement and T2, T8 and T9 were distinctly inferior to the POP treatment. Significant superiority was observed with VAM treatment T12 while T13, T14 and T15 showed only marginal improvement over T16.

4.1.2.7. Uptake of nutrients

4.1.2.7.1. Uptake of major nutrients (Table 31, Fig. 15)

During 93 - 94 period uptake of nitrogen, phosphorus and potassium by all treatments except T1 and T2 recorded an improvement over T0. The uptake values recorded by T7 was superior to the other Azospirillum treatments but were inferior to T16. The Azotobacter treatments also recorded progressive improvement in nutrient uptake with increasing levels of applied fertilizers but were inferior to T16. Combination doses of VAM and chemical fertilizers at 0, 25 and 50 per cent phosphorus levels (T12, T13 and T14 respectively) were on par with T16 while the

Table 30. Effect of microbial biofertilizers on the crude protein yield of congosignal (kg ha^{-1})

Treatments	93-94	94-95
T0	641.45	589.40
T1	698.83	601.75
T2	581.05	607.20
T3	863.95	736.50
T4	1028.40	748.25
T5	1046.00	911.60
T6	1184.55	972.85
T7	1318.60	1045.65
T8	830.10	823.15
T9	1016.70	1001.00
T10	1096.20	1098.60
T11	1226.40	1218.76
T12	1524.25	1238.50
T13	1491.25	1211.90
T14	1436.95	1205.90
T15	1331.85	1114.10
T16	1477.10	1111.19
F	56.47**	39.56**
SE	40.71	36.49
CD	122.04	109.40

Table 31. Effect of microbial biofertilizers on the uptake of nitrogen, phosphorus and potassium by congo-signal (kg ha^{-1})

Treat-ments	nitrogen		phosphorus		potassium	
	93-94	94-95	93-94	94-95	93-94	94-95
T0	102.63	94.31	18.00	16.54	101.21	93.04
T1	114.18	99.49	20.22	17.61	112.15	97.71
T2	92.97	97.16	15.82	16.55	89.99	94.11
T3	138.23	117.85	26.30	22.43	136.78	116.69
T4	164.55	119.72	29.13	21.19	155.23	112.92
T5	167.36	145.86	29.43	25.65	161.35	140.64
T6	189.53	155.66	32.80	26.96	179.53	147.44
T7	210.97	167.31	36.51	28.96	200.69	159.16
T8	132.81	131.70	23.76	23.54	131.56	130.44
T9	162.68	160.17	28.81	28.34	155.42	152.87
T10	175.39	175.78	31.04	31.14	169.82	170.01
T11	196.23	195.01	34.74	34.52	185.85	184.70
T12	243.88	198.16	43.46	35.31	231.01	187.70
T13	238.61	193.91	43.13	35.09	226.85	184.43
T14	229.91	192.95	42.13	35.36	218.70	183.52
T15	213.10	178.19	37.78	31.54	199.27	166.57
T16	236.33	177.79	40.99	30.80	220.05	165.50
F	59.98**	37.23**	40.36**	33.60**	52.13**	45.65**
SE	6.29	6.08	1.37	1.13	6.15	4.92
CD	18.87	18.24	4.12	3.39	18.43	14.74

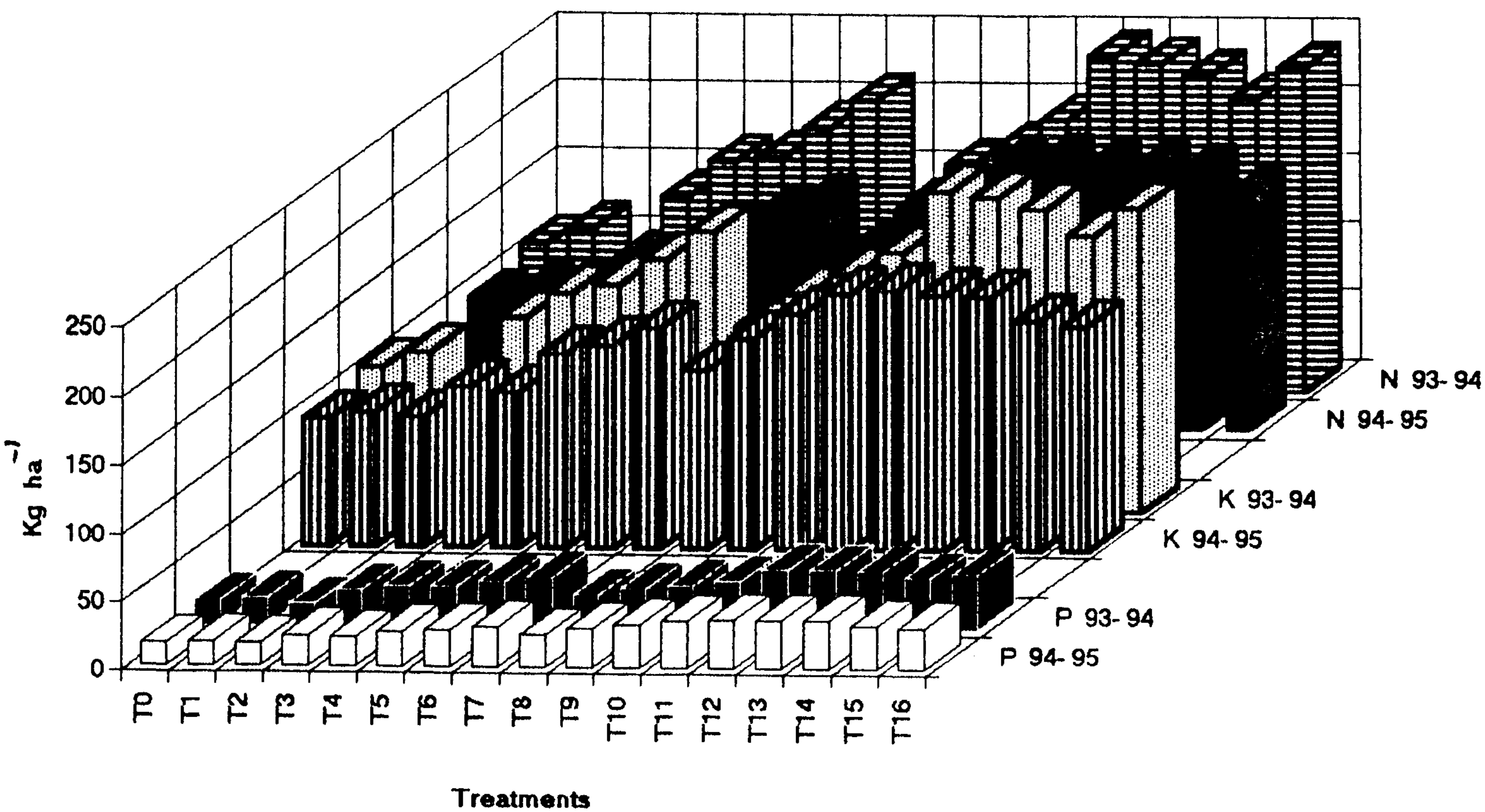


Fig. 15 Effect of microbial biofertilizers on uptake of major nutrients by Congosignal

75 per cent P level (T15) took up significantly lower quantity of nitrogen and potassium and comparable quantity of phosphorus.

During second year response to Azospirillum treatment T7 was comparable with T16 while T1, T4, T5 and T6 were distinctly inferior. Azotobacter treatment T9 and T10 recorded uptake of all three major nutrients on par with T16, while T11 registered distinct superiority over the POP treatment in phosphorus and potassium uptake. T12, T13 and T14 were significantly superior to T16 in phosphorus and potassium uptake. However the improvement in nitrogen uptake was significant only in T12. At 75 per cent P dose (T15) uptake of nitrogen, phosphorus and potassium recorded by the VAM inoculated plants was comparable with that of the POP treatment but inferior to T12, T13 and T14.

4.1.2.7.2. Uptake of calcium (Table 32)

During 93 - 94 period all treatments except T1, T2 and T3 recorded significant improvement in uptake of calcium over T0. Azospirillum and Azotobacter treatments recorded progressive increase in uptake values with increasing levels of applied fertilizers. The response of T7 was on par with T16 and the other Azospirillum treatments recorded distinctly lower calcium uptake. All Azotobacter treatments were found inferior to T16. In combination doses of VAM with chemical fertilizers, the level of applied phosphorus caused only marginal change in uptake of calcium and were comparable with T16.

Data on calcium uptake during 94 - 95 period revealed that T1, T2, T3 and T4 were on par with T0 and the other treatments were significantly superior. T6 and T7 were on par with T16 and the other Azospirillum treatments recorded lower calcium uptake. Among Azotobacter treatments T9, T10 and T11 responded similar to T16. VAM treatments T12, T13 and T14 registered significant improvement in calcium uptake while T15 was on par with the POP treatment.

4.1.2.7.3. Uptake of magnesium (Table 32)

During 93 - 94 period T1 and T2 showed only marginal variation in magnesium uptake over T0 but all other treatments recorded significant positive influence. When compared to T16 the magnesium uptake by all Azospirillum and Azotobacter treatments was distinctly lower. Among VAM treatments T12, T13 and T14 faired on par with the POP treatment and T15 was inferior.

The data on magnesium uptake during 94 - 95 period indicated significant improvement over T0 in all treatments except T1 and T2. Azospirillum treatments T5, T6 and T7 were on par among themselves but when compared with the POP treatment similar response was observed only in T7. Among Azotobacter treatments T2 and T8 recorded significantly lower quantity of magnesium uptake than the POP treatment, T9 and T10 were on par and T11 was significantly superior. The VAM treatments T12 to T15 responded more or less similar to T16.

4.1.2.7.4. Uptake of zinc (Table 33)

During 93 - 94 all treatments except T1 and T2 recorded significant increase in zinc uptake over T0. Azospirillum treatments recorded progressive improvement in zinc uptake at higher levels of applied fertilizers and T7 was on par with T16. Among Azotobacter treatments T11 responded similar to T16 and the other treatments were significantly inferior. Distinct improvement in zinc uptake over T16 was observed in VAM treatments T12, T13 and T14 while T15 showed only marginal difference.

Zinc uptake values during 94 - 95 period revealed that T1, T2 and T4 were on par with T0 and all other treatments were superior. Azospirillum treatments T5, T6 and T7 recorded zinc uptake on par with T16 while among Azotobacter treatments T9 and T10 responded in similar lines. Significant improvement over the POP treatment was recorded by T11. The significant positive influence of VAM treatments T12, T13 and T14 on zinc uptake over T16 was evident during 94 - 95 period but T15 remained on par.

Table 32. Effect of microbial biofertilizers on the uptake of calcium and magnesium by congosignal (kg ha^{-1})

Treat-ments	calcium		magnesium	
	93-94	94-95	93-94	94-95
T0	39.58	36.33	51.23	47.11
T1	41.37	36.01	56.03	48.83
T2	32.04	33.61	44.97	47.08
T3	46.62	42.08	67.22	57.39
T4	57.49	41.83	79.83	58.11
T5	58.45	50.94	82.31	71.76
T6	64.69	53.21	91.07	74.94
T7	76.99	61.05	99.36	79.19
T8	52.31	51.86	65.80	65.23
T9	58.83	57.71	77.64	76.52
T10	64.73	64.93	83.52	83.44
T11	65.47	65.08	93.71	93.12
T12	85.23	69.24	112.66	91.54
T13	85.12	69.26	112.10	91.08
T14	84.05	70.45	108.03	89.88
T15	74.49	62.31	98.80	82.62
T16	80.92	60.80	111.41	.3.76
F	25.72**	24.26**	52.27**	35.12**
SE	3.31	2.53	3.01	2.76
CD	9.93	7.60	9.03	8.26

4.1.2.7.5. Copper uptake (Table 33)

During 93 -94 period copper uptake by all treatments except T1, T2 and T3 recorded significant improvement over T0. Copper uptake by T7 was significantly superior to all other Azospirillum treatments and on par with that of T16. Azotobacter treatments T9, T10 and T11 responded more or less on par and the latter in turn was on par with POP treatment. Between T16 and the VAM treatments T12, T13, T14 and T15, the variation in copper uptake values was found marginal.

Copper uptake by T1, T2, T3 and T4 showed no significant improvement over T0 during 94 - 95 period. When compared to T16, the copper uptake by the Azospirillum treatment T7 was distinctly superior, T6 was on par and T1, T4 and T5 were inferior. Azotobacter treatments T8 to T11 recorded copper uptake on par with T16. The combination doses of VAM treatments responded in similar lines.

4.1.2.7.6. Manganese uptake (Table 33)

During 93 - 94 period revealed significant positive influence of all treatments except T1 and T2. When compared to T16 all the Azospirillum treatments took up significantly lower quantity of manganese. A similar response was observed in Azotobacter treatments also. Among VAM treatments T12 and T13 recorded manganese uptake on par with T16, while T3, T14 and T15 were inferior.

During 94 - 95 period T1, T2 and T3 recorded manganese uptake on par with T0 and the other treatments were significantly superior. All Azospirillum treatments were inferior to T16 in terms of manganese uptake. Azotobacter treatments T10 and T11 responded on par with T16. VAM treatments T12 to T15 recorded manganese uptake comparable among themselves and also with T16.

Table 33. Effect of microbial biofertilizers on the uptake of zinc, copper and manganese by congosignal (kg ha^{-1})

Treat-ments	zinc		copper		manganese	
	93-94	94-95	93-94	94-95	93-94	94-95
T0	0.287	0.261	0.157	0.143	1.488	1.365
T1	0.305	0.266	0.180	0.158	1.722	1.500
T2	0.260	0.272	0.138	0.144	1.341	1.407
T3	0.418	0.357	0.204	0.173	1.967	1.674
T4	0.432	0.314	0.222	0.162	2.514	1.833
T5	0.447	0.390	0.231	0.202	2.681	2.337
T6	0.464	0.381	0.262	0.215	2.776	2.279
T7	0.566	0.449	0.370	0.294	3.112	2.293
T8	0.380	0.376	0.231	0.229	1.922	1.904
T9	0.421	0.414	0.247	0.241	2.353	2.317
T10	0.459	0.460	0.273	0.274	2.605	2.614
T11	0.521	0.517	0.289	0.287	2.883	2.865
T12	0.743	0.602	0.328	0.267	3.428	2.785
T13	0.705	0.573	0.310	0.253	3.299	2.680
T14	0.688	0.578	0.341	0.286	3.233	2.712
T15	0.581	0.487	0.292	0.247	2.959	2.471
T16	0.571	0.468	0.336	0.253	3.705	2.780
F	32.09**	29.47**	14.96**	15.30**	22.21**	21.70**
SE	0.025	0.020	0.017	0.013	0.148	0.109
CD	0.076	0.060	0.052	0.040	0.445	0.328

4.1.2.8. Soil properties after the experiment

4.1.2.8.1. Soil physical properties

4.1.2.8.1.1. Bulk density (Table 34)

The bulk density of soil under all treatments was less than that of T0 and the negative effect was significant in all treatments except T1 and T2. The Azospirillum treatments T4 to T7 showed marginal variation in bulk density among themselves and were on par with T16. A similar response was observed with Azotobacter treatments also. Among VAM treatments T12 recorded significantly lower bulk density than T16 while T13, T14 and T15 were on par.

4.1.2.8.1.2. Water holding capacity (Table 34)

The biofertilizer treatments positively influenced the water holding capacity of soil but in treatments T1 to T5 the effect was marginal. All Azospirillum and Azotobacter treatments recorded water holding capacity on par with T16. The effect of VAM treatments on water holding capacity of soil showed no distinct improvement over T16.

4.1.2.8.1.3. Porosity (Table 34)

The soil porosity under all treatments recorded an improvement over T0 but under T1 to T5 the difference was not significant. The response of all Azospirillum treatments to soil porosity was on par among themselves and also with T16. The combination doses of Azotobacter and chemical fertilizers recorded soil porosity significantly superior to T2 and were comparable with T16. The response of VAM inoculation treatments was similar to that of T16.

4.1.2.8.1.4. Hydraulic conductivity (Table 34)

The hydraulic conductivity of soil differed significantly between treatments.

Table 34. Effect of microbial biofertilizers on the bulk density(BD), water holding capacity (WHC), porosity, hydraulic conductivity(HC) and mean weight diameter (MWD) of soil after the experiment

Treat-ments	BD ($g\ cc^{-1}$)	WHC (%)	Porosity (%)	HC ($cm\ hr^{-1}$)	MWD (mm)
T0	1.375	21.50	32.00	8.75	0.515
T1	1.356	22.75	33.15	8.84	0.506
T2	1.368	21.90	32.05	7.74	0.522
T3	1.355	22.75	34.50	11.83	0.551
T4	1.348	23.50	34.80	9.91	0.537
T5	1.344	23.80	34.65	11.58	0.519
T6	1.338	24.75	36.80	13.21	0.529
T7	1.330	25.50	36.10	13.93	0.529
T8	1.342	24.75	35.65	9.80	0.534
T9	1.337	26.50	36.50	13.80	0.525
T10	1.328	26.00	37.50	12.63	0.524
T11	1.326	26.25	37.00	13.09	0.520
T12	1.315	26.00	36.63	15.34	0.569
T13	1.322	27.25	37.65	13.73	0.556
T14	1.320	26.75	37.80	14.04	0.538
T15	1.323	25.75	37.38	12.08	0.526
T16	1.336	25.00	35.30	9.75	0.510
F	7.652**	2.71*	3.72**	3.25*	3.496**
SE	0.006	1.07	0.97	1.25	0.009
CD	0.019	3.20	2.99	3.73	0.026

When compared to T16, the hydraulic conductivity of T7 was distinctly higher and the other Azospirillum treatments were on par. Among Azotobacter treatments T9 recorded the highest value which was significantly superior to that of the POP treatment. Significantly higher hydraulic conductivity over T16 was recorded by VAM treatments T12, T13 and T14.

4.1.2.8.1.5. Mean weight diameter (Table 34)

Significant increase in mean weight diameter over T0 was observed only in T3, T12 and T13. Among Azospirillum treatments T4 recorded significant improvement over T16 while the others were on par. The response of Azotobacter treatments showed no significant difference over the POP treatment. The effect of VAM inoculation in increasing the mean weight diameter was distinctly superior to T16 in T3, T12, T13 and T14.

4.1.2.8.2. Nutrient status of soil

4.1.2.8.2.1. Available nitrogen (Table 35)

The effect of microbial inoculants on available nitrogen status of soil was not significant.

4.1.2.8.2.2. Available phosphorus (Table 35)

The available phosphorus status of soil improved significantly over T0 in all treatments except T1, T2 and T3. When compared to T16, the combination doses of biofertilizers with chemical fertilizers recorded comparable available phosphorus status.

4.1.2.8.2.3. Available potassium (Table 35)

The available potassium status of soil was not significantly influenced by the microbial inoculants.

4.1.2.8.2.4. Available calcium content (Table 35)

No significant influence was observed under various treatments.

4.1.2.8.2.4. Available magnesium (Table 35)

The available magnesium status of soil was not significantly influenced by the inoculation treatments.

4.1.2.8.2.5. Organic carbon (Table 35)

The data indicated that organic carbon status of soil improved under the biofertilizer treatments. Among Azospirillum treatments T6 and T7 recorded significant increase over T0 while in T1, T4 and T5 the effect was marginal. Significant improvement in organic carbon status over T0 was recorded by all Azotobacter treatments except T2. When compared to T16 the Azospirillum and Azotobacter treatments showed no significant positive change in organic carbon status. Under VAM treatments T12 and T14, the improvement was significant over the POP treatment but T3, T13 and T15 were on par .

4.1.2.9. Economics

4.1.2.9.1. Net income (Table 36, Fig. 16)

The net income from all treatments was positive. Significant improvement over T0 was recorded by all treatments except T1 and T2. When compared to the POP treatment, the net income from T7 was on par and the other Azospirillum treatments were inferior. When compared to T16 the Azotobacter treatments were less profitable. The income from VAM treatments T12, T13 and T14 were on par among themselves and also the POP treatment while T15 was significantly inferior.

During 94 - 95 period also significant improvement in net income was obtained from all treatments except T1 and T2. Azospirillum treatments T6 and T7

Table 35. Available nitrogen, phosphorus, potassium, calcium, magnesium (kg ha^{-1}) and organic carbon (%) status of the soil after the experiment

Treatments	N	P	K	Ca	Mg	organic carbon
T0	219.52	23.06	65.46	329.00	67.46	0.543
T1	218.52	23.52	59.55	317.00	63.30	0.543
T2	209.44	24.59	60.90	332.00	65.59	0.535
T3	216.28	24.53	58.70	325.00	73.73	0.569
T4	221.96	31.15	80.00	314.00	62.04	0.604
T5	219.12	30.70	75.60	307.00	64.25	0.604
T6	216.28	30.03	67.65	298.50	60.55	0.630
T7	219.52	28.09	60.60	295.00	59.48	0.638
T8	223.44	31.88	75.30	318.00	73.89	0.628
T9	216.28	31.53	72.00	312.00	72.11	0.630
T10	224.94	28.02	59.75	301.00	62.76	0.655
T11	223.44	29.52	52.80	290.00	56.12	0.655
T12	231.28	27.53	60.00	304.00	58.83	0.690
T13	225.78	28.59	59.60	293.00	55.49	0.664
T14	223.70	31.09	61.20	300.00	58.58	0.690
T15	228.44	30.69	60.25	296.00	62.18	0.638
T16	215.20	30.09	59.40	310.00	61.46	0.621
F	0.31	11.54**	2.08	0.94	1.10	5.54**
SE	9.75	0.86	5.16	13.24	5.36	0.020
CD	--	2.58	--	--	--	0.061

were on par with T16. Azotobacter treatment T9 and T10 recorded net income on par with T16, while significant superiority was observed under T11. Significant increase in net income over T16 was recorded by T12, T13 and T14 but T15 faired on par.

Pooled analysis showed that year was a significant factor on the response pattern in terms of net income. Season - treatment interaction was found significant. The net income from all treatments except T1, T2 and T3 was significantly superior to that of T0. Azospirillum treatments T6 and T7 were comparable with T16 and the others were less profitable. The Azotobacter treatments T10 and T11 were also on par with T16 in terms of net income. All combination doses of VAM irrespective of the level of applied phosphorus were found as profitable as the POP treatment.

4.1.2.9.2. Benefit : cost ratio (Table 37, Fig. 17)

The data on benefit : cost ratio during 93 - 94 indicated an improvement over T0 in all treatments except T2 but in T1 and T8 the difference was not significant. Azospirillum treatments T6 and T7 were on par with each other and the latter in turn was comparable with T16. All Azotobacter treatments recorded significantly lower benefit : cost ratio than the POP treatments. Among VAM treatments T12, T13 and T14 were on par with T16 while T15 was inferior.

During 94 - 95 period the benefit : cost ratio recorded by T1, T2 and T4 were comparable with T0 and the other treatments faired significantly superior. Azospirillum treatments T5, T6 and T7 were on par among themselves and also with T16. Among Azotobacter treatments T9 recorded benefit : cost ratio on par with T16 while significant improvement was registered by T10 and T11. VAM treatments T12, T13 and T14 recorded distinctly superior benefit : cost ratio over the POP treatment but the difference was marginal with T15.

Pooled analysis indicated that the benefit : cost ratio from all treatments except T1, T2 and T3 were significantly superior to T0. Azospirillum treatments T5, T6 and T7 were comparable with T16. Azotobacter treatments T10 and T11 also

Table 36. Effect of microbial biofertilizers on the net income from congosignal cultivation (Rs.)

Treatments	93-94 cost of cultivation	93-94 net income	94-95 cost of cultivation	94-95 net income	pooled
T0	10650	7910	8675	8061	7986
T1	10810	10151	8835	9613	9882
T2	10810	5302	8835	7803	6553
T3	10975	13913	8675	12626	13270
T4	11550	16861	9575	11510	14186
T5	11849	18305	9874	16352	17329
T6	12148	21193	10173	16723	18958
T7	12447	24681	10472	19511	22096
T8	11550	12004	9575	13762	12883
T9	11849	15692	9874	17230	16461
T10	12148	19380	10173	21952	20666
T11	12447	22703	10472	23180	22942
T12	12521	31230	10221	25294	28262
T13	12619	29315	10319	23580	26448
T14	12711	28490	10411	23513	26001
T15	12811	23346	10514	19860	21603
T16	12586	28093	10611	19423	23758
F		43.18**		38.37**	13.88**
SE		1190		920	1770
CD		3560		2740	5306

Cost(Rs.):1 kg Nitrogen- 5.98/- 1 kg phosphorus- 7.80/-
1 kg Potassium- 7.00/- Labour cost @ Rs. 65/-
-1

Price of green fodder - Rs. 600 ton

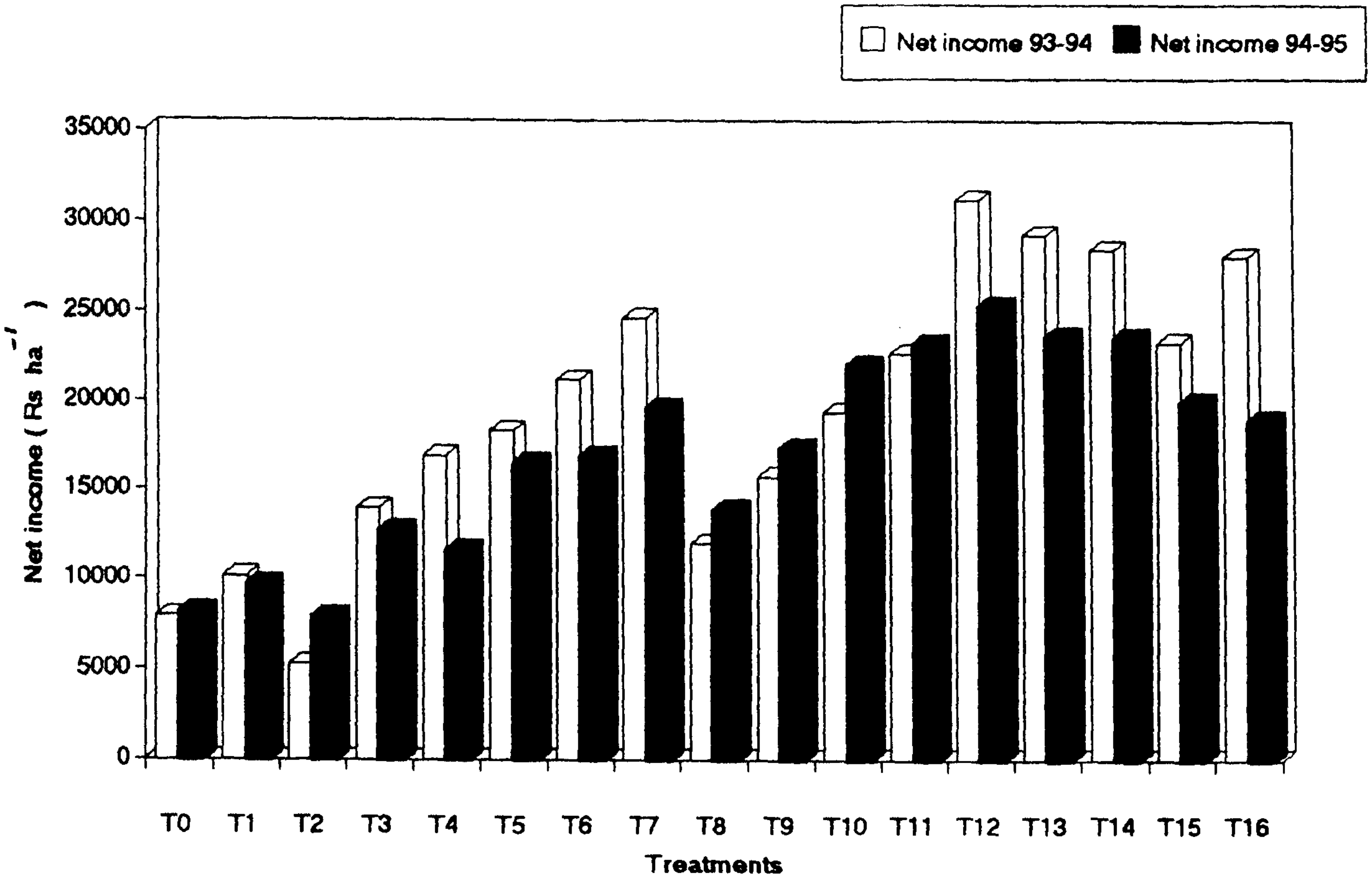


Fig.16. Effect of microbial biofertilizers on Net income from Congosignal

Table 37. Effect of microbial biofertilizers on benefit: cost ratio of congosignal

Treatments	93 - 94	94 - 95	pooled
T0	1.74	1.93	1.84
T1	1.94	2.03	1.99
T2	1.50	1.89	1.69
T3	2.27	2.46	2.37
T4	2.46	2.20	2.33
T5	2.55	2.66	2.61
T6	2.75	2.65	2.70
T7	2.98	2.86	2.92
T8	2.04	2.44	2.24
T9	2.32	2.74	2.53
T10	2.60	3.16	2.88
T11	2.82	3.21	3.02
T12	3.50	3.48	3.49
T13	3.32	3.29	3.31
T14	3.25	3.26	3.23
T15	2.81	2.89	2.85
T16	3.23	2.77	3.03
F	33.21**	29.02**0	14.85**
SE	0.10	0.09	0.13
CD	0.30	0.27	0.40

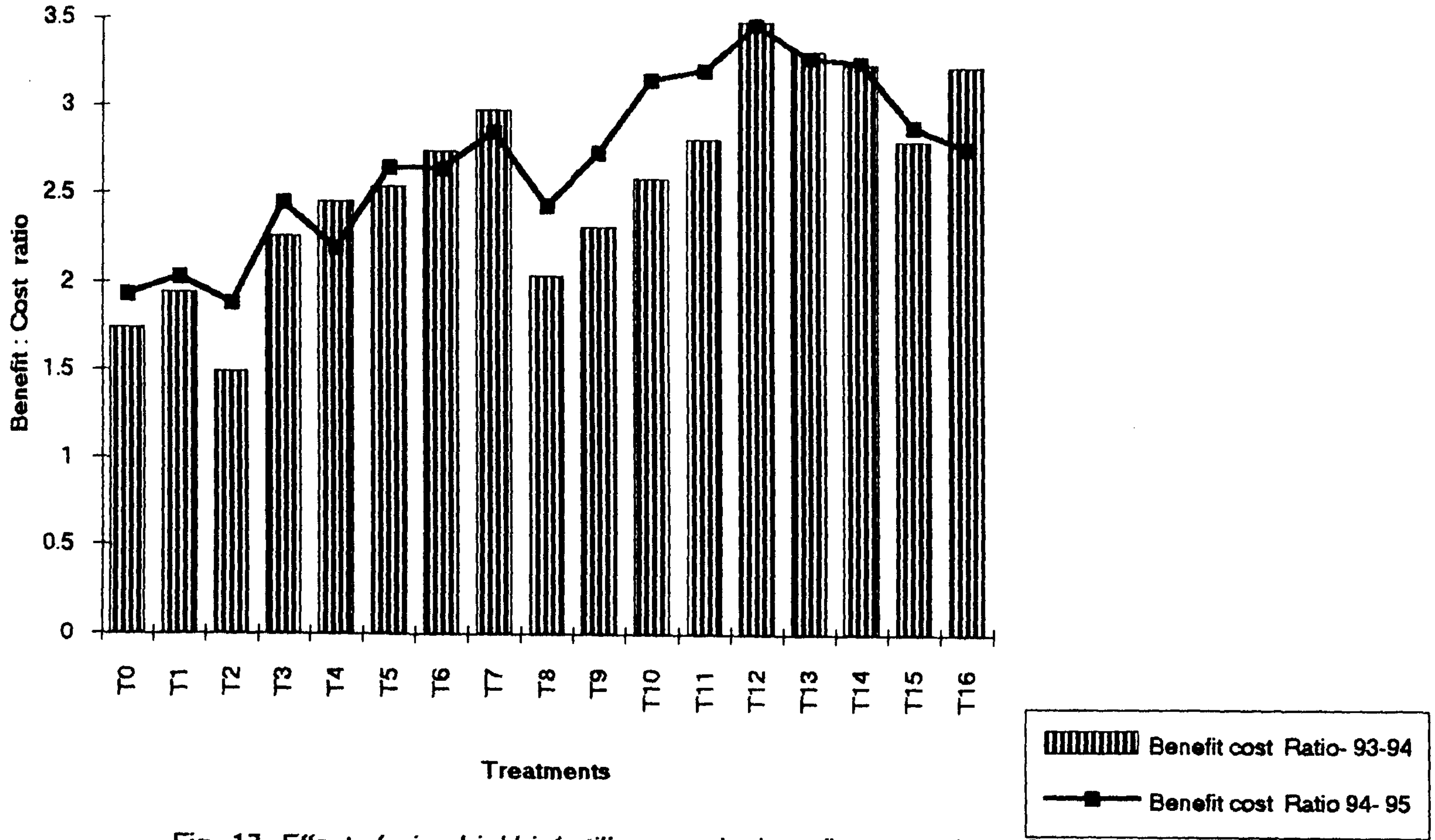


Fig. 17. Effect of microbial biofertilizers on the benefit : cost ratio of Congo signal

responded in similar lines. Among VAM treatments T12 recorded significant enhancement in benefit : cost ratio over T16 while T13, T14 and T15 were on par.

4.1.2.10. Correlation studies (Table 38)

The correlation studies revealed that during both 93 - 94 and 94- 95 periods dry fodder yield of congosignal was significantly and positively correlated with plant height, number of tillers, leaf area index, absolute growth rate and nutrient uptake. The root weight and root volume towards the end of the experimental period was significantly and positively correlated with the dry fodder yield of 94 - 95 period. The root : shoot ratio indicated significant positive correlation.

Among the soil properties organic carbon recorded the maximum positive correlation with the dry fodder yield. Bulk density recorded a high negative correlation with dry fodder yield during 94 - 95.

4.1.2.11. Path analysis studies (Table 39(a), 39(b), Fig. 18, Fig. 19)

Path analysis studies on the cause and effect relationship of root parameters on dry fodder yield of congosignal during 94 - 95 period revealed that root weight had the maximum direct effect on yield. Root volume exerted maximum positive indirect effect on yield through its influence on root weight while root : shoot ratio had the highest negative indirect effect.

Cause and effect relationship of soil properties with dry fodder yield of 94 - 95 period indicated that organic carbon status of the soil which recorded the highest correlation coefficient also had the maximum positive direct effect on yield. Bulk density of soil recorded high negative direct effect on yield. Organic carbon exerted high indirect effect through its influence on soil bulk density.

Table 38. Simple correlation coefficients of important parameters with dry fodder yield of congosignal

Parameters	Correlation coefficients with yield	
	93-94	94-95
Plant height	.8953**	.8793**
Tiller count	.9713**	.9334**
LAI	.9773**	.9537**
AGR	.9899**	.9913**
Root length	-	.5831**
Root weight	-	.9380**
Root volume	-	.9605**
Root : shoot ratio	-	-.5942**
Uptake of N	.8895**	.9896**
Uptake of P	.8881**	.9927**
Uptake of K	.8933**	.9993**
Soil bulk density	-	-.8776**
Water holding capacity	-	.7582**
Porosity	-	.7944**
Hydraulic conductivity	-	.7223**
Mean weight diameter	-	.3392
Organic carbon	-	.8128**

Table 39(a). Direct and indirect effects of root parameters on dry fodder yield of congosignal during 94- 95

Root length	Root weight	Root volume	Root :shoot	Total correlation
<u>-0.0590</u>	0.6530	-0.0014	-0.0095	0.5831
-0.0385	<u>0.9990</u>	-0.0023	-0.0202	0.9380
-0.0352	0.9774	<u>-0.0023</u>	0.0211	0.9605
0.0178	-0.6419	-0.0016	<u>0.0315</u>	-0.5942

residue 0.3438

Table 39(b). Direct and indirect effect of soil properties after the experiment on the dry fodder yield of congosignal during 94- 95

Bulk Dens-ity	Water holding capacity	Porosity	Hydraulic conduct-ivity	Mean weight diameter	Organic carbon	Total corre-lation
<u>-0.4196</u>	0.0827	-0.1422	-0.1451	0.0593	-0.3068	-0.8716
0.3137	<u>-0.1106</u>	0.1601	0.1218	-0.0330	0.3061	0.7582
0.2977	-0.0883	<u>0.2004</u>	0.1176	-0.0439	0.3110	0.7944
0.3082	-0.0682	0.1193	<u>0.1975</u>	-0.0862	0.2517	0.7223
0.1594	-0.0233	0.0564	0.1091	<u>-0.1561</u>	0.1937	0.3392
0.3294	-0.0866	0.1595	0.1272	-0.0774	<u>0.3908</u>	0.8428

residue 0.3740

(The underlined figures are the direct effects)

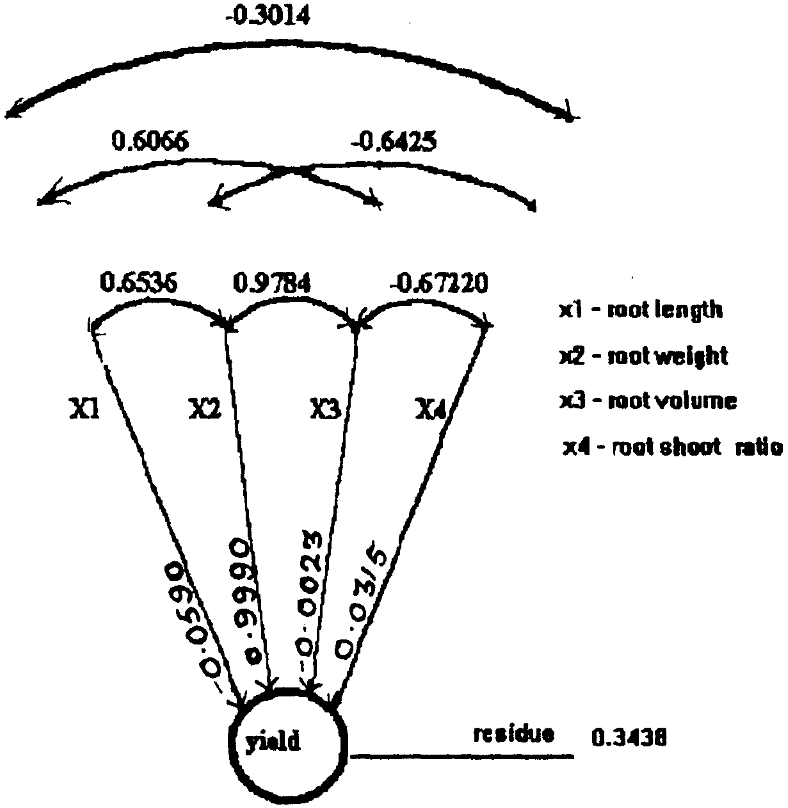


Fig . 18. Path diagram showing direct effects and interrelationships of root parameters with dry fodder yield of congosignal. (direct effects shown in single arrows and correlation coefficients shown in double arrows)

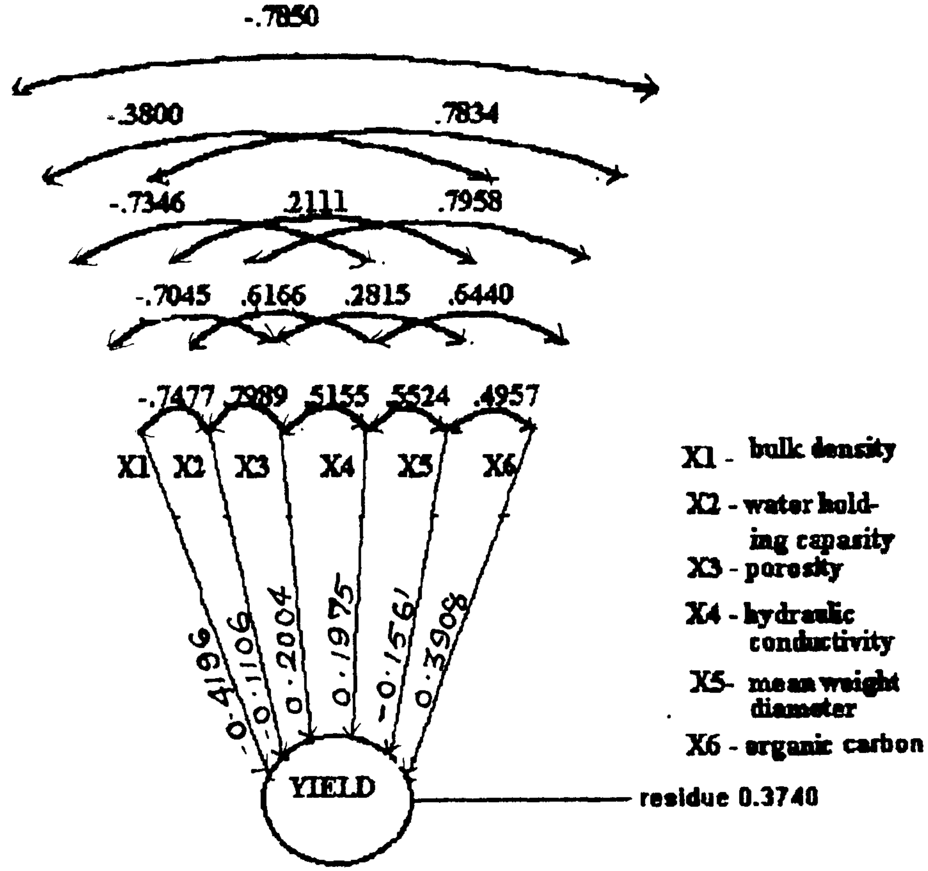


Fig 19. Path diagram showing direct effects and interrelationships of soil properties with dry fodder yield of congo signal (94-95). Direct effects shown in single arrows and correlation coefficients shown in double arrows

4.2. Experiment no.2 Vermitechnology for forage production

One of the major objectives of the study was to investigate the potential of vermicompost use for forage production in coconut gardens. It was also envisaged to compare the impact of the integrated use of manures and fertilizers with chemical fertilizers alone. The results obtained are presented accordingly to highlight the achievements.

4.2.1. Growth and yield characters

4.2.1.1. Plant height (Table 40)

During 93 -94 period vermicompost application favourably affected the plant height of guinea grass. T2, T3 and T4 recorded significant increase in plant height over T0. The response of T4 to plant height was comparable with the chemical fertilizer treatment T9 and others were less effective. Among the farm yard manure (FYM) treatments T7 and T8 recorded significant positive influence over T0. Plant height recorded by T8 was on par with T9.

During 94 - 95 period the response of vermicompost treatments to plant height in comparison with the control treatments followed more or less the same pattern as in the previous year. Among FYM treatments significant improvement over T0 was recorded by T6, T7 and T8 and the latter two were comparable with T9.

Pooled analysis revealed that combination doses of manures with fertilizers improved the plant height of guinea grass. In both vermicompost and FYM treatments plant height increased with increasing levels of applied fertilizers. Vermicompost treatment T4 and FYM treatment T8 recorded plant height on par with T9 while the other treatments were inferior.

4.2.1.2. Number of tillers hill^{-1} (Table 40)

All vermicompost treatments recorded significant improvement in tiller

Table 40. Effect of vermicompost on plant height, number of tillers $hill^{-1}$ and leaf:stem ratio of guinea grass

Treat-ments	plant height(cm)			tiller number			leaf:stem	
	93-94	94-95	pooled	93-94	94-95	pooled	93-94	94-95
T0	86.67	83.00	84.84	7.33	6.67	7.00	2.22	2.12
T1	91.00	88.33	89.67	9.68	9.27	9.48	2.11	2.15
T2	97.62	95.00	96.31	12.00	11.08	11.54	2.18	2.24
T3	101.50	98.67	100.09	13.25	12.83	13.04	2.12	2.17
T4	107.33	106.33	106.83	14.00	14.25	14.12	2.22	2.22
T5	88.33	86.33	87.83	8.67	8.93	8.80	2.13	2.12
T6	93.83	92.33	93.08	11.17	10.50	10.84	2.19	2.22
T7	104.67	107.00	105.84	13.50	14.17	13.84	2.13	2.06
T8	111.00	110.00	110.50	15.83	16.33	16.08	2.24	2.21
T9	113.67	108.67	111.17	15.95	14.50	15.23	2.25	2.25
F	13.31**	10.94**	27.93**	18.96**	18.63**	41.80**	1.02	1.35
SE	2.62	3.03	1.84	0.67	0.72	0.46	0.05	0.05
CD	7.78	8.99	5.25	1.99	2.15	1.32	--	--

production over T0 during 93 - 94 period. The response of T4 was on par with that of T9 while T1, T2 and T3 were inferior. Among FYM treatments T6, T7 and T8 produced significantly higher number of tillers than T0 while T5 was on par. When compared to T9, the response of T8 was in similar lines and the other FYM treatments were inferior.

During 94 -95 all treatments produced significantly higher number of tillers than T0. Among vermicompost treatments T3 and T4 were on par with T9. FYM treatments T7 and T8 also responded similar to T9.

Pooled analysis showed that all treatments improved tiller production over that of T0. Incremental doses of NPK resulted in progressive increase in tiller production in both vermicompost and FYM treatments and T4 and T8 were comparable with T9.

4.2.1.3. Leaf : stem ratio (table 40)

The leaf : stem ratio of guinea grass was not significantly influenced by the treatments.

4.2.1.4. Green fodder yield (Table 41)

The data during 93 - 94 revealed that green fodder yield increased significantly over T0 in all treatments except T5. The vermicompost treatments showed progressive enhancement in fodder yield with each incremental dose of chemical fertilizers but were less effective than T9. Among FYM treatments T8 yielded distinctly higher. T5, T6 and T7 and was on par with the chemical fertilizer treatment T9.

The positive influence of all treatments on green fodder yield was significant during 94 - 95 period. Progressive increase in fodder yield with each incremental dose of NPK fertilizer was evident in both vermicompost and FYM treatments. Among vermicompost treatments T4 responded on par with T9 and T1,

Table 41. Effect of vermicompost on green and dry fodder yield of guinea grass ($t\ ha^{-1}$)

Treat-ments	green fodder yield			dry fodder yield		
	93-94	94-95	pooled	93-94	94-95	pooled
T0	13.79	12.81	13.30	3.35	3.20	3.28
T1	16.22	17.84	17.03	4.06	4.63	4.35
T2	24.19	26.08	25.13	6.05	6.52	6.29
T3	29.57	30.90	30.24	7.39	7.72	7.56
T4	34.10	36.75	35.43	8.41	9.05	8.73
T5	14.63	16.67	15.65	3.66	4.16	3.91
T6	23.51	26.87	25.19	5.88	6.72	6.30
T7	31.34	35.55	33.45	7.84	8.88	8.36
T8	37.57	41.36	39.50	9.13	9.93	9.53
T9	38.79	36.53	37.66	9.31	9.01	9.16
F	130.40**	116.47**	87.04**	141.31**	119.87**	116.49**
SE	0.82	0.91	1.02	0.19	0.21	0.21
CD	2.43	2.69	3.26	0.56	0.64	0.68

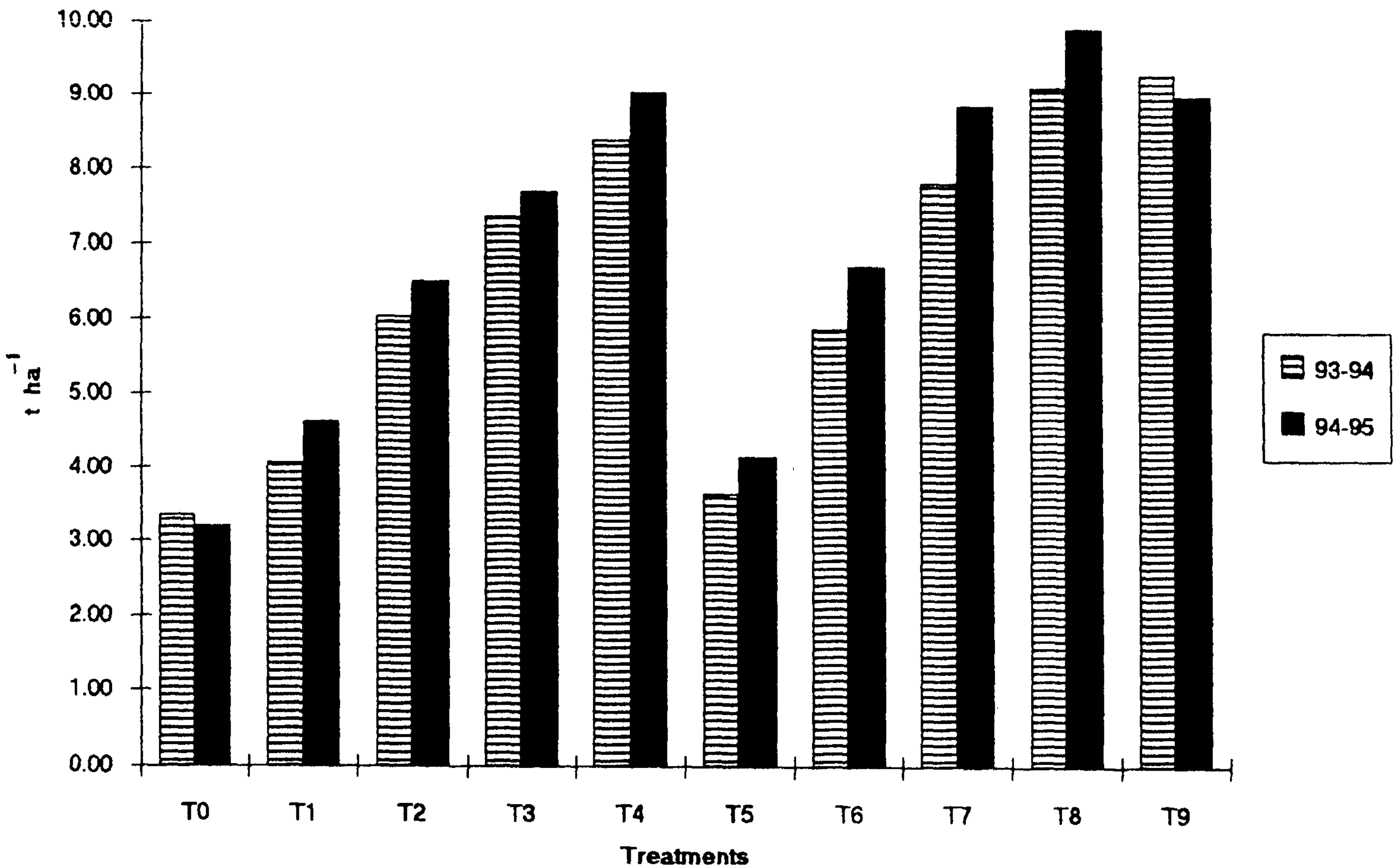


Fig 20. Effect of vermicompost on dry fodder yield of Guinea grass

T2 and T3 were inferior. FYM treatments T5 and T6 remained less effective than T9 while T7 responded on par. The effect of T8 on green fodder yield was found distinctly superior over the 100 per cent NPK treatment.

Pooled analysis studies indicated that year was a significant factor affecting yield. The treatment- season interaction was also found significant. The green fodder yield from all treatments except T5 was found significantly superior to T0. When compared to T9, the vermicompost treatment T4 and the FYM treatments T8 were on par and all other treatments were less effective.

4.2.1.5. Dry fodder yield (Table 41, Fig. 20)

Perusal of the data on dry fodder yield indicated that the influence of the treatments followed the same pattern as on green fodder yield.

4.2.2. Physiological parameters

4.2.2.1. Leaf area index (Table 42)

All treatments except T5 recorded significantly higher leaf area index than T0 during 93 - 94 period. Both vermicompost and FYM treatments recorded increased LAI with increasing levels of applied NPK. T4 was significantly superior to T1, T2 and T3 but when compared to T9 all vermicompost treatments were inferior. Among FYM treatments T8 recorded more or less the same LAI as T9 and the others were inferior.

During 94 - 95 period all treatments registered significantly higher LAI than T0. The combination doses of manures and fertilizers responded superior to manures applied alone. Among vermicompost treatments T4 recorded the highest LAI and was on par with T9. FYM treatment T5 and T6 were inferior to the chemical fertilizer treatments while T7 and T8 responded on par.

Table 42. Effect of vermicompost on the leaf area index(LAI) and the absolute growth rate(AGR) of guinea grass

Treat-ments	LAI		AGR(g $plant^{-1}$ day^{-1})	
	93-94	94-95	94-95	94-95
T0	2.93	2.28	0.49	0.33
T1	3.70	3.11	0.59	0.51
T2	4.63	4.27	0.88	0.71
T3	5.54	5.44	1.08	0.85
T4	6.30	6.09	1.23	0.99
T5	3.33	3.15	0.53	0.45
T6	4.30	4.17	0.86	0.74
T7	6.09	6.00	1.14	0.97
T8	6.81	6.73	1.33	1.09
T9	6.96	6.62	1.36	0.99
F	68.74**	50.58**	146.05**	165.05**
SE	0.18	0.23	0.03	0.02
CD	0.53	0.67	0.08	0.06

4.2.2.2. Absolute growth rate (Table 42)

Absolute growth rate(AGR) of all treatments except T5 was significantly superior to T0 during 93 - 94 period. Both vermicompost and FYM treatments recorded significant increase in AGR with each incremental dose of NPK fertilizers added. T4 was found significantly superior to T1, T2 and T3 but all four vermicompost treatments were inferior to T9. Among FYM treatments T8 performed similar to T9 while T5, T6 and T7 recorded distinctly lower AGR.

During 94 - 95 all treatments recorded significantly higher AGR than T0. When compared with T9, the vermicompost treatment T4 was on par and the others receiving lower NPK were significantly inferior. FYM treatment T8 was superior to T5, T6 and T7. The response of T7 was more or less similar to that of T9 while T8 recorded significant improvement over the chemical fertilizer treatment.

4.2.2.3. Chlorophyll content (Table 43)

A perusal of the data indicated that under all treatments the total chlorophyll as well as its components ' a ' and ' b' enhanced significantly over T0. Vermicompost treatments T3 and T4 recorded chlorophyll content on par among themselves and were comparable with T9. FYM treatments T7 and T8 recorded chlorophyll content comparable with that of T9.

The chlorophyll a : b ratio was not significantly influenced by the treatments.

4.2.3. Quality

4.2.3.1. Crude protein (Table 44)

Application of vermicompost and FYM favourably influenced the crude protein content of guinea grass and the improvement was significant in all treatments except T5. Between vermicompost treatments the difference in crude

Table 43. Effect of vermicompost on the chlorophyll content of guinea grass (mg g^{-1} fresh weight)

Treat-ments	chlorophyll a	b	a:b	a+b
T0	0.983	0.843	1.160	1.830
T1	1.167	1.010	1.210	2.123
T2	1.340	1.110	1.207	2.433
T3	1.410	1.163	1.213	2.573
T4	1.453	1.220	1.193	2.673
T5	1.157	0.997	1.160	2.150
T6	1.343	1.137	1.183	2.473
T7	1.457	1.240	1.177	2.697
T8	1.507	1.283	1.177	2.787
T9	1.493	1.247	1.200	2.737
F	17.032**	17.054**	0.823	17.464**
SE	0.042	0.034	0.022	0.076
CD	0.125	0.100	--	0.225

protein content was marginal and they faired on par with T9. The FYM treatments T2, T3 and T4 responded similar to T9 in terms of crude protein content.

4.2.3.2. Crude fibre (Table 44)

The data indicated that the treatments had a negative effect on crude fibre content. Integrated use of manures and fertilizers effectively lowered the crude fibre content over T0. The vermicompost treatments T3 and T4 responded on par with the chemical fertilizer treatment T9. Among FYM treatments T6, T7 and T8 were on par with T9 while T5 recorded distinctly higher crude fibre content.

4.2.3.3. Phosphorus content (Table 44)

The phosphorus content of guinea grass was not significantly influenced by the treatments.

4.2.3.4. Potassium content (Table 44)

Among vermicompost treatments T1 and T2 showed no distinct improvement in potassium content over T0 while T3 and T4 recorded significant improvement. Between themselves the vermicompost treatments had only marginal variation in potassium content and were comparable with T9. The FYM treatments showed no significant influence on the potassium content of the grass.

4.2.3.5. Calcium content (Table 44)

The calcium content of guinea grass was not found significantly influenced by the treatments.

4.2.3.6. Magnesium content (Table 44)

Application of manures and fertilizers had a significant effect on the magnesium content of guinea grass but the effect was not statistically significant.

Table 44. Effect of vermicompost on crude protein(CP),crude fibre(CF),phosphorus,potassium,calcium and magnesium content of vermicompost(%)

Treat-ments	CP	CF	P	K	Ca	Mg
T0	8.380	32.833	0.240	1.300	0.543	0.627
T1	8.627	32.583	0.243	1.303	0.543	0.623
T2	8.750	32.500	0.243	1.313	0.540	0.633
T3	8.750	32.333	0.247	1.317	0.543	0.643
T4	8.750	32.167	0.247	1.327	0.547	0.640
T5	8.503	32.683	0.243	1.307	0.543	0.627
T6	8.627	32.417	0.247	1.307	0.550	0.623
T7	8.750	32.333	0.243	1.310	0.543	0.633
T8	8.750	32.167	0.250	1.313	0.543	0.637
T9	8.750	32.167	0.247	1.317	0.547	0.633
F	3.885**	5.950**	0.844	2.766*	0.078	1.185
S	0.066	0.095	0.003	0.005	0.010	0.006
CD	0.197	0.282	--	0.014	--	--

Table 45. Effect of vermicompost on zinc,copper,manganese,ash content and K:(Ca+Mg) ratio of guinea grass

Treat-ments	zinc (ppm)	copper (ppm)	manganese (ppm)	ash (%)	K:(Ca+Mg) ratio
T0	27.067	22.600	210.100	9.340	1.110
T1	29.167	20.833	178.733	9.467	1.117
T2	30.767	20.133	176.467	9.567	1.117
T3	30.167	20.667	187.233	9.610	1.110
T4	31.733	20.733	183.633	9.677	1.120
T5	33.333	19.367	186.600	9.463	1.117
T6	29.933	22.200	203.333	9.527	1.113
T7	30.467	19.833	218.833	9.627	1.117
T8	29.933	23.000	211.500	9.673	1.120
T9	28.033	25.233	206.300	9.620	1.117
F	0.769	1.390	0.856	7.155**	0.089
SE	2.015	1.517	16.574	0.040	0.012
CD	--	--	--	0.120	0.035

4.2.3.6. Content of micronutrients (Table 45)

Zinc, copper and manganese content of guinea grass was not significantly influenced by the treatments.

4.2.3.8. Ash content (Table 45)

The data indicated that all treatments influenced the ash content significantly and positively over T0. Vermicompost treatments T2, T3 and T4 recorded ash content on par among themselves and also with T9. FYM treatments T6, T7 and T8 also recorded a similar response.

4.2.3.9. K :(Ca + Mg) ratio (Table 45)

The treatments showed no significant influence on the K : (Ca + Mg) ratio of guinea grass.

4.2.4. Crude protein yield (Table 44)

During 93 - 94 period all treatments except T5 recorded significant increase in crude protein yield over T0. Among vermicompost treatments T4 recorded crude protein yield significantly higher than T1, T2 and T3 but all four treatments were inferior to T9. FYM treatment T8 responded similar to the chemical fertilizer treatment T9 while T5, T6 and T7 yielded distinctly lower.

The crude protein yield recorded by T5 also showed significant improvement over T0 during 94 - 95 period. Among vermicompost treatments T4 recorded higher protein yield than T1, T2 and T3 and was comparable with T9. FYM treatment T5 and T6 yielded significantly lower crude protein than T9 but the performance of T7 was on par and that of T8 was superior.

Table 46. Effect of vermicompost on the protein yield of guinea grass(kg ha^{-1})

Treatments	93-94	94-95
T0	282.70	268.08
T1	349.50	399.40
T2	529.40	570.53
T3	646.97	675.80
T4	735.60	792.17
T5	310.57	354.50
T6	507.27	571.80
T7	685.73	777.01
T8	799.17	868.60
T9	814.67	788.10
F	155.13	113.05
SE	16.12	19.66
CD	47.91	58.43

4.2.5. Nutrient uptake

4.2.5.1. Uptake of major nutrients (Table 47)

A perusal of the data indicated that the influence of the treatments on uptake of nitrogen, phosphorus and potassium followed more or less a similar pattern and hence are dealt together hereunder.

During 93 - 94 period all treatments except T5 recorded significantly higher uptake values than T0. With incremental doses of applied fertilizers the nutrient uptake increased progressively. Uptake of major nutrients by T4 was found significantly superior to the other vermicompost treatments but when compared to T9 all vermicompost treatments were inferior. Among FYM treatments T8 recorded uptake of all three nutrients on par with T9 but T5, T6 and T8 were distinctly inferior.

Uptake of major nutrients by all treatments recorded significant improvement over T0 during 94 - 95 period. T4 recorded significant superiority over the other vermicompost treatments and faired on par with the chemical fertilizer treatment T9. FYM treatment T8 recorded distinct improvement in nutrient uptake over T9. Comparable results were obtained with T7 while T5 and T6 were inferior.

4.2.5.2. Uptake of secondary nutrients (Table 48)

During 93 - 94 period the uptake of calcium and magnesium recorded by all treatments except T5 showed significant improvement over T0. The treatments revealed progressive increase in uptake values with each incremental dose of NPK applied. However the uptake values recorded by all vermicompost treatments were significantly inferior to T9. Among FYM treatments T8 faired on par with T9 *while T5*, T6 and T7 were inferior.

T5 also recorded significant improvement in calcium and magnesium uptake over T0 during 94 - 95 period. T4 remained superior to the other vermicompost treatments and was comparable with T9. Uptake of both the nutrients

Table 47. Effect of vermicompost on the uptake of nitrogen,phosphorus and potassium by guinea grass (kg ha^{-1})

Treatments	nitrogen		phosphorus		potassium	
	93-94	94-95	93-94	94-95	93-94	94-95
T0	45.11	43.72	8.15	7.77	43.78	41.77
T1	55.98	63.96	9.87	11.27	52.87	60.35
T2	84.70	91.28	14.74	15.88	79.47	85.62
T3	103.51	108.13	18.06	18.87	97.34	101.68
T4	117.69	126.75	20.59	22.18	111.54	120.10
T5	49.79	56.83	8.92	10.17	47.82	54.49
T6	81.15	92.86	14.31	16.44	76.84	87.82
T7	109.71	124.32	19.08	21.62	102.66	116.61
T8	127.87	138.97	22.44	24.39	119.93	130.35
T9	130.34	126.09	22.85	22.10	122.60	118.60
F	159.03**	107.47**	128.03**	113.57**	143.31**	129.6**
SE	2.55	3.21	0.49	0.54	2.49	2.72
CD	7.57	9.53	1.46	1.61	7.41	8.09

Table 48. Effect of vermicompost on the uptake of calcium and magnesium by guinea grass (kg ha^{-1})

Treat-ments	calcium		magnesium	
	93-94	94-95	93-94	94-95
T0	18.42	17.04	20.91	19.56
T1	22.01	25.14	25.27	28.84
T2	32.64	35.18	38.33	41.32
T3	40.20	41.99	47.56	49.67
T4	45.93	49.50	53.78	57.96
T5	19.83	22.65	22.97	26.14
T6	32.34	36.98	36.64	41.88
T7	42.59	47.95	49.64	55.94
T8	49.59	53.90	58.14	63.19
T9	50.86	49.21	58.98	57.05
F	135.40**	111.68**	163.49**	133.14**
SE	1.05	1.21	1.14	1.31
CD	3.13	3.60	3.38	3.90

by T8 showed distinct improvement over the chemical fertilizer treatment. T7 performed on par and the other FYM treatments were inferior to T9.

4.2.5.3. Uptake of zinc (table 49)

The results indicated that during 93 - 94 the uptake of zinc improved significantly over T0 under all treatments except T1 and T5. T4 recorded higher zinc uptake values than the other vermicompost treatments and was comparable with T9. Among FYM treatments T7 and T8 were on par among themselves and also T9.

The zinc uptake by all treatments showed significant improvement over T0 during 94 - 95 period. Among vermicompost treatments T4 recorded the highest zinc uptake and both T3 and T4 were comparable with T9. Zinc uptake by T7 was on par with T9 while T8 recorded significant improvement over T9.

4.2.5.4. Copper uptake (Table 49)

Copper uptake by combination doses of manures and fertilizers showed significant improvement over T0 during 93 - 94 period. Vermicompost treatments T3 and T4 were on par among themselves and when compared to T9 all vermicompost treatments were significantly inferior. Among FYM treatments T8 responded similar to T9 while T5, T6 and T7 recorded lower response.

Copper uptake by T1 and T5 were on par with T9 during 94 - 95 period also. Vermicompost treatments recorded lower copper uptake values than T9. FYM treatment T8 was comparable with T9 and the others remained inferior.

4.1.5.5. Manganese uptake (Table 49)

T1, T2 and T5 recorded manganese uptake on par with T0 and the other treatments were superior during 93 - 94 period. Vermicompost treatments took up distinctly lower quantity of manganese than T9. Among FYM treatments T7 and T8 were comparable and T5 and T6 were inferior to T9.

Table 49. Effect of vermicompost on the uptake of zinc, copper and manganese by guinea grass (kg ha^{-1})

Treat- ments	zinc		copper		manganese	
	93-94	94-95	93-94	94-95	93-94	94-95
T0	0.097	0.087	0.073	0.067	0.730	0.667
T1	0.120	0.133	0.083	0.100	0.720	0.820
T2	0.187	0.197	0.123	0.130	1.067	1.157
T3	0.223	0.233	0.153	0.160	1.383	1.450
T4	0.267	0.290	0.177	0.190	1.537	1.663
T5	0.120	0.140	0.070	0.083	0.680	0.777
T6	0.177	0.203	0.133	0.150	1.193	1.363
T7	0.237	0.273	0.157	0.183	1.710	1.940
T8	0.273	0.300	0.210	0.227	1.923	2.093
T9	0.260	0.250	0.237	0.230	1.923	1.863
F	29.563**	22.578**	27.060**	21.985**	17.444**	13.948**
SE	0.012	0.015	0.011	0.012	0.116	0.138
CD	0.036	0.045	0.032	0.036	0.345	0.409

During 94 - 95 period T1 and T5 recorded uptake values on par with T0 and the other treatments were significantly superior. The response of vermicompost treatment T4 was comparable with T9 and T1, T2 and T3 were inferior . The response of FYM treatments followed the same pattern as found during the previous year.

4.2.6. Soil properties after the experiment

4.2.6.1. Soil physical properties

4.2.6.1.1. Bulk density (Table 50)

Bulk density of soil showed a decreasing trend under various treatments. T1 and T9 recorded marginal difference with T0 and in other treatments the effect was significant. When compared to T9 the bulk density recorded by vermicompost treatments T3 and T4 were distinctly lower while T1 and T2 responded on par. The effect of FYM treatments on soil bulk density also followed a similar trend.

4.2.6.1.2. Water holding capacity (Table 50)

Water holding capacity of soil improved over T0 under all treatments but the effect was not statistically significant in T9. The water holding capacity recorded by the vermicompost treatments showed only marginal difference among themselves and were significantly superior to T9. FYM treatments also showed a similar response.

4.2.6.1.3. Porosity (Table 50)

The porosity of soil improved significantly over T0 under all treatments. Among vermicompost treatments T3 recorded the maximum porosity and T3 and T4 were significantly superior to T9. The response was distinctly superior to T9 in FYM treatments T6, T7 and T8.

Table 50. Effect of vermicompost on the bulk density(BD), water holding capacity(WHC), porosity, hydraulic conductivity(HC) and mean weight diameter(MWD) of soil after the experiment

Treat-ments	BD ($g\ cc^{-1}$)	WHC (%)	porosity (%)	HC ($cm\ hr^{-1}$)	MWD (mm)
T0	1.363	23.670	33.737	17.881	0.473
T1	1.357	26.213	35.793	10.740	0.517
T2	1.350	26.347	36.743	12.437	0.533
T3	1.340	26.860	37.560	12.913	0.533
T4	1.343	26.757	37.337	13.653	0.527
T5	1.350	25.983	35.793	11.240	0.523
T6	1.347	26.190	37.417	13.137	0.537
T7	1.340	27.347	38.403	14.773	0.543
T8	1.333	27.700	38.833	13.217	0.543
T9	1.357	24.307	35.427	11.170	0.497
F	7.862**	8.948**	11.435**	7.363**	27.750**
SE	0.003	0.422	0.453	0.830	0.004
CD	0.010	1.253	1.347	2.470	0.013

4.2.6.1.4. Hydraulic conductivity (Table 50)

The hydraulic conductivity of soil was the highest under T0. The vermicompost treatments recorded hydraulic conductivity on par among themselves and T4 was superior to T9. Among FYM treatments T7 was significantly superior to T9 and all other treatments were on par. Between FYM treatments the variation in hydraulic conductivity was insignificant.

4.2.6.1.5. Mean weight diameter (Table 50)

There was significant increase in mean weight diameter of soil under organic manure treated plants over that under T0 and T9. Among vermicompost treatments T2 and T3 recorded higher mean weight diameter than T1 and T4. FYM treatments T6, T7 and T8 were on par among themselves and were superior to T5.

4.2.6.2. Nutrient status of soil

4.2.6.2.1. Available nitrogen (Table 51)

Available nitrogen content under all treatments recorded significant improvement over T0. Vermicompost treatments showed an increasing trend in nitrogen status with increasing level of applied nutrients but the difference was not significant. FYM treatments also recorded a similar trend. When compared to T9 all treatments except T0 were on par.

4.2.6.2.2. Available phosphorus (Table 51)

Application of manures and fertilizers caused significant improvement in the available phosphorus status of soil. Vermicompost treatments showed an increasing trend with increasing levels of applied nutrients. T3 and T4 recorded P status on par among themselves and also T9. The P status of FYM treatments T6, T7 and T8 also were comparable with T9.

Table 51. Effect of vermicompost on the available nitrogen, phosphorus, potassium, calcium, magnesium (kg ha^{-1}) and organic carbon (%) of the soil after the experiment

Treat-ments	N	P	K	Ca	Mg	organic carbon
T0	193.80	27.19	64.23	220.00	42.57	0.453
T1	217.36	30.86	71.83	264.00	48.50	0.583
T2	225.20	31.53	70.67	272.00	49.17	0.610
T3	229.97	32.20	70.00	271.33	48.50	0.603
T4	231.97	35.86	74.37	268.00	47.47	0.617
T5	226.59	32.25	69.27	264.00	49.32	0.583
T6	231.15	31.93	69.00	265.33	47.61	0.617
T7	232.09	32.91	73.87	264.00	46.79	0.657
T8	231.87	33.85	76.33	249.33	45.02	0.663
T9	219.33	34.33	71.43	218.00	37.82	0.547
F	4.47**	5.15**	1.28	3.32**	1.01	11.959**
SE	5.60	1.02	2.98	11.13	3.61	0.017
CD	16.65	3.04	--	33.06	--	0.052

4.2.6.2.3. Available potassium (Table 51)

The available potassium status of soil differed between treatments but the difference did not reach the level of significance.

4.2.6.2.4. Available calcium (Table 51)

The available calcium status of soil improved significantly over T0 when guinea grass was treated with manures and fertilizers. Between vermicompost treatments the variation in calcium status was marginal and all the treatments were superior to T9. FYM treatments T5, T6 and T7 were superior to T9 while T8 was on par..

4.2.6.2.5. Available magnesium (Table 51)

The available magnesium status of soil was not significantly influenced by the treatments.

4.2.6.2.6. Organic carbon (Table 51)

Application of manures improved the organic matter status of soil. Vermicompost treatments were on par among themselves and T2 and T4 were significantly superior to T9. FYM treatments T6, T7 and T8 showed significant superiority in organic carbon status over T9.

4.2.7. Economics

4.2.7.1. Net income (Table 52, Fig. 21)

During 93 - 94 T5 recorded the lowest net income which was on par with that of T1 and significantly inferior to all other treatments including T0. Net income from vermicompost and FYM treatments increased with increasing levels of applied fertilizers but all treatments were significantly inferior to the chemical fertilizer treatment T9.

The net income from T5 was the lowest during 94 - 95 period also but it was on par with that from T0 and T1. Combination doses of manures and fertilizers caused significant improvement in net income over T0. Vermicompost treatments recorded improvement in net income with increasing levels of applied fertilizers but were inferior to T9. Maximum net income was registered by T8 which was comparable with T9 and significantly superior to income from all other treatments.

Pooled analysis indicated that net income from T1 and T5 were on par with that from T0. The net income from vermicompost treatments was inferior to that from T9. Among FYM treatments T8 recorded the highest net income and was on par with T9.

4.2.7.2. Benefit : cost ratio (Table 53)

During 93 - 94 T5 recorded the lowest benefit : cost ratio which was on par with T0 and T1. The combination doses of manures and fertilizers recorded benefit : cost ratio significantly higher than that of T0 but was inferior to T9.

During 94 - 95 period also the lowest benefit : cost ratio was recorded by T5 which was on par with T1 and significantly inferior to all other treatments including T0. The benefit : cost ratio from T9 remained significantly superior to all other treatments during the second year also .

Pooled analysis showed that the benefit : cost ratio was the lowest in T5 which was significantly inferior to T0. All treatments except T1 and T5 recorded significant superiority over T0. When compared to T9 both vermicompost and FYM treatments were significantly inferior.

Table 52. Effect of vermicompost on the net income from guinea grass cultivation(Rs/ha)

Treat-ments	93-94 cost of cul-tivation	93-94 net income	94-95 cost of cul-tivation	94-95 net income	pooled net income
T0	6175	2069	5330	2357	2213
T1	8675	1057	7830	2873	1965
T2	9160	5353	8315	7333	6343
T3	9643	8097	8798	9730	8914
T4	10128	10333	9283	11893	11113
T5	9175	103	8330	1670	887
T6	9660	4447	8815	7307	5877
T7	10143	8753	9298	12030	10392
T8	10628	11913	9783	15037	13475
T9	7266	15163	8111	14653	14908
F		105.66**		67.85**	68.06
SE		483		607	599
CD		1434		1803	1916

Cost(Rs.):1 kg Nitrogen -5.98/- 1 kg Phosphorus- 7.80/-

1 kg potassium - 7.00 Labour cost @ Rs 65/-

Vermicompost Rs. 500 ton^{-1} FYM Rs. 300 ton^{-1}

Price of green fodder - Rs 600 ton^{-1}

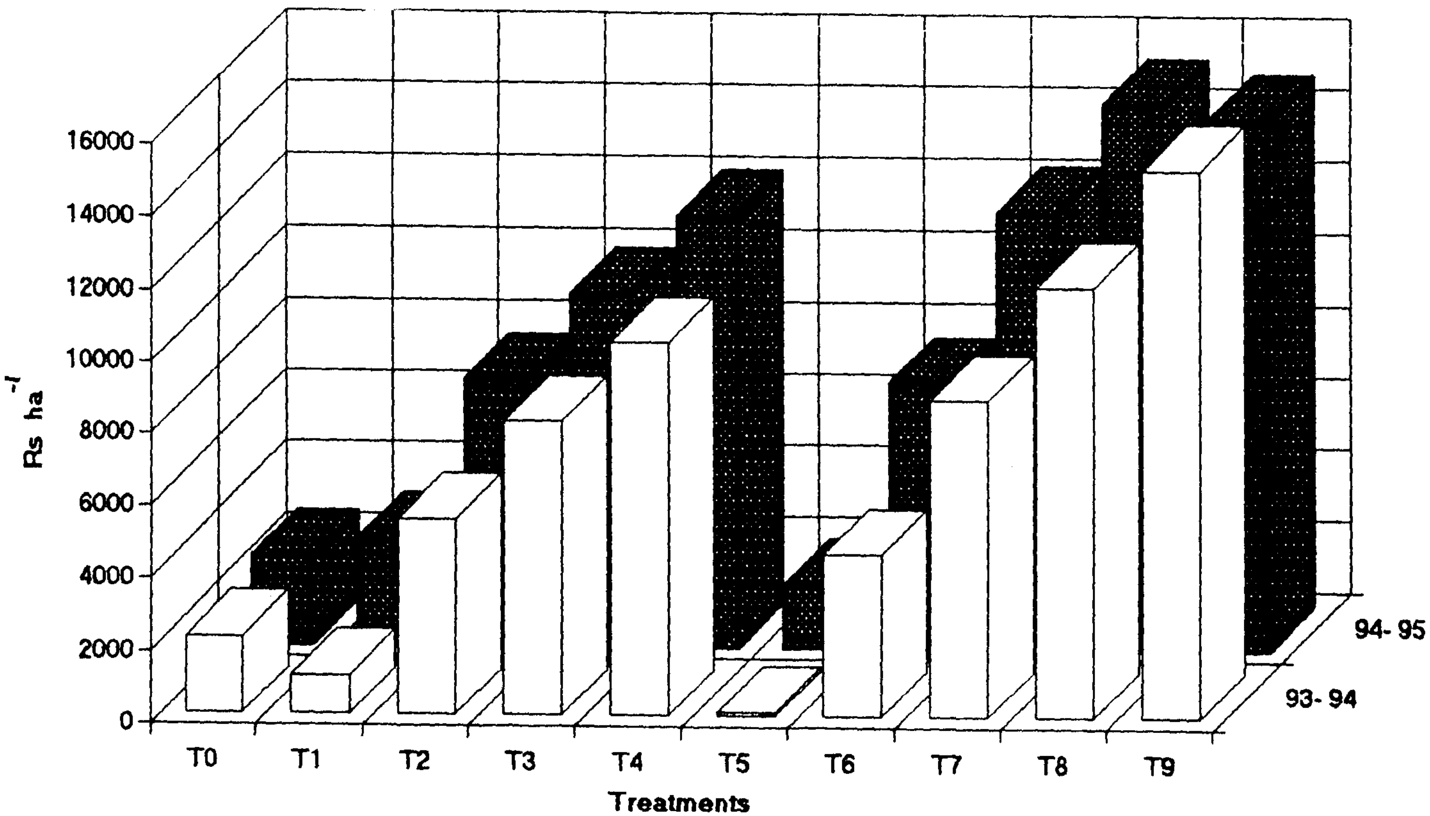


Fig . 21. Effect of vermicompost on net income from Guinea grass cultivation

Table 53. Effect of vermicompost on the benefit: cost ratio of guinea grass

Treatments	93 - 94	94 - 95	pooled
T0	1.44	1.34	1.39
T1	1.36	1.12	1.24
T2	1.88	1.58	1.73
T3	2.11	1.84	1.98
T4	2.28	2.02	2.15
T5	1.20	1.01	1.11
T6	1.83	1.46	1.65
T7	2.29	1.86	2.08
T8	2.54	2.12	2.33
T9	3.02	2.87	2.95
F	47.37**	106.87**	121.61**
SE	0.08	0.05	0.05
CD	0.24	0.16	0.14

4.3. Yield of coconuts (Table 54)

The data on yield of coconuts (nuts/palm) obtained from November, January, March and May harvests during the pre experimental period, experimental period and post experimental period is shown in Table 54.

The data indicated that coconut yield was favourably influenced by fodder intercropping. The average yield increase during the post experimental period over the pre experimental period was worked out to be 16.75 per cent.

Table 54. Yield of coconuts (nuts /tree) during November, January, March and May harvests before, during and after the experimental period

	Pre experimental period								Experimental period				Experimental period				Post experimental			
	91-92				92-93				93-94				94-95				95-96			
Palm no	Nov	Jan	Mar	May	Nov	Jan	Mar	May	Nov	Jan	Mar	May	Nov	Jan	Mar	May	Nov	Jan	Mar	May
89	6	12	10	10	6	13	12	9	8	11	11	11	12	8	11	13	9	13	13	12
92	8	6	8	6	8	6	11	6	10	8	18	7	9	7	12	7	11	8	10	7
106	12	10	8	5	13	11	9	8	13	11	10	10	14	11	10	6	14	12	11	11
107	6	8	14	6	8	8	10	13	7	9	6	16	9	9	8	18	10	9	11	9
108	10	14	10	8	11	15	11	10	11	12	7	9	11	12	11	16	12	9	12	9
109	9	12	8	10	8	13	8	11	13	9	9	11	10	14	9	12	6	11	12	8
110	13	13	12	6	14	14	13	6	18	14	13	7	15	9	9	7	11	9	12	13
111	12	10	7	9	18	11	14	11	13	11	8	15	14	11	8	12	11	12	8	11
133	6	14	9	8	9	15	8	10	7	9	10	9	7	16	9	9	11	10	11	9
134	8	8	10	12	10	15	11	18	9	12	11	13	11	9	11	14	9	11	12	11
135	6	8	8	9	8	8	13	9	6	9	14	10	9	18	9	10	11	9	10	12
136	10	13	10	8	11	14	9	11	13	14	11	9	11	15	10	9	12	8	12	9
138	8	8	12	6	7	11	13	8	10	13	7	7	10	10	14	9	11	13	16	17
139	8	12	10	9	5	13	8	7	7	13	11	10	11	14	8	10	7	8	12	11
140	12	8	8	8	13	8	12	8	13	9	16	9	14	8	11	9	14	9	16	9
141	8	14	10	12	6	12	9	13	9	8	11	13	9	6	9	4	9	6	12	11
142	5	10	8	6	5	11	11	6	6	8	9	17	6	11	9	7	6	12	9	7
143	9	7	14	9	9	7	7	9	10	8	13	10	10	8	12	10	11	8	11	11
147	10	6	10	9	11	6	8	9	11	7	11	10	11	7	11	10	12	8	14	15
148	6	8	8	12	6	8	9	13	7	9	15	17	11	8	7	14	10	9	9	11
149	9	12	8	6	7	13	9	6	10	12	10	11	10	8	10	16	11	14	11	13
Total	179	214	204	174	188	230	216	197	208	215	225	229	223	215	209	216	217	209	242	228
Mean	8.5	10.2	9.7	8.3	9.0	11.0	10.3	9.4	9.9	10.3	10.7	10.9	10.6	10.3	10.0	10.3	10.3	10.0	11.5	10.7

DISCUSSION

DISCUSSION

The present investigation was undertaken with the objective of assessing the potential of biofarming techniques for production of forage grasses in coconut gardens. The results of the two experiments presented in the previous chapter are discussed hereunder with an approach to bring about the impact of these technologies for sustaining optimum crop production and preventing soil degradation. Under experiment no. 1 the response of guinea and congosignal grasses to different microbial inoculants are discussed separately and conclusions summarised. The potential of vermicompost use for forage production is examined under experiment no. 2 and the effect of integrated use of manures and fertilizers is compared with continuous use of chemical fertilizers alone.

5.1. Experiment no. 1 Microbial inoculants for forage production

5.1.1. Inoculation response of Guinea grass

5.1. 1.1. Response of Guinea grass to Azospirillum inoculation

Results of the present investigation indicated significant positive influence of Azospirillum inoculation on growth and yield of guinea grass. The inoculated plants grew taller than those under absolute control and responded well to fertilizer application. With 75 per cent of the recommended nitrogen they were as tall as those receiving 100 per cent NPK. The enhancement in tiller production through Azospirillum inoculation was distinct during the entire cropping period. During the first year the tiller number produced by the inoculated plants receiving 75 percent of the recommended nitrogen was comparable with that of the recommended fertilizer treatment and during the second year the response was found distinctly superior. Such beneficial effects of Azospirillum inoculation on plant height and tiller production have been reported by Jayaraman and Ramiah (1986) in rice and Govindarajan (1987) in fodder sorghum. Sumner (1989) observed that the increased number of tillers in Azospirillum inoculated plants could be attributed to production of growth regulators in the rhizosphere.

The response in terms of fodder yield was found consistent with the influence on plant height and tiller production. Azospirillum inoculation elicited significant yield increase over the absolute control alone and in combination with fertilizers. When inoculation was combined with fertilizer application the fodder yield increased progressively with incremental doses of nitrogen. During the first year the inoculated plants had to be supplemented with full dose P and K fertilizers and 75 per cent of the recommended fertilizer N to yield on par with 100 per cent NPK treatment whereas during the second year 50 per cent of the combined nitrogen was sufficient to give comparable yields. With 75 percent of the recommended nitrogen the inoculated plants out yielded the chemical fertilizer treatment by 12 per cent, though the increase was not statistically significant.

Pooled analysis of the yield data revealed that the season - treatment interaction was insignificant and that the response of guinea grass to inoculation treatments was consistent during the two cropping periods. Inoculation combined with 75 per cent of the recommended fertilizer nitrogen responded more or less similar to the recommended fertilizer treatment. Thus from the results it could be inferred that part of the nitrogen requirement of the fodder grass was supplemented by the biofertilizer. This concurred with the findings of Smith *et al.* (1978) who reported that when guinea grass was lightly fertilized and inoculated with Azospirillum 39 kg nitrogen per hectare could be saved.

It is unequivocal that agriculturally important tropical C4 grasses like *Panicum maximum* can obtain significant proportion of plant nitrogen from associative nitrogen fixation(Chalk, 1991). Miranda and Boddey (1987) obtained a substantial input of 5 to 10 kg nitrogen ha^{-1} per 30 days in guinea grass. O' Hara *et al.* (1987) suggested three factors to control growth response to Azospirillum inoculation, i.e. ; excretion of biologically fixed nitrogen (Rennie, 1980), production of plant growth hormones by the bacteria (Tien *et al.*, 1979) and a stimulation of nutrient uptake (Lin *et al.*, 1983).

According to Neyra and Dobereiner (1977) the presence of combined nitrogen in soil reduced the favourable effect of Azospirillum. However the results of the present study showed that guinea grass was responsive to Azospirillum inoculation under conditions of both low and high levels of fertilizer nitrogen. Similar results have come from Millet and Feldman (1984) and Zambre *et al* . (1984). O' Hara *et al.* (1987) observed that the growth of Azospirillum associated with plant roots was stimulated by the presence of inorganic nitrogen. In the present study, since the soil of the experimental site was low in available nitrogen (196 kg N ha^{-1})

it is logical to assume that even the 150 kg N ha^{-1} applied (75 percent N dose) as two split doses was not high enough to deter the activity of Azospirillum in the rhizosphere. The addition of 500 kg ha^{-1} of lime to combat the acidity of soil as well as the application of FYM @ 10 t ha^{-1} every year to improve the organic matter status of the soil must have provided a better environment for establishment and proliferation of the diazotroph. It is likely that the re-inoculation at every six month period ensured a continuous, steady and effective population of the bacteria in the rhizosphere resulting in the remarkable growth response.

The yield trend discussed above was in agreement with the response in terms of leaf area index (LAI) and absolute growth rate (AGR). At 75 per cent N level the LAI of the inoculated plants was more or less similar to that of the recommended fertilizer treatment during the first year while the 50 and 75 percent N levels were comparable during the second year. Increased plant height and enhanced number of tillers in inoculation treatments might have contributed to a corresponding increase in the number of leaves which in turn increased LAI in the inoculation treatments. There are earlier reports that LAI of guinea grass was highly responsive to plant availability of nitrogen (Pillai, 1986). In inoculation treatments these plants might have been able to obtain some nitrogen from associated biological nitrogen fixation, in addition to the applied nitrogen as reported by Miranda and Boddey(1987). Such enhancement in LAI indicated higher ability of inoculated plants to utilise solar energy for the development of vegetative parts which directly contributed to fodder yield. The increased LAI is of special practical importance under coconut garden situations where a greater leaf area exposed will ensure better trapping of solar energy.

A perusal of the data on absolute growth rate (AGR) indicated that the influence of Azospirillum on AGR was very much similar to its effect on dry fodder yield. The increased availability of nitrogen as well as the greater foraging capacity of the more prolific root system (as indicated by the data on root parameters -Table 8), for water and nutrients must have contributed to the enhanced growth rate of the inoculated plants.

Azospirillum inoculation enhanced the content of total chlorophyll as well its components while the a : b ratio remained unaffected. At 50 and 75 per cent N doses the inoculated plants registered chlorophyll content on par with that of the recommended fertilizer treatment. The enhancement in chlorophyll content indicated greater availability of nutrients especially nitrogen which is an integral part of chlorophyll molecule (Tisdale *et al.*, 1985).

Evidence indicated that the positive effects of Azospirillum inoculation was probably also through altered root growth and subsequent effects on nutrient uptake and capacity to out grow adverse climatic conditions. The root weight and root volume of guinea grass showed distinct improvement when inoculated with the bacteria. under inoculation alone both the parameters were significantly superior to that under absolute control. Maximum values were at 75 percent N level closely followed by the 0 N level and all combination doses were on par with the recommended fertilizer treatment. Venkateswarlu and Rao(1983) observed that

Plate - 2 Root growth of Guinea grass as influenced by Azospirillum treatments and POP treatment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Azospirillum which live on or in the roots could continuously release phytohormones which affected plant growth by inducing proliferation of lateral roots. The data on root weight as well as the root shoot ratio indicated that the root proliferating effect of Azospirillum in guinea grass was more pronounced in the absence of combined nitrogen. The root : shoot ratio was maximum at inoculation alone and with incremental doses of combined nitrogen, the ratio went down. This finding is in agreement with the reports of Hurd and Spratt (1981) who observed that at low levels of nitrogen supply roots were stimulated to grow more than shoots which increased the translocation of photosynthates to the roots. However at all levels of nutrients the ratio in inoculation treatments was higher than that of the POP treatment. Earlier studies have indicated that following inoculation, Azospirillum adsorbed to and proliferated in the roots (Okon *et al.*, 1977) and apparently invaded the internal parts (Patriquin *et al.*, 1983), where it promoted root hair development and branching (Kapulnik *et al.*, 1983).

A critical review of the yield data revealed that the yield of guinea grass increased during the second year. An interesting point was that while under full dose chemical fertilizers the yield increase was 12.45 per cent, the Azospirillum treatments registered yield increase in the range of 24.49 to 30.33 percent. Such improved sustenance in production in the inoculated plants is of great practical significance especially for perennial forage production. The altered root growth must have increased the mineral uptake by the inoculated plants (Okon *et al.*, 1983) and improved the water status of the plants (Okon, 1988) which in turn might have helped the inoculated plants to tide over the stress due to frequent dry spells during the second year (as evidenced from the weather data) better than those treated with chemical fertilizers alone.

Quality of forage is as important as quantity in animal nutrition. The crude protein content of guinea grass inoculated with Azospirillum was higher than that of the plants under absolute control which was in agreement with the reports of Smith *et al.* (1976). In inoculated plants supplemented with fertilizers the crude protein content was on par with the recommended fertilizer treatment. The crude protein yield improved under inoculation treatments in conformity with the reports of Singh *et al.* 1980) who observed that the crude protein yield of sorghum and cowpea through Azospirillum inoculation was equal to that obtained with 45 kg nitrogen ha^{-1}. According to Capriel and Ashcroft (1972) nitrogen increased the crude protein yield of forages and no management practices other than the application of nitrogen appreciably influenced the protein content of guinea grass. The enhancement in the crude protein content of inoculated plants indicated an increase in plant availability of nitrogen attributable to the biological nitrogen fixation as well as the better foraging capacity of the plant roots. The data on nitrogen uptake of the inoculation treatments gives added emphasis to this inference.

The effect of inoculation on crude fibre content was reverse to its effect on crude protein. With inoculation there was a substantial decrease in the crude fibre content thus improving the quality and acceptability of the fodder grass. Pillai (1986) has reported that in guinea grass the crude protein content increased and the crude fibre content decreased with increasing levels of nitrogen.

Though not significant the Azospirillum inoculation treatments showed an enhancement in the content of P, K, Ca, Mg , Zn, Cu and Mn. Obviously there was no dilution effect in treatments recording higher dry weight which might be due to an enhanced mineral uptake by the altered root system. This was reflected in the ash content also. When supplemented with fertilizers, the ash content of inoculated plants was better than that of the absolute control and comparable with the recommended fertilizer treatment.

The K : (Ca + Mg) ratio of guinea grass was not influenced by Azospirillum inoculation. The ratio remained within the safe limit of 2.2 as suggested by Hendrikson (1960) and Thill and George (1975), thus avoiding the risk of grass tetany in animals. The safe K : (Ca + Mg) ratio indicated that the enhanced uptake of nutrients in the inoculation treatments was well balanced with respect to forage quality.

Uptake of nutrients in the present study showed significant variation between treatments. The uptake of all nutrients under Azospirillum inoculation alone was higher than that by the plants under absolute control. With incremental doses of nitrogen the uptake of nutrients by the inoculated plants increased progressively. The 50 and 75 per cent N doses responded more or less similar to the recommended fertilizer treatment. Lin *et al.* (1983) attributed the enhanced growth of inoculated plants to the increased uptake of nutrients. Okon and Kapulnik (1986) observed that the bacteria increased nutrient availability by altering the root surface characteristics involved in nutrient uptake. Elgably (1962) observed that application of nitrogen increased the root cation exchange capacity which enhanced the absorption of nutrients.

Data on the properties of soil after the experimental period revealed a general improvement in the physical and chemical properties of soil over the initial soil status. According to Reid and Gross (1980) the positive impact of grass cultivation on the soil properties was mainly because there was much greater root biomass and also associated microbial biomass in the rhizosphere. The bulk density of soil lowered under the two year long guinea grass cultivation and there was significant variation between treatments. Under the Azospirillum inoculated plants the bulk density of soil was lower than that under absolute control and the lowest value was at 0 N level. Several studies have shown that a decrease in bulk density is associated with an increase in the organic carbon status of the soil (Suresh Lal and Mathur, 1989). The organic matter decreases the bulk density of soil directly by dilution of soil matrix with a less dense material and indirectly by improving the aggregate stability (Allison, 1973). The results of the present study recorded an increase in the organic carbon content of soil under inoculation treatments and the highest value was at 0 N level.

The porosity and the water holding capacity of soil improved under grass cultivation over the initial status. In the inoculation treatments it was higher than that under absolute control. The mean weight diameter showed a higher value but the difference was only marginal. It is well documented that combined application of fertilizers and manures improved soil structure, increased the porosity and lowered the bulk density of soil (Biswas *et al.*, 1967). The inoculation treatments registered soil properties on par with that of the recommended fertilizer treatment even at lower nutrient doses which itself can be considered as a beneficial effect from the bacterial association.

The available nutrient status of soil improved under grass cultivation. Though not statistically significant the nitrogen content under inoculation treatments was higher than that under both the control treatments which could be attributed to a steady enrichment of the rhizosphere through biological nitrogen fixation. The level of nitrogen applied did not significantly influence the residual status probably because at higher nitrogen levels the uptake was also higher.

Among the Azospirillum treatments the available P status of soil was maximum at 0 N level and it decreased with increasing levels of applied nitrogen. At lower N levels the uptake values was lower which indicated that the fertilizer phosphorus added was not fully utilised thus leading to an accumulation of phosphorus in the soil.

Unlike in the case of available nitrogen and phosphorus, the potassium content of soil after the experiment registered a lower value over the initial status. Potassium depletion of soil through guinea grass cultivation has been reported by Pillai (1986) and can be easily explained by the fairly lower quantity of applied potassium and the higher uptake values by the grass crop. Between treatments the variation was not significant but the content was higher at lower N levels. The influence of the diazotroph on content of calcium and magnesium in the soil after the experiment did not vary significantly between treatments.

The results of the economic analysis indicated that Azospirillum inoculation was a paying preposition for guinea grass cultivation. During the first year the absolute control recorded a net loss of Rs 1280/ indicating that with application of organic manures and lime alone, guinea grass did not pay back on a short term basis. However Azospirillum inoculation alone could enhance the net income As per the pooled analysis the net income from inoculated plants receiving 75 per cent of the recommended N dose was comparable with that from the POP treatment. This observation reaffirmed that through Azospirillum inoculation 25 per cent of the recommended nitrogen could be saved without economic loss. The benefit : cost ratio also favoured the use of the biofertilizer for guinea grass.

The general conclusions from the discussions on response of guinea grass to Azospirillum inoculation may be summarised as follows.

1. Guinea grass responded significantly and positively to Azospirillum inoculation under conditions of both low and high levels of nitrogen application.

2. The combination dose of Azospirillum with 75 per cent of the recommended nitrogen responded more or less similar to the POP treatment. which indicated that part of the nitrogen requirement of guinea grass was supplemented through the biofertilizer.

3. Root growth of guinea grass was stimulated by Azospirillum inoculation.

5. 1. 1. 2. Response of Guinea grass to Azotobacter inoculation

Results of the present investigation revealed that Azotobacter inoculation alone could not elicit significant response in growth and yield characters of guinea grass. When combined with fertilizers there was an enhancement in growth characters and during the second year the inoculated plants at 50 and 75 per cent N doses recorded plant height and tiller number on par with that of the uninoculated plants treated with 100 per cent recommended fertilizers. Pooled analysis studies of the yield data showed that the response of the combination dose of Azotobacter with 75 per cent of the recommended N was more or less similar to that of the recommended fertilizer treatment.

The above discussed response pattern indicated that Azotobacter inoculation had only limited effects on growth and yield of guinea grass during the first year but the effect was appreciable during the second year. Brown *et al.* (1964) has observed that Azotobacter inoculation improved crop growth only when the bacteria established and grew well in the rhizosphere The proliferation and activity of Azotobacter is very much pH dependent (Verma, 1993) and the lack of organic matter is another limiting factor (Kundu and Rao, 1980). The experimental site in the present study being acidic with low organic carbon status(as revealed from the data on initial soil properties) it s likely that the development of the diazotroph in the rhizosphere of guinea grass was slow. Effective population might have been built up after re-inoculation which was given at every six month period. The gradual improvement in the physical and chemical properties of soil under the grass crop over the initial status must have provided a better environment for the establishment and proliferation of the bacteria in the rhizosphere with the passing of time.

From the results it was evident that under inoculation alone there were no distinct improvement in growth and yield characters of guinea grass while the combination doses were effective. From such a response pattern it could be inferred that inorganic nitrogen had a positive interaction with the bacterial activity. Fedrove (1952) has observed that applied nitrogen increased the effectiveness of Azotobacter inoculation. Reddy *et al.* (1977) reported that yield of fodder maize increased by inoculation of Azotobacter with applied nitrogen upto 150 kg ha $^{-1}$.

An insight into the probable reasons for the yield response pattern can be had from the data on leaf area index (LAI) and absolute growth rate (AGR). All inoculation treatments recorded significantly lower LAI than the 100 per cent NPK treatment during the first year while the 50 and 75 per cent N doses were comparable with the chemical fertilizer treatment during the second year. The influence of the inoculation treatments on AGR of guinea grass was more or less similar to its effect on dry fodder yield.

Unlike the effect on fodder yield, the Azotobacter effect on root

Plate - 3 Root growth of Guinea grass as influenced by Azotobacter treatments and POP treatment


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proliferation was quite distinct. Guinea grass inoculated with Azotobacter without fertilizers recorded root weight and root volume significantly higher than that under absolute control. Application of P and K fertilizers caused significant increase in root weight and volume but the presence of fertilizer nitrogen produced no further improvement. The root : shoot ratio steadily decreased with increasing levels of applied nitrogen which is in agreement with the observations made by Hurd and Spratt (1981). However the root shoot ratio of all Azospirillum treatments was higher than that of the recommended fertilizer treatment. Such response pattern indicated that the root growth of guinea grass was positively and significantly influenced by Azotobacter inoculation and that it was more responsive in the absence of combined nitrogen. This high root : shoot ratio might be the reason why the bacterial association failed to show significant improvement on fodder yield in the absence of inorganic nitrogen. Dewan and Subba Rao (1979) observed that the increment in root biomass in sterilised soil by inoculation of Azotobacter at 0 N level was more than that obtained by the addition of 30 kg N ha^{-1}. Yahalom *et al.* (1984) has reported increase in root branching, root dry weight and root/shoot ratio with Azotobacter inoculation in graminaceous plants. The improvement in root growth probably helped the inoculation treatments to tide over the frequent dry spells during the second year.

The yield data indicated that in the Azotobacter inoculation treatments the yield increase during the second year over the first year ranged from 26.81 to 50.48 per cent while that under the chemical fertilizer treatment was only 12.45 per cent. Such trends in yield was indicative of the sustaining effect of the biofertilizer for perennial forage production.

Quality of the forage grass was favourably affected by Azotobacter inoculation. When combined with varying levels of fertilizer nitrogen, the crude protein content of the inoculated grass was on par with that of full dose recommended fertilizer treatment. Contrary to the effect on crude protein, the crude fibre content lowered under inoculation treatments. The possible reasons for such response pattern are the same as those discussed under response of guinea grass to Azospirillum inoculation.

Though there was a general increase in the content of P, K, Ca, Mg, Zn, Cu and Mn in the inoculation treatments, the enhancement was only marginal. However the ash content of Azotobacter inoculated plants was found significantly higher than that of absolute control and on par with the recommended fertilizer treatment which in itself may be considered as a positive effect of the biofertilizer.

The K : (Ca + Mg) ratio was unaffected by the inoculation treatments and under all treatments the ratio was within safe limits for animal nutrition. The uptake of nutrients which was computed from the dry matter production and the nutrient content followed a response pattern similar to that of the dry matter production. Similar improvement in nutrient uptake with Azotobacter inoculation treatments has been reported by Hussain *et al.* (1987) in both fertilized and unfertilized soil.

The data on physical and chemical properties of soil after the experimental period revealed positive influence of guinea grass cultivation on the soil system. The data on bulk density, water holding capacity and the porosity of soil registered values on par with that under the recommended fertilizer treatment and the hydraulic conductivity registered an improvement. The mean weight diameter was maintained near to the optimum of 0.5 mm indicating the favorable effect of grass cultivation on aggregate stabilisation.

The available nitrogen content of soil improved under grass cultivation which could be attributed to the addition of plant debris during the two year cropping period. Between treatments the variation in nitrogen status was marginal. However the phosphorus and potassium content showed significant variation between treatments. Maximum content was recorded at 0 N level and with increasing doses of applied nitrogen the available phosphorus and potassium lowered. The organic carbon content of soil also improved substantially over the initial status. Under combination doses of Azotobacter and chemical fertilizers, the organic carbon status of soil was on par with that under full dose of recommended fertilizers and significantly higher than that of the absolute control.

During the first year the net income from guinea grass cultivation was negative under Azotobacter inoculation alone. Combination doses of the biofertilizer and chemical fertilizers increased the net returns significantly. During the second year there was substantial increase in the net income from all treatments. Azotobacter inoculated plants receiving 50 and 75 per cent N doses recorded net income of Rs. 16677/- and Rs. 17372/- respectively which were comparable with that obtained from the plants treated with 100 per cent NPK alone(Rs. 17745/-). Pooled analysis confirmed that in guinea grass 25 per cent of the recommended nitrogen could be saved through Azotobacter inoculation.

The benefit :cost ratio during the first year from all inoculation treatments was significantly inferior to that from recommended fertilizer treatment. However during the second year the 25, 50 and 75 per cent N levels responded more or less similar to the recommended fertilizer treatment.

The general conclusions from the discussions on the response of guinea grass to Azotobacter inoculation may be summarised as follows.

1. Azotobacter inoculation alone did not elicit significant yield response in guinea grass. Combination doses with chemical fertilizers including low levels of inorganic nitrogen was found effective.

2. Through Azotobacter inoculation 25 per cent of the recommended fertilizer nitrogen could be saved without yield reduction.

3. Root growth was significantly influenced by Azotobacter inoculation. The root proliferation was more perceptible in the absence of combined nitrogen.

5.1.1.3. Response of guinea grass to VAM inoculation

The results of the present study revealed that guinea grass responded positively and significantly to VAM inoculation. Under inoculation alone the plants were taller than those under absolute control and when supplemented with nitrogen and potassium fertilizers, the plants grew more vigourous. The level of fertilizer phosphorus showed no significant influence on the height of mycorrhizal plants and at all levels they were on par with the recommended fertilizer treatment.

The effect of VAM inoculation on tiller production of guinea grass was more distinct than its effect on plant height. Under inoculation alone the mycorrhizal plants had significantly higher number of tillers hill^{-1} than those under absolute control. When compared to the recommended fertilizer treatment the tiller production in mycorrhizal plants at 0, 25 and 50 per cent P doses was found distinctly improved. However the 75 per cent P dose responded more or less similar to the POP treatment.

The enhanced fodder yield from VAM inoculated plants confirmed the potential of VAM treatments for increased forage production. Under inoculation alone the fodder yield increased significantly over the absolute control and when supplemented with N and K fertilizers, VAM treatments receiving 0, 25 and 50 per cent of the recommended fertilizer phosphorus registered remarkable superiority over the POP treatment. The pooled analysis confirmed the effectiveness of these treatments.

Significant responses to mycorrhizal infection in graminae have been reported by many earlier workers(Howeler *et al.*, 1987., Thompson, 1990). Gerdemann (1965) reported that maize inoculated with VAM produced twice as much dry weight as uninoculated maize while Hazra (1994) observed 24 per cent increase in dry fodder yield of guinea grass through mycorrhizal association.

A perusal of yield data indicated that when the level of fertilizer phosphorus was increased to 75 per cent there was a decline in yield over that at lower P doses. Reduction in VAM effect at higher levels of soluble phosphate has been reported by Smith and Gianinazzi-Pearson (1988). Marschner and Dell (1994) observed that with increasing levels of soil phosphorus the growth enhancement effect of VAM declined and was either abolished or led to growth depression (shift from mutualism to parasitism), if carbon cost of symbiosis was not compensated by other beneficial effects.

The yield data clearly indicated that VAM inoculation could completely substitute the phosphorus requirement of the crop and gave added advantage in terms of fodder yield over the POP treatment. It is well documented that VAM contributed to better utilisation of soil phosphate and to more efficient utilisation of applied nutrients (Azcon-Aguilar and Barea, 1981., Krishna *et al.*, 1982). De Geus (1977) observed that grasses showed low response to phosphorus fertilizers. Studies on phosphorus requirement of guinea grass conducted by Meerabai *et al.* (1993) at College of Agriculture, Vellayani has also shown that the fodder grass responded to phosphorus fertilizer levels upto 30 kg per ha^{-1} only. Thus it may be inferred that the comparatively lower phosphorus requirement of the crop was completely met from the soil phosphorus itself in the mycorrhizal plants.

However the significant yield enhancement through combination doses of VAM with N and K fertilizers was contradictory to the reports of Chambers *et al.* (1980) who observed that addition of combined nitrogen decreased the mycorrhizal effect in young clover roots. Mosse *et al.* (1981) also observed that VAM formation was favoured by low to moderate fertility levels. A possible explanation was that in the present study since the initial nutrient status of the soil was very low the 200 kg nitrogen /ha applied as two split doses was not high enough to deter the activity of the fungi.

The yield response pattern also indicated that the VAM effect persisted more or less steady during the entire cropping period, the lower P levels being superior and the 75 per cent P level remaining on par with the recommended fertilizer treatment.

The increase in yield during the second year over the first year ranged from 16.87 to 40.48 per cent in the VAM treatments while in the chemical fertilizer treatment it was only 12.45 per cent. This again indicated the potential of the mycorrhizal association for sustained production in perennial grass cultivation.

The data on response of guinea grass to VAM inoculation in terms of leaf area index (LAI) was consistent with the above discussed yield trend. The LAI of grass is dependent on the number of leaves, leaf width and number of tillers. The positive influence of VAM association on leaf area and number of leaves had been reported by Geethakumari *et al.* (1990) and Lu and Koide (1994). The more vigorous growth of the inoculated plants and the enhanced number of tillers might have contributed to the increased LAI. The increased leaf surface exposed and the increased availability of nutrients as evident from the data on nutrient uptake might have helped the VAM inoculated plants to synthesise and accumulate more photosynthates thus increasing the dry matter production.

Remarkable positive response in terms of dry matter production per unit time was reaffirmed from the data on absolute growth rate (AGR). The combination doses of VAM and chemical fertilizers upto 50 per cent P dose registered AGR significantly superior to the recommended fertilizer treatment and the 75 percent P level was on par. Increase in dry matter production through mycorrhizal association has been reported by several workers (Gerdemann, 1965., Saif and Khan, 1977)

VAM association positively affected chlorophyll content of guinea grass. Though not significant there was an increase in the content of total chlorophyll as well as its components under inoculation alone over the absolute control. Combination doses of VAM with chemical fertilizers recorded chlorophyll content on par with the chemical fertilizer treatment. Marked increase in chlorophyll content of plants with mycorrhizal association was observed by Tinker (1975). Mohan Raj Samuel (1984) suggested a close link between chlorophyll content of plants and colonisation of VAM in their roots in some vegetable crops.

Among the root parameters the root weight and root volume were significantly influenced by the fungal association. Under inoculation alone the root weight and root volume increased significantly over that of absolute control. At 0, 25 and 50 per cent phosphorus doses the root weight and volume of the mycorrhizal plants were significantly superior to that of uninoculated plants treated with 100 per cent NPK. Such root stimulating effect of mycorrhizal association has been reported by Bagyaraj and Manjunath (1980). The root stimulation was found more perceptible at 0 P dose and this observation was in conformity with the reports of Osonubi (1994) in maize.

The root : shoot ratio of mycorrhizal plants at inoculation alone showed a marginal decrease over the absolute control and when combined with fertilizers it lowered significantly. At all levels of applied phosphorus the combination doses were on par with the POP treatment which indicated that though mycorrhizal association stimulated root growth there was no excess flow of photosynthates for root proliferation.

The data on VAM colonisation rate on guinea grass roots revealed mycorrhizal association in uninoculated plants also in line with the reports of Girija and Nair (1985). With inoculation there was a sharp increase in the colonisation percentage. The 0, 25 and 50 per cent phosphorus doses recorded high infection rate and the maximum was at 25 per cent. This was in line with the findings of Saif (1986) who reported stimulated mycorrhizal infection at low levels of applied phosphorus. In a VAM inoculation study Sreedurga (1993) obtained maximum

Plate - 4 Root growth of Guinea grass as influenced by VAM treatments and POP treatment


GUINEA

infection rate of 81.8 per cent in stylosanthes at 50 per cent of the recommended fertilizer dose. However when the applied phosphorus was increased to 75 per cent of the recommended rate the colonisation per cent went down substantially. There are earlier reports that soluble phosphates in the soil decreased both the extent of extramatricial mycelium (Abbott *et al.*, 1984) and the number of arbuscles formed (Smith and Gianinazzi-Pearson, 1988). It was thus obvious that in the present study the poorer performance of the VAM treatment at the highest level of applied phosphorus was related to the decline in the infection rate.

Studies on the effect of VAM on quality of forage grass gave encouraging results. In combination doses the crude protein content was on par with that of the recommended fertilizer treatment. The elution of the expected dilution effect in treatments showing enhanced growth rate is attributable to the better foraging ability of the VAM infected roots (Azcon and Barea, 1992). The protein yield which is dependent on the dry matter production as well as the crude protein content followed a response pattern similar to that of dry fodder yield.

Contrary to the effect on the crude protein, the crude fibre content lowered significantly under inoculation treatments over that of the absolute control indicating an improvement in quality of fodder. When supplemented with fertilizers the quality of the forage in terms of crude fibre was on par with the recommended fertilizer treatment.

A significant enhancement in the tissue concentration of phosphorus was observed in the mycorrhizal plants in agreement with the findings of several earlier workers (Stribley *et al.*, 1980., Lu and Koide, 1994) indicating the effectiveness of the VAM association in phosphorus nutrition.

The effect of VAM on potassium content of forage was non significant. The content of calcium and magnesium was also unaffected by the fungal association. Tissue concentration of both copper and zinc improved in the mycorrhizal plants but the enhancement was of significance only with zinc. The manganese content registered a lowering trend but the variation fell short of statistical significance. The increase in concentration of zinc and copper was in agreement with the reports of Marschner and Dell (1994) who observed that the depressing effect of phosphorus fertilization on concentration of zinc and copper can be overcome by the VAM association.

Cumulative effect of VAM influence on tissue concentration of minerals was reflected in the ash content. Under inoculation alone the ash content of VAM plants was higher than that of the absolute control and in combination doses they were on par with that of the uninoculated plants treated with recommended fertilizers. As already mentioned the elution of the expected dilution effect in these treatments which produced a greater biomass is attributable to the enhanced uptake of nutrients by the external hyphae of the fungus and also the stimulated root system. Marschner and Dell (1994) have opined that a greater uptake of nutrients by mycorrhizal plants can be attributed not only to the uptake through the fungal hyphae but also to the increased root growth. This will again explain the higher uptake of nutrients like potassium for which the capacity for hyphal translocation have not yet been proved.

As a rule the increased plant growth through mycorrhizal association is attributed to the increase in nutrient uptake (Marschner and Dell, 1994). In the present study VAM inoculation was found to increase the uptake of all the nutrients except manganese during the whole cropping period. The thorough permeation of the soil volume by the VAM hyphae and the stimulated root growth makes a relative increase in ion uptake easy to explain. A great deal of work has been reported which confirms the importance of VAM in improving the mineral nutrition functioning as a modified root system, greatly modified for nutrient uptake (Barea, 1991). Marschner and Dell (1994) observed that VAM enhanced nutrient uptake in plants by increasing the absorbing surface area, by mobilising sparingly available nutrient sources or by excretion of chelating compounds or ectoenzymes. Kothari *et al.* (1991) attributed the decrease in manganese uptake in VAM plants to VAM induced changes in the rhizosphere micro organisms.

When compared to the initial soil status the physical and chemical properties of soil was found improved under the VAM inoculated guinea grass. Between treatments the effect on soil properties varied significantly. When compared to the absolute control the soil under inoculation alone had lower bulk density, higher water holding capacity and a corresponding increase in the porosity. When combined with N and K fertilizers and varying levels of fertilizer phosphorus, all three properties were comparable or superior to the recommended fertilizer treatment.

The mean weight diameter of soil under VAM inoculated plants was higher than that under uninoculated treatments indicating an increase in the macroaggregates. The role of VAM in aggregate stabilisation is well documented (Tisdall and Oades, 1982). Miller and Jastrow (1990) observed that in many soils stability of macroaggregates was related to the length of VAM hyphae. The VAM hyphae produce extracellular polysaccharides to which microagrregates are attached and bound in to stable macroaggregates by the net work of hyphae. Lowering of bulk density and the increase in water holding capacity and porosity may be attributed to the combined effect of increased root biomass and the better aggregation of soil under VAM inoculation.

The available nutrient status of soil was favourably influenced by the VAM inoculation. The available nitrogen content of soil was higher than that of the initial soil status but between treatments the variation was not significant. The available phosphorus content of soil also improved with grass cultivation.

Unlike available nitrogen and phosphorus, the potassium content of soil lowered under grass cultivation. The calcium and magnesium status of soil improved over the initial soil status.

Economic analysis revealed very bright prospects for utilisation of VAM technology for guinea grass production. During the first year when the inoculated plants were supplemented with fertilizers the net income registered by 0, 25 and 50 per cent P doses were Rs. 17543/, Rs. 17843/ and Rs. 20353/ respectively while that with chemical fertilizers was only Rs. 12540/. At 75 per cent P level the net income obtained from VAM inoculated plants was comparable with that of the chemical fertilizer treatment. During the second year the VAM plants at 50 per cent P level recorded the maximum net income of Rs. 28254/ while with recommended fertilizer treatment it was Rs. 17745/. The benefit : cost ratio from guinea grass inoculated with VAM confirmed the superiority of VAM treatments over the POP treatment.

The general conclusions from the above discussions on the inoculation response of guinea grass to VAM may be summarised as follows.

1. In guinea grass VAM inoculation substituted fertilizer phosphorus and gave added advantage in terms of fodder yield over the POP treatment.

2. The better utilization of native phosphorus by the VAM hyphae and the comparatively lower phosphorus requirement of the forage grass may be the factors which contributed to the remarkable VAM effect even in the absence of applied phosphorus.

3. The growth promoting effect of VAM declined when applied phosphorus level was increased to 75 per cent of the recommended dose.

Plate 5. Root growth of guinea grass as influenced by inoculation of biofertilizers alone in comparison with T0 and T16

4. The response of guinea grass to VAM inoculation was positive and significant during the whole cropping period.

5. The physical and chemical properties of the soil was favourably influenced by the VAM treatments.

5.1.1.4. Comparison of the inoculation response of guinea grass to Azospirillum, Azotobacter and VAM

Since the nitrogen fixers and VAM were tested under varying levels of nitrogen and phosphorus respectively it was not possible to arrive at a clear cut conclusion on their relative effectiveness. However the results clearly indicated that 25 per cent of the recommended nitrogen could be saved through the inoculation of either of the diazotrophs. On the other hand VAM inoculation could completely substitute fertilizer phosphorus and recorded distinct superiority over the POP treatment. Under inoculation alone Azospirillum and VAM recorded significant yield increase over absolute control while the response of Azotobacter was found insignificant. The average yield increase from the inoculation treatments over that of absolute control under Azospirillum, Azotobacter and VAM were 126.18, 111.04 and 242.12 per cent respectively during the first year and 122.70, 111.24 and 214.54 respectively during the second year. Thus it was obvious that the VAM treatments were superior to the others. The data on net income also indicated that VAM inoculation was more profitable than the use of the nitrogen fixers. Hazra (1994) has made similar observations with perennial forage grasses.

5.1.1.5. Correlation and path analysis studies

Plant height, number of tillers $hill^{-1}$, LAI, AGR and uptake of nutrients were significantly and positively correlated with the dry fodder yield of guinea grass. Among the root parameters, the root weight and volume recorded significant positive correlation indicating that increase in shoot growth was associated with an increase in root growth as well. However since the root : shoot ratio was found negatively correlated with yield it may be inferred that with increased availability of inorganic nutrients in the rhizosphere proportionally more photosynthates were translocated to the shoot than to the roots, in agreement with the observations of Hurd and Spratt (1981).

Among the soil properties studied after the experiment, the bulk density was found negatively correlated with yield. Water holding capacity, porosity, hydraulic conductivity, mean weight diameter and organic carbon status showed positive correlation. A lower bulk density and enhanced value for the other parameters corresponded to a more congenial environment for plant growth and yield.

Path analysis studies indicated that the root parameters could account for 69 per cent of the variation in fodder yield recorded during the second year of cropping. Maximum direct effect was shown by root weight. The direct and indirect effects of root : shoot ratio on fodder yield was negative and so was its correlation value. This observation indicated that the treatments recording lower fodder yield had a higher root : shoot ratio and that in nutrient poor situations roots were stimulated to grow more than the shoots probably as an adaptation for survival. Independent path analysis investigations on the cause and effect relationships of soil properties after the experiment on the fodder yield revealed that porosity had the maximum direct effect. This was probably through the impact on water holding capacity which in turn recorded high indirect effect on yield.

5.1.2. Inoculation response of Congosignal

5.1.2.1. Response of congosignal to Azospirillum inoculation

The results revealed that Azospirillum inoculation alone did not elicit significant improvement in growth and yield characters of congosignal. When combined with fertilizers the inoculated plants at 25, 50 and 75 per cent N levels recorded plant height on par with those receiving full dose recommended fertilizers. However the tiller production at all nutrient levels was inferior during the first year. During the second year the Azospirillum inoculated plants at 50 and 75 per cent N levels recorded comparable tiller count.

The influence of Azospirillum inoculation on plant height and tiller production was reflected on the fodder yield response pattern. During the first year the Azospirillum treatments yielded distinctly lower than the 100 per cent NPK treatment while during the second year the inoculated plants at 75 per cent N dose yielded on par. Pooled analysis studies showed that the 50 and 75 per cent N doses were comparable with the POP treatment in terms of fodder yield.

The above discussed response pattern indicated that the effect of Azospirillum on the growth and yield of congosignal alone as well as in combination with fertilizers was marginal during the first year. This was in agreement with the reports of some of the earlier workers (Barber *et al.*, 1979., Albrecht *et al.*, 1981). However the response was of significant consequence during the second year. Significant yield increase through Azospirillum inoculation has been reported by Govindarajan(1987) in fodder sorghum. Chalk (1991) has observed that tropical forage grasses belonging to *Brachiaria* sp. could obtain significant proportion of plant nitrogen through associative nitrogen fixation. The inconsistency in response pattern during first and second year of cropping might have resulted from the slow rate of population build up in the rhizosphere. The yearly addition of organic manure, the application of lime at the beginning of the experiment, re-inoculation with the bacterial culture at every six months and the improvement in physical and chemical properties of soil with grass cultivation must have provided a more congenial environment for the growth, development and activity of the bacteria with passing of time.

Another indication from the yield data was that the response of congosignal to Azospirillum was distinct only when the inoculation was combined with fertilizer application. This showed that the presence of combined nitrogen stimulated the bacterial activity in the rhizosphere. It might be because the levels of nitrogen fixed by the bacteria was too low to meet the requirement of the grass and the positive response obtained in the presence of combined nitrogen resulted from some other factors like production of plant growth regulators, altered root growth and subsequent effects on nutrient uptake as reported by earlier workers (Jain and Patriquin, 1984., Yahalom, 1984). Stimulation in bacterial activity in the presence of combined nitrogen has been reported earlier by O' Hara *et al.* (1987). Such response pattern also indicated that an integrated nutrient management involving the use of the biofertilizer and chemical fertilizers would be a better preposition for optimum sustained production of congosignal.

Under inoculation alone the Azospirillum inoculated congosignal recorded leaf area index (LAI) on par with the absolute control. When combined with fertilizers the LAI increased significantly and was maximum at 75 percent N level. During the first year the Azospirillum treated plants at all levels of nutrients had leaf area index lower than that of the plants treated with full dose of recommended fertilizers while it was on par with that of the recommended fertilizer treatment at 50 and 75 per cent N levels during the second year.

The data on the absolute growth rate (AGR) of Azospirillum inoculated congosignal showed that fertilizer application positively influenced the dry matter production per unit time in the inoculation treatments. During the first year all inoculation treatments were inferior to the recommended fertilizer treatment while during the second year the Azospirillum treated plants at 75 per cent N dose registered comparable value.

Observations on the root parameters showed variation between treatments. The root length recorded by plants treated with combination doses of the biofertilizer and chemical fertilizers was significantly superior to that of the absolute control. Root weight and root volume increased with increasing levels of applied nitrogen. Azospirillum treated plants at 50 and 75 per cent N levels registered root weight and root volume on par with that of the recommended fertilizer treatment. Obviously there was an improvement in root growth in inoculation treatments which was in line with the reports of Lin *et al.* (1983) and Yahalom *et al.* (1984). Sumner (1989) while reviewing the inoculation response to Azospirillum observed that the bacterial association enhanced water and nutrient uptake through a kind of sponge effect and it was the primary reason for the yield increases resulting from inoculation. Such improved uptake properties along with the enhanced root growth must have helped the Azospirillum inoculated congosignal at 75 per cent N dose to perform on par with the recommended fertilizer treatment during the second year.

The quality of the forage showed an improvement with Azospirillum inoculation. The major factor which enhance protein content being the plant availability of nitrogen (Capriel and Ashcroft, 1972) such an improvement in the protein factor indicated increased availability of nitrogen through greater foraging capacity of the root system as well as the possible enrichment through biological nitrogen fixation. There was a decrease in the crude fibre content in the inoculation treatments thus improving the quality and palatability of the forage. Among the other nutrients phosphorus, potassium calcium, magnesium, zinc and manganese

Plate -5 Root growth of congosignal as influenced by Azospirillum treatments and POP treatment


CONGO

showed no significant variation between treatments but the copper content at 75 per cent N dose was superior to that of absolute control as well as the recommended fertilizer treatment. The K : (Ca + Mg) ratio did not vary between treatments and remained within the safe limits of 2.2 as suggested by Thill and George (1975).

The protein yield of congosignal was positively influenced by the inoculation of Azospirillum. During the second year the 75 per cent N dose recorded protein yield on par with the 100 per cent NPK treatment. The enhancement in protein content as well as the increased dry matter production together contributed to such increased protein yield which is of great significance in animal nutrition.

Uptake of nutrients by congosignal treated with Azospirillum inoculation alone did not show significant variation over the absolute control. When combined with fertilizers there was progressive increase in uptake values and was maximum at 75 per cent N level. When compared to recommended fertilizer treatment the inoculation treatments at all levels of nutrients were inferior during the first year while during the second year the 75 per cent N dose was on par. The improvement in uptake of nutrients ensured increase in plant availability of nutrients and was probably responsible for the positive yield response.

Cultivation of congosignal had some positive impact on physical and chemical properties of soil over the initial status. Between treatments the soil properties showed significant variation. Under inoculation alone the bulk density was less than that of absolute control and it lowered further with increasing levels of applied nutrients. Such decrease in bulk density was effected possibly through an improvement in organic carbon status of soil at higher levels of applied nitrogen which in turn was due to the increased root biomass. Similar decrease in bulk density with increase in root biomass production under grass growth was reported by Reid and Gross(1981). The water holding capacity, porosity and water holding capacity of soil under inoculation treatments improved over absolute control and were comparable to the treatment receiving 100 per cent NPK. The marginal Increase observed in mean weight diameter must have contributed to the increased hydraulic conductivity in agreement with the reports of Mahendran and Mathen (1994).

The data on available nutrient status of soil after the experiment revealed that congosignal cultivation had a favourable influence on the soil properties over the initial status. However the available nitrogen content showed no significant variation between treatments. The phosphorus content was the highest at the 0 N level indicating that in the absence of inorganic nitrogen the applied phosphorus tends to accumulate in soil. The contents of potassium, calcium and magnesium were not influenced by the treatments.

Economic analysis revealed that cultivation of congosignal in coconut gardens was a highly paying preposition for the dairy farmers. During the first year the income obtained from Azospirillum inoculated plants receiving 75 per cent of the recommended nitrogen was on par with that from the recommended fertilizer treatment while during the second year the 50 and 75 per cent N doses gave comparable profit. The influence of Azospirillum inoculation on benefit : cost ratio followed more or less a similar trend.

The general conclusions from the discussions on the Azospirillum inoculation response of congosignal may be summarised as follows.

1. Azospirillum inoculation had only limited effects on the growth and yield of congosignal during the first year while the response was found significant during the second year. Pooled analysis indicated that when inoculated with Azospirillum, 50 per cent of the recommended nitrogen was adequate for good yields.

2. An integrated nutrient management programme involving combination doses of the biofertilizer with chemical fertilizers including lower levels of nitrogen was profitable for congosignal.

5.2.2. Response of congosignal to Azotobacter inoculation

Azotobacter inoculated congosignal under inoculation alone, recorded no significant improvement in plant height over absolute control while the combination doses of the biofertilizer with chemical fertilizers responded significantly. All Azotobacter treatments except inoculation alone recorded plant height on par with the recommended fertilizer treatment during the second year. The variation between treatments was more distinct in terms of tiller production $hill^{-1}$. While during the first year all inoculation treatments were inferior to the recommended fertilizer treatment, the 50 and 75 per cent N doses responded more or less similar to the POP treatment during the second year. Enhancement in tiller production through Azotobacter inoculation was reported earlier by Jones and Collins (1978) and by Dhillon *et al.*(1980) in wheat.

Being a fodder crop in which the yield is equivalent to the biomass production, the yield response of congosignal is naturally the resultant of the influence of the bacteria on plant height and tiller production. During the first year all inoculation treatments were inferior to the recommended fertilizer treatment. During the second year the 50 per cent N dose yielded on par and 75 per cent N dose showed significant superiority over the full dose recommended fertilizer treatment. Pandey and Kumar (1989) related the improvement in yield through Azotobacter inoculation not only to nitrogen fixation but also to the ability of bacteria to produce anti-fungal and anti-bacterial compounds and growth regulators.

As in the case of the inoculation response to Azospirillum here again the response was more distinct during the second year. Possible reasons for such response pattern have been discussed under 5.1.2. 1.

In congosignal there was a general decline in yield during the second year of cropping. The extent of yield variation in Azotobacter inoculation treatments ranged from + 4.62 to - 4.27 per cent while in chemical fertilizer treatment the decline was as high as -27.63 per cent. It may be inferred that the dry spells during the second year adversely affected the growth and yield of congosignal and the effect was greater when the plants were treated with full dose chemical fertilizers. The observation that under absolute control the decline in yield was only -9.83 per cent, emphasised that the chemical fertilizers had an aggravating effect on the yield decline of the grass. Azotobacter inoculated plants possibly avoided this declining trend at all levels of nutrients. Thus the sustained yield rather than the increased biomass production helped the Azotobacter inoculated plants to outyield the chemical fertilizer treatment during the second year.

The leaf area index (LAI) of the inoculated plants at 50 and 75 per cent N levels recorded LAI on par with the chemical fertilizer treatment during the second year. Such increased leaf surface exposed to sunlight might have contributed to the increased fodder yield registered by inoculation treatments.

Inoculation alone elicited no significant response in the absolute growth rate of congosignal. When combined with fertilizers the response pattern was identical to the effect on dry fodder yield. During the second year the AGR of Azotobacter inoculated plants receiving 50 per cent of the recommended nitrogen was on par with that of plants treated with full dose recommended fertilizers while the 75 percent N dose was found distinctly superior. This increase in dry matter production per unit time was directly reflected in the dry fodder yield.

The data on chlorophyll content showed that the inoculation treatments at 50 and 75 per cent N doses had total chlorophyll and its components on par with that of the recommended fertilizer treatment. Such comparable chlorophyll content indicated increased availability of nitrogen in the inoculated plants which might be attributed to the better foraging capacity of the root system as well as the possible enrichment through biological nitrogen fixation.

As already mentioned the observations on root parameters of Azotobacter inoculated congosignal showed an improvement over the controls. At 75 percent N dose the root weight of inoculated plants was significantly higher than that of the recommended fertilizer treatment. Though not statistically significant, the volume and length of roots were also higher in the inoculation treatments. The root : shoot ratio of inoculated plants went down with increasing levels of applied nutrients but at all levels it was significantly higher than that of the recommended fertilizer treatment. Thus though not as distinct as in guinea grass, in congosignal also Azotobacter inoculation had a favourable influence on root growth in agreement with the reports of Dewan and Subba Rao (1979).

The quality aspects showed marginal improvement over the absolute control when congosignal was inoculated with Azotobacter. In combination treatments the content of crude protein as well as the other nutrients showed an increasing trend while there was a decrease in the content of crude fibre thus indicating an improvement in the quality and acceptability of the forage. The K: (Ca + Mg) ratio remained within the safe limit of 2.2.

The data on nutrient uptake was consistent with the yield trend emphasising the direct effect of nutrient availability on fodder yield.

Plate - 6 Root growth of congosignal as influenced by Azotobacter treatments and POP treatment


CONGO
T2
T8
T10
T11

The general improvement in physical and chemical properties of soil under the grass cultivation as observed by Reid and Gross (1980) was evident in the Azotobacter inoculation treatments. The bulk density progressively decreased and the water holding capacity, porosity and hydraulic conductivity improved with increasing levels of nitrogen application. The effect of Azotobacter treatments on the available nutrient status of soil after the experiment was similar to its effect under guinea grass.

Economic analysis revealed that the net income of the Azotobacter inoculation treatments was maximum at 75 per cent N dose. During the first year it was less than that obtained from uninoculated plants treated with 100 per cent NPK. But during the second year the net income from Azotobacter inoculated plants was on par with the recommended fertilizer treatment at 25 and 50 per cent N doses and the 75 per cent nitrogen level was significantly superior. The benefit : cost ratio followed more or less a similar trend.

The general conclusions from the results and discussions on the response of congosignal to Azotobacter inoculation may be summarised as follows.

1. The effect of Azotobacter inoculation on growth and yield of congosignal was limited during the first year but the response was significant during the second year.

2. The yield of congosignal showed a general decline during the second year. When treated with Azotobacter the decline in yield was found much less than that recorded by the chemically fertilized plots which revealed the significance of the biofertilizer for sustained forage production.

3. The influence of Azotobacter inoculation was of significance only in combination doses of the biofertilizer with chemical fertilizers which indicated the importance of an integrated nutrient management system.

4. Pooled analysis data showed that when Congosignal was treated with Azotobacter 50 per cent of the recommended nitrogen dose was adequate for obtaining good yields.

5.1.2.3. Response of congosignal to Vesicular Arbuscular Mycorrhiza

The beneficial effect of Vesicular Arbuscular Mycorrhiza (VAM) inoculation on growth and yield of congosignal was quite evident during the entire cropping period in the present study. The plant height of mycorrhizal plants under inoculation alone was higher than that of the absolute control and the increase was of significance during the second year. When treated with combination doses of VAM and chemical fertilizers, the plants grew significantly taller and irrespective of the level of applied phosphorus they were on par with the uninoculated plants receiving full dose recommended NPK. The positive effect of VAM inoculation on tiller production was remarkable. The VAM inoculated plants produced significantly higher number of tillers than the absolute control. During the first year the 0, 25 and 50 per cent P levels recorded tiller number on par with the recommended fertilizer treatment and during the second year they were significantly superior. When the fertilizer phosphorus level was increased to 75 per cent, the tiller number recorded was inferior to the lower P doses and also the chemical fertilizer treatment during the first year while it was on par with the latter during the second year.

The yield response pattern of congosignal was identical to its response in terms of tiller production. The VAM inoculated plants responded well to N and K fertilizers and recorded maximum yield at 0 P level. With incremental doses of fertilizer phosphorus there was a gradual decrease in yield but when compared to the recommended fertilizer treatment the 0, 25 and 50 per cent P doses were on par during the first year and significantly superior during the second year. The decrease in yield with applied phosphorus fertilizer was sharper when the dose increased to 75 per cent. The treatment registered fodder yield significantly inferior to that at the lower P levels and also the recommended fertilizer level during the first year. During the second year it remained inferior to the lower P levels but was comparable with the chemical fertilizer treatment. The pooled analysis results showed that irrespective of the level of applied phosphorus the combination doses of VAM with chemical fertilizers were as effective as the recommended fertilizer treatment.

The VAM effect of enhancing the biomass production is well documented (Hayman, 1980., Howeler *et al.*, 1987) and has been reaffirmed in guinea grass and congosignal in the present study. The phosphorus requirement of congosignal was found completely substituted by the fungal inoculation. The possible reasons for such remarkable effect as discussed under inoculation response of guinea grass may be considered here also. The VAM inoculated congosignal responded well to N and K fertilizers but the presence of applied phosphorus was found to decrease the fodder yield even at lower levels. The decrease was sharper when the applied P level was 75 per cent of the recommendation. Marschner and Dell (1994) observed that with increasing levels of soluble phosphate the growth enhancement effect of VAM declined and was either abolished or led to growth depression. Since the yield of mycorrhizal plants at 75 per cent P level was comparable with the recommended fertilizer treatment during the second year it might be inferred that there was only a decline in VAM effect and that the effect was not totally abolished.

In congosignal fodder yield declined during the second year. The extent of decline in VAM inoculation treatments ranged between -14.40 to -19.13 per cent while when treated with chemical fertilizers alone the decline was as high as -27.63 per cent. This indicated a more stabilised production trend in VAM inoculated plants and these treatments thus excelled the chemical fertilizer treatment during the second year.

The effect of VAM treatments on LAI and AGR of the grass was consistent with their effect on fodder yield. The LAI is a critical factor determining the photosynthetic efficiency of plants which in turn determines the dry matter production and consequently the fodder yield.

The chlorophyll content of congosignal under inoculation alone was significantly higher than that of the absolute control. Tinker (1975) reported marked increase in chlorophyll content with VAM inoculation. Application of N and K fertilizers enhanced the chlorophyll content of inoculated plants and irrespective of the level of fertilizer phosphorus they were on par with the those treated with recommended fertilizers.

Under VAM inoculation treatments the root length, root weight and root volume of congosignal was higher than that of the control plants. When combined with fertilizers the root weight and root volume of inoculated plants increased progressively and at 0, 25 and 50 per cent P doses, these parameters were superior to that of the recommended fertilizer treatment. Such stimulation in root growth concurred with the reports of Bagyaraj and Manjunath (1980). The better foraging capacity of the prolific root system along with the acquisition of nutrients and water by the fungal hyphae (Barea, 1991) must have contributed to the increased biomass production of the mycorrhizal plants. Such root stimulation explained the increased availability of nutrients for which the hyphal capacity for translocation was not established (Marschner and Dell, 1994). However since the root : shoot ratio of the mycorrhizal plants showed no superiority over the chemical fertilizer treatment, it might be inferred that there was no excess translocation of photosynthates for root proliferation.

The mycorrhizal colonisation in roots of inoculated plants was maximum in the absence of applied phosphorus. With incremental doses of phosphorus there

Plate - 7 Root growth of congosignal as influenced by VAM treatments and POP treatment

was progressive decrease in per cent of colonisation. Earlier reports have shown that soluble soil phosphorus in soil decreased both the extent of extramatricial mycelium {Abbott *et al.*, 1984) and the number of arbuscles formed (Smith and Gianinazzi-Pearson, 1988). Mycorrhizal association of the uninoculated congosignal was in agreement with the reports of Girija and Nair (1985).

Studies on the quality parameters of the forage indicated that the crude protein and the fibre content of the inoculated plants were on par with that of the uninoculated plants. The content of other nutrients and ash also showed a similar response. As already mentioned the thorough permeation of the root volume by the VAM fungi along with the better foraging capacity of the root system explains the relative increase in the tissue concentration of nutrients. Under all treatments the K : (Ca + Mg) ratio remained within the safe limits of 2.2.

The capacity of VAM plants for increased nutrient uptake as reported by earlier workers (Barea, 1991) was reaffirmed by the results of the present study.

The data on the effect of VAM inoculated congosignal on properties of soil after the experimental period revealed pronounced improvement over the initial status. Under inoculation treatments the bulk density of soil was lower while the water holding capacity and porosity improved over the control treatments. Suresh Lal and Mathur (1989) reported that the lowering of bulk density could be directly attributed to the increase in organic matter status of soil and in the present study the data on organic carbon content of soil recorded higher values under VAM treatments. Such improvement in organic carbon status might have resulted from the increased root biomass and the greater quantity of microbial biomass in the rhizosphere. The mean weight diameter of soil increased which indicated an improved soil structure favourable for plant growth. The role of VAM in aggregate distribution and stability has been reported by Barea (1991) and Tisdall(1991). The increase in the hydraulic conductivity of soil under VAM plants was in agreement with the findings of Mahendran and Mathen (1994) who observed that the MWD was positively correlated with hydraulic conductivity mainly due to the formation of stable pores which caused steady conductivity of water through soil. However the increase in hydraulic conductivity did not show a corresponding decrease in water holding capacity of soil probably because of the better organic matter status which improved the water retention capacity of the soil.

The status of all available nutrients except potassium improved after the two year period of grass cultivation. Between treatments the variation was of significance only in the case of phosphorus where the content was higher in treatments receiving combination doses of VAM with chemical fertilizers.

Economic analysis revealed that VAM technology for congosignal was highly profitable both in terms of net profit and benefit : cost ratio. The data on economics under inoculation alone favoured the technology. During the first year the net income registered by the inoculation treatments at 0, 25 and 50 per cent P doses were Rs. 31230/-, Rs. 29315/- and Rs. 28490/- respectively while that of the recommended fertilizer treatment was Rs. 28093/.- During the second year the VAM treatments at P levels upto 50 per cent gave net income and benefit : cost ratio higher than that from recommended fertilizer treatment while the 75 per cent phosphorus level fared on par. Such improvement in economic returns emphasize the need for more research for overcoming the limitations associated with the practical utilisation of VAM technology in the field by the farmers.

The general conclusions from the results and discussions on inoculation response of congosignal to VAM may be summarised as follows.

1. VAM inoculation was found to be a recommendable technology for congosignal cultivation both in terms of fodder production and economics.

2. In congosignal fertilizer phosphorus could be fully substituted by VAM inoculation. The growth promoting influence of VAM declined in the presence of applied phosphorus but the effect was not abolished.

3. The medium phosphorus status of the experimental site, better utilization of native phosphate by the symbiotic association and the low phosphorus requirement of the grass may be taken as factors which contributed to the remarkable VAM effect in the absence of applied phosphorus.

4. The physical and chemical properties of soil improved under VAM treatments.

Plate 9. Root growth of congosignal as influenced by inoculation of biofertilizers alone in comparison with T0 and T16

5.1.2.4. Comparison of the inoculation response of congosignal to Azospirillum, Azotobacter and VAM

As in the case of guinea grass here also the nitrogen fixers and VAM were tested for their ability to substitute N and P fertilizers respectively. The results revealed that only VAM could elicit significant yield increase under inoculation alone. The average yield increase over the absolute control from Azospirillum, Azotobacter and VAM treatments were to the tune of 102.04, 80.35 and 152.28 per cent respectively during the first year and 80.65, 98.81 and 131.58 per cent respectively during the second year. Thus among the two nitrogen fixing organisms, the performance of Azospirillum treatments seemed better during the first year whereas Azotobacter inoculated plants gave a more sustained production trend indicating its special significance in perennial forage production. In terms of fodder yield VAM inoculated plants performed better than both Azospirillum and Azotobacter. A critical analysis of the economics indicated that the farmers could expect a higher profit from congosignal cultivation through VAM technology.

5.1.2.5. Correlation and path analysis studies

Plant height, number of tillers hill^{-1}, LAI, AGR and nutrient uptake were found significantly and positively correlated with dry fodder yield. Among the root parameters, the root weight, root volume and root length recorded positive correlation indicating that the treatments which increased the fodder yield increased root growth also. However the root : shoot ratio had a negative correlation which showed that in treatments recording higher yield proportionally more of the photosynthates were utilised for shoot growth.

Correlation studies of the properties of soil after the experiment showed that bulk density of soil was negatively correlated with fodder yield. On the other hand the water holding capacity, porosity, hydraulic conductivity, mean weight diameter and organic carbon status were positively correlated with yield.

Path analysis investigations indicated that the root parameters could account for 66 per cent of the yield variation during the second year. Maximum direct effect was registered by root weight while root volume influenced fodder yield indirectly through root weight. These two parameters showed high positive correlation values with yield. The root : shoot ratio recorded high negative indirect effect. Similar studies conducted to find out the cause and effect relationships of soil properties on fodder yield of 94 - 95 period revealed that soil organic carbon had the maximum positive direct effect on yield. The organic carbon content had high indirect effect on yield through its influence on soil bulk density which in turn recorded high negative direct effect on yield.

5.1.3. Comparison of the production potential of guinea grass and congosignal as influenced by the microbial inoculants

A comparison between the two grasses is attempted hereunder by considering their response pattern in terms of fodder yield, net income and the influence on soil properties.

Azospirillum influenced the growth and yield of guinea grass positively and significantly during the entire cropping season, under inoculation alone and also in combination with fertilizers. From the results it was inferred that through the use of the diazotroph 25 per cent of the recommended fertilizer nitrogen could be saved. In congosignal the bacteria showed only limited effects during the first year but the influence was of significant consequence during the second year. The pooled analysis results indicated that when the forage grass was treated with Azospirillum 50 per cent of the recommended fertilizer nitrogen was adequate for good yields. Under inoculation alone the bacteria failed to elicit significant response in congosignal.

The effect of Azotobacter inoculation was marginal in both the crops during the first year. However during the second year significant positive response was obtained from the integrated use of the biofertilizer with chemical fertilizers including inorganic nitrogen at lower doses. In guinea grass Azotobacter inoculation treatments at 75 per cent N dose yielded on par with the recommended fertilizer treatment and in congosignal the 50 per cent N level was on par and the 75 per cent N level was significantly superior to the chemical fertilizer treatment. The extent of fertilizer nitrogen that could be saved was the same as that observed with Azospirillum.

VAM effect in enhancing the biomass production was evident in both the grasses under inoculation alone as well as in combination with fertilizers. The inoculated plants responded well to N and K fertilizers. When guinea grass was treated with combination doses of VAM with chemical fertilizers, the 0, 25 and 50 per cent phosphorus doses performed significantly superior to the POP treatment. It was obvious that the fertilizer phosphorus was completely substituted through VAM inoculation and the association gave added advantage in terms of fodder yield. In the case of congosignal also the production trend indicated the possibility for substituting the phosphorus requirement through VAM inoculation. but the yield enhancement over the POP treatment did not reach the level of statistical significance. Thus the growth promoting effect of VAM treatments seemed to be of was greater magnitude in guinea grass. In both the grasses the performance of the VAM treated plants at 75 per cent P dose was found inferior to that of the lower P levels.

Congosignal yielded higher than guinea grass during the whole cropping period. Similar results of congosignal recording higher fodder yield than guinea grass was reported by Lakshmi *et al.* (1989). Congosignal recorded a decline in yield during the second year while there was an enhancement in fodder yield in guinea grass. Such a yield trend indicated the significance of guinea as a perennial forage intercrop for sustained production.

The net income obtained from congosignal was higher than that from guinea grass during the whole cropping period.

Cultivation of either of the grasses improved the physical and chemical properties of the soil over the initial status. Pooled analysis of the data after the experiment(Appendix-2) revealed that there was no striking variation in their influence.

5.2. Vermitechnology for forage production

Guinea grass responded well to application of manures and fertilizers alone as well as in combination. The fodder yield recorded by all treatments was higher than that of absolute control and the enhancement was of significance except when plants were treated with FYM alone during the first year. Such positive response was in agreement with the observations of Chatterjee *et al.* (1980). Fodder yield increased progressively with each incremental fertilizer dose in both vermicompost and FYM treated plants. During the first year the 100 per cent NPK treatment recorded maximum yield and was significantly superior to vermicompost treatments but FYM treated plants supplemented with 75 per cent of the recommended NPK fertilizer gave comparable fodder yield. During the second year the plants treated with both the organic sources showed an improved yield trend . The vermicompost treated plants supplemented with 75 per cent of the recommended fertilizers recorded fodder yield on par with the chemical fertilizer treatment while the FYM treatment at equivalent nutrient level was significantly superior. Pooled analysis results indicated that 25 per cent of the recommended NPK could be saved through the use of either of the organic manures.

Nambiar and Ghosh (1984) and Manickam (1993) observed that often there was a slow but steady decline in crop production with continuous use of chemical fertilizers alone. The yield trend obtained in the present study reaffirms their observations. When the soil was amended with organic manures, irrespective of the source used the yield of guinea grass increased during the second year whereas plants supplied with chemical fertilizers alone recorded a decline in yield. This was in conformity with the reports of Nambiar and Abrol (1989) who observed that the declining trend in productivity caused by continuous use of NPK fertilizers could be checked by the use of organic manures. The beneficial effect of organic manures in terms of sustained production could be related to the enhanced biological activities in the rhizosphere, improved soil structure and increased nutrient availability (Nambiar and Ghosh, 1984., Muthuswamy *et al.*, 1990).

The usefulness of FYM in increasing crop yield is well documented. Ghosh (1987) observed that FYM alone as well as in combination with chemical fertilizers resulted in the highest degree of yield stability. Recently the use of vermicompost in place of FYM and the potential for reducing chemical fertilizer using vermicompost as organic fertilizer (Kale and Bano, 1986) has become a subject of active research. The possibility of replacing chemical fertilizers by using vermicompost as an organic manure has been reported by Senapati *et al.* (1985).

The significant increase in fodder yield through application of manures and fertilizers was consistent with the effect on in plant height and tiller production. The LAI, AGR and chlorophyll content of guinea grass showed corresponding improvement in treated plants. Such beneficial effect of organic amendments on growth and yield of rice was observed by Ravi (1969). Significant increase in plant height and number of leaves per plant has been reported by Sharma (1986) through combined application of organic manures and NPK over controls using no organic manures. More number of leaves and better tillering induced by the combined application of organic and inorganic nutrient sources contributed to the increased LAI. Being an important parameter of plant 's photosynthetic efficiency LAI must have directly increased the AGR values as well. The increased content of chlorophyll indicated increased plant availability of nutrients especially nitrogen and the data on the nutrient uptake in the present study confirms this.

Another point of interest that could be elucidated from the yield data was that when applied alone as well as with a booster dose of 25 per cent NPK, the growth stimulating effect of vermicompost @ 5 t ha^{-1} was on par with FYM @ 10 t ha^{-1}. But at higher fertilizer levels the FYM treatments were superior. Such a contradictory observation might be because the nutrients in the vermicompost were in a more readily available form as observed by Albanell *et al.* (1988). Manickam (1993) has reported instances where FYM alone did not reveal its superiority when used alone. Thus with FYM, its usefulness in terms of crop yield was shown more pronounced when combined with fertilizers whereas vermicompost stimulated crop growth alone as well as in combination with fertilizers. However in both cases the fodder yield increased progressively with each incremental dose of fertilizers indicating that a judicious combination of manures with fertilizers was more desirable for enhancing crop production. From the results it could also be inferred that a higher quantity of vermicompost would be required to replace FYM at equivalent levels of applied nutrients in soils of low organic carbon status as in the present study. Since in terms of nutrient content 5 tonnes of vermicompost would be equal to 10 tonnes of FYM because of the higher NPK content(p.44.3.2.2.) the possible reasons could be carbon suppply, effect on physical properties of soil etc. This indication is supported by the reports of Anina (1995) who obtained comparable yields in chilli when treated with similar quantities of vermicompost and FYM.

Application of manures and fertilizers alone as well as in combination with fertilizers improved the quality of the forage over that of the absolute control. Crude protein content of all treatments except FYM applied alone was on par with the chemical fertilizer treatment. The crude fibre content on the other hand decreased with increasing levels of nutrient application. Among the other nutrients studied, significant improvement with organic amendment was observed in the case of potassium. The ash content of the plants treated with combination of manures and fertilizers showed an increase over absolute control and was on par with the chemical fertilizer treatment. The K : (Ca + Mg) ratio remained within the safe limits of 2.2 under all treatments

Application of manures and fertilizers was helpful in increasing the uptake of nutrients. As a rule the increased plant availability of nutrients increased crop growth. With both vermicompost and FYM, the uptake values were maximum at the highest level of applied nutrients and , the yield also showed a similar trend. Increase in nutrient recovery from soil through organic matter addition have been reported by several workers (Muthuvel *et al.*, 1977., Azam, 1990). Manickam (1993) observed that increased organic matter in the soil increased nutrient retention capacity of the soil and minimised nutrient loss. Increased nutrient uptake by vermicompost application have been reported by Kale et al. (1992), Syres and Springett (1984) and Anina (1995). Shuxin *et al.*(1991) observed that application of organic manures improve the soil environment helping in better root proliferation and increased nutrient availability.

The physical properties of soil after the experiment revealed an improvement over the initial status and it was more evident in treatments receiving organic amendments. The bulk density of soil was the highest under absolute control. Combined use of manures and fertilizers decreased the bulk density significantly and between the two sources the variation was only marginal. The influence of organic matter addition on lowering the bulk density of soil is well documented and Suresh Lal and Mathur (1989) attributed this to an improvement in soil aggregation. The porosity and water holding capacity showed an increasing trend with the addition of both the organic manures alone as well as in combination with the fertilizers. This was in agreement with the findings of Bhatia and Shukla (1982) and Aravind (1987). Allison (1973) observed that organic matter being colloidal in nature increased the capacity of soil for water retention. Increased water storage in organically amended soil have been reported by Nambiar and Ghosh (1984). Increase in mean weight diameter of soil was another change observed in the organically amended soil indicating an enhancement in the water stable aggregates. Nambiar and Ghosh (1984) have observed marked increase in water stable aggregates and mean weight diameter of soil with application of organic manures. The increase in hydraulic conductivity of soil under absolute control was in line with the reports of Brady (1984) who observed that in soils low in organic matter, in spite of the low total porosity the movement of air and water was surprisingly rapid because of the dominance of macropores.

The two year extended grass cultivation improved the available nutrient status of soil. Between treatments the nitrogen status of soil grown under guinea grass supplemented with manures and fertilizers was significantly higher than that of absolute control. The integrated use of organic and inorganic nutrient sources showed an improved nitrogen status over the treatments receiving chemical fertilizers alone. A similar improvement was observed in available phosphorus and calcium also. In the case of potassium and magnesium the variation was not significant. The organic carbon status of soil in treatments receiving either vermicompost or FYM was higher than that of absolute control and the enhancement was significant when combined with fertilizers. These treatments were superior to the chemical fertilizer treatment. Increase in available nutrient status of soil with the use of organic manures has been reported by Muthuvel (1977). Nutrient balance studies conducted by Nambiar and Ghosh (1984) indicated considerable build up of NPK with FYM application in combination with fertilizers. Thus the physical and chemical properties of soil was found poorer when guinea grass was grown without organic manures.

Economic analysis of the treatments revealed that during the first year the net income received from guinea grass treated with full dose chemical fertilizers was higher than that of all other treatments. During the second year the highest net income was recorded with FYM at 75 per cent fertilizer level which was on par with the chemical fertilizer treatment and both treatments were significantly superior to vermicompost treatments. The benefit : cost ratio recorded was maximum with chemical fertilizer treatment. Both vermicompost and FYM treatments recorded maximum benefit : cost ratio at 75 per cent NPK level but were inferior to the chemical fertilizer treatment.

A careful study of the production trend and economics revealed that application of full dose of chemical fertilizers gave maximum income to the farmers on a short term basis but it was at the cost of soil health. For sustained production and profit the integrated use of manures and fertilizers was recommendable. The economics pointed out that purchasing the organic manures at the present market rate make organic farming techniques uneconomic and emphasized the need for reducing the reliance on purchased inputs. Farmers should be trained in vermicomposting techniques right in their own field which would make the process less costly and thus more attractive and practical. As observed by Ismail (1993) the excellence of vermitechnology was that it could be used even at homes in a simple domestic recycling unit.

The general conclusions of the results and discussions on the use of vermicompost for forage production can be summarised as follows.

1. Integrated use of manures and fertilizers was the most effective preposition for the long term productivity of guinea grass.

2. Through combination doses of vermicompost with NPK fertilizers 25 per cent of the recommended NPK fertilizers could be saved.

3. Application of organic manure was important for improving the physical and chemical properties of soil and maintaining the productivity. Without manures and fertilizers as well as with continuous use of chemical fertilizers alone there was a decline in crop productivity.

4. Use of purchased organic manures make biofarming techniques less remunerative. Farmers should be trained in organic recycling techniques right in their own field.

5.3. Effect of fodder Intercropping on coconut yield

A comparison of the nut production tree^{-1} of November, January, March and May harvests during pre-experimental, experimental and post-experimental period was done to assess the effect of fodder intercropping on coconut yield. The data revealed that the favourable effect of grass cultivation on soil health(as evidenced from the data on soil properties) was reflected in plant health also. When compared to the pre-experimental period there was a gradual improvement in nut production during the experimental period and post experimental period and the average yield increase during the post experimental period was worked out to be 16.75 per cent. This observation concurred with the reports of Pillai (1986) who observed that coconut yield increased to the tune of 20.54 per cent due to fodder intercropping which he attributed to be a complimentary benefit from the increased attention paid to the intercrop. This finding along with the remarkably high net income registered by the intercropped grasses, bring us to the conclusion that both guinea and congosignal grasses can be profitably incorporated into the coconut based farming systems prevalent in Kerala.

SUMMARY

SUMMARY

This investigation entitled ***Agronomic evaluation of biofarming techniques for forage production in coconut gardens*** was taken up in the Instructional farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala state, for a period of two years from September 1993 to August 1995. Two field experiments were included in the study.

In experiment no. 1 the inoculation response of guinea and congosignal grasses to the biofertilizer cultures Azospirillum, Azotobacter and VAM was investigated. There were 17 treatments, viz., Azospirillum and Azotobacter alone and in combination with 0, 25, 50 and 75 per cent of the recommended fertilizer N, VAM alone and in combination with 0, 25, 50 and 75 per cent of the recommended fertilizer phosphorus and two control treatments, namely absolute control and the Package of Practices Recommendation fertilizer dose. The experiment was laid out in Randomised Block Design with two replications. The response of guinea and congosignal to the microbial inoculants was studied independently.

The potential of using vermicompost for forage production was examined under experiment no. 2. There were 10 treatments viz., vermicompost and FYM alone and in combination with 25, 50 and 75 per cent of the recommended NPK fertilizers, and two control treatments namely absolute control

and the 100 per cent recommended chemical fertilizers without organic manures. The micro plot study was laid out in Randomised Block Design with three replications. Guinea grass was the test crop used for the study.

The salient findings of the two field experiments are summarised below:

1. The biofertilizer treatments improved the plant height and tiller production in guinea grass. In Azotobacter treatments the enhancement was evident only in combination doses with chemical fertilizers.

2. During the first year the Azospirillum inoculated plants with 75 per cent fertilizer nitrogen yielded on par with the 100 per cent NPK treatment and the lower N levels were less effective. During the second year both 50 and 75 per cent N treatments were on par with the 100 per cent NPK treatment. Azotobacter inoculation failed to elicit significant yield response in guinea during the first year. However during the second year the inoculated plants at 50 and 75 per cent N yielded on par with the 100 per cent NPK treatment. Combination doses of VAM and chemical fertilizers showed significant improvement over the POP treatment during the whole cropping period at 0, 25 and 50 per cent P doses. The VAM inoculated plants at 75 per cent P level was comparable with the POP treatment.

3. Pooled analysis studies revealed that 25 per cent of the recommended nitrogen could be saved through Azospirillum and Azotobacter inoculation. The results indicated that fertilizer phosphorus could be fully substituted with VAM application. VAM inoculated plants in combination with 0, 25 and 50 per cent of the applied phosphorus and full dose N and K fertilizers yielded significantly superior to the uninoculated plants treated with 100 per cent NPK.

4. The effect of the microbial inoculants on LAI and AGR of guinea grass followed a trend more or less similar to their effect on fodder yield.

5. The total chlorophyll content and its components enhanced under inoculation treatments.

6. Microbial inoculants stimulated root growth in guinea grass. In Azospirillum and Azotobacter inoculated plants the root proliferation was more distinct in the absence of combined nitrogen.

7. VAM association in guinea grass was evident in all treatments. Colonisation increased sharply with VAM inoculation and was maximum with 25 per cent applied phosphorus.

8. Microbial inoculation improved the quality of the fodder grass.

9. Influence of microbial inoculants on uptake of nutrients in guinea grass followed a trend similar to that on dry fodder yield.

10. The physico chemical properties of the soil improved under grass cultivation. At varying levels of applied nutrients the inoculation treatments recorded soil properties on par or superior to that of uninoculated plants treated with 100 per cent NPK indicating their positive impact.

11. During the first year the net income obtained from Azospirillum treated guinea grass at 75 per cent N level was on par with that from the recommended fertilizer treatment and the other Azospirillum treatments were inferior . All Azotobacter treatments were significantly inferior to the POP treatment. During the second year the Azospirillum inoculated plants at 50 per cent N level and Azotobacter plants at 50 and 75 per cent N levels were on par and Azospirillum at 75 per cent N level was significantly superior. VAM treatments at 0, 25 and 50 per cent phosphorus doses were significantly superior and the 75 per cent dose was on par with the chemical fertilizer treatment during the whole cropping period.

12. The effect of microbial inoculants on benefit : cost ratio of guinea grass followed more or less a similar trend as the effect on net income.

13. Dry fodder yield was significantly and positively correlated with plant height, tiller count, LAI, AGR, root weight, root volume and nutrient uptake. Among the

soil properties water holding capacity, porosity, hydraulic conductivity and organic carbon status of soil also recorded significant positive correlation with yield while bulk density showed negative correlation.

14. Path analysis studies on the cause and effect relation of root parameters with dry fodder yield revealed that root weight had the maximum direct effect on yield. Root volume influenced yield indirectly through root weight. Among the soil properties porosity was found to show the highest direct effect on dry fodder yield.

15. In congosignal Azospirillum and Azotobacter inoculation treatments had only limited effects on plant height and tiller production during the first year. The effect of inoculation on growth characteristics was of significant consequence during the second year of cropping. The response to VAM inoculation was obvious during the whole cropping period.

16. During the first year Azospirillum and Azotobacter treatments yielded significantly inferior to the POP treatment while VAM inoculated plants at 0,25 and 50 per cent phosphorus doses yielded on par. During the second year Azospirillum inoculated plants at 50 and 75 per cent N levels, Azotobacter treated plants at 50 per cent N level and VAM plants at 75 per cent P level were on par with the 100 per cent NPK treatment. Significant improvement in fodder production over the recommended fertilizer treatment was recorded by

Azotobacter at 75 per cent N and VAM treatments at 0, 25 and 50 per cent applied phosphorus.

17. As per the pooled analysis results, 50 per cent of the recommended nitrogen could be saved through Azospirillum and Azotobacter inoculation. The results also revealed that fertilizer phosphorus could be completely substituted through VAM inoculation.

18. The effect of the microbial fertilizers on LAI and AGR of congosignal was more or less similar to their effect on fodder yield.

19. The biofertilizers enhanced the content of total chlorophyll and its components.

20. Mycorrhizal association in congosignal was evident in all treatments and it was significantly higher in VAM inoulated treatments. Maximum colonisation rate was recorded by treatments under VAM inoculation alone.

21. Root growth was found stimulated under inoculation treatments and the improvement was more distinct in Azotobacter treatments.

22. Quality characteristics in terms of crude protein, crude fibre and mineral nutrient content was favourably influenced by the biofertilizers.

23. The influence of the biofertilizers on nutrient uptake followed a trend similar to their effect on dry fodder yield.

24. The physico-chemical properties of soil under inoculation treatments improved over the initial soil status.

25. During the first year the net income from Azospirillum inoculated plants at 75 per cent N and VAM treated plants at 0, 25 and 50 per cent applied phosphorus were on par with the recommended fertilizer treatment and the other treatments were inferior. During the second year the Azospirillum treatments at 50 and 75 per cent N levels, Azotobacter inoculated plants at 25 and 50 percent N doses and VAM plants at 75 per cent phosphorus were comparable with the POP treatment. Azotobacter at 75 per cent nitrogen and VAM plants at 0, 25 and 50 per cent phosphorus were distinctly superior. Pooled analysis studies indicated that the Azospirillum and Azotobacter treatments receiving 50 and 75 per cent nitrogen as well as all combination doses of VAM were comparable with the POP treatment in terms of net profit.

26. Azospirillum inoculated plants at 75 per cent N and VAM inoculated plants at 0, 25 and 50 per cent phosphorus recorded benefit : cost ratio on par with the 100 per cent NPK treatment during the first year. During the second year Azospirillum at 25, 50 and 75 per cent N, Azotobacter treated plants at 25 per cent N, and VAM inoculated plants at 75 per cent phosphorus registered benefit : cost ratio on par with the recommended fertilizer treatment.

Azotobacter at 50 and 75 per cent N, VAM at 0, 25 and 50 per cent P doses were significantly superior.

27. Dry fodder yield of congosignal was significantly and positively correlated with plant height, tiller count, LAI, AGR, and nutrient uptake. Root weight and root volume recorded positive correlation with yield. Among the soil properties bulk density recorded negative correlation with dry fodder yield of second year and the other parameters were found to have positive correlation.

28. Path analysis studies with root parameters showed that root weight had the maximum direct effect on yield. Among the soil properties, maximum direct effect on fodder yield was exerted by soil organic carbon.

29. Guinea grass responded positively to vermicompost and FYM application alone and also in combination with fertilizers.

30. During the first year FYM at 75 per cent NPK yielded on par with the treatment receiving 100 per cent NPK alone but the levels vermicompost treatments were inferior. During the second year at 75 per cent NPK the vermicompost treated plants yielded on par and the FYM treated plants were significantly superior to the chemical fertilizer treatment. The effect of the treatments on growth characters and physiological parameters were consistent with the effect on fodder yield.

31. Quality of the forage was favourably influenced by the organic amendments. Between the vermicompost and FYM treatments at equivalent NPK doses the variation was not significant.

32. The effect of vermicompost treatments on uptake of nutrients and protein yield followed a trend similar to its effect on fodder yield.

33. The net income and benefit : cost ratio from guinea grass treated with FYM was higher than that from vermicompost treated plants at 50 and 75 per cent of the recommended NPK fertilizer doses. At lower nutrient levels both organic sources were on par. Highest net income was obtained from 100 per cent NPK treatment during the first year whereas during the second year FYM treated plants receiving 75 per cent NPK fertilizers recorded the maximum income.

34. Pooled analysis studies showed that guinea grass treated with either vermicompost @ of 5 t ha^{-1} or FYM @ 10 t ha^{-1} in combination with 75 per cent NPK yielded on par with the chemical fertilizer treatment thus indicating a saving of 25 per cent of the chemical fertilizers. At 50 and 75 per cent NPK levels FYM treatments were significantly superior to the vermicompost treatments but at lower NPK levels both the organic sources were on par.

35. Coconut yield was favourably influenced by the intercropping of the fodder grasses.

Future lines of work

From the results of the present investigations we could arrive at the extent to which chemical fertilizers could be substituted with the biofertilizers. In future studies the scope of investigation may be extended to find out the inorganic fertilizer level at which inoculation response would be optimum. The impact of dual inoculation of the nitrogen fixers and VAM on production of forage grasses may also be studied. Enhancement of the efficiency of native VAM fungi through agronomic practices may be investigated as a means of overcoming the practical difficulties associated with utilisation of VAM technology in the field. The scope of vermitechnology for forage production may be investigated in detail with different levels of vermicompost application.

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*Orginals not seen

APPENDICES

APPENDIX - 1

CLIMATIC PARAMETERS (FOUR WEEKLY AVERAGES) DURING THE CROPPING PERIOD AND THE PREVIOUS FIVE YEARS

Four weekly interval	Temperature(o C) Maximum			Temperature(o C) Minimum			Relative Humidity(%)			Rainfall(mm)			Evaporation(mm)		
	Five years average	93-94	94-95	Five years average	93-94	94-95	Five years average	93-94	94-95	Five years average	93-94	94-95	Five years average	93-94	94-95
1	30.20	30.50	30.10	23.75	23.63	23.68	79.96	81.33	85.39	33.67	19.70	23.28	3.48	4.03	3.25
2	29.98	29.88	29.58	23.70	23.25	23.28	81.45	83.46	86.68	43.47	74.40	77.30	3.12	2.70	1.70
3	30.30	29.83	30.13	23.19	23.28	23.23	78.97	87.39	83.81	57.06	99.98	53.50	2.80	2.38	2.08
4	30.83	29.65	31.00	22.50	23.05	22.53	72.85	83.13	83.06	8.88	34.58	50.23	2.90	2.68	2.30
5	30.73	30.89	31.63	21.74	22.90	22.73	74.29	84.65	78.39	11.74	12.03	19.05	3.13	2.90	3.13
6	31.18	31.03	31.55	21.13	22.60	23.00	74.10	78.45	73.79	12.91	8.83	0.00	3.44	3.58	3.78
7	32.13	29.35	32.22	22.77	22.23	23.10	72.95	76.29	72.63	15.68	0.00	1.00	4.14	4.23	4.64
8	32.34	33.33	33.10	24.60	24.55	24.74	74.29	86.33	73.13	11.02	14.83	12.85	4.17	4.05	5.05
9	33.05	31.33	31.69	25.26	25.58	24.65	78.44	79.25	80.20	26.16	19.63	110.40	3.90	4.43	3.68
10	30.56	30.90	31.71	24.38	24.28	25.26	82.81	87.78	76.96	76.94	118.30	25.30	3.25	3.10	3.93
11	29.61	29.95	29.33	23.92	23.95	24.02	84.21	83.58	85.05	66.68	18.40	31.28	3.47	3.23	2.54
12	28.99	29.15	28.83	23.06	23.18	23.85	83.42	85.98	78.20	34.21	100.15	29.65	4.73	2.03	2.93
13	29.23	29.60	29.08	23.74	23.75	24.33	83.88	83.39	80.00	15.33	18.63	16.75	3.54	2.33	3.42

APPENDIX-2

Effect of microbial biofertilizers on the green fodder yield of guinea grass during individual harvests (1993 - 94)

Treatments	Green fodder yield (t ha^{-1})				
	I	II	III	IV	V
T0	2.308	3.120	2.955	3.035	2.585
T1	3.428	5.595	4.950	3.645	3.560
T2	2.604	3.319	3.885	3.275	2.410
T3	3.527	4.560	3.920	3.213	3.570
T4	5.014	5.535	5.740	4.215	4.765
T5	4.276	7.220	5.600	6.250	5.575
T6	5.210	8.680	7.165	8.890	3.250
T7	5.039	11.240	5.815	12.435	4.965
T8	3.991	4.905	4.905	4.295	4.340
T9	5.645	8.045	5.845	5.790	3.540
T10	4.808	8.840	6.420	7.765	4.035
T11	3.299	10.698	4.770	12.215	4.080
T12	4.210	12.710	10.265	13.905	7.385
T13	4.080	13.048	10.585	15.765	5.710
T14	4.427	12.218	11.200	17.855	7.770
T15	2.518	11.845	8.250	11.025	4.860
T16	3.298	11.195	6.490	14.320	4.945
F	3.249*	23.393**	14.824**	88.398**	9.935**
SE	0.551	0.706	0.625	0.529	0.469
CD	1.652	2.115	1.873	1.587	1.405

APPENDIX - 3

Effect of microbial biofertilizers on the green fodder yield of guinea grass during individual harvests (1994 - 95)

Treatments	Green fodder yield (t ha^{-1}) I	II	III	IV	V	VI
T0	3.405	3.905	2.580	2.480	2.860	3.080
T1	4.725	4.945	2.520	5.120	5.295	3.860
T2	4.080	4.295	2.605	5.035	4.340	2.950
T3	4.510	4.860	2.775	4.775	5.340	4.125
T4	8.335	5.295	3.215	4.950	7.725	3.560
T5	9.550	5.945	3.215	5.645	7.770	4.515
T6	13.845	5.555	2.865	5.035	10.680	5.290
T7	16.580	6.340	3.125	6.945	12.545	5.205
T8	6.080	5.510	3.040	6.160	5.425	3.770
T9	10.465	5.165	3.190	4.775	8.135	6.100
T10	11.460	5.555	3.125	6.165	10.940	5.555
T11	14.130	5.210	2.385	6.275	10.940	5.555
T12	19.445	9.375	3.170	6.855	14.755	6.425
T13	19.555	8.840	3.235	7.815	14.305	4.685
T14	18.405	8.640	4.145	8.815	15.975	6.510
T15	16.060	8.335	2.865	6.620	12.410	3.995
T16	13.320	5.990	3.600	5.925	12.845	3.730
F	60.555**	10.513**	1.351	4.131**	90.360**	7.565**
SE	0.717	0.511	0.368	0.698	0.422	0.412
CD	2.148	1.533	1.102	2.093	1.265	1.236

APPENDIX - 4

Effect of microbial biofertilizers on the green fodder yield of congosignal during individual harvests (1993 - 94)

Treatments	Green fodder yield (t ha^{-1})				
	I	II	III	IV	V
T0	2.865	6.530	9.820	6.480	5.230
T1	3.560	7.010	11.260	7.550	5.560
T2	3.150	6.310	8.545	5.700	3.140
T3	5.250	7.985	14.450	9.240	4.555
T4	5.185	9.635	15.800	11.565	5.165
T5	4.795	10.545	15.190	14.540	5.170
T6	5.120	13.685	14.930	17.615	4.210
T7	5.510	15.710	14.080	22.525	4.055
T8	3.820	7.115	11.340	13.565	3.405
T9	3.560	9.525	14.370	14.840	3.600
T10	4.035	11.980	15.430	16.640	4.455
T11	4.600	15.055	16.060	18.530	4.405
T12	6.190	18.160	19.035	24.085	5.255
T13	5.100	16.750	18.515	26.055	3.455
T14	5.320	18.750	21.330	18.970	4.295
T15	4.255	13.065	18.750	19.180	4.775
T16	4.510	15.080	20.335	23.525	4.340
F	7.040**	16.701**	13.816**	28.648**	2.748
SE	0.345	1.030	0.974	1.179	0.437
CD	1.035	3.089	2.919	3.534	--

APPENDIX - 5

Effect of microbial biofertilizers on the green fodder yield of congosignal during individual harvests (1994 - 95)

Treatments	Green fodder yield (t ha^{-1})					
	I	II	III	IV	V	VI
T0	5.140	4.365	3.600	5.180	5.075	4.515
T1	5.210	4.040	3.470	7.115	5.730	4.340
T2	5.080	3.735	3.520	6.945	5.730	3.080
T3	7.055	4.925	3.885	6.945	6.250	6.425
T4	7.465	4.690	4.060	7.855	6.205	4.860
T5	12.105	4.945	4.165	8.765	8.075	5.645
T6	15.710	5.105	3.645	6.685	10.070	3.600
T7	17.665	6.205	4.580	6.165	11.280	4.080
T8	8.505	5.730	4.470	8.075	8.180	3.950
T9	14.280	4.820	4.645	8.120	7.940	5.600
T10	15.925	6.120	4.930	8.505	12.505	5.560
T11	17.620	7.615	6.250	8.855	11.455	4.295
T12	16.750	7.120	5.100	8.680	15.975	5.555
T13	19.620	6.665	5.640	8.860	12.325	3.730
T14	16.775	7.205	5.555	9.810	12.065	5.175
T15	16.210	5.945	4.685	8.090	10.955	4.575
T16	15.365	6.775	4.425	7.730	9.570	5.210
F	25.592**	22.515**	7.796**	2.869	14.921**	1.784
SE	1.012	0.248	0.288	0.684	0.794	0.668
CD	3.035	0.744	0.863	--	2.379	--

APPENDIX - 6

Effect of vermicompost on green fodder yield of guinea grass during the individual harvests (1993 - 94)

Treatments	Green fodder yield (t ha^{-1})				
	I	II	III	IV	V
T0	1.723	2.767	1.930	3.750	3.623
T1	2.410	2.743	2.747	4.303	3.897
T2	2.793	6.723	3.107	6.240	5.480
T3	3.333	7.503	3.843	8.087	6.747
T4	4.053	8.100	4.457	9.083	8.413
T5	2.180	3.013	2.643	3.143	3.407
T6	2.543	5.887	3.227	5.740	6.270
T7	3.097	7.657	3.230	9.603	7.670
T8	3.570	11.013	4.217	9.743	9.127
T9	3.337	10.883	4.840	11.460	8.040
F	8.565**	40.167**	23.541**	25.291**	16.834**
SE	0.241	0.485	0.186	0.572	0.511
CD	0.716	1.440	0.554	1.699	1.518

APPENDIX - 7

Effect of vermicompost on green fodder yield of guinea grass during the individual harvests (1994 - 95)

Treatments	Green fodder yield (t ha^{-1})					
	I	II	III	IV	V	VI
T0	2.777	1.870	1.783	2.153	2.173	2.177
T1	2.973	3.097	2.067	2.700	4.613	2.693
T2	4.770	4.920	3.560	3.680	5.743	3.703
T3	6.030	5.860	3.727	3.983	6.707	4.460
T4	8.917	6.323	3.797	4.793	7.750	5.140
T5	0.000	0.000	0.000	0.000	0.000	0.000
T6	4.170	4.920	3.293	4.190	5.840	4.193
T7	6.987	5.260	3.860	4.550	10.040	4.687
T8	9.583	6.217	4.440	5.540	10.633	4.947
T9	10.250	4.297	3.680	4.247	9.453	4.503
F	60.020**	83.496**	48.431**	30.956**	46.304**	24.016**
SE	0.429	0.224	0.193	0.287	0.502	0.327
CD	1.275	0.666	0.573	0.851	1.492	0.971

APPENDIX -8

Pooled analysis of the effect of microbial biofertlizers on the physical properties of the soil under Guinea and Congosignal after the experiment

Source	df	MSS				
		Bulk density	Water holding capacity	Porosity	Hydraulic conductivity	Mean weight diameter
Loc/crops(A)	1	1.7395E-03**	97.5312**	139.1172**	8.3320**	4.1847**
Treatments(B)	16	7.1716**	11.2504**	12.0840**	16.1483**	1.2722
A x B	16	1.2779E-04	1.3821	0.9746	3.5788	1.7965
Error	48	1.0926E-04	1.4881	1.5416	2.8128	1.5988

Pooled analysis of the effect of microbial biofertilizers on available nutrient status and organic carbon content of soil under Guinea and Congosignal after the experiment

Source	df	MSS					
		N	P	K	Ca	Mg	Organic carbon
Loc/crops(A)	1	3775.25**	0.5430	1330.50**	111.50	1792.09**	5.0501E-02**
Treatments(B)	16	202.58	28.8938**	357.50**	171.31	88.19	6.6836E-03**
A x B	16	73.3594	2.5691	54.8731	392.50	18.36	1.1215E-03
Error	48	140.81	2.3353	53.85	651.26	39.71	7.7384E-04

AGRONOMIC EVALUATION OF BIOFARMING TECHNIQUES FOR FORAGE PRODUCTION IN COCONUT GARDENS

By

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ABSTRACT OF THESIS
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ABSTRACT

Two field experiments were conducted at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala state to study the potential of biofarming techniques for forage production in coconut gardens. The study was carried out for a period of two years from September 1993 to August 1995. The influence of the different nutrient management techniques on uptake of nutrients, quality of produce and physico-chemical properties of soil was also investigated.

In experiment no. 1. the influence of two nitrogen fixing organisms., viz. Azospirillum and Azotobacter and the role of Vesicular Arbuscular Mycorrhiza (VAM) in improving the growth and production of guinea grass and congosignal was studied under inoculation alone and also in combination with chemical fertilizers. The nitrogen fixers were tested under varying levels of fertilizer nitrogen and for VAM the level of phosphorus varied between treatments. The prospects for vermicompost use for guinea grass production was examined under experiment no. 2. It was also envisaged to compare the impact of integrated use of manures and fertilizers with the continuous use of chemical fertilizers alone.

Results of experiment no. 1 revealed that Azospirillum inoculation alone and in combination with fertilizers had significant positive influence on guinea grass production. Azotobacter inoculation showed only limited effects on growth and yield of the forage grass during the first year but the effect was significant

during the second year. The results indicated that 25 per cent of the recommended nitrogen could be saved through the use of either of the biofertilizers. VAM inoculation when combined with full dose of recommended fertilizer nitrogen and potassium, showed significant superiority over the POP treatment at 0, 25 and 50 per cent phosphorus doses while the 75 percent P dose gave comparable yields. The quality parameters of the forage recorded values on par or superior to that of the recommended fertilizer treatment. The use of biofertilizers improved the net income and benefit : cost ratio from guinea grass cultivation. The inoculation treatments were found to have a favourable influence on the physical and chemical properties of the soil.

Integrated use of the nitrogen fixing organisms with chemical fertilizers was found effective for Congosignal cultivation. Pooled analysis studies indicated that when inoculated with either Azospirillum or Azotobacter, 50 per cent of the recommended fertilizer nitrogen was adequate for good yields. VAM inoculation alone elicited significant yield increase over the absolute control. Combined doses of VAM with chemical fertilizers at all levels of applied phosphorus responded more or less similar to the recommended fertilizer treatment. This indicated the possibility of completely substituting the need for fertilizer phosphorus in VAM inoculated congosignal. The VAM effect in promoting growth and yield of the forage was found to decline in the presence of applied phosphorus. The data on economics also favoured the use of biofertilizers.

Experiment no. 2 revealed that guinea grass responded well to integrated use of manures and fertilizers. As per pooled analysis vermicompost @ 5 t ha^{-1}

or Farm yard manure @ 10 t ha^{-1} when combined with 75 per cent of the recommended NPK were comparable with the 100 per cent NPK treatment. Application of the organic manures improved the quality of the produce . The physico-chemical properties of the soil was also favourably influenced by the integrated use of manures and fertilizers. The economic analysis of the data emphasised the need for reducing the reliance on purchased inputs.

Coconut yield was found favourably influenced by intercropping of the fodder grasses.